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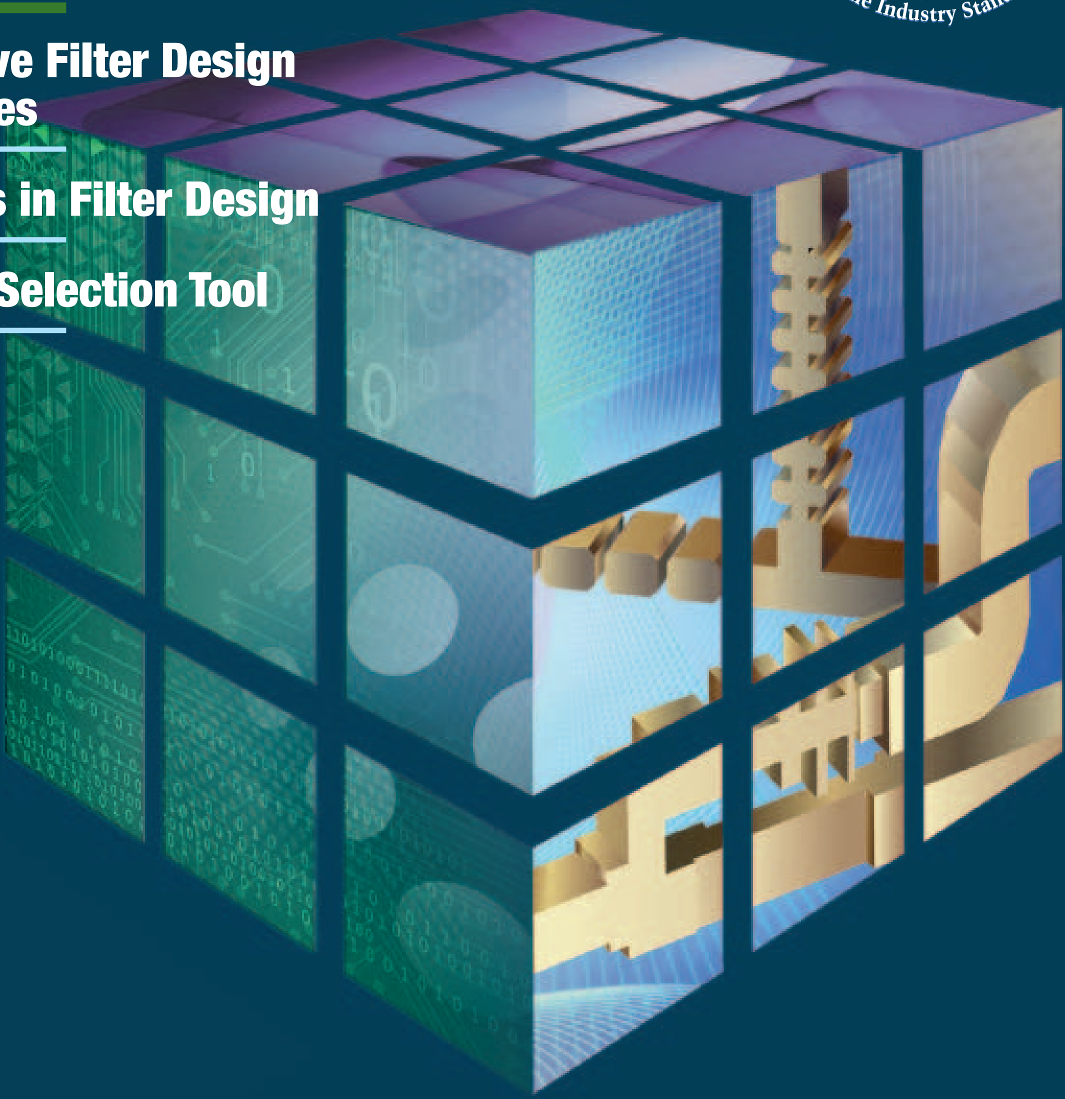

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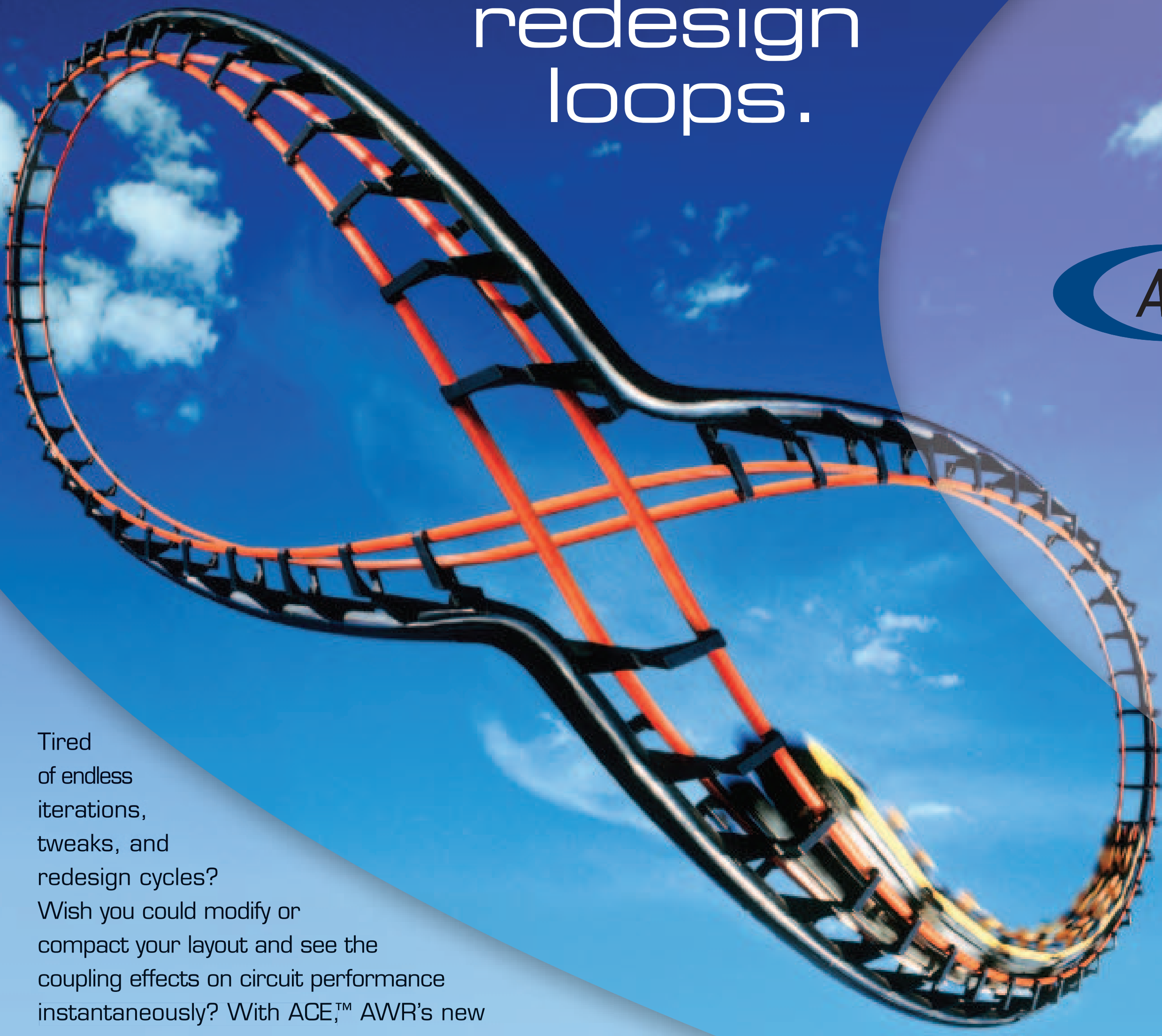

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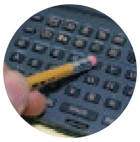

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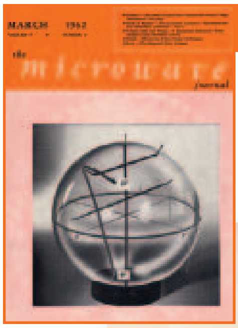

MICROWAVE FILTER DESIGN TECHNIQUES

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APPLIED RESEARCH LABORATORY
SYLVANIA ELECTRONIC SYSTEMS
Waltham • Massachusetts

Introduction

Many papers have been written on the theoretical design of microwave filters and the methods for computing the theoretical constants of a particular filter are known. The gap between the computation of the constants of the filter parameters and the fabrication and alignment of the filter to realize the required response is one that requires some attention since this is the stage which generally consumes much of the time in any development program. This paper will discuss a filter technique which has been developed for the design of direct coupled microwave filters permitting the design engineer to build and align the filter so that the resulting response curve will essentially duplicate the theoretical performance curve.

A direct coupled filter consists of a number of waveguide cavities, each cavity being coupled to an adjacent cavity by an aperture or iris. The theoretical design of these filters is well known and design data for networks capable of realizing a Butterworth or maximally flat response and the Tchebyscheff or equal ripple response is available[1,2,3,4] A typical arrangement and associated low frequency equivalent circuit is shown in Figure 1. The series resonant circuits are represented by the cavities and

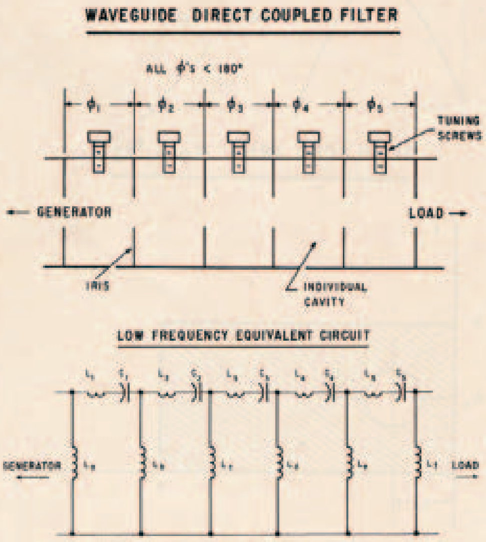

Figure 1.

the irises represent the shunt inductance in Figure 1b. Having computed the constants of a particular filter such as the number and length of individual cavities, and iris susceptances, the next step in the development program is the fabrication process. This is a very important stage since the final performance of any filter relies heavily on the tolerances and surface finishes of the individual parts. These factors behave in such a manner as to widen the gap between the theoretical and actual response.

A control of three basic parameters is required in any filter design so that the final filter response will closely approximate the theoretical response. These are

1. Resonant frequency of the individual cavities
2. Loaded Q of the individual cavities
3. Mutual coupling between the adjacent cavities, input and output terminations.

The usual technique for varying the frequency of the cavities in a microwave filter consists of a capacitive screw located at a point of maximum electric field. The insertion of a screw into the cavity lowers the resonant frequency and in effect increases its length. Cavities are usually cut shorter than required and the capacitive screw allows the designer to vary the frequency of the individual cavity above and below the design frequency. Penetration of the screw into the cavity has the effect of reducing the unloaded Q of the section; therefore, the penetration of this tuning element should not be in excess of tuning requirement. A rule of thumb which has worked out successfully at X-band is to cut the cavities about 0.015 inch below the theoretical length. All screws should be silver plated to realize a lower insertion loss per cavity.

The loaded Q of the individual cavities and the mutual coupling between them is a function of the irises terminating each section of the filter. Two of the more commonly used irises are shown in Figure 2. Both types are useful and yield essentially the same results. Variation in the iris parameters required in any filter alignment is usually achieved by interchanging iris sizes until an acceptable response curve results. This tuning arrangement requires a large library of irises of different sizes and is very costly, inefficient and time consuming; in addition, it does not result in achieving the ultimate response curve (especially for a Tchebyscheff filter having greater than 1 db ripples) since the irises are varied in steps, the size of which are limited by cost and machining techniques.

A more desirable arrangement is one providing a smooth continuous variation in iris susceptance and utilizing only one iris to replace the library of fixed irises. This iris is

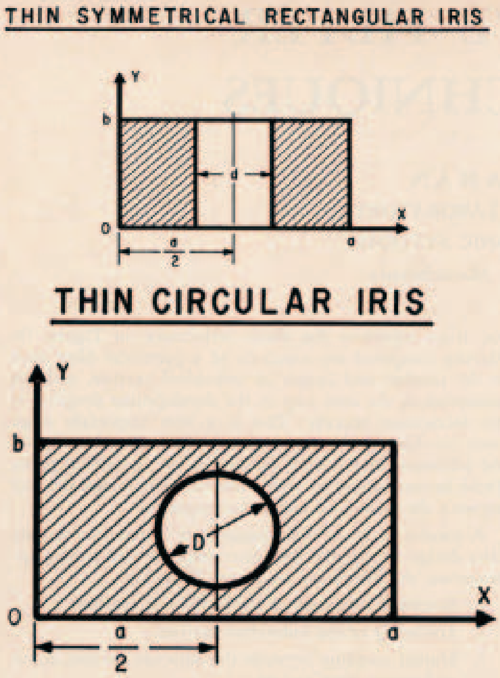

Figure 2.

known as the "adjustable or variable iris" and is the new technique which will be described in this paper.

Iris Considerations

The realization of the proper value of the shunt inductive susceptance in the direct coupled filter represents the most important requirement if one is interested in achieving a selectivity curve which essentially duplicates the theoretical response. The field configurations within the rectangular guide for the dominant TE_{10} mode are such that the iris is located in a region where the transverse magnetic field as shown in Figure 3 is a maximum. For zero thickness irises, the following formulas are available for computing the inductive susceptances[5,6,7,8,9]

(a) for a circular iris centrally located across the guide

$$B_o = \frac{3}{2\pi}\frac{ab}{D^3}\lambda_g$$

where

B_o = normalized iris susceptance, B_{actual}/Y_0; for $D << b$
a is the width of the waveguide
b is the height of the waveguide
λ_g is the guide wavelength
D is the diameter of the iris

(b) for a rectangular iris or window centrally located across the guide

centrally located across the guide

$$B_o = \frac{\lambda_g}{a}\cot^2\pi\frac{d}{2a} \qquad (2)$$

where

B_o = normalized iris susceptance, for $\frac{d}{a} << 1$
a is the width of the waveguide
d is the width of window
λ_g is the guide wavelength

As the thickness of a particular iris increases, the equivalent shunt inductive susceptance of the iris increases and series impedance terms are introduced into the equivalent circuit. A rule of thumb generally used for irises is that the effective susceptance of a thick iris having an aperture, D, is equal to the susceptance of a theoretical iris having an aperture equal to $(D-t)$, where t is the thickness of the iris, i.e.,

$$B_{thick}(D) \approx B_{thin}(D-t) \qquad (3)$$

The circular iris is preferred over the rectangular window because it is easier and less expensive to machine and consequently has been used in all filters discussed in this paper. Coupling between the adjacent cavities varies as D varies, increasing if D increases and vice versa. This same phenomenon can be displayed by using an iris of fixed diameter, D, and varying the position of the iris across the waveguide as shown in Figure 3. As the iris is displaced from

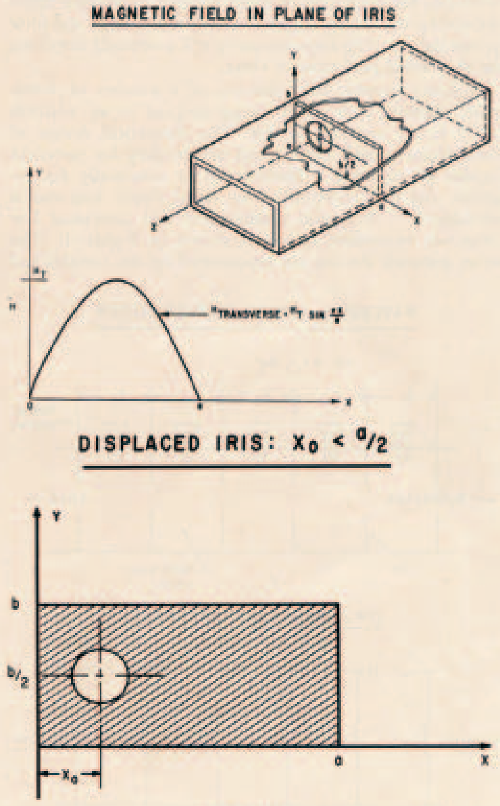

Figure 3.

112

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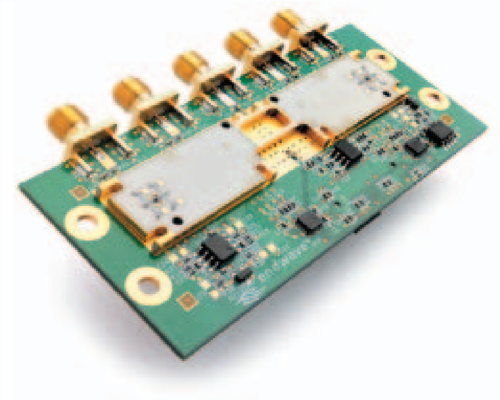

ADVANCES IN MICROWAVE FILTER DESIGN TECHNIQUES

An overview of advances in filter design techniques in the framework of the evolution of the microwave area is presented in this article. Several types and implementations of filters developed during the last decades to satisfy the demands of modern communication services are described, emphasizing the new technologies and designs that fulfill the stringent electrical, mechanical, time and production cost requirements of actual systems. In this context, this article revisits some of the advances in this area, where the role of Computer Aided Design (CAD) has enormous impact on the microwave industry.

The last two decades have witnessed the introduction of several new communication services that presented extraordinary challenges to microwave filter designers. Mobile communications cellular base stations and handsets require very tight electrical requirements to conserve precious frequency spectrum, miniaturization, large production volumes and low production cost. Filters for space applications in communications and broadcast satellite payloads have very challenging electrical requirements to be met under severe environmental conditions, high power handling, small mass and size. Millimetre-wave diplexers for Ka-band high speed multimedia Internet access satellite terminals pose challenging electrical requirements, very low production cost and large production volumes.

To meet these challenges, filter designers have developed design techniques, realization methods, new transmission media and innovative packaging configurations. The design techniques used circuit synthesis to obtain ideal optimum filter responses with finite real frequency transmission zeros for improved selectivity and complex transmission zeros to achieve group delay equalization. The ideal circuit models are then approximated by elements of transmission media (resonators and coupling elements) to construct a starting model of the microwave filter structure. Electromagnetic simulation and optimization is then applied to make the response of the real-

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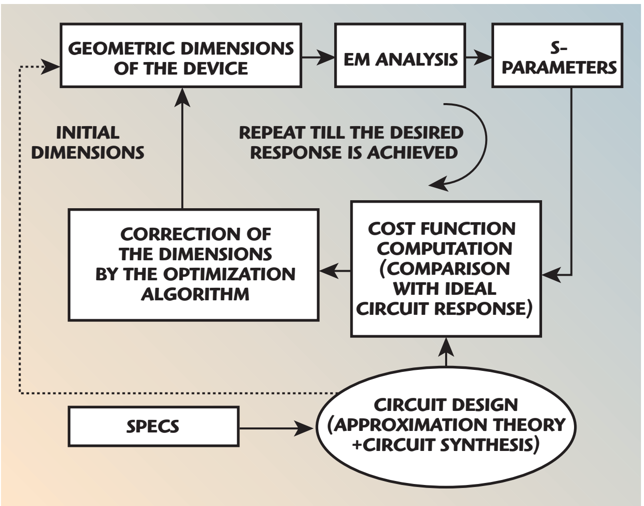
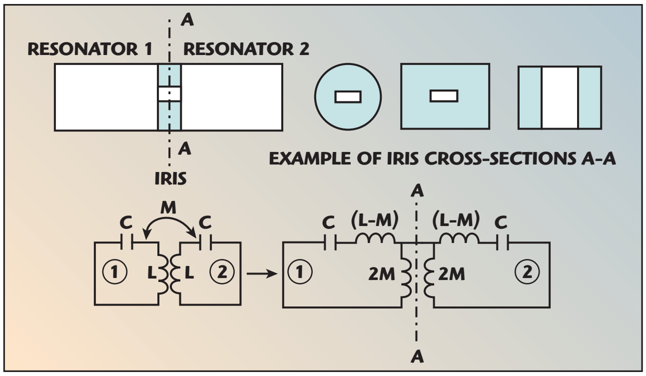


▲ *Fig. 1 Flow chart for the filter design process.*

ized microwave structures close to the idealized circuit response. The design procedures were vastly enabled by the availability of high speed computers, development of efficient electromagnetic simulation tools, numerical optimization techniques and innovative structures in various transmission media that enable realization of the optimal performance. Further, the models used in the simulation can take into account actual manufacturing details, such as finite milling tool sizes that can have major impact on the response. Once a final acceptable simulated response is achieved, the filters could be directly manufactured and its measured performance should be almost identical to the simulated response. This process largely eliminates the need for experimental tuning or repeated modification of the hardware, greatly reducing production cost and time.

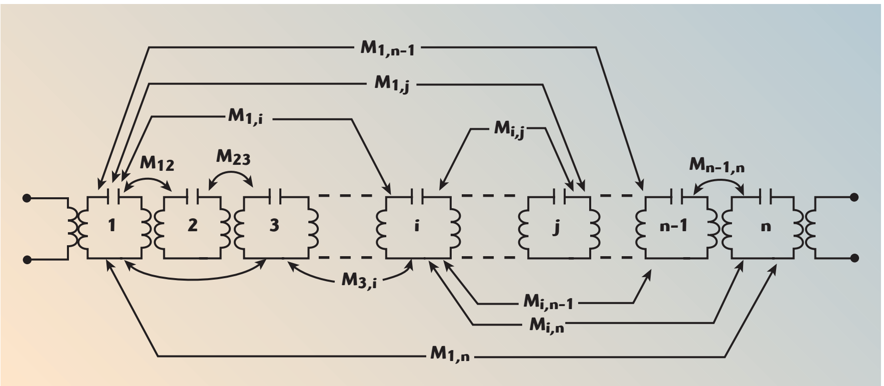


▲ *Fig. 3 Example of initial dimensions determination.*

This article presents a review of some modern filter design techniques, comparing these techniques with the well established design methods of more than four decades ago.[1] The techniques are illustrated by several designs using different transmission media, including metallic waveguides, ridge waveguides realized in Low Temperature Co-fired Ceramics (LTCC) and dielectric loaded resonators.

MODERN FILTER DESIGN TECHNIQUES

Figure 1 illustrates the flow chart for modern filter design. From the given specifications, a circuit model is obtained in terms of a coupling matrix and input/output couplings. This process involves two steps. The first step is the solution of the approximation problem, which determines the order (number of filter poles) and the poles/zeros location of a transfer function that meets the given specifications. The second step is to synthesize a coupling matrix with a desired topology corresponding to a desired configuration. The lumped circuit model consists of resonant circuits coupled by frequency independent couplings,[2] as shown in ***Figure 2***.



▲ *Fig. 2 General equivalent circuit model (normalized) for a microwave filter of order n, with cross-couplings among all the resonators.*

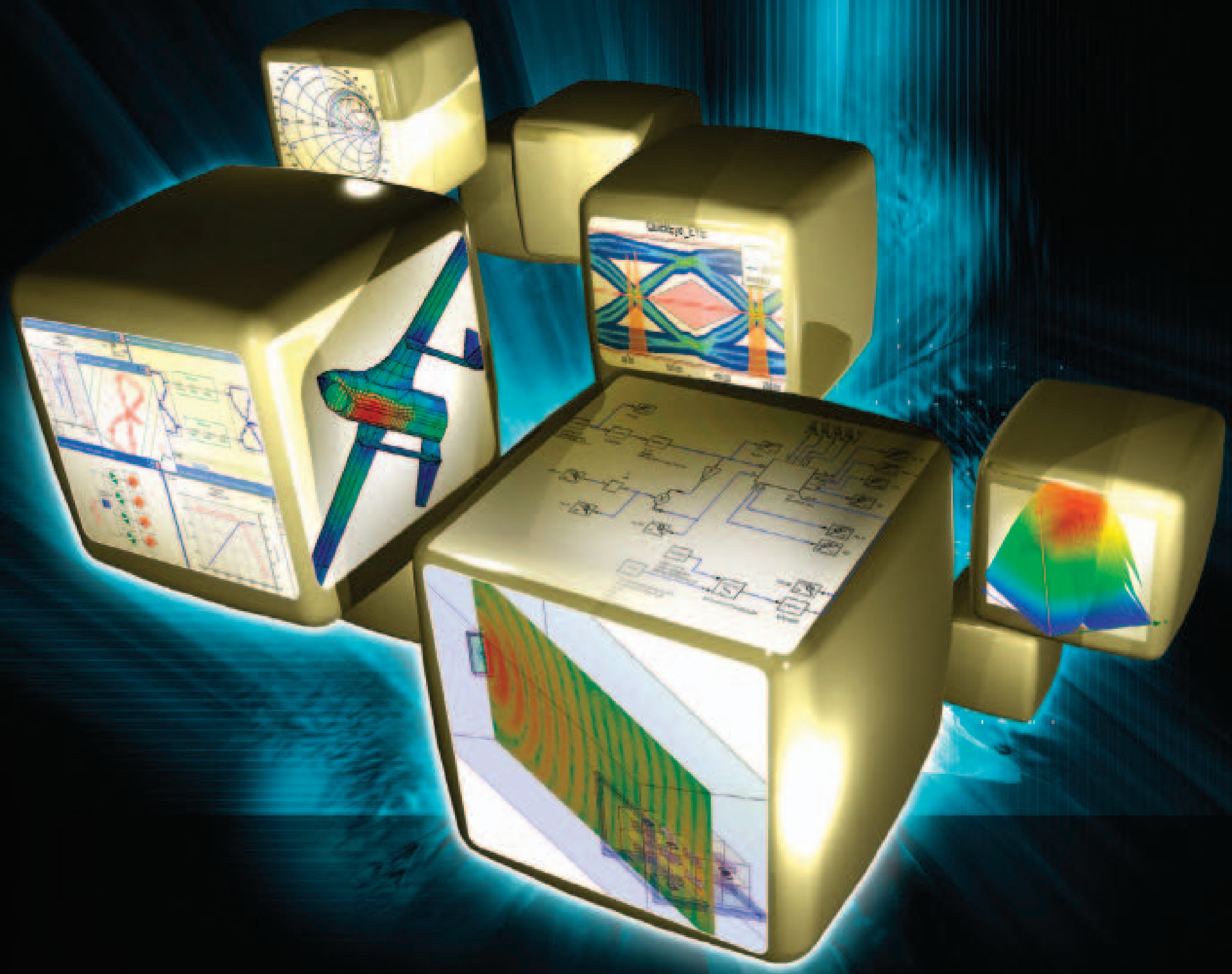
Next, from the filter centre frequency, bandwidth, desired transmission medium in which the filter is to be realized, and coupling matrix element values, an initial set of physical dimensions are determined based on an electromagnetic model simulating the coupling between two isolated resonators. ***Figure 3*** shows a simple example of how the iris dimensions are mapped to the circuit coupling values for a window between two rectangular or circular waveguide resonators.

Once the complete filter physical model is generated, EM model simulation of the S-parameters is performed. In many practical cases, the EM simulation is carried out using the Mode Matching (MM) method,[3] since it is computationally very efficient. However, depending on the complexity of the shapes and materials of the structure to be analyzed, other general numerical

TABLE I

COMPARISON BETWEEN DESIGN STEPS "NOW" AND "THEN"

Design Step	*"NOW"*	*"THEN"*
Approximation	Finite transmission zeros	All pole functions (Tchebycheff)
Synthesis	General topology, multiple coupling, uses positive and negative couplings	Used only cascaded resonators with same sign couplings
Initial dimensions	Uses EM simulation	Approximate analytical models
Response optimization	EM simulation and optimization algorithms	Empirical adjustments of structure dimensions
Tuning	Usually not required	Requires tuning



methods may be used such as the Finite Element Method, Finite Differences Time Domain Differences, etc., or hybrid combinations between them. Actually, there are many commercially available software packages that implement these techniques,[4-8] even offering modules for dealing with high power effects (multipaction, passive intermodulation).[9] They have an implicit trade-off between the structures that they are able to handle (complex shapes and material), computer resources (RAM memory, computation time, etc.) and accuracy.

Moreover, the response of the filter using the initial dimensions will usually be relatively poor, since the original design did not take into account the interactions among the resonators and the loading effects due to the multiple couplings. The simulated response is compared with the circuit model response, and an error or cost function is computed. Using an optimization routine, the dimensions of the filter are adjusted to minimize the cost function (see Figure 1). This process is repeated until the desired response is achieved.

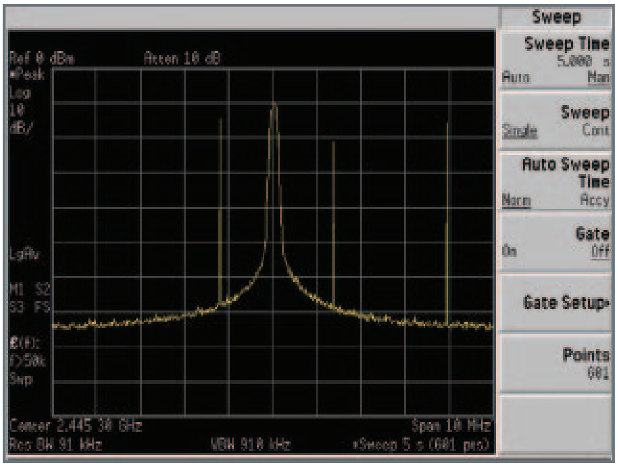
It is interesting to contrast this modern design process with the techniques used four decades ago.[1] Many of these designs are found in Reference 10. ***Table 1*** summarizes the differences between what was used then and now. Although essentially the same design steps are employed, the major differences include:

- Use of advanced filter synthesis techniques
- Introduction of finite transmission zeros using the new coupling topologies employing the concepts of positive and negative couplings
- Use of full-wave simulators in powerful CAD tools

Choosing the transmission medium is one of the key issues in the realization of filters and multiplexers and its selection is related to many factors. An initial classification could be based on frequency range and would consider aspects such as physical size, unloaded quality factor Q, power handling capability, temperature drift and production cost.

Some transmission media and corresponding filter technologies include:

- The lumped element filters employed in the microwave range operate typically in hundreds of MHz's (they can be used even at higher frequencies), with unloaded Q in the hundreds. Their dimensions must be much smaller than the operating wavelength and, thus, at high frequencies they are very difficult to manufacture with good performance. Hence, the distributed components (larger size) are used for higher microwave frequencies.
- Microwave filters implemented in air-filled rectangular waveguides, ridge waveguides and circular waveguides operating in their fundamental TE mode. For silver-plated resonators, unloaded Q factors of 10000 to 20000 can be achieved. Their insertion loss is low and they can handle higher power. However, they are usually bulky and their mass and temperature stability must be carefully



Traditional Spectrum Analyzer
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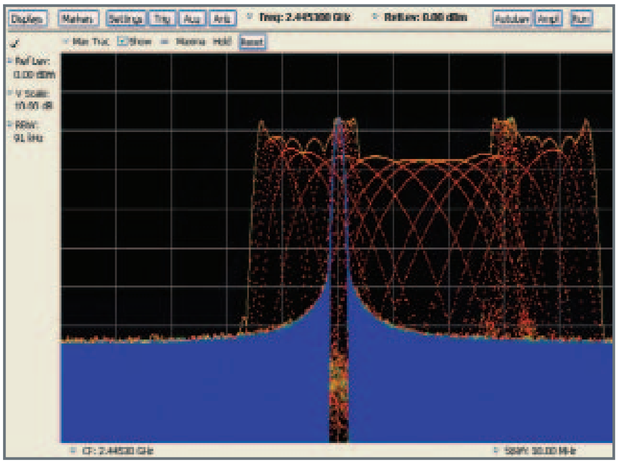

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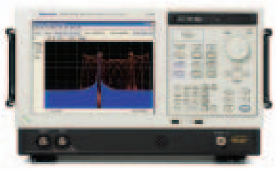

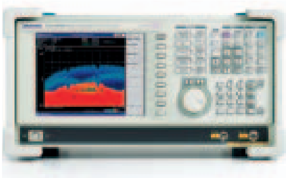

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considered in satellite applications. Aluminium can be used to reduce the weight. The temperature stability can be improved by an adequate design methodology, using special materials (e.g. invar) and smart mechanical structures to affect temperature compensation.[11] Coaxial line filters can also be considered in the waveguide category, in this case operating in the TEM mode. They have higher losses and are common in wireless base stations and TV broadcasting.

- Planar structures are mostly employed for microwave integrated circuits (MIC) and monolithic microwave integrated circuits (MMIC). Microstrip lines, striplines, coplanar lines and suspended striplines belong to this category, whose main features are low cost and miniaturization. The power handling capability and Q factors (they can usually have Q fewer than 100) are usually very low, unless special materials are used.
- Dielectric resonator filters achieve higher unloaded Q (more than 40000 can be obtained) and very good temperature stability (temperature coefficient in the vicinity of one ppm/°C). A typical resonator is a ceramic cylindrical puck (where the electromagnetic field is mainly concentrated) suspended on a support within a metallic housing, operating in either single or hybrid modes. These filters have the disadvantages of close out-of-band spurious response, and relatively low power handling capability.
- LTCC technology is commonly used for designing compact filters. It is possible to integrate on the same substrate baseband/digital components together with RF miniaturized filters, active and passive devices.
- Other technologies used nowadays range from high temperature superconducting (HTS) components, surface acoustic wave (SAW) filters to micromachined electromechanical systems (MEMS), which cover a broad range of applications.

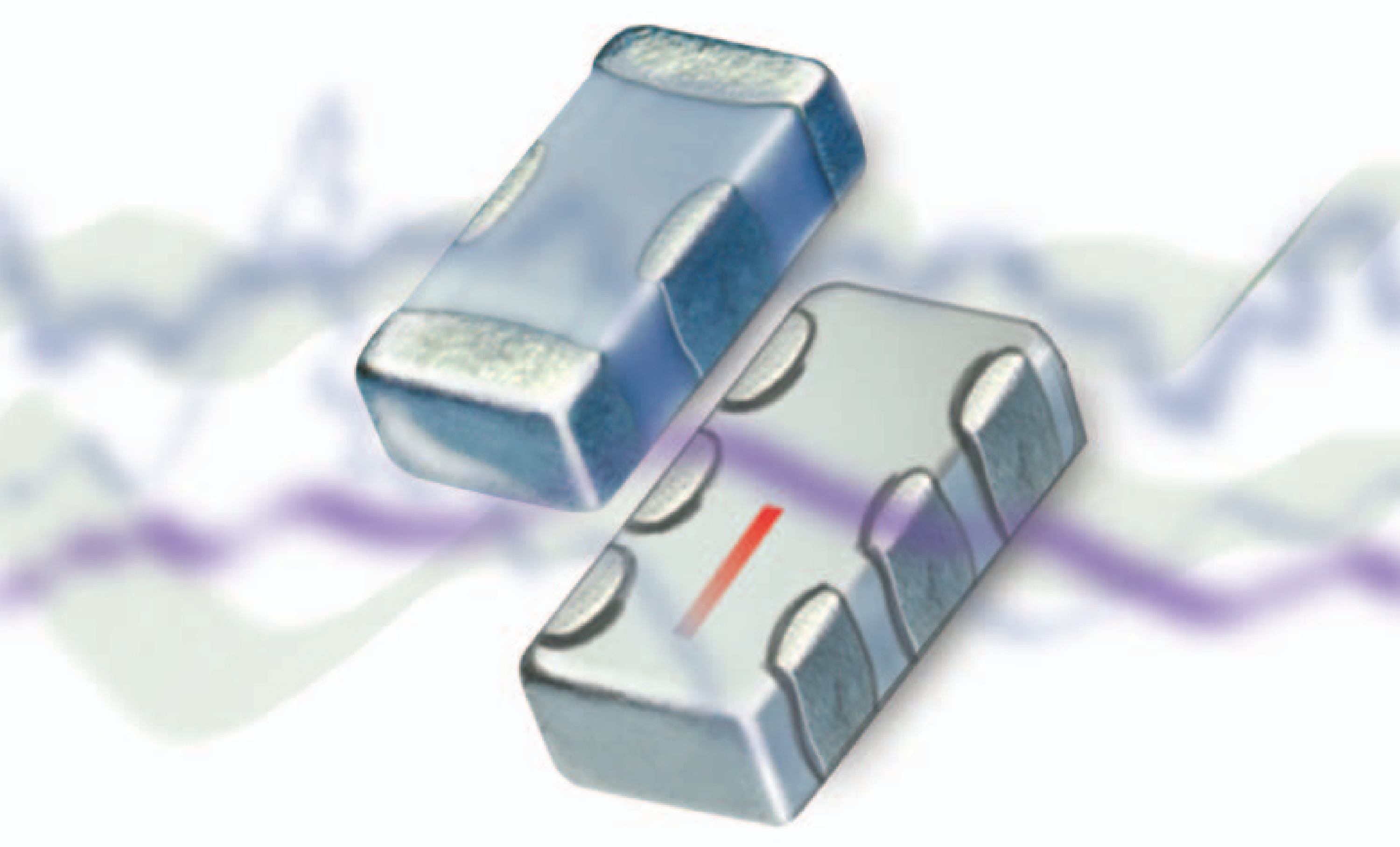
EXAMPLES OF MODERN FILTER DESIGN TECHNIQUES

This section presents examples of the application of modern design techniques to microwave and millimetre-wave filters and diplexers, ultra-wide band LTCC filters and dielectric resonator filters.

Millimetre-wave Filters and Diplexers

Diplexers are widely used in communication systems for reducing mass and volume of the required hardware. They enable use of the same antenna for different frequency bands, resulting in more compact systems. Their function is to separate the different bands of a signal into different ports. Alternatively, a diplexer combines two different signals with different spectral components into one common port.

A diplexer consists of a power divider and two channel filters, as shown in ***Figure 4***. Electrical para-



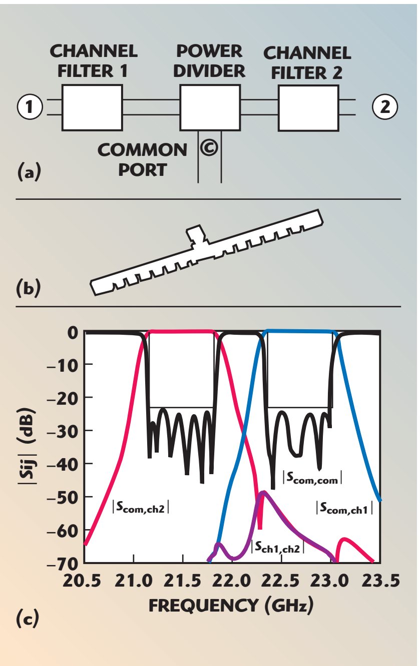


Fig. 4 H-plane T-junction diplexer: (a) block diagram; (b) diplexer configuration with asymmetric T-junction and two six-order channel filters with asymmetric inductive windows; and (c) diplexer performance.

meters that must be maintained over operating temperature range include: bandwidths of the channels and their separation, out-of-band rejection, insertion loss, in-band transmission and group delay responses flatness, power handling, low passive intermodulation and multipactor effects. Mechanical packaging and geometrical characteristics play an important role in order to achieve compact designs. A general theory for diplexers and multiplexers synthesis can be found in this reference.[12] Several configurations and design procedures have been studied in the literature for realizing the multiplexing function.[13-15] Some usual multiplexer configurations with different numbers of channels in rectangular waveguide can be seen in ***Figure 5***.

Diplexer design starts with the channel filters, which must achieve the required channel performances before they are connected into the power divider. Then, two methods are usually followed to obtain the final device. In the first one, the channel filters are re-optimized within the diplexer environment, which includes the effects of the power divider discontinuities as well as the interaction between the channel filters. For the second method, the original channel filter designs are maintained and additional matching elements (as seen in Figure 4b) are incorporated into the power divider junction to obtain the required matching in the passbands. One of the main differences with the approach followed in the past is that these adjustments are done on the computer, and the diplexer that is manufactured already includes all the higher-order mode interactions within the structure.

Furthermore, other effects that are accurately taken into account are the round corners in the rectangular waveguides resulting from the finite radius tools in the manufacturing. At low frequency bands, this corner problem may not be serious, but it becomes critical for millimetre-wave frequencies, since the dimensions of the filter resonators are now comparable to the round

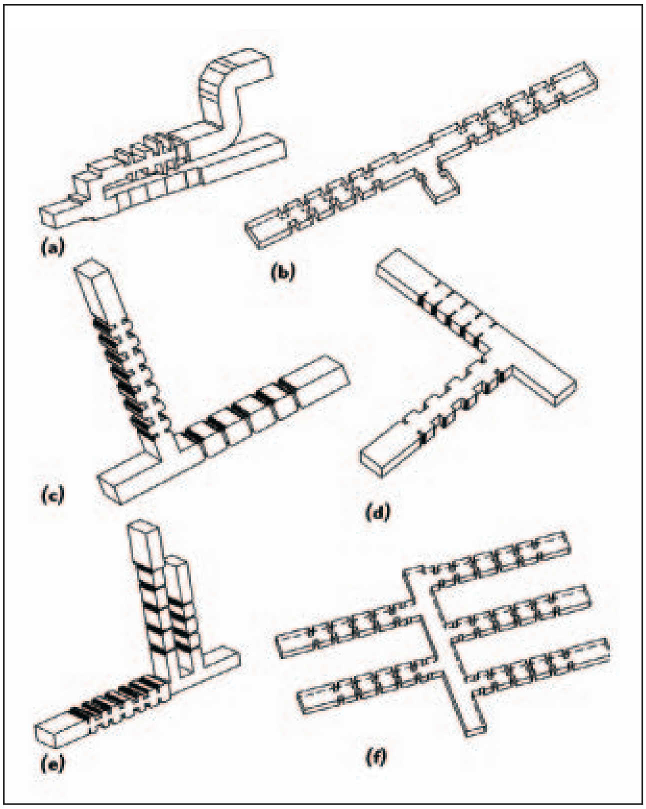


Fig. 5 Rectangular waveguide multiplexer configurations: (a) diplexer made up of a stepped impedance low-pass filter and corrugated high-pass filter; (b) full H-plane diplexer; (c) E-plane divider and inductive windows filter with E-plane rounded corners; (d) full H-plane diplexer with H-plane rounder corners; (e) triplexer with E-plane rounded corners; and (f) manifold five-channel multiplexer.

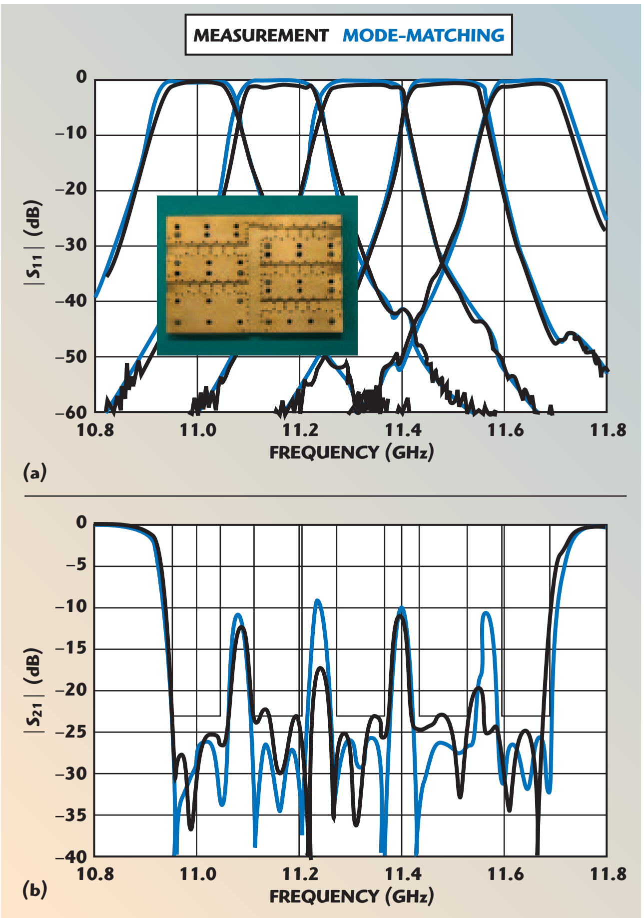


Fig. 6 Simulation and measurement of a five-channel manifold multiplexer in H-plane rectangular waveguide.[16]

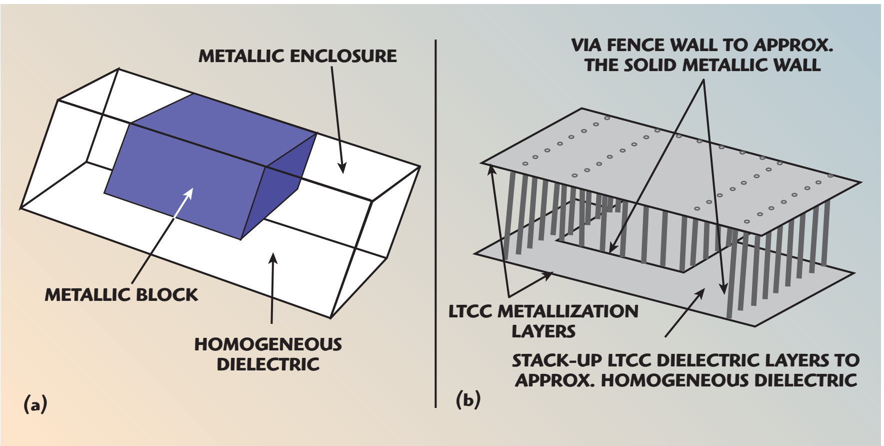


Fig. 7 (a) Homogeneously dielectric-filled ridge waveguide with solid metallic wall; (b) LTCC implementation: the vertical solid walls of the ridge waveguide are approximated by a via fence.

corners. To overcome this problem modified models are used in the simulations, including the effect of the tool in the manufacturing (see for instance the different rounding in Figures 5c and 5d, related to different types of construction). Manufactured diplexers using such modified filter models have almost identical measured and simulated responses. The modified filters also allow the use of relatively large radius tools, which can reduce the manufacturing difficulty and cost.

Other additional considerations can be easily included in the simulations to reduce the production cost. For instance, the asymmetric inductive window filters shown in Figure 4b (instead of using symmetric irises as in Figure 5b) reduce to almost one half the path that a milling tool must cover in the production line (and thus the time and cost). All these considerations have been taken into account into the millimetre-wave diplexer in Figure 4c.

Finally, it is important to adequately select the elements of the diplexer. Specifically for the power divider, E- or H-plane T-junctions are used for narrow to medium bandwidth applications. However, E-plane bifurcation is preferred for diplexers with broadband channels or with large frequency separation between channels. The manifold structures, where all the filters are connected to a main waveguide, are very common in contiguous band applications. An example is shown in ***Figure 6***. All the channel interactions are considered in the full-wave analysis of the structure, as well as higher-order mode effects.

LTCC Ridge Waveguide Filters for Ultra-wideband (UWB) Applications

Filters implemented in LTCC are very well suited for the integration with other microwave components on a multilayer stack-up substrate, reducing size and weight. This technology employs a multilayer substrate manufactured by deposition, layer by layer of dielectric and metallic patterns. This process allows the realization of three-dimensional transmission media (rectangular waveguides and ridge waveguides, for example), which can be used to obtain resonators with higher unloaded Q than planar structures. To realize waveguides in LTCC,[17] the bottom and top walls are replaced by metallization layers. Via fences are incorporated to approximate the side conducting walls and the metallic housing, as shown in ***Figure 7*** for the implementation of a LTCC ridge waveguide.

Ridge waveguides have low cut-off frequency and wide monomode range of the fundamental mode. They have larger size than planar filters, but they can provide lower insertion loss, wide spurious-free response and wideband performance.[18] This LTCC approach may be seen as an intermediate alternative between metallic waveguides and planar circuits.

Recently, UWB components and filters have gotten the attention of many researchers, with designs mainly focused on planar circuits.[19] The structure presented in ***Figure 8*** is an approach for realizing UWB filters based on LTCC.[20] The module shown in Fig-

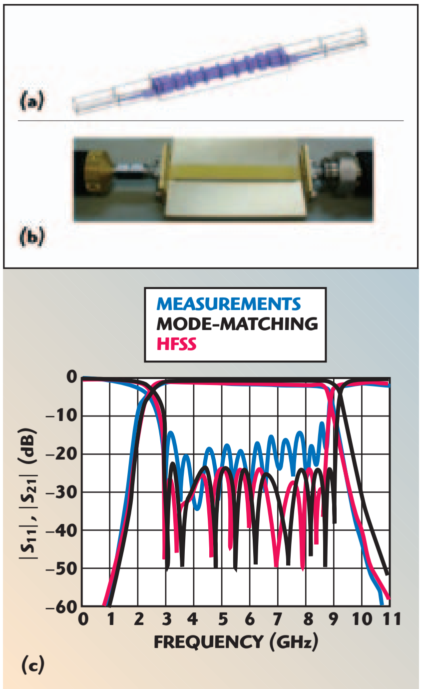


Fig. 8 Theoretical and experimental results for the LTCC filter module in the fixture.[20]

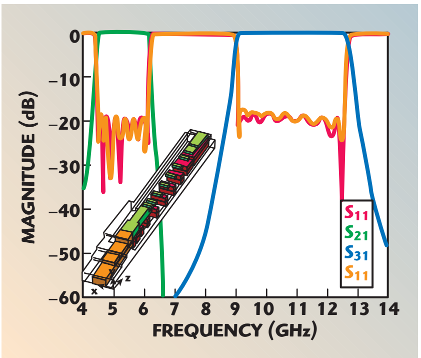


Fig. 9 Simulated performance (mm and HFSS) for a LTCC ridge waveguide diplexer.

ure 8a is made up of a ninth-order ridge waveguide filter, designed for a passband from 3 to 9 GHz. It includes the input and output transitions to 50 Ω striplines used for the experimental evaluation of the filter. The whole LTCC module was built and a fixture designed to enable scattering parameter measurements. Figure 8b shows a photograph of the filter and the fixture.

The initial design of this structure is carried out assuming ideal solid metallic wall waveguides as in Figure 7a. Thus, the full-wave analysis and design of the waveguide structures can be obtained by MM in a very efficient way using the procedure discussed in the previous section. Before the manufacturing, the parasitic effect of the via fence and the losses is investigated

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AML412L3002	4.0 – 12.0	30	±1.5	1.5	+10	1.8:1	150
AML218L0901	2.0 – 18.0	9	±1.0	2.2	+5	2.5:1	60
AML0518L1601-LN	0.5 – 18.0	16	±1.0	2.7	+8	2.2:1	100
AML0126L2202	0.1 – 26.5	22	±2.25	3.5*	+8	2.2:1	170
AML1226L3301	12.0 – 26.5	33	±2.0	2.8	+8	2.5:1	200
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AML218P3203	2.0 – 18.0	32	±2.5	4	+25	2.0:1	450
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AML1718L2401	17.0 – 18.0	24	±0.75	1.6	+10	1.8:1	150

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AML811PN1808	8.5 – 11.0	18	18	-152.5	-157.5	-165.5	-168
AML811PN1508	8.5 – 11.0	15	28	-145.5	-153.5	-158.5	-164.5
AML26PN0904	2.0 – 6.0	9	20	-150	-165	-165	-178
AML26PN1201	2.0 – 6.0	11	15	-155	-160	-160	-175

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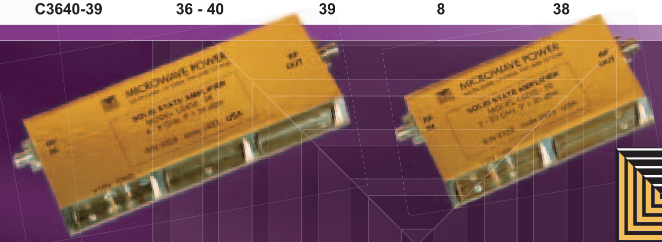
L0204-44	2 - 4	44	25	42.5	45	14
L0206-40	2 - 6	40	10	38.5	40	8.5
L0208-41	2 - 8	41	12	40	40	17
L0218-32	2 - 18	32	1.4	31	35	5
L0408-43	4 - 8	43	20	41.5	45	17
L0618-43	6 - 18	43	20	41.5	45	22
L0812-46	8 - 12	46	40	45	45	28
Millimeter-Wave Power Amplifiers						
L1826-34	18 - 26	34	2.5	33	35	4
L1840-27	18 - 40	27	0.5	26	30	2
L2240-28	22 - 40	28.5	0.7	27	30	3
L2630-39	26 - 30	39	8.0	38	40	15
L2632-37	26 - 32	37	5.0	36	38	10
L2640-31	26 - 40	31	1.2	30	30	5
L3040-33	30 - 40	33	2.0	32	33	9
L3337-36	33 - 37	36	4.0	35	40	12
L3640-36	36 - 40	36	4.0	35	40	10

High-Power Rack Mount Amplifiers

Model	Frequency (GHz)	Psat (dBm)	Psat (W)	P1dB (dBm)	Pac (kW)	Height (in)
C071077-52	7.1 - 7.7	52.5	170	51.5	1.8	10.25
C090105-50	9 - 10.5	50	100	49	1	8.75
C140145-50	14 - 14.5	50.5	110	49.5	2	10.25
C1416-46	14 - 16	46	40	45	0.35	5.25
C1820-43	18 - 20	43	20	41.5	0.25	5.25
C2326-40	23 - 26	40	10	39	0.25	5.25
C2630-45	26 - 30	45	30	44	0.45	5.25
C3236-40	32 - 36	40	10	39	0.25	5.25
C3640-39	36 - 40	39	8	38	0.24	5.25



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with a general purpose tool such as HFSS.[4] This part of the design is carried out when one feasible set of dimensions have already been obtained and, thus, the longer simulation times can be tolerated. The comparisons between the simulations and the experimental measurements are shown in Figure 8d, showing good agreement.

