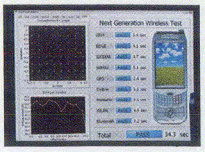
INSIDE TRACK with CENTELLAX's JULIO PERDOMO p32



WIRELESS DEVICES AID MEDICAL COMMUNICATIONS p38



MODULAR INSTRUMENTS TACKLE FULL-SIZED MEASUREMENTS p88



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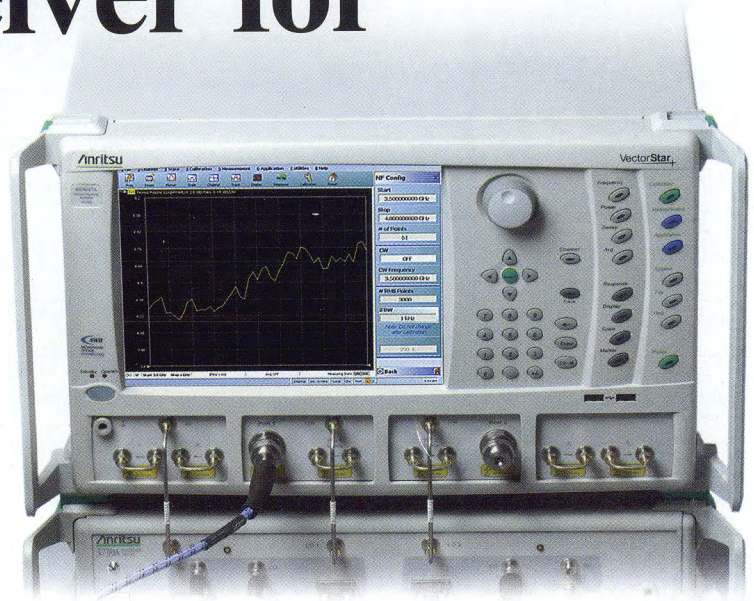
INDUSTRIAL/MEDICAL APPLICATIONS ISSUE

Microwave VNAs Recruit Receiver for Noise-Figure Testing to 125 GHz



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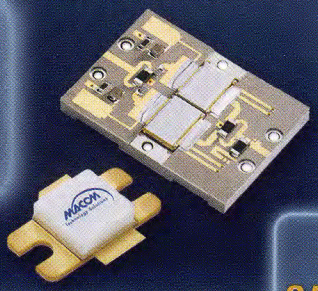


INTEGRATED CIRCUITS



ACTIVE COMPONENTS

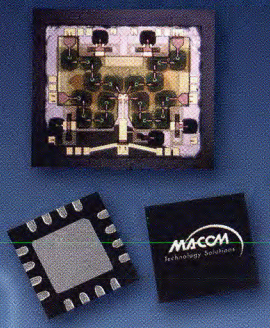


QUOTE

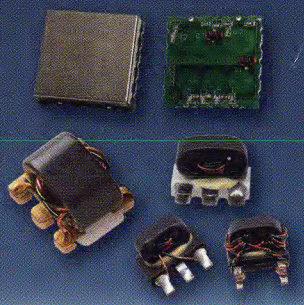
SAMPLES

PURCHASE

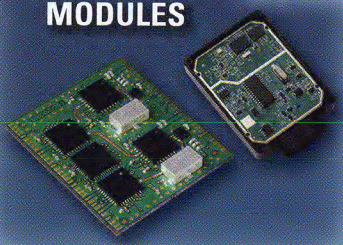
SWITCH LIMITERS, SWITCHES, DIODES



PASSIVE COMPONENTS



MULTI-CHIP MODULES



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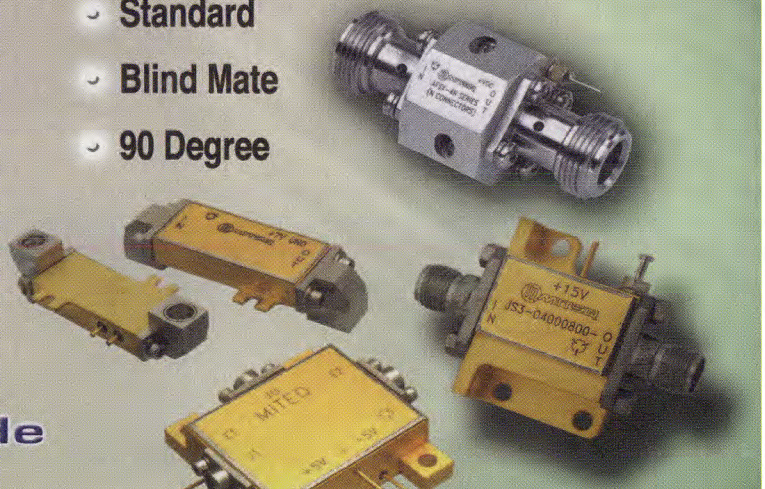

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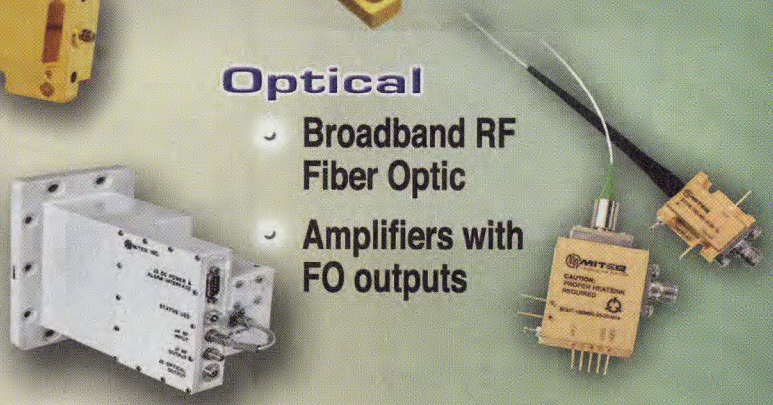
- Amplifiers
- Converters



Optical

- Broadband RF Fiber Optic
- Amplifiers with FO outputs



Drop in/open Substrate

- Mixers
- Amplifiers



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- Flat Pack Logs
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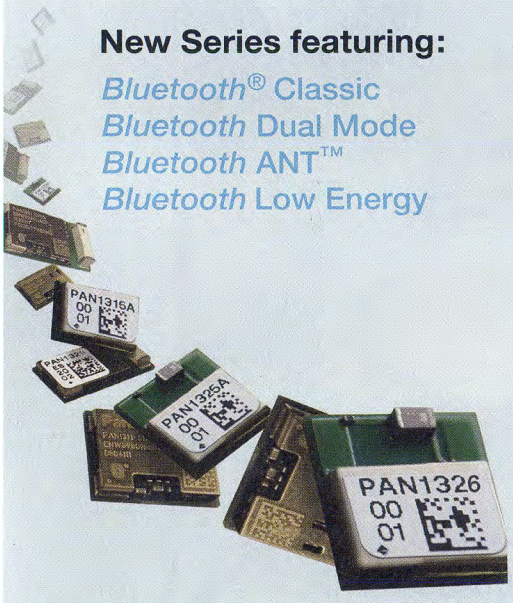

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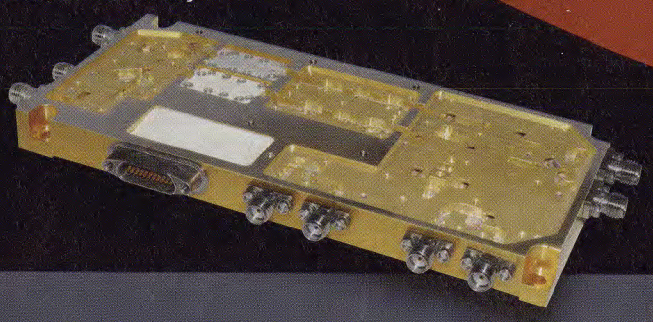

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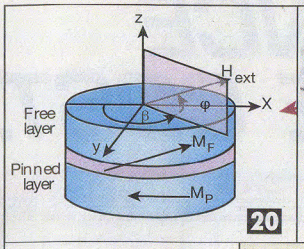
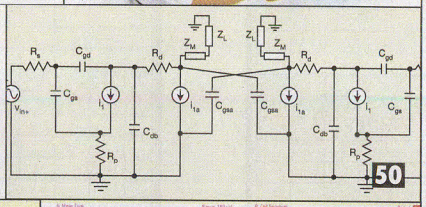
CONTENTS

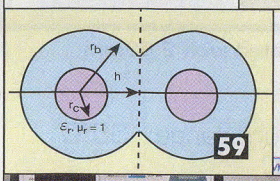


20

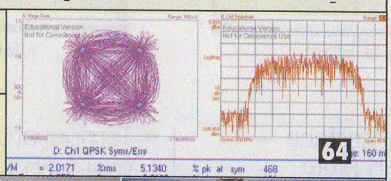

38

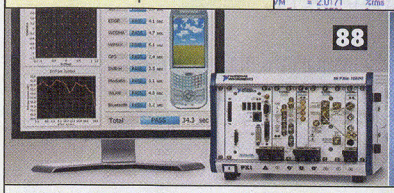

20


50



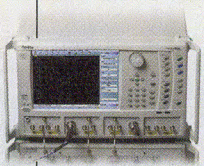
59


64


88


91

COVER STORY



84 VNAs Measure Noise From 70 kHz To 125 GHz

Two new options arm an established line of microwave vector network analyzers for making accurate noise figure measurements, along with the capability to make those measurements up to 125 GHz.

NEWS & COLUMNS

9 Web Table Of Contents
13 Editorial
19 Feedback
20 News
26 People
28 Company News
32 Inside Track with Centellax's Julio Perdomo
34 R&D Roundup
36 Microwaves In Europe
82 Application Notes
93 New Products
95 Advertiser's Index



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INDUSTRY TRENDS AND ANALYSIS

38 | Medical Applications Seek Wireless Solutions
The healthcare industry is hoping to adopt wireless technology for patient monitoring on a large scale.

42 | RF ESSENTIALS
Transceivers Trim Power In WPANs
These highly integrated circuits and modules are designed to provide short-range wireless networking functions.

46 | INDUSTRY INSIGHT
Assemblies Combine Multiple Components
Integrated microwave assemblies allow for the combining of multiple component functions in a single compact package.

DESIGN FEATURES

51 | Mixer Translates Multiple Standards
This broadband frequency-upconversion mixer is suitable for multiple-standard wireless applications from 1.0 to 10.6 GHz.

59 | Create UWB Filters With Coaxial Cables
With the aid of a commercial EM simulator, sliced coaxial cables can be used to design a high-performance bandpass filter.

64 | Transmitter/Receiver Manages MIMO
This low-cost two-way transmitter and receiver design achieves high-data-rate transmissions at 8 GHz.

70 | Tiny Spiral Spans 1.4 To 10.0 GHz
This miniature arm-width-tapered ATARSA features tapered antenna arms, enabling significant size reduction.

76 | Compact Monopole Sleeve Antenna Reaches 11.8 GHz
A sleeve and ladder-shaped ground-plane structures help to widen the impedance bandwidth of a planar monopole antenna.

PRODUCT TECHNOLOGY

88 | PRODUCT TRENDS
Making Microwave Measurements Modular
An increasing number of measurement functions are now available in modular form, allowing for smaller system sizes.

91 | TO-8 YIGs Tune 3 To 13 GHz
These compact microwave oscillators can tune across customer-specified bands with generous output power.

92 | Envelope Tracking Makes Phones Smarter
Using envelope-tracking techniques, the efficiency of the power amplifiers found in cellular telephones can be improved.

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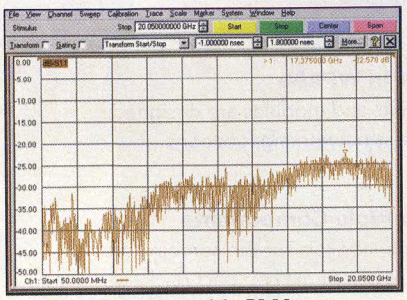

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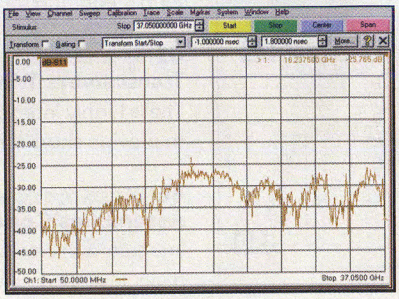
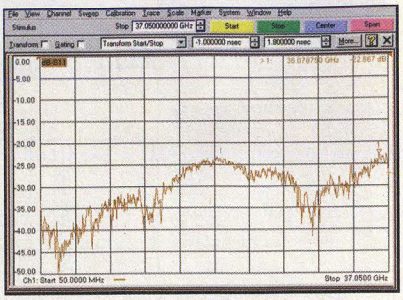


Mated with 3.5mm



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	Part # RoHS Compliant	OAL in FT.	IL (dB)	Ret Ls (dB)
SMA+m-SMA+m RTK-Flex 405	L71-404-305	1.0	1.4	25
	L71-404-457	1.5	1.9	25
	L71-404-610	2.0	2.4	25
	L71-404-915	3.0	3.5	25
	L71-404-1220	4.0	4.5	25
	L71-404-1830	6.0	5.6	25

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Transformers			
Model Number	**Frequency (MHz)**	**Impedance Ratio**	**Schematic**
TM4-0	0.2 - 350	4:1	
TM1-0	0.3 - 1000	1:1	
TM1-1	0.4 - 500	1:1	
TM1.5-2	0.5 - 550	1.5:1	
TM2-1	1 - 600	2:1	
TM1-6	5 - 3000	1:1	
TM2-GT	5 - 1500	2:1	
TM4-GT	5 - 1000	4:1	
TM8-GT	5 - 1000	8:1	
TM4-1	10 - 1000	1:4	
TM4-4	10 - 2500	1:4	
TM1-2	20 - 1200	1:1	
TM1-9	100 - 5000	1:1	
TM1-8	800 - 4000	1:1	

Couplers			
Model Number	**Frequency (MHz)**	**Coupling**	**Coupling Flatness**
GC6-2	1 - 700	6 dB ±0.5 dB (Nom.)	±1.0 dB
GC6-1	10 - 500	6 dB ±0.5 dB (Nom.)	±1.0 dB

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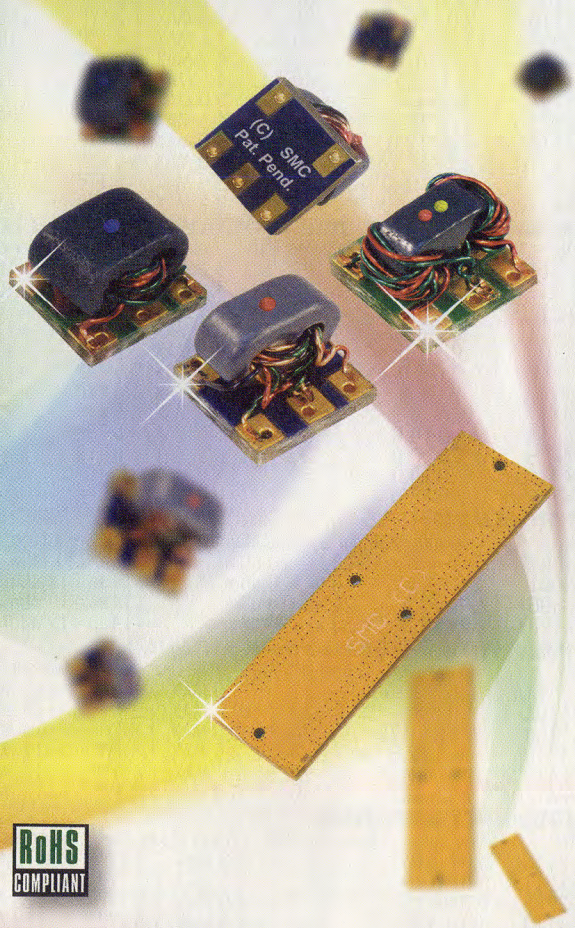

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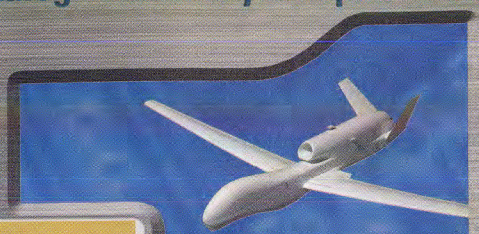

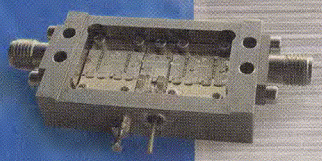



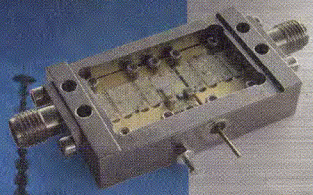



OCTAVE BAND LOW NOISE AMPLIFIERS

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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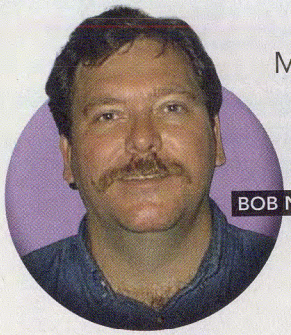
Techniques for Making Measurements of Noise-Like Signals with a SPECTRUM ANALYZER



MANY OF TODAY'S COMMUNICATION FORMATS, such as W-CDMA, cdma2000®, and WLAN, produce signals that are noise-like in nature. Accurately measuring these types of signals requires tools and setups that are different than traditionally used for continuous-wave (CW) signals. In this web-exclusive article, Agilent Technologies' Bob Nelson examines the best approach for doing so.

To read the article in its entirety, *visit www.mwrf.com.*

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The 2012 installment of the RF/microwave industry's flagship event, the *International Microwave Symposium*, has come and gone. Luckily for you, it needn't live on just in memory. Visit *www.mwrf.com* to check out our show coverage, as well as www.engineering tv.com to view exclusive videos from the show floor.

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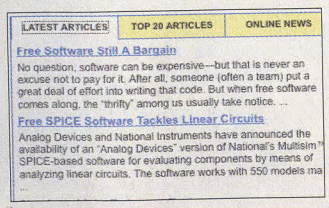
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LATEST POLL RESULT:

Will traditional radio architectures eventually be replaced by software-defined radios (SDRs) and cognitive radios?

73% YES
14% NO
14% DON'T KNOW

NEW POLL QUESTION:

Can the microwave/wireless industry contribute technology useful to the medical/healthcare industries?