The same type of manufacturing concepts can be used to design wideband multiplexers.[21] For instance, ***Figure 9*** shows a diplexer designed for LTCC integration. Channel filter 1 and channel filter 2 are ridge waveguide filters based on the same approach as in Figure 7. The two filters are connected by a ridge waveguide power divider in E-plane configuration. The analysis and design of the diplexer is carried out by MM, and then is checked with HFSS. The responses are shown in Figure 9.

Dielectric Loaded Resonator Filters

The breakthrough in ceramic material technology, the significant progress in satellite communications in the late 80s and the rapid expansion of mobile communications in the 90s have revived interest in dielectric resonator (DR) applications for a wide variety of microwave circuit configurations and subsystems.[22,33] New high dielectric constant materials with high quality factor and low temperature coefficient were developed. The material can have the desired small controllable temperature coefficients over the useful operating temperature range. In addition, new filter configurations such as single and dual-mode filters with elliptic function responses were developed. These filters have the advantages of low loss, smaller size and superior temperature stability. A detailed review

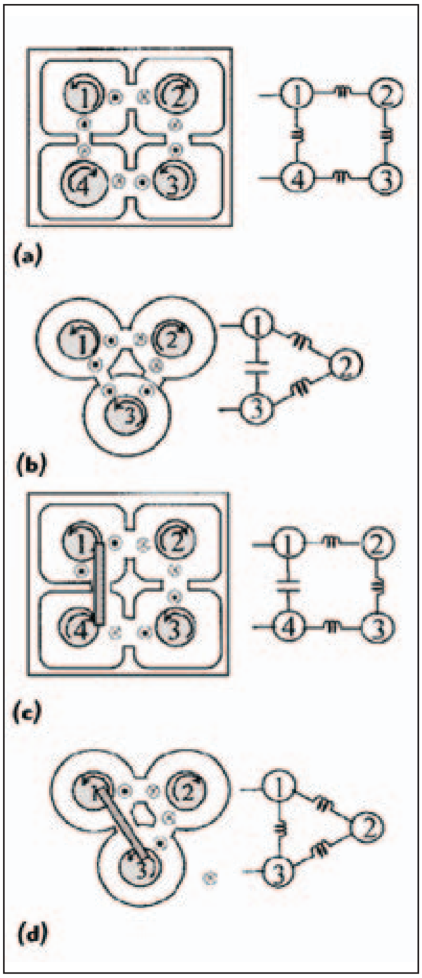


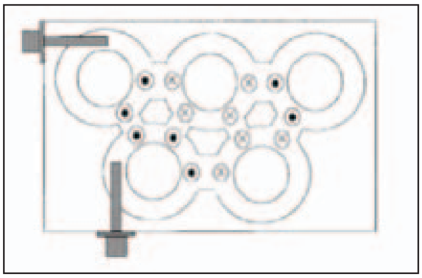
Fig. 10 Basic building blocks of TE mode DR filter: (a) aperture coupled quadruplet; (b) probe coupled tri-section; (c) probe coupled quadruplet; and (d) probe coupled tri-section.

of the design and realization of several dielectric resonator filters can be found in Reference 22.

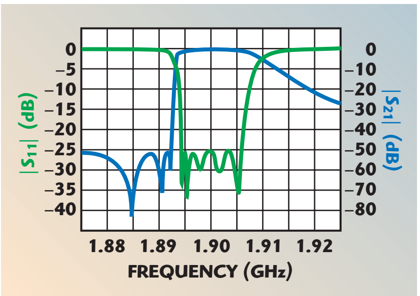
The $TE_{01\delta}$ mode filter with planar layout offers many advantages over an in-line configuration and therefore it has been widely used in the base stations for mobile communication systems.[26,33] $TE_{01\delta}$ mode is the most commonly used mode in DR filters because it is the fundamental mode of the DR and it has no degenerate mode. As a result, $TE_{01\delta}$ single-mode filters offer the advantages of design simplicity, flexibility in layout options and low-cost manufacturing. TE mode filters can have planar layout which is very suitable for mass production.

Non-adjacent coupling can be used to realize advanced filter features, such as quasi-elliptic function, constant delay and asymmetric responses. Quadruplet and tri-sections can be regarded as basic building blocks to generate symmetric and asymmetric transmission zeros. A non-adjacent coupling can be realized with quadruplet and tri-sections for TE mode cavities and their equivalent coupled-resonator model are shown in ***Figure 10***,[33] where magnetic coupling is regarded as positive coupling and denoted by an inductor. The non-adjacent coupling, which has opposite sign with adjacent coupling, is regarded as negative coupling and denoted by a capacitor. It is interesting to note that relative signs of the cross-coupling realized by an iris in a planar quadruplet and tri-sections are different, as is the cross-coupling by probe. The coupling property of the tri-section is also different from other commonly used types of cavities, such as waveguide and comb-line cavities because of the different field distributions of the resonator mode.

An example of a five-pole TE mode DR filter can be found in this reference.[33] The filter used three non-adjacent aperture couplings including both inductive and capacitive couplings and achieved frequency response with three transmission zeros all at the lower side of the passband. The coupling matrix of this filter is:



▲ *Fig. 11 Layout of the five-pole TE mode DR filter and the magnetic field orientation of the resonator.*



▲ *Fig. 12 Measured frequency responses for the five-pole TE mode DR filter.*

$R_1 = R_2 = 1.3000$

$$[M] = \begin{bmatrix} -0.0108 & 1.0120 & 0 & 0 & -0.1093 \\ 1.0120 & -0.0114 & 0.3328 & -0.4933 & 0.4608 \\ 0 & 0.3327 & -0.5362 & 0.2042 & 0 \\ 0 & -0.4933 & 0.2042 & -0.2641 & 0.9011 \\ -.1093 & 0.4608 & 0 & 0.911 & -0.0140 \end{bmatrix}$$

The filter layout is shown in ***Figure 11***. The orientation of the magnetic field near the cavities sidewall is also shown in Figure 11 to justify that the couplings $M_{24}(-)$, $M_{25}(+)$ and $M_{15}(-)$ are all implemented by coupling irises. The measured results are shown in ***Figure 12***. This is an illustrative example of how new couplings and topologies are combined with improved materials to provide advanced filters.

CONCLUSION

This paper has illustrated some relevant aspects in the evolution of filter design methods in the last decades. Although the main theory remains very solid, a deep comprehension of filter concepts and the improvement of CAD tools have led to significant advances in the design techniques. In addition, there are many stringent specifications to be met in the applications demanded by the industry. High selectivity, group delay flatness, power handling, insertion loss or mass and volume constrains are some of the usual requirements that have to be fulfilled by a microwave filter. As a result, many technologies and physical configurations have been introduced and developed to satisfy the features needed in diverse applications. The achieved design advances have followed directions mandated by the industry to improve the features of the filters, reducing the cost and development time to market. ■

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OCTAVE BAND LOW NOISE AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA01-2110	0.5-1.0	28	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA12-2110	1.0-2.0	30	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA24-2111	2.0-4.0	29	1.1 MAX, 0.95 TYP	+10 MIN	+20 dBm	2.0:1
CA48-2111	4.0-8.0	29	1.3 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA812-3111	8.0-12.0	27	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA1218-4111	12.0-18.0	25	1.9 MAX, 1.7 TYP	+10 MIN	+20 dBm	2.0:1
CA1826-2110	18.0-26.5	32	3.0 MAX, 2.5 TYP	+10 MIN	+20 dBm	2.0:1

NARROW BAND LOW NOISE AND MEDIUM POWER AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA01-2111	0.4 - 0.5	28	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA01-2113	0.8 - 1.0	28	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA12-3117	1.2 - 1.6	25	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA23-3111	2.2 - 2.4	30	0.6 MAX, 0.45 TYP	+10 MIN	+20 dBm	2.0:1
CA23-3116	2.7 - 2.9	29	0.7 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA34-2110	3.7 - 4.2	28	1.0 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA56-3110	5.4 - 5.9	40	1.0 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA78-4110	7.25 - 7.75	32	1.2 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA910-3110	9.0 - 10.6	25	1.4 MAX, 1.2 TYP	+10 MIN	+20 dBm	2.0:1
CA1315-3110	13.75 - 15.4	25	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA12-3114	1.35 - 1.85	30	4.0 MAX, 3.0 TYP	+33 MIN	+41 dBm	2.0:1
CA34-6116	3.1 - 3.5	40	4.5 MAX, 3.5 TYP	+35 MIN	+43 dBm	2.0:1
CA56-5114	5.9 - 6.4	30	5.0 MAX, 4.0 TYP	+30 MIN	+40 dBm	2.0:1
CA812-6115	8.0 - 12.0	30	4.5 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA812-6116	8.0 - 12.0	30	5.0 MAX, 4.0 TYP	+33 MIN	+41 dBm	2.0:1
CA1213-7110	12.2 - 13.25	28	6.0 MAX, 5.5 TYP	+33 MIN	+42 dBm	2.0:1
CA1415-7110	14.0 - 15.0	30	5.0 MAX, 4.0 TYP	+30 MIN	+40 dBm	2.0:1
CA1722-4110	17.0 - 22.0	25	3.5 MAX, 2.8 TYP	+21 MIN	+31 dBm	2.0:1

ULTRA-BROADBAND & MULTI-OCTAVE BAND AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA0102-3111	0.1-2.0	28	1.6 Max, 1.2 TYP	+10 MIN	+20 dBm	2.0:1
CA0106-3111	0.1-6.0	28	1.9 Max, 1.5 TYP	+10 MIN	+20 dBm	2.0:1
CA0108-3110	0.1-8.0	26	2.2 Max, 1.8 TYP	+10 MIN	+20 dBm	2.0:1
CA0108-4112	0.1-8.0	32	3.0 MAX, 1.8 TYP	+22 MIN	+32 dBm	2.0:1
CA02-3112	0.5-2.0	36	4.5 MAX, 2.5 TYP	+30 MIN	+40 dBm	2.0:1
CA26-3110	2.0-6.0	26	2.0 MAX, 1.5 TYP	+10 MIN	+20 dBm	2.0:1
CA26-4114	2.0-6.0	22	5.0 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA618-4112	6.0-18.0	25	5.0 MAX, 3.5 TYP	+23 MIN	+33 dBm	2.0:1
CA618-6114	6.0-18.0	35	5.0 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA218-4116	2.0-18.0	30	3.5 MAX, 2.8 TYP	+10 MIN	+20 dBm	2.0:1
CA218-4110	2.0-18.0	30	5.0 MAX, 3.5 TYP	+20 MIN	+30 dBm	2.0:1
CA218-4112	2.0-18.0	29	5.0 MAX, 3.5 TYP	+24 MIN	+34 dBm	2.0:1

LIMITING AMPLIFIERS

Model No.	Freq (GHz)	Input Dynamic Range	Output Power Range Psat	Power Flatness dB	VSWR
CLA24-4001	2.0 - 4.0	-28 to +10 dBm	+7 to +11 dBm	+/- 1.5 MAX	2.0:1
CLA26-8001	2.0 - 6.0	-50 to +20 dBm	+14 to +18 dBm	+/- 1.5 MAX	2.0:1
CLA712-5001	7.0 - 12.4	-21 to +10 dBm	+14 to +19 dBm	+/- 1.5 MAX	2.0:1
CLA618-1201	6.0 - 18.0	-50 to +20 dBm	+14 to +19 dBm	+/- 1.5 MAX	2.0:1

AMPLIFIERS WITH INTEGRATED GAIN ATTENUATION

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	Gain Attenuation Range	VSWR
CA001-2511A	0.025-0.150	21	5.0 MAX, 3.5 TYP	+12 MIN	30 dB MIN	2.0:1
CA05-3110A	0.5-5.5	23	2.5 MAX, 1.5 TYP	+18 MIN	20 dB MIN	2.0:1
CA56-3110A	5.85-6.425	28	2.5 MAX, 1.5 TYP	+16 MIN	22 dB MIN	1.8:1
CA612-4110A	6.0-12.0	24	2.5 MAX, 1.5 TYP	+12 MIN	15 dB MIN	1.9:1
CA1315-4110A	13.75-15.4	25	2.2 MAX, 1.6 TYP	+16 MIN	20 dB MIN	1.8:1
CA1518-4110A	15.0-18.0	30	3.0 MAX, 2.0 TYP	+18 MIN	20 dB MIN	1.85:1

LOW FREQUENCY AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure dB	Power-out @ P1-dB	3rd Order ICP	VSWR
CA001-2110	0.01-0.10	18	4.0 MAX, 2.2 TYP	+10 MIN	+20 dBm	2.0:1
CA001-2211	0.04-0.15	24	3.5 MAX, 2.2 TYP	+13 MIN	+23 dBm	2.0:1
CA001-2215	0.04-0.15	23	4.0 MAX, 2.2 TYP	+23 MIN	+33 dBm	2.0:1
CA001-3113	0.01-1.0	28	4.0 MAX, 2.8 TYP	+17 MIN	+27 dBm	2.0:1
CA002-3114	0.01-2.0	27	4.0 MAX, 2.8 TYP	+20 MIN	+30 dBm	2.0:1
CA003-3116	0.01-3.0	18	4.0 MAX, 2.8 TYP	+25 MIN	+35 dBm	2.0:1
CA004-3112	0.01-4.0	32	4.0 MAX, 2.8 TYP	+15 MIN	+25 dBm	2.0:1

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US Army Awards Contract for JAG Missile

The US Army awarded Raytheon Co. and Boeing a $125 M contract for the Joint Air-to-Ground Missile (JAGM) program. The contract funds a 27-month technology development program to develop and fire three prototype missiles with fully integrated tri-mode seekers.

"There is an urgent warfighter need to field this system and meet future needs," said John Weinzettle, Raytheon's JAGM program director. "The goal of the Raytheon-Boeing JAGM team is to deliver an affordable, reliable and complete system solution that can be integrated into the program's six required aircraft."

The JAGM program will produce a single missile solution for rotary- and fixed-wing platforms and unmanned aircraft. It is designed to defeat moving and stationary targets at extended ranges in all weather conditions.

The Raytheon-Boeing JAGM team brings mature, advance seeker and missile technologies to the program. The team also has decades of fixed- and rotary-wing integration expertise. The expected JAGM in-service date is 2016, and Raytheon is the prime contractor. "The Raytheon-Boeing JAGM team offers the US Army, Navy and Marine Corps an outstanding track record of performance in weapons program development, while delivering reliable products on time and on cost," said Carl Avila, director, Advanced Weapons, Boeing Integrated Defense Systems.

Lockheed Martin Upgrades Space Communications Processing System for USAF

Lockheed Martin announced the successful delivery of a space communications system that will bring more accurate and timely decision-making information to the US Air Force Space Commanders. This upgrade to the Combatant Commanders Integrated Command and Control System (CCIC2S) communications processing system enhances space message delivery reliability to and from the Space Data Operation center. This final delivery of CCIC2S Block 1 allows air mission operators, missile warning operators and space communications operators to effortlessly reach across the full spectrum of the nation's space and strategic assets.

"The CCIC2S Block 1 completion modernizes Cheyenne Mountain Air Force Station's Command and Control infrastructure, and significantly improves battlespace awareness, collaboration and effects based planning for the warfighter," said Gerry Fasano, vice president of C4ISR Solutions for Lockheed Martin's Information Systems & Global Services (IS&GS) Mission & Combat Support Solutions. "The entire team is to be commended for its significant effort to improve our nation's defense."

The CCIC2S Communications Processing System upgrades are part of the Integrated Space Command and Control (ISC2) contract to modernize and integrate 40 systems inside the Cheyenne Mountain Air Force Station. With this release, the current Cold-War era system can be decommissioned, as operations are migrated to this new system with a flexible, open standard infrastructure that takes full advantage of commercial products and technologies. This common architecture allows faster and more accurate decisions to be made by strategic and theater commanders. This is the third release of the messaging system, adding the space domain to the previously delivered air domain, deployed in 2002, and the missile warning domain, deployed in 2005. CCIC2S provides comprehensive command and control capabilities to support existing and future North American Aerospace Defense and US Northern Command missions as well as space & missile defense operations for US Strategic Command. It integrates previously stovepipe systems for air surveillance and warning and replacing old hardware and software with state-of-the-art technology.

Northrop Grumman Completes Integration for Advanced EHF Military Satellites

Northrop Grumman Corp. has completed integrating all electronics units of the payload module for the third Advanced Extremely High frequency (EHF) military communications satellite. The company is under contract to provide three communications payloads to advanced EHF prime contractor Lockheed Martin, Sunnyvale, CA.

The Advanced EHF system will provide global, highly secure, protected, survivable communications to warfighters operating on ground, sea and air platforms. Integrated with Lockheed Martin's A2100 space vehicle structure, the payload module consists of the complete set of radio frequency, processing, routing and control hardware and software that perform the satellite's protected communications function. The equipment includes approximately 20 electronics units and approximately 500,000 lines of software code.

"The successful integration of the third payload module keeps us right on track for delivering this payload on or ahead of schedule, as we did for the first two payload modules," noted Scott Willoughby, program director of Advanced EHF payloads for Northrop Grumman's Space Technology sector. "This consistent performance is a testament to the experience this team has developed over generations of protected MILSATCOM systems."

Advanced EHF is the successor to the current Milstar system. Milstar is the only protected satellite communications system operating in geosynchronous orbit. It alone provides US warfighters and leaders with assured, global communications in the face of jamming and other threats. One AEHF satellite will provide greater total capacity than the entire Milstar constellation. Individual user data will be five times better. The higher data rates will permit transmission of tactical military communication such as real-time video, battlefield maps and targeting data. In addition to its critical tactical mission, AEHF will also provide the survivable, assured communications to National Command Authority in all levels of conflict. Lockheed Martin is currently under contract to provide three Advanced EHF satellites and the Mission Control System to the US Air Force Military Satellite Communications Systems Wing, located at the Space and Missile Systems Center, Los Angeles Air Force Base, CA. The program is also in the process of producing long-lead items for a potential fourth spacecraft.

Harris Corp. Introduces Broadband Global Area Network Satellite Terminals

Harris Corp., an international communications and information technology company, introduced the first tactical satellite terminals with the capability of transmission/reception of TOP SECRET global wideband data communications. These new terminals are designed to military standards for operation in harsh environments.

The new Harris RF-7800B Broadband Global Area Network (BGAN) terminals offer a high-performance satellite solution for voice and data connectivity in beyond line of sight, SATCOM-on-the-move and SATCOM-at-the-quick-halt applications. When linked to next-generation Harris Falcon III manpack radios or SecNet 54® encryption modules, the RF-7800B terminals provide unique end-to-end Type 1 HAIPE-certified security for data transmissions over long range commercial networks.

The RF-7800B terminals can also be utilized as stand-alone terminals in other configurations to extend voice and data connectivity. The first two products in the Harris Tactical BGAN line are the RF-7800B-DU024, a Class 2 Land portable BGAN terminal for dismounted applications, and the RF-7800B-VU104, a Class 10 Land Mobile BGAN terminal for vehicles on the move. Both terminals meet MIL-STD-810F requirements and are specifically designed to work in harsh environments where commercial units fail. The terminals utilize the Inmarsat-4 BGAN satellite constellation and will be available to domestic and international customers in the first quarter of next year.

"The RF-7800B product line will benefit warfighters by allowing them to transmit Type-1 voice and data and access intelligence networks anywhere in the world, including in the most adverse environmental conditions," said Steve Marschilok, vice president and general manager, US Department of Defense Business. ■


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Lime Microsystems Joins Femto Forum

UK-based fabless semiconductor company Lime Microsystems has joined the Femto Forum, the independent industry and operator association that supports femtocell deployment worldwide. The Forum promotes the adoption of femtocell technologies through open standards, market education and ecosystem development. The working groups' mission is to ensure the rapid and effective deployment of femtocells to support a wide variety of customer propositions and operator business models.

Lime Microsystems announced first silicon in April 2008 and the company's transceiver design can be digitally configured to operate in any required frequency band between 375 MHz and 4 GHz, with 16 user-selectable bandwidths up to 28 MHz. This means it can transmit and receive data across all WiMAX bands (including those used in different geographical areas), as well as those used for W-CDMA and HSPA, and those that are planned for LTE.

The company will immediately participate in two of the Forum's working groups—Marketing and Promotion and the Radio and Physical Layer. The former looks at how the industry should best position femtocells within the industry and to the wider public, build usage cases, agree on common terminology and manage any potential concerns. The Radio and Physical Layer group is developing standardised RF interfaces, clarifying the various capability classes of femtocell and examining interactions with outdoor cells.

GSMA Aims to Turn Base Stations Green

The GSMA has launched the Green Power for Mobile programme with the goal of helping the mobile industry use renewable energy sources to power 118,000 new and existing off-grid base stations in developing countries by 2012. Achieving that target would save up to 2.5 billion litres of diesel per annum and cut annual carbon emissions by up to 6.3 million tonnes.

The GSMA, the global trade body for the mobile industry, forecasts that by 2012 up to 50 percent of new off-grid base stations in the developing world could be powered by renewable energy. Backed by 25 mobile operators, the Green Power for Mobile programme will provide expertise to support the deployment of base stations that use renewable energy.

The major suppliers of base stations have anticipated the growing demand for green networks and have introduced a variety of low-energy products as well as renewable energy power solutions. New entrants are also emerging, providing tailored bolt-on power solutions for base stations. The GSMA is developing metrics for 'green' base stations, to support operators in their decision-making on providers and products.

The GSMA Development Fund is already working with several mobile operators to develop renewable power solutions for a variety of base stations located in diverse geographies, including the Pacific island of Vanuatu and in the state of Andhra Pradesh in India.

UK MOD Sells Shareholding in QinetiQ

The UK Ministry of Defence has sold the remainder of its shares in international aerospace and defence group QinetiQ. Over 124 million shares were sold at a price of £2.06 each, completing the final stage of the company's privatisation, raising £257.3 M for the UK taxpayer.

In February 2006, QinetiQ Group plc was listed on the London Stock Exchange. In the year to 31 March 2008, the Group delivered a 19 percent increase in revenue to £1,366 M, including organic growth of 8.6 per cent, and a 20 per cent increase in underlying operating profit to £127 M.

QinetiQ is an international defence and security technology company with over 8,000 employees in Europe, the Middle East and Australasia and over 5,500 in North America. The company's vision is to be the world's leading provider of defence and security-based technology solutions and services.

Commenting on the sale, Sir John Chisholm, QinetiQ non executive chairman, said, "The MoD's sale of QinetiQ shares is consistent with its previously stated intention that it would sell its entire holding of ordinary shares. Our commercial relationship with the MoD is unaffected by this sale. The MoD retains its special share in the company which has no economic value but, in common with other privatised companies with strategically important roles, allows the Government to protect the national interest."

Space Council Considers European Space Policy

At a meeting of the fifth Space Council, ministers in charge of space activities within the European Space Agency (ESA) and European Union Member States welcomed the progress made in the implementation of the European Space Policy and identified further priority areas for its implementation.

In particular, the Space Council adopted a Resolution that highlights the significant advances in the two initial priorities and flagship space programmes of the European Space Policy—Galileo and Kopernikus. The Council identified the need to draw up a plan that provides for sustainable operational funding for Kopernikus and welcomed the proposal by the European Commission to start this with a new preparatory action in the preliminary budgets for 2009.

The Resolution also addressed the need to strengthen existing mechanisms for coordinating European expertise and investments in space as well as to set up mechanisms to improve synergies between civil and defence space programmes, respecting the specific requirements of both sectors, including their decision-making competences and finance schemes.

The Space Council recognised the substantial contribution of space, as a high tech R&D domain and through the economic exploitation of its results, to attaining the Lisbon goals and fulfilling the economic, educational, social and environmental ambitions of Europe and the expectations of its citizens.

On space and security, the Space Council highlighted the need to define ways and means to improve the coordination between civil and defence programmes through a structured dialogue among European institutional actors, including ESA.

TCS and Saab Set Up Design Centre in India

Saab and Tata Consultancy Services Ltd. (TCS) have signed a Letter of Intent to create an aviation technology design and development centre in India. The Aeronautical Design and Development Centre (ADDC) will be aimed at the global aviation market and will create design and development opportunities in India for both civil and military applications.

Through this collaboration Saab and TCS intend to establish a common development centre that both parties can benefit from and is considered to be the start of a long relationship that will increase both companies' opportunities to do business within the aviation and defence sectors.

Within Saab, Combitech will be responsible for establishing the ADDC, which will create design and development opportunities in India for both civil and military applications. Saab will transfer technology and expertise within aviation technology. The markets for aero structures, aero systems, avionics and aftermarket support are of special interest to the work in the centre. ■

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Broadcast RF Power Semiconductor Market Larger than Assumed

The global market for RF power semiconductors used in broadcasting is much larger than years of "conventional wisdom" have suggested, according to a new study from ABI Research. Its growth is being driven by the current explosion in digital broadcasting, both television and radio. This market is expected to remain very healthy for the next decade. "Historically, this market has been viewed as flat and not very exciting," says research director Lance Wilson. "In general, most RF power semiconductor vendors have overlooked and dismissed it. That, it turns out, is a grave error. To date, this market has never been comprehensively examined and we found that it is much bigger—approximately twice the size—than suggested by the conventional wisdom." This sizable market is being powered by the explosion in digital broadcasting, both television and radio, but especially TV. Some analog TV services are starting to decline somewhat, but the total demand for RF power semiconductors for broadcasting looks very promising for the next 10 years. Regionally, growth will be driven by the phased switchover to digital TV as it occurs in different countries.

Part of the reason for earlier assessments of this market has been that many of these semiconductors have been sold through electronic component distribution sales channels, making it more difficult to know where the parts are going. These channels have now been factored into the market forecast.

What kind of opportunity does this unexpectedly thriving market environment present for existing and new vendors? "Historically, this market favored well-established incumbents," says Wilson. "But it is not at all an adverse environment for new entrants if performance and pricing goals are met."

The Road to 4G

In 2008, the road to 4G has cleared a bit, with Ultra-mobile Broadband (UMB) left publicly by the roadside. However, the two remaining "4G" technologies, LTE and WiMAX, still present much speculation and confusion, InStat reported. Generally, "4G" technologies are considered those which are expected to meet the ITU's IMT-Advanced's requirements, i.e. LTE and IEEE 802.16m WiMAX. Both of these are based on OFDM and offer the potential for download speeds of 100 Mbps and upload speeds of 50 Mbps. Both 4G technologies, talking from the perspective of 100 Mbps technologies, are far from being commercially deployed. However, 802.16e Mobile WiMAX (802.16m's slower predecessor) is starting to come on the scene, with Clearwire expected to launch its network in September 2008. For this reason, LTE proponents have jumped up their efforts to speed up development.

Several factors are expected to affect the rate of adoption of LTE and WiMAX over the next three to five years:

- All of the world is watching the Sprint-backed Clearwire Mobile WiMAX network roll-out. The success of this roll-out is expected to have a huge effect on whether large worldwide carriers will roll out Mobile WiMAX. Launch is scheduled for 4Q08.
- Verizon Wireless has chosen LTE as its 4G technology of choice instead of WiMAX. Verizon Wireless, like Sprint, had been a strong candidate for WiMAX adoption, due to its core CDMA network. Its decision puts a damper on the assumption that carriers with CDMA networks will choose WiMAX; on the contrary, now the assumption is that most will choose LTE. The company is also targeting an aggressive roll-out of LTE in 2010.
- HSPA may turn into 802.16e WiMAX's true competitor, as HSPA roll-outs increase worldwide, and carriers look to HSPA Evolution to push network throughputs to 20 Mbps and beyond.
- Edge Evolved may come on the scene in regions where WCDMA has not yet been deployed by GSM operators, offering a fairly inexpensive and easy upgrade with promising throughput gains. Carriers' decisions to adopt Edge Evolved may delay these carriers' upgrade to WCDMA/HSPA, and furthermore, LTE.
- Carriers that have rolled out HSPA are more inclined to roll out HSPA Evolution, which offers high throughputs of up to 40 Mbps. This is expected to delay the beginning of commercial LTE roll-outs until the 2012-2013 timeframe.

Forecasts Highlight Rapid Evolution of Ultra-mobile Device Market

The fledging market for ultra-mobile devices (UMD)—a catch-all term that includes ultra-mobile PCs (UMPC), netbooks and mobile Internet devices (MID)—is already complex and will become more complicated as it grows. A few salient forecast numbers may serve to guide vendors and investors as they negotiate this tricky landscape. According to ABI Research principal analyst Philip Solis, "Total revenues earned by vendors in the UMD market are expected to increase from \$3.5 B in 2008 to nearly \$27 B in 2013."

This year, retail sales account for only 14 percent of shipments, while UMDs provided by mobile operators stand at nearly 30 percent; the balance are sold directly by manufacturers. Over five years, however, that distribution mix will change significantly. Operators currently subsidize UMDs for the sake of their potential service revenue, but they would prefer not to. By 2013, only 20 percent will be operator-provided, while retail sales are expected to account for 75 percent.

In 2013, more than half of all UMDs will have x86 processors at their heart (largely Intel's Atom), with the balance based on ARM processors. When it comes to operating systems, in 2013 Linux will outnumber Windows devices by two to one across all UMDs, despite the higher return rate for Linux products (compared to Windows products) experienced by netbook vendors today.

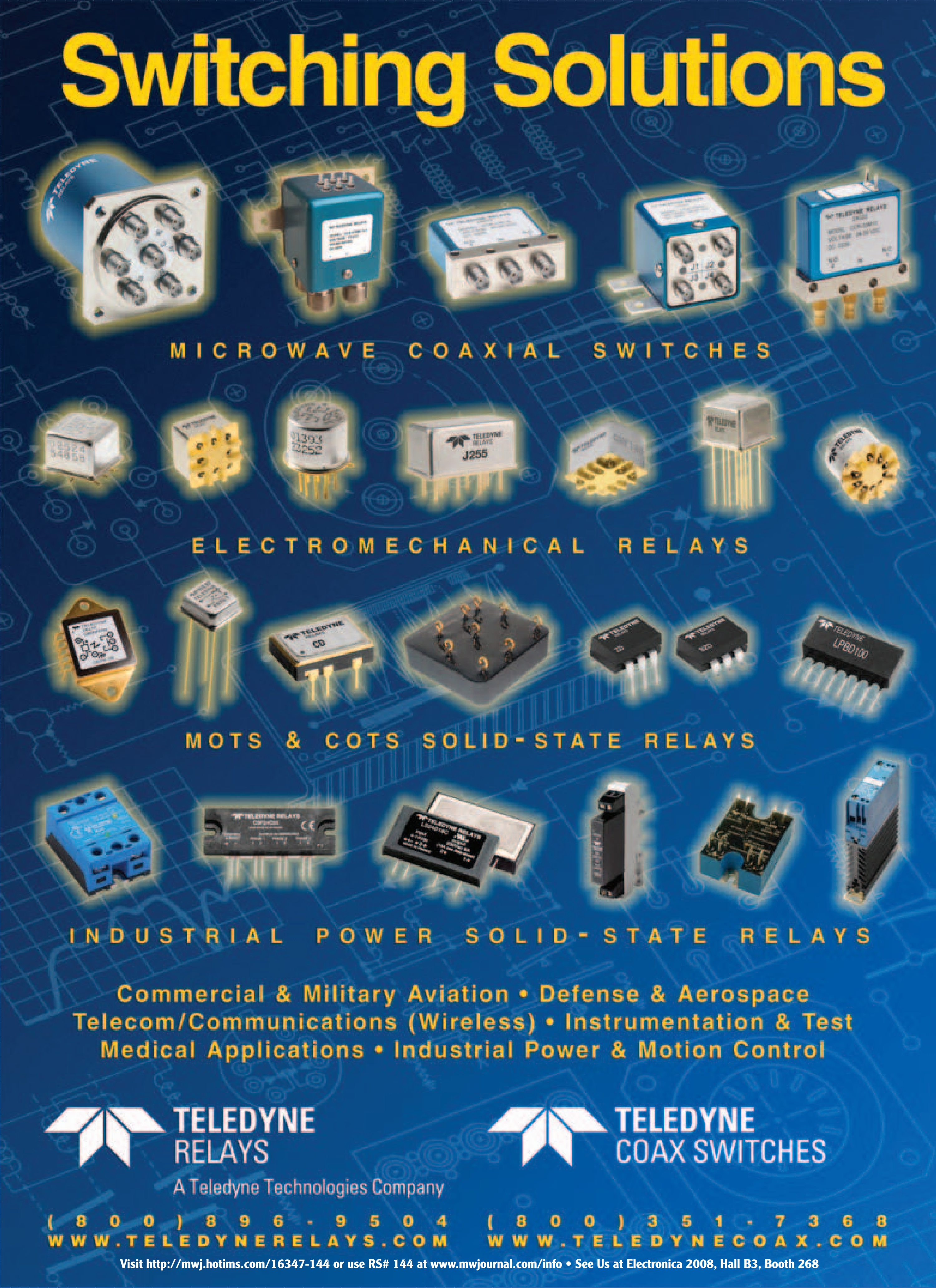
Healthy Growth in Global Home Networks Despite Potential Issues

Driven by the still rising number of broadband subscribers, the desire to share bandwidth, residential gateway use by telecom broadband providers, and increases in Asia/Pacific, the worldwide installed base of home networks is expected to break the 200 million mark by the end of 2008. Compared to previous years, the growth of the total market for broadband and network customer premises equipment (CPE) is slowing, but is expected to remain positive through at least 2012 as technological upgrades will spur replacements, reports In-Stat. The total CPE market includes broadband modems, routers and residential gateway equipment for DSL, cable, fiber-to-the-home (FTTH), Fixed Wireless Broadband (FWB) and Fixed Satellite Broadband (FSB), the high-tech market research firm says.

"With worldwide broadband subscribers predicted to exceed 500 million in 2010, there will be a very significant installed base of equipment that presents opportunities for replacements and upgrades," says Joyce Putscher, In-Stat analyst. "Gigabit Ethernet, VoIP, the DSL Forum's TR-69 and 802.11n are examples of drivers for CPE upgrades and replacements over the next several years. But we see a potential issue in terms of consumers' lack of knowledge regarding the benefits and differences between 802.11g and 802.11n, which could spell trouble for 802.11n upgrades."

Recent research by In-Stat found the following:

- Worldwide CPE unit shipments grew 15 percent in 2007 by 149 millions.
- By 2010, gateways will garner a majority share of global annual CPE revenue.
- By 2012, routers are expected to still be comprised of a higher percentage of wireless units than DSL gateways. Asia/Pacific's share of routers will continue to increase through 2011.
- Worldwide home LAN PHY interface shipments will surpass 500 million during 2010.
- "Green" network equipment is not among the most important features in consumers' minds. ■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INDUSTRY NEWS

■ **The Fordahl Group** based in Switzerland and **FOQ Piezo Technik GmbH** based in Germany have signed a Management, Commercial and Technical agreement that will lead to the creation of the largest European crystal and oscillator manufacturing group. This initiative is not only aimed at strengthening Fordahl-FOQ's activities in the crystal and oscillator market worldwide, but will also enable customers to benefit from a wider product range through one single commercial channel. It is claimed that the combination of the merged group's three factories, engineering and commercial teams will enable it to provide the best technical and cost-effective solutions to any requirements under one single umbrella. Nils Engdahl has been appointed as the new CEO of FOQ Piezo Technik GmbH.

■ Following the purchase by **Cobham Defense Electronic Systems** of M/A-COM Inc. on 26 September, **M/A-COM Technology Solutions Inc.** (M/A-COM Tech) has been formed. The company will continue to focus on commercial, industrial and government markets, specializing in RF, microwave and millimeter-wave component and technology solutions that are utilized around the globe in some of the most challenging applications. These include wireless infrastructure, handsets, WLAN, WiMAX, CATV, VSAT, automotive, test and measurement, radar and government solutions and applications. Headquartered in Lowell, MA, M/A-COM Tech will build on some 60 years of experience to develop and manufacture active and passive products, including Si- and GaAs-based semiconductors from facilities in Lowell, MA and Torrance, CA. Infrastructure products will continue to be provided by the company's facility in Cork, Ireland and Laser Diode products in Edison, NJ.

■ **Skyworks Solutions Inc.** and **Ember**, a leader in ZigBee® technology, announced that they are partnering to develop a portfolio of ZigBee front-end modules (FEM) targeting applications such as smart meters in energy management, home area networks (HAN) and industrial automation. ZigBee is a wireless network standard that solves the unique needs of remote monitoring and control, and sensor-network applications.

■ **The Micromanipulator Co.**, a supplier of analytical probing solutions for semiconductor wafer testing, announced that it has entered into a collaborative business development alliance with **Presto Engineering**, San Jose, CA. Presto provides product engineering services to the semiconductor industry. The primary objective of this alliance is to enhance access to Presto's wafer-level advanced in-silicon analysis services for customers needing 300 millimeter wafer probing support. Micromanipulator and Presto can now offer probing support services to integrated device manufacturers (IDM) and fabless semiconductor manufacturers, which are broadly represented in Silicon Valley. Under this agreement, the Presto facilities in San Jose, CA will also serve as a product demonstration site for Micromanipulator.

■ **Agilent Technologies Inc.** and **Altair Semiconductor** announced they will collaborate to accelerate the development of Mobile WiMAX devices. The companies plan to optimize the calibration and verification of Altair's Mobile WiMAX chipset using Agilent's Wireless Networking Test Set. As a result, handheld-device manufacturers implementing Altair's Mobile WiMAX chipset will be able to quickly and efficiently test and verify their Mobile WiMAX devices.

■ **TECOM Industries**, a Smiths Interconnect company that is part of the global technology business Smiths Group, and German antenna developer **QEST Quantenelektronische Systeme GmbH** announced a teaming agreement to jointly produce and market airborne broadband antennas for in-flight connectivity. In response to the growing market demand, the partnership between the two companies aims to deliver antenna products that are technologically superior within shortest time-to-market.

■ **RMI Corp.**, a provider of high performance processors for communication and media, has increased its partner alliance members to include **CSR** and **SiGe Semiconductor.** These new partners were selected to work with RMI to deliver a low cost GPS implementation in RMI's mPND reference solution.

■ **AWR**, a leader in high frequency EDA, and **Mentor Graphics® Corp.**, a market and technology leader in printed circuit board (PCB) design solutions, announced AWR Connected™ for Mentor Graphics. This new synergy of design flow between AWR and Mentor Graphics obsoletes file translation between Mentor Graphics' Expedition Enterprise design environment and AWR's Microwave Office® microwave and RF design environment. The resulting design and simulation solution is easy to learn and use and its operation is fully transparent to the user.

■ **7 layers** upgraded its Irvine, CA, test and service center with High Speed Uplink Packet Access (HSUPA) test capabilities from **Rohde & Schwarz**. 7 layers operates independent laboratories for wireless technologies, accredited in accordance to ISO 17025. By adding these new services to its already extensive test capabilities for the mobile industry, it will become the first independent laboratory in North America that can run the required HSUPA test cases locally.

■ **Tektronix Inc.**, a provider of test, measurement and monitoring instrumentation, announced plans to open a series of Test and Measurement Centers of Excellence around the world equipped with state-of-the-art technology. Each center will be staffed by application engineers to consult with customers and demonstrate testing solutions for high speed serial data technologies like Serial ATA and DisplayPort. Initially, centers are planned for Santa Clara, CA, Shanghai, China, Taipei, Taiwan, and Tokyo, Japan.

■ **EMS Technologies Inc.** held a groundbreaking celebration for a new, 30,000-square-foot expansion of its De-

fense & Space Systems Division (D&SS) facilities, located in Gwinnett's Technology Park, Norcross, GA. More than 300 employees and special guests attended the event on September 29. The expanded facility is scheduled to be completed in March 2009 and will serve as the new home for much larger labs and facilities for the division's machine shop, B-2 lab, environmental lab and integration and test lab, among others.

■ **RF Micro Devices Inc.** (RFMD®), a leader in the design and manufacture of high performance semiconductor components, announced it has captured design wins on more than 10 upcoming **Samsung** 3G handsets, supporting Samsung's anticipated growth in 3G handset sales. Based upon current customer forecasts, RFMD anticipates volume shipments to commence in the December 2008 quarter and accelerate into calendar 2009.

■ **Jacket Micro Devices Inc.** (JMD), a leader in embedded passive technology, announced that it has been awarded patent number 7,439,840 from the US Patent and Trademark Office. The patent, entitled "Methods and Apparatus for High-performing Multi-layer Inductors," is JMD's seventh patent related to organic embedded component design and technology.

■ **Rogers Corp.**'s Bisco® Silicones quality management system has been accredited by Underwriters Laboratories for AS9100, the quality management system standard for the aerospace industry for the design and manufacture of high performance silicone elastomer materials.

■ **IMI Inc.**, a provider of technologically-advanced commercial, military and RF/microwave (Teflon) printed circuit boards, has received the AS 9100B:2004/ISO 9001:2000 registration for its Haverhill, MA facility. AS9100 is an internationally recognized aerospace industry standard for quality assurance in design, development, production and service.

CONTRACTS

■ **Elcom Technologies Inc.** announced receipt of orders totaling $2.8 M from two major US military contractors for Elcom's Ultra Fast Switching series of direct analog synthesizers. The application demands exceptionally fast switching speeds and low phase noise, technologies where Elcom is an industry leader.

■ **OEwaves Inc.** has been awarded a contract by UCLA to develop a wideband, high dynamic range EO resonator modulator prototype that is highly sensitive and small in size, weight and power (SWAP), ideal for high performance receiver front-end applications. OEwaves will prototype the EO resonator modulator and integrate it with an all-dielectric antenna for the radio front-end. The UCLA ADNERF effort is part of the DARPA Electro-Magnetic Pulse Tolerant Microwave Receiver Front-end (EMPIRE) program.

■ **DragonWave Inc.**, a supplier of next-generation point-to-point microwave radio systems, announced that **Altitude Infrastructure**, a subsidiary of Altitude Group, has selected DragonWave products to provide high capacity Ethernet backhaul as part of its rollout of WiMAX broadband services across France. Altitude has pioneered WiMAX service introduction in France. Its first deployments took place in 2004. To date, DragonWave's Ethernet backhaul solution has been selected for four regional deployments in the Département de la Haute Garonne, Département des Deux Sèvres, Département du Jura and Département des Pyrénées Atlantiques.

NEW MARKET ENTRIES

■ **Incyte Inc.** announced complete digital IC design support for analog/RF design groups. Incorporated in 1996 with focus on IC physical design services and consulting, Incyte has expanded its capabilities to offer full digital design and integration support. With extensive experience in custom analog, custom digital and ASIC-based design flows, Incyte is well positioned to assist analog design groups with their digital needs. A strong CAD engineering background ensures well thought out and proven design flows. Whatever the approach, analog on top, digital on top or mixed signal on top, Incyte offers the experience to successfully implement RTL through verified IC layout. To learn more, e-mail: info@incyte-inc.com or visit www.incyte-inc.com.

■ **RFCONNEXT Inc.** has been established to provide new interconnect products and services for high speed digital and RF/microwave/optical communication systems. The company has developed PMTL™, a new patent pending, transmission line technology, for high speed interconnect and packaging of devices and systems. The initial PMTL uflex cables provide stable phase, group delay and impedance, with low insertion loss and extremely low cross talk, under bending, twisting, and mechanical distress, from DC to 50 GHz, and scalable to work to 220 GHz and beyond. For more information, visit www.rfconnext.com, e-mail: info@rfconnext.com or call (408) 981-3700.

■ **Nuvotronics** announced that its PolyStrata™ Microfabrication process is now available for use in commercial markets including RF electronics, medical and biomedical, and sensing. This process, originally developed under DARPA grant funding, has never before been released for commercial availability. Nuvotronics is a small business that was established by a group of seasoned high-tech entrepreneurs in June of 2008. Nuvotronics acquired the Rohm and Haas Microfabrication business in Blacksburg, VA this past July. For more information on PolyStrata multi-user runs, visit www.nuvotronics.com or e-mail: sales@nuvotronics.com.

■ **NuSil Technology** is a manufacturer of silicone-based materials for the aerospace, electronics, photonics and healthcare industries. NuSil's offerings include dispersions, gels, adhesives, sealants, coatings, resins, fluids, fluorosilicones, high-consistency elastomers, electrically and thermally conductive elastomers, liquid silicone rubbers and controlled volatility materials. ISO-9001-certified since 1994, NuSil operates state-of-the-art laboratories and processing facilities in North America and Europe and provides on-site, in-person application engineering support worldwide.

PERSONNEL

■ ProVision Communications, a wireless video and RF network planning company, has announced the appointment of former Lucent EMEA chief executive **David C W Rogers** as its new chairman. The appointment comes at a strategic time for Bristol, UK-based ProVision as it is rapidly developing its business to take advantage of new market opportunities for wireless video. Rogers has held a number of senior positions in the broadcast and consumer electronics industry, including those of CEO of Amstrad, vice president, Philips Consumer Communications, and president and CEO EMEA of Lucent Technologies. He was the founding chairman and CEO of BluArc Inc., and is also chairman of Mirifice Ltd.

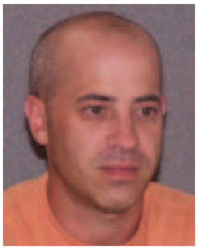
▲ *David C W Rogers*

■ Park Electrochemical Corp. announced the appointment of **Patrick Crowley** as president of Nelco Products Pte. Ltd., Park's high technology electronics circuitry materials and advanced composite materials subsidiary located in Singapore. Crowley will also serve as president of Nelco Technology Ltd., Park's electronics circuitry materials subsidiary located in Zhuhai, China. Crowley will be located in Singapore.

■ Quantum Leap Packaging Inc., a provider of high performance semiconductor packaging, announced the appointment of **Byoung Lee** as chief financial officer. Lee has over 15 years of experience in RF/microwave, semiconductor, and defense & space electronics industries. He served as executive/senior finance positions in both publicly-held and private research, engineering and manufacturing companies. He was most recently the chief financial officer/VP special projects at REMEC Defense & Space.

■ Mimix Broadband Inc., a supplier of microwave and millimeter-wave gallium arsenide (GaAs) semiconductors, announced that it has appointed **Guy Krevet** as vice president special projects. Krevet will focus on establishing strategic practices to maintain operational excellence across manufacturing, engineering and quality functions as Mimix continues to grow. Most recently with RFMD and Sirenza Microdevices, Krevet brings to Mimix more than 35 years experience at leading RF manufacturing companies. By providing expertise in the areas of new product line development, off-shore manufacturing, operational integration, acquisition outsourcing and product line optimization, Krevet has enabled growth oriented organizations to achieve operational excellence.

■ ClearComm Technologies LLC, a custom designer of custom designed filter products for the commercial, military and wireless markets located in Fruitland, MD, announced the appointment of **Joe Bartholomew** to the role of VP of engineering. In his role, he will be responsible for managing the engineering department, designing and prototyping cavity combline and ceramic waveguide filter products, and assisting



▲ *Joe Bartholomew*

manufacturing for ClearComm Technologies LLC. In addition, he is tasked with maintaining excellent relations with ClearComm's existing clients as well as introducing new products and services to their clients and to prospective customers. Most recently, Bartholomew was employed at Powerwave Technologies in Salisbury, MD as a senior principal design engineer. Prior to Powerwave, he was employed at FSY Microwave in Columbia, MD as a design engineer.

■ Tahoe RF Semiconductor Inc., a growing RF semiconductor company, announced that **Hans Dropmann** has joined as VP of marketing and business development to help guide the company in its next phase of growth. Dropmann brings to Tahoe RF a wealth of experience as a proven executive in RF semiconductor business. He previously worked for Maxim Integrated Products Inc. as a director and business manager of wireless products where he grew the handset and cellular component business to an aggregate reaching well into the triple digit million dollars.

■ Analog Devices Inc. has appointed **Shalini Palmer** as Northern Europe sales director and **Kevin Carlin** as Central Europe sales director. Both appointments bring a wealth of experience into the European sales operation as the company looks to expand its coverage in the region. Palmer joins from Intersil where she served as regional sales director for Northern Europe and played a major role in engaging with key customers, understanding customer needs, and recommending sustainable solutions. Carlin most recently served as regional sales manager for Central Europe at Texas Instruments, a role he held for four years. With 10 years' experience in technical sales, he has a strong understanding of the European semiconductor market.

▲ *Shalini Palmer*

▲ *Kevin Carlin*

■ Crane Aerospace & Electronics, a segment of Crane Co., has announced the appointment of **Dominic Chow** as director of custom power solutions. In this capacity, Chow will be responsible for program management, new business development, strategic planning, management of business relationships with key customers, as well as Custom Power Solutions profit and loss. Chow joined Crane in 1984 as a mechanical engineer and has held a series of successively more responsible positions in the company since that time. Most recently, he led the business development and business management functions for Custom Power.

▲ *Dominic Chow*

■ Renaissance Electronics Corp. announced the appointment of **Frank Balsamo** as the new manager of ferrite products. The North American sales manager for ferrite products, Balsamo will manage and develop the ferrite product line throughout the US and Canada. Balsamo is a degreed engineer with over 10 years of professional B2B sales experience (both financial and technical).

■ Labtech Microwave, a UK designer and manufacturer of microwave solutions and microwave component technology, has appointed **Stephen Melvin** as its new principal engineer, with the aim of developing the company's monolithic microwave integrated circuits (MMIC) packaging and liquid crystal polymer (LCP) offering. Prior to joining Labtech Microwave, Melvin was the senior design engineer for RFMD (formerly Filtronic Compound Semiconductors), where he designed MMICs for power amplifiers as well as microwave radio components and broadband microwave integrated circuit (MIC) amplifiers for electronic warfare applications.

REP APPOINTMENTS

■ **Richardson Electronics Ltd.**, a specialized international distributor of RF and microwave components, announced that **Avago Technologies** has selected Richardson to distribute its wireless products in the European market. Effective immediately, this is an expansion of Avago's existing distribution agreement with Richardson, which previously covered Southeast Asia, Japan and the entire western hemisphere.

■ **IET Labs Inc.**, a manufacturer of manual and programmable standards, substituters and instruments for calibration, test, measurement and metrology applications, announced a new exclusive government services partnership with Technical Communities, a service provider for technical organizations that sell to US government agencies, military organizations and prime federal contractors. The agreement authorizes Technical Communities to provide IET Lab products.

■ **C&K Components**, an international supplier of tact switches, toggle, rocker and push button switches, and smart card interconnect devices, announced that it has signed a distribution agreement with **TTI Inc.**, a passive, connector and electromechanical specialist distributor in the electronics industry.

■ **MITEQ Inc.** announced the appointment of **Beacon Technical Sales Inc.** as the company's exclusive sales representative in Connecticut (excluding Fairfield County), Maine, Massachusetts, New Hampshire, Rhode Island and Vermont. Beacon Technical Sales Inc. will represent MITEQ's Component division of products that includes amplifiers, mixers, frequency multipliers, passive power components, switches, attenuators, limiters, phase shifters, IF signal processing components, oscillators, synthesizers, integrated multifunction assemblies and fiber optic products. Beacon Technical Sales Inc. can be contacted at (603) 880-0092 or e-mail: sales@beacon-tech.com.

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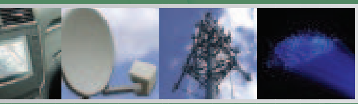
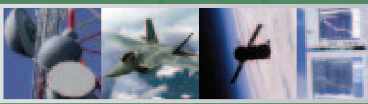
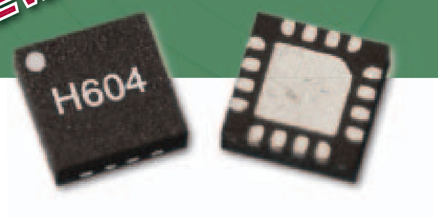


Analog & Mixed-Signal ICs, Modules, Subsystems & Instrumentation



New!