YES NO
DOESN'T MATTER

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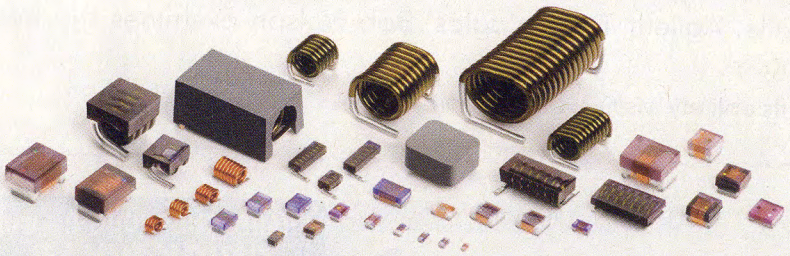

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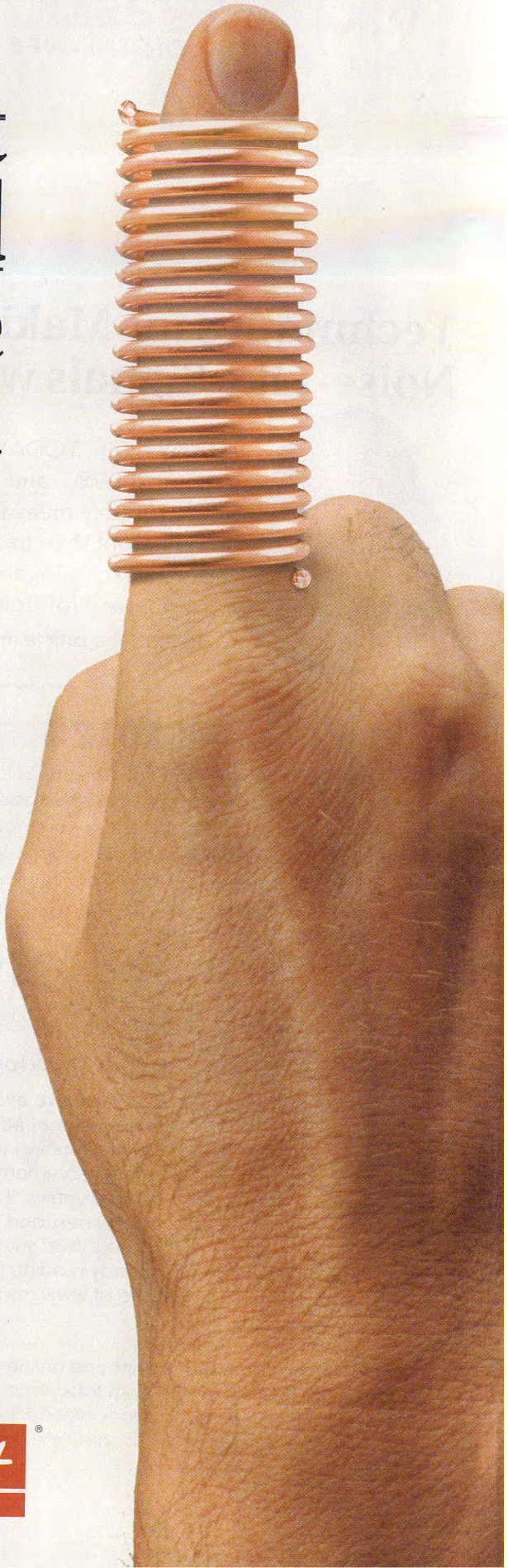

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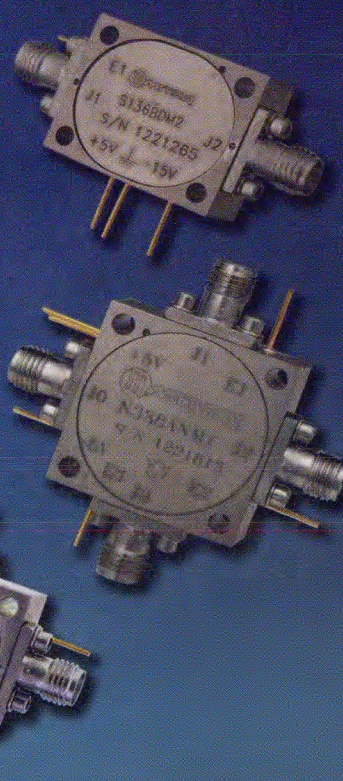

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- Multioctave bands 0.2 to 18 GHz
- Reflective or Absorptive
- Current or TTL control
- Low insertion loss
- High isolation

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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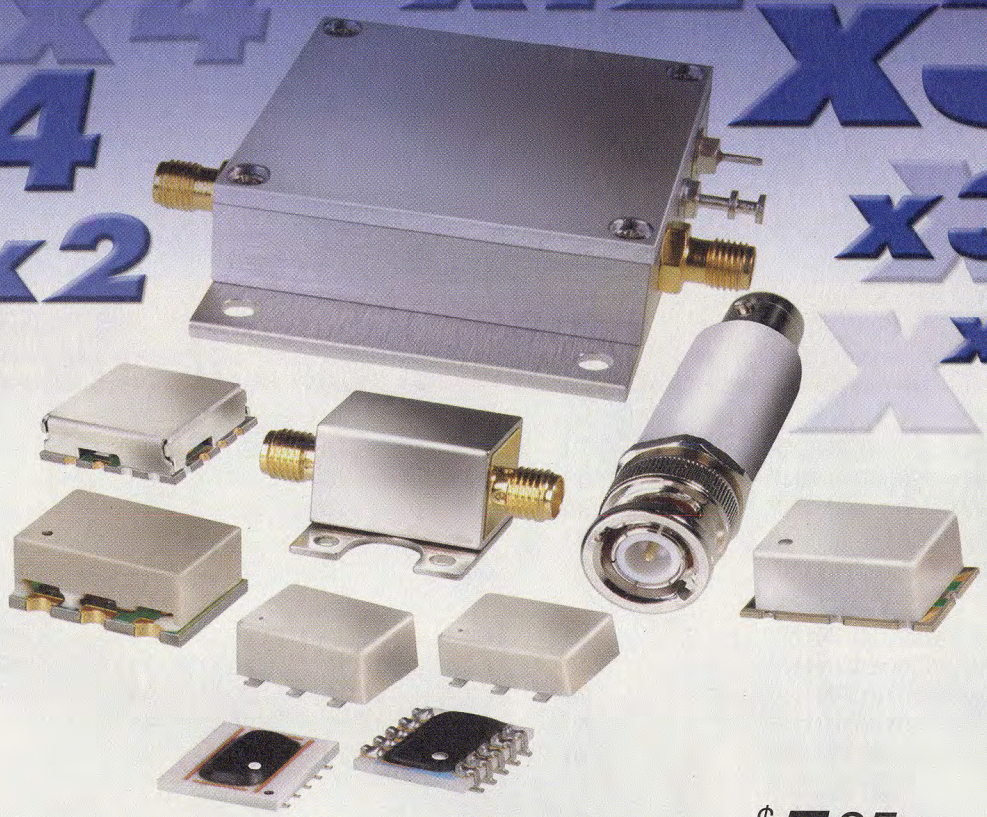

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From the Editor

Grappling With Old-Cell-Phone Guilt

A FEW DAYS ago, my six-year-old daughter was rifling through our junk drawer. She was delighted to discover a number of old cell phones, which she promptly used to "call" her ex-boyfriend—supposedly a boy named Jake. (I guess when you're six, it's okay for an ex to come before an actual boyfriend.) While it was fun watching her play, it reminded me—guiltily—that my family still had not recycled our old cell phones. From a personal to a global level, it seems that the process of recycling cellular phones—and electronics in general—could stand a lot of improvement.

To me, one should be able to get rid of an old cell phone much the way one disposes of an old mattress: Buy a new one and the retailer offers to take the old one away. Instead, it often falls to the individual consumers to hunt down someone at their local recycling centers, who will hopefully advise them on where they can bring their old cell phones. Alternatively, one could look for a solution online or find someone who is collecting used cell phones for a cause (although this raises security concerns if any of your information is still on the phone).

Even if I find a way to recycle these old phones, it's likely that only a few parts will be plucked out while the rest is simply discarded. e-Cycle (www.e-Cycle.com) notes that only a small percentage of e-waste is sent to recyclers (as little as 11% to 14% in the US). The remainder is often dumped or burned. The US Environmental Protection Agency estimates that 70% to 80% of supposedly reputable electronics-recycling companies in the US are directly or indirectly (through downstream vendors) shipping e-waste into "toxic wastelands" in developing countries.

e-Cycle recommends that organizations and businesses work with a recycler that is e-Stewards-certified (simply visit http://e-stewards.org/find-a-recycler/). e-Stewards is a globally recognized electronics-recycling certification. Among other lofty goals, it prohibits the landfilling and incineration of e-waste.

In addition to the proper disposal of electronic waste, many manufacturers are trying to design products that are "greener." This month, for example, AT&T is launching a fourth-generation (4G) Long-Term Evolution (LTE) smartphone with "sustainable" features. The Samsung Galaxy Exhilarate boasts a rear casing made from 80% recycled (post-consumer waste) material and a low-load, energy-efficient charger. It also is the first 4G LTE smartphone to receive platinum certification from UL Environment, the environment-minded business unit of Underwriters Laboratories (UL).

"Green" requirements can complicate the challenge of juggling size, performance, power, and cost tradeoffs. The Restriction of Hazardous Substances (RoHS) directive, which was passed in 2003, will probably end up being the first of many such "green" mandates. Despite the resulting design pressures, the upshot will be products that are more easily dismantled, recycled, and even reused. After I recycle our old cell phones, I may even go about recycling some other stuff in that junk drawer. Judging by the amount of rubber bands, I could make a decent-sized rubber-band ball for the kids. MWRF

Nancy K. Friedrich

Editor-In-Chief

DETECTORS FOR VERY LOW SIGNALS

Direct Measurement of Microwave Signals at -80 dBm or lower over 1 to 40 GHz



MODEL	FREQ RANGE (GHz)	MIN VOLTAGE SENSITIVITY K (mV/µW)	TYP TSS (dBm)
DTA1-1860A	1-18	10	-60
DTA1-1870A		100	-70
DTA1-1880A		1000	-80
DTA182660A	18-26	10	-60
DTA182670A		100	-70
DTA182680A		1000	-80
DTA264060A	26-40	10	-60
DTA264070A		100	-70
DTA264080A		1000	-80
DTA184060A	18-40	10	-60
DTA184070A		100	-70
DTA184080A		1000	-80

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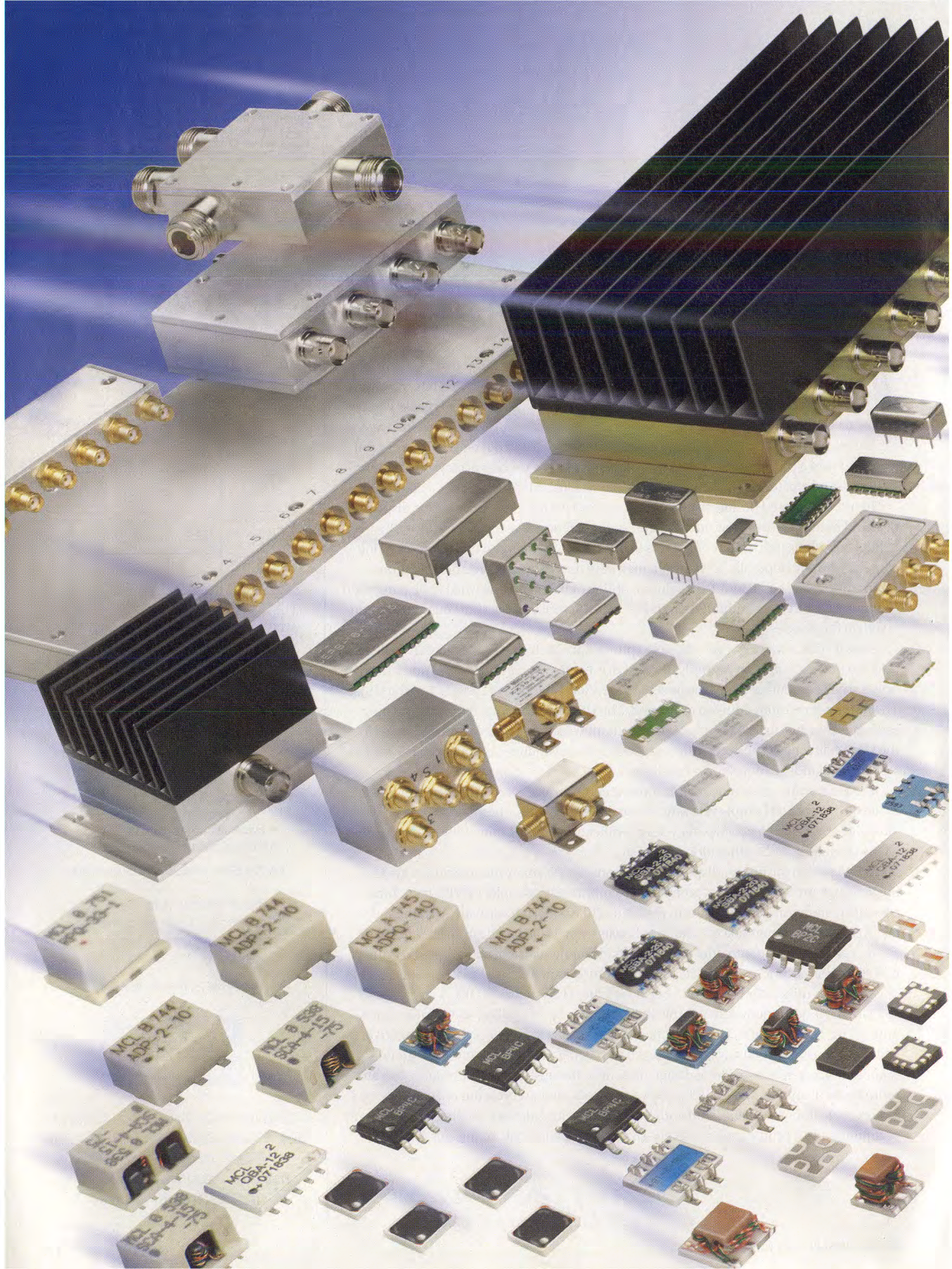

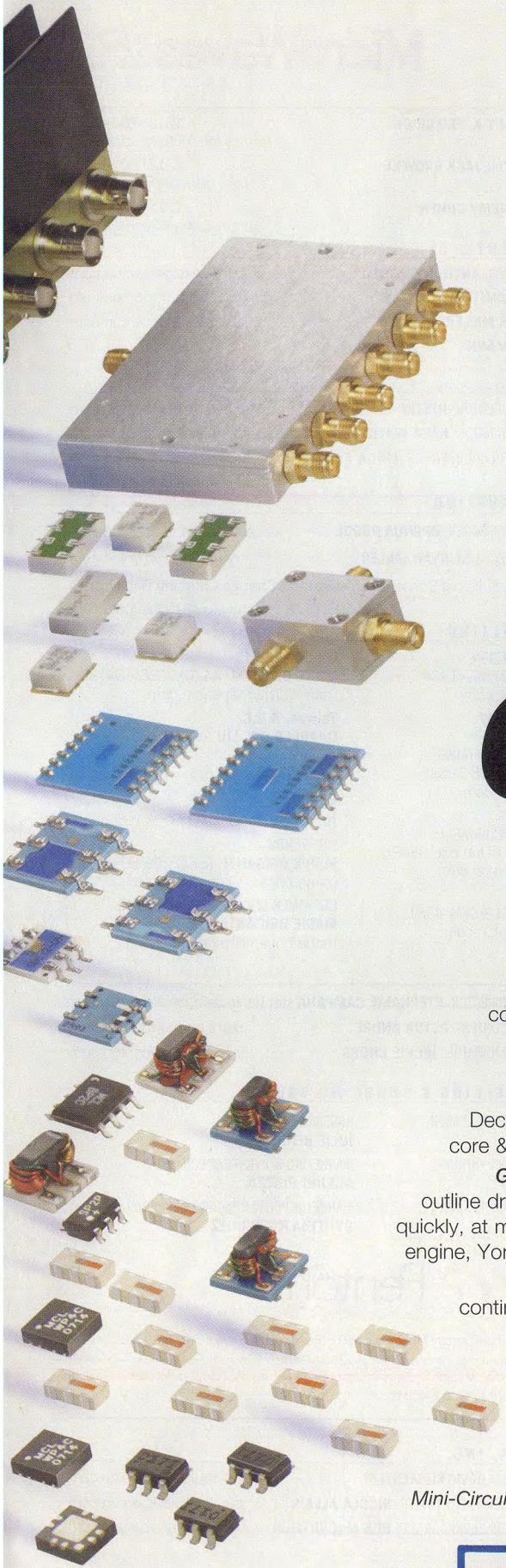

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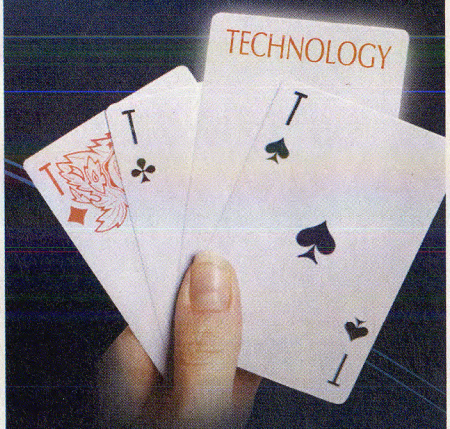

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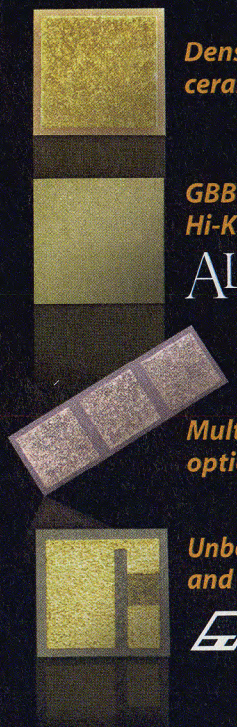

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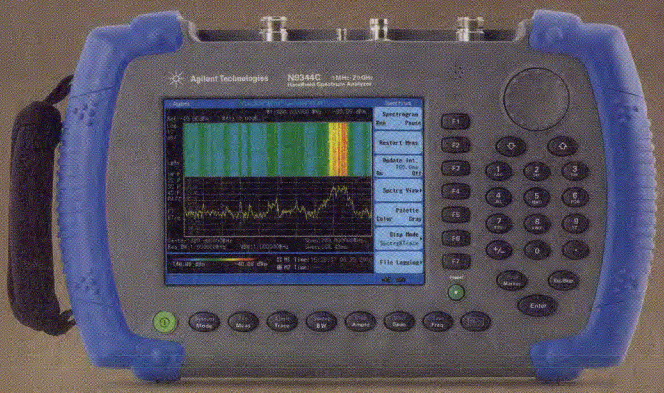