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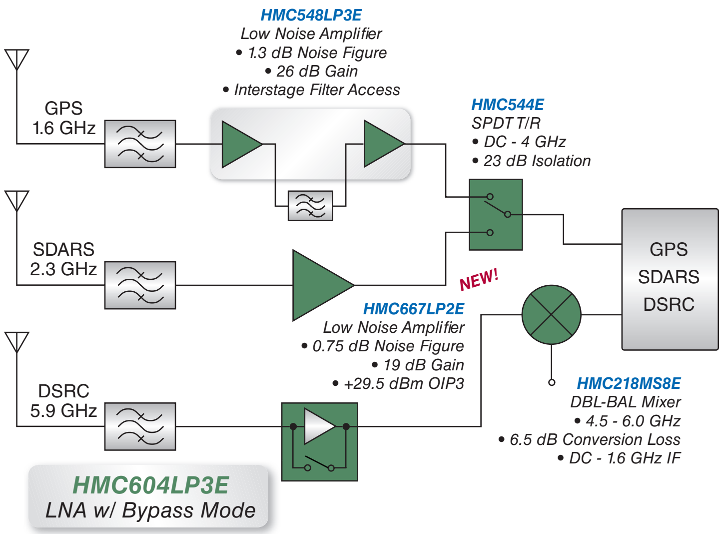

A SELECTION OF IN-STOCK LNAs INCLUDING 12 NEW PRODUCTS

	Frequency (GHz)	Function	Gain (dB)	OIP3 (dBm)	NF (dB)	P1dB (dBm)	Bias Supply	Package	Part Number
NEW!	0.175 - 0.66	Low Noise	24	37	0.5	19	+5V @ 90mA	LP3	HMC616LP3E
NEW!	0.2 - 4.0	Low Noise, High IP3	13	38	2.3	22	+5V @ 110mA	ST89	HMC639ST89E
NEW!	0.2 - 4.0	Low Noise, High IP3	13	40	2.2	22	+5V @ 155mA	ST89	HMC636ST89E
	0.35 - 0.55	Low Noise	17	38	1	21	+5V @ 104mA	LP3	HMC356LP3E
NEW!	0.55 - 1.2	Low Noise	16	37	0.5	21	+5V @ 88mA	LP3	HMC617LP3E
NEW!	0.7 - 1.2	Low Noise, Failsafe Bypass	16	33	0.9	13	+5V @ 57mA	LP3	HMC668LP3E
NEW!	1.7 - 2.2	Low Noise, Failsafe Bypass	17	29	1.4	12	+5V @ 86mA	LP3	HMC669LP3E
NEW!	1.7 - 2.2	Low Noise	19	36	0.75	20	+5V @ 117mA	LP3	HMC618LP3E
NEW!	2.1 - 2.9	Low Noise	19	33	0.9	19	+5V @ 95mA	LP3	HMC715LP3E
NEW!	2.3 - 2.7	Low Noise	19	29.5	0.75	16.5	+5V @ 59mA	LP2	HMC667LP2E
	2.3 - 2.7	Low Noise w/ Bypass	20	31	1.1	17	+5V @ 74mA	LP3	HMC605LP3E
NEW!	3.1 - 3.9	Low Noise	18	33	1	19	+5V @ 65mA	LP3	HMC716LP3E
	3.3 - 3.8	Low Noise w/ Bypass	19	29	1.2	16	+5V @ 40mA	LP3	HMC593LP3E
NEW!	4.8 - 6.0	Low Noise w/ Bypass	15	26	1.5	14	+5V @ 42mA	LP3	HMC604LP3E
NEW!	4.8 - 6.0	Low Noise	16.5	31.5	1.1	18.5	+5V @ 73mA	LP3	HMC717LP3E

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■ **Florida RF Labs** and **EMC Technology** announced the appointment of **Mechtronics Sales Inc.** to cover the territory of Maryland, Virginia, Delaware and Washington, DC. Mechtronics Sales is located in Columbia, MD. For more information, visit www.mechtronics.net.

■ **Vaunix Technology Corp.** has announced that **National Test Equipment Inc.** is now an authorized distributor of its Lab Brick® family of USB test equipment. The Lab Brick family presently consists of low cost signal generators and digital attenuators covering RF and microwave frequencies up to 6 GHz. National Test Equipment offers an extensive inventory of electronic test and measurement equipment including the Lab Brick attenuators and signal generators. For more information, contact Vaunix Technology at (978) 662-7839, or visit www.labrick.com or contact National Test Equipment at (888) 683-2872 or visit www.nationaltestequipment.com.

■ **CAP Wireless Inc.**, a supplier of high performance microwave and RF amplifiers and amplifier-based subsystems, announced that in order to provide dedicated service and support to customers in the southern region of the United States, the company has signed **McBride Scientific Sales Inc.** as a manufacturer's representative for Texas (except El Paso), Oklahoma, Arkansas and Louisiana. McBride specializes in providing technical services and support for many of the top communications companies in the military, commercial and industrial markets. McBride can be reached by phone at (800) 322-5788 or e-mail: mssi1997@aol.com. For more information, visit the company's web site at: www.mcbridescientificsales.com.

■ **KOR Electronics** announced it has signed a marketing partnership agreement with **HyTech Associates**, Westlake Village, CA, to enhance its coverage to valued customers in the Southern California region. Headquartered in Westlake Village, CA, HyTech Associates is the exclusive worldwide applications/representative for a wide range of manufacturers in the Southern California region, specializing in value added high end RF/microwave components, subsystems and various supporting services. For further information, contact HyTech Associates, 717 Lakefield Road, Suite A, Westlake Village, CA 91361, ph: (818) 991-7491 or visit: www.hyth.com.

■ **International Manufacturing Services Inc.** (IMS), a leading manufacturer and supplier of high quality thick film resistors, terminations, attenuators, planar dividers and planar filters to the electronics industry, announces the appointment of **CBC Electronics** as its Florida representative. Since 1972, CBC Electronics has been addressing the electronic component needs of Florida at both the design and manufacturing levels. CBC has offices in Sorrento, Fort Meyers and Odessa.

CIRCUIT SIMULATION OF DUAL-MODE WAVEGUIDE CAVITY FILTERS

Dual-mode circular resonator (DMCR)-based waveguide filters, introduced in the beginning of the 1970s,[1-6] have well known advantages, compared to traditional waveguide filters. DMCR-based filters allow for two orthogonal TE_{111} modes to be employed by each circular cavity, thereby reducing by a factor of two the number of actual resonant cavities while maintaining a necessary number of filter sections. This results in a significant filter size reduction. The Q-factor of circular resonators employing TE_{111} modes is approximately twice that of the rectangular resonators employing TE_{101} modes,[7] which has a direct effect on the filter insertion loss. Finally, the major advantage of the DMCR-based waveguide filters is that such a structure allows for the cross-coupling between electrically non-adjacent elements.

The subject of this article is a transmission line (TL) circuit model representation of the dual-mode resonator-based waveguide filters in a variety of configurations. The TL circuit models presented allow for the evaluation of the expected filter parameters, based on an accurate solution, which includes a passband amplitude response, skirt selectivity, filter asymmetry, true real frequency transmission zeroes (reject notches) location, group delay flatness, phase slope, etc. The cross-coupling nature (capacitive or inductive) and filter configuration/topology related phasing issues are also reflected in the modeling, which makes it a useful tool during the design path. A separate analysis of the filter constituent elements

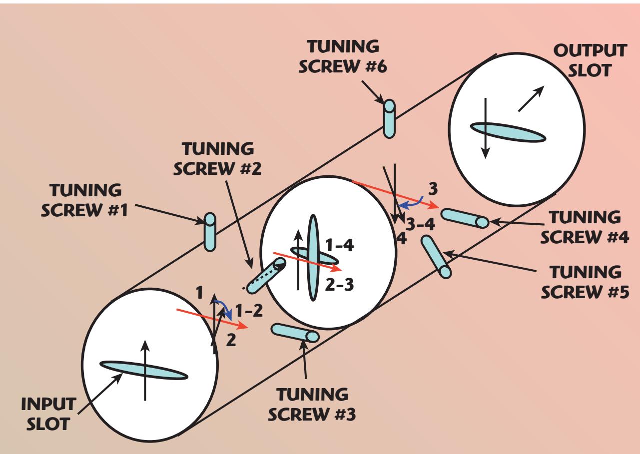

Fig. 1 Four-element dual-mode filter.

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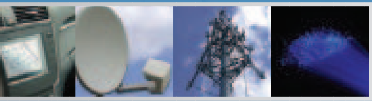
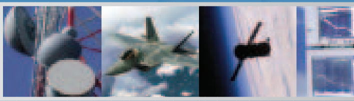
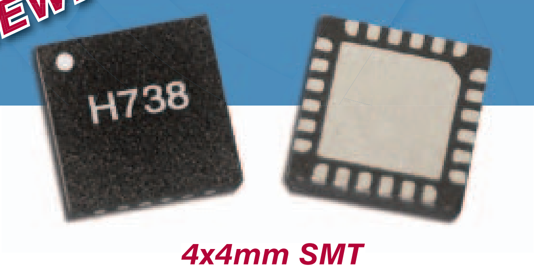


Analog & Mixed-Signal ICs, Modules, Subsystems & Instrumentation



NEW!



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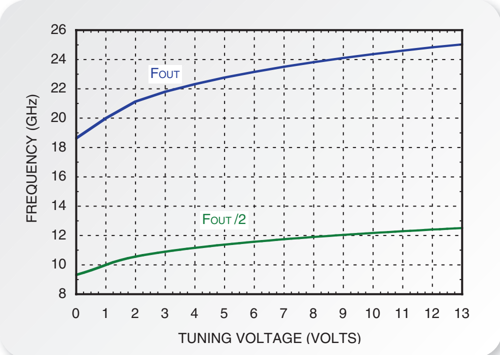

HMC738LP4E Frequency vs. Tuning Voltage, Vcc= +5V

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	Fo Frequency (GHz)	Fo/2 Frequency (GHz)	Function	Fo Output Power (dBm)	100KHz SSB Phase Noise (dBc/Hz)	Bias Supply	Package	Part Number
	8.45 - 9.55	4.225 - 4.775	VCO with Fo/2 & ÷4	13	-113	+5V @ 315mA	LP5	**HMC510LP5E**
	9.5 - 10.8	4.75 - 5.4	VCO with Fo/2 & ÷4	11	-110	+5V @ 350mA	LP5	**HMC530LP5E**
	9.6 - 10.8	4.8 - 5.4	VCO with Fo/2 & ÷4	9	-110	+5V @ 330mA	LP5	**HMC512LP5E**
	10.43 - 11.46	5.215 - 5.73	VCO with Fo/2 & ÷4	7	-110	+3V @ 275mA	LP5	**HMC513LP5E**
	10.6 - 11.8	5.3 - 5.9	VCO with Fo/2 & ÷4	11	-110	+5V @ 350mA	LP5	**HMC534LP4E**
	11.1 - 12.4	5.55 - 6.2	VCO with Fo/2 & ÷4	9	-110	+5V @ 350mA	LP5	**HMC582LP5E**
	11.17 - 12.02	5.585 - 6.01	VCO with Fo/2 & ÷4	7	-110	+3V @ 275mA	LP5	**HMC514LP5E**
	11.5 - 12.5	5.75 - 6.25	VCO with Fo/2 & ÷4	10	-110	+5V @ 200mA	LP5	**HMC515LP5E**
	11.5 - 12.8	5.75 - 6.4	VCO with Fo/2 & ÷4	11	-110	+5V @ 350mA	LP5	**HMC583LP5E**
	12.4 - 13.4	6.2 - 6.7	VCO with Fo/2 & ÷4	8	-110	+5V @ 260mA	LP5	**HMC529LP5E**
	12.5 - 13.9	6.25 - 6.95	VCO with Fo/2 & ÷4	10	-110	+5V @ 330mA	LP5	**HMC584LP5E**
	13.6 - 14.9	6.8 - 7.45	VCO with Fo/2 & ÷4	7	-110	+5V @ 260mA	LP5	**HMC531LP5E**
	14.25 - 15.65	7.125 - 7.825	VCO with Fo/2 & ÷4	9	-107	+5V @ 350mA	LP5	**HMC632LP5E**
NEW!	20.9 - 23.9	10.45 - 11.95	VCO with Fo/2 & ÷16	9	-95	+5V @ 200mA	LP4	**HMC738LP4E**
NEW!	23.8 - 26.8	11.9 - 13.4	VCO with Fo/2 & ÷16	8	-93	+5V @ 192mA	LP4	**HMC739LP4E**

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provides the design engineer with coupling coefficients and loaded input/output Q-factors, the information necessary for the actual filter development. The experimental filter responses compared against the circuit simulation are also presented.

GENERAL CONSIDERATIONS AND BASIC FILTER CONFIGURATIONS

Figure 1 illustrates a four-element dual-mode circular resonator-based waveguide elliptic filter structure and the mode formation in the resonators as described by Williams.[1] The incident wave applied to the input magnetic slot excites a vertical TE_{111v} mode, whose frequency is controlled by the tuning screw #1. The coupling screw #2, located at +45° to the vertical plane, produces an angular E-field component and, consequently, contributes to the orthogonal horizontal TE_{111h} resonant mode controlled by tuning screw #3. The horizontal TE_{111h} mode (second filter resonance element) of the first circular resonator is coupled to the third resonance element, which belongs to the second circular resonator via the vertical slot as shown, and the further mode formation in the second cavity occurs. The cross-coupling between vertical TE_{111v} modes of the first and second cavities (or between first and forth filter elements of the filter) is implemented via the horizontal magnetic slot, which is much smaller than a vertical slot of the main filter path.

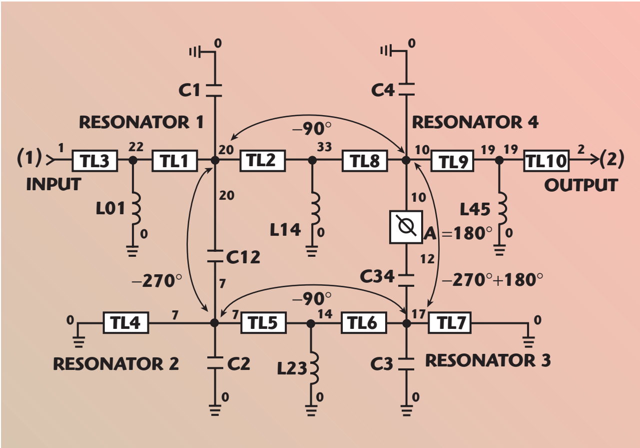
The phase and response analysis of the dual-path signal propagation in the filter structure is illustrated by the circuit represented in ***Figure 2***. Shown here are four half wavelength resonators each formed by two quarter-wave pieces of physical transmission lines (slightly shorter for tuning purposes) and coupled to each other and to the input/output transmission lines via inductive or capacitive elements. The frequency tuning of each filter element/resonance mode is provided by capacitors (C_1, C_2, C_3 and C_4) as shown. The first and second filter elements TE_{111} vertical and horizontal modes of the first resonator are coupled through the capacitive (electric coupling) tuning screw #2 (C_{12} of the circuit) as shown in Figures 1 and 2, so they maintain a 270° electrical phase shift at the center frequency.[8,9] The second and third filter elements, TE_{111} horizontal modes of the first and second resonators, are coupled through the vertical magnetic slot of the main path in the partition separating two cavities and represented by L_{23} inductance, so the phase between them is 90°. Coupling between horizontal and vertical modes of the second resonator is provided by the capacitive coupling screw #5 located at –45° or +135° angle to the vertical plane. The angular location of this coupling screw (C_{34}) assures the out-of-phase excitation of the vertical TE_{111v} mode[1] and can be introduced by a 180° electrical phase inverter in the circuit.

The resulting phase shifts for the main and cross-coupled paths are presented in ***Table 1***. Incorporation of an out-of phase cross-coupling in reality delivers an electrically in-phase "skip two" (quadruple) cross-

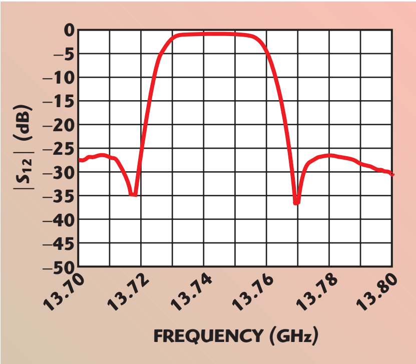
TABLE I

PHASE SHIFT FOR TWO PATHS

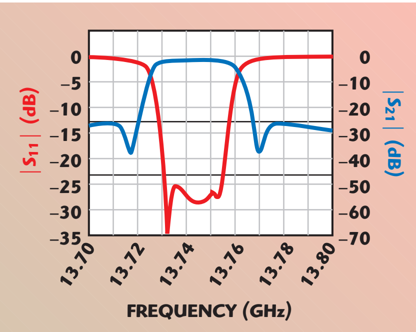
	Phase Shifts (°)	Total Phase Shift (°)
Main path, elements 1-2-3-4	-270 -90 (-270 +180)	-450
Cross-coupling path 1-4	-90	-90
Resulting phase shift		In-phase



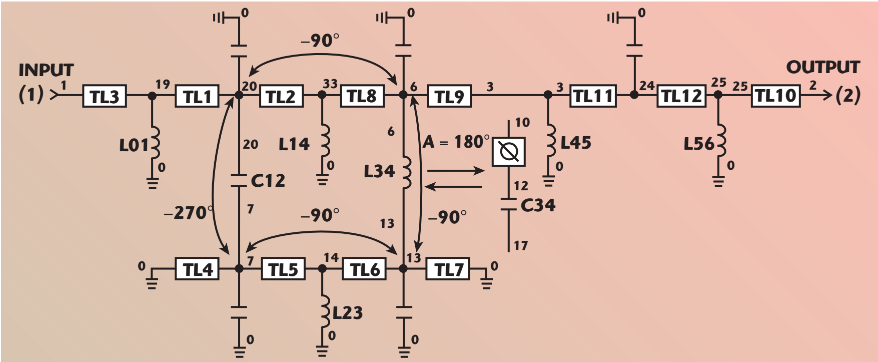
▲ *Fig. 2 Four-elememt dual-mode filter circuit.*



▲ *Fig. 3 Four-element dual-mode filter circuit amplitude response.*



▲ *Fig. 4 Four-element dual-mode filter prototype response.*



▲ *Fig. 5 Five-element dual-mode filter circuit.*

coupling that results in two real frequency transmission zeroes (jω-axis) on the filter skirts,[8] as shown in ***Figure 3***. Analogously, removal of the 180° phase inverter is equivalent to a +45° location of the coupling screw #5, which leads to the out-of-phase condition for both paths at the center frequency and consequently,[8] a flattened group delay and sluggish skirt selectivity responses.

For an accurate representation of the waveguide resonators, pieces of physical transmission lines used for simulation were modeled with characteristic impedances, electrical lengths and insertion losses (optional) dependent on the cut-off frequencies and Q-factors of the actual resonators. Shown below is a typical Genesis simulation software equation block containing all necessary variables:


```
f=FREQ/1000
l1= 14.2
l2=17.2
F0=13.7425
Fcoin=7.87
Fcoout=7.87
fco1=9.261
fco2=10.943
Zw1=377/SQR(1-(fco1/f)^2)
Zw2=377/SQR(1-(fco2/f)^2)
Zin = 377/SQR(1-(fcoin/f)^2)
Zout=377/SQR(1-(fcoout/f)^2)
WGWL1=300/SQR(f^2-fco1^2)
Tet1=0.5*l1*360/WGWL1
WGWL2=300/SQR(f^2-fco2^2)
Tet2=0.5*l2*360/WGWL2
```

where

- FREQ=Genesys frequency definition in MHz.
- l1, l2=an actual physical length of the first and second resonators (mm).
- fcoin, fcoout=cut-off frequency of the input/output waveguides (WR-75).
- fco1, fco2=cut-off frequencies of both resonators, directly related to the diameters of the actual resonators. The varying resonator diameters are used for a practical consideration in order to suppress an undesired high-order resonant mode, especially TE_{010} of the circular resonator whose frequency is determined by the cavity diameter only.
- Zw1, Zw2=characteristic impedances of the circular waveguides the resonators are based on.
- Zin, Zout=characteristic impedances of the input / output waveguides.
- WGWL1, WGWL2=waveguide wavelengths.
- Tet1, Tet2=cut-off frequency dependent electrical lengths of the resonators.

The input/output port impedances for this particular example are assigned as a WR-75 waveguide impedance at the center frequency 13.74 GHz. ***Figure 4*** shows an actual prototype response for the four-element dual-mode filter circuit.

It should be mentioned that the capacitive coupling element in cascade with the 180° phase inverter representing the out-of-phase excitation of the vertical TE_{111v} mode in the circuit can be replaced with an inductive element with a minimal

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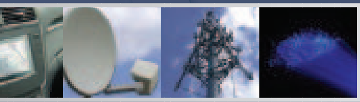

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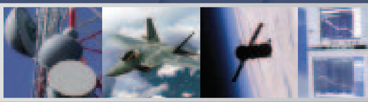

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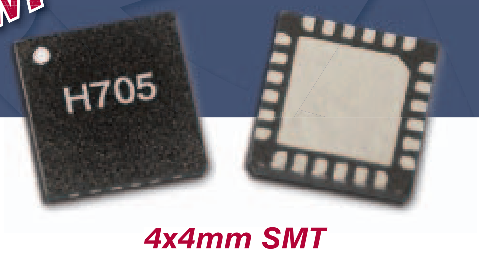

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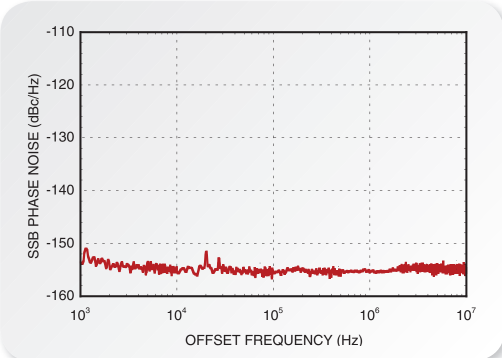

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	Input Freq. (GHz)	Function	Input Power (dBm)	Output Power (dBm)	100kHz SSB Phase Noise (dBc/Hz)	Bias Supply	Package	Part Number
	DC - 18	Divide-by-2	-15 to +10	-4	-150	+5V @ 77mA	LP3	**HMC492LP3E**
	DC - 8	Divide-by-3	-12 to +12	-2	-153	+5V @ 69mA	MS8G	**HMC437MS8GE**
	DC - 18	Divide-by-4	-15 to +10	-4	-150	+5V @ 96mA	LP3	**HMC493LP3E**
	10 - 26	Divide-by-4	-15 to +10	-4	-150	+5V @ 96mA	LC3	**HMC447LC3**
	DC - 7	Divide-by-5	-12 to +12	-1	-153	+5V @ 80mA	MS8G	**HMC438MS8GE**
	DC - 18	Divide-by-8	-15 to +10	-4	-150	+5V @ 105mA	LP3	**HMC494LP3E**
NEW!	0.02 - 6.5	Programmable Divider (N= 1 - 17)	-15 to +10	0	-153	+5V @ 200mA	LP5	**HMC705LP5E**
	DC - 2.2	5-bit Counter (N= 2 - 32)	-15 to +10	4	-153	+5V @ 194mA	LP4	**HMC394LP4E**
	Connectorized Frequency Divider Modules							
	0.5 - 18	Divide-by-2	-15 to +10	-4	-150	+5V @ 75mA	C-1 / SMA	**HMC-C005**
	0.5 - 18	Divide-by-4	-15 to +10	-4	-150	+5V @ 93mA	C-1 / SMA	**HMC-C006**
	0.5 - 8	Divide-by-5	-15 to +10	-1	-155	+5V @ 80mA	C-1 / SMA	**HMC-C039**
	0.5 - 18	Divide-by-8	-15 to +10	-4	-150	+5V @ 98mA	C-1 / SMA	**HMC-C007**
	0.5 - 17	Divide-by-10	-15 to +10	-1	-155	+5V @ 152mA	C-1 / SMA	**HMC-C040**

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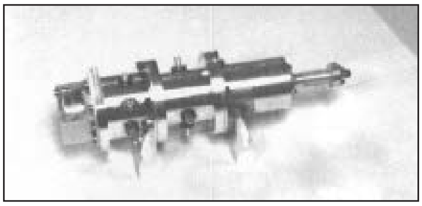
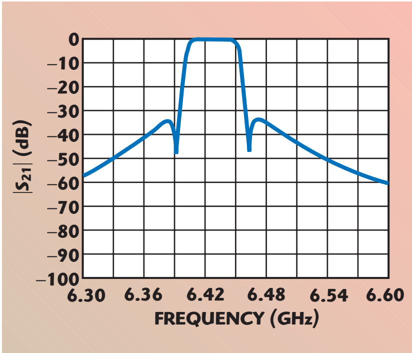
coupled resonator length (frequency) adjustment. An example of this statement, shown in ***Figure 5***, is a five-element dual-mode filter circuit resulting from the addition of a single resonance element to the four-element filter similar to one discussed above. The actual prototype is shown in ***Figure 6***. Here the capacitive coupling screw located at +135° (–45°) and delivering the out-of-phase excitation of the vertical TE_{111v} mode is replaced by an inductive element (L_{34}). Both theoretical and experimental responses (location of the transmission zeros, asymmetry and rejection overshoot) shown in ***Figures 7*** and ***8*** demonstrate a great deal of similarity.

SIX-ELEMENT DUAL-MODE CIRCULAR WAVEGUIDE FILTER

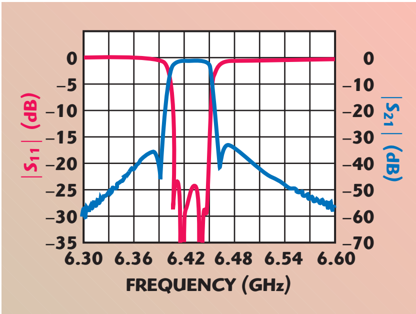
Figure 9 illustrates a six-element DMCR-based waveguide elliptic filter structure and the mode formation inside the resonators. The practical importance of this filter topology, mentioned in a number of papers,[8,10,11] is based on the fact that a single negative (out-of-phase) cross-coupling delivers an improved skirt selectivity along with a flattened group delay response.



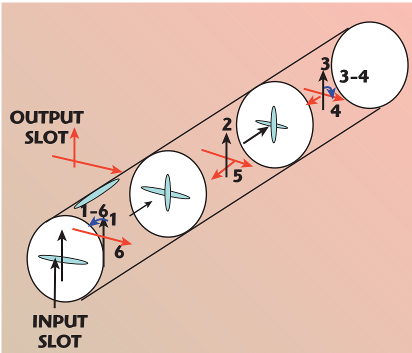
▲ *Fig. 6 Five-element dual-mode filter prototype.*



▲ *Fig. 7 Five-element dual-mode filter circuit response.*



▲ *Fig. 8 Five-element dual-mode filter prototype response.*



▲ *Fig. 9 Six-element dual-mode filter.*

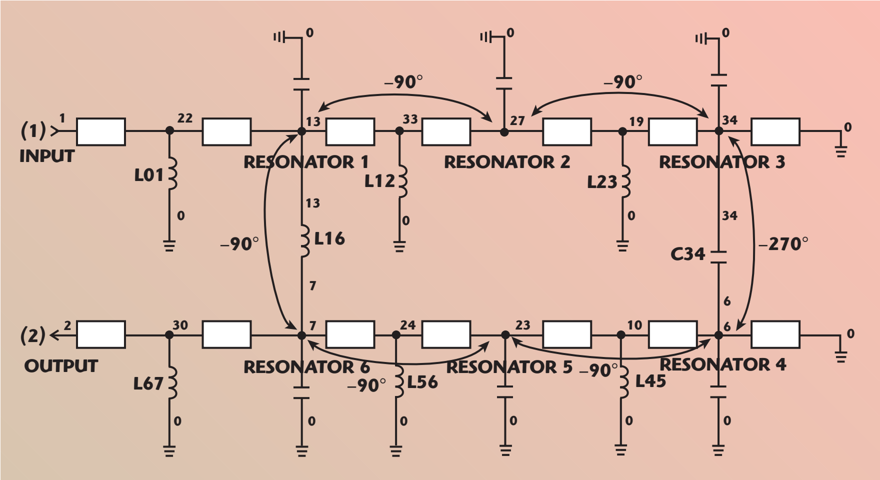


Fig. 10 Six-element dual-mode filter circuit.

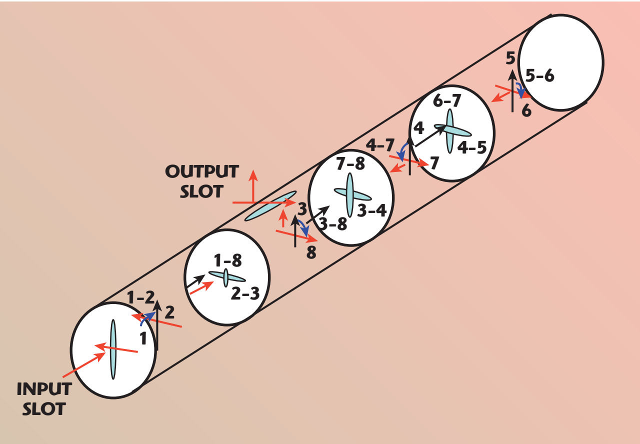


Fig. 12 Eight-element dual-mode filter.

The vertically polarized signal of the main path (black arrows) propagates through the resonators (exciting a TE_{111v} mode) and the horizontal coupling irises in the direction indicated by black dashed arrows. Coupled by the angular coupling screw (+45°) of the last (3rd) resonance cavity into the horizontal mode TE_{111h}, the main path signal travels back (red arrows) through the same cavities and vertical coupling slots. The out-of-phase cross-coupled signal delivered by the angular coupling screw (–45°) of the 1st resonance cavity is superimposed with the main path TE_{111h} mode. The transmission line circuit for this configuration is presented in ***Figure 10***. Applying the same argument as before and assuming that the center frequency phase shifts between resonators are related to the coupling means (inductive L_{16}, L_{12} to L_{56}, –90° and capacitive C_{34}, –270°) between resonance elements, the overall phase shift can be found (see ***Table 2***).

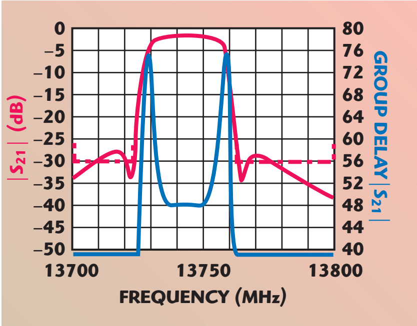


Fig. 11 Six-element dual-mode filter circuit amplitude and GD responses.

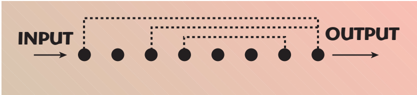


Fig. 13 Eight-element dual-mode circular waveguide filter cross-coupling.

Two signal paths, main and cross-coupled, maintain out-of-phase conditions provided by the angular coupling screw at the center frequency, which produces a pair of real axis (equalization) and real frequency (jω-axis) transmission zeroes. Due to a significant phase slope difference between the two paths, the in-phase signal summation occurs near the passband edges, but does not have any noticeable effect on the overall response.[8] Typical amplitude and group delay responses of this filter topology are shown in ***Figure 11***.

EIGHT-ELEMENT DUAL-MODE CIRCULAR WAVEGUIDE FILTER

Shown in ***Figure 12*** are the configuration and the signal propagation for a four-cavity/eight-element DMCR-based filter with an elliptic function response.[12] Such a topology allows three cross-couplings between non-adjacent resonators that place

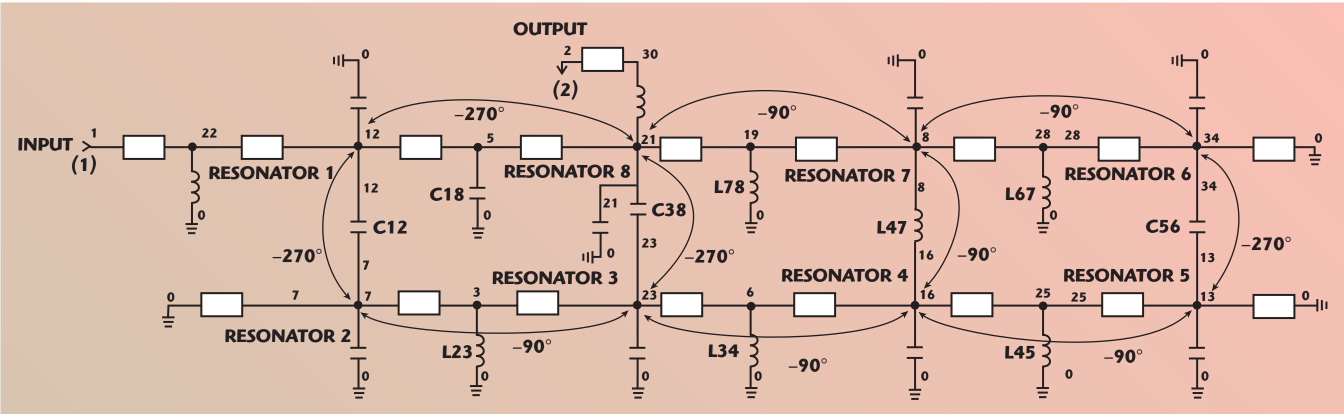
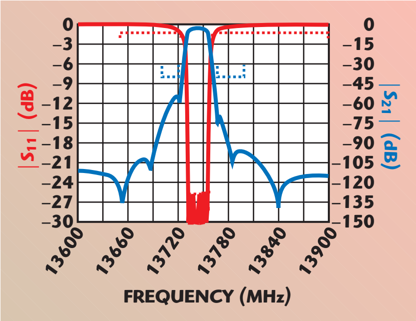


Fig. 14 Eight-element dual-mode filter circuit configuration for elliptic function response.

three pairs of real frequency transmission zeroes on both sides of the passband, thus significantly improving skirt selectivity and out-of-band rejection. The cross-coupling topology[12] is shown in ***Figure 13***, the transmission line-based circuit in ***Figure 14*** and its simulated response in ***Figure 15***.

With such a complicated nested topology (one loop inside another), when a specific transmission zero is not trivially conditioned by a particular cross-coupling, it is very important to verify the filter response of the circuit model as it relates to the cross-coupled loop phase shifts. The analysis of the transmission line circuit was performed based on the phase shift between resonance elements and conditioned by inductive or capacitive couplings. This analysis proved that all three cross-coupling loops deliver in-phase dual-path signal propagation which, in its turn, results in the desired response. It should be mentioned that formal selection of coupling elements for the transmission line circuit (Lij, Cij or Cij + 180° inverter) makes no difference as long as the loop phase requirement is met. For example, in order to provide in-phase cross-coupling between elements 1 and 8, the capacitive elements C_{18} and C_{12} of the circuit can be replaced with inductances, which after some tuning and optimization would result in the same response. As demonstrated in the section below, the required cross-coupling phasing may be determined at the initial design stage based on the simplified L-C circuit. However, it is a good practice to set the circuit coupling (inductive or capacitive) between adjacent elements (main path) according to their waveguide implementation, that is inductance for the slots and capacitance for the screws.



▲ *Fig. 15 Eight-element dual-mode filter response.*

The actual dual-mode filter design is based on the transmission line circuit representation and topology, with cross-coupling loops maintaining a required phase shift. It is assumed that angular coupling screws located at +45° produce a −270° electrical phase shift at the center frequency and screws located at −45° (135°) produce −90° (−270°+180° phase inversion =−90°). The horizontally polarized input signal (indicated by red arrows) is launched to the first resonator where it excites the TE_{111h} resonance mode.

The −45° angular coupling screw (C_{12}) transforms the horizontal into TE_{111v} vertical mode of the same circular cavity that

TABLE II

SIX-ELEMENT FILTER PHASE SHIFTS

	Phase Shifts (°)	Total Phase Shift (°)
Main path, elements 1-2-3-4-5-6	-90 -90 -270 -90 -90	-270
Cross-coupling path 1-6	-270 +180	-90
Resulting phase shift		Out-of-phase

TABLE III

EIGHT-ELEMENT FILTER PHASE SHIFTS

	Phase Shifts (°)	Total Phase Shift (°)	Phasing
Main path, elements 4-5-6-7	-90 -270 -90	-450 (-90)	In-phase
Cross-coupling path 4-7	-270 +180	-90	
Main path, elements 3-4-5-6-7-8	-90 -90 -270 -90 -90	-270	In-phase
Cross-coupling path 4-7	-270	-270	
Main path, elements 1-2-3-4-5-6-7-8	(-270 +180) -90 -90 -90 -270 -90 -90	-90	In-phase
Cross-coupling path 1-8	-90	-90	

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	1 WATT MODEL 9167			5 WATT MODEL 9165				
PARAMETER	**MIN**	**TYP**	**MAX**	**MIN**	**TYP**	**MAX**	**UNITS**	**CONDITIONS**
Operating Frequency	20		3000	20		3000	MHz	
Gain	**37**	**40**	**43**	**45**	**48**	**51**	dB	
P_{1dB}	**28.0**	**28.5**		**36.0**	**36.5**		dBm	
P_{5dB}		**30**			**37**		dBm	
IP_3/IP_2	**40/50**			**46/60**			dBm	
Noise Figure		2.8	3.0		2.8	3.0	dB	
In/Out VSWR			1.5:1/2:1			1.5:1/2:1		
Maximum Input			+18			+18	dBm	
DC Power		**500**	**600**		**725**	**800**	mA	
Operation Voltage		**12**			**15**			May Specify for 1 watt: 10V to 15V, 5 watt: 12V to 28V
Humidity	0		100	0		100	%	Non-Condensing
Altitude	0		50,000	0		50,000	ft	
Operating Temperature	-20		65	-20		65	°C	
RF/DC Connectors	SMA/Pins							
Dimensions	2.212″ x 1.625″ x 0.565″						Inches	Fin Option height: 1 watt 1.313″ 5 watt 1.813″

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propagates through the resonators and horizontal coupling irises (L_{23}, L_{34} and L_{45}) in the direction indicated by black dashed arrows. The angular coupling screw located at +45° (C56) of the last cavity transforms the TE_{111v} into the TE_{111h} horizontal mode, which propagates back through the vertical coupling slots (L_{67}, and L_{78}) to the output as indicated by the red dashed arrows. That is how the main path of the signal is formed. Two coupling screws, –45° in cavity #3 and +45° in cavity #2, along with a small size vertical slot in the partition separating first and second cavities, deliver a required in-phase cross-coupling between 4 to 7, 3 to 8 and 1 to 8 elements of the filter, respectively. The phase shifts for all three loops are presented in ***Table 3***.

Graphically, the 180° cross-coupling phase inversion provided by the angular –45° (135°) coupling screws can be seen as a main path electrical vectors superimposed with an oppositely directed (electrically 180° inversion may deliver both in and out-of-phase dual-path signal propagation) cross-coupled vector.

DESIGN STEPS

Preliminary Circuit Analysis

A simplified circuit analysis should be performed at the initial stage of the design in order to generate a response similar to the required one and verify phase shifting between cross-coupled and main paths. Shown in ***Figure 16*** is the eight-element L-C filter circuit with three nested cross-coupling loops, which produces a similar (but not accurate) response to that shown previously. This configuration is a starting point in the design of the eight-element dual-mode circular waveguide filter discussed above. Such a circuit can be easily generated using, for example, Genesis filter synthesis and optimization tools.[8] Simplicity of the implementation and the analysis of the circuit presented allows one to determine crucial factors for the end filter design, such as the total number of elements, number and type of the cross-couplings (positive for in-phase, negative for out-of-phase, etc.), as well as preliminary coupling coefficients between elements. It should be noted that the dual-mode waveguide filter topology assumes only an even number of elements skipped for structural reasons.[13]

Transmission Line Circuit Synthesis

The transmission line circuit synthesis and simulation is tied to the circular waveguide pieces selected for filter resonators. Diameters of the actual waveguides are introduced to the circuit by the cut-off frequencies and characteristic impedances of the transmission lines, and set in the equation block as illustrated in the general considerations and basic filter configurations covered previously. The Q-factors of the circular resonators utilized in the design are translated into the transmission line loss in dB. In the beginning of the simulation process, inductive and capacitive coupling elements of both main and cross-coupled paths as well as input/output Q-factors can be set approximately, based on the J-invertors or coupling coefficients[7] obtained from the L-C circuit as follows:

$$J_{ij} = \omega_0 C_{ij}, \text{ or}$$

$$J_{ij} = 1/\omega_0 L_{ij} \qquad (1)$$

$$k_{ij} = J_{ij}/\sqrt{b_1 b_j}$$

and

$$Q_{el} = b_1 \times G_0 \times (L_{01}\,\omega_0)^2$$

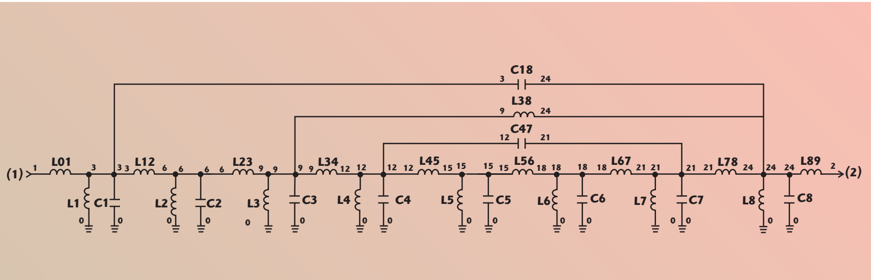

Fig. 16 Initial eight-element three cross-coupling filter circuit.

PIN DIODE SWITCHES

FEATURES:

- Multioctave bands 0.2 to 18 GHz
- Reflective or Absorptive
- Current or TTL control
- Low insertion loss
- High isolation

Frequency Range (GHz)	Model Number	Insertion Loss (dB, Max.)	Isolation (dB, Min.)	VSWR (Max.)	Rise/Fall Time (ns, Typ.)	On/Off Time (ns, Typ.)	On/Off Time (ns, Max.)	DC Power Positive/Negative (mA, Max.)
SPST								
0.2 – 2	SW1-002020RN1NF	1.7	70	1.6:1	10/10	20	35	35/70
2 – 8	SW1-020080RN1NF	2	80	1.7:1	10/10	20	35	35/70
4 – 12	SW1-040120RN1NF	2.2	80	1.7:1	10/10	20	35	35/70
2 – 18	SW1-020180RN1NF	3	80	2:1	10/10	20	35	35/70
1 – 18	SW1-010180RN1NF	3	70	2:1	10/10	20	35	35/70
SP2T								
0.2 – 2	SW2-002020RN1NF	1.5	70	1.6:1	10/10	20	35	60/60
2 – 8	SW2-020080RN1NF	1.8	80	1.7:1	10/10	20	35	60/60
4 – 12	SW2-040120RN1NF	2.2	80	1.7:1	10/10	20	35	60/60
2 – 18	SW2-020180RN1NF	2.8	80	2:1	10/10	20	35	60/60
1 – 18	SW2-010180RN1NF	3	70	2:1	10/10	20	35	60/60
SP3T								
0.2 – 2	SW3-002020RN1NF	1.6	70	1.6:1	20/20	150	180	85/85
2 – 8	SW3-020080RN1NF	1.9	80	1.7:1	20/20	150	180	85/85
4 – 12	SW3-040120RN1NF	2.4	90	1.7:1	20/20	150	180	85/85
2 – 18	SW3-020180RN1NF	3	80	2:1	20/20	150	180	85/85
1 – 18	SW3-010180RN1NF	3.1	70	2:1	20/20	150	180	85/85

Note: The above models are all reflective switches. Absorptive models are also available, please contact MITEQ.

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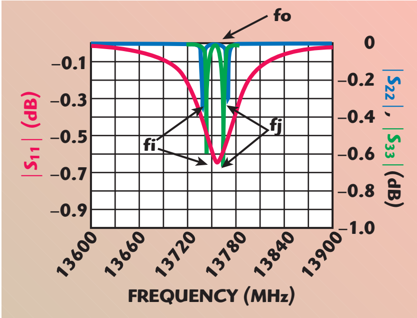

Fig. 17 Example of the input/output element external Q-factor (red) and two adjacent element coupling coefficient verification.

where

L_{ij} and C_{ij} = inductive or capacitive couplings,

b_i, $b_j = \sqrt{Ci / Li}$ are the slope parameter of the L-C shunt resonators,

k_{ij} = a coupling coefficient between L-C shunt resonators,

$G_0 = 1/Z_0$ is an input transmission line (port) admittance and

Q_{e1} = input (or output) external Q-factor.

The process of the TL circuit synthesis may take a few steps, including:

a) Adjustment of the each main path adjacent pair of TL resonator coupling responses. This adjustment is performed in order to meet k_{ij} value of the preliminary L-C circuit. A typical coupling response is shown in ***Figure 17***.

b) Adjustment of the input/output element S_{11} responses of the input/output inductive element for the determination of the external Q-factor.

c) Adjustment of the cross-coupling path pairs of TL elements coupling responses, similar to step a.

d) Full circuit response simulation and optimization.

Practical Aspects of the TL Circuit Analysis

After the desired response of the transmission line-based circuit is achieved (return loss, bandwidth, rejection, etc.), actual couplings and external Qs for further 3D or filter prototype development can be de-embedded. Shown in ***Figure 18*** are resonance elements extracted from the eight-element dual-mode filter circuit for coupling and external Q determination. Since the element resonance frequencies extracted from the circuit will slightly shift, they need to be re-adjusted to the center frequency of the filter using tuning capacitors. In case of paired element coupling value verification, the input shunt inductance should be minimized for better accuracy. All unterminated ends of the transmission lines should be shortened to the ground as shown. The typical S_{11} responses for a singly loaded resonator having a finite unloaded Q-factor and paired transmission line resonators are demonstrated in the figure. The methodology described by Matthaei, et al.[7] for a singly loaded resonator can be utilized for the input/output external Q-factor definition. The coupling value between two resonance

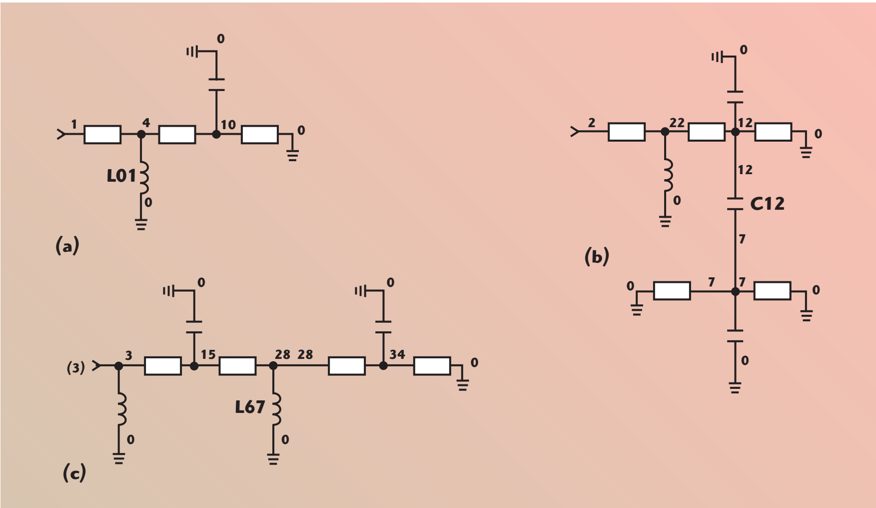

Fig. 18 Example of the circuit fragments adjusted for input external Q (a) and element coupling coefficient (b and c) verification.

elements is found as followed:

$$k_{ij} = (f_j - f_i) / f_0 \qquad (2)$$

The coupling values found are a key factor for the actual prototype development. The non-tunable coupling slots between either pair of actual coupled resonators of the filter should be adjusted prior to the full assembly so as to produce responses approaching the de-embedded ones from the circuit. When all actual coupling and Q values are obtained experimentally from pre-assembled parts and all slot dimensions are finalized, the fully assembled unit prototype may only need a minor tuning provided by capacitive screws. ■

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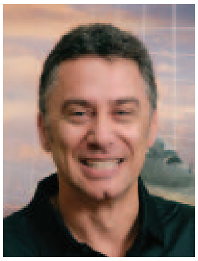

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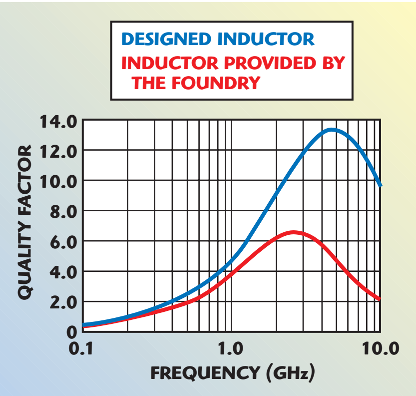
IMODEL: A NOVEL TOOL FOR HIGH-PERFORMANCE INDUCTOR SELECTION

Starting from a small number of fabricated integrated inductors, and by means of accurate electromagnetic simulations and a physical-based inductor model, a new method to generate an integrated inductor library is reported in this article. The parametric model permits to find the geometric parameters of the inductor that provide the highest quality factor for a particular inductance and frequency of operation. A powerful scalable inductor selection tool (IMODEL) has been developed. This tool has been employed to generate a complete library of inductors integrated on a 0.35 μm SiGe process foundry.

Radio frequency integrated circuits (RFIC), operating in gigahertz bands, require high quality factor integrated inductors at a low cost. The behavior of voltage-controlled oscillators (VCO), low noise amplifiers (LNA), matching networks and distributed amplifiers depends strongly on them. However, low cost silicon technologies use low resistivity substrates that result in important losses and quality factor degradation.



▲ *Fig. 1 Performance comparison between two different 2 nH inductors.*

Many foundries offer a set of inductors that the RF designer may employ in their circuits. However, they are not designed for a specific application, so the quality factor may not be as high as the designer needs, or not centered at the required frequency. Alternatively, the inductor may be taken from a complete library, provided that it has been previously built-up. This library must be comprised of inductors for any desired inductance, exhibiting high quality factors at different frequencies and with a minimum occupied area.

Figure 1 shows an example of the difference between the quality factor of an inductor offered by a SiGe 0.35 μm foundry and a custom designed element. In this case, the designer required a 2 nH inductor to work in the 5 GHz range. Among the inductors available from the foundry, all of them square, the most suitable for the requirements was chosen. It can be seen that the newly designed inductor doubles the quality factor and shifts the maximum peak to the required frequency range.

In this article, a new approach to generate an integrated inductor library is proposed. To accomplish it, a new coil selection tool called IMODEL was developed. By this means, a high-quality inductor library for the 0.35 μm foundry process has been generated.

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METHODS TO BUILD-UP AN INTEGRATED INDUCTOR LIBRARY

Classical Procedure

Figure 2 shows the design flow of the typical method to generate an integrated inductor library. The first step in the process is the simulation of a large number of inductors by means of a fast simulator such as ASITIC.[1] The time consumed by ASITIC simulations is negligible compared to the time required by an electromagnetic tool. However, numerical simulators provide the inductor performance only for a given frequency, and not the whole behaviour when frequency varies as with an EM simulator.[2] In spite of this, ASITIC is employed to select the group of coils that will make up the library.

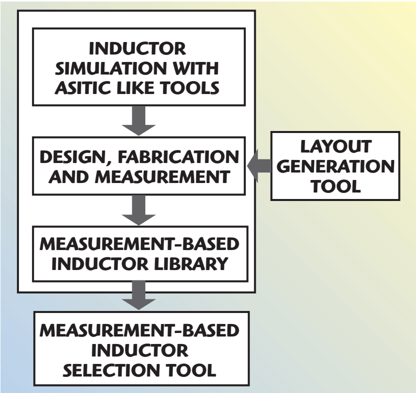
The next step of the approach is laying out the whole library. Afterwards, it is necessary to measure and characterize the fabricated inductors in order to obtain the S-parameters. Finally, the inductor measurement information may be organized as a database and a tool to assist the designer to select the appropriate device for the required inductance and frequency values can be developed.[3]

This is a reliable and robust method to generate an inductor library because it is based on actual measurements. Therefore, the designer knows exactly the performance of the inductor chosen for their circuit.

TABLE I

TEST INDUCTOR GEOMETRIC PARAMETERS

r_{EXT} (µm)	w(µm)	n	s(µm)
90-130	6-10	3.5-6.5	2



▲ *Fig. 2 Design flow of a traditional procedure to generate an inductor library.*

However, this approach is very time consuming and increases the overall cost since a huge number of coils should be fabricated and measured to generate a wide and diverse library.

On the other hand, the method does not assure the best inductor for a specific application, since it provides only the most suitable among the library coils. Therefore, it is necessary to develop a fast and cheap approach to assure the optimum inductor for the required inductance and frequency.

New Procedure

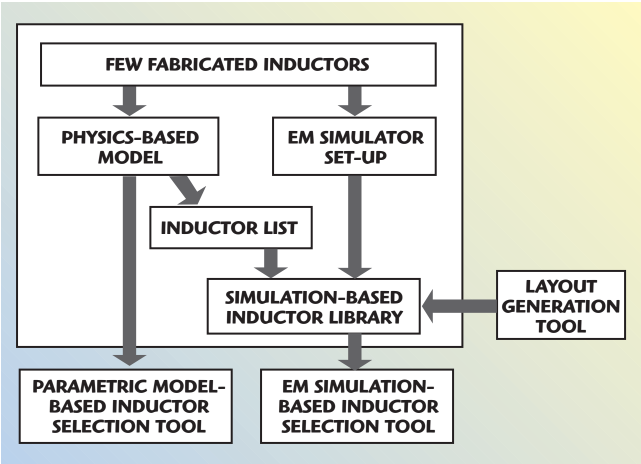
Figure 3 shows the design flow of the proposed method. It is based on the fabrication and measurement of a few integrated inductors. Hence, the final cost in time and silicon area is reduced.

On one side, the parametric model proposed previously[4] is employed to develop an algorithm to define the geometry of the best inductors for the different inductance and frequency values. If this based-on-physics model is considered accurate enough, an inductor selection tool could be developed.

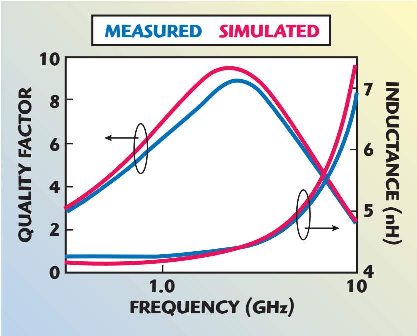
However, EM simulations are considered more reliable. Hence, the parametric model can be used to generate a list of inductors that will be simulated with the EM simulator to corroborate the model estimations. An inductor selection tool based on the simulations will then be developed.

In this case, the measured results are used to set up correctly an electromagnetic simulator. Momentum©,[5] a 2.5D-EM simulator based on the method of moments,[6] was employed. Although it does not consider the entire phenomena that occur in an inductor as a 3D tool does,[7] Momentum is faster and a very good solution in this case.