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Frequency	1 MHz–20 GHz	1 MHz–13.6 GHz	100 kHz–7 GHz
DANL	-155 dBm/Hz	-155 dBm/Hz	-164 dBm/Hz
Sweep time	< 0.9 s	< 0.7 s	< 0.4 s
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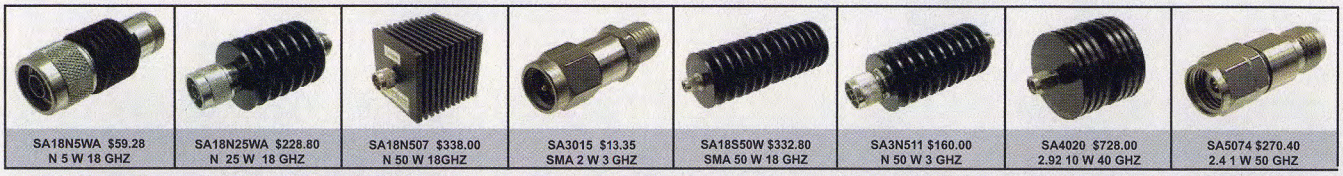
ADAPTERS



SM5250 $55.62 SMA SWEPT 27GHZ | SM4979 $37.08 SMA 27 GHZ | SM4923 $93.00 SMA FLANGE 27 GHZ | SM3224 $216.30 2.92 BULKHEAD 40 GHZ | SM3321 $135.96 3.5-3.5 34 GHZ | SM3935 $421.27 1.85-1.85 65 GHZ | SM8867 $155.00 SMP-2.4 40 GHZ | SM2927 $132.87 1.85-1.85 65 GHZ

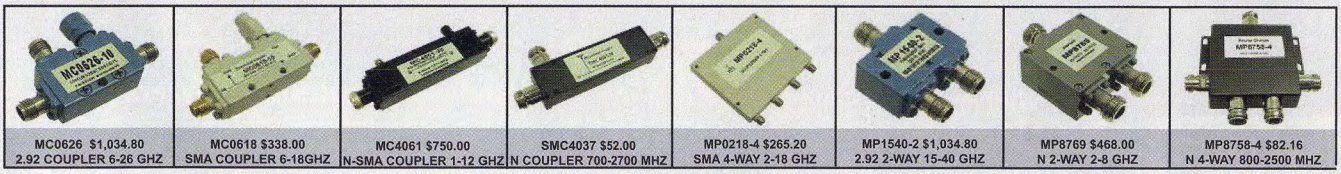
SM3358 $216.30 7mm-3.5 18 GHZ | SM3397 $49.50 7/16 90° 6 GHZ | SM4531 $165.00 N 90° 18 GHZ | SM3547 $37.08 TNC-BNC 8 GHZ | SM5514 $139.05 ZMA-SMA 18 GHZ | SMW75ACN $295.00 WR75-N 10-15 GHZ | 28AC206 $345.00 WR28-2.92 26-40 GHZ | SM4835 $165.00 SSMA-2.92 40 GHZ

ATTENUATORS



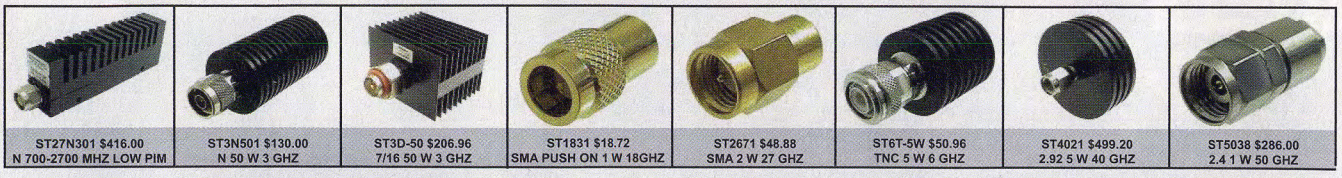
SA18N5WA $59.28 N 5 W 18 GHZ | SA18N25WA $228.80 N 25 W 18 GHZ | SA18N507 $338.00 N 50 W 18GHZ | SA3015 $13.35 SMA 2 W 3 GHZ | SA18S50W $332.80 SMA 50 W 18 GHZ | SA3N511 $160.00 N 50 W 3 GHZ | SA4020 $728.00 2.92 10 W 40 GHZ | SA5074 $270.40 2.4 1 W 50 GHZ

COUPLERS, POWER DIVIDERS



MC0626 $1,034.80 2.92 COUPLER 6-26 GHZ | MC0618 $338.00 SMA COUPLER 6-18GHZ | MC4061 $750.00 N-SMA COUPLER 1-12 GHZ | SMC4037 $52.00 N COUPLER 700-2700 MHZ | MP0218-4 $265.20 SMA 4-WAY 2-18 GHZ | MP1540-2 $1,034.80 2.92 2-WAY 15-40 GHZ | MP8769 $468.00 N 2-WAY 2-8 GHZ | MP8758-4 $82.16 N 4-WAY 800-2500 MHZ

TERMINATIONS



ST27N301 $416.00 N 700-2700 MHZ LOW PIM | ST3N501 $130.00 N 50 W 3 GHZ | ST3D-50 $206.96 7/16 50 W 3 GHZ | ST1831 $18.72 SMA PUSH ON 1 W 18GHZ | ST2671 $48.88 SMA 2 W 27 GHZ | ST6T-5W $50.96 TNC 5 W 6 GHZ | ST4021 $499.20 2.92 5 W 40 GHZ | ST5038 $286.00 2.4 1 W 50 GHZ

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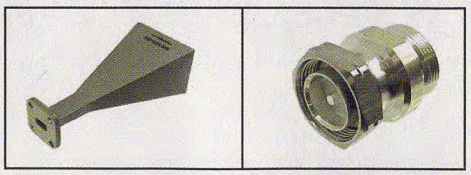



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FEELING OUT FILTER OPTIONS

I was reading your article "Searching through Software for a Filter" (March 2012). You've covered lots of useful software I didn't even know about that captures both synthesis and realization of different filters. However, there are also pure synthesizers out there that are equally important, especially for coupled filters (pretty much all narrowband bandpass/bandstop filters). There's the CMS tool from Guided Wave Technology (www.guided-wavetech.com) and a similar tool from CoupleFil (www.couplefil.com), both about $1000 for a license. I've also just started developing a synthesizer for iPhone/iPad called Couplings Designer, which is a $30 download from the Apple iPhone AppStore (www.applied.com/iphone) or free for the lite version.

These synthesizers are not capable of realizing a filter in terms of physical dimensions, but the couplings can be easily found from tools like Momentum from Agilent Technologies and HFSS from Ansoft (www.ansys.com), Microwave Wizard from Mician (www.mician.com) is another great tool you didn't write about that can be used to fully design filters and uses mode-matching, which is incredible fast compared to method-of-moments (MoM) or finite-element-method (FEM) approaches (but quite expensive).

I hope these tips can be useful in future articles on filter design. Many think it's some kind of black art. But as you pointed out, there are lots of tools available—many even for free—to the engineer that can be helpful to understand and demystify filter design.

GÖRAN GRANSTRÖM

SOFTWARE SUPPLEMENTS

I was enjoying my May issue and the article "Matching Software to Design Needs." I noticed you hadn't mentioned the program BAMP that was an early S-Parameter CAD tool in the '70s, that ran on HP Basic controllers/desktop calculators from Hewlett-Packard Co. (www.hp.com). Also, there is a GPL-license freeware simulation tool called QUCs (Quite Universal Circuit Simulator; http://qucs.sourceforge.net). It doesn't have all the tools and bells and whistles that are available in the commercial programs, but it's not bad!

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Microwaves & RF welcomes mail from its readers. The magazine reserves the right to edit letters appearing in "Feedback." Address letters to:

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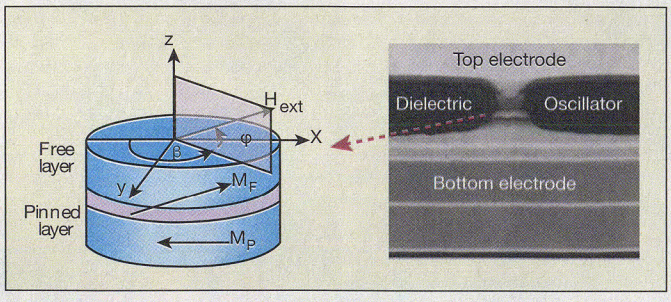
Is An Oscillator Upgrade On The Horizon?

CELL PHONES, WIFI-ENABLED TABLETS, and other electronic devices all incorporate oscillators, which are traditionally silicon-based structures that generate signals by means of an electron-charge mechanism. Recently, however, a team of researchers from the University of California, Los Angeles (UCLA)—Zhongming Zeng, Pedram Khalili Amiri, Ilya N. Krivorotov, Hui Zhao, Giovanni Finocchio, Jian-Ping Wang, Jordan A. Katine, Yiming Huai, Juergen Langer, Kosmas Galatsis, Kang L. Wang, and HongWen Jiang—have developed a new type of oscillator that utilizes the spin of an electron. This development could potentially pave the way for cheaper, more energy-efficient mobile communication devices that deliver much better signal quality.



Pictured is a schematic representation of an STNO showing free and pinned magnetic layers (left), along with a cross-section showing top and bottom metallic electrodes (right).

The new oscillators grew out of research at the UCLA Henry Samueli School of Engineering and Applied Science, which had been sponsored by the Defense Advanced Research Projects Agency (DARPA). The researchers' focus was originally on spin-transfer torque magnetoresistive random access memory (STT-RAM), which has demonstrated several advantages over other types of computer memory. But in the process, they realized that STT-RAM's layered nanoscale structures could also be developed for microwave oscillators, and utilized in communications applications.

These structures, known as spin-transfer nano-oscillators (STNOs), are composed of two distinct magnetic layers: One has a fixed magnetic polar direction, while the other can be made to gyrate in response to an electric current **(see figure)**. This allows the structure to pro-

duce very precise and stable microwave oscillations. The SNTO was tested to show output power of close to 1 μW, with a record narrow signal linewidth of 25 MHz.

In addition, the new nanoscale system is about 10,000 times smaller than current silicon-based oscillators. The nano-oscillators can easily be incorporated into existing integrated circuits (ICs), as they are compatible with current IC fabrication techniques. Best of all, the oscillators can be used in both analog and digital communications, which means smartphones can take full advantage of them.

To learn more about these new oscillators, the researchers' findings can be reviewed in their article "High-Power Coherent Microwave Emission from Magnetic Tunnel Junction Nano-oscillators with Perpendicular Anisotropy." This report has been published online in the journal *ACSNano* (http://pubs.acs.org).

Extra Defense For Mobile Devices

CONDUCTING BUSINESS over commercial cell phone networks has become an increasing risky proposition, particularly when your job necessitates the sharing of sensitive information. To address this threat, General Dynamics C4 Systems (www.generaldynamics.com) is integrating its defense-grade cyber and information security technologies into Samsung's (www.samsung.com) line of smartphones and tablets.

Known as the Samsung Approved for Enterprise (SAFE) line, these devices are being targeted to customers ranging from government and law enforcement agencies to financial and utility personnel—essentially, any entity whose employees need to browse the public Internet as well as access secure networks. The secure technologies being integrating into the Samsung products are similar to those utilized for the US Department of Defense, Department of Homeland Security, federal agencies, and coalition partners to secure classified information.

In total, 20 different SAFE devices are being made available across all major US carriers, addressing different price points and form factors. In addition, all will be upgraded with Samsung's new Secure Android platform. Expected to be made available by mid-2013, the devices will be sold directly by General Dynamics, as well as through government contract vehicles [including the General Services Administration (GSA; www.gsa.gov)].

Defense Heavyweight Makes Microwaves Play



ATTEMPTING TO ESTABLISH a strong foothold in the RF/microwave industry, Chelmsford, MA-based Mercury Computer Systems (www.mc.com) has signed an agreement to acquire Micronetics (www.micronetics.com). A provider of intelligence, surveillance, and reconnaissance (ISR) and electronic-warfare (EW) subsystems for defense prime contractors, Mercury will acquire Micronetics via merger for $14.80 per share. This represents a fully diluted equity value of approximately $71.7 million and an enterprise value of approximately $75.4 million (including $3.7 million of net debt).

Based in Hudson, NH, Micronetics designs and manufactures RF/microwave subsystems and components used in defense and commercial applications. These include EW, radar, electronic countermeasures (ECM), satellite communications (satcom), and commercial wireless products. Approximately 78% of the company's revenues are defense-related.

For its fiscal year ended March 31, Micronetics reported revenues of $46 million with net income of $3.4 million. The firm has more than 200 US-based employees with additional manufacturing sites in West Caldwell, NJ; Ewing, NJ; and Manteca, CA.

The acquisition is subject to customary closing conditions and the approval of Micronetics' shareholders. The boards of directors of both companies have unanimously approved the transaction. At present, the deal is expected to close within the first quarter of Mercury's 2013 fiscal year.

MarketQuote



By 2017, the annual volumes of smart payment and banking cards shipped are forecast to reach 3.5 billion—a dramatic increase from the 1.1 billion shipped in 2011.

Source: IMS Research (www.imsresearch.com)

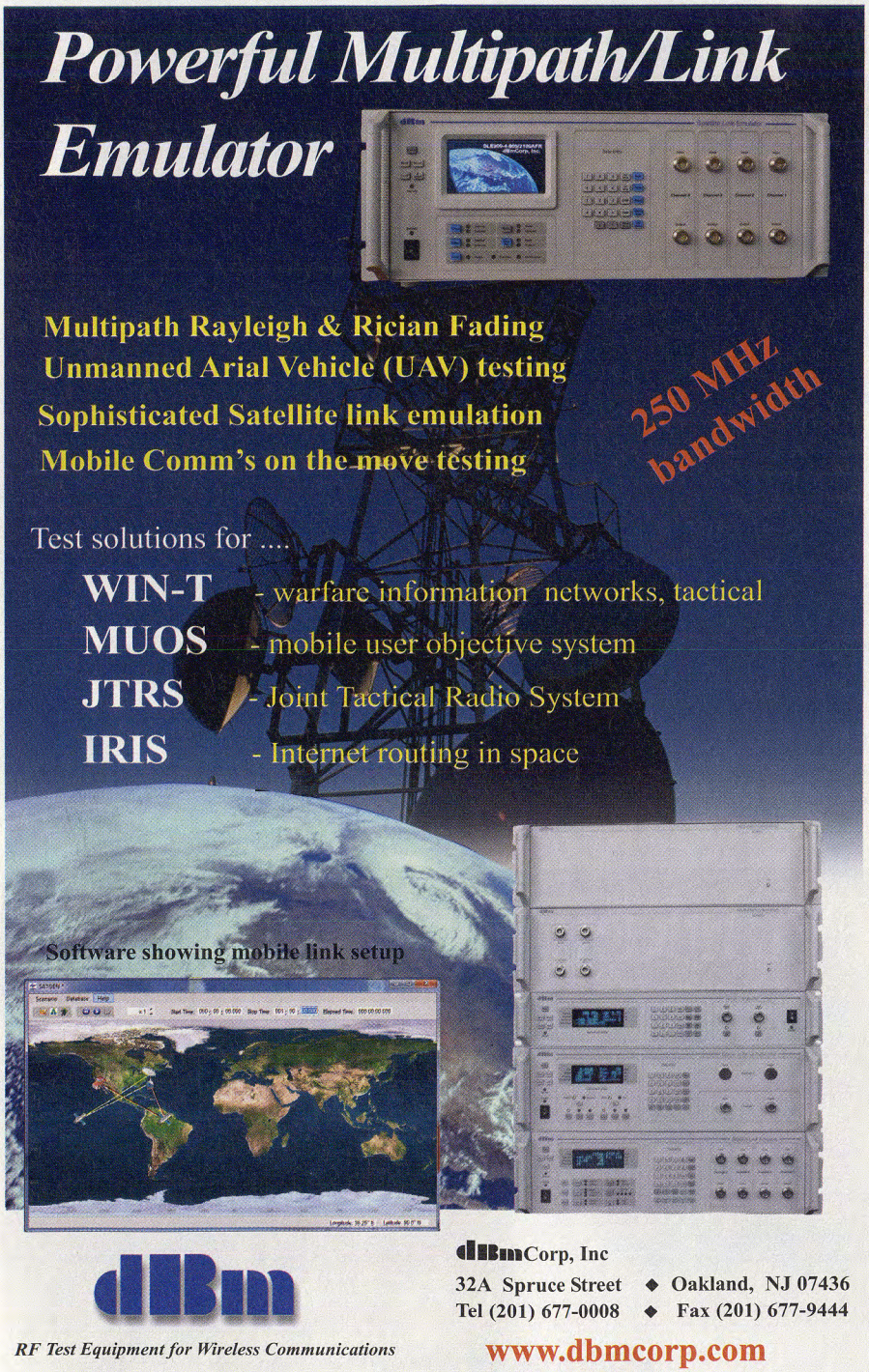
IMS 2012 Posts Strong Attendance Figures

Leading up to this year's International Microwave Symposium (IMS), some had questioned whether holding the traditionally US-based show in Montreal, Canada would hurt its attendance. As it turned out, however, the show received very good attendance. According to event organizers, IMS 2012—held June 17 to 22 at Montreal's Palais des Congrès—was visited by more than 7600 RF/microwave designers, researchers, developers, academics, executives, and exhibitor staff. The symposium also boasted strong international involvement, featuring representation from some 57 countries.

Leading the pack in attendees was the US (46%). Host country Canada occupied the runner-up spot with 17%. Of particular note was China, which posted a 200% increase in attendees over the previous year. More attendees also came from multiple European countries including Germany, France, the United Kingdom, and The Netherlands.

In total, IMS 2012 welcomed 569 exhibitors from 21 countries. Impressively, a record 1225 paper submissions were received from 49 different countries Of the 4118 symposium registrants, 2653 registered for the technical program with 1465 registering for the exhibits alone.

Next year, IMS will be making a return to the United States. The event is scheduled for June 2 to 7, 2013 at the Washington State Convention Center in Seattle, WA. For more information, visit www.ims2013.org.



STANDARDS WATCH

Wi-Fi Users Get Ready To Roam

WITH WI-FI CAPABILITY built into devices ranging from smartphones to laptops, many consumers rely on hotspots for mobile connectivity. Unfortunately, a good Wi-Fi user experience has usually been a fixed one, where the user remains in one place so as not to lose his or her connection and/or provider. Now, the Passpoint certification program is looking to foster multi-provider Wi-Fi roaming. As a result, Wi-Fi networks will soon offer a cellular-like connectivity experience.

Based on the Wi-Fi Alliance Hotspot 2.0 specification, Passpoint promises to provide a consistent, streamlined, Wi-Fi-hotspot connection process. Just as im-

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IF/RF MICROWAVE COMPONENTS

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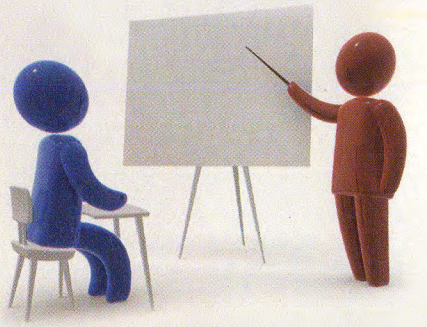
portantly, it supports the use of one set of account credentials for multiple hotspots. Service providers will benefit from Passpoint's underlying technology, which allows them to ease data offload while enabling roaming agreements. Passpoint network equipment will provide users with the assurance of enterprise-grade Wi-Fi Protected Access (WPA2) security for hotspots.