Nevertheless, getting precise results from a general purpose EM simulator is not a simple task. The substrate and metallization layers provided by the technology should be carefully defined, and the simulator has to be adequately configured, so as to fit measured and simulated results. For this purpose the measurements of 10 octagonal inductors fabricated in the 0.35 µm SiGe foundry process have been employed. The test inductor geometries are summarized in ***Table 1***, where r_{ext} is the inductor external radius, w the metal width and n the number of turns. The spacing between metal tracks of different turns, s, is fixed to the minimum allowed by the technology in order to minimize the occupied area and maximize the inductance value.

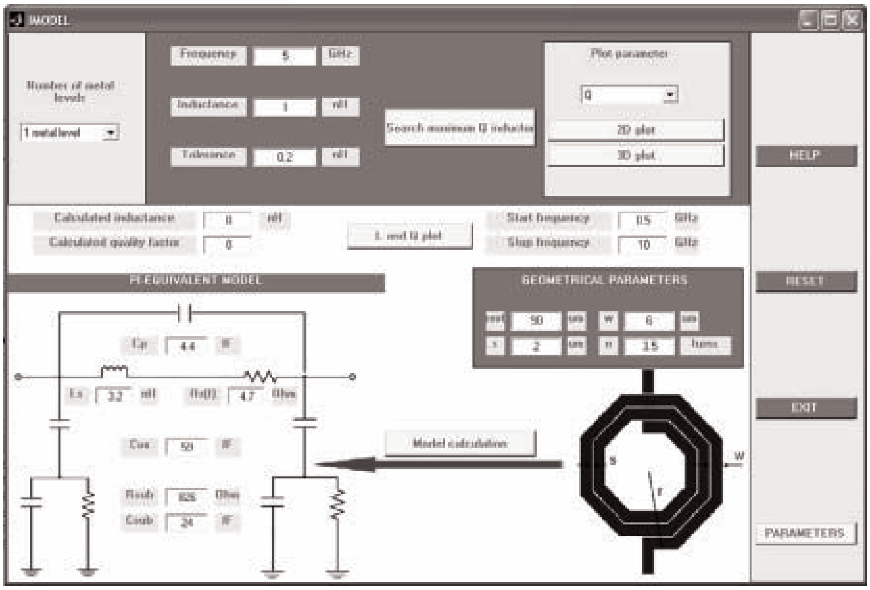


▲ *Fig. 3 Design flow of the new method to generate an inductor library.*



▲ *Fig. 4 Measured and simulated results for one of the fabricated inductors.*

The measurement system used for the inductor characterization consists of the HP8720ES vector network analyzer and the Summit 9000 probe station. To calibrate the measurement system, the short-open-load-through (SOLT) method was applied. Finally, a four-step de-embedding method[8] was followed to remove the parasitic effects introduced by the measurement structures.



▲ *Fig. 5 Main menu window of the inductor selection tool IMODEL.*

By using the inductor measurements, Momentum was set up correctly, achieving relative errors less than 5 and 10 percent for the inductance value and the maximum quality factor, respectively. As an example, ***Figure 4*** shows the measured and simulated data for one of the fabricated inductors with r_{ext}= 90 µm, w= 6 µm and n= 4.5. It is worth noting, however, that the relative errors increase for inductors where skin effect or eddy currents are particularly significant.[9]

IMODEL

The analytical model[4] was validated to be applicable over a wide range of octagonal inductor geometries fabricated on the SiGe 0.35 µm process. The model shows excellent agreement with measurements, and the generated relative errors are similar to those given by the EM simulator. Since building up an inductor database based on EM simulations is a more time-consuming task, the inductor selection tool proposed in this study is based on the parametric model.

The set of equations the model consists of have been implemented by an optimization algorithm that provides the geometry of the inductor with the best quality factor for a given inductance value and frequency of operation. For this purpose, a sweep for the different inductor geometrical parameters is run. The algorithm can be summarized in the following steps:

- The user determines the required inductance value and the frequency of operation. In addition, the allowed tolerance in the inductance calculation must be set up.
- Once the input data has been established, the algorithm searches the coils with the required inductance by sweeping the values of w, r_{ext} and n. As mentioned before, s is fixed to the minimum allowed by the foundry process in order to maximize the inductance value per area.
- Each set of w, r_{ext} and n that provides the required inductance is saved in a database together with the inductance and quality factor values at the required frequency.
- Finally, the algorithm chooses among the inductors of the database the one with the highest quality factor, which will be the output of the procedure.

This algorithm, together with other functions, has been implemented in MATLAB to compose an inductor selection tool called IMODEL. ***Figure 5*** shows the tool main menu window. Apart from the selection of the best inductor for a required inductance and frequency, the software offers other useful features:

- Provides the two-port π-equivalent model of an inductor from the geometrical parameters r_{ext}, w, s and n.
- Generates a text file with the characteristics of all the inductors that provide the inductance and frequency requirements.

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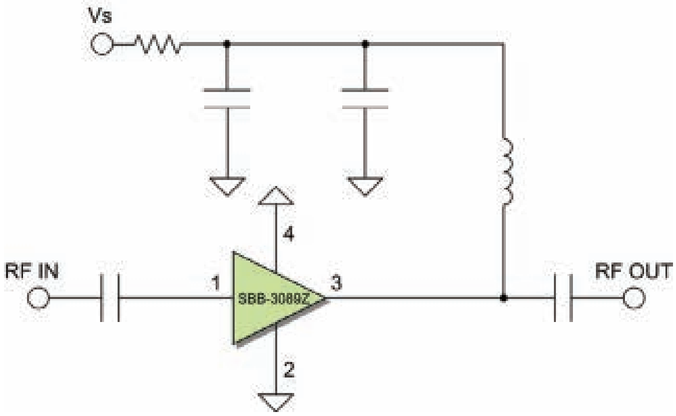

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SBB SPECIFICATIONS

Part Number	Frequency	Gain	Id	NF	Output IP3	P1dB	Vd
SBB-1089Z	50-850 MHz	15 dB [1]	90 mA	3.1 dB	43 dBm [2]	19 dBm	5
SBB-2089Z	50-850 MHz	20 dB [1]	90 mA	2.6 dB	42 dBm [2]	20 dBm	5
SBB-3089Z	50-6000 MHz	16.5 dB	40 mA	3.8 dB [3]	28 dBm	15 dBm	5
SBB-4089Z	50-6000 MHz	15 dB [1]	80 mA	4.6 dB	35 dBm	19 dBm	5
SBB-5089Z	50-6000 MHz	20.5 dB [1]	75 mA	4.2 dB	35 dBm	20.5 dBm	5

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TABLE II

MAIN PARAMETERS OF THE LIBRARY INDUCTORS

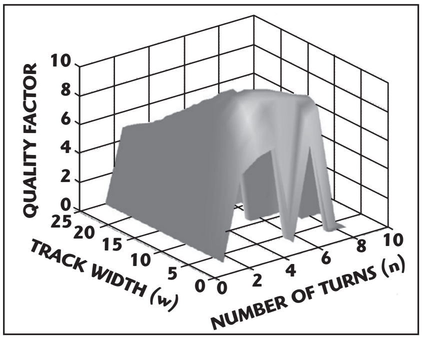
f(GHz)	.85	1.5	1.8	2.4	5.6
$Q_{average}$	6.5	8.0	8.4	9.0	9.8
r_{min} (μm)	110	95	90	85	55
r_{max} (μm)	190	140	125	110	115
n_{min}	1.5	1.5	1.5	1.5	2.5
n_{max}	4.5	5.5	5.5	5.5	5.5
w_{min} (μm)	18	10	8	5	5
w_{max} (μm)	26	19	16	16	9

- The option "Number of metal levels" allows running a search among two-metal level inductors, which are a better choice in some cases.
- Visualizes the quality factor and inductance plots for a given inductor.
- Visualizes, through 2D and 3D plots, the dependence of the quality factor and inductance on the geometrical parameters for all the inductors that satisfy the input requirements. As an example, ***Figure 6*** shows a three-dimensional plot of the quality factor dependency on w and n of 3 nH inductors at 3 GHz. It is observed that the best inductor performance is obtained for track widths from 6 to 15 μm and number of turns from 3 to 7.

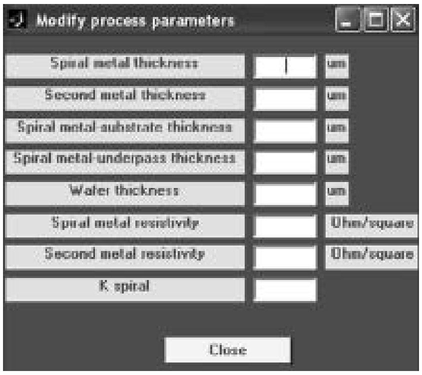
The tool is scalable and applicable to any foundry process, provided that the parametric model predicts the performance of the inductor correctly. By choosing the option "PARAMETERS" in the main menu, the user can modify the process parameters that are required for the search (see ***Figure 7***). Finally, the tool provides on-line help and a user's manual to explain the different software features and the error messages that the designer could find when employing the software.

INTEGRATED INDUCTOR LIBRARY

By using the coil selection tool IMODEL, a library of inductors integrated on the 0.35 μm process has been generated. The coils have been generated for the frequencies 0.85, 1.5, 1.8, 2.4 and 5.6 GHz, corresponding to different known standards. Each set offers inductance values from 0.5 to 6.5 nH, in 0.5 nH steps. The maximum error on the inductance value for the parametric model has been set to 0.2 nH.



▲ *Fig. 6 Example of a three-dimensional plot generated by IMODEL.*



▲ *Fig. 7 Modification of the process parameters.*

As explained before, the algorithm searches the coils with the required inductance by sweeping the geometrical parameters. In this case, the limits for this sweep have been set according to empirical criteria in order to avoid too large inductors and model applicability.[7,10,11]

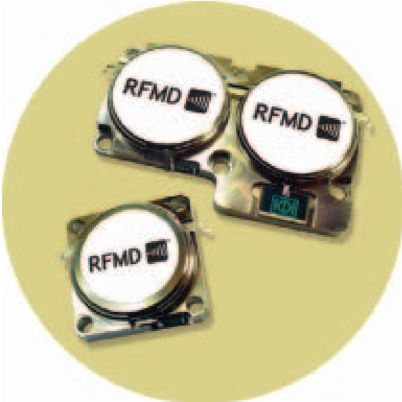
The covered range in the search is given by:

- External radius (r_{ext}): between 25 and 200 μm
- Number of turns (n): between 1.5 and 10.5
- Track width (w): between 5 and 30 μm
- External to internal radius ratio (r_{ext}/r_{int}): lower than 3

Table 2 summarizes the main

RFMD® Isolators

Single and Dual Junction Samarium Cobalt Isolators



RFMD® introduces a new family of samarium cobalt isolators, which includes the PIxxxxAG-21H line of 30W reverse power single junction isolators and the PDxxxxAQ-21H line of 100W reverse power dual junction isolators. Delivering excellent electrical performance, these isolators also have the rugged construction needed for the demanding operational requirements of high-power, linear amplification sections of cellular base stations.

Both the PIxxxxAG-21H line and the PDxxxxAQ-21H line of isolators are constructed with samarium cobalt (SmCo) magnets packaged in aluminum housings, providing immediate improvements in reliability and performance versus existing generations of isolators.

PIxxxxAG-21H SPECIFICATIONS

Part Number	Frequency Range (MHz)	Insertion Loss (dB)	Isolation (dB)	Return Loss (dB)	IMD (dBc) 2T x 37.5 Watts
PI0882AG-21H	869 to 894	< 0.2	> 20	> 20	-65
PI0940AG-21H	920 to 960	< 0.2	> 20	> 20	-65
PI1843AG-21H	1805 to 1880	< 0.2	> 20	> 20	-70
PI1960AG-21H	1930 to 1990	< 0.2	> 20	> 20	-75
PI2140AG-21H	2090 to 2190	< 0.2	> 20	> 20	-75

PDxxxxAQ-21H SPECIFICATIONS

Part Number	Frequency Range (MHz)	Insertion Loss (dB)	Isolation (dB)	Return Loss (dB)	IMD (dBc) 2T x 37.5 Watts
PD0882AQ-21H	869 to 894	< 0.35	> 50	>20	-60 Forward and -90 Reverse
PD0940AQ-21H	920 to 960	< 0.35	> 50	>20	-60 Forward and -90 Reverse
PD1843AQ-21H	1805 to 1880	< 0.35	> 50	>20	-60 Forward and -90 Reverse
PD1960AQ-21H	1930 to 1990	< 0.35	> 50	>20	-60 Forward and -90 Reverse

FEATURES

- Designed for wireless infrastructure systems
- RoHS and Pb-free
- Industry-standard 1" x 1" and 1" x 2" drop-in package

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TABLE III

MAIN PARAMETERS OF THE TWO-METAL LEVEL INDUCTORS AT 0.85 GHz

Q_{av}	r_{min} (µm)	r_{max} (µm)	n_{min}	n_{max}	w_{min} (µm)	w_{max} (µm)
8.9	120	170	1.5	4.5	16	30

parameters obtained for each set of inductors (from 0.5 to 6.5 nH) of each frequency. As it can be seen, the higher the operation frequency is, the lower the r_{ext} values (r_{min} and r_{max}) and w values (w_{min} and w_{max}) become. This is associated to the decrease of the parasitic capacitance when the external radius or the metal width decreases. Therefore, the resonant frequency becomes higher, and the quality factor peak is given at a higher frequency.

At the lowest frequency of the library (0.85 GHz), the average quality factor is lower and the occupied areas are larger than the rest. It is well-known that the quality factor increases when other layers are added to the metallization structure due to the decrease of the final conductor resistance.[12] However, the inductance value is hardly changed by shunting another metal level. According to this consideration, an additional set of inductors has been developed by using the two metal layers option offered by IMODEL at 0.85 GHz. The new parameters obtained by designing two-metal level inductors at 0.85 GHz are summarized in ***Table 3***. The average quality factor is now higher, and the maximum external radius is slightly lower, which saves silicon area.

CONCLUSION

In this article, a new method to generate a full inductor library has been introduced. From a few fabricated inductors in a given technology, the EM simulator Momentum is configured accurately to provide consistent results. On the other hand, a parametric model is developed. If this model is not accurate enough, it will be used to generate a list of optimal inductors. These coils will be simulated to obtain more reliable data, and the results will be organized to develop an optimal inductor selection tool based on simulations. Alternatively, if the physical-based model predicts the coil behaviour correctly, the inductor selector will be based on it.

In this work, a high quality factor searching tool named IMODEL has been developed based on a parametric model. By means of this useful software, the RF designer can obtain in a fast and reliable way the best inductor for a required inductance value and working frequency. Based on this powerful tool, a wide inductor library has been developed consisting of high performance coils integrated on a 0.35 µm SiGe foundry process.

Readers interested in the program can obtain a free executable file by writing to Dr. Amaya Goñi, Instituto Universario de Microelectronica Aplicada, Universidad de Las Palmas de Gran Canaria, 35017 Las Palmas de Gran Canaria, Spain. ■

ACKNOWLEDGMENTS

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NEW TUNABLE TECHNOLOGY FOR MOBILE-TV ANTENNAS

Mobile-TV is poised to become the next great mobile accessory, with analysts projecting that 50 million digital-TV-ready mobile handsets will ship in 2009.[1] For designers, making this task a reality is somewhat daunting, given the significant user-experience complexities that mobile-TV introduces, such as battery life, reception and range, screen size and picture quality. While these challenges are sure to be overcome, the impact on the antenna is often overlooked in the early planning stages. Designers soon realize the challenges involved with supporting a wide range of voice and data frequencies in the same device as a mobile-TV antenna that must span 470 to 862 MHz. Inevitably, RF tunable technologies are required in order to keep embedded mobile-TV antennas on track, but which technologies are robust enough to handle the job?

▲ *Fig. 1 Initial mobile-TV handsets required use of an external whip antenna.*

If an antenna is constrained to a small form factor, it cannot receive all of the required mobile-TV bands at high efficiency without some sort of reliable tuning technology. Because they could not cover the wide mobile-TV frequency range with a traditional embedded antenna, designers of the first mobile-TV handsets used a traditional external whip antenna (see ***Figure 1***).

The challenges to using a whip antenna like the one shown in Figure 1 occur on two fronts. Most importantly, it is a potential point of failure because of repeated handling by the end user and other external forces that can cause damage. Additionally, because mobile-TV applications are so new, handset manufacturers generally have adopted a "push" marketing strategy; they have added this functionality in anticipation that consumers will eventually use it (much like with Bluetooth). However, including an awkward external whip antenna to support a function that the user might not use may be counter-productive to generating demand for that model. What is needed is a new design scheme for an antenna that can span 400 MHz mobile-TV and still be embedded into a handset.

MOBILE-TV ANTENNA CHALLENGES

Mobile-TV applications such as DVB-H and ISDB-T require adding very broadband reception and delivering good coverage to an already complex system, all in a small space. According to the European Telecommunications Standards Institute (ETSI) Technical Report "DVB-H Implementation Guidelines,"

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it is very difficult to design a high-performance antenna for the UHF band mobile-TV. Because the handset is very small compared to the wavelength, typical antenna gain for handheld terminals is –10 dBi at 474 MHz increasing to –5 dBi at 858 MHz. This means that the antenna loses 10 dB of power at the low end of the band. Also, guaranteeing a good input match across the whole UHF-IV/V band (470 to 862 MHz) is challenging, and is likely to require a tunable matching circuit.[2]

To date, designers have typically had only two antenna choices: a passive internal antenna with poor performance, or the external whip antenna, which many consumers view as archaic. For future designs, however, the embedded, internal antenna is demanded by the market; therefore, some type of antenna tuning is critical in order to ensure a good user experience. While mobile-TV is a fairly new service, it is experiencing market penetration in Europe (DVB-H) and Japan (ISDB-T),[3] so providers are becoming motivated to find a suitable antenna tuning technology to support it.

For mobile-TV applications, the achievable bandwidth and input match is directly related to the physical size of the antenna and the mobile phone. For this reason, most traditional internal mobile-TV antennas have very poor performance; radiation efficiency suffers, and voltage standing wave ratio (VSWR) gets very high (easily 6:1 across the 470 to 862 MHz bandwidth). This causes the receiver to lose 3 dB of sensitivity simply due to the antenna mismatch, which for the mobile-TV functionality would significantly reduce the range and degrade reception quality.

As a result of these performance issues, interest in a “tunable” internal antenna that could cover a narrow section of the bandwidth—one that can be “retuned” as the receive channel changes—is increasing. This would deliver significantly better VSWR making sure that most of the signal power captured by the antenna actually ends up in the receiver. With this tunable architecture, the frequency of the antenna resonance could be moved up and down as needed in order to match the desired channel. ***Figure 2*** shows the input impedance of an embedded mobile-TV antenna with fixed matching (2a) and with a tunable matching circuit (2b). Note the VSWR of the antenna without tuning is 6:1, and with tuning circuitry the matching is very good at better than 2:1 across the whole band.

Because mobile-TV is a receive-only system, the open-loop antenna tuning method must be used, in which the center frequency of the antenna is tuned based on a look-up table for the tunable component as a function of the desired receive frequency. The antenna center frequency is shifted as necessary in order to cover specified frequencies within the 470 to 862 MHz range, and the tuning technology quickly retunes the antenna as the receive channel is changed. In effect, the manufacturer sets the antenna element to cover a small section of the band, and the tuning element moves this window around. The UHF band for DVB-H is divided into 48 channels 8 MHz apart. Typically 16 or 32 tuning states will be required to give fine resolution to tune the narrow-band antenna element to any channel in the mobile-TV band and to enable high-quality reception.

GSM/DVB-H INTEROPERABILITY POWER HANDLING REQUIREMENTS

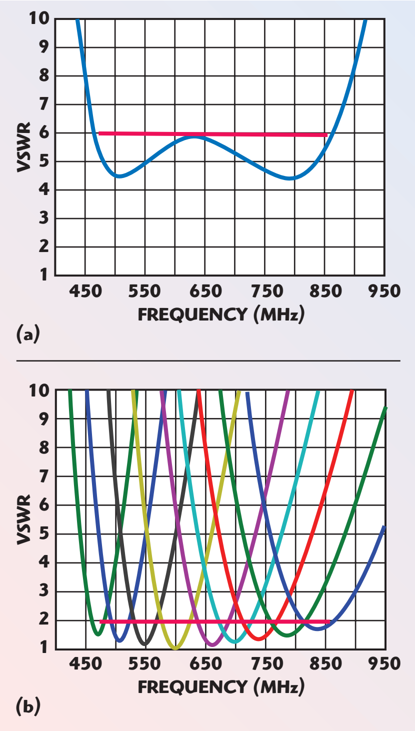
When there is a mobile-TV antenna and a GSM cellular antenna embedded in the same phone, the tuning element for the mobile-TV antenna has to be able to handle high levels of coupled GSM power. For example, the isolation between the GSM and the DVB-H antennas inside a mobile phone can be as low as 7 dB, and GSM antennas transmit at power levels up to +33 dBm. As a result, when the GSM transmitter is transmitting at full power, the tuning element might actually see coupled power levels near +26 dBm. Unless the tuning circuitry can withstand these high power levels, the coupled power can modulate it and change the center frequency of the mobile-TV antenna or generate a high level of harmonics in the tuning element.

To address this problem, one might consider simply switching off the GSM transmitter when the mobile-TV receiver is engaged, or employ time-scheduling methods to prevent collisions between the two modes. However, the GSM phone has to transmit periodic location updates to the base station, causing disruptions in mobile-TV reception.

In some countries, the handset also needs to send billing information over the cellular line when the user is watching TV, or the user might receive a phone call while the TV is on. A tuning method that allows simultaneous operation of GSM and mobile-TV is thus highly desirable, but imposes a very challenging power handling constraint for the antenna tuning element.

MOBILE-TV ANTENNA TUNING DESIGN OPTIONS

What is needed is an antenna tuning technology that can handle more than +26 dBm of coupled GSM power in order to keep mobile-TV on track with an embedded antenna. Since it is connected to the antenna, the tuning circuit also needs to be extremely linear so as not to generate harmonics or intermodulation distortion. The tunable element, such as variable capacitor, needs to have a tuning ratio of at least 3:1 or better. In addition, the whole circuit must have power consumption of less than 1 mA. Finally, the tuning circuitry must be small, rugged and reliable. It needs low insertion loss and a high quality factor (Q) (see ***Table 1***).



▲ *Fig. 2 Input VSWR of a traditional DVB-H antenna (a) and tunable internal antenna (b).*

Varactor Diodes

Sometimes a varactor diode approach is proposed for mobile-TV antenna tuning, since it is a straightforward and fairly inexpensive solution. Since varactor diodes are analog components, they require a dedicated analog tuning voltage output for the mobile-TV chipset. However, varactor diodes cannot typically meet the high power handling and linearity requirements to support the GSM/DVB-H interoperability by allowing simultaneous GSM and DVB-H operation.

Switch-based Tuning

Since varactor diodes cannot handle the power requirements of embedded mobile-TV antenna tuning, a "brute force" approach of switch-based tuning, such as using a GSM SP4T switch with a tuning circuit on each of the four legs of the switch, has been developed. This approach provides very coarse tuning, which may not be sufficient to guarantee good performance across the whole band.

FET Switched Capacitor Banks

FET Switched Capacitor Banks based on bulk CMOS technology showed early promise as the technology to satisfy this challenging list of requirements for mobile-TV antenna tuning.[4] They have a high quality factor, but their linearity is typically on the order of IIP3 =+25 dBm, which suggests less than +15 dBm of power handling. Even though this is high enough for receiving the mobile-TV signal itself, it cannot support simultaneous operation of GSM and DVB-H in the same handset. However, compared to bulk CMOS FETs, Peregrine's UltraCMOS™ FETs have the fundamental advantage of stacking due to the fully insulating sapphire substrate, making it possible to use multiple low-voltage FETs in series to handle the high power signals encountered in GSM and WCDMA operation.

TABLE I
KEY REQUIREMENTS FOR TUNABLE ELEMENTS FOR MOBILE-TV ANTENNA TUNING

Parameter	Typical Values
Capacitance values	1-15 pF
Capacitance ratio	>3:1
Quality factor	≥40 @ 470 to 862 MHz
Resolution	≥5 bits (32 states)
Power handling	> +26 dBm
Current consumption	< 1 mA

TABLE II
KEY PARAMETERS FOR A DuNE DTC DEVICE FOR MOBILE-TV

Parameter	Typical Values
Capacitance range	1.36 to 6.3 pF
Capacitance ratio	4.6:1
Quality factor	40 to 70 @ 470 to 862 MHz
Resolution	5 bits (32 states)
Power handling	> +28 dBm
IIP3	> +62 dBm
Power supply voltage	2.4 to 3.0 V
Current consumption	11 μA
Interface	3-wire serial interface

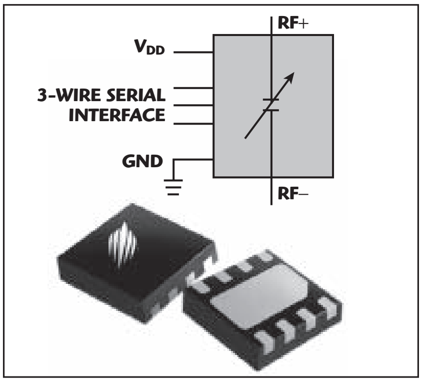
DUNE™ TECHNOLOGY: A NEW ANTENNA TUNING SOLUTION

DuNE™ Technology, a patent-pending design methodology made possible by the UltraCMOS process and HaRP™ design innovations, has enabled the tunable capacitor circuit—referred to as a Digitally Tunable Capacitor (DTC)—which can handle the GSM/DVB-H interoperability requirements. DTCs designed for mobile-TV applications can be housed in a 2x2 mm package with a built-in 3-wire serial interface (see ***Figure 3***).

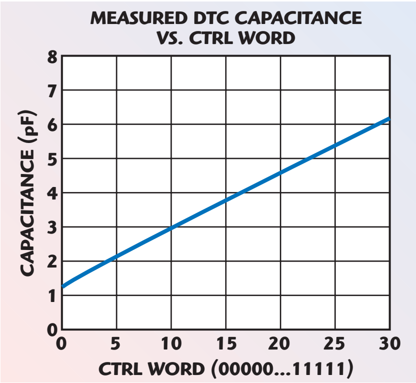
Initial DuNE DTCs have been designed for 5 bits of resolution or 32 tuning states, which provides the level of fine resolution that is required to tune the antenna across the entire mobile-TV band. ***Figure 4*** shows the 1.36 to 6.3 pF capacitance range (4.6:1 tuning ratio) for a 5-bit mobile-TV DuNE DTC.

Low losses for the tunable element are very important in reducing the insertion loss for the tunable matching network and optimizing the total antenna efficiency. The mobile-TV DuNE DTC has been designed for Q = 40-70 at 470 to 862 MHz (see ***Figure 5***). The current consumption for the device is only 11 μA at +2.75 V.

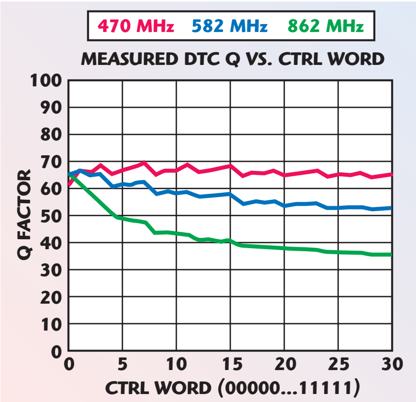
Due to the fundamental advantages of UltraCMOS,[5] such as perfectly insulating sapphire substrate and highly linear FETs, DuNE technology can be scaled to handle any power level without degrading Q or tuning ratio, simply



▲ *Fig. 3 DuNE DTC device schematic (top) and packaged in 2 × 2 mm 8L DFN (bottom).*



▲ *Fig. 4 Measured capacitance as a function of state for a DuNE DTC.*



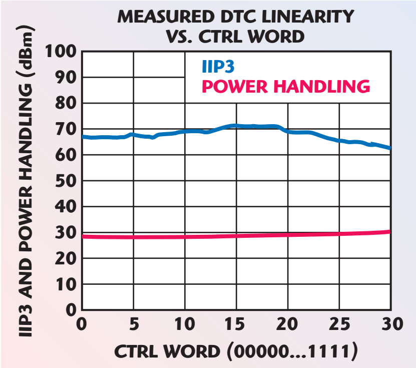
▲ *Fig. 5 Measured quality factor as a function of state for a DuNE device.*


Mini-Circuits
LAVI

by changing the number of FETs in the stack. As a result, it can be scaled to handle power levels anywhere from +20 to +40 dBm and higher. For mobile-TV applications, DuNE DTCs have been designed for +28 dBm nominal power handling and GSM/WCDMA applications, power handling is better than +38 dBm. ***Figure 6*** shows IIP3 > +62 dBm and better than +28 dBm power handling measured at 900 MHz for the moblie TV DuNE DTC.

It is also noteworthy that all performance parameters of the DTC (capacitance range, tuning ratio, quality factor, power handling) can be changed by circuit design instead of materials engineering, enabling rapid time to market.

Because they are manufactured on the UltraCMOS process, the new DuNE DTC products can integrate the digital functions (CMOS control, digital processing, serial peripheral bus, tuning algorithm), analog functions (mismatch sensors, charge pumps, biasing circuitry), as well as RF passive (high Q capacitors) and RF active (switches, ESD protection) circuitry in addition to the DTC core. See ***Table 2*** for a list of the key parameters for mobile-TV.



▲ *Fig. 6 Measured DTC IIP3 and power handling as a function of state.*

THE FUTURE OF MOBILE-TV ANTENNA TUNING

DuNE technology addresses the required performance points for embedding a tunable mobile-TV antenna. These self-contained RFIC solutions communicate directly with the mobile-TV receiver chipset and integrate a digital communication interface and all the other required functionality monolithically on the die, which simplifies implementation as well as minimizes lines/connections between the two devices. High-performance, compact, and simple antenna tuning solutions, proven process technologies, and high-volume capability are critical to the successful adoption of complex mobile-TV products. Mobile handset designers now have a way to successfully design in tunable embedded antennas for mobile-TV, and uncover new market opportunities. ■

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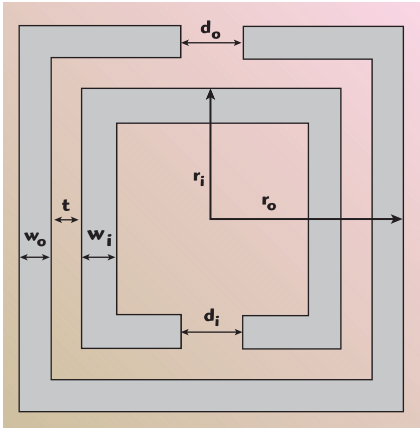
METAMATERIAL-BASED COMPACT MULTILAYER FILTER WITH SKEW-SYMMETRIC FEEDS

Split ring resonator (SRR) metamaterials are introduced to the design of a multilayer filter. Considering the electrical coupling to the magnetic resonance, careful examination of SRR orientations to the external stimulation is presented through a full wave analysis. With the skew-symmetric feed scheme, the compact multilayer filter has a center frequency of 6.07 GHz and 7 percent fractional bandwidth with two transmission zeros at 5.79 and 7.1 GHz. Compared with the conventional microstrip filter, the proposed filter shows a significant size reduction and improved selectivity.

Microwave filters are an essential component in modern wireless communication systems. It is important to reduce their size and weight in order to integrate them with other components in a single chip system.[1] Using a multilayer filter is the main trend in filter design, since it shows a better performance than a planar version.[2] At microwave frequencies, a negative permeability can be realized over a given frequency range in the magnetic resonance frequency of a periodic array of SRRs.[3] In this article, a multilayer technology and an SRR structure are combined for the design of a novel multilayer filter. Compared with the conventional microstrip filter, the proposed filter shows a significant size reduction and an improved selectivity. The measured results have a good agreement with the simulated results.



▲ *Fig. 1 Schematic drawing the SRR.*

THEORY

The SRR, shown in ***Figure 1***, is made of two concentric rings separated by a gap, both having splits at opposite sides. The geometrical parameters, such as the split gap width, gap distance, metal width and radius are respectively represented by d, t, w and r. The subscripts i and o denote the inner and outer rings. Besides the electric and magnetic coupling, the incident field also induces the magnetoelectric coupling. The SRR not only has an electric resonance, but also a magnetic resonance. Moreover, the magnetic resonance frequency is lower than the electric resonance frequency.[4] Using the magnetic resonance of the SRR in the filter design, a significant size reduction can be obtained.

The magnetic resonance of the SRR depends on its orientation with respect to the external electric field *E* and the direction of propagation k, which implies six distinct orien-

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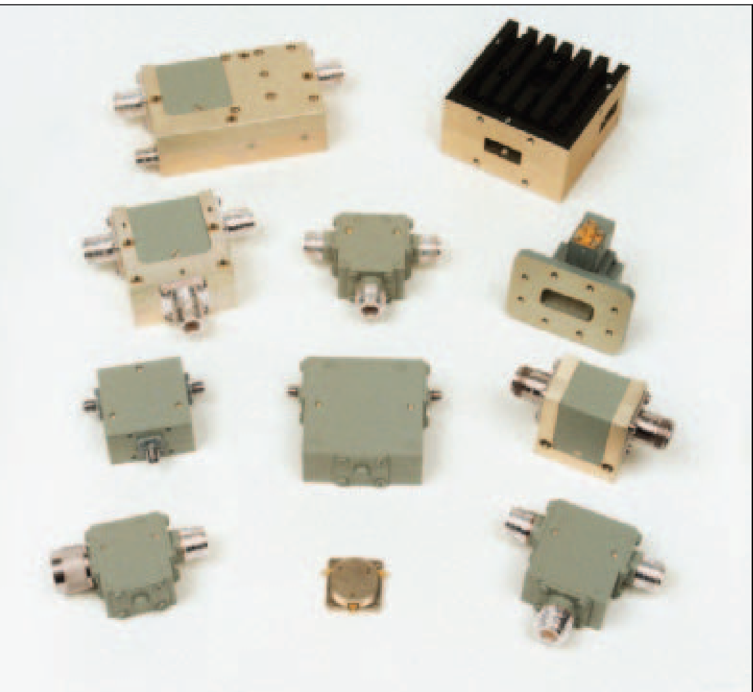
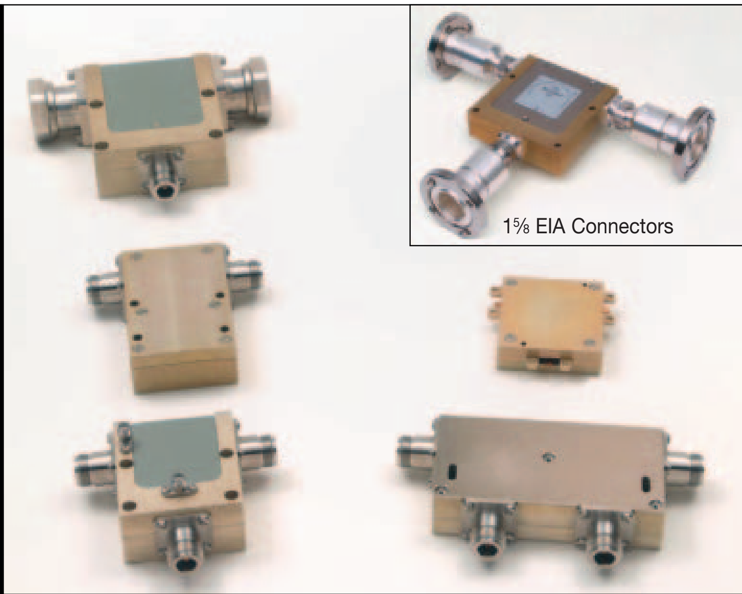
Xidian University, Xi'an Shaanxi, China

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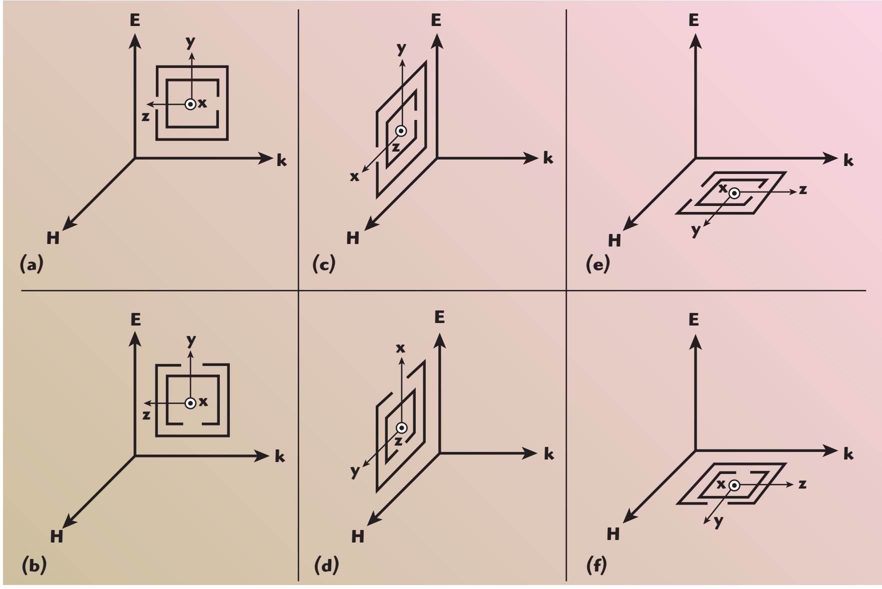

▲ *Fig. 2 The six orientations of the SRR with respect to the k, E and H of the incident TEM field.*

tations. In the first two cases (see a and b of **Figure 2**), in which the magnetic field E penetrates through the rings, the magnetic resonance of the SRR is excited by the magnetic field. The electric field can also excite the magnetic resonance when the incident wave penetrates through the rings and the external electric field. E is parallel to the split-bearing sides.[5] However, when the external electric field E is rotated perpendicularly to the split-bearing sides, as in case c and d, no magnetic response is produced. In the other two cases, e and f, the external electric field E penetrates through the rings. No magnetic response is produced.

To account for the magnetoelectric coupling in Maxwell's equations, the SRR metamaterials can be described by the constitutive relations.[6]

$$D = \varepsilon_0(\bar{\varepsilon} \cdot E + Z_0 \bar{\kappa} \cdot H) \qquad (1a)$$

$$B = \mu_0\left(-\frac{1}{Z_0}\bar{\kappa}^T \cdot E + \bar{\mu} \cdot H\right) \qquad (1b)$$

where $Z_0 = \sqrt{\mu_0/\varepsilon_0}$, $\bar{\varepsilon}$ and $\bar{\mu}$ are the relative electric permittivity and relative magnetic permeability tensors and $\bar{\kappa}$ is the magnetoelectric coupling dimensionless tensor. For different axes fixed to the SSR, only certain components $\bar{\varepsilon}$, $\bar{\mu}$ and $\bar{\kappa}$ tensors are of significance.

Considering a forward plane wave propagation of the form exp (-iβz'), for the case 2c, which will be used in the following filter design.

$$\beta^2 = \varepsilon_{yy}\mu_{xx} \qquad (2)$$

where $\varepsilon_{yy} = a + \dfrac{b\omega^2}{(\omega_0^2 - \omega^2)}$ and $\mu_{xx} = 1$.

So when $e_{yy}<0$, the stop band will occur. Through a similar analysis, the other cases can be proved.

DESIGN AND SIMULATION

Figure 3 shows the proposed filter, which is composed of three dielectric layers with the same relative permittivity 2.2 and two SRR layers embedded between the dielectric layers in the same plane, with splits laid in opposite directions. The most important innovation here is the ground that is located on the right and left sides, as shown. This design makes the external electric field E parallel to the split-bearing sides and makes sure that the magnetic resonance of the SRR takes place, in accord with the third case (c). The SRR filter, with skew-symmetric input and output feed-lines coupling on the first and last resonators, can generate two transmission extra zeros lying on either side of the passband because the delays in the upper path and the lower path are the same. The photograph of the fabricated filter is also shown in Figure 3b. The thickness of the first and third layers is 0.8 mm and the middle layer is 2.5 mm thick. The circuit dimensions are: r_0=2 mm, r_i= 1.3 mm, w_0=0.25 mm, w_i=0.4 mm, t= 0.45 mm, d_0=0.5 mm and


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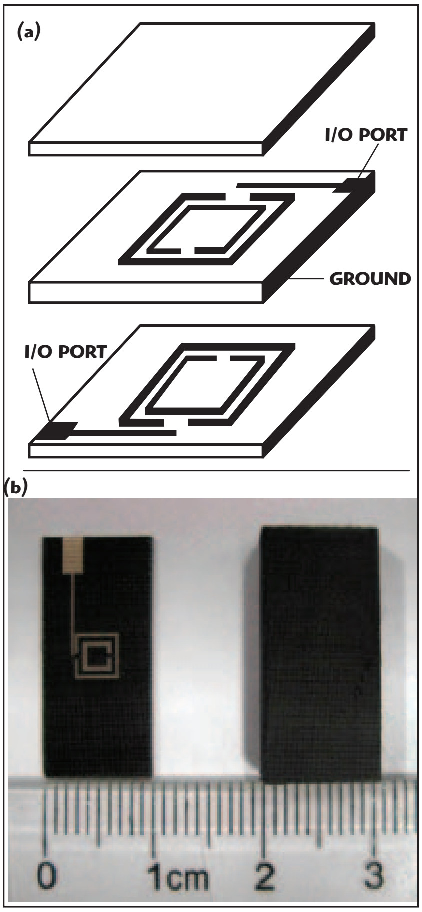


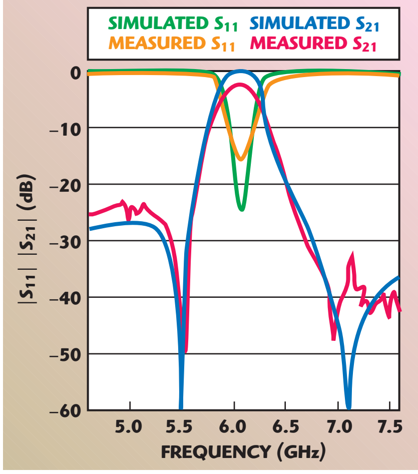
▲ *Fig. 3 Structure of the two-pole SRR filter with skew-symmetric feed (a) and photograph of the filter (b).*

d_i=0.4 mm. The width of the feed line is 0.2 mm. In the photograph, the left is the inner structure of the filter and at right is the whole structure.

The simulated and measured results are shown in ***Figure 4***. From the EM simulation, the filter has a fractional bandwidth of 7 percent centered at 6.07 GHz, an in-band return loss of 20 dB and a minimum out-of-band loss of 25 dB. The transmission zeros are obtained near the passband at f_1= 5.49 GHz and f_2= 7.1 GHz. This structure can realize a good transmission characteristic and a compact size that is less than one third of the free space wavelength. From the measured data, two transmission zeros, at 5.53 and 6.96 GHz, are found in the passband response of the filter. Good agreement can be observed between the simulated responses and measured results.

CONCLUSION

In this article, the relationship between the magnetic resonance of an



▲ *Fig. 4 Simulated and measured filter results.*

SRR and its orientation relative to the incident wave has been analyzed. A filter using two resonators has been successfully designed with a compact size, a low insertion loss and a sharp rejection loss. Furthermore, with the skew-symmetric feed structure, two transmission zeros can be achieved. Good agreement between measured and simulated data has been demonstrated. ■

ACKNOWLEDGMENT

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RF AND MICROWAVES IN ASIA: ECONOMIES OF SCALE

The entire spectrum, from high income to emerging economies, is represented in Asia. The region has shown an insatiable appetite for innovation and technology, making it a hub of activity and a magnet for global enterprise and investment. This report examines the current state of the RF and microwave market in the region and asks whether, in the current global economic climate, technological development can continue and if growth can be maintained.

It is not an easy task to predict the behaviour and future of regional and global markets at the best of times. So now, in the wake of the global financial crisis, when there is deep uncertainty and concern surrounding how far reaching the effects will be, such crystal ball gazing is nigh on impossible. Initially, the banking sector has been worst hit by the global economic downturn. For the RF and microwave industry, the key question is, will a lack of consumer confidence, restrictions on borrowing, lack of investment, etc., impact on manufacturing, production and technological development?

Without putting faith in Tarot Cards, divine guidance or mystical powers, that question is impossible to answer with any conviction. However, on recent evidence and current statistics, the Asia-Pacific region seems best placed to ride out the storm and remain an area of growth and keen adopter of new technology.

This is pure speculation, of course, and a barometer of the region's RF and microwave market will be the 2008 Asia-Pacific Microwave Conference (APMC 2008), being held from 16 to 20 December in Hong Kong, with the conference moving to Macau for the final day. Intended as an opportunity to showcase the region's technological innovation and activity and a platform for interaction and networking, the show will also provide a window on the market's mood and provide an indication of its future intent.

Hong Kong is the perfect place to compare and contrast the achievements of the 20th century with the potential of the 21st, as it spent 156 years as a British colony before being returned to Chinese rule. Its handover in 1997 coincided with China beginning to emerge from a manufacturing base of low cost products to a major global player. With its voracious appetite for materials and products, China has driven an economic boom in the Asia-Pacific region.

Fuelled by the launch of mobile phones and the development of wireless interconnect systems, the country has progressed from a technological novice to a major contributor and consumer. Initially the emphasis was on producing low cost, labour intensive product and the low-end OEM and mid-range ODM processes. However, newly produced standards in China for TD-SCMA mobile phones and

RICHARD MUMFORD
Microwave Journal *International Editor*

wide-area access Internet coverage are generating higher end development.

The choice of Hong Kong as the host of APMC 2008 demonstrates its perception as China's gateway to the West. However, in reality, is that gateway truly open to the outside world or is there still a closed door policy restricting competition and free trade? Further afield, can India satisfy the increasing demand for the technical skills necessary to feed its growth? And will the established economies in the Asia-Pacific region be able to develop and implement innovative technologies and fend off competition from emerging nations?

This article addresses these questions by considering the economic, commercial and technological environment in which the Asian RF and microwave industry is currently operating. It is not intended to be a comprehensive market overview, but attempts to present a window on the current status of academic and industrial development and identify the main trends influencing it. It also provides a commercial perspective as executives from a small cross section of companies actively participating in the Asian RF and microwave industry contribute to the 'company survey'.

MOBILE TELECOMMUNICATIONS

As has been mentioned, it is difficult in the current climate to make market predictions and this report makes every effort to use the latest statistics and quote renowned sources. For example, the International Telecommunications Union (ITU) Secretary-General, Hamadoun Touré, stated that worldwide mobile cellular subscribers are likely to reach the four billion mark before the end of 2008, which is a continuation of impressive statistics that saw year-on-year growth averaging 24 percent between 2000 and 2008. While in 2000, mobile penetration stood at 12 percent, it surpassed the 50 percent mark in early 2008 and the ITU estimates it will reach about 61 percent by the end of 2008.

However, the statistics are skewed by some regions, mainly in Western Europe, approaching saturation allied to the relatively slow world economy, while the BRIC economies of Brazil, Russia, India and China are experiencing significant growth as more people gain access to their first mobile phone, which is often also their first phone of any kind.

In the Asia-Pacific region ITU figures show that China surpassed the 600 million mark by mid-2008, representing by far the world's largest mobile market. By the end of July 2008, India had around 296 million mobile subscribers, which is a penetration rate of about 20 percent, thus offering great potential for growth especially if the existing high levels of competition between mobile operators are sustained, thus keeping prices down.

In the Asia-Pacific region, like in all markets, the early adoption of mobile/wireless has been in the cities and conurbations with the densest population and where investment in infrastructure is lucrative. Regulatory constraints are a concern in some sectors and to ensure continued growth network operators are considering the expansion of their networks to cater for increased traffic and to take advantage of the market potential for delivering services to rural areas. Rural areas bring their own challenges of price sensitivity and logistics. However, with affordable entry level handsets, realistic pricing and backing from governments and foreign investors, it is likely to be a lucrative market.

Further up the value chain the market for the GPS phone remains small, with fairly low penetration. However, its growth rate is significant in China, primarily due to the fact that a number of chipset manufacturers are integrating GPS functionality into the mobile phone's main chipset, aiding handset manufacturers and driving the market penetration of GPS.

BROADBAND

ITU figures show that, in terms of broadband access, the Asia-Pacific region has progressed impressively over the past few years, with subscriber numbers growing almost five-fold in five years: from 27 million at the beginning of 2003 to 133 million at the start of 2008. As such the region is the world's largest broadband market with a 39 percent share of the global total at the end of 2007.

In the region's high-income economies, this growth is being fuelled through competition to provide faster fixed broadband access. Operators in Hong Kong and Japan having launched 1 Gbps broadband and triple-play services for the residential market, featuring applications such as Internet telephony and television. South Korea is also at the forefront and leads the world in terms of the percentage of households with fixed broadband access.

However, the gap in available broadband speeds between rich and poor countries is as wide as the Great Wall of China is long. For instance, in the three countries previously mentioned (Japan, Hong Kong and South Korea), the minimum advertised broadband speed is faster than the maximum broadband speed in Cambodia, Tonga, Laos and Bangladesh.

In Malaysia the government has a mandate to increase broadband penetration. The country has a relatively high GDP per capita and high PC usage, but there is a significant digital divide between central urban conurbations and the rest of the country, along with entrenched wireline competition. Four licenses have been awarded but rollout has been delayed from the original deadline of March, 2008, with the commercial launch of a WiMAX service in Malaysia still uncertain at the time of going to press.

It is the established economies that lead the way in terms of 3G mobile cellular deployment. They profit from the fact that fixed and mobile broadband technologies complement each other and users can enjoy continuous high-speed Internet access. However, 3G is beginning to be considered for many emerging markets where it will be important to keep handset prices low. In the lower-end economies, Indonesia and Sri Lanka are early 3G adopters but have yet to see significant success, while highly populous nations like China, India and Pakistan are yet to migrate to 3G.

Commercially, though, these countries are the key battlegrounds with great potential. India in particular, with its large subscriber base, licensing plans for three metropolitan and up to five rural area 3G licenses and a vast resource of local content developers looks a prime candidate for 3G implementation.

The latest study of 3G in Emerging Markets, from the Strategy Analytics' Emerging Markets Communications Strategies service, concludes that 3G will meet a pressing need for voice and some data services in under-served markets. In order to establish a critical

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mass of acceptance, however, operators will need to offer affordability in what are generally price sensitive markets.

SEMICONDUCTORS/ICS

According to the spring 2008 forecast of the World Semiconductor Trade Statistics (WSTS), the global semiconductor market is expected to grow 4.7 percent on an annual basis to $267.7 B in 2008 with projected growth increasing from 3.2 percent growth in 2007. Mobile communications, PCs, digital consumer products and automotive electronics are key contributors to this growth, with a significant factor being the increased semiconductor content per item. As has been the trend over recent years, the Asia-Pacific region continues to be the fastest growing area fuelled by the continued manufacturing shift to the region and a rapidly rising domestic demand.

India's strengths lie in semiconductor design, with In-Stat forecasting Indian design services revenue increasing from $1.4 B in 2007 to $3.4 B in 2012. Although healthy growth is forecast, the industry faces problems created by its own success, including a shortfall in the supply of design engineers and increasing salaries, together with the wider issue of the weakening of the dollar against the rupee. On the plus side, Indian design companies are building up competencies to increase the depth and breadth of their services and making acquisitions to gain complementary skills.

The power semiconductor devices market has seen significant growth in recent years as their applications have extended into a variety of electronic applications, notably communications, networking, consumer electronics and the automotive industry. These applications demand discrete power semiconductors with a small footprint, high efficiency and good integration. Suppliers are striving to enhance process technology and packaging, while more efficient manufacturing and increased capacity, together with improvements in technology have reduced prices.

The sales of discrete power semiconductors have increased significantly in recent years in the Asia-Pacific region, particularly China, South Korea and Taiwan. Technologically, the MOSFET and IGBT segments are seeing greatest expansion.

With regards to foundries, outsourcing from IDM is rising, with pure play foundries becoming increasingly important as they take the lead in developing cutting-edge technologies. There were twenty five 300 mm fabs operational in the Asia-Pacific region in 2006 with Taiwan being the leader, followed by South Korea, with Singapore likely to grow significantly due to active investment.

ELECTRONICS

In the global electronics market, the Asia-Pacific region (particularly China), Eastern Europe and leading South American countries have benefitted from being low cost manufacturing locations. In fact, a recent report published by Reed Electronics Research and distributed by In-Stat stated that between 1995 and 2006 Asia-Pacific's share of global electronics production increased from 20 percent to 42 percent, with China's share increasing from 3 percent to 20.5 percent during that period. In 2006 electronics production in India increased by 22 percent.

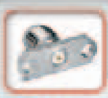
Malaysia and Singapore are not in the same league but are seeing growth, as is Vietnam, which is benefitting from favourable government policies and a strong work ethic as well as low operational and labour costs. Such conditions are attracting global EMS/ODM companies while leading OEMs like Sony, Samsung, Fujitsu and LG have set up manufacturing operations in Vietnam.

However, while the emerging countries are seeing sustained growth, others in the Asia-Pacific region have witnessed a downturn in fortunes. The migration of production to low-cost locations has particularly affected Japan. According to the Reed Electronics Research Report, by the end of 2006, the country's electronics output had fallen by 23.5 percent from the peak in 2000 and its share of global electronics output fell 12.7 percent from 26 percent in 1995. Despite the underlying trends, production stabilised in 2006 with production rising by 4 percent and by a modest 0.6 percent in 2007.

GENERAL

With the high profile communications industry grabbing the headlines

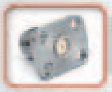
Field Replaceable SMA

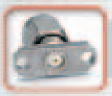

2 Hole, .625", with Ground Plane


4 Hole, .500", with Ground plane


2 Hole Diamond with Ground Plane


2 Hole, .550" with EMI Gasket


4 Hole, .500" x .375" with EMI Gasket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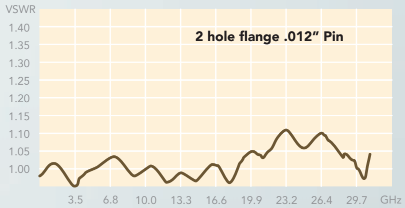

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and the limelight, other sectors of the RF and microwave industry tend to get overshadowed in the Asia-Pacific region. For example, although many countries in the region invest a small proportion of their GDP in defence, the more developed nations such as Japan, South Korea, Singapore and Australia are investing more heavily. Radar for intelligence, surveillance and reconnaissance (ISR) is a case in point, with the major powers in the region making finances available for modernisation and upgrades. Figures from Frost & Sullivan show that Japan accounted for 39.8 percent of the total Asia-Pacific air ISR radar market in 2007, followed by South Korea and Australia.

Technologically, developed countries are upgrading to active electronically scanned array radar technology and investing in R&D. Also, network-centric warfare is raising its head above the parapet, with an increasing number of countries in the region shifting their military doctrines toward a networked-defence strategy. However, the high cost of these next-generation platforms with advanced radar systems is likely to restrict their adoption by small to medium sized countries.

In the commercial sector, the rapid growth of the economy of emerging nations in the Asia-Pacific region has produced significant growth in the domestic sensors market. There has been increased interest in sensors to meet the demand for high quality process control and monitoring and for their utilisation to satisfy new standards and protocols for emerging technologies such as wireless. Japan, Malaysia and Singapore have embraced the transition from traditional sensing methods, while others such as Vietnam, Thailand and Indonesia are lagging behind with implementation.

Significantly, though, foreign investors have shown an interest in funding R&D activities to develop new technologies that when combined with the improvement of existing processes can improve the performance of sensors and also deliver them at competitively low prices.

COMPANY SURVEYS

Technologically and economically the above briefly sets the context in which the Asian RF and microwave industry is currently functioning, but what are the realities for companies developing, manufacturing and marketing new products in the region? To provide an insight into current market conditions and technological development, a commercial perspective is offered via the ‘company survey’ of executives from companies representing a cross section of industry—namely the host of APMC, Hong Kong, the growth economy of China and the established market of Japan. The format is generally a brief overview of the company’s activity, followed by comments on technological and market initiatives.

HONG KONG

YAN TAT

Formerly Shen Zhen Enda Electronics Co. Ltd., Enda established YAN TAT (Hong Kong) Industrial Ltd. in 1992. The company specializes in the manufacture and supply of printed circuit boards to the global electronics industry and has successfully grown into a professional organization that offers a wide range of products. These include double-sided and multi-layer PCBs on standard and exotic laminates and special base materials as well as thick copper backed PCBs (5 mm) for heat dissipation.

The applications for these products are primarily in the communications and automotive industries, with antennas, filters, connectors and power amplifiers (pre-bonded copper and post bonding) mostly used in base stations. These solutions require special materials/designs and a high level of quality.

As a result, YAN TAT does business in North America, Europe and Asia. Its approach to customers is the same the worldwide and with existing customers being global, the company has the necessary knowledge and expertise to support each geographical area. The key approach is good communication with customers and a keen understanding of their requirements, with flexibility of manufacture also being an important factor.

The company believes that, in general, Asian producers provide volume manufacturing with good quality and technical support, but also points

out that there are Asian designed products that offer older, simpler, lower-end technology solutions for developing countries. On a larger scale where YAN TAT is seeing significant activity is among its bigger global communications customers that are working on cost reduction to gain market share. This is likely to be achieved through improved design and the reduction of PCB and PCBA/box build manufacturing costs.

CHINA

Shenzhen Shennan Circuit Company

Established in 1984, SCC is a hi-tech enterprise engaged in the production of high-precision, high-density and high-reliability double-sided/multi-layer PCBs that the company manufactures to customer specifications. Its RF and microwave PCBs are manufactured primarily for communication, medical, automotive and automation applications.

The company takes its social responsibilities seriously both in terms of enterprise and the community. It continuously explores and practices ways of integrating social responsibilities into the entire management process of production and operation. The aim is to attain economic, community and environment benefits in order to create coordinated and sustained development of the business.

Shenzhen Shennan Circuit Company currently has two factories in Nanshan and Longgang, staffed by over 3000 employees. The PCBs in mass production can be up to 52 layers. When it first began, the company introduced advanced production equipment and process technologies from abroad that enabled it to become a leader in domestic industry.

Its mission is to improve product quality and manufacture according to the highest international standards. Products comply with both Chinese national standard and US IPC standards, and are UL certified. This means that SCC not only supplies China and Hong Kong, but is also an international player that markets its products in North America, Europe and Southeast Asia. The company's long-term aim is for multiple services expansion, rolling development and deployment into new areas.

JAPAN

Hirai Seimitsu Kogyo

The company provides high-precision photo-etching including the fabrication of multi-layered Low Temperature Co-Fired Ceramic (LTCC) substrates, precision photo etching of various metals and polyimide. It is also a world leader in the field of metal etching. Other capabilities include the plating of metals and other surface treatment along with mechanical forming such as NC machining, laser cutting, wire EDM, welding, thermally pressurized bonding and stamp forming. Specifically, in the RF field, the company provides in-house plated LTCC substrates for RF modules and lead frames for RF and/or RF power devices. Particular effort is going into providing a design library or RF design support for the LTCC foundry service and miniaturization of LTCC substrates.

New technologies that Hirai SK is currently developing include: thin film metallization of the LTCC substrates for the higher Q at micro and mm-wave frequency bands and for finer pitch patterning, improvement of the metal paste printing, shape and materials, for the higher Q or lower resistivity at mm-waves, and microwave sintering to reduce the costs of LTCC, etc. As the reduction of size and losses are vital for any mobile equipment, including 4G mobile phones, a miniaturized and low loss BPF is currently under development in a project being carried out in association with Ryukoku University. Also significant is the company's work on waveguide implementation in the LTCC at mm-waves.

The company's manufacturing, development and international sales are based in Japan. The company has sales partners throughout Asia and in the US, but expects to see growth in BRIC countries and the European Union as there are few LTCC suppliers there. Geography is not viewed as a boundary as the Internet and e-mail make the exchange of technical information and layout data easy and immediate. In fact, design information and the RF design kit for the LTCC foundry service is downloadable from the company's web site, which eliminates location problems and simplifies overseas communication.


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Hirai SK has the traits of a typical Japanese company as it is good at precision handling, has high yield and quality, is traditionally good at ceramics fabrication, can carry out a large number of iterations to optimize processes and can ship samples quickly.

With regards to technology, the company sees the following stimulating the market it operates in: high frequency magnetic materials, nano-wire or nano-particles for the improvement of the Q factor at mm-wave frequencies, dielectric materials or LTCC green sheet with higher Q factor at mm-waves, direct bond technology of the LTCC and the metal plate or sheet for accurate internal patterning, and thin film metallization, artificial dielectric materials/nano technologies and frequency agile or tuneable materials.

Looking to the future, Hirai SK sees groundbreaking development being the realisation of CMOS device integrating mm-wave circuits with the memory + antenna, with integration to a small sized mm-wave antenna + FEM + digital processing/memory. Such miniaturized modules could be attached to any device such as ear-phones for TV sets. The company will also strive for higher accuracy of the LTCC process to produce higher yields at lower costs.

CONCLUSION

Over the last 12 months the Asia-Pacific region has, in general, continued to see consumer markets grow, fed by new technology. For the RF and microwave industry it is the mobile communications and wireless technology sectors where there has been significant growth, with China now being the world's largest mobile market. This sector also demonstrates the contrast that this vast continent reveals: in the established high-income economies such as Japan, where the possession of mobile phones is near the saturation point, the emphasis is for greater content and added value services while emerging nations require cheap handsets, low prices and access in rural areas. With a mobile penetration rate of around 20 percent, India in particular has significant potential for growth.

The provision of broadband access is a key issue too with the launch of faster rates and triple-play services being significant in the high-income economies while the priority for the emerging economies is the implementation of services at any speed.

Asia remains at the forefront of semiconductor manufacturing and foundry services. It has benefited from migration from declining markets in other regions buoyed by an increasing local consumer market. In the foundry market, Japan, South Korea and Taiwan remain dominant, but China has seen significant investment in this sector too. India has become a key player in semiconductor design, but faces challenges to provide training and education to meet the demand for skilled technicians.

While the emphasis and focus has been on the high profile industries such as telecommunications and electronics, the more general and understated sectors of the industry have gone relatively unnoticed. However, there is growth in defence systems in general and radar systems in particular and sensors are being used in applications from industrial processes to wireless technologies.

Finally, at the time of going to press, the global economic downturn cannot be ignored and although Asia is likely to be more immune than most, it is inevitable that there will be some consequences. Those countries that could suffer are likely to be at the opposite ends of the economic spectrum. The high-income economies such as Japan, South Korea and Taiwan will be most susceptible to a cut back in consumer spending and the competition from cheaper, imported goods, while the low-end economies, which are just beginning to emerge, could be stunted by a lack of investment and consumer reluctance at a critical stage of development. However, it is hard to see the growth economies of countries such as China and India losing much momentum. ■

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Manufactured using Avago's revolutionary "WaferCap" chip scale package technology, these ultra small, low-profile low noise devices occupy less than 5% of the space of standard SOT-343 packages without sacrificing performance. The 0402 package-size VMMK products are designed to operate up to 26 GHz and are priced up to 3 times less than comparable devices from other manufacturers.

VMMK devices are suitable for a variety of wireless applications, including:

- Cellular/PCS and WCDMA Base Stations
- Military Radar, Radio and ECM Systems
- WLAN and WiMAX
- Instrumentation
- Satellite Communications
- Broadband Wireless Access Systems

	Bias Condition			Specifications @ 50 Ohms match					
Part No.	Freq (GHz)	Vd (V)	Id (mA)	Test Freq	NF (dB)	Gain (dB)	P1dB (dBm)	OIP3 (dBm)	
VMMK-1218	DC - 18	3	20	10	0.71	9	+12	+22	GaAs FET
VMMK-1225	DC - 26	2	20	12	0.87	11	+8	+23	GaAs FET
***Coming Soon in Q4 2008!**									
VMMK-2103*	0.5 - 6.0	5	25	3	2.4	14	—	+23	50 ohm RFIC with built-in bypass switch
VMMK-2203*	1.0 - 10	5	28	5	2.4	16	—	+15	50 ohm RFIC
VMMK-2303*	0.5 - 6.0	1.8	20	6	2.2	13	+10	+24	50 ohm RFIC
VMMK-2403*	2.0 - 4.0	5	50	3	2.5	15	+20	+32	50 ohm RFIC
VMMK-2503*	1.0 - 12	5	60	3	3.7	14	+17	+28	50 ohm RFIC

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A MICROWAVE JOURNEY, PART V: THE 1990S

Past *Microwave Journal* articles provide a fascinating look at the life and times of our industry and how we have weathered economic and social change. This fifth installment in our series recounts the 1990s, a decade that is still clearly visible in our recent memories. In the world at large, we witnessed the fall of the Soviet Union brought about by the Reagan military build-up of the 1980s. Much of the advanced technology developed for the Cold War would get its first massive public display during the first Gulf War. Terrorists, mostly homegrown ones, would endanger the public with bombings in Oklahoma City, OK, the World Trade Center in New York and Olympic Park in Atlanta, GA. Federal agents raided the Branch Davidian compound in Waco, TX, OJ Simpson went for a televised ride in his white Ford Bronco and his trial became a national obsession, NAFTA got ratified, Germany was re-united, a sheep got cloned and a president got caught being... un-presidential.

With the Cold War nearing an end, defense spending began to drop-off precipitously and guest editorial from industry leaders quickly reflected the concern over the disappearing revenue. Fortunately, the seeds had been planted for faster, higher-capacity data communication as well as mobile personal communication. The massive research and innovation that served the needs of the military would soon be redirected to serve the wireless revolution.

JANUARY 1990

The decade starts out without any editorial hint of a pending downturn in military spending. This month featured a special report on Modern Radars and Antennas (still our January theme) by JT Nessmith of the Georgia Tech Research Institute, and four technical articles on other various radars and antenna arrays (two weather radars, an airborne active array and radar antenna testing). The article, "Airborne Active Element Array Radars Come of Age" by RM Lockerd and GE Crain, both of Texas Instruments, examines 25 years of development in active electronically-scanned array (AESA) antennas and praises the evolution of the MMIC and its role in making "X-band active element phased arrays suitable for application in tactical aircraft and other defense systems." The authors frequently referred to

DAVID VYE
Editor, Microwave Journal

the maturity of AESA technology and how it was the "final step in system efficiency and cost reduction making it the preferred technology for all future multimode radar developments." Much of the MMIC technology presented went back five years to 1985. In hindsight, the article looks more to the past than the future, which may be the year's first indication of trouble in this sector.

FEBRUARY 1990

The year was also filled with innovation and the first public display of many new technologies. The February cover featured a new software program called HFSS, an electromagnetic simulator from Hewlett Packard (initially developed by Ansoft and marketed by HP, now Agilent). The cover showed a 3D microwave structure (waveguide to coax adapter) that was characterized by computing Maxwell's equations to derive a set of S-parameters and field plots. The application note by Alexander Anger of HP introduced the technology to the world. Within a few short years, field visualization and obtaining S-parameters without physical prototype would revolutionize high frequency design.

MARCH 1990

Concern over the changing economics is made clearer in this month's special report, "Company in Transition: An Interview with Dr. Thomas A. Vanderslice, M/A-COM CEO." Vanderslice, formerly of Apollo Computer, had just taken the top spot at M/A-COM the previous November. The company had been experiencing problems with some of the non-microwave acquisitions from the mid-70s. Vanderslice was focused on re-structuring the company around the parts that were profitable and divesting those that weren't. The previous CEO Tom Burke, who had died in an automobile accident in September 1989, believed M/A-COM's future lied in concentrating on the defense sector. By the time of this interview, Vanderslice was specifically asked how he felt about moving in this direction with "the prospects for the defense budgets as they are." His response was an acknowledgment that the company would trim its businesses, steer toward the commercial, and keep the businesses that were heavily focused in this area and bring the commercial side up from 20 percent of their overall portfolio to 30 percent. New business would not be in the defense market, but would look to international opportunities and applications such as collision avoidance (automobile), radar speed detection and boating radar (more consumer electronics).

APRIL 1990

Look out JR—Dallas skyscrapers cover the April issue. Our annual IMS coverage featured MTT-S president Tatsuo Itoh authoring a guest editorial, "Merging Technologies for the New Decade." Itoh had deep roots in the microwave community going back to his school days at the University of Illinois in 1969, research days at Radio Physics Lab in Menlo Park, CA, serving on the faculty at the Universities of Kentucky and Texas, Austin, and guest researcher at AEG-Telefunken among his many credits. The MTT-S president wrote about the symposium's theme of incorporating diverse technologies into the conference reflecting the variety of disciplines behind the complex microwave systems of the day. In particular, the MTT-S was joining with the Antenna and Propagation Society (APS) and the International Scientific Radio Union (URSI) in scheduling a number of symposia. Also, the Microwave and mm-Wave Monolithic Integrated Circuits Symposium and ARFTG conference were placed closely together on the schedule.

In this issue another simulation technology would grace the pages of *Microwave Journal*. This time, Steve Maas would present his alternative to the existing nonlinear computer-aided design techniques in an article called, "Analysis and Optimization of Nonlinear Microwave Circuits by Volterra-Series Analysis." As a seasoned designer, Maas knew the importance of fast simulation times when optimizing circuit performance. His approach attempted to improve simulation speed and efficiency over standard harmonic balance. The technique, which was limited to weakly-coupled nonlinear circuit analysis, would eventually find a home when it became a subset to the simulation engines in Microwave Office a few years later and made a big splash with real-time tuning at the 1998 IMS in Baltimore, MD.

SEPTEMBER 1990

This issue took a hard look at the EW market in the '90s with two special reports: "Not Ready for Plowshares" (subtitled "EW Checks its Vital Signs. Prognosis: Firmer, Leaner, Meaner and in Good Physical Health") by S. Herskovitz of the *Journal of Electronic Defense* (a former MWJ sister publication) and "The Microwave Component Industry: Two Views of the Future" by Joseph Saloom of M/A-COM and George Caryotakis of Varian. The first report spelled out the Government Accounting Office's plan to cut 16,000 DoD jobs in the next year as well as major cut-backs among defense contractors, an estimated 65,000 workers. The scale of the budget cutting (13 major weapon programs, 35 US military bases, 25 percent force reduction by mid-decade) was truly frightening to companies and workers heavily vested in defense spending.

JANUARY 1991

For the second time in its history the publisher's torch was passed. This time Bill Bazzy writes the tribute announcing the "partial retirement" of Howard Ellowitz and placement of Harlan Howe as the new Publisher/Editor. Howe, a seasoned engineer and microwave text book author, wrote his first editorial as publisher in this issue, outlining his plans to introduce some changes where he felt we could do a better job of reporting while keeping the successful aspects of the magazine unchanged.

As Bill Bazzy states, "We are proud and happy that Harlan has elected to join us. Ensuring that our dependence on military activity can be reduced by moving aggressively into commercial areas of the communications industry will be a major target for Harlan. The convergent technologies that are now providing the marvelous new tools of global networking, high speed data transport, mobile and cellular techniques and wireless communications are developing opportunities of great promise for the industry's expansion into commercial opportunities." Along with the Internet, the public was interested in technology for personal use and thus the opportunity for commercial applications was as ripe as ever.

Howe would be the face of the *Journal* during these transformative years about to reshape the industry and technology affecting our day to day lives.

Encouraged by individual governments and new corporate investment, a re-direction of technology away from military applications and toward commercial ones would become a global effort. Systems developed during the Cold War for defense purposes would be seen by the public for the first time during the Gulf War, marked by quick victory and the performance of smart weapons. Advance guidance systems and mobile communication would awaken many to what applied microwave technology could achieve. Millions of Americans witnessed Raytheon's anti-Scud Patriot system (see ***Figure 1***) during a live TV coverage of a missile attack on Riyadh during operation Desert Storm. Despite some controversy over the true effectiveness of this system in downing the incoming missile, Raytheon would capitalize on this seeming success with a *Microwave Journal* advertisement reminding readers of their contribution in fighting the "evil one" (see ***Figure 2***). The event and analysis of the technology used in this conflict was reported by contributing editor Howard Bierman in "Microwave and mm-Wave Technology: The Brains Behind Smart Weapons." Bierman also wrote some months later about another bright spot for the industry in his special report, "The Defense Budget Shrinks, but Electronics Gains Larger Share."

Fig. 1 Raytheon Patriot anti-missile system.

And yet the scramble to find new commercial opportunities was on as Howe reported in December in "The 1991 (Microwave Hybrid Circuit) MHC Conference Stresses Commercial Transition." No specific direction for the industry was offered at the conference, yet keynote speaker Bill Jones, VP at Westinghouse, suggested companies take greater consideration of their core competencies rather than specific products when deciding which commercial markets to pursue. Guided by Harlan's editorial mandate,

Fig. 2 Raytheon ad from Microwave Journal *in 1991.*

Journal contributors offered some their own advice in the new Commercial Applications Series, which was launched as a monthly feature in 1991. Notable articles presented emerging commercial opportunities in personal communication, motor vehicle and highway automation, microwave heating in medicine, a "roaring" DBS receiver market, and mobile satellite communication for consumers.

JANUARY 1993

Keeping with the editorial directive to focus on commercial opportunities, *Microwave Journal* expanded the commercial applications series to include lightwave applications. The Commercial Application Series article for this issue was a special report on the European Market for Digital Cellular Communications. Contributing International Editor Guy Daniels wrote, "Of all the varied commercial markets for microwave and near-microwave technologies, personal communications seem to hold the greatest potential. This year sees the official commencement of the single European market, which brings with it the lowering of trade barriers, free consumption and economic unity. It is also the year when digital cellular communications are set to take off in Europe." Daniels continued in great detail discussing the roll-out plan by the group special mobile or GSM for worldwide digital cellular communications.

Interest in lightwaves and fiber optics had been appearing in *Microwave Journal* for over a decade as long haul telecommunications was looking to address the growing need for network capacity. Fiber optic communication was developed for commercial use in the early 1980s, operating at 1.3 μm using InGaAsP semiconductor lasers. By 1987, these systems were operating at bit rates of up to 1.7 Gb/s with repeater spacing up to 50 km. As Hugo Vifian of Hewlett-Packard noted in his article, "From Microwave to Lightwave," "The transition from microwaves to lightwaves has been a natural and fruitful development. Affinities between the two fields are presenting microwave engineers with many opportunities to expand the technology." This particular article went on to discuss optical measurements. Other topics in this series would include: Mode-locked semiconductor lasers, Photonic CAD, Optoelectronic mm-wave sources and Digital Transmitters.

APRIL 1993

Ken Carr of Microwave Medical Systems Inc. continued our reporting on the shift from military to commercial applications with a special report entitled, "A Company's Transition from the Military to the Commercial Marketplace." Carr pointed out that despite the success of the technology that grew out of military necessity (and government investment), the US was experiencing the greatest slowdown in R&D since the early 1970s. Carr pointed out that "while twenty years previous the US produced 94 percent of its electronics, in 1993 it imported 94 percent." The author then pointed to underinvestment in engineering and manufacturing technology, the mean culprit being lack of funding. He compared his effort to build a new start-up company in 1993 with his role co-founding Ferrotec in 1970, which was later acquired by Microwave Associates. His experience taught him that, "the idea that all it takes is brains, perseverance and luck is nice, but very outdated. It now takes a great deal of money." The author directed readers toward private (venture capital firms) and public (Small Business Innovation Research—SBIR) funds. Unfortunately, the dire situation of declining American competitiveness in business depicted in this article is still up for debate today.

JULY 1993

Several items of note in this, the *Journal*'s 35-year anniversary issue. A special report from Harlan Howe and Christine Blanchard on "Dual-use Technologies: Defense Technology Conversion, Reinvestment and Transition" discussed the government agencies and programs being directed by the Clinton White House to "stimulate the transition to a growing, integrated, national industrial capability that provides both the most advanced affordable military systems, as well as the most competitive commercial products." The official title of the Advanced Research Projects Agency (ARPA) program was Technology Reinvestment Project (TRP), but it was more commonly known as "dual-use" or "Operation Restore

Jobs." The timing to redirect the technical community couldn't have been better. From the 30 million cellular phones in use at the time, in ten years after this article was written there will be 159 million cell phone users. Strikingly close to the 150 million predicting in a M/A-COM advertisement running in this same issue.

MARCH 1995

A special report, "Get onto the World Wide Web - Now," introduced the new *Microwave Journal* web site and many readers to the web itself. The article bears witness to the primitive early days of the "world wide web" as basic web concepts such as hypertext links, mouse-based systems, point and click, browser and cyberspace are explained to our readers. The author tried to educate readers on service providers (limited e-mail or newsgroups to "full service ones") and browsers (Mosaic was described as the archetypical browser). The author recommended users get a fast modem to "connect the computer to the telephone line" (a 9600 bps was bottom of the line, 28.8 kps or ISDN "should be seriously considered"). At the time, "server computers on the Net were generally connected with either a T1 (1.54 mbps) or a T3 (45 mbps) high speed network link."

JUNE 1995

The term "RFIC" may or may not have yet been coined at this point, but the special report by Robert Clarke of Analog Devices, "RF and IC Designers: Two Professions Separated by an Uncommon Language," suggested the time was near. The author wrote, "Are RF and IC designers two different species? Or are they the same species and just practicing two different religions? Let's consider their beliefs. RF engineers proclaim the gospel according to Armstrong and the mysteries of Maxwell's equations and Faraday's law. They speak of the glories of power and impedance. On the other hand, IC designers chant the mantra of Ohm. They mediate on the teachings of Volta, Ampere, Haynes, Shockley, and Bardeen." The editor's instruction discussed the disappearance of bulky microwave components as more and more products take chip form and became hidden inside little SOIC packages. His message was clear: "The industry must once again embrace change." Within a year, CMOS RFIC designs and applications would be well represented among the technical features appearing frequently.

SEPTEMBER 1995

Howe's note from the publisher, "Five Years—What a Difference," commented on the many changes he witnessed in the industry since talking the helm. He touched upon the facts that in 1990 the industry markets were 80 percent military and that the anticipated downturn was much deeper than anyone had anticipated. Yet, despite the layoffs, mergers, acquisitions and business failures in 1991 and 1992, the industry had found commercial markets and restructured companies had been able to grow. By 1995, 80 percent of the industry was working in commercial applications. Howe reflected on a much improved atmosphere at the most recent MTT-S exhibitions and noted that the technical revolution had even touched the publishing business as the Microwave Journal was now fully produced electronically.

JANUARY 1998

This issue included a special section with technical features on MMIC-based Double-Y Baluns, SAW IF filters and an ALGaAs/GaAs HBT Transceiver chip for wireless applications along with reports from the Wireless/Portable by Design Exhibition. The wireless term encompassed a wide range of technologies that included cellular and cordless phones, wireless networks (WLAN), Bluetooth, GPS, satellite television and many others. The published articles throughout the year reflected the industry's attention toward specific applications, standards, modulation schemes and competing semiconductor technologies. Attention turned to every other component in the wireless radio, including the antenna, all RF/microwave passives, chip packaging, PCB design and filters.

Driven by the demands of the wireless systems covered in the early issues of 1998 (and previous years), the need to focus on individual component performance was evident by the scope and depth of the technology described in this year's technical articles. The ef-

fort to shift microwave engineering away from the military and toward commercial opportunities yielded impressive research in all areas of hardware design and supporting activities such as simulation and test.

With this shift to commercial wireless, devices and related articles shifted from broad to narrow frequency bands and device performance was increasingly tied to specific applications such as power amps for GSM handsets, IF ASICs for CDMA cellular/PCS telephones, phase-locked loops for CDMA, GaAs HBT transceiver for PHS cordless phones, CDMA RFIC upconverters, and driver amps for PCS base stations.

The quest for high power amplification, once the realm of TWTs, was now being fought among MESFET, pHEMT, HBTs and LDMOS, silicon, GaAs, InP and SiGe. In addition to power, many amplifier papers concerned themselves with monitoring and improving linearity. Featured papers included: "Digital Data Signal Spectral Side Lobe Regrowth in Soft Saturating Amplifiers," "1.9 GHz Feed-forward Adaptive Amplifier," "Linear RF Power Amplifier Design for CDMA" and "Spectral Containment by Pre-distortion of OQPSK Signal." From a financial perspective, the *Microwave Journal* commercial markets update would report on the favorable business climate for many RFIC companies whose stocks at the time were soaring.

FEBRUARY 1998

Another recurring commercial application in 1998 was the GPS system, which was discussed in articles such as "Quadrafilar Helical Antenna for Low Elevation GPS," "An Integrated GPS Receiver RF Front End," "GPS Frequency and Time Standards," "A GPS Chipset with Low Power Consumption" and a special report on "GPS in 10 Years." Karl Kovach of ARINC Inc. and Karen Van Dyke of the US Department of Transportation predicted that enhancements to GPS, removal of Selective Availability (SA) combined with user equipment would improve accuracy, integrity and availability of GPS. What was truly fascinating about this article was their explanation (in easy to understand terms) of how the system functioned in 1998, what its limitations were (from a user perspective) and what the plan was to upgrade the system into what we experience today.

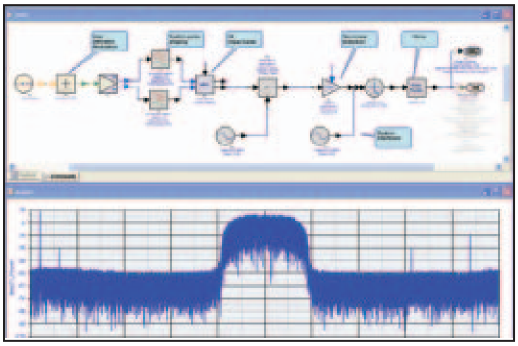
OCTOBER 1998

A special report by Rob Van Brunt on "Third-Generation Wireless Test Requirements" looked toward the future of mobile communications. Test manufacturers were among the first to deliver products to market for these new standards. The author spelled out the goals for the IMT-2000 system that was, according to his article, "still several years away." The principle challenge in deployment cited in the article was the issue of graceful evolution from existing 1G and 2G systems. This challenge was perhaps greater than anyone at the time, including the author anticipated. However, 80 percent of the European population would be covered by 2005 and by December 2007, 190 3G networks in 40 countries would be operational.

CONCLUSION

It was a watershed decade for the industry, perhaps more than any other. Businesses were put under intense pressure to become lean and efficient in the wake of an all but disappearing military market. Companies that were able to re-focus their core competencies toward commercial applications not only stemmed their bleeding, but were able to grow significantly by mid-decade. Where 80 percent of companies manufactured for military end-use in 1990, that same percentage would claim to manufacture mostly for commercial applications by the end of the decade. Encouraged by the government, companies would embrace the notion of dual-use components.

Simulation technology would take great strides in capability and change the way we designed forever, while semiconductor process technology made CMOS viable at radio frequencies and allowed new HEMT and HBT technologies to co-exist on a single IC. These innovations ignited the wireless revolution and made personal communication applications and mobile handsets possible. In the 1990s the microwave industry would answer that Verizon guy's question, "Can you hear me now?" with a resounding, "Loud and clear." ■



CREATING HIGH-PERFORMANCE SDR ARCHITECTURES

Developers of Software Defined Radio (SDR) waveforms are fortunate to have a myriad of high-performance technologies and targets available for waveform implementation in heterogeneous DSP and RF architectures. The challenge is how to co-design RF architectures together with baseband signal processing to create high performance and flexible SDR architectures that can achieve the critical performance specifications necessary in the operational environment.

SDR waveform architectures found in military and commercial applications (see ***Figure 1***) incorporate broadband high dynamic range RF subsystems, which act as the interface between the baseband processing engine and the real transmission channel. These analog/RF subsystems and associated transmission channels are never ideal and always introduce noise, distortion and other non-ideal impairments that limit the performance of the overall physical layer (PHY). In real systems, the non-ideal effects of these "real" analog/RF subsystems are either accounted for by over-design or through pain-staking, after-the-fact manipulation of the baseband algorithms to correct for these impairments. Being able to model and account for these RF/channel impairments along with the DSP functions is critical, but many existing design methodologies simply ignore them or use greatly simplified math functions to model these impairments.

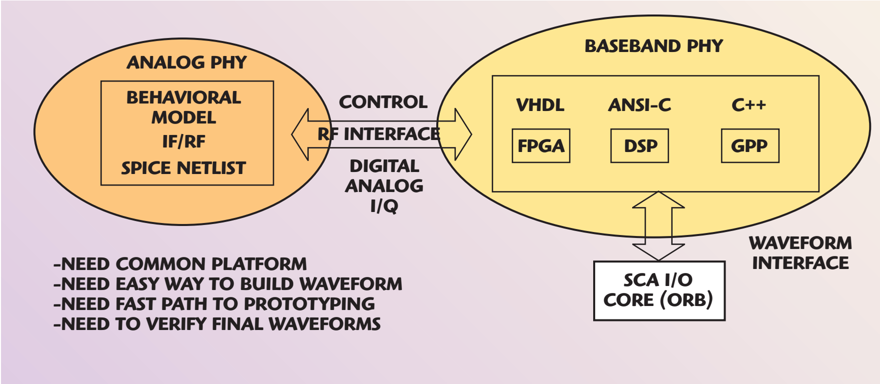
For the baseband designer, FPGA architectures and embedded DSP/GPP engines have reached new reference points in size, performance and power consumption, giving developers of military and airborne systems and lower volume applications plenty of target choices for the creation of high performance, flexible and re-programmable SDR waveform architectures. Taking advantage of the horsepower in these advanced HW targets continues to stretch the development methodologies that have served the SDR community for many years.

These methodologies, which rely heavily on general purpose design and math modeling, are now becoming a bottleneck for efficient SDR design. Many engineers continue to use general purpose Register Transfer Level (RTL) design and math modeling tools, with simple and mostly ideal models of the RF subsystems or utilize

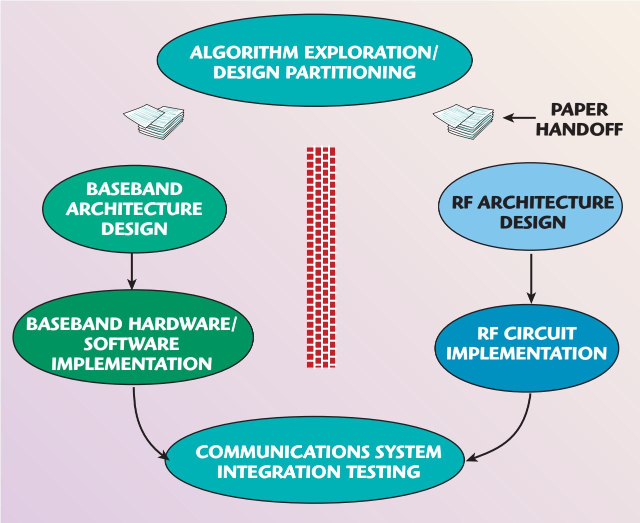
AGILENT EESOF EDA
Santa Clara, CA

MILLIMETER WAVE RECTANGULAR TE_{10} WAVEGUIDE INFORMATION

WG Band	Waveguide Frequency Range (GHz)	Wavelength Rangeλo (mil)	Wavelength Rangeλo (mm)	Guide Wavelength Range (λg/λo)	Waveguide Impedance Range (Ω)	TE_{10} Cutoff Freq (GHz)	TE_{10} Cutoff λc (mil)	TE_{10} Cutoff λc (mm)	Internal Dimensions (mils)	Internal Dimensions (mm)
WR-28	26.5 - 40.0	445.4 - 295.1	11.313 - 7.495	1.650 - 1.177	621.9 - 443.6	21.1	560.0	14.22	280.0 x 140.0	7.112 x 3.556
WR-22	33.0 - 50.0	357.7 - 236.1	9.085 - 5.996	1.661 - 1.177	626.0 - 443.6	26.3	448.0	11.38	224.0 x 112.0	5.690 x 2.845
WR-19	40.0 - 60.0	295.1 - 196.7	7.495 - 4.997	1.613 - 1.173	608.3 - 442.4	31.4	376.0	9.55	188.0 x 94.0	4.775 x 2.388
WR-15	50.0 - 75.0	236.1 - 157.4	5.996 - 3.997	1.657 - 1.181	624.8 - 445.1	39.9	296.0	7.52	148.0 x 74.0	3.759 x 1.880
WR-12	60.0 - 90.0	196.7 - 131.1	4.997 - 3.331	1.690 - 1.186	637.2 - 447.1	48.4	244.0	6.20	122.0 x 61.0	3.099 x 1.549
WR-10	75.0 - 110.0	157.4 - 107.3	3.997 - 2.725	1.620 - 1.185	610.9 - 446.7	59.0	200.0	5.08	100.0 x 50.0	2.50 x 1.270
WR-08	90.0 - 140.0	131.1 - 84.3	3.331 - 2.141	1.746 - 1.177	658.1 - 443.6	73.8	160.0	4.06	80.0 x 40.0	2.032 x 1.016
WR-06	110.0 - 170.0	107.3 - 69.4	2.725 - 1.763	1.771 - 1.183	667.7 - 445.9	90.8	130.0	3.30	65.0 x 32.5	1.651 x 0.826
WR-05	140.0 - 220.0	84.3 - 53.6	2.141 - 1.363	1.777 - 1.176	669.7 - 443.3	115.7	102.0	2.59	51.0 x 25.5	1.295 x 0.648
WR-04	170.0 - 260.0	69.4 - 45.4	1.763 - 1.153	1.695 - 1.177	638.8 - 443.9	137.2	86.0	2.18	43.0 x 21.5	1.092 x 0.546
WR-03	220.0 - 325.0	53.6 - 36.3	1.363 - 0.922	1.627 - 1.183	613.5 - 445.9	173.6	68.0	1.73	34.0 x 17.0	0.864 x 0.432
WR-02.8	260.0 - 400.0	45.4 - 29.5	1.153 - 0.749	1.708 - 1.177	643.8 - 443.6	210.8	56.0	1.42	28.0 x 14.0	0.711 x 0.356
WR-02.2	325.0 - 500.0	36.3 - 23.6	0.922 - 0.600	1.771 - 1.185	667.7 - 446.7	268.2	44.0	1.12	22.0 x 11.0	0.559 x 0.279
WR-01.9	400.0 - 600.0	29.5 - 19.7	0.749 - 0.500	1.587 - 1.169	598.3 - 440.6	310.6	38.0	0.97	19.0 x 9.5	0.483 x 0.241
WR-01.5	500.0 - 750.0	23.6 - 15.7	0.600 - 0.400	1.620 - 1.175	610.9 - 442.8	393.4	30.0	0.76	15.0 x 7.5	0.381 x 0.191
WR-01.2	600.0 - 900.0	19.7 - 13.1	0.500 - 0.333	1.746 - 1.194	658.1 - 450.1	491.8	24.0	0.61	12.0 x 6.0	0.305 x 0.152
WR-01.0	750.0 - 1100.0	15.7 - 10.7	0.400 - 0.273	1.620 - 1.185	610.9 - 446.7	590.1	20.0	0.51	10.0 x 5.0	0.254 x 0.127



▲ *Fig. 1 Typical SDR architecture for military and commercial waveform implementation.*



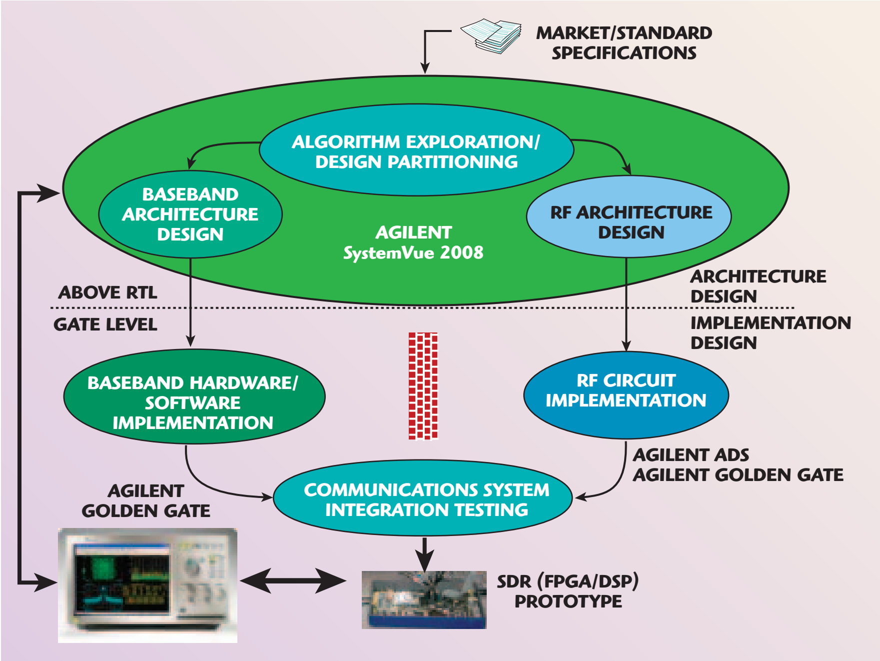
▲ *Fig. 2 Discontinuous system architecture flow.*

in-house, hand-coded methodologies that tend to create discontinuities in the overall task of system architecture design and algorithm implementation. ***Figure 2*** shows a discontinuous system architecture flow.

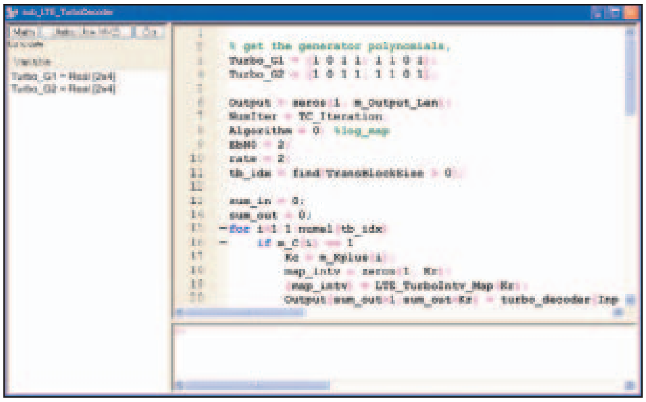
With the emergence of electronic-system-level (ESL) design methodologies there are new classes of design automation tools available today to help with older strained methodologies. However, most of these ESL solutions are focused on high-level design synthesis of digital systems, allowing higher modeling abstractions. Often these ESL tools ignore the analog/RF systems, providing value only for the digital baseband and SW engineers. Agilent Technologies EDA division has recently announced its new SystemVue 2008 product, which is focused on the task of rapid development of SDR waveform architectures and algorithm development. The software unifies the disjointed architectural and algorithm design flow, connecting high level algorithm design with lower level HW architectural design for both baseband HW and analog/RF architectural design. This new tool bridges the architectural design "gap" allowing seamless integration of algorithms, HW descriptions and analog/RF behavioral modeling all in a simple and intuitive graphical design environment. ***Figure 3*** shows the connected design methodology afforded by Agilent SystemVue 2008.

Most algorithm developers prefer textual-based modeling and debugging over graphical design tools. SystemVue 2008 provides algorithm developers with an integrated design environment (IDE) for developing and debugging text-based algorithm models in familiar M-code (math) and C/C++ formats. These integrated code development interfaces allow complete mathematical and algorithmic coding, including the ability to model algorithms in fixed point using industry standard SystemC fixed point class. Developers can quickly model algorithmic behavior with immediate creation of simulation models that can be wired graphically into the rest of the design to form the basis of the design architecture.

Figure 4 is a screen shot of the M-code modeling interface. From this interface M-code algorithms can be written and debugged. This inter-



▲ *Fig. 3 SystemVue 2008 connected design methodology.*



▲ *Fig. 4 The floating point M-code.*

face is also used for bringing real world data into the environment or scripted to control a simulator.

As algorithms move through baseband architecture and HW implementation, libraries of architectural building blocks support fixed point design for implementation in FPGA or ASIC. The fixed point simulation offers advanced analysis and optimization of finite precision math, displaying histograms of numerical overflow and underflow, along with the ability to manipulate word-length to maximize performance and minimize implementation size.

Specific GUI features allow users to associate alternate model views for different architectural building blocks, allowing floating-point schematic, floating-point M-code or C++, fixed-point C++, fixed-point schematic and fixed-point user-supplied HDL model views for each block. This simplifies the task of having separate environment and test harnesses to validate fixed-point and HDL functionality against early algorithmic models. SystemVue 2008 also integrates Mentor Graphics ModelSim co-simulation, allowing simple inclusion of user supplied HDL to be simulated using this industry standard simulator.

Optional HDL code generation from fixed-point algorithmic descriptions supports fully synthesizable IEEE compliant VHDL and Verilog RTL generation as an added convenience to fixed-point algorithm developers. This allows designers to quickly generate fully synthesizable HDL from early algorithmic descriptions for early and rapid algorithm prototyping in FPGAs.

Figure 5a and ***5b*** show a fixed-point GFSK modulator built from Agilent SystemVue 2008 with the resulting VHDL for the top level architecture. Because all SDR waveform architectures contain an analog/RF subsystem, real-world channel impairments will

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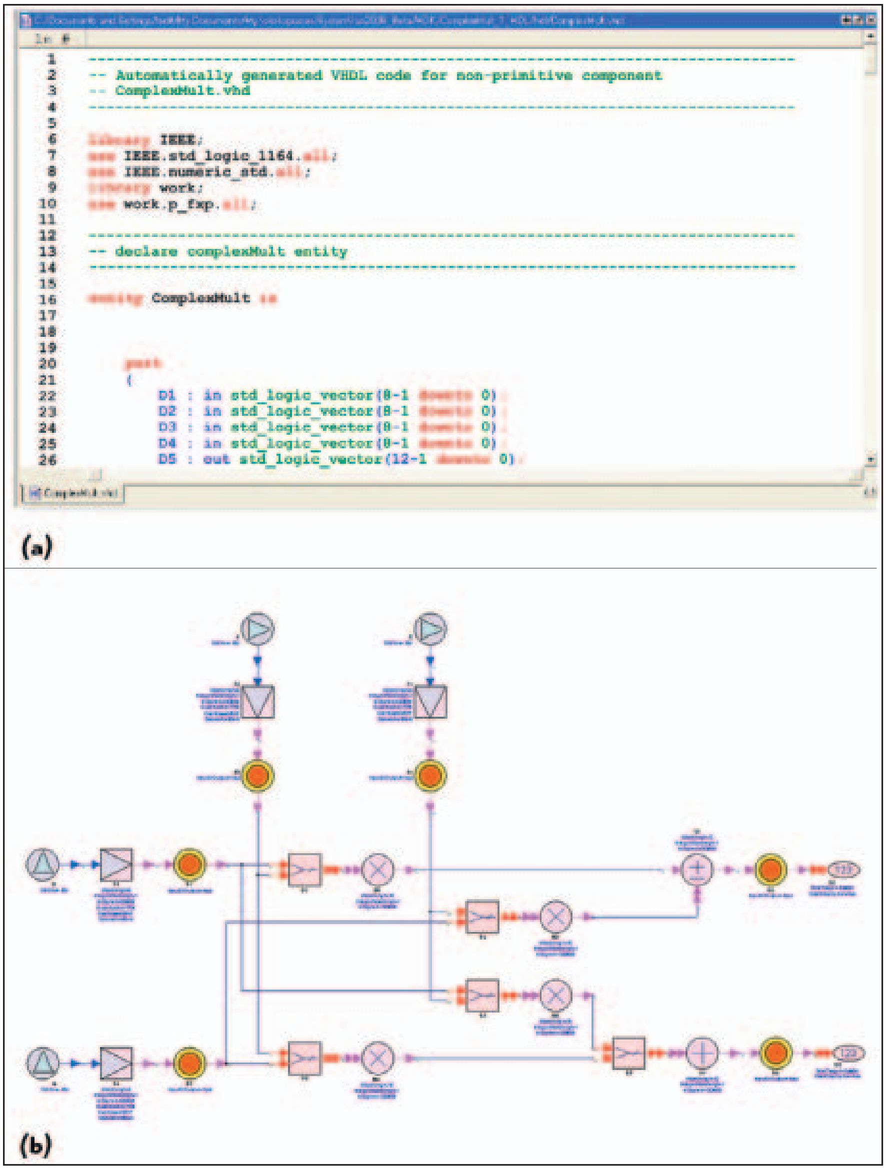
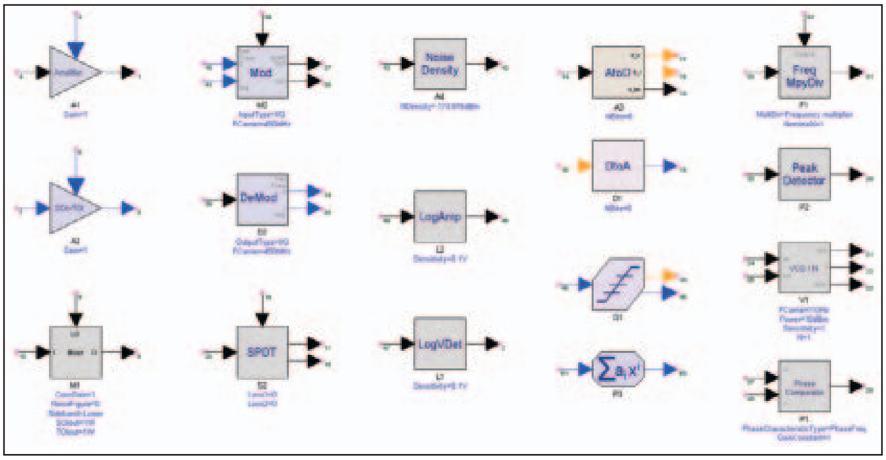
degrade the overall PHY performance upon final implementation of the system. It is imperative that early system architects and algorithm developers have a quick and easy way to prototype virtual RF architectures including the



▲ *Fig. 5 A fixed-point GFSK modulator built using SystemVue 2008 and resulting VHDL.*



▲ *Fig. 6 RF/IF/analog processing blocks—standard with SystemVue 2008.*

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effects these impairments will have on the system and to explore algorithmic means for correcting or accounting for these impairments.

The underlying simulator in the SystemVue 2008 platform is uniquely designed to handle modeling and analysis of the real modulated signals propagating through a channel, providing, in some cases, orders of magnitude more computational efficiency than the leading "math" tools, without requiring the need for additional HW acceleration or compute farm support. Some of the unique models in SystemVue 2008 for analog and RF/channel impairments include:

- RF and mixer models that support both second- and third-order effects, allowing modeling of DC offsets in ZIF receiver architectures and image reject/alternate channel receiver degradation
- I/Q modulator and demodulators
- Complete library of RF communications and analog filters
- Data converters, quantizers and phase detectors

Figure 6 shows the collection of RF/IF/analog processing blocks that are standard with this package. Each of these blocks supports full envelope simulation of modulated signals and can impart bandpass impairments to the signal.

SystemVue 2008 is built on a new infrastructure that allows complete scripting of test instrument connectivity, allowing the program to link with the full array of Agilent instrumentation, including signal generators, signal analyzers, oscilloscopes, vector analyzers, logic analyzers and vector network analyzers. Seamless links to hardware and scripting ability allow the software to extend functional test to include performance metrics of BER/PER of fully coded systems, swept power/frequency characterization of receiver performance looking at digital output, and full algorithm implementation testing of designs in FPGAs and DSPs. SDR waveform architectures can now be verified at the HW prototype level and easily compared to early descriptions of waveform performance in simulation.

CONCLUSION

SystemVue 2008 brings together the needed design disciplines to accelerate the development of innovative heterogeneous SDR waveform architectures. By combining text-based code development methodologies with a GUI block editing environment, the new software can cut the time it takes to get ideas (algorithms) into real hardware. This brings real-world RF impairments into the hands of early architects and algorithm developers, allowing for true high performance designs, and avoiding overdesign while reducing the chances of poor implementation choices.

SystemVue 2008 configurations start at US $14,000 for full featured comms PHY focused capability that includes comms, DSP, logic and RF models, along with the fast simulator for modulated, multi-rate systems.

Agilent EEsof EDA,
Santa Clara, CA 800-829-4444,
www.agilent.com/find/systemvue.

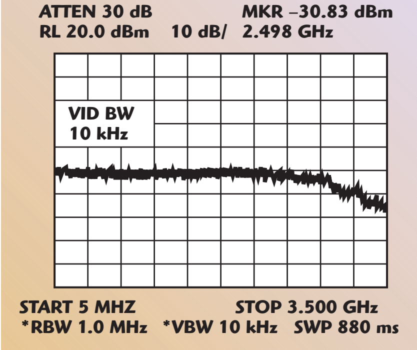
RS No. 300

BROADBAND NOISE GENERATORS SPAN 10 HZ TO 18 GHZ

Noise considerations are a key factor in the design of radio systems of all types and designers expend much effort in reducing system noise. Testing radio systems by inserting white Gaussian noise along with the signal has been a recognized test method for decades, but there are surprisingly few providers of test platforms with the capability to use this simple methodology. The prime users are both commercial and military and encompass both terrestrial and satellite networks as well as radar systems.

To address this market and to satisfy the various applications, AtlanTecRF has developed the ANG series of broadband noise generators, in both benchtop and rack-mount packages, that cover a wide frequency range and can be uniquely customized for testing many types of radio systems. The ANG series includes units that start at 10 Hz and operate up to a few hundred kHz for testing audio and baseband circuits, while the upper frequency limit of the range includes units with outputs up to 18 GHz. ***Figure 1*** shows the frequency response and roll-off for AtlanTecRF model ANG1613, 10 MHz to 2.5 GHz.

Fig. 1 Noise output over full operational band.

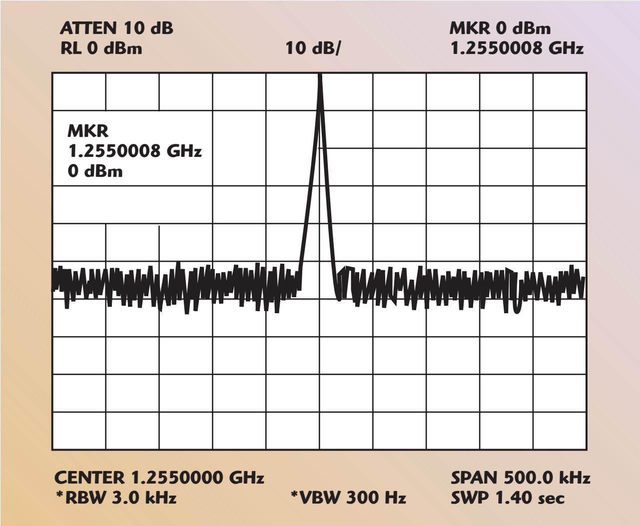


The range also includes models that offer high output power, up to +30 dBm total power, and all units are available with built-in variable attenuators, both manual and remotely controllable, that can be user specified for lower levels of injection. In addition to internal attenuators, key options include an internal signal combiner for injecting a signal from an external signal generator for carrier to noise ratio (CNR) testing, as illustrated in ***Figure 2***.