These efforts are just getting underway with the Wi-Fi Alliance's Wi-Fi CERTIFIED Passpoint test-bed program. That program will use comprehensive testing to ensure that wireless-local-area-networking (WLAN) products from multiple manufacturers work together. All Passpoint-certified devices implement a single solution for many operator networks. Among the initial participants in this program are Marvell (www.marvell.com) and Qualcomm Atheros (www.qca.qualcomm.com). The list of Wi-Fi CERTIFIED Passpoint products and more is available at www.wi-fi.org/passpoint.





STEM Teachers Go To Summer School

BUILDING YOUTH INTEREST in science, technology, engineering, and math (STEM) has garnered much attention in recent years. Lockheed Martin (www.lockheedmartin.com), however, has long recognized the importance of this directive. This summer, the company is hosting 20 middle- and high-school teachers in support of the Industry Initiatives for Science and Math Education (IISME; www.iisme.com). In all, the company has sponsored 354 such fellowships since 1985.

The IISME's primary initiative, the Summer Fellowship Program, places qualified teachers into local companies and research labs for an eight-week learning experience. During this period, each teacher—paired with industry mentors—augments his or her science and math skills by solving real-world problems. The challenges posed to Lockheed Martin's fellows and the teachers pertain to space systems under development by the company including satellite communications and missiles. The expectation is that participants will transfer their newfound knowledge and enthusiasm to their students upon returning to the classroom in the fall.

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PEOPLE

ANADIGICS—TIM LAVERICK has joined the company as Vice President, Infrastructure Products. Most recently, he served as Vice President of Engineering and Product Development at Jacket Micro Devices. Laverick has held previous positions at Anadigics both as General Manager of the company's fiber-optic product segment and Vice President of Design Technology. In addition, ROBERT BAYRUNS has been appointed Vice President and Chief Technology Officer.


LAVERICK


BAYRUNS

LEMKO CORP.—ROBERT CONDON has been named President of Lemko Europe. Condon, the Founder of Atlantic Telecom, also served as President and Chief Operating Officer of Comcast BroadNet.

MICREL—THOMAS S. WONG, Vice President of the company's High Bandwidth Division, has announced his retirement. Wong joined Micrel in 1998, following the company's acquisition of Synergy Semiconductor Corp. RAMI KANAMA, Vice President of Clock and Timing Products, will take over responsibility for the High Bandwidth Division.

WEST WIRELESS HEALTH INSTITUTE—RODGER CURRIE has been appointed Senior Vice President of Government Affairs—a newly created appointment. Previously, Currie served as Senior Vice President for DEKA Research & Development.


CURRIE

INMARSAT GOVERNMENT—DAVID HELFGOTT has been named President and Chief Executive Officer. Helfgott joined Inmarsat in 2011 as both President of Inmarsat, Inc. and Senior Vice President of Business Development and Strategy for parent company Inmarsat plc.

LOCKHEED MARTIN—The board of directors has appointed President and Chief Operating Officer CHRISTOPHER E. KUBASIK to the newly established position of Vice Chairman. Kubasik will succeed ROBERT J. STEVENS as Chief Executive Officer on Jan. 1, 2013.

GLOBAL SEMICONDUCTOR ALLIANCE (GSA)—The industry group has named DR. ABHIJIT GUPTA Analog/Mixed-Signal/Radio Frequency (AMS/RF) Working Group Chairman. Gupta is the Director of Foundry Technology for SanDisk.

ETISALAT GROUP—KHALIFA AL SHAMSI has been named Chief Digital Services Officer. Al Shamsi most recently served as the company's Senior Vice President of Technology Strategy.


AL SHAMSI

INDIUM CORP.—ROBERT PLOESSL, Ph.D., has been named Product Manager for indium, gallium, germanium, and tin compounds. Ploessl, who joined Indium Corp. in 2010, is based out of the company's global headquarters located in Clinton, NY.


PLOESSL

ANALOG DEVICES (ADI)—Has appointed SOMSHUBHRO (SOM) PAL CHOUDHURY as Managing Director for Operations in India. Pal Choudhury joins ADI from NETGEAR, where he served as Product Line Director.

New Corporate Structure Shields IP

In addition to delivering products to customers more quickly, Qualcomm, Inc. (www.qualcomm.com) wishes to insulate its patent portfolio from any claims resulting from actions and activities by portions of the company other than the Qualcomm Technology Licensing Division (QTL). As a result, a new corporate structure will feature the parent company, Qualcomm, Inc., which includes QTL and corporate functions as well as most of Qualcomm's patent portfolio. A new, wholly owned subsidiary, Qualcomm Technologies, Inc. (QTI), will—along with its subsidiaries—operate substantially all of Qualcomm's research and development activities. It also will be in charge of the product and services businesses including the semiconductor business, QCT.

The new corporate structure essentially formalizes the way that the company has been operating its primary businesses. Yet Qualcomm does expect QTI and its subsidiaries' product and service businesses to increase their volume of work with open-source software in the future. The restructuring will help to ensure that the activities of QTI and its subsidiaries will not result in the licensing of any patents belonging to Qualcomm, Inc.—including its third- and fourth-generation (3G and 4G) patents.

The new structure will help ensure the activities of QTI and its subsidiaries will not result in the licensing of any patents belonging to Qualcomm, Inc.

Under the new structure, QTI and its subsidiaries will own patents that were specifically developed to provide their open-source software contributions. Substantially all of the remainder of the company's patent portfolio will continue to be owned by Qualcomm, Inc. QTI and its subsidiaries will have no rights to grant licenses or other rights to patents held by Qualcomm, Inc. There will be no changes to the IP that is currently owned by Qualcomm Innovation Center, Inc., which works closely with the open-source community to accelerate the advancement of the wireless industry. Qualcomm anticipates that the new corporate structure will become effective during the first fiscal quarter of 2013.

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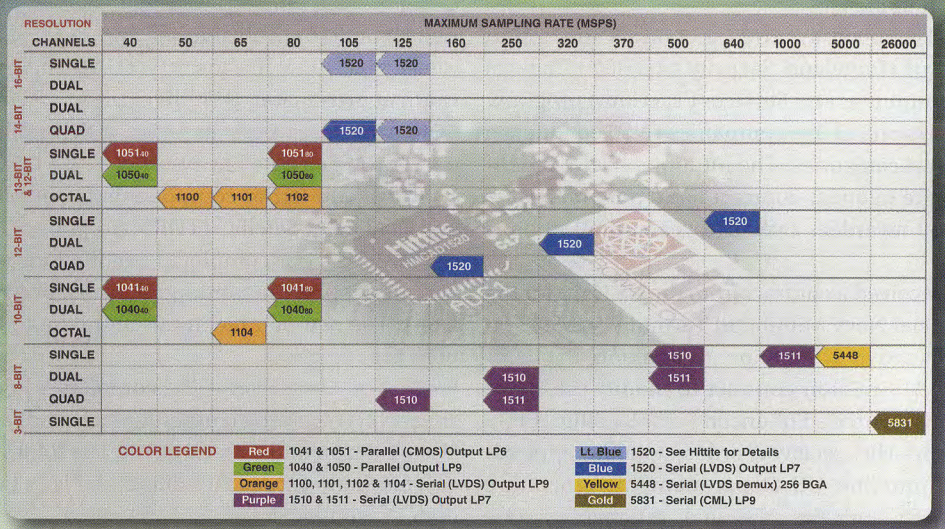

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	HMCAD1511	8-Bit	1 GSPS	1, 2, 4	710 mW	49.8	49 / 64 [1]	EKIT01-HMCAD1511
	HMCAD1510	8-Bit	500 MSPS	1, 2, 4	295 mW	49.8	49 / 65 [1]	EKIT01-HMCAD1510
NEW!	HMCAD1104	10-Bit	65 MSPS	8	30 mW / Channel	61.6	81	EKIT01-HMCAD1104
	HMCAD1102	13 / 12-Bit	80 MSPS	8	59 mW / Channel	70.1	77	EKIT01-HMCAD1102
	HMCAD1101	13 / 12-Bit	65 MSPS	8	51 mW / Channel	72.2	82	EKIT01-HMCAD1101
	HMCAD1100	13 / 12-Bit	50 MSPS	8	41 mW / Channel	72.2	82	EKIT01-HMCAD1100
	HMCAD1050-40 / 80	13 / 12-Bit	40 / 80 MSPS	2	55 / 102 mW	72.7 / 72	81 / 77	EKIT01-HMCAD1050
	HMCAD1051-40 / 80	13 / 12-Bit	40 / 80 MSPS	1	33 / 60 mW	72.7 / 72	81 / 77	EKIT01-HMCAD1051
	HMCAD1040-40 / 80	10-Bit	40 / 80 MSPS	2	43 / 78 mW	61.6	81 / 75	EKIT01-HMCAD1040
	HMCAD1041-40 / 80	10-Bit	40 / 80 MSPS	1	25 / 46 mW	61.6	81 / 75	EKIT01-HMCAD1041

[1] *Excluding Interleaving Spurs.*

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CONTRACTS

Lockheed Martin—Has been awarded a $68-million contract by the US Air Force in support of the first and second GPS III satellites. Lockheed Martin will provide mission readiness, launch, early orbit checkout, and on-orbit operations engineering support. In addition, the company has been awarded a Phase I Airborne Launch Assist Space Access (ALASA) program study contract by the Defense Advanced Research Projects Agency (DARPA). The contract is valued at approximately $6.2 million.

General Dynamics—Has been awarded a contract to support the US Department of Homeland Security's (DHS's) Tactical Communications Equipment and Services (TacCom) program. General Dynamics was one of five companies selected for each of six defined technical categories. The multiple-award, indefinite delivery, indefinite quantity contract has a potential value of $3 billion to all 30 awardees over five years, if all options are exercised.

Raytheon Co.—Has received a contract from the US Navy for the delivery of 47 additional Navy Multiband Terminal (NMT) systems. The order is valued at $79 million. In addition, the company has received a $19-million contract to modify the NMT, linking it with the US Air Force's Enhanced Polar Satellite (EPS).

RELM Wireless Corp.—Has received orders totaling approximately $2 million from the US Department of Agriculture Forest Service (USFS) and the National Interagency Fire Center (NIFC). The orders are for RELM's D-Series digital P-25 portable and mobile radios, in addition to accessories.

GENERAL DYNAMICS Tapped For DHS TacCom Contract

RAYTHEON Receives Dual NMT Orders

Nordic Semiconductor—The company's wireless technology is being used by Qingdao Haier Intelligent Electronics Co. in its QWERTY-keypad-equipped RF/infrared (IR) remote control. The remote is designed for use by consumer-electronics (CE) manufacturers of emerging "connected" products, such as smart TVs.

Ceragon Networks—Has signed a contract to supply high-capacity microwave solutions and turnkey services to the Navajo Tribal Utility Authority (NTUA). The combined orders are worth approximately $4 million.

COM DEV—Has been awarded a $12-million follow-on contract by Boeing Satellite Systems. COM DEV will supply filters, switches, and ferrite components for use in NASA's Tracking and Data Relay Satellite (TDRS) program.

Giga-tronics—Has completed negotiations with an undisclosed aircraft supplier to continue delivery of its high-performance filters. The new contract totals more than $4.9 million if all options are exercised.

Frequency Electronics—The company's FEI-Elcom Tech subsidiary has received an order for its broadband 18-GHz synthesizers from an undisclosed client. The total value of the contract is expected to exceed $4 million and is to be completed in less than 12 months.

FRESH STARTS

Qualcomm—Is establishing an integrated-circuit (IC) design and engineering R&D center in Singapore. The new facility will focus on chip-set design and development including analog and power, mixed-signal, and digital design.

Underwriters Laboratories (UL)—Has been accredited as a Bluetooth 4.0 testing laboratory by the United Kingdom Accreditation Service (UKAS). UL is now able to test and certify products equipped with the latest Bluetooth standard in the UK.

National Instruments (NI)—Is collaborating with the Technical University of Dresden (Dresden, Germany) on new technologies for fifth-generation (5G) wireless systems. NI's LabVIEW system design software is being utilized in the effort.

xG —Has been granted six new patents related to its cognitive-radio (CR) work. The technologies covered by the new patents include spectrum sharing, media-access control (MAC), mobile voice-over-Internet-protocol (VoIP) signaling, and interference detection/mitigation.

IF Engineering (IFE)—Has signed a distribution agreement with East Coast Microwave Distributors (ECM). Per the arrangement, ECM will stock and distribute IFE's line of power dividers, couplers, transformers, and switches.

LadyBug Technologies—Has named Bangalore-based VigVen Tech Mark Pvt. as its authorized distributor in India. VigVen will carry LadyBug's entire range of Universal-Serial-Bus (USB) power sensors.

Federal Communications Commission (FCC)—Has proposed expanding eligibility in the 4.9-GHz band to include utilities and other critical-infrastructure industries (CII) on a primary basis. This band would provide utilities with access to 50 MHz of spectrum, supporting high-capacity and short-range communications for a variety of applications.

RFMW—Has announced a distribution agreement with Aeroflex/Metelics covering Europe, the Middle East and Africa (EMEA), and the Americas. Per the agreement, RFMW will distribute Aeroflex/Metelics' full product portfolio. In addition, RFMW has announced immediate delivery of selected cable assemblies from Florida RF Labs.

Modelithics—Has signed a comprehensive representative and reseller agreement with Medeos SRL. Medeos will sell all Modelithics products and services throughout Italy.

Indium Corp.—Has acquired a new manufacturing facility in Rome, NY. The plant is currently being outfitted to expand production capacities of various compounds including indium-, gallium-, germanium-, and tin-based materials.

Mindspring Technologies—Is forming a joint development lab with China Mobile Communications Corp. The collaboration will support China Mobile's recent deployment of Time-Division Synchronous Code Division Multiple Access (TD-SCDMA) femtocells.

Silicon Labs—Has signed a definitive agreement to acquire Ember Corp. Based out of Boston, MA, Ember is a provider of silicon, software, and development tools for 2.4-GHz wireless-mesh-networking solutions.

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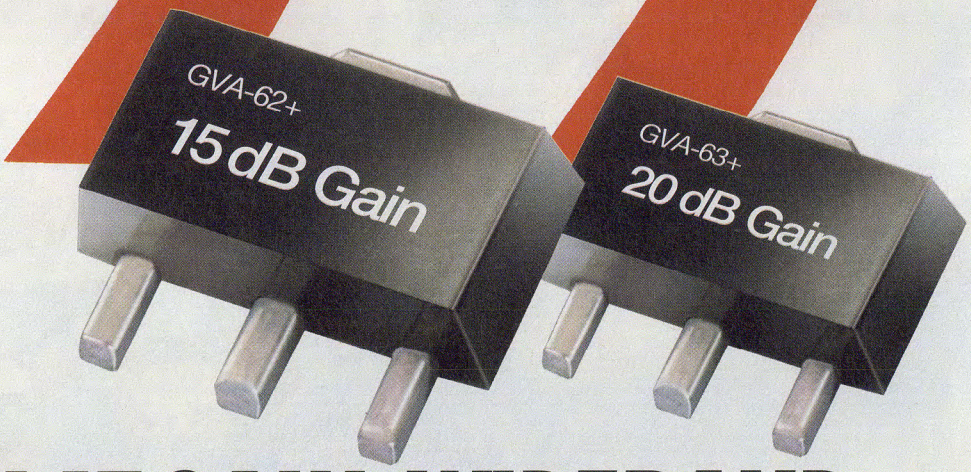

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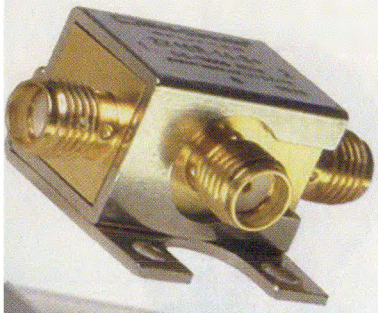

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Inside Track with Julio Perdomo,

CEO, CENTELLAX

Interview by NANCY FRIEDRICH



NF: Although this is an evolving market, many firms have made their living by offering the same types of products for decades. Recently, however, Centellax made a bold change by selling its test and measurement business to Agilent Technologies. What inspired this move?

JP: Centellax's initial mission was to develop high-speed components for optical communications. Our test business grew from the need to test our own products and the opportunity for others to benefit from our test development. Both businesses have grown substantially. And both demanded dedicated focus from management as well as investment to capitalize on opportunities. Considering the choices of where to focus as a company and the challenges ahead, we decided to continue with our original mission and divest our test business.

NF: As part of Centellax, did you feel that the test and measurement business was limited in its growth potential?

JP: No. We are very proud of the products that we developed. And the acquisition by Agilent is a validation of the innovation and value that we created. There is great potential for these products in the growing markets that they serve. I am sure that Agilent, with its extensive sales channel and worldwide coverage, will take full advantage of that business potential.

NF: The test and measurement product line was one of the firm's "babies;" I'm sure it was hard to let it go. What gave you the confidence to sell the business to Agilent in particular? Did the company have a relationship with Agilent prior to the transaction that might have encouraged your choice?

JP: Agilent is the number-one test company in the world. Under its leadership, I feel confident that the team and the technology that we developed will thrive. Although many of us are familiar with the excellence of Agilent as a company and as a technology leader, there was no specific prior relationship other than as a customer.

NF: What is the firm's core concentration since selling the test business?

JP: Our focus is to design and manufacture components for optical communications used in telecommunications, data communications, and data-center applications. We also offer a product line for RF

and microwave applications.

NF: With more of a streamlined operation, what do you feel that Centellax can better accomplish?

JP: We are focusing on being more responsive to changing market needs and better supporting our customers. We are expanding our current portfolio to better serve our customers with the technologies and products that they want.

NF: Do you have any advice for other microwave companies looking to make bold moves to reorganize their firms?

JP: I believe the key to success is focusing on core competencies and product roadmaps to better serve your customer base.

NF: Centellax was established in 2001. The last 11 years have been quite a bumpy ride. How has the company weathered the storms?

JP: We have adapted our core technology of integrated circuit (IC)/packaging design to address the changing demand for high-speed, high-performance products. Our test-business success was also based on this core technology.

NF: Do you expect the role of optical technology in future communications rollouts [fourth generation (4G) and beyond] to shrink or remain stable? Why?

JP: Due to the bottleneck in high-speed data transmission, there is a growing demand for greater capacity in optical-communication systems operating at 40 Gb/s, 100 Gb/s, and soon-to-come 400 Gb/s. Centellax has experienced major growth in 40G in the last three years. We see the same trend in 100G for 2013 and beyond. This supports the market-research studies that indicate the large growth of these markets through the next five years.

NF: What are the major technical challenges that your customers are trying to overcome to succeed in those rollouts?