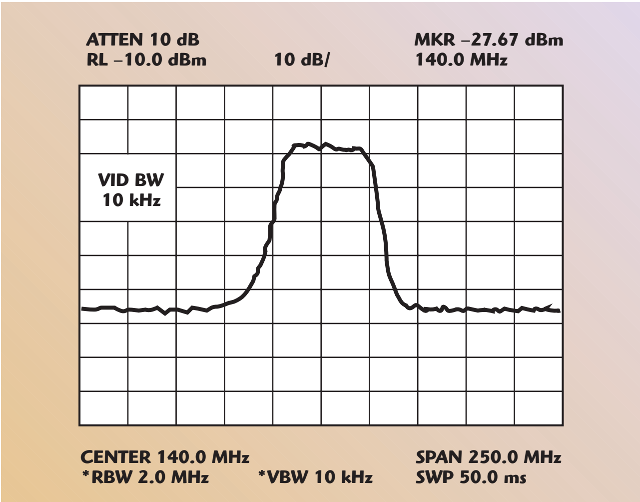
Output connector styles (SMA, N type, BNC, TNC) can be selected to suit the user application, and for low frequency units (< 2 GHz) an output impedance of 75 Ω can be specified. Adding attenuators reduces the maximum noise output level by the insertion loss of the selected attenuator module.

Typical applications can be both military and commercial, with perhaps the most well-

ATLANTECRF
Braintree, UK



▲ *Fig. 2 Noise output with signal combiner input.*



▲ *Fig. 3 Noise output used to view band-pass filter characteristic.*

known being carrier/noise testing of commercial radio networks, satellite systems and radar systems. The units can also be used for baseband signal simulation of communications systems to mimic simulated models and jitter testing. Noise generators are also frequently used as part of a built-in test equipment (BITE) system, particularly in the military arena.

COMMERCIAL APPLICATIONS

Over many years commercial frequency division multiplex (FDM) telecommunications providers utilized noise power ratio (NPR) as a measurement of signal quality and distortion in their analogue radio systems. Although not used so frequently today, it remains a valid methodology for which a higher power noise source, like those of the AtlanTecRF ANG series, is required. Matching bandpass and bandstop filters are required to use this test method.

Modern digital radio and satellite systems utilize related methods, the most common being CNR versus Bit Error Rate (BER) or EbNo versus BER, where EbNo is defined as bit energy divided by noise power density in dBm per Hz of bandwidth.

The ANG series includes units that cover the intermediate frequency (IF) ranges of both digital radio systems (70 and 140 MHz) and satellite systems (950 to 2150 MHz) that can be employed for either CNR or EbNo measurements. The optional signal combiner input would normally be specified for these measurements. A real signal can then be injected into the receiving system and then degraded with an increasing level of Gaussian white noise from the noise generator until the signal to noise ratio for a CNR measurement or BER measurement becomes unacceptable.

The semiconductor industry has used white noise to provide dithering circuits for A/D converters to reduce spurs. White noise jitter testing is also employed for testing optical systems.

MILITARY APPLICATIONS

In the military arena the two most well known applications of white noise testing are airborne, wideband jammers and built-in test equipment. White noise jammers consist of a noise source followed by bandpass filters from which the signal is input to a high power amplifier and an antenna. The resulting effect is to raise the noise floor of all local receivers.

Noise generators are frequently included as part of the BITE system within a receiving system. The noise source is again fed into an amplifier and a filter or switched filters and then switched into the input of the receiver on receipt of a self-test command. It enables the receiver system to determine its sensitivity before being connected to the antenna.

A tracking generator is a useful but relatively expensive option for a spectrum analyzer for performing scalar network analyzer measurements. In cases where only low dynamic range network measurements are required, a broadband white noise source can provide a cost-effective alternative. Furthermore, microwave spectrum analyzers rarely have a full band tracking generator, so a broadband noise source such as the ANG 2618 can provide reasonably flat output power up to 18 GHz.

The addition of an RF bridge, which would also be the case for a tracking generator, allows return loss/VSWR measurements over the frequency range of the noise generator. One proviso of this system is that the spectrum analyzer resolution bandwidth (RBW) must be kept relatively wide to provide sufficient noise power for the measurement. For example, the ANG 2618 has a noise density of –122 dBm/Hz and with a RBW setting of 1 kHz would provide –92 dBm of displayed power. Increasing the RBW to 100 kHz will provide –72 dBm of displayed power. At this level the displayed signal should be at least 30 to 40 dB above the spectrum analyzer noise floor.

CONCLUSION

These ultra-wideband, high output instruments offer genuine versatility in a piece of test and measurement equipment including some very specialised applications in both the commercial and military arenas. However, they are equally at home in the general purpose radio frequency laboratory for simple evaluations and tests, such as a basic frequency response characteristic of the type illustrated in ***Figure 3***.

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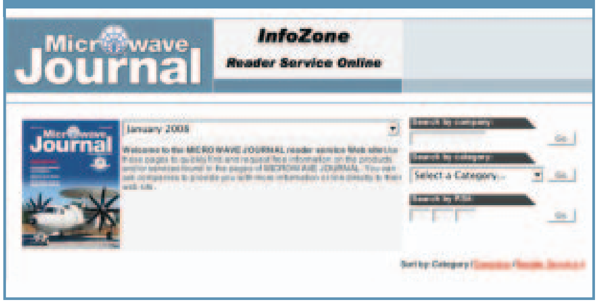


VIRTUAL FIELD MONITOR FOR AR FIELD PROBES

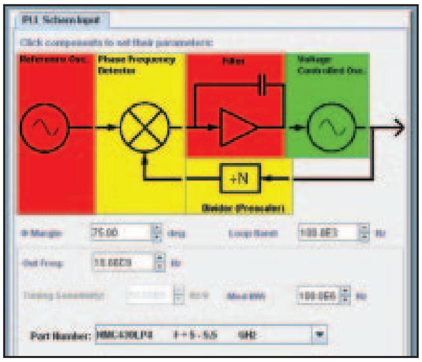
AR's virtual field monitor provides a graphical user interface that allows control of all probe functions, while displaying probe data and status. The probe can control up to 16 probes – any combination of AR's battery or laser powered field probes – through available RS-232, GPIB or USB ports. Field strength data can be displayed in four ways: XYZ, Min/Max Avg, Min/Max Hold and Graphical. The VM7000 also has the ability to correct probe readings at a user defined frequency using a table of frequency response correction factors.

AR RF/Microwave Instrumentation,
Souderton, PA (215) 723-8181, www.ar-worldwide.com.
RS No. 310

ANISOTROPIC PLANAR MULTILAYER DESIGN CODE

Tromma™ is a multilayer design code for planar radome, absorber and shielding structures. Tromma calculates the complex transmission and reflection coefficients of structures containing anisotropic materials as a function of frequency, incidence angle, polarization angle and orientation. Layers can be of isotropic and anisotropic materials, impedance and admittance sheets, C Sheets, RC Sheets and RLC Sheets. Tromma includes an optimizer that can be used to maximize or minimize the reflection or transmission coefficient over a specified frequency. In addition to the standard rectangular plots the program can display Smith Charts, which can be used to achieve a design goal more quickly.

Damaskos Inc.,
Concordville, PA (610) 358-0200, www.damaskosinc.com.
RS No. 311



PLL PHASE NOISE SOFTWARE

The widely popular PLL Phase Noise Calculator tool on Hittite's web site was specifically designed to help synthesizer designers select the best Hittite Divider, Phase Frequency Detector and VCO for their PLL circuit needs. The interrelation of these building blocks is critical to achieving optimal PLL phase noise, and each component in the PLL circuit will impact overall performance. A graphical interface guides the user through the component selection process, and the calculator uploads the key performance attributes for each Hittite component selected. The PLL Phase Noise Calculator quickly provides the phase noise contribution of each PLL element, as well as the total for the entire loop.

Hittite Microwave Corp.,
Chelmsford, MA (978) 250-3343, www.hittite.com.
RS No. 312

FILTER SYNTHESIS AND SELECTION TOOL

Filter Wizard℠ has been enhanced to provide deviation from linear phase information on the electrical response graph, refine the presentation of information on the details screen and improve the band reject (notch) search interface. The web-based selection tool encompasses a large portion of the standard filter types addressed in the company's 2008 catalog, including Chip & Wire and Tubular, Ceramic, Cavity, High-Q Ceramic Puck and Waveguide filters. Filter Wizard accelerates user progress from specs to RFQ for RF and microwave filters spanning an ever-increasing range of response types, bandwidths and unloaded Q values from 300 kHz to 40 GHz.

K&L Microwave,
Salisbury, MD (410) 749-2424,
www.klmicrowave.com or www.klfilterwizard.com.
RS No. 313

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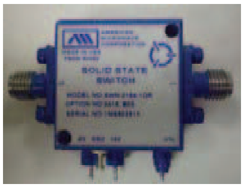
Frequency	0.5 to 18 GHz	Rise/Fall Time	10 nS type 15 nS max.
Insertion Loss	(R) 2.5 dB max., (NR) 3.5 dB max.	Switching Speed	75 nS typ., 100 nS max.
VSWR	2.0:1 typ.	Power Supply	(R/NR) +5VDC @70 mA max. (R) -5VDC @50 mA max. (NR) -5VDC @100 mA max.
Isolation	60 dB min.		



SPST NON-REFLECTIVE/ABSORPTIVE SWITCHES

SWCH1K-DC40-SK

Frequency	DC to 40 GHz	Rise/Fall Time	900 pS typ., 1 nS max.
Insertion Loss	5.5 dB typ., 6.8 dB max.	Switching Speed	5 nS typ., 6 nS max.
VSWR	2.0:1 typ., 2.2:1 max.	Power Supply	+8 to +15VDC @15 mA max.
Isolation	65 dB typ., 55 dB min.		-8 to -15VDC @40 mA max.

SPST NON-REFLECTIVE/ABSORPTIVE SWITCHES

SWM-DJV-1DT-2ATT

Frequency	DC to 20 GHz	Rise/Fall Time	1 nS typ., 2 nS max.
Insertion Loss	4.5 dB max.	Switching Speed	12 nS typ., 15 nS max.
VSWR	2.0:1 max.	Power Supply	-5VDC @25 mA max.
Isolation	60 dB min.		

SPDT SWITCHES

SWN-218-2DR-STD / SWN-218-2DT-STD

Frequency	0.5 to 18 GHz	Rise/Fall Time	10 nS typ., 15 nS max.
Insertion Loss	(R) 2.5 dB max., (NR) 3.5 dB max.	Switching Speed	75 nS typ., 100 nS max.
		Power Supply	(R/NR) +5VDC @100 mA max. (R) -5VDC @75 mA max.
VSWR	2.0:1 typ.		
Isolation	60 dB min.	Non-Reflective	-5VDC @100 mA max.

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Frequency	2 to 18 GHz	Log Slope	50 mV/dB
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Log Linearity	±0.5 dB (room temp.)	VSWR	3.0:1 MAX.
		TSS	-42 dBm
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SOFTWARE UPDATE

AUTOMATED CHARACTERIZATION SUITE

Keithley has enhanced its Automated Characterization Suite (ACS) software to include optional wafer level reliability (WLR) test tools for semiconductor reliability and lifetime prediction testing applications. Version 4.0 builds on the ACS software's existing single- and multi-site parallel test capabilities, adding a database capability, as well as software tools and optional licenses for the new Reliability Test Module (RTM) and ACS Data Analysis capabilities. Together, the new Reliability Test and Data Analysis tools allow ACS-based test systems to produce lifetime predictions as much as five times faster than traditional WLR test solutions. By accelerating WLR testing during the technology development, ACS systems can significantly reduce time to market for new products.

Keithley Instruments Inc.,
Cleveland, OH (440) 248-0400, www.keithley.com.
RS No. 314

ACTIVE MEASUREMENT SOFTWARE

ORBIT/FR Inc. is releasing version 3.4 of its active measurement software for characterization of handsets and wireless devices. The software may be used as part of a system to conduct testing according to CTIA's Test Plan for Mobile Station Over-The-Air Performance. A variety of transmitter and receiver performance measurements are supported including those for Radiated Power (EIRP/TRP/NHPRP) and Isotropic Sensitivity (EIS/TIS/NHPIS). Device drivers support many of the common protocols used today from all major vendors. The 3.4 release adds independent trajectories for each dimension and brings new features such as Safe Stepping and Omit Positions to increase measurement reliability. This upgrade will be available free of charge to all customers with a valid Software Maintenance & Support contract at the time of release.

ORBIT/FR Inc.,
Horsham, PA (215) 674-5100, www.orbitfr.com.
RS No. 315


MAKE THE RIGHT CONNECTIONS

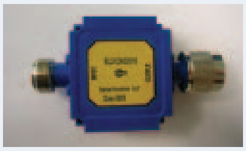
Programmable Attenuator

The M-DVAN-6018-60DD-SK is a programmable attenuator that incorporates a new linearization circuit to enable fast and accurate attenuation switching. The new design focuses on quick settling and stable operation over temperature extremes. Switching between any attenuation level is typically settled within 1 dB in about 400 ns. This attenuator offers temperature stability of ±1 dB over -10° to 85°C. The M-DVAN-6018-60DD-SK uses a hermetic MIL-C-28747 14 pin connector. Size: 1.34" x 1.34" x 0.5".

American Microwave Corp.,
Frederick, MD (301) 662-4700,
www.americanmicrowavecorp.com.

RS No. 216

L-band Limiter

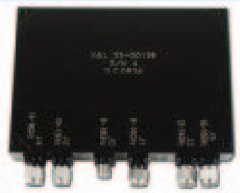


The model EL21Z401016 is an L-band limiter that features low insertion loss parameter less than 0.6 dB at the input peak power of 450 W, and pulse duration of 250 microsec. This limiter was specially designed for next generation air-traffic control radars.

Dorado International Corp.,
Seattle, WA (206) 574-0900,
www.dorado-intl.com.

RS No. 217

8 to 18 GHz Multiplexer



For wideband receiver applications, the 8 to 18 GHz spectrum is divided into medium-size slices (2 GHz) prior to the amplification stage. The role of the multiplexer is to pass the spectrum with flat insertion loss (1.25 dB) and provide adequate isolation of 70 dB between the channels, which directly affects the dynamic range of the signal detection. At cross-over regions, the requirement is to have overlapping channels, leaving the ambiguity of detection to finer filtration schemes further down the chain. Spectral overlapping regions can be realized using a power divider and isolators splitting of RF signals into equal paths. The SS-00159 is K&L Microwave's solution for passband flatness and tight isolation, achieved using degree 10 cavity TEM combline filters, with resonators machined directly into the housing. This reduces the number of parts and provides greater control over RF leakages. The unit measures 4" x 3" x 0.5" with SMA connectors located on one side.

K&L Microwave,
Salisbury, MD (410) 749-2424,
www.klmicrowave.com.

RS No. 218

PCS Ceramic Duplexer

The DR-1880/1960 is a ceramic duplexer for the full Personal Communication System (PCS) frequencies. The DR-1880/1960 duplexer exhibits less than 3.5 dB of insertion loss across the passbands of 1850 to 1910 MHz and 1930 to 1990 MHz while providing greater than 45 dB of rejection. Size: 1.7" x 0.7" x 0.4".

Lorch Commercial and Wireless,
Salisbury, MD (410) 860-5100,
www.lorchwireless.com.

RS No. 219

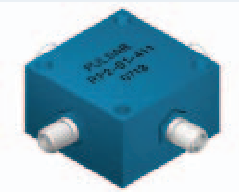
Wideband Hybrid Couplers

MECA 3 dB, 90° hybrid couplers cover all wireless band applications from 700 MHz thru 2.7 GHz. Ideal for BTS/DAS head end systems or combining amplifiers for antenna sharing applications with high isolation. These couplers offer N and SMA-female connectors and 120 W (3 kW peak) and low insertion loss with excellent VSWR.

MECA Electronics,
Denville, NJ (973) 625-0661,
www.e-meca.com.

RS No. 220

Resistive Power Dividers



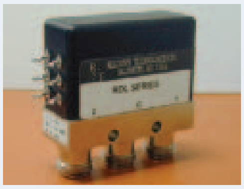
These multi-octave resistive power dividers are designed for broadband test equipment. Model RP2-01-411 is a two-way divider covering the frequency range from DC to 10 GHz with 6.8 dB maximum insertion loss, 0.3 dB amplitude, and a maximum VSWR of 1.4. Maximum input power is 1 W. Dimensions are 1.25" x 1.25" x 0.75" and SMA connectors are standard.

Pulsar Microwave Corp.,
Clifton, NJ (973) 779-6262,
www.pulsarmicrowave.com.

RS No. 221

RF Coaxial Relay

This 1P2T relay with type 'N' connectors offers a pulse latching 'Make before Break' contact configuration. Actuating current is 250 milliamps maximum at 12 V DC (also available in 28 V) and provides a 2 to 3 millisecond contact overlap between switching cycles. Standard mounting package measures 2.25" x 1.00" x 2.00" and performance is rated to 8 GHz with a maximum

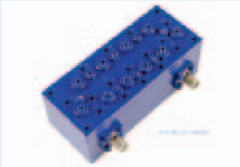


VSWR of 1.35, insertion loss of 0.35 dB, -65 dB minimum isolation and RF power handling of 200 W CW. Available options include self cutoff operation, TTL logic and auxiliary position indicators.

RelComm Technologies Inc.,
Salisbury, MD (410) 749-4488,
www.relcommtech.com.

RS No. 223

Dual Cavity Filter



Reactel part number DF-1227/1575-S11 is a narrowband dual filter that passes both the L1 and L2 GPS frequencies. It is the perfect unit for applications that are utilizing both of these GPS bands simultaneously, yet can only tolerate a two-port device. This small unit features loss of less than 1 dB and isolation in excess of 40 dB. Reactel manufactures many different varieties of GPS filters; please contact them with your specific need.

Reactel Inc.,
Gaithersburg, MD (301) 519-3660,
www.reactel.com.

RS No. 222

50 W Isolators

This latest isolator product is designed to serve and further develop the company's customers with a quality engineered product that will have a unique feature of 50 W isolator at 5 GHz in a 0.75" x 1" housing that can operate from -20° to +70°C. The challenge it is equipped for is to extract heat and stabilize 50 W at 5 GHz in a small reliable footprint.

Renaissance Electronics Corp.,
Harvard, MA (978) 772-7774,
www.rec-usa.com.

RS No. 224

Programmable Step Attenuators

This PA Series of attenuators are binary programmable step attenuators designed to operate from DC to 20 GHz. Two basic models offer attenuation ranges of 15 and 70 dB. Control is in standard format: 1-2-4-8, etc. The attenuators are available with failsafe or latching operation, 12 or 28 V coils and optional TTL drivers, with a choice of frequency ranges.

RLC Electronics Inc.,
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RS No. 225

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- *Power level offset*
- *Scheduled data recording*
- *Average of measurements*
- *Interface with test software*
- *Multi sensor support software* (up to 16 sensors support software)

Now, Mini-Circuits offers a USB Power Sensor and software that will reduce your equipment costs and provide new application features that will simplify your power measurements.

All you need is a personal computer (PC) or laptop computer and a Mini-Circuits PWR-6G+ USB Power Sensor. It turns any computer into a powerful power meter having a measurement range of -30 to +20 dBm at frequencies from 1 to 6000 MHz. The PWR-6G+ is supplied with easy-to-use, Windows-compatible measurement software to speed and simplify your power measurements, allowing you to set as many as 999 averages and to record results for further analysis. The PWR-6G+ USB Power Sensor provides 0.01-dB measurement resolution and impressive accuracy over temperature. Visit the Mini-Circuits' web site at www.minicircuits.com to learn more.

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IF/RF MICROWAVE COMPONENTS

457 rev org

Bench-mount Step Attenuator

The model BMA-35110-R is a high performance bench step attenuator that features a dynamic range of 110 dB in 1 dB steps over a wide frequency range of DC to 3000 MHz. Attenuation accuracy is ±0.5 dB or 3.0 percent (whichever is greater) for attenuation levels up to 100 dB. Maximum VSWR is 1.5 and insertion loss is specified at 1.7 dB maximum. Connector options include: SMA, BNC and N. This product is ideal for test bench, lab and other applications that require precise control of the RF signal level. Delivery is from stock.

Trilithic Inc.,
Indianapolis, IN (317) 895-3600,
www.trilithic.com.

RS No. 226

Dual Directional Coupler

Werlatone's patented dual directional coupler design provides continuous 0.5 to 32 MHz bandwidth with 500 W CW power handling at 30 dB coupling. Available with N or SMA connectors, this low loss design provides superior performance throughout the entire bandwidth. The model C5085 offers the following specifications: insertion loss of 0.15 dB, VSWR (ML) of 1.15, coupling flatness of 30 dB ± 0.25 dB and directivity of 25 dB. Size: 4" x 2" x 2".

Werlatone Inc.,
Brewster, NY (845) 279-6187,
www.werlatone.com.

RS No. 227

Current Sense Transformer

This WE-CST range of current sense transformers offer a dimension of 5.33 x 7.70 x 6.90 mm and are able to transform current of up to 10A into measurable currents. The current sense transformers are available with eight different turns ratios from 1:20 to 1:125. The transformers are suited for a frequency range from 50 kHz to 1 MHz. The transformers of the WE-CST can be applied in switching units with big input currents to measure the current for regulation.

Wurth Electronics Midcom Inc.,
Watertown, SD (605) 886-4385,
www.we-online.com

RS No. 228

Active Components

Traffic Collision Alerting System

The D2-729B003 SPDT switches high frequency RF signals between the top and bottom fuselage mounted antennas and numbers 1 and 2 systems transponders. The D2-729B003 switch is directly applicable to all TCAS systems, such as Honeywell and Rockwell/Collins. Air Agency Certificate No.: MMF-S46-40; weight (maximum) of 11.5 oz; RF impedance of 50 ohms nominal, operating temperature of -36° to +71°C ambient; operating life of 1,000,000 cycles; and switching time of 35 ms max.

Ducommun Technologies Inc.,
Carson, CA (310) 513-7214,
www.dt-usa.com.

RS No. 230

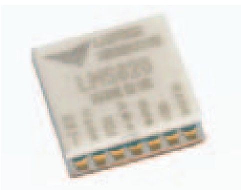
Double-balanced Mixer

The HMC663LC3 is a general purpose, double-balanced mixer that is housed in a 3x3 mm ceramic SMT package and can be used as an upconverter or downconverter. Optimized balun structures allow the HMC663LC3 to provide up to 42 dB of LO to RF and LO to IF isolation, while conversion loss is specified at only 8 dB across the frequency range of 6 to 12 GHz. This passive mixer is fabricated in a GaAs MESFET process, and requires no DC bias, external components or matching circuitry. This GaAs MMIC high IP3 double-balanced mixer is designed for use in point-to-point and point-to-multipoint radio, test equipment, laboratory and military applications.

Hittite Microwave Corp.,
Chelmsford, MA (978) 250-3343,
www.hittite.com.

RS No. 231

Switch Driver Series

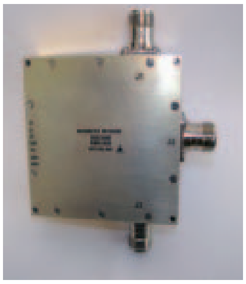


The LMS8XX series, designed to meet the demanding drive requirements of PIN diode microwave switches, offers small size, high power and selectable transition times. The basic unit (LMS820) is designed for single pole double throw (SPDT) applications, with units for three- and four-way (LMS821) and five- and six-way (LMS822) switches becoming available soon. The in-house designed and developed series is a discrete, cost-effective addition to the company's product range, for example, a switch driver as opposed to a RF PIN switch. Key target customers are other PIN switch and higher-level subsystem manufacturers who would integrate PIN switches into their higher-level products.

Labtech Microwave,
Presteigne, Powys, UK +44 1544 260 903,
www.labtechmicrowave.com.

RS No. 232

1500 W CW Switches



This line of 1500 W CW switches switch in under 2 micro-seconds. The switches are equipped with fault detection and switch-state sensing. In addition, these switches feature and on board voltage converter, eliminating the need for high voltage power supplies.

Micronetics Inc.,
Hudson, NH (603) 546-4132,
www.micronetics.com.

RS No. 233

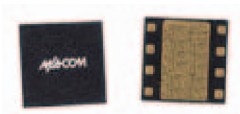
Modulator Driver

The model FO-MDA-40-15D-1 is a low-cost, high-performance EML driver for 40-Gb/s lightwave communication systems. The FO-MDA-40-15D-1 joins Narda's growing family of products for lightwave systems, including clock oscillators, phase-locked oscillators, lithium niobate and electro-absorptive modulator driver amplifiers, and pulse carver drivers. The FO-MDA-40-15D-1 is optimized for VSR 300-pin MSA SFF transponders. It offers dual inputs that mate directly with standard multiplexers. It operates at a maximum data rate of 44 Gb/s, features electronic eye-crossing control of 40 to 70 percent, and has variable output between 2.5 and 3.4 Vpp. The driver has a 3 dB bandwidth of 35 GHz and gain at 20 GHz of 23 dB.

Narda Microwave-East,
Hauppauge, NY (631) 231-1700,
www.nardamicrowave.com/east.

RS No. 235

High Linearity SP3T Switch



The MASW-008955 is a new DC to 3.5 GHz SP3T RoHS compliant switch designed for applications that require high linearity, low insertion loss, and fast settling time over a wide frequency range in an ultra small package size. M/A-COM's MASW-008955 is fabricated on a low-cost 0.5-micron gate-length GaAs process with full passivation added for robust reliability, which is achieved in a miniature 2 mm 8 lead PDFN package. Each MASW-008955 switch is 100 percent RF tested to ensure performance compliance, similar to many of M/A-COM's switch offerings. Price: $0.24 for quantities of 100,000.

Tyco Electronics M/A-COM,
Lowell, MA (800) 366-2266,
www.macom.com.

RS No. 237

NEW PRODUCTS

Coaxial Resonator-based VCO

The new model, ZRO0915C2LF, is an RoHS compliant coaxial resonator-based VCO in the UHF-band. This model operates in a frequency range from 902 to 928 MHz with excellent linear tuning voltage range of 0 to 11 VDC. This VCO features an excellent typical phase noise of -128 dBc/Hz at 10 kHz offset and a typical tuning sensitivity of 3 MHz/V. The ZRO-0915C2LF is designed to deliver a constant typical output power of 5 dBm at 10 VDC supply while drawing 23 mA (typical) over the temperature range of -40° to 85°C. The ZRO0915C2LF offers a typical phase noise value of -100 dBc/Hz at 1 kHz offset and -148 dBc/Hz at 100 kHz offset. This VCO features typical second harmonic suppression of -35 dBc and comes in Z-COMM's newly developed ZMX-14-SM package, measuring 0.75" x 0.75" x 0.22".

Z-Communications Inc., San Diego, CA (858) 621-2700, www.zcomm.com.

RS No. 238

Amplifiers

Broadband Power Amplifier

The model SSPA 1.65-2.50-30 is a high power, broadband, Gallium Nitride (GaN) RF

amplifier that operates from 1650 to 2500 MHz. This PA is ideal for broadband military platforms as well as commercial applications because it is robust and offers high power over a large bandwidth with decent power added efficiency. This amplifier was designed for broadband jamming and communication systems platforms. This model operates with a base plate temperature of 85°C with no degradation in the MTBF for the GaN devices inside. It is packaged in a modular housing that is approximately 2.5" (width) by 6.4" (long) by 1.00" (height). This amplifier has a typical P3dB of 30 to 45 W at room temperature. Noise figure at room temperature is 9.0 dB typical.

Aethercomm Inc., San Marcos, CA (760) 598-4340, www.aethercomm.com.

RS No. 239

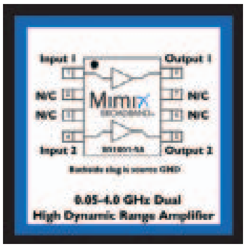
Magnetic Immunity Amplifier

AR RF/Microwave Instrumentation has unveiled a new magnetic immunity amplifier for susceptibility testing. Model 350AH1 (350 W, 10 Hz to 1 MHz) automatically accepts voltages from 90 to 260 VAC in the 47 to 63 Hz frequency range. The new amplifier, which has very low output impedance, will be used primarily for susceptibility testing for magnetic and audio frequency tests in MIL-STD-461D/E, D0160D/E, and a variety of automotive test standards. It can also be used as an AC voltage source, for watt-meter calibration, and as a driver for higher-power amplifiers.

AR RF/Microwave Instrumentation, Souderton, PA (215) 723-8181, www.ar-worldwide.com.

RS No. 240

High Dynamic Range Amplifier

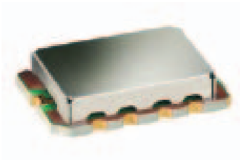


The model XG1001-SA is a dual high dynamic range amplifier that operates in a frequency range from 0.05 to 4 GHz and is assembled in an RoHS compliant SOIC-8 package. This versatile, multi-purpose amplifier delivers +44 dBm output IP3, 2.1 dB noise figure and 13 dB gain at 2 GHz. The combination of low noise figure and high IP3 at the same bias point makes it an ideal transmit or receive solution when used in applications, including CATV, cellular and PCS, MMDS and WLAN. The XG1001-SA can be implemented in balanced or push-pull design configurations and has the flexibility of being optimized for a number of wireless applications. This amplifier uses a single positive supply from +3 to +5 V.

Mimix Broadband Inc., Houston, TX (281) 988-4600, www.mimixbroadband.com.

RS No. 241

Surface-mount Amplifier

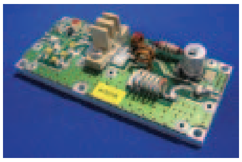


This ultra low noise TAMP-960LN+ amplifier boasts a noise figure of only 0.55 dB, while delivering 18 dB gain and a high output power of up to 16.5 dBm, making it a very desirable amplifier in today's market. These ultra reliable tiny 0.591" x 0.394" x 0.118" (15 x 10 x 5 mm) aqueous washable surface-mount +5 V amplifiers provide for a broad range of applications from 824 to 960 MHz, including: CDMA: 824 to 894 MHz, GSM Rx: 880 to 915 MHz and GSM Tx: 925 to 960 MHz. Mini-Circuits TAMP-960LN+ are available from stock at the low price of $9.95 (5-49).

Mini-Circuits, Brooklyn, NY (718) 934-4500, www.minicircuits.com.

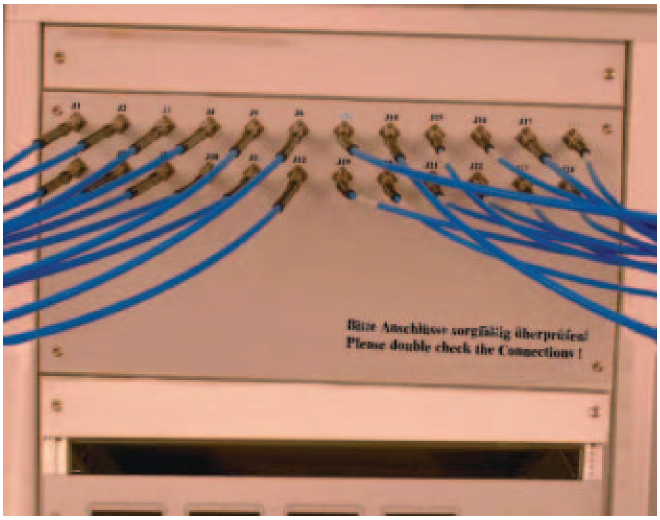
RS No. 242

300 W FM Pallet Amplifier

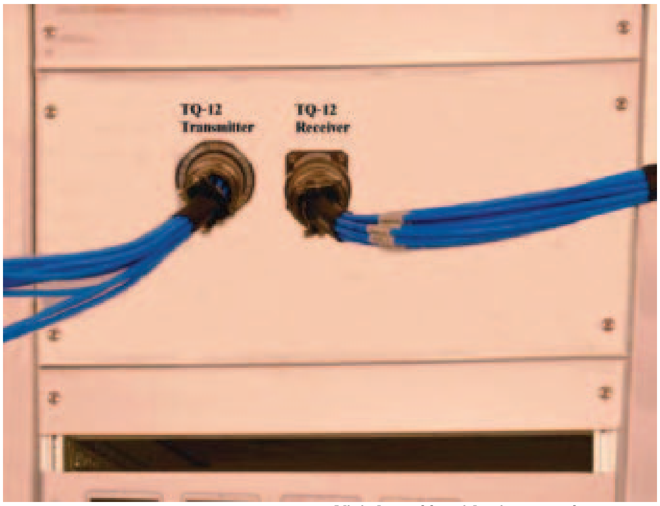


The RES-INGENIUM FM310-108 is a new high performance pallet amplifier designed for FM and HDFM radio-broadcast. It features 300 W CW output power, 78 percent collector efficiency and superior harmonic suppression (-40 dB). Both rugged and reliable, featuring the MRF6V2300NBR1 LDMOS transistor, it operates from -10° to +60°C. Enhanced gain (23 dB) allows the system designer to use lower in-

Catalogue RF Multipin Connectors
52 pages showing in detail 4 coaxial Multipin Connector Series, demonstrating how to connect and disconnect up to 23 coaxial lines in seconds and saving space.



The Problem: In various applications many coaxial microwave links have to be connected and disconnected. This means threadening and unthreadening, torquing and untorquing. Very dense packaging is not possible, as there is still room needed for manual threadening and for the use of a torque wrench. In helicopters and aircrafts all connectors usually have to be safely secured, wiring the coupling nuts of the connectors, using wire holes, a time-consuming process.



The Solution: Spectrum's Multipin Connectors are available with four (4), seven (7), eight (8), twelve (12) and twenty three (23) coaxial inserts (terminating the coaxial cable assemblies) at the Multipin end, and connecting all the coaxial cable assemblies at once and in seconds with no need of a torque wrench, no need for safety wires and using minimum space.

Spectrum Elektrotechnik GmbH
P.O.Box 450533 80905 Munich Tel. +49-89-3548-040
Email: Sales@Spectrum-et.com www.Spectrum-et.com

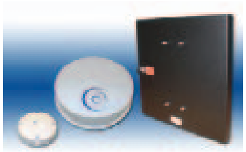
put power (1.4 W), eliminating one or more gain stages, and saving cost. The FM310-108 is ideal for FM transmitter, transposer and broadcast exciter designs. Connectorized versions are available upon request.

Richardson Electronics Ltd.,
(800) 737-6937,
www.rfwireless.rell.com.

RS No. 243

Antennas

Directional Flat Panels

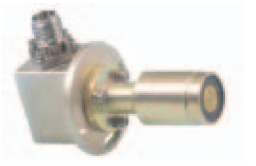


Three flat panel antennas are the latest additions to the company's range of over 400 flat panel antennas covering a wide range of frequencies and gain measurements, for all types of applications. The 2.1 to 2.3 GHz Model FPA17-2.2V/1371, which is used for security and telemetry point-to-point applications is rugged and has colour and connector options. Model LPA7-1.6L-GPS/1450 is an active GPS antenna for SATCOMs applications for regions where coverage is greater than 45° and can be mounted on a vehicle. The FPA3-0.8-6.0R/1329 is an ultra-wideband antenna with circular polarisation, for testing, measurement and security applications.

European Antennas Ltd.,
Newmarket, Suffolk, UK +44 1638 732177,
www.european-antennas.co.uk.

RS No. 245

Millimeter-wave Spiral Antennas



Cobham SASL's ASK-2163 millimeter-wave spiral antennas provide superior performance for use in applications requiring circular polarization. With excellent input VSWR, these antennas provide smooth broadband gain, low axial ratios and consistent pattern performance over 18 to 40 GHz. This model was designed and developed for applications requiring extremely close unit-to-unit amplitude and phase matching, and is an excellent choice for airborne interferometry and direction finding systems. The less than half-inch diameter design allow close element spacing in arrays to satisfy geometry for upper frequency ambiguity resolution.

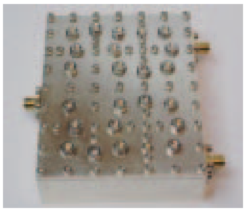
Sensor and Antenna Systems,
Lansdale Inc. (SASL), a division of
Cobham Defense Electronic Systems,
Lansdale, PA (215) 996-2416,
www.cobhamdes.com.

RS No. 246

Subsystems

3.5 Cavity Duplexer

This 3.5 GHz cavity duplexer is designed for use in WiMAX applications. The duplexer features mutual isolation of greater than 70 dB and a passband insertion loss of 1.5 dB maximum. The



duplexer operates within specification between -40° and +90°C and is available in a profile of 4" x 3" x 1.1". Custom designs are available.

Networks International Corp.,
Overland Park, KS (913) 685-3400,
www.nickc.com.

RS No. 236

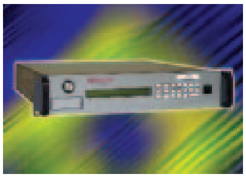
Receivers and Downconverters

This SIGINT FlxGen™ family of HF-VHF/UHF-MW receivers and downconverters feature a new generation of flexible, high performance SIGINT sensors that combine proprietary RF topologies with commercial off-the-shelf (COTS) DSP hardware. The FlxGen series includes six receivers and downconverters ranging from 10 kHz to 40 GHz and offers the flexibility to control IF bandwidths, IF frequencies, application specific functions and communications protocols/formats. In addition, the end user can use the proprietary DSP architecture to embed mission sensitive signal analysis and detection schemes. The modular architecture also allows for adaptation to multiple form factors depending on the end user environment.

Elcom Technologies Inc.,
Rockleigh, NJ (201) 767-8030,
www.elcom-tech.com.

RS No. 248

Ultra-broadband Downconverters



MITEQ introduces its new DC Series, Models DC-0.5/20G and DC-8/20G, of high performance ultra-broadband 2 Hz step agile downconverter systems. Model DC-0.5/20G accepts RF signals from 0.5 to 20 GHz. Model DC-8/20G accepts RF signals from 8 to 20 GHz. Both models provide one selectable IF output of 70, 140 or 160 MHz and simultaneously one L-band output at 1200 MHz. The frequency conversion sense of both the outputs on both models can be independently programmed as inverted or noninverted. The superb phase noise on both of these models makes these systems ideal for most applications including the stringent requirements of high order QAM.

MITEQ, Hauppauge, NY
(631) 436-7400,
www.miteq.com.

RS No. 249

Test Equipment

Compact Calibration Kits

These kits combine all standards needed for the calibration of a network analyzer in one handy unit, which is ergonomically designed to be easy to handle as well as being small size and lightweight. For laboratory utilization the product line offers 4-in-1 versions, which include Open, Short, Load and Through for the complete calibration of a network analyzer with two and more ports. Available 50 W versions are 7-16, N and 3.5 mm male or female. These 4-in-1 versions are delivered with lot independent calibration coefficients. The 3-in-1 OSL combination includes Open, Short and Load for one connector type and is available for 7-16 and N (50 W) connectors male or female. It is designed for one port spectrum and network analyzers used for mobile communication base station field measurements and other outdoor applications.

Spinner GmbH,
Munich, Germany +49 89 12601-0,
www.spinner.de.

RS No. 247

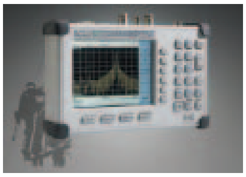
Clock Generators

This pair of clock-generation and distribution ICs offers a great combination of device integration, low-noise, low-jitter performance and signal output flexibility. The AD9520 and AD9522 include a 512-byte embedded EEPROM memory block, affording system engineers a programmable clock solution that can serve as both the source and system clock. By programming their own specific set of output conditions using the on-chip memory, designers can easily configure the AD9520/2 as the source clock to ensure initial processing functions are synchronized when the system is powered on or reset. Competing clock ICs require a separate source clock, which must be independently matched to the system processor or microcontroller in order to program the system clock chip, adding component count, cost and complexity to network line cards, wireless and broadband infrastructure, medical imaging, and data converter clocking designs.

Analog Devices Inc.,
Norwood, MA (781) 329-4700,
www.analog.com.

RS No. 250

Handheld Analyzers



Anritsu Co. announces enhancements to its Site Master™ family that continue to position the handheld analyzers as the de facto instruments for deploying, installing and maintaining wireless networks. The new enhancements, which are also available in the Cell Master™ handheld base station analyzer, include a 30 percent improvement in sweep speed, optical Distance-To-Fault (DTF) measurement capability, advanced post analysis tools and a ruggedized phase stable cable with reinforced handgrip. Site Master now has improved firmware that allows users to make cable and antenna sweeps 30 percent faster, for more efficient field operations. Complementing the improved speed is the high accuracy of the analyzers, which eliminates costly "false fails" and increases the confidence in measurements. Price: starts at $4,950. Delivery: six to eight weeks ARO.

Anritsu Co.,
Morgan Hill, CA (800) 267-4878,
www.us.anritsu.com.

RS No. 251

Frequency Synthesizer

The LX-2400 Series of frequency synthesizers operates at fixed frequencies between 2400 and 2480 MHz, supporting RF Ablation Probes for use in minimally-invasive cancer treatment systems inside hospital operating rooms. Housed in a small surface-mount package, 0.75" x 0.75" x 0.15" (19 x 19 x 3.8 mm), the LX-2400 is supplied with an internal reference and features excellent phase noise, typically <-85 dBc/Hz at 10 kHz offset. The LX-2400 is available with outputs of 0 to +10 dBm and operates off +3.3, +5 or +8 VDC with extremely low power consumption. This product is a versatile, custom source ideal for use in ISM band and other commercial applications requiring small, cost-effective frequency synthesizers, with excellent performance.

EM Research Inc.,
Reno, NV (775) 345-2411,
www.emresearch.com.

RS No. 252

Battery-Powered Devices

Model 2308 Portable Device Battery/Charger Simulator is a dual-channel battery- and charger-simulating power supply designed to provide the lowest cost testing of both the growing range of mobile phones with new, complex transmission schemes and other types of new portable devices that consume extremely low amounts of power. The Model 2308's fast transient output response maximizes production yields by maintaining a stable voltage level under dynamic loading conditions. In addition, its measurement engine enables more accurate characterization of both full power operation and low current sleep modes for quantifying power consumption so that design and manufacturing can ensure that battery life of the latest portable electronic devices is maximized.

Keithley Instruments Inc.,
Cleveland, OH (800) 688-9951,
www.keithley.com.

RS No. 253

VNA Calibration Kits

Maury's 8650P calibration kits are designed for calibrating vector network analyzers (VNA) for measuring devices equipped with TNC connectors from DC to 18 GHz. Each kit is supplied with a full complement of calibration standards (shorts, opens and fixed loads) and can be configured for most any VNA version. All required calibration standards, along with a 3-1/2" disk (containing the VNA software) and operating instructions, come in an attractive foam-lined wood instrument case.

Maury Microwave Corp., Ontario, CA
(909) 987-4715,
www.maurymw.com.

RS No. 254

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Full Name	Complete Mailing Address

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i. Percent Paid (*15c divided by 15f times 100*)		92.77%	85.13%

16. Publication of Statement of Ownership
☒ If the publication is a general publication, publication of this statement is required. Will be printed in the November, 2008 issue of this publication.
☐ Publication not required.

17. Signature and Title of Editor, Publisher, Business Manager, or Owner: Carl S. Sheffres, Publisher
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PS Form **3526**, September 2007 (*Page 2 of 3*)

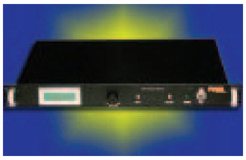
Pulse Pattern Generators

This new series of generators includes the model 12000 165 MHz/20 V_{pp} generator, the model 12010 800 MHz/2.5 V_{pp} generator and the model 12020 1.6 GHz/2.5 V_{pp} generator. Each of these instruments has fully programmable pulse and pattern capabilities with numerous user selectable modes of operation. In addition, the 12000 series generators share a similar mechanical configuration and include both a front panel GUI interface and GPIB/USB programmability. Applications for the 12000 series generator include serial data, semiconductor (e.g. pulsed IV device testing), and general purpose high-speed pulse testing.

Picosecond Pulse Labs Inc., Boulder, CO (303) 209-8100, www.picosecond.com.

RS No. 255

0.5 to 18 GHz Frequency Synthesizer



The model PFS-0518-60 is an ultra-wideband programmable frequency synthesizer that offers a frequency range of 0.5 to 18 GHz, with a step size of 100 kHz and a flatness of ±2.0 dB. The device's reference output is 10 MHz at 0 dBm nominal and the switching time is 10 mS to within 1 radian. The product further offers high rejection ability with harmonics being -20 dBc typical, sub harmonics at -50 dBc maximum and the spurious is at -60 dBc maximum. Presently the synthesizer is in a 1U rack-mount housing with Ethernet control and +28 VDC power supply.

Planar Monolithics Industries Inc., Frederick, MD (301) 631-1579, www.planarmonolithics.com.

RS No. 256

High Resolution Synthesizer

This high performance, high resolution synthesizer operates in the frequency range from 5 to 5.3 GHz and is housed in a small connectorized package measuring only 20 x 12 x 3 cm. The step size in the 300 MHz operating bandwidth is 1 Hz with maximum phase noise of -105 dBc/Hz at 1 kHz, -120 dBc/Hz at 10 kHz, -120 dBc/Hz at 100 kHz, and -120 dBc/Hz at 1 MHz offset. Non-harmonic spurious suppression is -60 dB typical with RF output power of +10 dBm over the specified operating band. Additional features include support for locking with external GPS 1 PPS source for long-term stability and manual field adjustable frequency tuning. The KHPS500530 supports RS-232, parallel, and SPI programming interfaces and with a +12 VDC supply at 1A maximum current in steady state.

Synergy Microwave Corp., Paterson, NJ (973) 881-8800, www.synergymwave.com.

RS No. 257

Transmission-line Components

Solderless N Connector

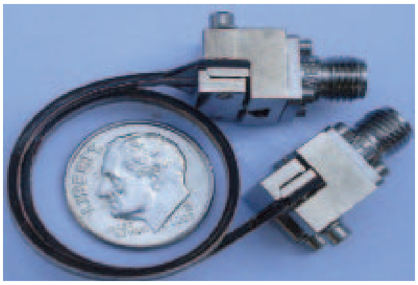
Part number RFN-1006-I-WB features white bronze plating for a non-tarnish finish with enhanced electrical performance. The plating is ferrous metal free, which reduces inter-modulation interference. A ridged back end provides better sealing for the heat shrink boot included with the connector. A combination hex/knurl coupling nut allows for wrench or finger mating. The connector may be attached to multiple brands of high performance cables including Times LMR®-400, Andrew CNT®-400, CommScope WBC®-400 and Belden®RF-400. The connector is assembled with industry standard crimp tools with 0.429 inch and 0.118 inch hex dies.

RF Industries, San Diego, CA (800) 233-1728, www.rfindustries.com.

RS No. 258

NEW PRODUCTS

uflex Cables



The company has developed PMTL uflex cables™, a new patent pending, transmission line technology, for high speed interconnect and packaging of devices and systems. The initial PMTL uflex cables provide stable phase, group delay, and impedance, with low insertion loss and extremely low cross talk, under bending, twisting, and mechanical distress, from DC to 50 GHz, and scalable to work to 220 GHz and beyond. RFCONNEXT initially will provide a family of products, such as single and differential impedance flex/rigid jumper/connectors, wafer and PCB probes, test fixtures and sockets, and technical service targeting the signal integrity, and testing connectivity market, across the spectrum. The beautify of the PMTL technology is that it can be implemented on current low cost materials, rigid or flex, and uses the existing photolithographic technology for PCB or CMOS processes, thus allowing to increase density and achieving high speed with digital pulses of fractional pSec rise times.

RFCONNEXT Inc.,
San Jose, CA (408) 981-3700,
www.rfconnext.com.

RS No. 259

High Performance Cable Assemblies

San-tron Inc. has announced the release of a new high performance connector to address the problem of signal transmission and fragility of solder joints in hand-formable cable assemblies. This new eSMA connector features a new extended ferrule and enhanced performance from an innovative internal design. This connector also features: failure-proof coupling nuts; EZ style, solder free, captivated center contacts; and a solder damming positive cable stop. They come standard with gold plated bodies and gold plated center contacts. They are also weatherproof and provide 50 ohm constant impedance.

San-tron Inc.,
Ipswich, MA (978) 356-1585,
www.santron.com.

RS No. 260

High Power
Caseless 90° Couplers
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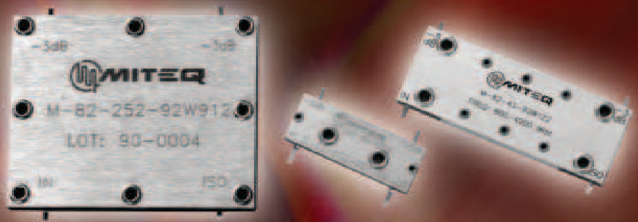

FREQUENCY (MHz)	MODEL NUMBER	AVERAGE POWER (CW Watts)	AMPLITUDE BALANCE (±dB, Max.)	PHASE BALANCE (±Deg., Max.)	ISOLATION (dB Min./Typ.)	INSERTION LOSS (dB, Max.)	VSWR (Max.)
50 – 110	M-51-111-96W802	600	0.3	2.0	20/23	0.30	1.2:1
100 – 500	M-12-52-92W502	200	0.85	2.5	14/18	0.85	1.35:1
100 – 500	M-12-52-98WF502	800	0.8	2.0	18/20	0.30	1.2:1
120 – 230*	M-121-231-92W012	300	0.5	2.0	20/27	0.30	1.2:1
150 – 250	M-151-251-94W012	400	0.3	2.0	20/25	0.30	1.2:1
200 – 400*	M-22-42-92W102	250	0.5	2.0	20/25	0.30	1.2:1
200 – 400	M-22-42-95WB302	500	0.4	2.0	19/23	0.25	1.2:1
200 – 1000*	M-22-13-92WD502	250	0.75	3.0	20/23	0.50	1.3:1
250 – 500	M-251-52-92W102	250	0.5	2.0	20/25	0.30	1.2:1
300 – 500	M-32-52-92W102	250	0.4	2.0	20/23	0.25	1.2:1
300 – 950	M-32-951-92W102	250	0.6	2.0	20/23	0.25	1.25:1
400 – 550	M-42-551-92W102	250	0.2	2.0	20/25	0.20	1.2:1
400 – 700	M-42-72-92W012	250	0.5	2.0	20/25	0.30	1.2:1
400 – 1000*	M-42-13-92W102	250	0.6	2.0	18/20	0.25	1.2:1
400 – 1000	M-42-13-95WB302	500	0.6	2.0	20/23	0.20	1.2:1
400 – 1000	M-42-13-91KW402	1000	0.6	2.0	20/25	0.20	1.2:1
440 – 880	M-441-881-92W102	250	0.5	2.0	20/25	0.20	1.2:1
700 – 1400*	M-72-142-92W102	250	0.5	2.0	18/25	0.30	1.25:1
800 – 1600	M-82-162-92W102	250	0.5	2.0	20/23	0.25	1.2:1
800 – 1600	M-82-162-95WB302	500	0.5	2.0	20/25	0.20	1.25:1
800 – 1600	M-82-162-91KWB912	1000	0.5	2.0	20/25	0.20	1.3:1
800 – 2500*	M-82-252-92W122	200	0.6	4.0	18/20	0.40	1.25:1
800 – 4200	M-82-43-92W122	200	0.5	4.0	16/20	0.20	1.2:1
960 – 1220	M-961-1221-92W102	200	0.3	2.0	18/25	0.30	1.25:1
960 – 1220	M-961-1221-95WB302	500	0.4	2.0	20/23	0.20	1.2:1
1000 – 2000	M-13-23-92W102	200	0.5	3.0	18/24	0.30	1.25:1
1000 – 2000	M-13-23-95WB302	500	0.5	3.0	18/22	0.20	1.2:1
1200 – 1400	M-122-142-92W102	250	0.4	3.0	20/23	0.25	1.2:1
1200 – 1400	M-122-142-95WB302	500	0.4	2.0	20/25	0.20	1.2:1
1300 – 3000	M-132-33-92W102	200	0.6	3.0	18/23	0.25	1.2:1
1400 – 2400	M-142-242-92W102	200	0.5	3.0	16/20	0.25	1.2:1
1400 – 2800	M-142-282-92W102	200	0.5	3.0	16/20	0.25	1.2:1
1500 – 3000	M-152-33-92W102	200	0.6	3.0	18/22	0.25	1.25:1
1700 – 2500	M-172-252-92W102	200	0.4	3.0	20/23	0.25	1.2:1

* Multiple packages are available on these models, please contact MITEQ.180 degree and coaxial versions are available upon request

For additional information or technical support, please contact our Sales Department at (631) 439-9220 or e-mail components@miteq.com

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ASIA PACIFIC MICROWAVE CONFERENCE 2008, HONG KONG

Hong Kong Convention and Exhibition Center, Wanchai

16^{th} to 19^{th} of December 2008

Venetian Resort and Convention Center, Macau

19^{th} to 20^{th} of December 2008

Background

The Asia-Pacific Microwave Conference (APMC) is increasing popular among professionals and professionals-in-training in technical and non-technical disciplines in both manufacturing and service sectors. Often participants include professors, hardware engineers, software engineers, and graduate students engaged in research, design, manufacturing, marketing, installation, maintenance, and application of antennas, synthetic materials, components, devices, equipment, systems, and consumer products for users and providers of fixed-line and wireless communications at microwave and millimeter-wave frequencies. Besides the regular attendees, APMC is frequented by government regulators, industrialists, financers, and other professionals. In other words, APMC has now established itself as a unique world-class conference for the academic community of applied electromagnetics, for the manufacturing industry of microwave hardware and software, and for the service industry of telecommunications.

New Initiatives in APMC 08

1. Unlike the previous conferences, APMC 08 will last for four days, from 16^{th} to 20^{th} of December. These dates are deliberately chosen such that the last day is the ninth anniversary of the establishment of the Special Administrative Region of Macau.