JP: Our customers need to reduce system cost and maintain excellent performance with unquestionable quality and reliability. It is our job to provide them with products that offer lower power dissipation and packaging cost with the performance they need to meet their goals.

NF: Do you see those challenges becoming more complex? Or do you predict that you will be dealing with new issues in the future?

JP: We expect to see higher-level modulation schemes to achieve higher spectrum efficiency. This trend is similar to what we observed in the RF communications markets. The challenges make things more complex because some requirements contradict each other, like higher dynamic range, lower power dissipation, higher linearity, and lower noise. To meet these requirements, new techniques will have to be used at the IC level. That will make the design more complex.



NF: Right now, you are supporting 40G, 100G, and 400G optical communications with your products. Where do you see optical communications going beyond 400G? Will Centellax be prepared to support such an evolution?

JP: The drivers for the evolution of the optical-communications transmission rate are the need for lower cost and higher efficiency in data transfer. To some extent, cost is addressed with lower power dissipation and more integration. The higher-transmission efficiency requirements are addressed by higher degrees of complex modulation. We are engaged in developing the technology and products to address these requirements by integrating more functionality into the products, reducing form factors, and lowering power dissipation. MWRF

60-GHz HELICAL ARRAY Relies On LTCC

SEVERAL GIGAHERTZ of bandwidth are now available in the 60-GHz band for short-range communications applications. For antennas, this trend has reinforced the move from discrete designs to integrated on-chip or in-package solutions. For designs that are closer to bringing low-cost, highly integrated 60-GHz solutions to fruition, multilayer, low-temperature co-fired ceramic (LTCC) technology has been used successfully. At the National University of Singapore, for example, a 60-GHz wideband, circularly polarized helical antenna array of 4x4 elements has been designed and fabricated using LTCC technology. This antenna is the work of Changrong Liu, Yong-Xin Guo, Xiaoyue Bao, and Shao-Qiu Xiao.

LTCC has been heralded for its light weight, compactness, and high performance. In this design, the flexible via-hole distribution is leveraged to realize a helical antenna array with good circular polarization performance. For probe-station measurements, grounded coplanar waveguide (GCPW) to stripline is used. The fabricated antenna array, which measures 12 x 10 x 2 mm, shows a measured impedance bandwidth of 52.5 to 65.5 GHz for $|S_{11}|$ below –10 dB. See "60-GHz LTCC Integrated Circularly Polarized Helical Antenna Array," *IEEE Transactions On Antennas And Propagation*, March 2012, p. 1329.

WAVEGUIDE-BASED MIXER Excels In Terahertz Range

TO ROUGHLY 1.25 THz, the most sensitive and high-resolution heterodyne spectrometers are based on superconductor-isolate-superconductor (SIS) tunnel junction mixers. Beyond 1.25 THz, however, superconducting hot-electron-bolometer (HEB) mixers are considered a better option. Most HEB mixers operating above 2 THz couple the mixer element to a planar antenna on a dielectric substrate lens. Yet waveguide feeds boast better coupling efficiency to free space while naturally reducing the direct detection response of HEBs. It also is generally easier to implement compact, high-pixel-count, focal-plane arrays using waveguide technology. At NASA's Jet Propulsion Laboratory, a combination of conventional metal machining and metallic micro-plating techniques has been used to construct a low-noise superconducting mixer operating near 2.7 THz.

The JPL team—Faouzi M. Boussaha, Jonathan H. Kawamura, Jeffery A. Stern, Anders Skalare, and Victor White—adopted an approach that combined ultraviolet (UV) lithography with micro-plating techniques to make the waveguide embedding circuit. The resulting low-noise, waveguide-based heterodyne mixer uses a superconducting NbN hot-electron bolometer (HEB) operating near 2.7 THz. The NbN nano-bridge is integrated with a gold-bowtie planar antenna on a silicon substrate that is merely ~2 to 3 μm thick.

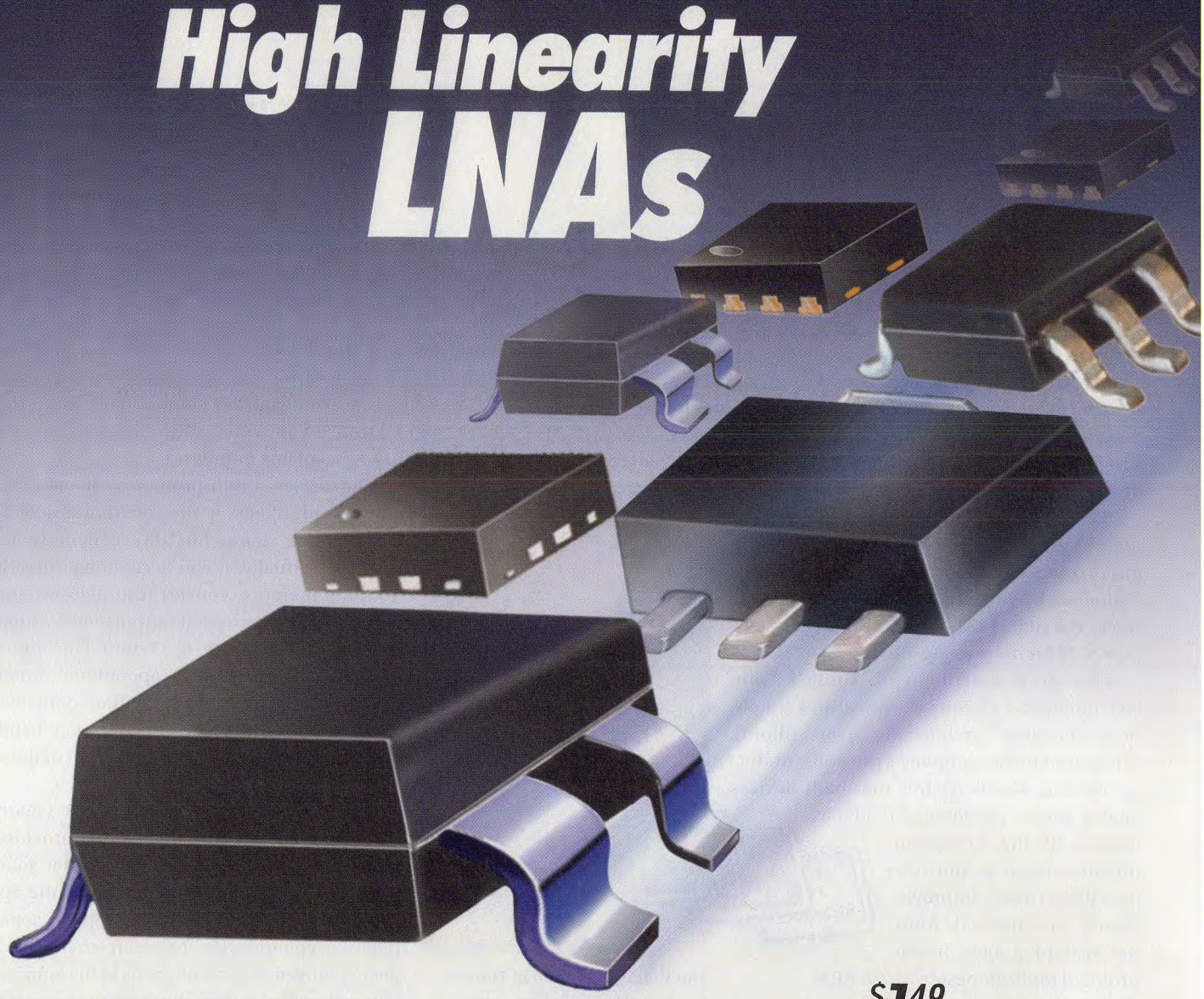
The mixer chip is placed in a channel across the input waveguide. These chips are produced using high-purity, silicon-on-insulator (SOI) substrate. The mixer chips are suspended at a distance corresponding to the substrate thickness plus an air-cavity depth from the waveguide backshort. With this configuration, the effective dielectric constant of the silicon substrate is reduced from 11.9 to ~2.8. See "A Low Noise 2.7 THz Waveguide-Based Superconducting Mixer," *IEEE Transactions On Terahertz Science And Technology*, May 2012, p. 284.

QUADRATURE LO Spans 5 To 10 GHz

TO MORE efficiently use spatial and temporal spectrum from 50 MHz to 10 GHz, many are eying cognitive radio (CR). On a system-on-a-chip (SoC), however, a heterodyne approach requires multiple local oscillators (LOs) to handle the potentially independent operations of the CR RF transceiver. Such an implementation can be very tricky, as the design of LO for CR applications demands silicon-area compactness and low power consumption. Recently, a low-quadrature LO was designed and implemented by the University of California's Ning-Yi Wang, Mau-Chung Frank Chang, and Jianhua Lu (who is also with Peregrine Semiconductor Corp.). Their LO can create 13.3-to-20.0-GHz signals from a differentially tuned, inductive-capacitive voltage-controlled oscillator (LC-VCO). It converts those signals to the 5-to-10-GHz band with continuous frequency coverage.

In this design, a frequency-extension solution takes advantage of the natural characteristics of a four-stage, differential, injection-locked ring oscillator (ILRO) to obtain the desired quadrature outputs with a precise 50% duty cycle. Impressively, both the output 50% duty cycle and quadrature matching can be maintained even with the input signal's duty cycle deviating from 50%. The team implemented the integrated, quadrature-phased LO in 65-nm general-purpose CMOS integrated-circuit (IC) technology. It occupies less than 0.11 mm^2 and consumes a maximum of 22 mA current from a 1-V supply. The LO exhibits worst-case phase noise of –104 dBc/Hz at 1 MHz offset across the entire 5-to-10-GHz band. See "A Compact and Low Power 5-10 GHz Quadrature Local Oscillator for Cognitive Radio Applications," *IEEE Journal Of Solid-State Circuits*, May 2012, p. 1131.

High Linearity LNAs



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PMA2-162LN+	700-1600	22.7	0.5	30	20	55	2.87
PMA-5452+	50-6000	14.0	0.7	34	18	40	1.49
PSA4-5043+	50-4000	18.4	0.75	34	19	33 (3V) 58 (5V)	2.50
PMA-5455+	50-6000	14.0	0.8	33	19	40	1.49
PMA-5451+	50-6000	13.7	0.8	31	17	30	1.49
PMA2-252LN+	1500-2500	15-19	0.8	30	18	25-55 (3V) 37-80 (4V)	2.87
PMA-545G3+	700-1000	31.3	0.9	33	22	158	4.95
PMA-5454+	50-6000	13.5	0.9	28	15	20	1.49

Model	Freq. (MHz)	Gain (dB)	NF (dB)	IP3 (dBm)	P_{out} (dBm)	Current (mA)	Price $ (qty. 20)
PGA-103+	50-4000	11.0	0.9	43	22	60 (3V) 97 (5V)	1.99
PMA-5453+	50-6000	14.3	0.7	37	20	60	1.49
PSA-5453+	50-4000	14.7	1.0	37	19	60	1.49
PMA-5456+	50-6000	14.4	0.8	36	22	60	1.49
PMA-545+	50-6000	14.2	0.8	36	20	80	1.49
PSA-545+	50-4000	14.9	1.0	36	20	80	1.49
PMA-545G1+	400-2200	31.3	1.0	34	22	158	4.95
PMA-545G2+	1100-1600	30.4	1.0	34	22	158	4.95
PSA-5455+	50-4000	14.4	1.0	32	19	40	1.49



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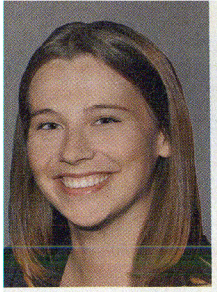

Microwaves in Europe

SALLY WARD-FOXTON, *Associate Editor*
Electronic Design Europe

Wireless SoCs Use Cortex-M0 Core To Slash Power Consumption

FOR MORE THAN A DECADE, designers of wireless products have been struggling to deliver ever-increasing performance while consuming less power. Among the latest products promising to satisfy these opposing demands are two wireless system-on-a-chip (SoC) devices from Nordic Semiconductor (www.nordicsemi.com). Conveniently, the first two low-power wireless SoCs in the nRF51 series share the same architecture and multi-protocol radio. While the nRF51822 has a Bluetooth-low-energy/proprietary 2.4-GHz stack, the nRF51422 has an ANT/ANT+ stack (see p. 42 for more on ANT).

This third generation of Nordic's wireless integrated circuits (ICs) features a new, power-efficient architecture **(see photo)**. Compared to the company's previous product generation, Nordic claims that both devices enable power reductions to 50% as well as RF link budget improvements of as much as 9.5 dB. These improvements are derived from the use of a new multi-protocol radio alongside a 32-b ARM Cortex-M0 core.



The third generation of Nordic Semiconductor's wireless ICs promises to deliver increased performance while consuming less power.

"This project was codenamed Princess," says Thomas Embla Bonnerud, Nordic's Director of Product Management. "We had very ambitious goals. We wanted to do Bluetooth low-energy and ANT single-chip SoCs that had the ease-of-use of two-chip solutions."

Perhaps most impressive of the nRF51's qualities is its extremely low power consumption. Nordic made small enhancements to the radio's current budget. But the biggest improvement came from a new power-management scheme. "Power modes 0, 1, 2, 3...We threw that away," Bonnerud explains. "These devices are not constrained by power modes. Simply power-on in software [the blocks] you want and everything else remains asleep."

Alongside the new power-management scheme is a programmable peripheral interface (PPI), which minimizes the central processing unit's (CPU's) active time to save power. Peripherals can therefore operate autonomously and talk to each other without waking the CPU. This approach also reduces real-time requirements on the CPU.

Introducing the ARM Cortex-M0 core to this IC generation improved processing speed by a factor of 10. Startup time has been reduced by a factor of 100 to 2.5 µs, which helps to save power. The company also managed to reduce the devices' supply voltage from 1.9 to 1.75 V in order to "squeeze the last juice out of a coin cell or AA," explains Bonnerud.

The devices' multi-protocol radio also was entirely redesigned. It now incorporates Easy-DMA (which stands for "direct memory access"). Essentially, it can access data directly from the memory, convert it to packets, and transmit it. An increased output-power range now stretches from –20 to +4 dBm. The radio's sensitivity depends on its operational mode: For example, it is –92.5 dBm in Bluetooth low-energy mode. The 9.5-dB improvement in link budget is derived from a combination of these two specifications.

In terms of software, the nRF51 clearly separates its application and Nordic-provided stack code. Comparing this IC to older solutions, which had a single framework, the application and stack are now compiled separately. Dependencies between them have been removed. As a result, bugs in the application code will not affect the stack or vice versa.

According to Suke Jawanda, Chief Marketing Officer for the Bluetooth SIG (www.bluetooth.org), reducing power consumption by 50% could extend the battery life of some consumer devices up to eight years. The battery life would therefore exceed the lifetime of the device—an important milestone. From the SIG's point of view, Jawanda adds, a chip that can do proprietary 2.4-GHz protocols and Bluetooth low-energy would definitely help ease companies' transition to Bluetooth low energy.

Rod Morris, Vice President of ANT Wireless, emphasizes that the launch of the nRF51422—the world's first ANT SoC—is a significant milestone. The IC's 60-kb/s burst rate makes it three times faster than previous generations. ANT requires less than 32 kB of code space and 2 kB of random-access memory (RAM), leaving more than 224 kB of Flash and 14 kB of RAM for the application code. Morris points out that the single-chip solution also will contribute to making ANT-compliant devices smaller. The 32-b M0 core has been implemented in around 12,000 silicon gates. In other words, it fits into the same physical space that was formerly occupied by 8-b devices.

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2-WAY								
CSBK260S	20 - 600	0.28 / 0.4	0.05 / 0.4	0.8 / 3	25 / 20	1.15:1	50	377
DSK-729S	800 - 2200	0.5 / 0.8	0.05 / 0.4	1 / 2	25 / 20	1.3:1	10	215
DSK-H3N	800 - 2400	0.5 / 0.8	0.25 / 0.5	1 / 4	23 / 18	1.5:1	30	220
P2D100800	1000 - 8000	0.6 / 1.1	0.05 / 0.2	1 / 2	28 / 22	1.2:1	5	329
DSK100800	1000 - 8000	0.6 / 1.1	0.05 / 0.2	1 / 2	28 / 22	1.2:1	20	330
DHK-H1N	1700 - 2200	0.3 / 0.4	0.1 / 0.3	1 / 3	20 / 18	1.3:1	100	220
P2D180900L	1800 - 9000	0.4 / 0.8	0.05 / 0.2	1 / 2	27 / 23	1.2:1	5	331
DSK180900	1800 - 9000	0.4 / 0.8	0.05 / 0.2	1 / 2	27 / 23	1.2:1	20	330
3-WAY								
S3D1723	1700 - 2300	0.2 / 0.35	0.3 / 0.6	2 / 3	22 / 16	1.3:1	5	316

◊ In excess of theoretical split loss of 3.0 dB
▫ With matched operating conditions

HYBRIDS

RoHS

Model #	Frequency (MHz)	Insertion Loss (dB) [Typ./Max.] ◊	Amplitude Unbalance (dB) [Typ./Max.]	Phase Unbalance (Deg.) [Typ./Max.]	Isolation (dB) [Typ./Min.]	VSWR (Typ)	Input Power (Watts) [Max.]	Package
90°								
DQS-30-90	30 - 90	0.3 / 0.6	0.8 / 1.2	1 / 3	23 / 18	1.35:1	25	102SLF
DQS-3-11-10	30 - 110	0.5 / 0.8	0.6 / 0.9	1 / 3	30 / 20	1.30:1	10	102SLF
DQS-30-450	30 - 450	1.2 / 1.7	1 / 1.5	4 / 6	23 / 18	1.40:1	5	102SLF
CSDK3100S	30 - 1000	0.8 / 1.2	0.05 / 0.2	0.2 / 3	25 / 18	1.15:1	50	378
DQS-118-174	118 - 174	0.3 / 0.6	0.4 / 1	1 / 3	23 / 18	1.35:1	25	102SLF
DQK80300	800 - 3000	0.2 / 0.4	0.5 / 0.8	2 / 5	20 / 18	1.30:1	40	113LF
MSQ80300	800 - 3000	0.2 / 0.4	0.5 / 0.8	2 / 5	20 / 18	1.30:1	40	325
DQK100800	1000 - 8000	0.8 / 1.6	1 / 1.6	1 / 4	22 / 20	1.20:1	40	326
MSQ100800	1000 - 8000	0.8 / 1.6	1 / 1.6	1 / 4	22 / 20	1.20:1	40	346
MSQ-8012	800 - 1200	0.2 / 0.3	0.2 / 0.4	2 / 3	22 / 18	1.20:1	50	226
180° (4-PORTS)								
DJS-345	30 - 450	0.75 / 1.2	0.3 / 0.8	2.5 / 4	23 / 18	1.25:1	5	301LF-1

◊ In excess of theoretical coupling loss of 3.0 dB

COUPLERS

RoHS

Model #	Frequency (MHz)	Coupling (dB) [Nom]	Coupling Flatness (dB)	Mainline Loss (dB) [Typ./Max.]	Directivity (dB) [Typ./Min.]	Input Power (Watts) [Max.] ▫	Package
KDS-30-30	30 - 512	27.5 ±0.8	±0.75	0.2 / 0.28	23 / 15	50	255 *
KFK-10-1200	10 - 1200	40 ±0.75	±1.0	0.4 / 0.5	22 / 15	150	376
KBS-10-225	225 - 400	10.5 ±1.0	±0.5	0.6 / 0.7	25 / 18	50	255 *
KDS-20-225	225 - 400	20 ±1.0	±0.5	0.2 / 0.4	25 / 18	50	255 *
KBK-10-225N	225 - 400	10.5 ±1.0	±0.5	0.6 / 0.7	25 / 18	50	110N *
KDK-20-225N	225 - 400	20 ±1.0	±0.5	0.2 / 0.4	25 / 18	50	110N *
KEK-704H	850 - 960	30 ±0.75	±0.25	0.08 / 0.2	38 / 30	500	207
SCS100800-10	1000 - 8000	10.5 ±1.5	±2.0	1.2 / 1.8	8 / 5	25	361
KBK100800-10	1000 - 8000	10.5 ±1.5	±2.0	1.2 / 1.8	8 / 5	25	322
SCS100800-16	1000 - 7800	16.8 ±1.5	±2.8	0.7 / 1	14 / 5	25	321
KDK100800-16	1000 - 7800	16.8 ±1.5	±2.8	0.7 / 1	14 / 5	25	322
SCS100800-20	1000 - 7800	20.5 ±2.0	±2.0	0.45 / 0.75	12 / 5	25	321
KDK100800-20	1000 - 7800	20.5 ±2.0	±2.0	0.45 / 0.75	14 / 5	25	322

* Add suffix - LF to the part number for RoHS compliant version.
▫ With matched operating conditions

Unless noted, products are RoHS compliant.

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Medical Applications Seek Wireless Solutions

THE HEALTHCARE INDUSTRY IS HOPING TO ADOPT WIRELESS TECHNOLOGY ON A LARGE SCALE, ALLOWING DOCTORS AND NURSES TO MORE EFFECTIVELY MONITOR THEIR PATIENTS' VITAL SIGNALS EVEN FROM REMOTE LOCATIONS.

MEDICAL AND INDUSTRIAL WIRELESS APPLICATIONS often involve machine-to-machine or machine-to-human communications. Typically using unlicensed frequencies in the industrial-scientific-medical (ISM) bands, these applications are considerably different from what most wireless users consider communications. Yet, these frequencies and the devices that support them are among the fastest growing applications for wireless technology—including for emerging applications in healthcare; in home and factory automation; in smart meters and wireless sensor networks; and in the wireless hospital of the future.

Most industrial and medical wireless applications are short range in nature, such as within a factory or a hospital, and many require low-power operation. *(See p. 44 for more on low-power wireless solutions.)* Other important considerations for these applications include the potential of a wireless system to interfere with other electronic systems, or itself to be subject to interference; how the choice of operating frequency translates into desired propagation characteristics; how long the system must be able to operate on a given power supply, such as a battery; the security of the transmission; and the amount of data or other content that must be transmitted and received.

The healthcare industry received a recent boost with the United States' Federal Communications Commission (FCC; www.fcc.gov) ruling to allocate additional spectrum for medical wireless applications, known as medical body area networks

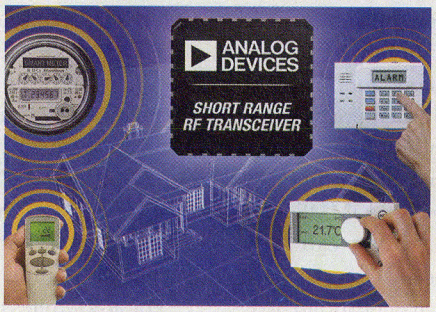
(MBANs). The use of this spectrum (from 2360 to 2400 MHz) for medical applications was supported by two large companies in the electronic healthcare industry: General Electric Healthcare (www.gehealthcare.com) and Phillips Electronics NV (www.phillips.com).

However, it was opposed by an even larger aerospace company, Boeing (www.boeing.com). Since this bandwidth was already occupied by aerospace applications—notably for flight testing—Boeing had initially blocked the use of this bandwidth for medical purposes. The positive ruling for the health-care industry comes after both sides submitted a joint proposal to the FCC on how the bandwidth could be effectively shared. The FCC's rule aligns with its National Broadband Plan, which set the goal of advancing several specific "national purposes" including healthcare.

This ruling provides more available spectrum for the development of MBAN devices, typically health-sign monitors worn by a patient that detect and transmit information about a patient's vital signals to a central monitoring station. The first 30 MHz of the newly available 40-MHz bandwidth is intended for indoor use (such as in hospitals) and will be regulated. The last 10 MHz can be used in any environment, including in the home.

Prior to the availability of this bandwidth, the FCC had established several frequency bands for use by the wireless medical telemetry service (WMTS) for medical telemetry over radio, such as ECG waveforms. These bands include 608 to 614 MHz, 1395 to 1400 MHz, and 1427 to 1432 MHz. WMTS electronic devices are licensed by rule under FCC Part 95 guidelines—that is, individual licenses are not required for each product; they must only comply with the established regulations for frequency occupancy, transmitted power, spurious levels, and other parameters.

As emerging WBAN devices may still have interference problems under certain circumstances with flight-data recorders and other transmitters in their band, WMTS devices have had some history of problems with higher-power digital-television (DTV) transmitters operating within their bands, notably in the lower-frequency channels. Effective WMTS designs require adequate filtering to remove adjacent-channel interference from nearby DTV transmitters. For hospitals considering the use of such devices for wireless medical telemetry applications, organizations such as American Society for Health Care Engineering (ASHE; www.ashe.org) can offer assistance. They perform risk assessments on potential interference to and from other electronic emitters.



1. The ADF7022 transceiver IC is designed for low-power building automation applications from 868 to 869 MHz. It is supplied in a 5 x 5 mm package. [Photo courtesy of Analog Devices (www.analog.com)]

Both GE Healthcare and Phillips are major suppliers of wireless healthcare products, such as the ApexPro® CH hospital telemetry system from GE for use in the WMTS frequency bands. It is designed to provide continuous patient surveillance, operating in both the 608-to-614-MHz and 1395-to-1400-MHz bands for flexibility and scalability. Patient information is available through a variety of viewing devices, allowing hospital staff convenient monitoring of patient vital signs. Phillips offers medical telemetry solutions for both the US and Europe, such as its 2.4-GHz IntelliVue Telemetry System (not for use in the US).

A somewhat smaller medical electronics supplier specializing in wireless electrocardiogram (ECG) monitors, Great Lakes Neurotechnologies (www.glneurotech.com), has developed a lightweight monitor for reading heart, brain, and muscle electrical activity. The firm's BioRadio™ product provides 12 channels: eight for external sensors; three embedded channels for accelerometry, pulse oximetry, and pressure-based airflow; and an embedded DC auxiliary channel. The physiological monitor operates from 2400 to 2484 MHz and provides a line-of-sight (LOS) range of about 100 ft. It measures 5.25 x 2.50 x 1.10 in. and weighs 7.4 oz. with batteries. The operating voltage range can be configured from +750 μV to +2 VDC, while sampling rates can be configured from 128 to 960 Samples/s per channel. It is designed to operate continuously for 10 hrs. on batteries.

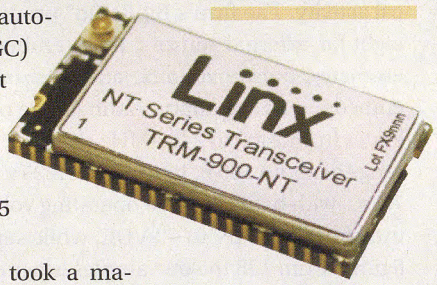
These wireless telemetry products require reliable but low-cost wireless technology, usually in the form of low-power integrated circuits (ICs). A number of IC manufacturers have responded to the needs of medical and industrial wireless electronic product developers with highly integrated transceivers capable of low-power operation in the WMTS, ISM, and other frequency bands.

Analog Devices (www.analog.com) offers a wide range of transceiver ICs for ISM-band applications through 2.4 GHz including its model ADF7021 narrowband transceiver IC for WMTS applications. It operates over frequency ranges of 80 to 650 MHz and 862 to 950 MHz supporting data rates to 32.8 kb/s by means of various modulation schemes, including two-state frequency-shift-keying (2FSK) and minimum-shift-keying (MSK) modulation. The chip can operate on voltages from +2.3 to +3.6 VDC, with only 0.1 μA leakage current in power-down mode.

This is a highly integrated device that requires only a handful of external components to fashion a complete WMTS transceiver. It features an on-chip voltage-controlled oscillator (VCO) and fractional-N frequency synthesizer, automatic frequency control (AFC) loop, and an on-chip temperature sensor with 7-b analog-to-digital converter (ADC) for readback of the sensor, as well as monitoring of battery voltage. The transceiver IC can set transmit levels from –16 to +13 dBm in 63 steps and provides receiver sensitivity of –130 dBm at 100 b/s with 2FSK and –122 dBm at 1 kb/s with 2FSK. It meets FCC Parts 15, 90, and 95 requirements

for use in the US, ARIB STD-T67 requirements for use in Japan, and ETSI EN 300 220 requirements for use in Europe. It can be used across operating temperatures from –40 to +85°C.

The company also offers a device specifically for home and building automation, its ADF7022 transceiver **(Fig. 1)**. Designed to operate at 868 to 869 MHz, it supports one-way and two-way communications at extremely low power levels. It runs on voltages of +1.8 to +3.6 VDC and consumes only 24.1 mA when transmitting at +10 dBm and only 12.8 mA in receive mode with the automatic-gain-control (AGC) circuitry active. Current consumption can be cut down as far as 0.75 µA in sleep mode. The chip is supplied in a 5 x 5 mm package.



2. The Linx NT module is designed to simplify the addition of wireless communications capabilities at ISM frequencies from 902 to 928 MHz. [Photo courtesy of Linx Technologies (www.linxtechnologies.com)]

Analog Devices also took a major step towards unleashing software-defined-radio (SDR) technology on any number of medical and industrial wireless applications. The technology allows radio frequencies and characteristics to change under software control. During the recent 2012 IEEE International Microwave Symposium (IMS) in Montreal, Canada, the company announced its collaboration with Avnet Electronics Marketing Americas (www.em.avnet.com) on the Zynq™-7000 Extensible Processing Platform (EPP), along with its own SDR kit to provide a starting point for radio developers. The kit includes the FMCOMMS1-EBZ field-programmable-gate-array (FPGA) mezzanine card from Analog Devices, facilitating wireless radio design.

Silicon Labs (www.silabs.com) offers a diverse portfolio of devices for wireless portable medical products, such as its Si446x EZRadioPro® transceiver IC family for ISM-band use in medical monitoring, industrial control, and home automation applications. The low-power transceivers offer continuous coverage from 119 to 1050 MHz. The firm also strengthened its position in ISM-band products with the acquisition earlier this year of Ember Corp. (www.ember.com) and their 2.4-GHz wireless mesh networking solutions, including the EM300 series of system-on-chip (SoC) devices. Based on the ZigBee low-power 2.4-GHz protocol, these devices combine a 2.4-GHz IEEE 802.15.4 radio transceiver with a 32-b microprocessor, Flash memory, and random-access memory (RAM).

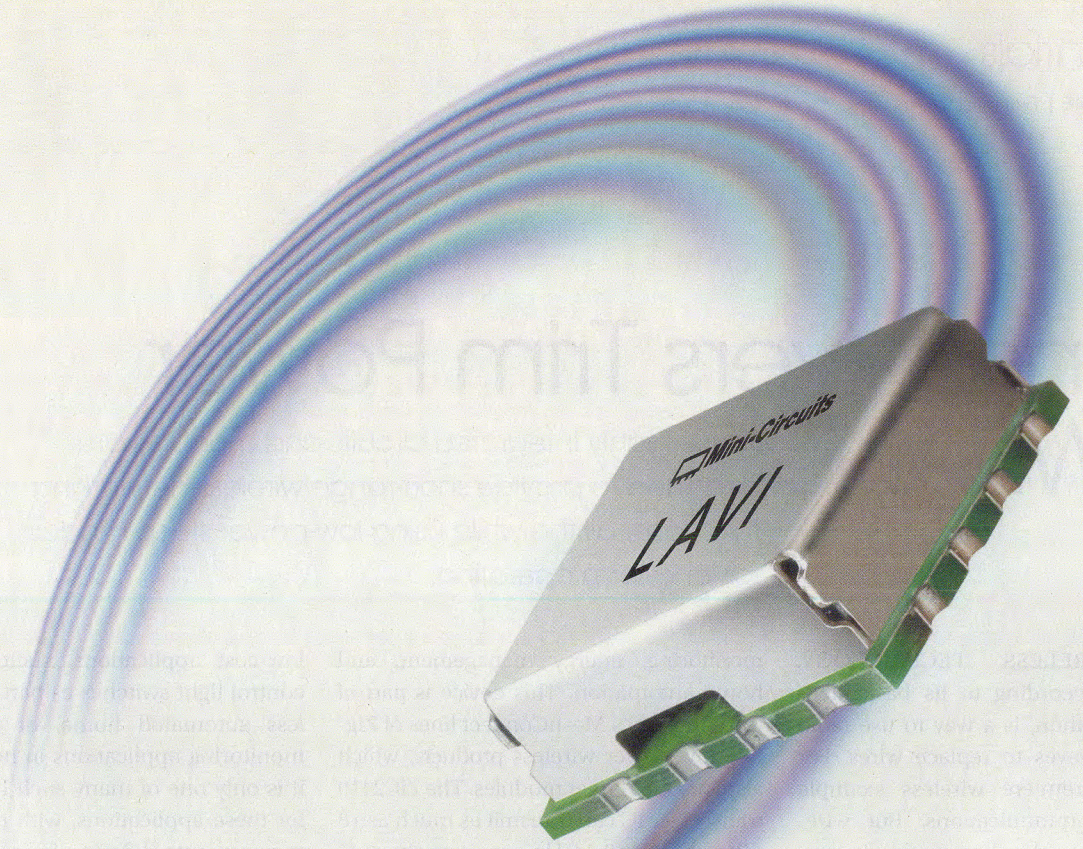
For industrial and medical wireless system developers who want a ready-to-use wireless subsystem, Linx Technologies (www.linxtechnologies.com) offers a series of transceiver modules that can simply be added to a higher-level design and integrated with some additional programming. For example, the firm's NT module uses what the company calls its True Transparency™ interface to allow users to create a "wireless wire" for use at nonstandard data rates, with custom protocols, and user-selected encoding, such as pulse-width-modulated (PWM) or Manchester encoding. The module is completely hardware-configurable. Although programming is not required, the NT Series allows for communication and microcontroller programming over a UART connection.

The Linx NT module **(Fig. 2)** operates at ISM frequencies from 902 to 928 MHz with transmit power levels from –15.5 to +12.5 dBm and receiver sensitivity from –102 to –113 dBm, depending on bit rate. The transceiver, which can be used with frequency-shift-keying (FSK) or Gaussian FSK modulation, provides data rates from 1 to 300 kb/s. It operates on supplies of +2.5 to +5.5 VDC, and consumes 15 mA current at 0-dBm transmit power and 19.2 mA current in receive mode, with less than 1 µA current in power-down mode. It is designed for operating frequencies from –40 to +85°C. To aid developers, the module is part of a master development system complete with two boards—each populated with a transceiver module.

Anaren Integrated Radio (AIR) modules from Anaren (www.anaren.com) are designed for use as embedded or stand-alone radio transceivers for industrial control, meter reading, and building automation applications. They are based on low-power transceiver ICs from Texas Instruments (ww.ti.com) and available for ISM frequency bands of 433 MHz, 915 MHz, 2.4 GHz, as well as dual-band operation at 868 and 915 MHz. For example, model A1101R04C is an AIR module based on the model CC1101 transceiver IC from Texas Instruments. The radio module measures just 9 x 12 mm and operates from 433.05 to 434.79 MHz. It offers receiver sensitivity of –112 dBm at a data rate of 1.2 kb/s and is certified to ETSI EN 300 220 for use in European applications. It operates from a supply at +1.8 to +3.6 VDC and draws only 15 mA current in receive mode and 200 nA in sleep mode. It includes a simple-to-use serial peripheral interface (SPI) bus.

For any wireless solutions to be effective in medical environments or in long-term factory-automation applications, they must operate at low power levels. The most recent version of Bluetooth (Version 4.0) is aimed at low-power consumption, such as in medical applications. Operating in the band from 2400 to 2480 MHz, this version of Bluetooth, also known as Bluetooth Smart and Bluetooth low energy (BLE), employs a new protocol stack designed to conserve power and to provide various power-saving modes.

The official Bluetooth website (www.bluetooth.com) has declared the new standard to be the future of medical wireless applications. The research firm IMS Research (www.imsresearch.com) has projected that Bluetooth Smart will be the most dominant wireless technology for medical devices in the years to come, with more than 4.7 million medical devices shipped in 2016 with Bluetooth Smart wireless capability. Regardless of approach, it is clear that the use of wireless technology for medical and industrial applications is growing rapidly. MWRF



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Transceivers Trim Power In WPANs

These highly integrated circuits and modules are designed to provide short-range wireless networking functions, all the while using low-power sleep modes for long-term operation.

WIRELESS TECHNOLOGY, according to its basic definition, is a way to use radio waves to replace wires. For many, the premiere wireless example is cellular communications. But wireless technology also has many shorter-distance, lower-power applications; the markets are vast for short-range wireless modules and integrated circuits (ICs) for such things as monitoring, remote control, and telemetry.

Standards developed for low-power wireless use include Wi-Fi (IEEE 802.11) and ZigBee (IEEE 802.15.4), both of which can operate in the unlicensed 2.4-GHz Industrial-Scientific-Medical (ISM) band. ZigBee also makes use of other available unlicensed bands, such as 868 MHz in Europe and 915 MHz in the United States. Both standards operate by establishing simple low-power wireless personal area networks (WPANs) whether indoors or outdoors, with typically coverage distances of about 5 to 10 m and low data rates.

Industry groups have grown large around these standards, including the WiFi Alliance (www.wi-fi.org); the ZigBee Alliance (www.zigbee.org), and more specialized manufacturer organizations, such as the HomePlug Powerline Alliance (www.homeplug.org).

Although these are typically very low-power devices, they tend to be highly integrated. For example, the model ZiC2410 transceiver IC from California Eastern Labs (www.cel.com) was developed to run on a +1.5-VDC (battery) supply for automatic meter reading, medical patient monitoring, energy management, and home automation. This device is part of the company's MeshConnect lines of ZigBee low-power wireless products, which also includes larger modules. The ZiC2410 transceiver IC can transmit as much as +8 dBm power at 2.4 GHz, requiring about 45 mA current, but it uses only about 4.6 mA in typical transmit/receive operation.