2. In addition to the traditional emphases on antenna designs and developments of microwave technologies, EMC/EMI and industrial microwave applications are also important components in APMC 08.

3. There will be several APMC Prizes for different streams and a Student Prize. The principal author and one of the co-authors of a shortlisted paper will be encouraged to use the latest multimedia technologies in “selling” their “products” repeatedly to all visitors, including the judging team of three to four distinguished scholars, throughout the entire morning or afternoon session.

APMC 08 Exhibition

An exhibition hall of 9000 m^2 in the Hong Kong Convention and Exhibition Center has been reserved for the APMC 08 Exhibition, making it larger than those held in Seoul and in Tokyo. A record-breaking number of overseas visitors are expected as Hong Kong is situated right at the center of the Asia Pacific Rim and the Pearl River Delta is the heart of the “Factory of the World.”

Tourist Haven

Coming to Hong Kong in December is the best time of the year because the weather will be mostly sunny with less than 30% precipitation. The temperature will range from 10°C to 25°C with mild northerly breeze. Visitors will be fascinated by our unique blend of western and eastern cultures. Macau is a small peninsula west of Hong Kong, a ferry trip of 60-70 minutes. Neither additional visa nor advanced ferry ticket is needed because there are over six ferries per hour during office hours. Macau boosts another unique mix of eastern and western cultures, as the first Portuguese settlement was established in Macau over 400 years ago. Besides the historical sceneries, visitors will be engrossed by the hundreds of modern hotels and casinos. After becoming the second SAR of China in 1999, Macau is the city of the fastest growth in China, and the turnover in all casinos has surpassed that in Las Vegas in 2007.

Additional Information

Please visit our website at http://www.apmc2008.org/ for more information. Enquiry: apmc2008@ee.cityu.edu.hk.

Microwave Journal CALL FOR PAPERS

To see one's work in print is the rightful reward of every creative engineer and scientist. The editors of *Microwave Journal* invite you to submit your technical manuscripts for consideration to be published in one of our upcoming issues. Technical articles, application notes and tutorial articles based on the monthly editorial themes are encouraged. Editorial themes include wireless, radar and antennas; RF components and systems; test, measurement and CAD; amplifiers and oscillators; semiconductors, MMICs and RFICs; satellite and mm-wave applications; communications and wireless applications; passive components; and control devices and modulation.

Design features should contain new and innovative technical ideas of practical use and interest to our predominantly engineering readers. Papers should be 14 to 16 double-spaced pages and contain 8 to 12 visual aids in the form of sketches, graphs, photographs or tables.

Papers should be submitted to the attention of the Technical Editor and will be reviewed promptly by our Editorial Review Board prior to acceptance. Articles outside of the monthly themes also will be encouraged.

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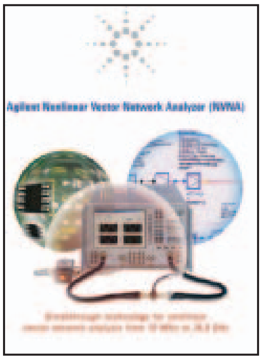
NETWORK ANALYZER BROCHURE

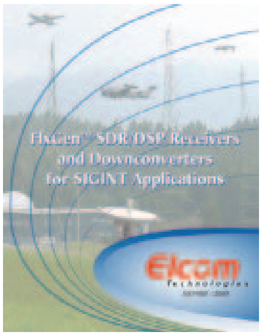


This free brochure explains how the company's nonlinear vector network analyzer can provide the critical leap in technology to go beyond linear S-parameters. The technology allows for efficient and accurate analysis and design of active devices under real-world operating conditions. The brochure is available for download at: www.agilent.com.

Agilent Technologies Inc., Santa Clara, CA (800) 829-4444, www.agilent.com.

RS No. 200

SIGINT BROCHURE



Elcom Technologies, a designer and manufacturer of synthesizers and receivers up to 40 GHz in the RF and microwave frequency spectrum for applications in the ATE, SIGINT, Custom Hi-Rel and SATCOM markets, has just released the new FlxGen™ family of HF-VHF/UHF-MW receivers and downconverters brochure.

Elcom Technologies, Rockleigh, NJ (201) 767-8030, www.elcom-tech.com.

RS No. 201

GUIDE TO OFDM/A, MIMO, WLAN AND WIMAX

Keep up with RF technology with a free copy of Keithley's new CD, *Guide to OFDM/A Technology, MIMO Configurations, and WLAN and WiMAX Applications*. It includes two white papers, a presentation and a number of tools demonstrating MIMO testing. Request your copy at www.keithley.com/at/509 or by calling Keithley Instruments Inc. at (800) 588-9238.

Keithley Instruments Inc., Cleveland, OH (800) 588-9238, www.keithley.com.

RS No. 202

PRODUCT CATALOG

This new 64-page fiber optic products catalog offers a compilation of individual data sheets that feature product descriptions, applications, electrical specifications, optical performance specifications, power requirements, typical test data, block diagrams, and outline drawings on MITEQ's full-line of fiber optic links, optical receivers and transmitters. To download the catalog, visit the company's web site at www.miteq.com.

MITEQ Inc., Hauppauge, NY (631) 436-7400, www.miteq.com.

RS No. 203

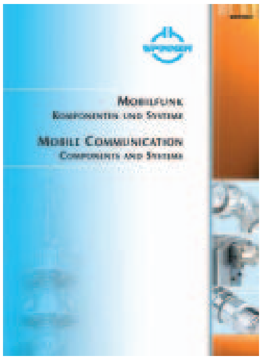
PRODUCT AND SERVICES CATALOG

This product and services catalog features the company's newly developed PMTL™, a new patent pending, transmission line technology for high speed interconnect and packaging of devices and systems. The initial PMTL uflex cables provide stable phase, group delay, and impedance, with low insertion loss and extremely low cross talk, under bending, twisting, and mechanical distress, from DC to 50 GHz, and scalable to work to 220 GHz and beyond. This catalog provides data sheets for a family of products based on the patent pending PMTL, such as single and differential impedance flex/rigid jumper/connectors, wafer and PCB probes, test fixtures and sockets, and technical service targeting the signal integrity, and testing connectivity market across the spectrum.

RFCONNEXT Inc., San Jose, CA (408) 981-3700, www.rfconnext.com.

RS No. 204

COMPONENTS AND SYSTEMS CATALOG

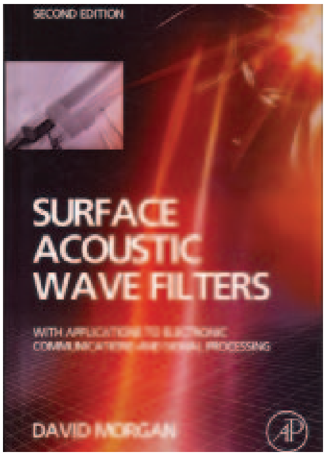


This product catalog features the company's connectors, jumper cables, splitters, couplers, di-/triplexers and multiplexers. This mobile communication catalog also highlights products required for the installation on site. The components and systems catalog is available as a printed hardcopy and a CD-ROM.

SPINNER GmbH, Munich, Germany +49 89 12601-0, www.spinner.de.

RS No. 205

Surface Acoustic Wave Filters: Second Edition



David Morgan
446 pages; $99.95, £59.99 • Academic Press
ISBN: 978-0-1237-2537-0

This book expands the coverage of the earlier edition, published in 1985. At that time, many devices had been established in practical electronic systems, including signal processing devices and bandpass filters for communications and television systems. These devices remain in widespread service now. However, the 1980s were something of a watershed for surface waves. The rise of communications systems, such as mobile telephony demanded new capabilities, particularly for low-loss bandpass filters satisfying exacting specifications. The new book includes the recent developments in this technology. The earlier material is described in Chapters 2 to 7. This includes various acoustic waves (Chapter 2), surface excitation (Chapter 3), propagation effects and materials (Chapter 4), quasi-static transducer theory (Chapter 5) and non-reflective bandpass filters (Chapter 6). Devices for correlation, used in pulse-compression radar and spread-spectrum communications are in Chapter 7. These accounts are similar to those of the earlier book, but to allow space for new material, there is some compression and some topics have been omitted. New areas include filters using unidirectional transducers (Chapter 9), waveguiding and transversely-coupled resonators (Chapter 10) and resonator filters (Chapter 11). Preceding these, Chapter 8 describes the theory of reflective transducers and gratings, including analysis using the Reflective Array Model (RAM) and Coupling-of-Modes (COM) theory. At the beginning, Chapter 1 gives a survey of the whole subject. This is intended to be readable independently of the rest of the book. The book is written at a post-graduate level, assuming some familiarity with topics such as matrix algebra and the Y- and S-matrix descriptions for linear devices. However, much of the material should also be comprehensible at an undergraduate level, particularly the survey of Chapter 1.

To order this book, contact:
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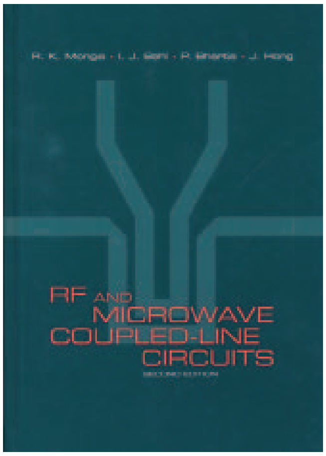
RF and Microwave Coupled-line Circuits: Second Edition



R.K. Mongia, I.J. Bahl, P. Bhartia and J. Hong
578 pages; $139, £77 • Artech House
ISBN: 978-1-59693-156-5

The successful first edition of this book was published in 1999. While the fundamentals of coupled-line circuits have not changed, further innovations in coupled-line filters and other applications have occurred with changes in technology and use of new fabrication processes, such as the use of low temperature cofired ceramic (LTCC) substrates. The first few chapters reflect only minor changes, as these incorporate the fundamentals of microwave transmission lines, networks and coupled lines, which have not changed. Some additions and changes have been made to accommodate the multilayer design of coupled lines for the sake of having a self-contained, complete text. Most of the changes occur in the "Applications" part of the text (i.e. Chapter 8 onward). Thus, Chapter 9, on filters, includes the design of bandstop filters using coupled lines and a discussion of software packages used for filter design, together with their limitations and strengths. Chapters 10 and 11 are new and discuss advanced filter technology and the design of filters using new materials and technologies. Chapter 10 concentrates on coupled-line filters with many specialized characteristics that are often encountered in practice. Chapter 11 takes a different direction, tackling filters using advanced materials and technologies, including superconductor coupled-line filters, micromachined filters, miniature interdigital filters on silicon, LTCC filters which require multilayer coupling, liquid crystal polymer filters and ultra-wideband filters. Chapters 12 and 13 are essentially the former Chapters 10 and 11 with revisions as appropriate and the inclusion of new material to update the chapters and make them current. Chapter 13 covers baluns of different configurations (e.g., microstrip to balanced stripline, planar transmission line and Marchand type) and are discussed in detail.

To order this book, contact:
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Microwave Engineers: For the Sake of the Future

Microwave Power Transmission: Space-based Solar Power Beams Become Next Energy Frontier

The idea of using satellites to beam solar power down from space is nothing new—the Department of Energy first studied it in the 1970s, and NASA took another look in the '90s. The stumbling block has been less the engineering challenge than the cost.

According to a Pentagon report released last year, space-based solar power (SBSP) is becoming more feasible, and eventually could help head off crises such as climate change and wars over diminishing energy supplies.

The SBSP is expected to become enormously profitable—and the hopes are that it will lure the growing private space industry. The government would fund launches to place initial arrays in orbit by 2016.

As envisioned, massive orbiting solar arrays, situated to remain in sunlight nearly continuously, will beam multiple megawatts of energy to Earth via microwave beams. The energy will be transmitted to mesh receivers placed over open farmland and in strategic remote locations, then fed into the nation's electrical grid. The goal: To provide 10 percent of the United States' base-load power supply by 2050.

I use this as another example of the potential prospect within RF engineering and how (again) it takes a role in shaping the future. Consider energy transmissions, RF tagging, multiple new wireless communication standards, medical applications, communications, security markets and more. Consider what all those upcoming sectors mean in terms of RF engineering jobs. The future for RF engineering never seemed more promising.

At times like these, as global economies shift and uncertainty rules, it is important to hang onto these real assets—education and creativity, and direct them to those areas that are most promising in the global arena. The fact that this country is not producing enough analog engineers, nor imports the missing talent from overseas in a deliberate attempt to meet the increasing demand is a reason for much concern. It is also a missed opportunity in times when such are needed most. It is inevitable that in 10 years from now the US job market will look different. Only combined operation boosting up the technology and science graduation, while filling in vacant expert positions with immigrant talent, will sustain those companies and positions in the country.

Conclusion:

Microwave engineering today lays the foundations for tomorrow's infrastructure in literally every aspect of life. Securing a good position in tomorrow's global economy requires the qualified human resources, which should be brought in from overseas while the industry, government and academy act to increase the number of graduates to meet the demand. Look forward and plan.

Isaac Mendelson
ElectroMagneticCareers.com
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13	Atlantic Microwave Ltd.	148	44-1376-550220	44-1376-552145	http://mwj.hotims.com/16347-13
14	Avtech Electrosystems	162	888-670-8729	613-226-2802	http://mwj.hotims.com/16347-14
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16	Bradford RF Sales	173	978-521-1701		http://mwj.hotims.com/16347-16
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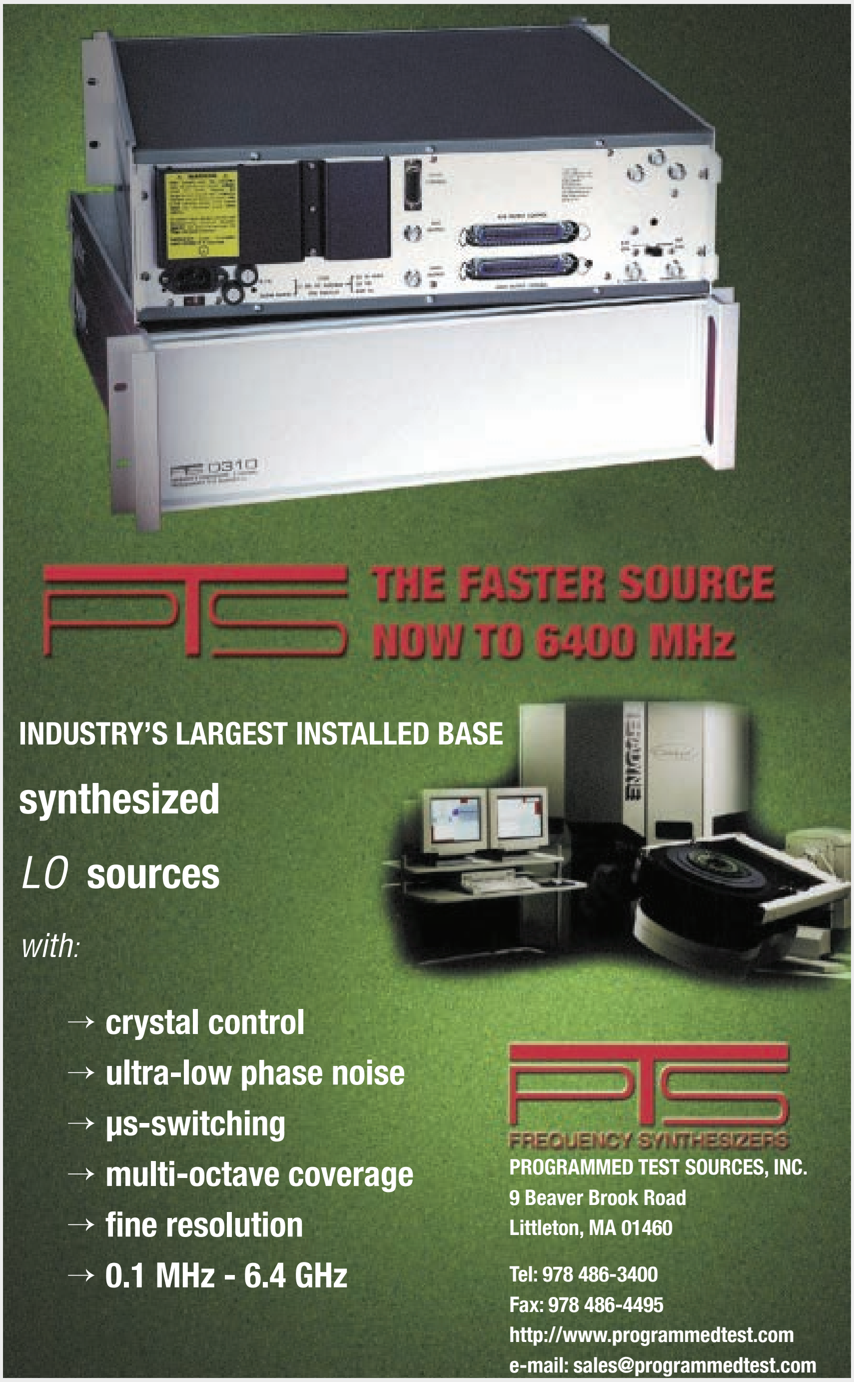

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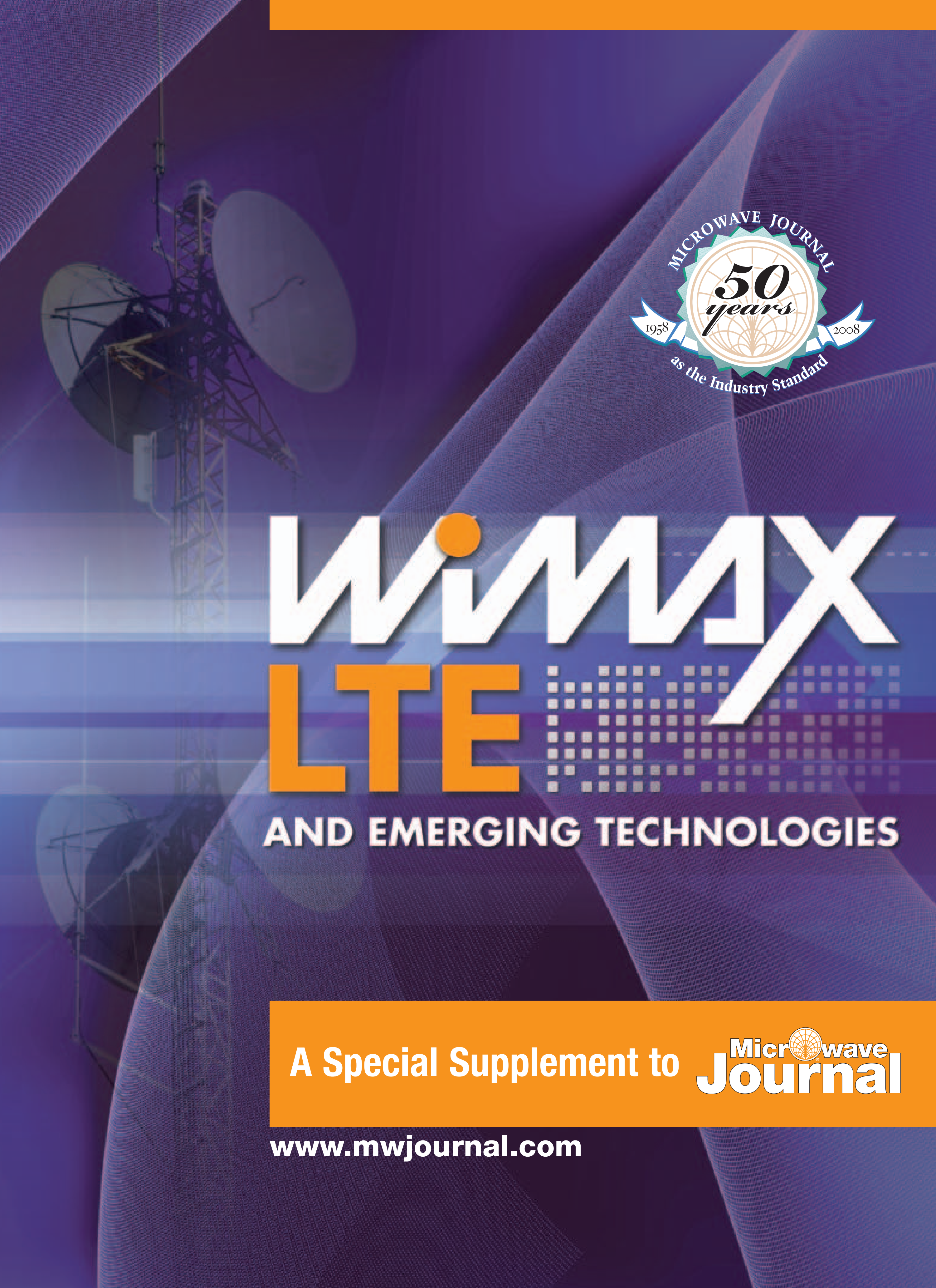
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WiMAX LTE TABLE OF CONTENTS

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A Look Forward into LTE

ANDY BOTKA
Agilent Technologies Inc., Santa Clara, CA

While a large majority of owners use their mobile phones for voice calls and short message services (texting) only, a growing number are using bandwidth-hungry applications such as Web browsing, music downloads and streamed video. The current explosion in wireless data use has been fuelled partly by the introduction of Apple's iPhones. While other so-called smartphones with similar capability have been available for years, the different perspective of Apple's advertising—that of a computer company showcasing its "whole product" rather than a phone manufacturer promoting a single feature that differentiates their new product, such as a better music player or higher resolution camera—has excited subscribers and driven up data revenues for all network operators (and not just those selling iPhones). In addition, operators will look for additional revenues from mobile advertising, which is forecast to grow to a multi-billion dollar business over the next few years, and which will come to depend on higher bandwidth services for fulfillment.

This article addresses some of the issues and challenges facing the wireless industry—from chipset providers to network operators, specifically from the perspective of a test equipment supplier. To service these needs and to match the speeds users experience on a home PC with a broadband connection (either ADSL or cable modem), mobile network operators have been continuously investing in technology upgrades to remain competitive.

Long Term Evolution (LTE) is the project name of a new air interface for wireless access being developed by the Third Generation Partnership Project (3GPP), aimed at evolving 3GPP's third generation system towards an all-IP network optimized for high speed data transmission. In parallel with its air interface development, LTE is linked closely with the concurrent System Architecture Evolution (SAE) project to define a simplified system architecture and Evolved Packet Core (EPC) network. Together, these projects provide a framework for increasing capacity, improving spectrum efficiency, improving cell-edge performance and reducing latency for real-time services such as video. They aim to offer a 100 Mbps download rate and 50 Mbps upload rate


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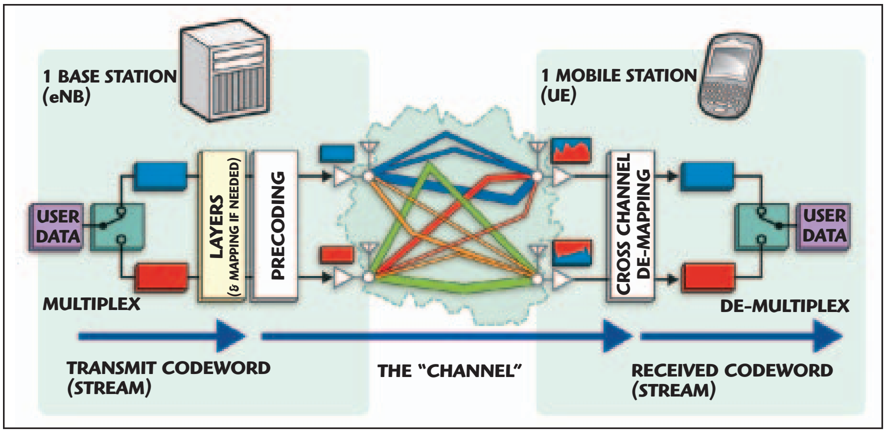

Fig. 1 MIMO assigns a different data stream to each transmit antenna.

for every 20 MHz of spectrum. Support is intended for even higher rates, to 326.4 Mbps in the downlink, using multiple antenna configurations.

Rather than further developing current High Speed Packet Access (HSPA) and modulation schemes based on the Wideband Code Domain Multiple Access (W-CDMA) used in third generation UMTS cellular systems today, LTE downlink and uplink transmissions are based on new air interfaces: specifically, Orthogonal Frequency Division Multiple Access (OFDMA), a variant of Orthogonal Frequency Division Multiplexing (OFDM) in the downlink, and Single-Carrier Frequency Division Multiple Access (SC-FDMA) in the uplink.

The LTE specifications inherit all the frequency bands defined for UMTS, which is a list that continues to grow. There are now 11 FDD bands covering frequencies from 824 to 2690 MHz and eight TDD bands covering 1900 to 2620 MHz. Significant overlap exists between some of the bands, but this does not necessarily simplify designs since there can be band-specific performance requirements based on regional needs. There is no consensus on which band LTE will first be deployed, since the answer is highly dependent on local variables. This lack of consensus is a significant complication for equipment manufacturers and contrasts with the start of GSM and W-CDMA, both of which were originally specified for only one band.

Already used in non-cellular technologies as far back as 1998, OFDM was at that time under consideration by 3GPP as a transmission scheme for 3G UMTS. However, the technology was deemed inappropriate, in part because of the large amounts of baseband processing it required. Today the cost of digital signal processing has been greatly reduced, such that it is now considered a commercially viable method of wireless transmission for the handset. Rather than transmit a high-rate stream of data with a single carrier, OFDM makes use of a large number of closely spaced orthogonal sub-carriers that are transmitted in parallel. Each sub-carrier is modulated with a conventional modulation scheme (such as QPSK, 16QAM, or 64QAM) at a low symbol rate. The combination of hundreds or thousands of sub-carriers enables high-data-rate transmission with much reduced inter-symbol interference compared to conventional single-carrier modulation schemes with the same capacity.

In addition to new air interfaces, the LTE specifications require the use of multiple antenna techniques that add substantial complexity to the system and are designed to take advantage of spatial diversity in the radio channel. These techniques are often loosely referred to as "MIMO," a term for multiple input, multiple output antenna configuration, and are considered essential for improving signal robustness and achieving goals for system capacity and single-user and "headline" peak data rates. The basic form of MIMO assigns a different data stream to each transmit antenna, as shown in ***Figure 1***. The two transmissions are mixed in the channel, such that at the receivers, each antenna sees some combination of each stream. Decoding the received signals is a clever process in which the receivers analyze the fading patterns that identify each transmitter to determine what combination is present. The application of an inverse filter and summing of the received streams recreates the original data.

The theoretical gains from MIMO challenge the limits of system performance and are a function of the number of transmit and receive antennas, the radio propagation conditions, the ability of the transmitter to adapt to the changing conditions and the basic signal to noise ratio. Further complicating the picture is the requirement for the antennas to support LTE's multiple frequency bands.

Since the LTE specifications support RF channel bandwidths of up to 20 MHz, compared to today's maximum of 5 MHz, a fundamental change in radio design is required. New integrated designs, based on the Common Public Radio Interface (CPRI) and the Open Base Station Architecture Initiative (OBSAI) standards for base stations and DigRF and Mobile Industry Processor Interface Digital Physical Layer (MIPI D-PHY) for user equipment, remove or hide traditional test interfaces. Now, people who previously dealt in only one domain must learn new ways to characterize devices. An example might be a transmitter module, where only digital signal inputs and RF outputs are available and pre-correction in the digital domain sets RF performance. Measurement products and solutions specifically designed to address these emerging cross-domain requirements must include support for new methods to address mixed analog/digital radios, and simula-

tion tools that can be integrated with real-world modules speed up overall system test. As well as targeted products such as Agilent's N5340A/41A (OBSAI) and N5343A/44A (DigRFV4) testers, the tools required include traditional pattern generators, logic analyzers, signal generators and signal analyzers. However, new measurement methods involve combining them and interpreting results in new ways.

Testing MIMO receivers and systems under realistic fading conditions poses a new challenge due to the large number of transmit-receive channel combinations. For example, in a 2x2 MIMO configuration, using two separate channel emulators is not adequate to model the four separate channels that exist between the pairs of transmit and receive antennas. Testing in a "real" wireless environment is not an effective method as the channel is very sensitive, not controllable and not repeatable. Specialized instrumentation that emulates realistic MIMO channels provides the best solution for these challenging test conditions. ***Figure 2*** shows one of several possible configurations for testing a 2x2 MIMO receiver. Using a software GUI, internal baseband generators and channel faders create the standards-compliant waveforms such as WiMAX, LTE and WLAN signals. Each fader can be independently configured with either standards-compliant or custom fading models, using a variety of path and fading conditions.

As with the original W-CDMA and now HSPA, chipsets for LTE are highly integrated and include data rates and functionality much greater than will actually be available to a single user in a network at introduction. They must be designed to have as long a life as possible so that manufacturers can recover their massive investment costs over a longer period. Therefore, developers must be able to confirm correct operation up to the maximum design specifications of the chipset, and they require test equipment today that is capable of this level of performance. For LTE, this includes single-user data rates up to 14.4 Mbps and MIMO functionality beyond the baseline specification in both uplink and downlink.

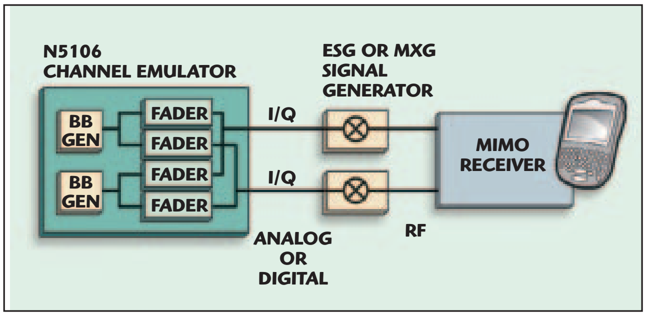

Fig. 2 Simplified block diagram for testing a 2 × 2 MIMO receiver.

The participation of the world's leading test equipment companies in the specific subgroups responsible for defining measurement techniques in next generation cellular systems continues to ensure that the ability to test functionality is designed in, making interoperability, conformance and production test easier and faster.

Today, LTE standards-setting is nearly complete, early development is well under way and networks are expected to be commercially introduced in approximately 2010. This goal is aggressive, and there is a greater focus than previously on finalizing interoperability and conformance testing specifications, to ensure that manufacturers can produce both network and user equipment to meet demand. A new initiative for LTE—the LTE/SAE Trial Initiative (LSTI)—aims to accelerate the availability of interoperable next generation LTE mobile broadband systems. With more than 17 active participants in total, this unique global initiative is able to drive the seamless introduction of end to end LTE solutions—including infrastructure, devices and chipsets—through collaborative technology trials and proof of concept work.

The latest laboratory and early field tests on prototype LTE systems have confirmed that baseline devices can achieve download speeds exceeding 100 Mbps, and high performance systems using 4x4 MIMO antennas can push this to beyond 300 Mbps. LSTI members have also demonstrated substantial improvements to network response times, which are essential to give the 'always on' experience and for latency-sensitive applications such as interactive gaming and mobile television.

The next steps in LTE system development will be early device interoperability testing, network interoperability tests and more comprehensive performance tests. Conformance tests will ensure that equipment meets the benchmarks specified in the LTE standard. How those tests correlate with real-world performance for individual users remains to be seen.

With widespread commercial deployment of LTE still a few years away, it may be some time before the behavior of the new systems is completely understood. In the meantime, test equipment suppliers are playing their part, adding new measurement capability for cross-domain testing, and new features such as MIMO precoding for signal generation and advanced emulation, measurement and analysis to their test equipment to facilitate LTE product development and move the industry ahead. ■

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Tackling UWB/WiMedia Measurement Challenges

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Ultra-wideband (UWB) wireless is a rapidly growing technology that promises to revolutionize low power, short-range wireless applications. UWB has quickly emerged as the leading technology for Wireless Universal Serial Bus (W-USB). UWB radios differ from conventional narrowband radios and have a variety of specialized test demands. Enormous signal bandwidths, short duration pulses and transmit Power Spectral Densities (PSD) near the thermal noise floor make UWB testing difficult. Fortunately, the current generation of test equipment has the bandwidth, sensitivity and software needed for testing UWB waveforms. In this article, the concepts behind UWB technology, its unique hardware and software architectures, and some of the associated test issues are explained.

Ultra-wideband technology is quickly gaining acceptance as a useful wireless technology. UWB offers bandwidth and the accompanying throughput needed for many of today's high data rate applications such as wireless video, PC connectivity and high data rate mobile devices.

While UWB signals simply cannot have their own spectrum in today's crowded RF environment, it is possible to transmit UWB signals over a spectrum dedicated to other uses as long as the power levels are sufficiently low, just above the noise floor. The combination of low power levels and the resultant low range minimizes expected interference levels. The very wide bandwidth of UWB signals gives immunity to single narrowband interference sources. Scenarios using multiple narrowband interferers may reduce UWB throughput, but pre-release testing can mitigate this concern.

In the same manner, destructive multipath phenomena that can greatly affect a narrowband signal transmission have a much smaller effect on a UWB signal, since any cancellation notch caused by multi-path will affect only a narrow band of frequencies. UWB's high data rate, multi-path immunity and robustness to interference make it an attractive wireless technology for today's bandwidth-hungry computer peripherals.

WHAT IS UWB?

UWB communications signals initially

went by other names, such as impulse radio, baseband communications, carrier-free transmission and impulse modulation. It was in the 1980s that the term UWB was first applied to this fascinating class of signals, which had grown vastly in bandwidth. Many UWB design approaches differed substantially from conventional wireless links by not employing the ubiquitous super heterodyne frequency conversion architecture. Although modern super heterodyne radio architectures can now produce signals of comparable bandwidths and pulse widths, the simplicity of baseband or homodyne architectures are still attractive. Since UWB signals have a wide variety of modulation formats and radio architecture, the US Federal Communications Commission (FCC) spectral regulatory agency has selected a definition of UWB based on fractional bandwidth, or equivalent bandwidth. The US FCC defined a UWB signal as any signal with a bandwidth at the 10 dB attenuation point greater than 20 percent of the modulation frequency or an equivalent bandwidth greater than 500 MHz, as illustrated in ***Figure 1***.

HOW UWB WORKS

There are several different approaches to generating ultra-wideband signals, including three popular methods: Time Hop UWB (TH-UWB), Direct Sequence UWB (DS-UWB) and Multi-band Orthogonal Frequency Division Multiplexing UWB (MB-OFDM).

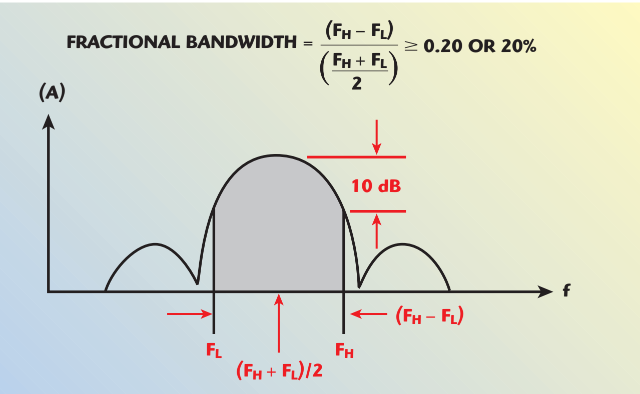


Fig. 1 UWB signal definition.

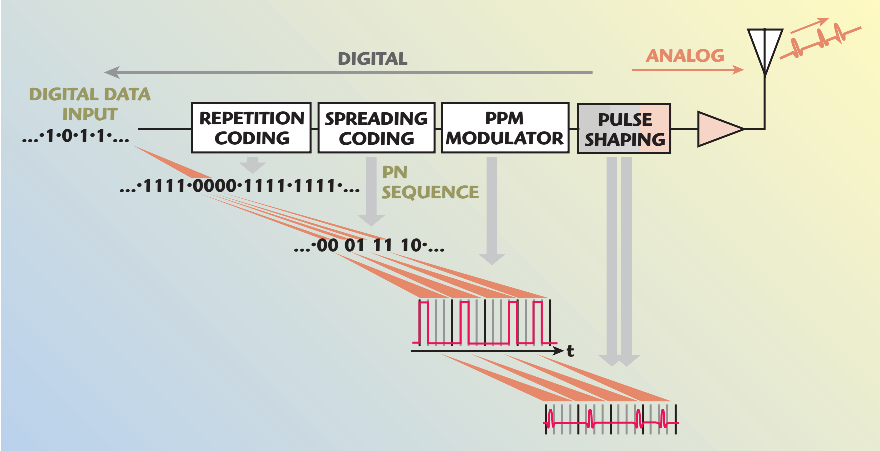


Fig. 2 TH-UWB signal generation.

TH-UWB

Time hop UWB signals are composed of a series of very short impulses at pseudo-random intervals. The TH-UWB signal begins by taking the data and repeating each bit multiple times. This repetition block coding adds signal redundancy and spectral diversity, increasing the signal's immunity to multi-path variation and interference. Next, TH-UWB assigns each coded bit a pseudo-random value for signal spreading. The TH-UWB Pulse-position Modulation (PPM) technique then uses the pseudo-random transmission spreading code to select a time slot proportional to the assigned pseudo-random value and generates a pulse. This technique modulates the position of each pulse, generating a pseudo-random stream of pulses. Of course, there are many variations possible, but this is the basic process used for time hopping UWB signals. Pulse shaping and amplifying is the last step in preparation for transmission. The TH-UWB generation with PPM is a simple process of coding, spreading, modulating and shaping the short impulses that make up the signal. TH-UWB creates the signal at baseband and does not need frequency up-conversion, as shown in ***Figure 2***.

Pulse Shaping

Pulse shaping is important because it affects the spectral properties of the UWB modulation (see ***Figure 3***). The frequency-domain spectral shape corresponds to the time-domain impulse shape. For example, the theoretical Dirac impulse, or infinitely narrow pulse width in the time domain, creates an infinitely wide spectral response in the frequency domain. Carefully changing the impulse shape can control the power spectral density of the TH-UWB signal.

Pulse shaping is also important because it can affect the Intersymbol Interference (ISI) and multi-path characteristics of a TH-UWB signal. Unlike many traditional narrowband digital modulations that use raised cosine filtering and controlled symbol timing to avoid ISI, UWB signals often favor Gaussian pulse shapes, which retain their shape better when confronted with dispersive channel effects. The Gaussian pulse shape does introduce some ISI, but UWB signals have plenty of bandwidth, so it is possible to make timing adjustments to minimize inter-symbol interference.

Baseband UWB Impulse Radio

It is important to note that the TH-UWB hardware can create almost the entire signal in base-

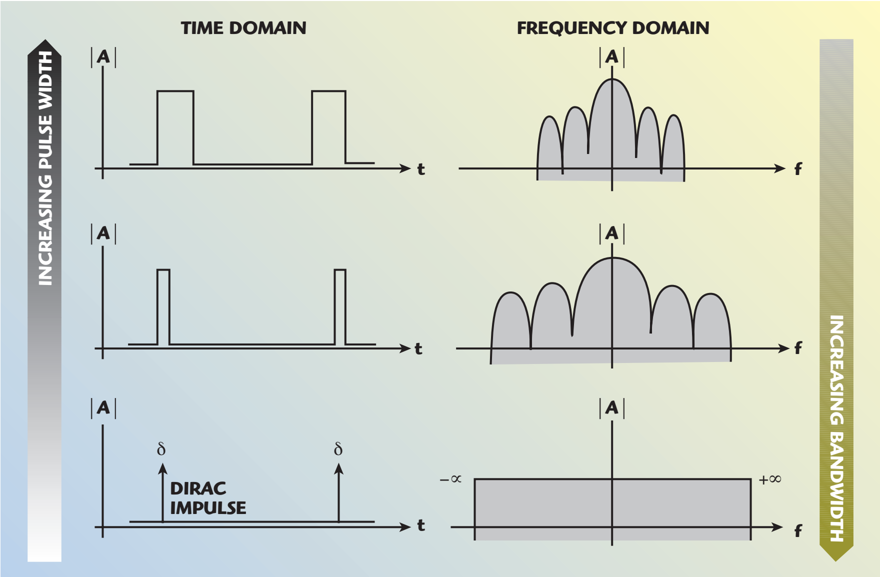


Fig. 3 The pulsed signal bandwidth is inversely related to the pulse width in the time domain.

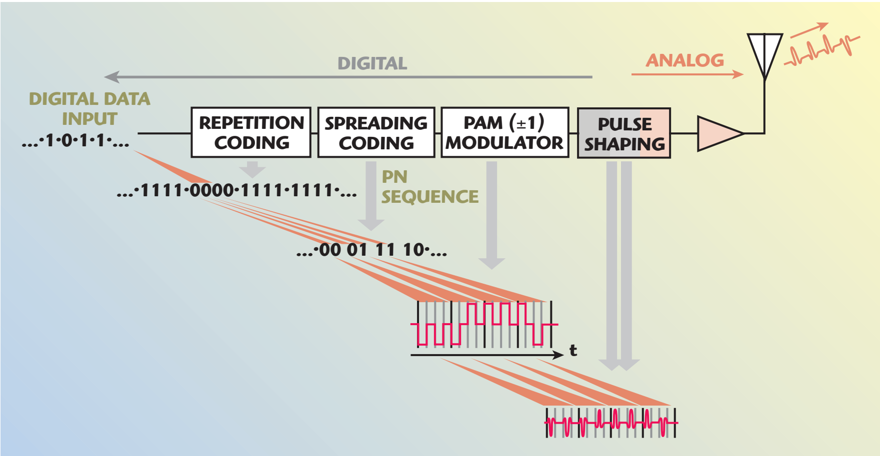


Fig. 4 DS-UWB signal generation.

band. Baseband generation of the transmitted signal eliminates the need for many conventional super heterodyne components, such as up and down converters, IF filters, amplifiers, mixers and LO sources. This makes Impulse Radio UWB designs significantly less complex and costly. It also allows extensive applications of the many benefits of Digital Signal Processing (DSP).

DS-UWB

Direct Sequence UWB (DS-UWB) is another modulation approach used to create ultra-wideband signals. As shown in ***Figure 4***, DS-UWB pulse amplitude modulation signal generation is similar to TH-UWB. A key difference is in the pulse modulator that inverts the phase of the pulse. DS-UWB employs techniques similar to Direct Sequence Spread Spectrum (DSSS). These techniques spread the impulse radio spectrum over ultra-wide bandwidths. The repetition block coder encodes bits and provides a positive or negative value for each. This increases redundancy and improves spectral diversity for robust transmission characteristics.

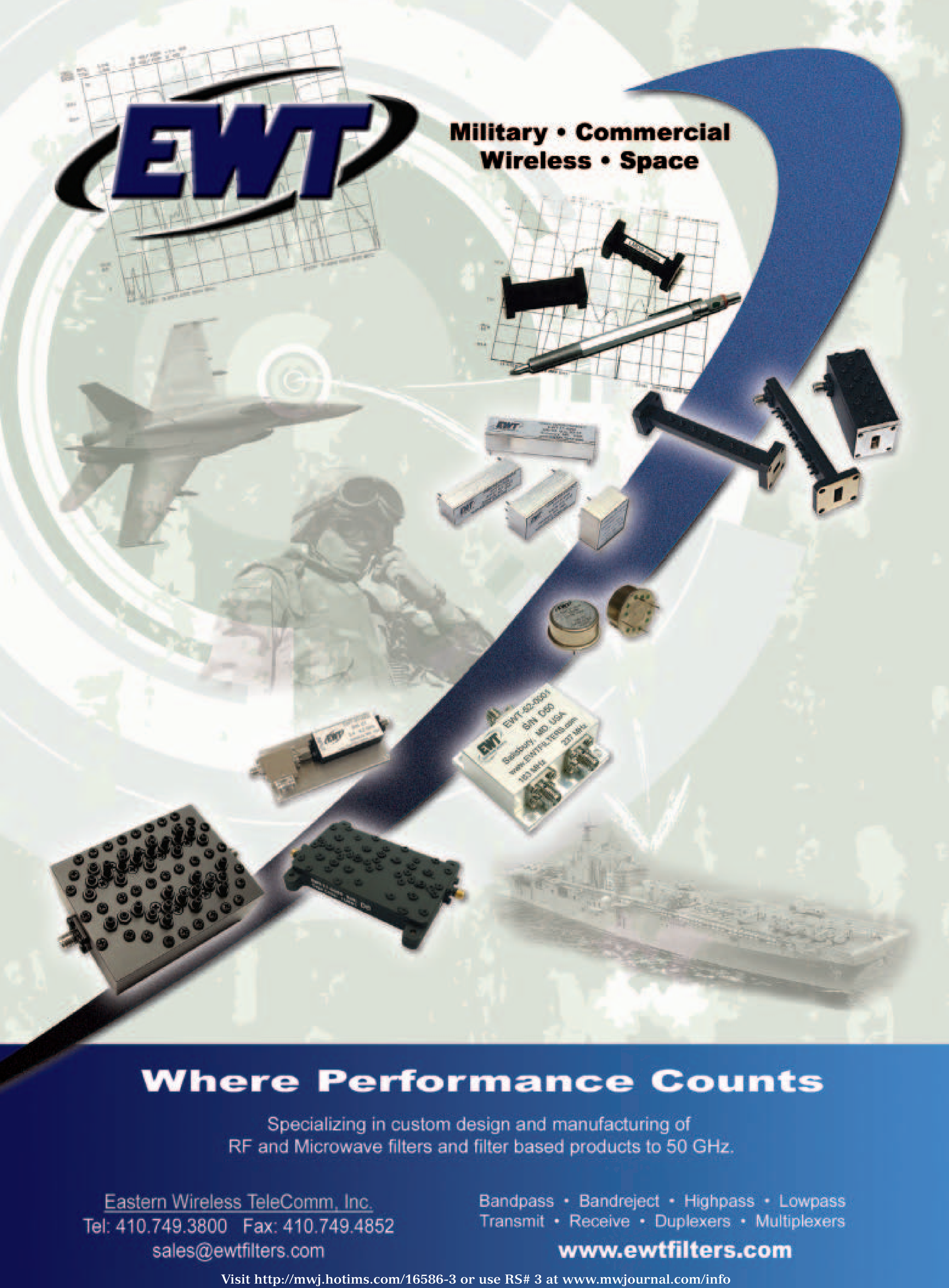
Next, the Pseudo Noise (PN) transmission channel encoder assigns a pseudorandom value to each redundant bit. The output is a spread sequence of positive and negative values. The Pulse Amplitude Modulator (PAM) then generates positive and negative pulses. These pulses are subsequently pulse shaped and amplified for transmission.

Though this process is similar to the DSSS BPSK modulation commonly used with continuous waveforms, pulse modulation, or inversion, is accomplished digitally prior to pulse generation and shaping. DS-UWB like TH-UWB can also use the simpler baseband, zero-IF, or homodyne architectures for signal generation and reception, allowing many hardware architectural simplifications, compared to a super-heterodyne radio.

MB-OFDM

Generating UWB signals with MB-OFDM is another important approach. Since the US FCC regulations stipulate only bandwidth and power spectral density requirements, they allow conventional modulations, like orthogonal frequency division multiplexing (OFDM), as long as the spectrum has sufficient bandwidth. Multi-band (MB) OFDM uses a frequency hopping technique. This allows further spreading of the conventional OFDM signal and makes it UWB for regulatory purposes. The problem is that current low cost OFDM modulators can only achieve a little over 500 MHz of modulated signal bandwidth. Using a simple frequency hop pattern over three bands in conjunction with a conventional OFDM signal, designers can create over 1.5 GHz of bandwidth.

OFDM signals have outstanding multi-path rejection. Since OFDM is composed of many signal carrier modulations closely spaced together yet still remaining orthogonal, each signal carrier can have a much slower data rate than the combined set of signals. Simultaneously sending many parallel, individually slower carriers allows corresponding longer symbol times when compared to a single carrier transmission. Even so, the parallel transmission preserves, and even enhances, the data rate. This greatly reduces Inter-symbol In-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terference (ISI) caused by time spreading from multi-path. OFDM thus provides very robust performance when channel characteristics are poor. In particular, MB-OFDM is an attractive modulation for indoor environments, where poor transmission channel conditions are prevalent.

THE WIMEDIA SIGNAL

The WiMedia® Alliance has selected an MB-OFDM signal as its high-speed multi-media UWB data link standard. The WiMedia signal is composed of an OFDM modulation with 128 carriers, using either Quadrature Phase Shift Keying (QPSK) or Dual Carrier Modulation (DCM) on each carrier. This modulation format allows at least eight data rates ranging up to 480 Mb/s.

The WiMedia OFDM modulation is frequency hopped over a band group composed of 528 MHz wide bands, as shown in ***Figure 5***. A Time Frequency Code (TFC) then controls the hopping of the OFDM signal across the band group. Relative to most Frequency Hop Spread Spectrum (FHSS) signals, the MB-OFDM WiMedia signal hops slowly, with an uncomplicated hopping pattern, sending many bits during each hop.

The US FCC was the first to open up radio spectrum for UWB use. Other countries have quickly followed the US FCC initiative; however, not all bands are available worldwide for UWB applications. Some countries require or will require Detect And Avoid (DAA) schemes where transceivers listen to the band for other signals before transmitting to help mitigate interference. WiMedia signals that rely on complex protocols, like many UWB signals, can be difficult to test with older traditional instruments. The unusual nature of the UWB signal combined with radically different hardware architectures that often lack traditional test-points present unique challenges for the engineer.

A CHALLENGING TEST PROBLEM

UWB signal requirements present broadband amplitude and phase flatness challenges. Test signal generators and measurement instruments can distort UWB signals due to spectral amplitude and phase flatness issues. These flatness issues create pulse distortions, which affects the spectral properties of UWB signals. The normal way to minimize flatness issues is to choose test equipment with a significantly wider bandwidth than the signal under test. However, for UWB signals, this is not always possible. Another problem encountered when testing UWB signals is the limited measurement bandwidth options available. Even simple power spectral density measurements can be difficult, as regulations require a 50 MHz resolution bandwidth (RBW) few spectrum analyzers support. Add to these challenges Time Frequency Codes (TFC) that spread and hop the UWB signal, and device test can be a major challenge without the right test equipment.

HOW TO TEST UWB DEVICES

There are many wireless test instruments on the market, but only a few are suitable for UWB devices. To follow are some common problems and the test solutions that are available for UWB applications.

EFFICIENT WIMEDIA SIGNAL SIMULATION

UWB signals, as the name implies, are very wide band. This makes signal generation a challenge, particularly when the signal generator needs to be flexible. Most common laboratory signal generators are capable of generating only a few tens or hundreds of megahertz (MHz) of bandwidth, which is far short of the one and a half gigahertz of bandwidth necessary for most UWB signals.

Different UWB modulation types require different signal generation approaches. Signals like TH-UWB and DS-UWB can be generated entirely at baseband and require many gigahertz of baseband bandwidth. Other signals like MB-OFDM are more typically upconverted to the appropriate RF band. Upconversion methods require less baseband bandwidth from the signal generator, but add the complexity of an external up-converter or modulator. A simple solution is to use the UWB's own system software to generate test signals, but this approach is not without issues. The primary problem is that, early in the development cycle, the design may not be working properly, leading to potentially serious test issues. In addition, the radio system under development usually lacks the ability to add impairments and can be cumbersome to manipulate for test purposes.

A preferred approach is to use a known good signal generator with a software package that can reliably synthesize both general purpose and standards based signals, with or without impairments. This eliminates uncertainty with the test signal and provides an easy-to-use human interface, accelerating the design and debug process. A modern Arbitrary Waveform Generator (AWG) can directly generate RF

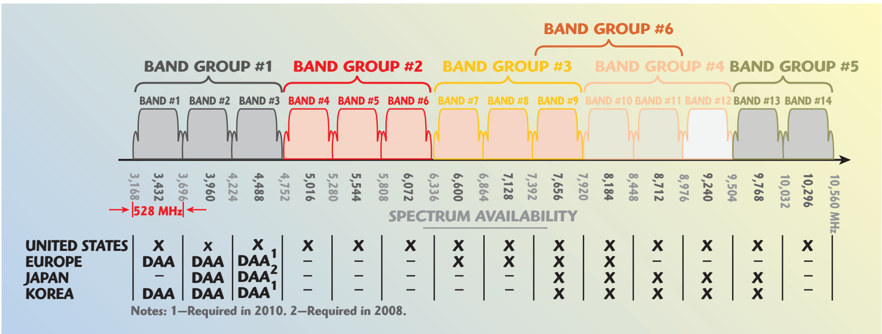
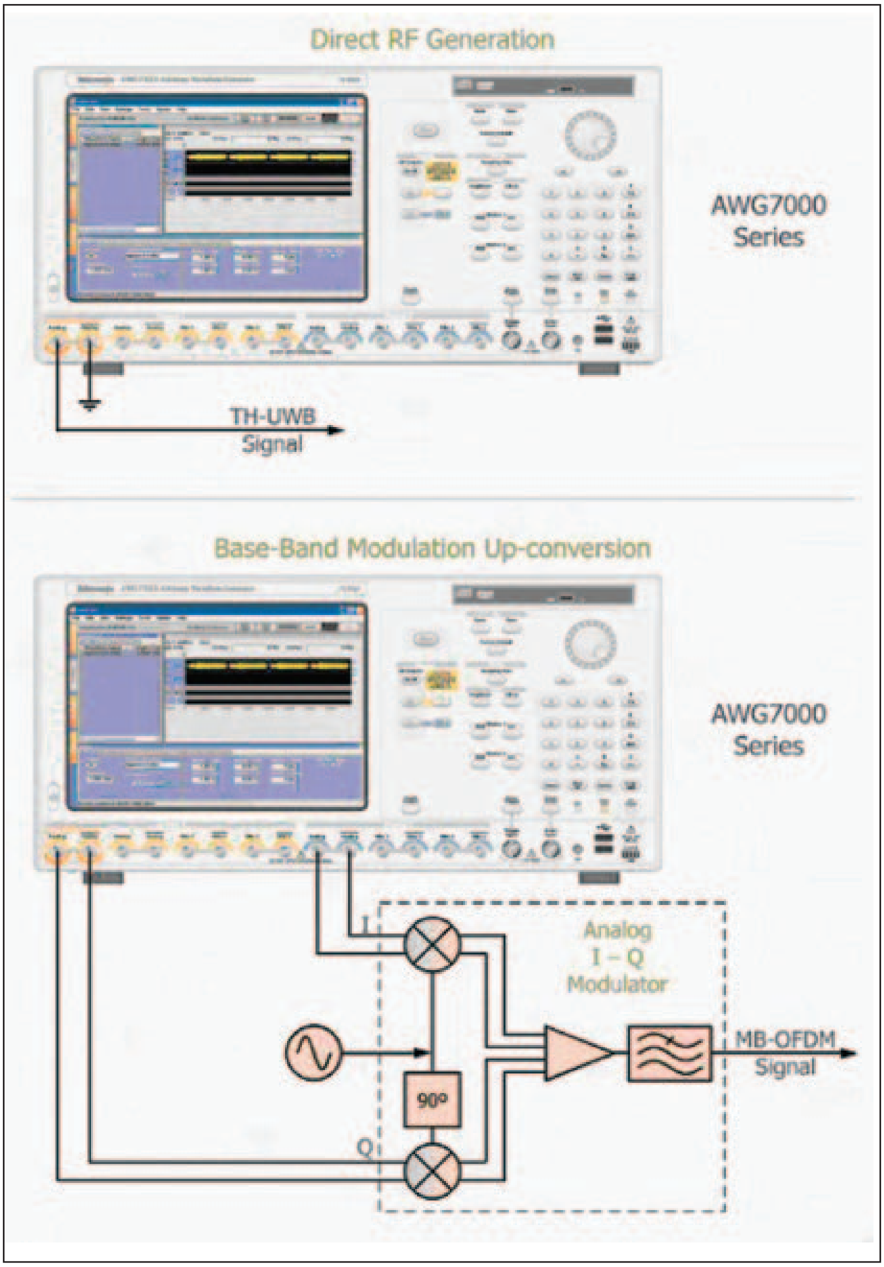


Fig. 5 MB-OFDM UWB spectrum bands.

for BG1 and BG2 of the WiMedia MB-OFDM signals. It can also provide direct baseband outputs or I-Q outputs for up-conversion needs, as illustrated in ***Figure 6***. These outputs will be available in differential form to allow a direct interface with popular balanced amplifier and mixer components and so offer the improved noise immunity of common mode rejection.

Several general-purpose signal-synthesizing software tools work with current AWGs. A software tool such as that illustrated in ***Figure 7*** is useful for general-purpose signal creation as well as signal creation for specific standards, including WiMedia, allowing for spectral environment simulation, functional test and conformance test of WiMedia devices. Specifically, a signal-synthesizing tool, in combination with an AWG, will allow engineers to create, modify and control protocol elements for functional test. It will also allow creation of a wide variety of signal impairments in the form of gated noise, distortion and I-Q impairments. On channel and adjacent channel interference from nearby UWB technology devices can be emulated. Development risks can be lowered and more robust radios created by using test signals that are impaired in known ways and receiver margin testing can be performed.



▲ *Fig. 6 A modern AWG supports direct baseband and external I-Q modulator/upconverter UWB signal generation approaches.*

EFFICIENT INTERFERENCE TESTING

Experts have cited UWB interference susceptibility as a significant challenge. The large bandwidth a UWB signal covers naturally invites a wide range of potential narrowband interference sources. Both in-band and nearby out-of-band interference sources can cause problems. UWB designs often lack the selectivity of sharp IF filters, necessitating even wider test bandwidths. Optimizing interference performance can be a particularly challenging issue as UWB links rarely have interference issues with just a single narrowband interferer. This requires engineers to create complex spectral test environments to completely characterize designs. Simulating harsh interference-filled spectral environments that encompass large bandwidths can be expensive. The conventional approach of summing multiple signal sources together in order to generate a realistic interference environment typically requires a significant investment in signal sources.

A better approach to creating interference test signals is to use an AWG, with ultra-wide bandwidth, and a signal-synthesizing program, to create an entire spectral environment from a single source. There are two ways to make this happen. The first is to generate an array of narrowband spectral interferers, sum this array with a desired UWB signal, and play it all back with an AWG. The second approach is to record an actual spectral environment with a wideband device such as a high-speed oscilloscope. Once captured, an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engineer can play back the off-the-air signal with an AWG, making it easy to judge the effectiveness of design improvements using consistent, repeatable, real-world interference.

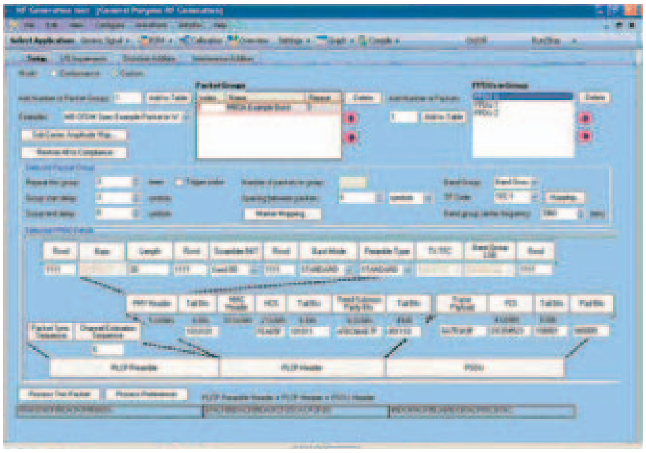
A single ultra-wideband AWG, the right software and a high-speed oscilloscope can replace many expensive independent signal generators, and is a much more cost-effective and flexible solution to evaluate UWB interference susceptibility with other UWB devices.

UWB SPECTRUM MEASUREMENTS

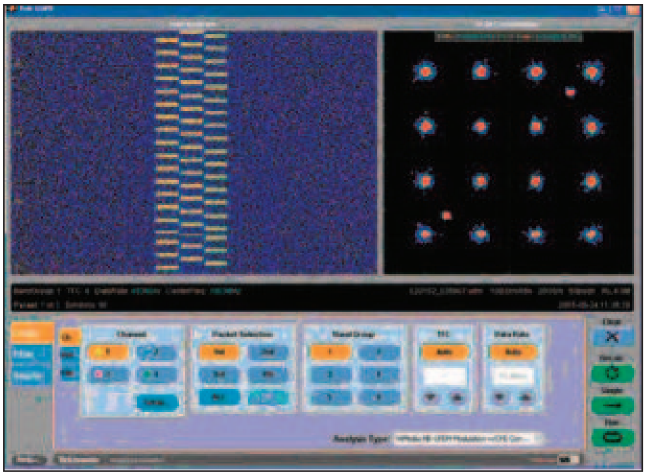
UWB spectral measurements present some unusual challenges for development and test engineers. Highly integrated UWB devices often allow spectral measurements only from radiated signals. Internal test point connections may not exist or may not reflect the attenuation characteristics of an ultra-broadband antenna. Adding to these issues, the transmit signal is likely to be near the noise floor, requiring a very sensitive spectrum analyzer or external preamplifier.

Regulatory requirements for UWB signals dictate a 50 MHz resolution bandwidth for spectral power measurements. UWB signals cover large swaths of spectrum and some of the licensed channels contained in this spectrum can be up to 50 MHz wide. This requires RBWs of 50 MHz to accurately assess the potential for interference. This requirement eliminates many popular spectrum analyzers as only a few have internal bandwidths this wide.

Oscilloscopes usually lack the dynamic range of the typical spectrum analyzer, making setup for some measurements more cumbersome. However, a few high-speed oscilloscopes have the needed sensitivity and have internal Fast Fourier Transform (FFT) capability. This allows the generation of spectral emission plots from the time-domain signal capture. Add a spectral mask measurement to the high-speed oscilloscope and you have a complete package for WiMedia UWB signals. In the case of WiMedia, it is important that the oscilloscopes' UWB analysis software automatically identifies the Time Frequency Code (TFC) of the signal and selects the correct spectral mask to apply. The software can then determine if the signal passes or fails the mask, and measure the total integrated channel power. For diagnostic purposes, it is important that the software measure mask hits independently for each band in, and outside of, a band group. Finally, an Adjacent Channel Power Ratio (ACPR) test will give developers insight into distortion issues.



▲ *Fig. 7 The RFX software package can synthesize WiMedia packet waveforms from the packet group level.*



▲ *Fig. 8 UWB analysis software automatically identifies the TFC and measures the constellation of a signal OFDM carrier.*

Once the UWB spectrum is compliant with regulations, the next measurement concern is usually optimizing modulation performance.

UWB MODULATION MEASUREMENTS

WiMedia's MB-OFDM UWB modulation is complex and presents several challenges when characterizing performance. Unlike many narrowband modulations that rely on outstanding component performance over narrow frequency ranges, ultra-wideband component characteristics often produce distortions. For example, amplitude flatness, group delay variations and frequency hopping glitches can all degrade valuable link performance. Detecting these and other problems within a multi-band signal requires capabilities far beyond simply capturing the time-domain waveform.

Another issue is that developers need to identify the TFC for the WiMedia signal under test. This is difficult if the operational mode of the device under test is unknown. An oscilloscope with strong UWB analysis capabilities will be able to take a captured waveform and identify the TFC, hopping sequence and data rate automatically for all WiMedia band groups, simplifying testing for compliance testing (see ***Figure 8***).

The next task is to run modulation quality checks, which should include Error Vector Magnitude (EVM), Peak EVM, data rate, center frequency, number of data symbols and Common Phase Error (CPE). The modulation quality values are essential to understanding signal accuracy and, ultimately, can affect device throughput in service and device margin in manufacturing.

The UWB EVM computation is more complex than traditional continuous wave measurements. UWB EVM includes an initial Channel Estimation (CE) using the CE symbols to provide a phase and timing estimation. As a result, EVM measurement software needs to be able to provide CE corrections to the pilot tones. In addition, the specific type of correction needs to be selectable by the user. This makes EVM measurements more complex than one might expect, requiring greater capability from the measurement software.

CONCLUSION

UWB technology offers many benefits. High-speed connections, interference protection and simple hardware architectures are a few of the characteristics that are propelling the rapid growth of UWB devices. TH-UWB, DS-UWB and MB-OFDM techniques are reshaping short-range high-speed wireless data links. The measurement challenges of UWB are often very demanding; bandwidth requirements alone eliminate many test instruments. However, it is now easier to design and produce UWB products because wideband AWG signal generators are now available. These wideband AWGs are capable of producing UWB signals, additive impairments and broadband interference test spectrums.

Software driven waveform synthesis tools are available to generate waveforms for playback on AWGs. These tools enable easy programming of complex waveforms. Signals like WiMedia's MB-OFDM can be quickly assembled from simple choices at the protocol bit level. Some waveform synthesis tools can also control oscilloscopes for unmatched "off-air" signal recording and playback. Real-time oscilloscopes complement the AWG signal sources. Some of these oscilloscopes offer not only the bandwidth to capture UWB signals, but also a unique set of UWB modulation measurements for popular WiMedia signals. The UWB analysis software provides unmatched insight into MB-OFDM signal performance. Testing UWB devices takes state-of-the-art measurement instruments. Fortunately, advanced testing of UWB signals is now easier than ever with the right UWB tools. ■

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Backhaul for WiMAX & LTE: High-bandwidth Ethernet Radio Systems

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With the current deployment of high-bandwidth access networks happening at an ever-increasing pace, the need for efficient, high-bandwidth backhaul infrastructure becomes more and more relevant. In fact, the construction of these new access networks depends upon the backhaul network for both technical and financial performance.

Today's cellular networks typically deploy leased T1 or E1 lines to get user traffic to/from base station sites in a given metropolitan area network. It is not unusual for a large metro city to have many hundreds or even thousands of base station sites. As WiMAX and other high-bandwidth mobile access technologies like LTE grow, deployment bandwidths on the order of 40 to 100 Mbps per base station are envisioned. With this large increase in bandwidth demand and the connectionless nature of the traffic comes the need for a highly capable, wireless metro Ethernet backhaul solution, one that can be deployed faster and more cost effectively than its predecessors or its optical cable counterparts.

This article investigates the application of high-bandwidth radio technology to the creation of the next generation metro backhaul networks. Typical network topologies and operating attributes are highlighted with emphasis on how these impact the underlying radio technology implementations.

WHAT IS DRIVING THE BANDWIDTH DEMANDS IN MOBILE NETWORKS?

Historically, bandwidth demand in mobile networks has been driven by voice services and services related to voice. This translated into steady growth for many years. However, there is now a large push for mobile data services. The industry has now seen that data-based services represent a larger portion of overall network traffic (see ***Figure 1***).

Data traffic has a different growth attribute than voice, primarily because general voice calling is dependant upon a 'human' application, which has not significantly changed. Our patterns of phone conversation have not changed much over time. Data sessions are largely dependant on the latest applications or services being consumed. For example, a low data-rate e-mail retrieval session can become a very high-bandwidth file

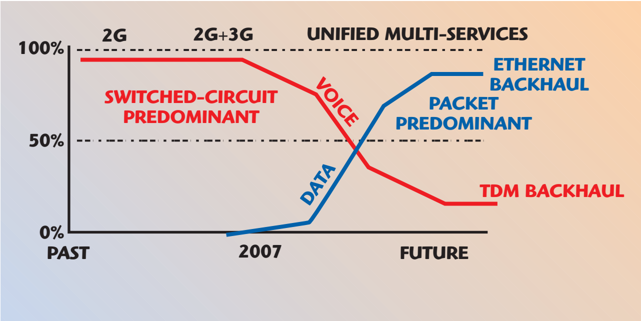

Fig. 1 Voice and data trends in mobile networks (source: International Wireless Packaging Consortium (IWPC), Milan 2008).

download session. Also shown in the figure is the trend toward Ethernet backhaul. This is no surprise since the selected transport technology generally performs most efficiently when it is transporting information already "packaged" in the same transport format. In this case, as packet-based data traffic dominates, it is naturally more efficiently transported in Ethernet form.

In response to this, the industry has evolved access technologies to enable more access data bandwidth to be available to end-users. ***Figure 2*** shows this trend. Additionally, it also shows the user-demanded access bandwidths and the backhaul technologies being applied. There are various technology labels along the plotted curve. These represent differing technology performance benchmarks associated with different technology streams over time. The vertical dotted line indicates the current position of the evolutions. For instance:

- The CDMA stream evolves to EVDO_rev0, then to EVDO_revA, then to EVDO_revB, then to EVDO_revC;
- The GSM stream evolves to HSDPA, then HSUPA, then LTE;
- The WiMAX stream evolves from 802.16d (fixed/nomadic) to 802.16e (full mobile)

In general, these technologies can be seen as competitors since various operators in a given service area would deploy one or the other. But they are similar in that they are all trying to deliver the required [high-bandwidth] access services. Further, they also have a common need for escalation in their demands on high-bandwidth, Ethernet-based metro backhaul networks. This latter element, the needed backhaul, is a vital but often unnoticed network segment. As obvious as it may seem, the concept of needing a large increase in backhaul bandwidth to support the corresponding large increase in access bandwidth is a much-overlooked, yet critical design element.

Wireless implementations of metro backhaul have long dominated in Europe. In North America, however, more TDM copper backhaul has been historically employed primarily as a result of low cost ILEC T1 TDM circuits available through US unbundling regulations. The onset of high-bandwidth backhaul demands is incompatible with these T1 circuits; wireless is therefore increasingly seen as a more optimal backhaul technology in this geographic region as well. Cumulatively, as shown in ***Figure 3***, there is a positive trend toward wireless Ethernet technology use, while PDH/SDH are declining. Interestingly enough, these trends are consistent with the bandwidth evolution overview. The connection between the two is that the high-bandwidth access technologies are increasingly relying on high-bandwidth Ethernet backhaul.

TYPICAL WIRELESS METRO ETHERNET BACKHAUL NETWORKS

With the increasing focus on high-bandwidth Ethernet backhaul networks to support the newer mobile access technologies comes an ability to harvest a series of inherent networking benefits that Ethernet can offer. Ethernet's cost effectiveness and connectionless nature make it highly suitable for distributed, self-hardened network topologies. The designer is free to design conventional, daisy-chained, ring or constrained mesh backhaul topologies (see ***Figure 4***), all of which are readily addressable with Ethernet as a transport structure. In addition to the cost effectiveness of Ethernet-based implementations, the ring and constrained mesh topologies offer a number of technical advantages, namely:

- Use of angle diversity to increase radio path availability. This can allow for the use of smaller antennas and/or can allow longer paths;
- Use of geographic-separation diversity to increase radio path availability; this can allow for the use of smaller antennas

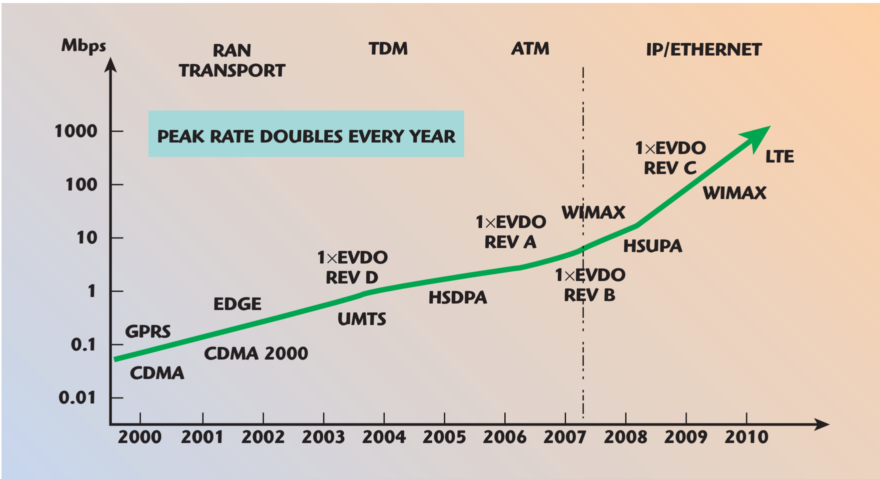

Fig. 2 Applications of various access technologies (source: IWPC/Alcatel, Milan 2008).

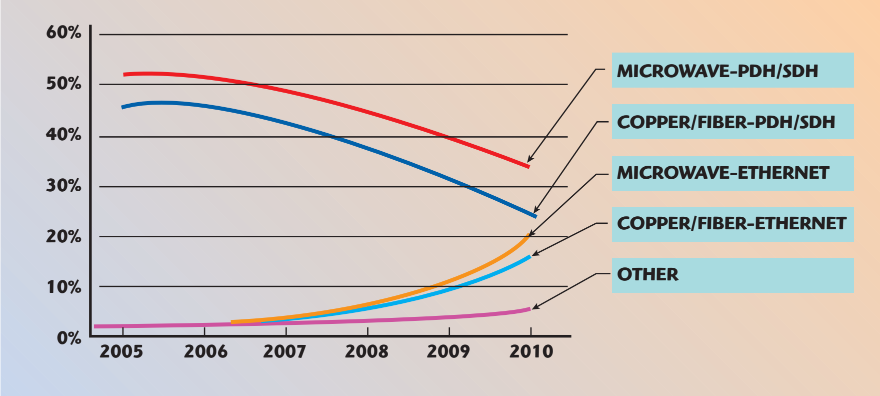

Fig. 3 Global trends in backhaul implementation/transport technology (source: Infonetics Research—Mobile Backhaul Equipment 2007).

and/or can allow longer paths;

- Ability to harden "N" network elements within a given sub-circuit with "N+1" cost incremental

The constrained mesh can also be considered as a future bandwidth expansion to the ring. Starting with a ring structure, a "crossbar" radio link can be added in the future to effectively double the overall throughput of the sub-circuit. When this is combined with software-based, highly-scalable radio link throughput capability, individual sub-circuits can be readily engineered to scale from a few 10's Mbps [full duplex, Committed Information Rate (CIR)] to many Gbps. Covering a metro service area often requires the replication of the backhaul sub-circuit topology in order to provide connectivity to many end BTS sites in the network. It is not uncommon for mid/large metro networks to have hundreds or even thousands of base station sites. In the future, networks using micro- or pico-cellular technologies, higher throughputs, or higher access-layer operating frequencies will drive the base station count up further, possibly by a factor of 10 or more.

TOP LEVEL REQUIREMENTS PLACED ON THE UNDERLYING RADIO SYSTEM BUILDING BLOCKS

With the drive toward advanced wireless metro Ethernet backhaul networks comes a series of new demands on the radio systems. Historically, TDM radio systems with relatively low throughput could be implemented with simple modulation schemes and low-fidelity transmitters and receivers. In addition, the availability of licensable spectrum at lower frequencies allowed these radio systems to attain long range without unattainable transmit power levels.

In today's deployment arena, spectrum scarcity and link deployment density are driving deployment toward higher frequencies where it is possible for operators to acquire radio channels from the local regulators. The advantage of this is that larger RF channels are often available (which helps to enable higher data rates over the air). However, the higher rain-related propagation losses at higher operating frequencies create disadvantages such as:

- Need for more RF transmit power
- Need for increased transmitter linearity
- Need for better receiver sensitivity

These disadvantages are partially offset by the ability to attain higher antenna gains [for a given antenna size] at higher operating frequencies.

In terms of operating data rates, the need to attain very high throughputs [on the order of 200 to 500 Mbps Full Duplex (FD) CIR] drives the need for high-order modulations. When combined with high-frequency operation of the radio systems, this creates extremely difficult challenges in:

- Attaining ultra-low phase noise local oscillator operation at high frequencies
- Low noise figure
- Low contributed noise (ultra-"quiet" electronics)
- High transmitter and receiver linearity
- Low AM/AM & AM/PM distortion transmitters

These requirements become significantly more aggravated when the radio systems are deployed in narrow channels (such as 14 versus 56 MHz) while simultaneously being licensed in high operating frequencies (such as 26 versus 13 GHz). This scenario is typical in European markets where operators, "rewarded" for high spectral efficiency, are pushed to narrower channels to minimize costs and ease constraints to access channels and are driven to higher operating frequencies due to congestion. Historically, the need for low delay operation was driven by voice-centric services. In the era of data-centric services, one line of thinking has been that delay is not a concern since data can be highly delay-tolerant. However, there are numerous data applications that are delay and delay-variability sensitive, including:

- Live interactive video conferencing
- Voice-over-IP
- Mobile networking (hand-offs)
- Live gaming
- Online navigation aids
- T1 or E1 over Ethernet

The result is that delay and delay variability are highly relevant and important operating parameters. In a typical network, a given backhaul sub-circuit will be composed of 8 to 10 radio "hops" to the nearest fiber. Typically 1 to 2 ms of delay will be allocated within the network. This translates into a necessary delay of approximately 100 to 200 μs per radio hop. When considering mesh and ring topologies, it is possible to also employ the sub-circuit topology to help control delay and delay variability. Delay variability of ±0.5 to 1 ms is readily

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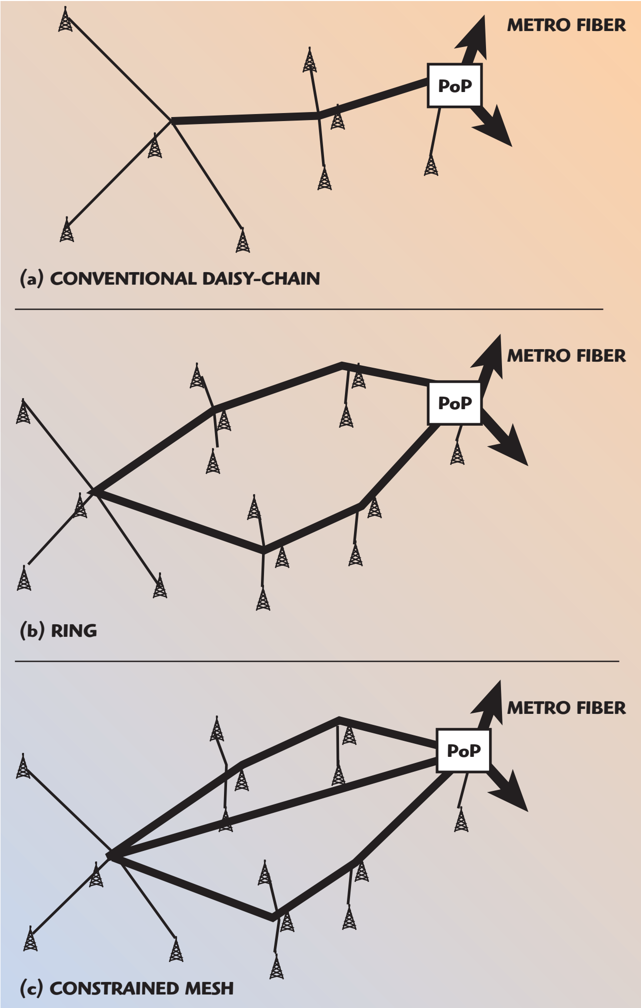

Fig. 4 Metro backhaul network sub-circuit topologies (source: Base Station, February 2008).

achievable provided ultra-low-latency radios are employed in an appropriate topology.

TYPICAL CONSTRAINED MESH METRO BACKHAUL NETWORK ARCHITECTURE

When the ring/mesh topology is employed to deliver metro backhaul coverage into a mobile access network, the network may look as shown in ***Figure 5***. This figure shows the utilization of the ring/mesh sub-circuit building blocks in the creation of a network able to deliver backhaul coverage across a large metropolitan service area. The use of high-performance Ethernet radio systems to realize each microwave/wireless link in the backhaul network enables the network to effectively extend the reach of the metro fiber out to each distributed base station site. To do this, a high system gain is required from the radio systems in order to attain high availability, while using the smallest possible antenna sizes. ***Figure 6*** shows a typical distribution of link ranges from a network design in a large US city. Typical distances are 4 to 5 km, but the possible range of distribution is roughly 1 to 8 km. Note also that the distribution is not "well behaved" (that is normally distributed).

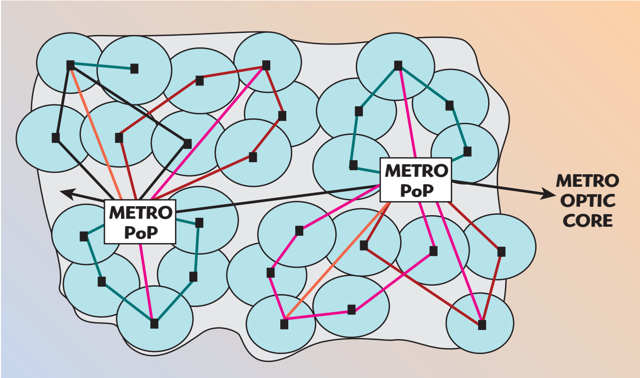

Fig. 5 Typical metro backhaul network construct using ring/mesh sub-circuit building blocks (source: IWPC, Washington 2007).

The system gain is a radio parameter, which is generally defined as the difference (in dB) between the average power in the transmitted signal at the antenna-transmitter interface and the Minimum Detectable/Processable Signal (MDS) in the receiver, measured at the antenna-receiver interface. It does not normally include antenna gain. High performance, high-frequency radio systems require as much system gain as possible. Since MDS is largely defined by parameters that are not easy to improve upon, $MDS=10 \log (KTB)+SNR_{@\ BER=10E-6}+NF$, the power in the transmitted signal remains the obvious vehicle for performance improvements. Low cost, high P1dB, high IM Intercept, low distortion transmitter MMICs are required to address this performance element.

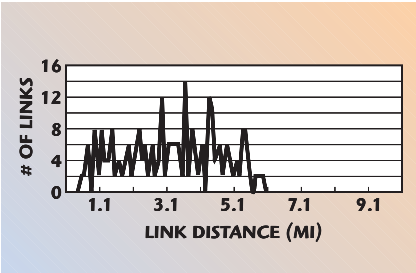

Fig. 6 Typical link distances in a large city (source: IWPC, Washington 2007).

CONCLUSION

Next generation access networks are driving wireless backhaul demands to deliver cost and performance that has not previously been available. A number of key system performance attributes fall directly or indirectly to the performance of the microwave front-end designs. ■

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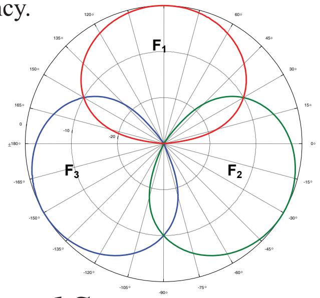
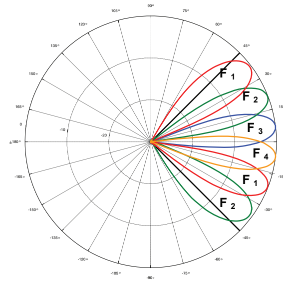
E.T. Industries, Antenna Systems:

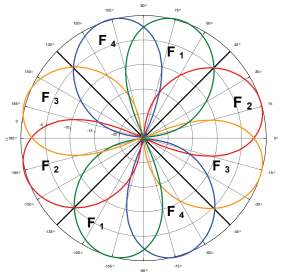
E.T. Industries has designed antenna systems which are both unique and revolutionary in the wireless industry. These antenna systems address the fundamental limitations of current wireless deployments offering unparalleled capacity, throughput and spectral efficiency.



Typical Cell Site using three separate frequency channels, F1, F2, F3



Beam Array diagram of four of E.T. Industries' 2-beam antennas using four frequency channels, F1, F2, F3, F4. Frequency reuse ratio of 4:1.



Beam Array diagram of an E.T. Industries' 6-beam antenna using four frequency channels, F1, F2, F3, F4. Frequency reuse ratio of 4:1.

Limitations of Traditional Systems –

The Problem

Many factors contribute to the limitations of wireless systems of which the most important arguably are frequency bandwidth and frequency efficiency. Though efficiency may be increased by higher modulation rates, more sensitive receivers, and more accurate bit error detection/correction methods, wireless telecommunications systems are built around the frequency bandwidth limitations that are set by governing authorities. Consequently, once bandwidth is used up in an area, no other system utilizing the same frequency bands can coexist and hence data speeds are limited.

Due to this fact, the current technologies of wireless systems have limited data and user capacity. A typical GSM cell site has three sectors in 360˚ and uses three frequency channels. Within a sparsely populated area this may be acceptable, however networks covering dense urban areas often require hundreds of such cell sites. Such a large number of cell sites incur high costs associated with the cell equipment, site management and site rental. In addition, with every new site, RF planning becomes more complex.

Overcoming Limitations

The Solution

ET Industries' antenna systems solve these problems by increasing the available bandwidth for an area. To achieve this, our systems have been designed to produce up to 48 sectors around a single cell site while using only four physical antennas. Additional sectors yield more data and user capacity. We can offer up to 16 times the user capacity and data rate of a typical 3-sectored wireless system.

In addition, whereas all sectors around a single base station in traditional systems use different frequencies, our multibeam antennas are able to reuse the same frequencies around the base station by spatially optimizing frequency usage. By using interference rejection technology, site interference between sectors is kept to a minimum. The ability to reuse frequency bands in the same area facilitates a substantial increase in throughput.

In brief, our systems offer:

- Substantially higher data throughput
- Substantially higher customer capacity
- Increased spectral efficiency
- Far reduced number of cell sites

How It Works –

Smart Antenna, Beam-forming, Beam-shaping Basics

E.T. Industries' systems achieve a high number of sectors by employing a smart antenna multiple times. A single 90° sectored smart antenna system can produce up to 12 individual beams in multiple directions within that area. Each beam is accurately spatially aligned by a beam-forming network (BFN) while a beam-shaping network (BSN) shapes the radiation pattern envelope (RPE) of each lobe. Essentially the BFN focuses each beam in a specified direction and the BSN minimizes any possibility of interference between beams using the same frequency band. The result produced is many exclusive high gain lobes radiating from one antenna in a 90° sectored area.

Because of the narrow focusing of the BFN, the accurate shaping of the BSN, and the resulting individual beam spatial isolation, our wireless systems are able to reuse frequency bands multiple times within the 90° area.

What We Offer –

Smart Antennas unrestricted by frequency or standard

E.T. Industries have designed antenna systems incorporating only passive components insuring that our antennas can integrate into the network infrastructure of any vendor. We offer a simple solution to scaling up throughput and capacity while insuring the flexibility to work with other vendors and to operate on any standard. Our systems are being optimized to work at multiple frequency bands including GSM 850, 900, 1800, 1900 MHz and the WiMAX bands, 2.4, 3.5, 5.4, 5.8 and 10.5 GHz.

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Challenges Facing Front Ends for 3G and 4G Multimode Handsets

Kevin Walsh and Jackie Johnson
RFMD, Greensboro, NC

As consumers, we are used to the continual productivity enhancements derived from having ever-increasing, computer-like handsets at our disposal. For those of us lucky enough to have in-depth RF industry knowledge, we know full well the complexity of a system that can deliver this near desk-like performance in the palm of your hand. Still, it helps to step back now and again to consider how such an intricate system actually works in order to appreciate the arduous nature of developing these state-of-the-art mobile devices. Much like the awe we experience watching a jumbo jet take off—we may know how the basic interaction of forces occur, enabling the jet to break the sound barrier or cruise at an altitude of 30,000 feet, yet we're still fascinated with how well it all works and how seamless designers have made it appear.

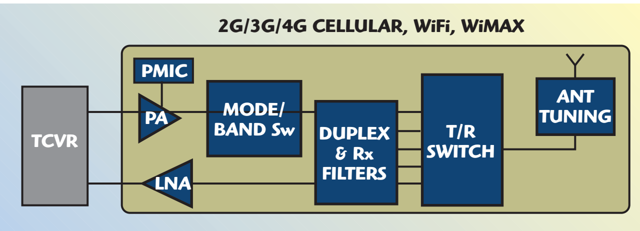


Fig. 1 Front end block diagram.

Similar to the jet analogy, engineers may know how these complex handsets, and the highly integrated systems they contain, function, but that knowledge doesn't preclude us from feeling a sense of awe when watching someone use their handset to check e-mail, download a video, or take a picture. There are also many parallels to the technical achievements and boundaries being pushed in the crop of current third-generation (3G) and future fourth-generation (4G) multimode phones under development. This article examines some of the drivers that are pushing designers to seek new and groundbreaking solutions for a key system in these mobile devices—the RF front end.

"RF front end" has become the industry-standard term for the radio frequency components functionally located between the wireless transceiver and the antenna, required to both transmit and receive the radio signal. More specifically, the entire cellular front end system is comprised of power and low noise amplifiers; filtering, such as receive filters and duplexers; RF

TABLE I

3GPP BAND DESIGNATIONS

Technology	Band Designator	Uplink to User Equipment Transmit (MHz)	Downlink to User Equipment Receive (MHz)	NA	LA	EMEA	Asia	Anzac	Japan
3GPP REL. 8 FDD	BAND I	1920 to 1980	2110 to 2170	Roaming	Used	Used	Used	Used	Used
3GPP REL. 8 FDD	BAND II	1850 to 1910	1930 to 1990	Used	Used		Roaming	Roaming	Roaming
3GPP REL. 8 FDD	BAND III	1710 to 1785	1805 to 1880		Used	Used			
3GPP REL. 8 FDD	BAND IV	1710 to 1755	2110 to 2155	Used		Roaming			
3GPP REL. 8 FDD	BAND V	824 to 849	869 to 894	Used	Used	Roaming	Roaming	Used	Roaming
3GPP REL. 8 FDD	BAND VI	830 to 840	875 to 885						Used
3GPP REL. 8 FDD	BAND VII	2500 to 2570	2620 to 2690			Used			
3GPP REL. 8 FDD	BAND VIII	880 to 915	925 to 960	Used	Roaming	Used	Used	Used	Roaming
3GPP REL. 8 FDD	BAND IX	1749.9 to 1784.9	1844.9 to 1879.9						Used
3GPP REL. 8 FDD	BAND X	1710 to 1770	2110 to 2170						
3GPP REL. 8 FDD	BAND XI	1427.9 to 1452.9	1475.9 to 1500.9	Roaming	Roaming	Roaming	Roaming	Roaming	Used

Used   Roaming

switches, including antenna, mode and bypass; the antenna, and the interface to the transceiver and baseband (see ***Figure 1***).

MARKET FORCES PROPELLING MULTIMODE HANDSET DEVELOPMENT

Communication has evolved quickly in the last two to three decades. Consumers expect and demand ubiquitous "communication" throughout their mobile world. The industry has developed multiple solutions to satisfy this need for high-quality communications. No longer is simple "on-the-go" voice communication, which is delivered mainly through 2G handsets, acceptable. Consumers expect frequent access to a variety of data-intensive information, such as corporate databases, e-mail, multimedia messaging, real-time financial information and social networking, regardless of where they may be or what time of the day it is. You can see this theme of "a world where everyone is connected to each other, to information and to entertainment, in all places, at all times" reflected in company advertising, taglines and mission statements. This captures the true essence of the wireless industry's main challenge over the next few years—to deliver a compelling ecosystem capable of a ubiquitous voice and data connection anywhere in the world. And, rightly so, this is the promise of the new 3G and future 4G networks—to deliver a better consumer experience with more accessibility and usability of the data content, which is both being generated and delivered.

CONSUMER EXPECTATIONS IMPACTING FRONT END DEVELOPMENT

In order for original equipment manufacturers (OEM) to satisfy these strong consumer requirements they must implement multimode systems that contribute toward a holistic handset solution. To gain a better sense of how comprehensively marketplace demands have affected 3G/4G multimode front end systems, one has to consider several key factors, including:

- Carrier spectrum necessitating multi-band requirements
- Handset complexity driving development resource requirements and other costs
- Technical issues specific to front end development
- Impact of system architecture choices on the handset battery life

HOW CARRIER SPECTRUM IS SHAPING MULTI-BAND REQUIREMENTS

Next-generation multimode phones are designed to support up to 16 different frequency bands and more than 20 different band combinations. As the number of bands and band combinations grow, frequency flexibility at the platform level has increased in importance as a critical parameter for 3G handset development. This is a far cry from the single global frequency originally envisioned for 3G.

FREQUENCY SPECTRUM AND REGULATION ISSUES

The motivation and benefits of a single, harmonized, global communication spectrum was one of the primary goals of the International Telecommunications Union (ITU) as they headed into the UN-sponsored global telecommunication meetings in 1992. The World Administrative Radio Conference 1992 (WARC-92 band 1920 to 1980 MHz, 2110 to 2170 MHz UL/DL) was intended to offer a single band plan that could be used both in GSM-based 3G technologies (3GPP WCDMA) and CDMA-based 3G technologies (3GPP2 CDMA-2000). It was hoped that a single worldwide frequency would accelerate the adoption of new technology as well as reduce implementation and deployment costs. Services such as global roaming and the inherent economies of scale were to prevail.

Competing technologies and a lack of clear spectrum, due to previous frequency allocation in some countries, caused some significant changes in spectrum policy. The resulting compromises allowed for as much commonality in frequencies as could be agreed upon.

International Mobile Telecommunications-2000 (IMT-2000) was the global standard born from years of collaborative work between ITU and the mobile industry. The first frequency bands for IMT-2000 were identified at the World Administrative Radio Conference in 1992, with additional bands identified at the 2000 World Radiocommunication Conference (WRC-2000).

The harmonization in effect after the World Radio Telecommunication meeting in 2000 resulted in the new 3G spectrum in 700 to 900 MHz and 2600 MHz as well as modifications to the existing UMTS spectrum. This led to some regional specialization of band combinations, whereby phones would need to be customized to the frequency spectrum allocated for specific geographical regions, typically by covering one or two of these frequency bands. Current WCDMA deployments can be found in 2100, 1900, 1800, 1700, 900 and 850 MHz bands throughout the world.

As one can see in ***Table 1***, there are multiple geographies calling for many different combinations of spectrum or radio frequency coverage. If we think about the increasingly desirable characteristic of global roaming, it is evident that the complexity required from the front end to be able to deal with all these frequencies and bands is accelerating at a fast clip. Mobile data networks must satisfy both local regulatory and physical transmission requirements.

Industry observers have noted the recent popularity of government-sanctioned auctions of frequency spectrum, usually for stipulated usage. Recent examples are AWS and vacated TV bands in the United States and Europe. US spectrum was auctioned off in 2007 for $19.6 B. Similar auctions are set to start in Europe for the 790 to 882 MHz bands, albeit with a delay in implementation, within a year's time. Spectrum auctions have delivered billions of dollars back to government agencies and created strong motivation by global carriers to see a return on their investment.

Another important event indicating which future band expansion will be allowed was at the World Radiocommunication Conference 2007 (WRC '07). That conference recommended that the expansion of IMT (IMS) services be made available with the following band allocations:

- 136 MHz allocated globally for IMT (450 to 470, 790 to 806, 2300 to 2400 MHz)
- Expansion of vacated TV bands for mobile systems (698 to 790, 790 to 806, 806 to 862 MHz)
- Addition of 3400 to 3600 MHz for regions 1&3, 3400 to 3500 MHz for region 2

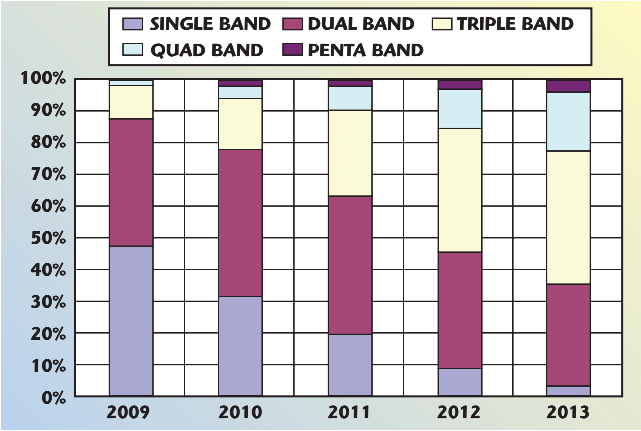


Fig. 2 RFMD forecast of the number of 3G bands.

DRIVERS FOR ADDITIONAL, LOWER FREQUENCY BANDS

One trend that is also affecting the radio front end is the growing desire by carriers to re-use (and re-farm) currently available GSM frequencies, so that it can be allowed to propagate UMTS signals. One of the rationales behind the movement is the ability to optimize connectivity depending upon the population density and physical layout of the coverage area of interest. In highly congested, urban scenarios, higher frequencies could become more popular as they can be more spectrally efficient for high data rate applications. Alternatively, in less dense environments, operators may prefer to take advantage of the benefits of lower frequencies (700 to 900 MHz) that, in this case, enable a far greater coverage area for each base station as compared with its higher frequency compliment. In fact, this is the rationale for the interest in re-farming existing GSM-allocated frequencies (850 and 900 MHz). If operators are allowed to convert from GSM to WCDMA service in these lower frequency bands, there are estimates showing up to 60 percent cost reductions while increasing coverage by two-to-four times that for 2100 MHz.[1]

One can infer from the complex nature of this background on carrier spectrum that there will be many different varieties of cel-

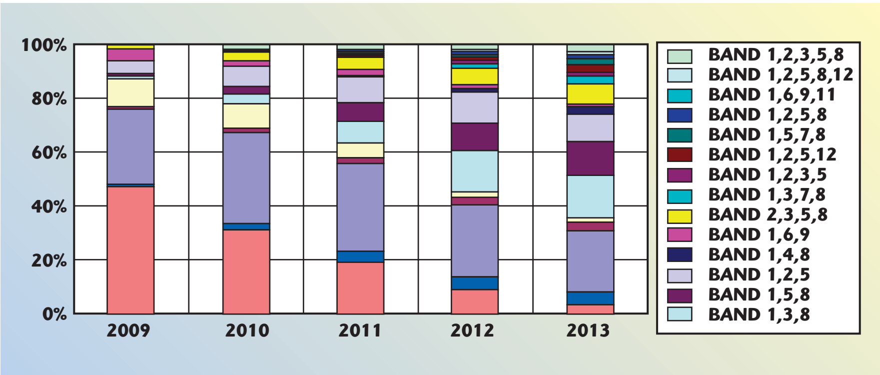


Fig. 3 Projected 3G multi-mode band combinations.

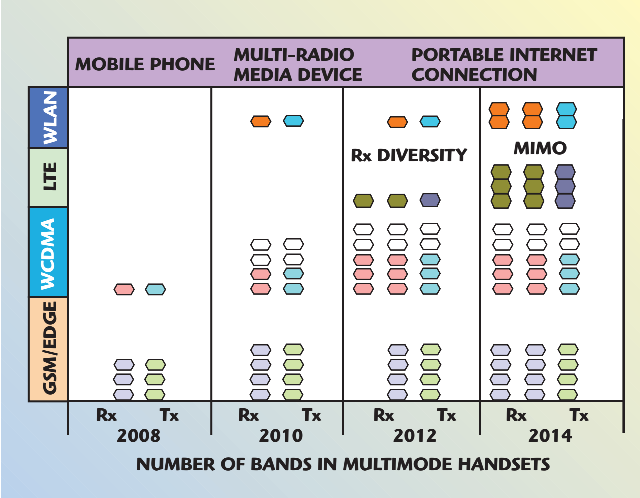


Fig. 4 Projected complexity of future phones.

lular front ends required for the complete cellular system to work in a handset, whereby information sent on different frequencies are required to be transmitted and received from a single radio source. In fact, RFMD® internal projections, based on deployment rates and industry conversations, indicate a likely scenario where the number of WCDMA bands in handsets will be as many as five by 2010, with the rate of expansion for band combinations depicted in ***Figure 2***.

The dichotomy of the 3G is that the diverse frequency allocations worldwide have been a significant departure from the original intent of the standard. Hopefully you can gain an appreciation for the technical challenge laid out when we look at requirements coming in to support carrier smartphone deployments across the globe. This leads to the first of many challenges for front end suppliers-developing filtering and switching solutions for each of the bands. To date, spectrum homogenization has not been realized in either 3G or 4G front ends. To add further perspective to this issue, ***Figure 3*** demonstrates the number of band combinations forecasted for the next five years. Since several of these bands will be used in combination for even the simplest 3G handset or data card, solutions must be developed in such a way as to allow suppliers to scale their offerings to accommodate the multiple bands.

To further complicate next-generation handset development, the evolution of the 3G standard has resulted in a relatively complex analog RF front end for these multimode, multi-band handsets. Depicted in ***Figure 4***, as networks evolve, so must the devices that consumers use to access them. Handsets, therefore, have quickly moved from their humble voice-only beginnings, with a relatively straightforward radio design, to a device enabling real time, high data-rate communications through the use of multiple, complex transmit and receive paths. Technological advances, such as the use of MIMO and receive diversity in mobile devices, will enable higher mobile productivity. Handsets will act much more like multi-radio media devices by offering a continual linkage not only to cellular networks, but all IP-based networks through the use of data portals such as Wi-Fi and WiMAX. As these cellular standards evolve even further with the addition of HSPA+ and Long Term Evolution (LTE), consumers will continue to see additional data-rate improvements in 3G networks. This, the ultimate goal of 4G, will enable true mobile broadband access through a portable internet connection.

NEXT-GENERATION HANDSET PLATFORMS: MORE RESOURCES, MORE COSTS

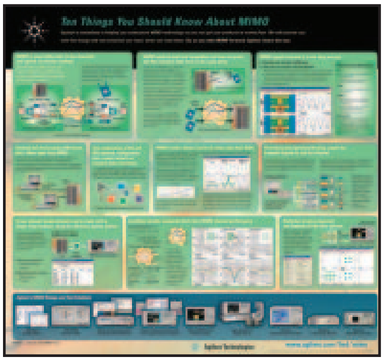
With the addition of these extra bands, modes and associated verification, the resource requirements for next-generation platforms is much more extensive than it was for 2G cellular handsets. Multimode phones are designed to work with EDGE and WCDMA air interface standards as well as LTE for high-speed data and media transport applications and, perhaps, WiMAX mobile applications as well. Additionally, mobile operators require customized handsets to meet various consumer roaming needs. Hence, the handset OEMs, who must configure 3G handsets with multiple frequency bands and operating modes (WCDMA r99, HSDPA, HSDPA+, EDGE), are left with the daunting issue of rapid customization in order to meet both market timing and mobile operator requirements. All the while handset OEMs are seeking to integrate these advanced features and multiple band configurations into a size-reduced, platform-capable form factor. Lest we not forget the continual cost-reduction pressures these consumer devices are under, which further aggravates the dilemma of increasing content in a cost-sensitive marketplace.

In conclusion, to be able to support the different standards, applications, band combinations and mobile operator requirements, handset designs must now utilize very specific power amplifiers, filters, switches, duplexers and other RF components to implement these highly specialized multimode front end systems. Given the number and specificity of RF components required to complete the multimode front end system, in combination with the growing list of handset features, it should come as no surprise that engineers are requiring longer amounts of time to complete front end system designs. Furthermore, with this highly specialized nature of the front end system, testing and calibrating during the various phases of the handset development process have also lengthened considerably. All of these additional resources—whether they take the form of additional specialized components, additional testing, or increased engineering time—raise costs. ■

Reference

1. Motorola Whitepaper Deploying UMTS in 900 MHz Band, http://www.motorola.com/mot/doc/6/6796_MotDoc.pdf.

WiMAX LTE LITERATURE SHOWCASE



Free MIMO Poster

This full-color poster from Agilent, "Ten Things You Should Know about MIMO," presents MIMO operation and test methodologies, using specific examples to highlight the impact on the radio system or associated test. Visit www.agilent.com/find/mimo-forward to order a copy.

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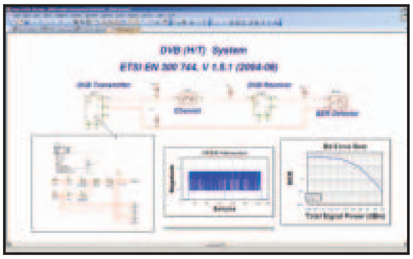


Visual System Simulator

AWR's Visual System Simulator™ (VSS) is complete and comprehensive software for the design of today's complex communications systems. In March of this year, the European Union officially endorsed Digital Video Broadcasting – Handheld (DVB-H) as the preferred technology for terrestrial mobile broadcasting that is specific to handheld devices. AWR now supports the addition of DVB-T/H (Terrestrial/Handheld) solutions to VSS. The test bench shown in the figure is tailored specifically for receiver sensitivity analysis.

Applied Wave Research Inc.,
El Segundo, CA (310) 726-3000, www.appwave.com.

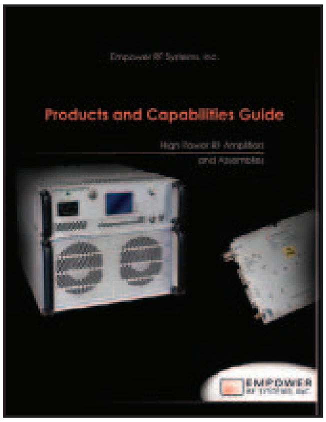
RS No. 321

Filter Catalog

This new short form catalog features a sampling of the company's RF and microwave filter products to 40 GHz utilized in military, commercial and wireless applications. The catalog also highlights some of the company's diverse filter design and manufacturing capabilities.

Eastern Wireless TeleComm Inc.,
Salisbury, MD (410) 749-3800, www.ewtfilters.com.

RS No. 322



High Power Broadband RF Amplifiers

This updated Products and Capabilities Guide provides a comprehensive overview of the company's capabilities and a listing of its most popular amplifier products. With products that cover from 150 kHz to 6 GHz and an extensive library of building block designs, there is an array of standard and semi-custom solutions available.

Empower RF Systems Inc.,
Inglewood, CA (310) 412-8100, www.empowerrf.com.

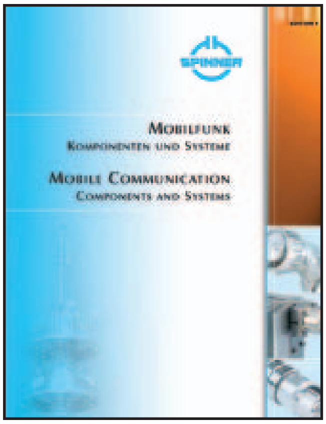
RS No. 323

RF and Microwave Filters

This catalog features the company's full line of RF and microwave filter products. The catalog highlights high reliability filters, multiplexers and switched filter banks that cover DC to 50 GHz and are tailored to meet the military market. To request a complimentary copy, e-mail: catalog@reactel.com.

Reactel Inc.,
Gaithersburg, MD (301) 519-3660, www.reactel.com.

RS No. 324

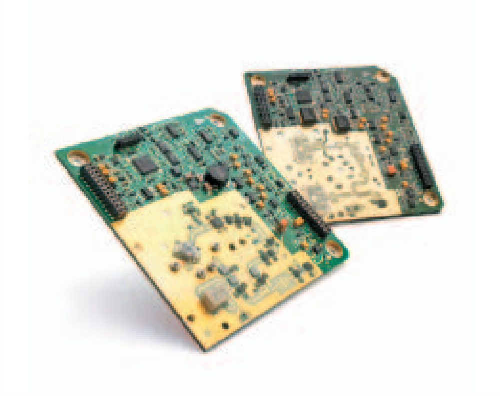


Components and Systems Catalog

This product catalog features the company's connectors, jumper cables, splitters, couplers, di-/triplexers and multiplexers. This mobile communication catalog also highlights products required for the installation on site. The components and systems catalog is available as a printed hardcopy and a CD-ROM.

SPINNER GmbH,
Munich, Germany +49 89 12601-0, www.spinner.de.

RS No. 325



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