The chip is compliant with ZigBee IEEE 802.15.4 specifications and contains an RF transceiver with baseband modem, hardwired medium access controller (MAC), and embedded 8051 microcontroller. It is available in a 7 x 7 mm QFN or 5 x 5 mm VFBGA package. The transceiver circuitry includes a receiver low-noise amplifier (LNA), frequency synthesizer with phase-lock loop (PLL) and voltage-controlled oscillator, crystal reference oscillator, and transmit power amplifier. The receiver can provide –98 dBm sensitivity and supports ZigBee data rates to 250 kb/s; The IC can also push data rates to 1 Mb/s for custom applications.

Although these are typically very low-power devices, they tend to be highly integrated.

The on-board synthesizer exhibits typical phase noise of –81.9 dBc/Hz offset 100 kHz from the carrier and –108.6 offset 1 MHz from the carrier. The 16-MHz crystal reference oscillator has ±10 ppm crystal frequency accuracy. The chip employs offset-quadrature-phase-shift-keying (OQPSK) modulation for reliability and only requires 0.3 µA current in sleep mode.

This is impressive integration for a device that is intended for extremely low-cost applications, such as remote control light switches as part of the wireless automated home, or for patient-monitoring applications in hospitals. But it is only one of many such ICs designed for these applications, with performance requirements differing for other parts of the world depending upon availability of unlicensed frequency bands.

The model SX1231J transceiver from Semtech (www.semtech.com), for example, is designed to meet ARIB STD-T67 (426 to 470 MHz) and ARIB STD-T108 (915 to 930 MHz) requirements for use in Japan. It is suitable for remote-keyless-entry (RKE), active radio-frequency-identification (RFID), wireless sensor networks, and industrial monitoring and control. The ARIB STD-T67 standard specifies narrow 12.5-kHz channel spacing at about 426, 449, and 469 MHz, GFSK modulation, with power output limited to +10 dBm. The ARIB STD-T108 standard defines 200-kHz channels in the 915-to-930-MHz band.

Based on the firm's TrueRF™ technology, the SX1231J transceiver features a complete frequency-synthesized ultra-high-frequency (UHF) transceiver capable of data rates to 300 kb/s using frequency-shift-keying (FSK) modulation. It includes a bit synchronizer for clock recovery and built-in temperature sensor and low battery indicator. It achieves receiver sensitivity of –120 dBm with only 16 mA cur-

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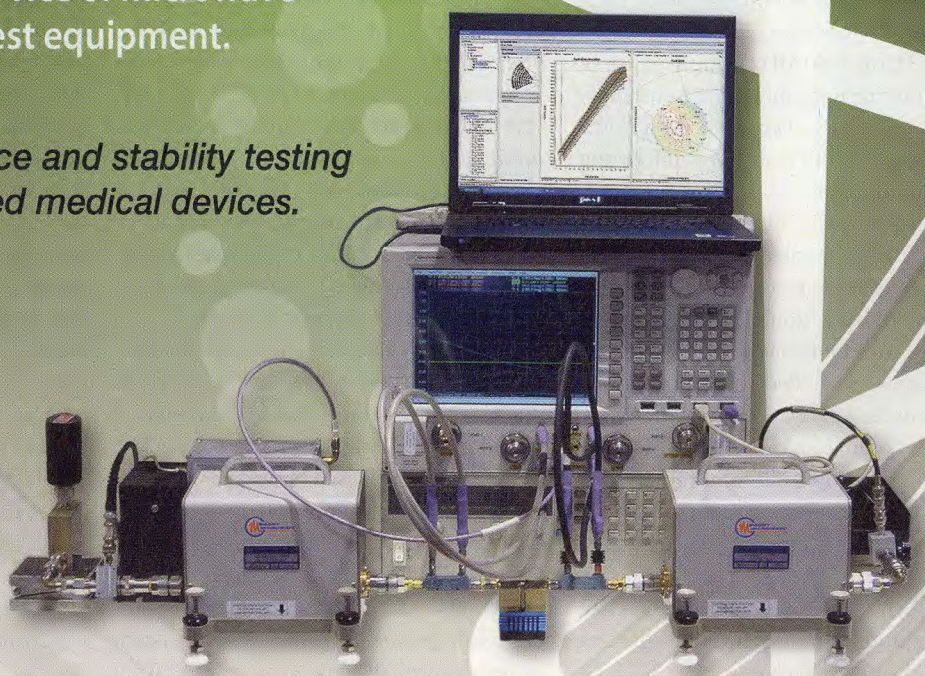

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rent consumption in receive mode and about 100 nA in sleep mode.

The IC includes a fractional-N frequency synthesizer with 61-Hz resolution and 32-MHz crystal oscillator; the synthesizer requires only 80-µs wakeup time from sleep mode to achieve a locked signal. The chip runs on voltages from +1.8 to +3.6 VDC and generates typical transmit power of +13 dBm, and as much as +17 dBm. Transmitter output power can be programmed in 1-dB steps from –18 to +17 dBm. The transmitter's phase noise is typically better than –95 dBc offset 50 kHz from any carrier.

BUILT FOR THE LONG HAUL

Silicon Labs (www.silabs.com) has developed a number of low-power RF transceivers for long battery life, including the new Si446x EZRadioPro® transceiver IC family for smart meters, security and home automation systems, industrial control systems, sensor networks, and electronic shelf labels. The devices offer continuous coverage from 119 to 1050 MHz using a variety of modulation formats, including frequency-shift-keying (FSK), Gaussian-minimum-shift-keying (GMSK), and on-off-keying (OOK) modulation.

The transceivers employ a patented antenna diversity algorithm developed to counteract the effects of multipath and fading, effectively doubling the wireless range in a multipath/fading environment. They comply with Federal Communications Commission (FCC) requirements for use in the US but also meet ARIB specifications for Japan and ETSI requirements for Europe. The extended frequency coverage of the transceivers enables them to serve emerging narrowband applications such as the 151-MHz multiuse-radio-service (MURS) band in the US and the 138- and 169-MHz bands in Europe.

Designed for coin-cell battery-powered operation, the transceivers draw only 17 mA current at +10-dBm transmit power and about 13 mA current in high-performance receive mode. The transceivers have a selling price starting at $1.57 in 10,000 piece quantities.

Analog Devices (www.analog.com) supports a range of low-power wireless applications, including in home automation and health-care monitoring. For example, its model ADF7023-J transceiver operates at ISM frequencies from 902 to 958 MHz with various modulation types. These include 2FSK, GFSK, MSK, and GMSK. The model can channel data rates from 1 to 300 kb/s. As with many of these highly integrated low-power RF transceiver ICs, it uses a fractional-N PLL/VCO-based frequency synthesizer with output channel frequency resolution of 400 Hz. To reduce spurious emissions, the synthesizer's VCO operates at twice the fundamental frequency. The synthesizer is locked to an on-board 26-MHz crystal oscillator.

The unique transceiver includes both single-ended and differential transmit power amplifiers, the better to accommodate transmit antenna diversity applications. The transmit output power can be programmed from –20 to +13.5 dBm. The programmable receiver provides IF bandwidths of 100, 150, 200, and 300 kHz. The ADF7023-J transceiver is designed for supplies from +2.2 to +3.6 VDC. It has only 12.8 mA current consumption in receive mode and 24.1 mA current consumption in transmit mode, with +10 dBm transmit output power. The transceiver, which is supplied in a 5 x 5 mm LFCSP package, is ideal for applications including smart metering and wireless sensor networks.

Infineon (www.infineon.com) also addresses sub-1-GHz low-power wireless markets with several IC product families, including its PMA 71xx SmartLEWIS™ MCU line of ADK/FSK transmitters with embedded microcontroller units (MCUs). Like the CEL transceivers, these highly integrated transmitters combine an on-board 8051 microcontroller with a high-efficiency power amplifier and advanced power control system, so as to minimize power consumption when using low-voltage battery power from +1.9 to +3.6 VDC. The device operates in the 315, 434, 868, and 915 MHz frequency bands using a PLL frequency synthesizer for tuning and ASK/FSK modulator for data rates to 32 kb/s. The transmitters, which include 128-b AES encryption, draw less than 0.6 µA in power-down mode. The firm offers a separate receiver IC for use in a transceiver system.

Texas Instruments (www.ti.com) offers its model C2500 transceiver for low-power wireless applications at 2.4 GHz. In a typical system, the CC2500 is used with a microcontroller and a few additional passive components. It operates from 2400 to 2483.5 MHz with a number of different modulation schemes, including OOK, GFSK, MSK, and 2FSK modulation, for data rates of 1.2 to 500.0 kb/s. It boasts –104 dBm receiver sensitivity with only 13.3 mA current consumption from a +3-VDC supply in receive mode and 250-kb/s data rate. The chip provides programmable output power to +1 dBm and features a PLL frequency synthesizer with 90-µs settling time and phase noise of –78 dBc/Hz offset 50 kHz from any carrier and –100 dBc/Hz offset 1 MHz from any carrier.

THE PROPRIETARY PATH

In addition to devices developed for low-power wireless ZigBee and Wi-Fi applications, the ANT™ and ANT+™ specifications are proprietary wireless network protocols developed for use in the 2.4-GHz ISM band. Developed by Dynastream Innovations, Inc. [a wholly owned subsidiary of GPS receiver supplier Garmin (www.garmin.com)] as a higher-speed (to 1 Mb/s) variation of ZigBee, ANT is aimed at providing wireless functionality for sports products (such as fitness monitors).

The ANT standard is supported by semiconductor suppliers like Nordic Semiconductor (www.nordicsemi.com) and Texas Instruments with low-power transceiver ICs. Nordic's nRF24AP2-8CH device provides eight-channel ANT connectivity at 2.4 GHz. It includes the transceiver and a fully embedded ANT protocol stack for flexible serial interface with a wide range of external microcontrollers. The chip is designed for use with coin-cell batteries from +1.9 to +3.6 VDC and draws only 11 µA average current and less than 17 mA peak current during transmit mode. The firm also supplies an older, single-channel version of the chip, as well as several developer's kits. MWRF

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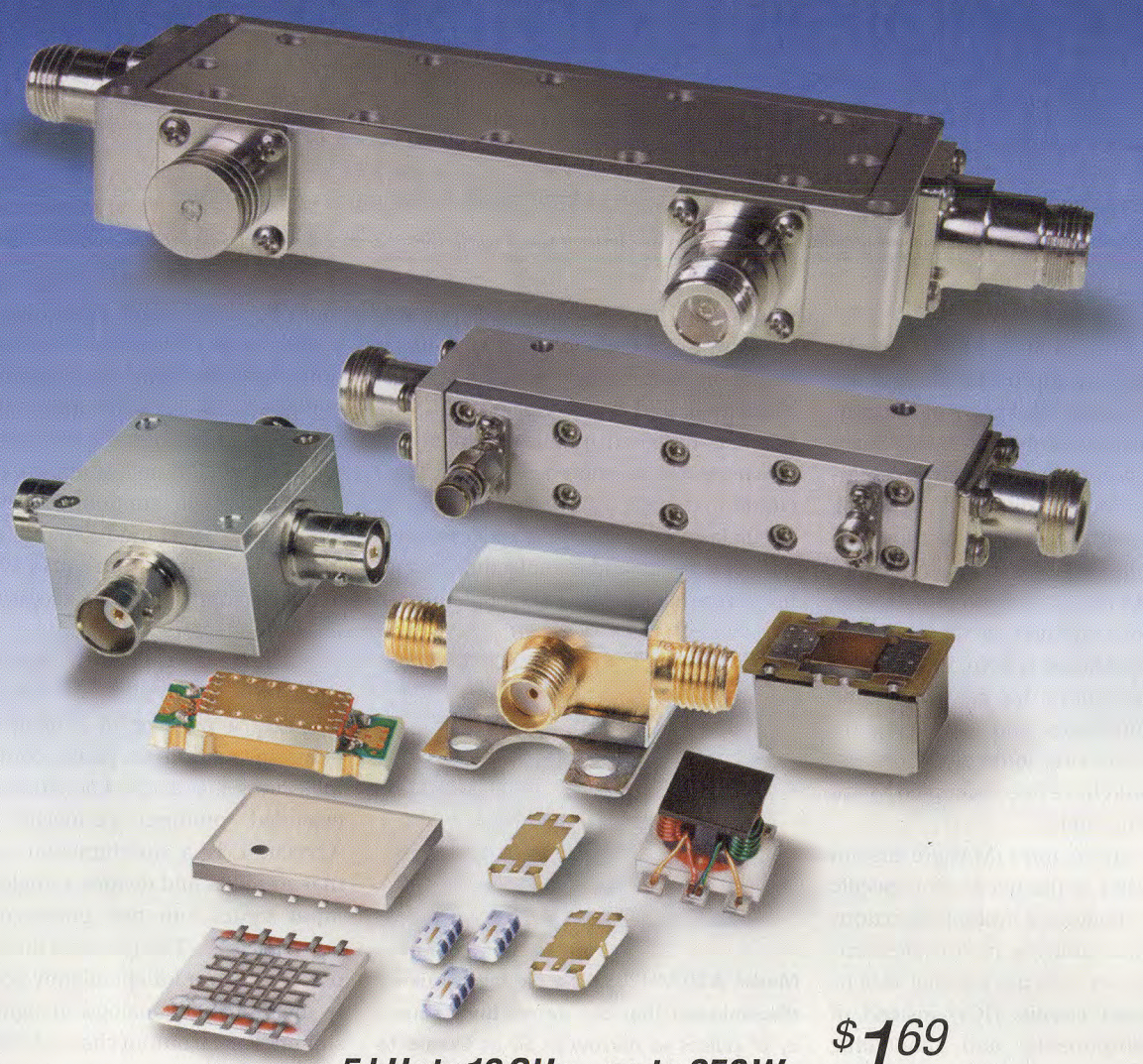

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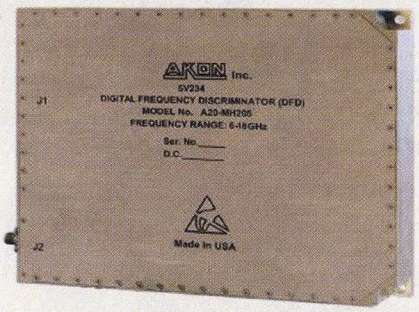
Assemblies Combine Multiple Components

Integrated microwave assemblies allow system designers to combine multiple component functions in a single compact package, avoiding crosstalk degradation.

MICROWAVE COMPONENT MANUFACTURERS take many approaches to what are commonly known as integrated microwave assemblies (IMAs). Some tie analog components together exclusively, with others adding digital control, signal processing, and even microprocessors. But while the design philosophies applied to IMAs may vary, the intent of these multifunction modules is the same: to save space in a larger system. IMA designers typically achieve that goal with some clever architectures and packaging—in the process, shaving some of the real estate that would have been occupied by the separate components.

By their nature, most IMAs are custom designs, aimed at the needs of a specific system. By integrating multiple functions into a common housing, microwave component designers can use internal switching, integrated circuits (ICs) instead of discrete components, and monolithic microwave integrated circuits (MMICs) instead of microwave integrated circuits (MICs). This allows them to fit three or more typical component functions into one package.

Design and manufacturing of IMAs typically requires broad expertise in a range of circuit technologies, circuit-board materials, and packaging approaches. Anaren (www.anaren.com), for example, cites its experience with many different circuit technologies. These include stripline, microstrip, and printed-wire board (PWB) circuits; soft and hard circuit substrate materials over a span of dielectric-constant values; and the skills to use the appropriate software design tools, including linear circuit simulators, electromagnetic (EM) simulators, and digital design tools. The firm has designed multilayer circuits on low-temperature-cofired-ceramic (LTCC) circuit materials, featuring as many as 30 circuit layers, to economize space in a system. The design and manufacturing capabilities are backed by a full complement of electrical and environmental test systems.



Model A20-MH205 is a digital frequency discriminator that can detect the frequency of pulses as narrow as 50 ns from 6 to 18 GHz. It measures 9.17 x 5.90 x 1.00 in. [Photo courtesy of Akon (www.akon.com)]

Aethercomm (www.aethercomm.com) shows its capabilities at achieving relative high transmit powers from a small volume. Its model TR 0.24-0.39-75 transmit/receive assembly measures just 3.70 x 8.125 x 1.00 in. with SMA connectors, but delivers transmitter output power to 100 W at frequencies from 290 to 390 MHz. It includes a receiver for use from 240 to 270 MHz with 18-dB gain and 3-dB noise figure. It is designed for use with nominal input power level of 2 W, but can handle a wide range of signal levels. The rugged unit is built for harsh environments, and is equipped with DC switching circuitry that enables and disables the transmitter and receiver functions in less than 10 µs. It can operate in both continuous-wave (CW) and pulsed signal modes, handling baseplate temperatures from –40 to +71°C. DC and logic connections are accessible via a DSUB connector.

Microwave Concepts (www.microcon.com), a division of Micronetics, squeezes a number of X-band components in a hermetic phase control unit measuring just 2.35 x 1.50 x 0.38 in. with extended multipin connector. Model A228001-1 is a multifunction assembly that amplifies and divides a single X-band input signal into two phase-controlled output signals. The phase of the two output signals are independently controlled by means of both analog and digital phase shifters in each output channel. The digital phase shifters control a change of 180 deg. while the analog phase shifters control as much as 400 deg. Differential interfaces are used to control the output signal phase at high speed.

The assembly operates from 9.5 to 12.0 GHz and even provides 3 dB small-signal gain with gain flatness within 1.5 dB. The unit achieves better than 12 dB return loss with better than 5-deg. accuracy for the digital phase shifters. In addition, it has a 1-dB compression point of better than +10 dBm and draws 120 mA at +15 VDC and 20 mA at –15 VDC. It was designed for clock phase control in high-capacity data com-

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				1dB	3dB	dB	dBm	Qty. 10
	fL-fU	Typ.		Typ.	Typ.	Typ.	Typ.	
YSF-122+	800-1200	20.4	0.2	20.5	21.3	3.4	36	2.69
YSF-2151+	900-2150	20.0	0.4	20.0	21.0	3.1	35	2.95
YSF-162+	1200-1600	20.1	0.2	20.0	21.0	3.2	35	2.69
YSF-232+	1700-2300	20.0	0.2	20.0	21.0	2.8	35	2.69
YSF-272+	2300-2700	19.0	0.7	20.0	21.0	2.5	35	2.59
YSF-382+	3300-3800	14.5	0.9	20.0	21.0	2.5	36	2.59
YSF-322+	900-3200	17.0	2.2	20.0	21.0	2.5	35	2.85

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IF/RF MICROWAVE COMPONENTS

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munication applications such as optical long-haul data networks.

TRAK Microwave Corp. (www.trak.com) specializes in combining switches and filters in compact assemblies for harsh environments. Model SWF002 is a prime illustration of that capability—a five-channel switched C-band filter assembly in a low-profile laser-welded hermetic housing for airborne use. The compact assembly includes a TTL driver for control. It incorporates five filter spaced 500 MHz apart, with stopband rejection of 60 dB ± 500 MHz from the channel and passband insertion loss minimized to 6 to 10 dB.

This is an extremely compact unit measuring just 2.29 x 1.40 x 0.265 in. and weighing only 0.8 oz. It uses hermetic SMP connectors and EMI filtered solder pins for DC connections, and handles RF power levels to +15 dBm. Power requirements are 80 mA at +5 VDC and 30 mA at –5 VDC.

Akon (www.akonic.com) provides custom IMAs for ground-based and airborne applications, with numerous examples of its integration capabilities in standard designs such as the model A20-MH205 digital frequency discriminator **(see figure)**. It covers 6 to 18 GHz and can process CW signals as well as pulses as narrow as 50 ns. It has a dynamic range of –63 to +7 dBm and 3 MHz RMS frequency accuracy. The externally triggered frequency discriminator provides 14-b resolution of measured frequency with fast 100-ns recovery time and only 200-ns shadow time. The broadband IMA draws 200 mA at +12 VDC, 1.3 A at +8 VDC, and 250 mA at –8 VDC. It operates at temperatures from –20 to +71°C.

K&L Microwave (www.klmicrowave.com) leverages its experience in filters to design and manufacture compact filter-based IMAs, including a TTL-controlled four-channel switched filter bank in a compact aluminum housing. As one would expect from K&L, the filter performance is outstanding. With four channels centered at 2975.0, 3132.5, 3332.5, and 3527.5 MHz, the maximum passband insertion loss is only 4 dB, with maximum amplitude ripple of only 0.4 dB. Phase deviation in any channel is within 1.5 deg. The out-of-band rejection for any of the channels ranges from a minimum of 50 dB to a maximum of 80 dB. The switching speed to select a channel under TTL control is less than 1 µs.

The firm has also developed the model 4SFB-00021 switched filter bank. Designed for military and airborne applications, it handles center frequencies of 698, 730, 762, and 794 MHz using lumped-component filter designs and surface-mount component technology. Each channel provides 35-MHz bandwidth with passband insertion loss of 7.5-dB or less and out-of-band rejection of typically 60 dB.

RAISING THE STAKES

MITEQ (www.miteq.com) has leveraged its successful component designs into more complex IMAs, typically for applications in satellite communications (satcom). Because weight and size are so critical in such systems, many of MITEQ's designs attempt to integrate multiple subsystems within a single package. Among these is the model 131724 frequency downconverter, which covers three separate bands in an aluminum housing measuring 5.58 x 2.850 x 0.67 in. with SMA female connectors. It covers S-, C-, and X-band frequencies of 3.62 to 4.20 GHz, 7.25 to 7.75 GHz, 10.95 to 11.90 GHz, and 11.70 to 12.75 GHz, providing an IF output at 2 GHz. It uses local oscillator (LO) frequencies of 5.62 to 6.20 GHz at +15 dBm power level and 9.25 to 12.75 GHz at +10 to +11 dBm power level, and restricts LO leakage to –80 dBm. The downconverter achieves linear group delay of 0.01 ns/MHz maximum for any 40-MHz band, suffering 16-dB maximum conversion loss.

For upconversion, the IF-driven model SME0618LI1MD* single-sideband upconverter transforms input signals across an IF bandwidth of DC to 500 MHz to an RF output range of 6 to 18 GHz, all in a package measuring 2.50 x 2.00 x 0.50 in. The upconverter, with 9-dB typical conversion loss, works with IF input power of +10 to +16 dBm and delivers RF power of 0 to +5 dBm. Sideband suppression is typically 35 dB while carrier suppression is typically 30 dB. The upconverter is designed to handle operating temperatures from –54 to +85°C. The firm also caters to those requiring complete receivers in IMA form. The model DC-50305091-12-0 C-band receiver has an RF input range of 5031.0 to 5090.7 MHz, an LO range of 5030.94 to 5090.64 MHz, and provides an IF output of 60 kHz for further processing. The receiver supplies at least 8 dB gain with a 5.8-dB noise figure and input 1-dB compression point of –14 dBm.

The input third-order intercept point is –4 dBm. The high-speed design consists of a single-pole, four-throw (SP4T) switch to select the input band, followed by a bandpass filter, limiter, two stages of amplification, isolator, and RF mixer fed by an external LO. The receiver has settling time of only 75 µs and the time to a readable signal of only 175 µs. It draws 120 mA at +12 VDC and 60 mA at +5 VDC.

Another company with a long history in designing multifunction IMAs is Narda Microwave (www.nardamicrowave.com), with assemblies operating in the frequency range from 500 MHz to 50 GHz. As with MITEQ, many of their assemblies are for satcom applications. They may include oscillators, frequency synthesizers, mixers, switches, filters, and limiters within component-sized housings.

The firm combines different technologies—such as MICs, MMICs, and surface-mount components—within a single housing to save space without limiting performance. More recently, the company coined the terms Ultimate MIC™ and Ultimate SMT™ The former describes IMAs that combine microwave hybrid manufacturing with multilayer printed circuit boards (PCBs) using analog and digital devices and components. The latter refers to IMAs based on the integration of surface-mount components on MICs.

Additional suppliers of microwave IMAs include Aeroflex (www.aeroflex.com), Microphase (www.microphase.com), Microsemi (www.microsemi), Phase Matrix (www.phasematrix.com), Planar Monolithics Industries (PMI; www.pmi-rf.com), Shireen, Inc. (www.shireen-inc.com), Sivers IMA (www.siversima.com), and Teledyne Cougar (www.teledyne-cougar.com). MWRF

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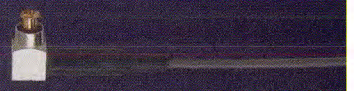

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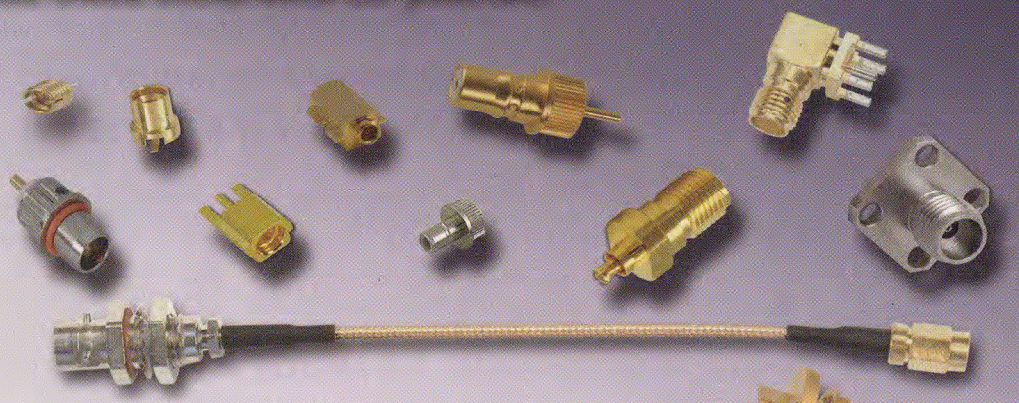



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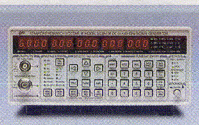

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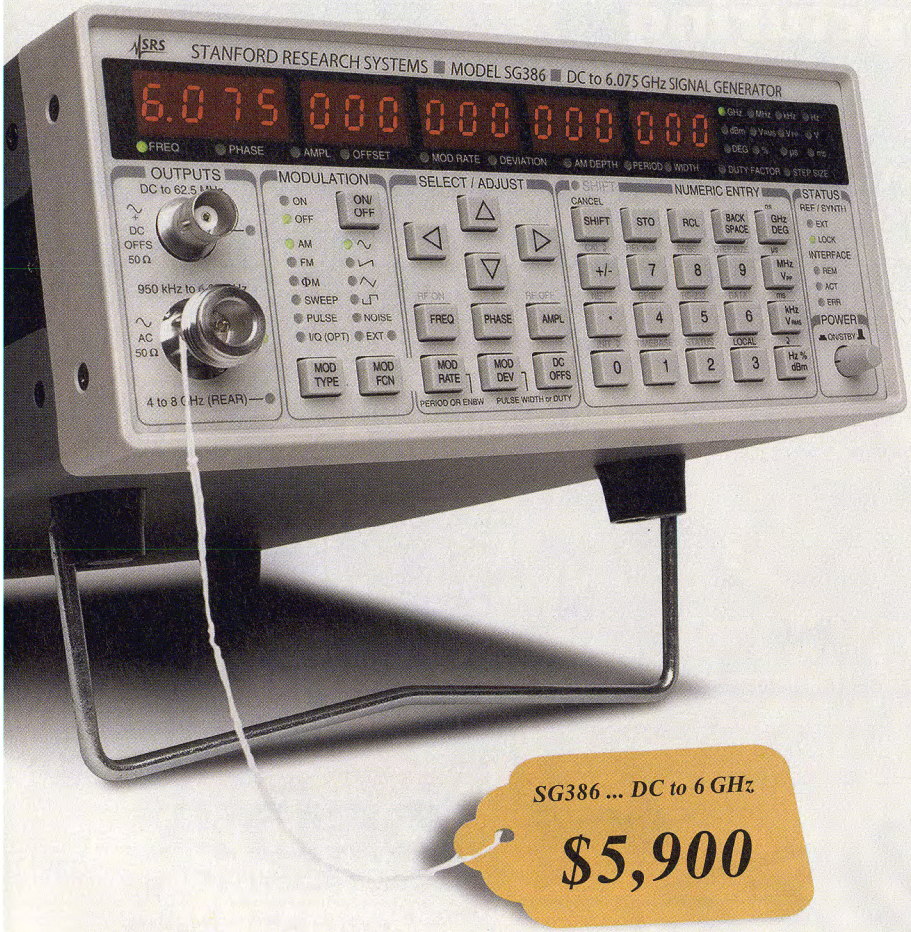

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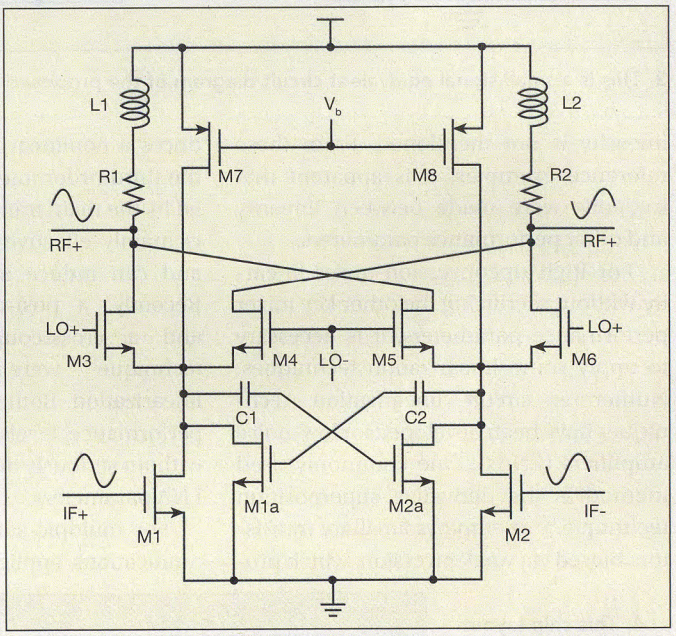
Mixer Translates Multiple Standards

This broadband frequency-upconversion mixer, which has been simulated with and without a novel linearity-enhancement circuit, is suitable for multiple-standard wireless applications from 1.0 to 10.6 GHz.

WIRELESS COMMUNICATIONS products continue to support multiple communications standards, pushing designers to develop components that can work across as many bands and standards as possible. Ideally, a single device would handle all wireless communications standards and bands. But before that day comes, it is necessary to develop components—such as upconversion mixers—that can operate with several wireless standards. By employing a cross-coupling post-distortion technique (CCPFT), it was possible to design an upconversion mixer with outstanding linearity for multiple wireless communications standards.

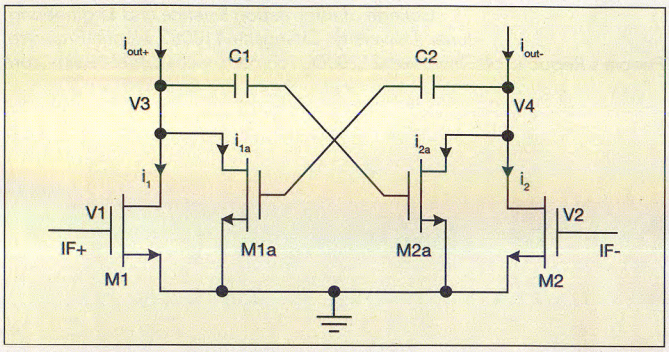
The mixer was simulated with commercial software, based on fabrication with a CHRT 0.18-µm silicon CMOS mixed-signal/RF semiconductor process. As will be shown, the mixer consumes only 5 mW power from a +1.2-VDC supply. It achieves a maximum input third-order intercept point (IIP3) of +16.56 dBm with 3.5 dB conversion gain (flat to within ±0.5 dB), with 10.7-dB noise figure (flat to within ±0.5 dB) across a frequency range of 1.0 to 10.6 GHz. This makes it ideally suited for software-defined radios (SDRs), as well as multiple-band ultrawideband (UWB) communications systems.[1]

An upconversion mixer should provide low noise figure with reasonable gain and high linearity while consuming low power to be effective in modern multiple-standard wireless transmitters. Such mixers have been developed, including the 3.0-to-5.1-GHz upconversion mixer of ref. 2 designed with a current-reuse technique to minimize power consumption. It delivers 3.8-dB gain and 8.4-dB noise figure, but only –7.6-dBm IIP3. In ref. 3, a 1.0-to-11.0-GHz upconversion mixer was proposed, with an adopted fold structure and inductor-free matching network. Although its IIP3 reaches +12 dBm, the conversion gain is below 0 dB (–6 dB).

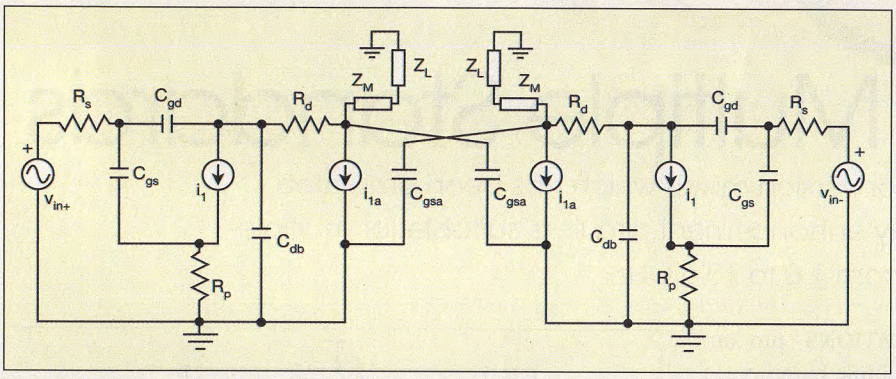


1. This schematic circuit diagram shows the proposed upconversion mixer for use from 1.0 to 10.6 GHz.

In ref. 4, a 3.0-to-5.0-GHz upconversion mixer with current-reuse bleeding technique was presented. It achieves 6.5-dB conversion gain and IIP3 of +11.6 dBm. However, its power dissipation is 11.0 mW, and the mixer has a very complicated structure. In ref. 5, a 6.0-to-8.0-GHz upconversion mixer was proposed which uses a feedback loop in its transconductance stage. It achieves 0-dB conversion gain and 7.0 dB noise figure, but its



2. This simple diagram provides the conceptual idea of the mixer's linearization technique.



3. This is a small-signal equivalent circuit diagram of the proposed upconversion mixer.

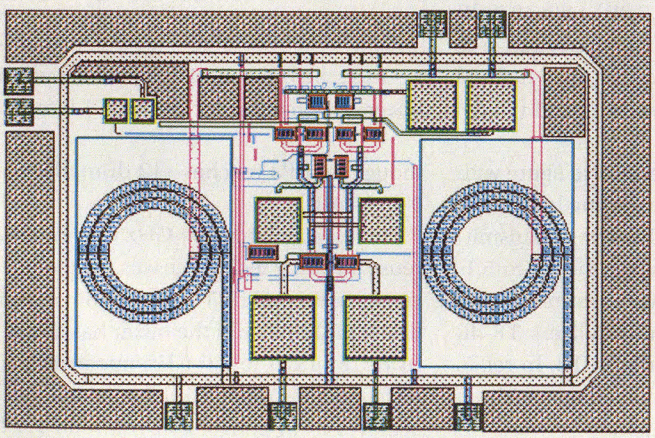
linearity is not mentioned. From these reference examples, it is apparent that tradeoffs were made between linearity and other performance parameters.

For high upconversion-mixer linearity without sacrificing the other key mixer performance parameters, it is necessary to apply some linearization techniques. Numerous circuit linearization techniques have been developed for low-noise amplifiers (LNAs). One commonly used method is the derivative superposition technique.[6,7] It employs auxiliary transistors biased via weak inversion, which produces a nonlinear current to cancel out the third-order intermodulation generated by the main transistors. This approach is mainly effective at lower frequencies and can induce additional gate noise. Recently, a post-distortion technique[8] and a cross-coupling post-distortion technique[9,10] were implemented for LNA linearization. Both methods yielded IIP3 performance levels exceeding +10 dBm without seriously degrading the other key LNA parameters.

For multiple-standard wireless communications applications, a low-voltage upconversion mixer was developed using a pseudodifferential double-balanced structure, allowing for high isolation between ports while operating with low supply voltage. It also employs a current-bleeding topology for improved noise and linearity performance.[11] A cross-coupling post-distortion technique was also adopted to further improve IIP3. The added linearization circuitry does not increase the size of the mixer, nor does it degrade conversion gain, noise figure, or power consumption.

Figure 1 shows a schematic circuit diagram for the UWB multiple-standard mixer, with a structure that is an improvement over a Gilbert-cell double-balanced mixer. Transistors M1 and M2 comprise the input pseudo-differential transconductance pairs. Transistors M1a and M2a employ weak inversion biasing. They form the cross-coupled post-distortion structure, which generates the nonlinear current needed to cancel the third-order intermodulation distortion generated by M1 and M2. Capacitors C1 and C2 are coupling capacitors, while transistors M3, M4, M5, and M6 work as switches. Transistors M7 and M8 serve as current sources to improve the noise and linearity performance of the whole circuit by adjusting the bias current. Resistors R1 and R2 are load resistors, while inductors L1 and L2 are useful for increasing the conversion gain at the upper edge of the desired frequency range.

The linearity of a Gilbert-cell mixer is determined mainly by its transconductance stage.[12] As a result, post-distortion linearization is implemented on the pseudo-differential transconductance stage (**Fig. 2**). To explain the basic operating principle of this approach, reactive components must be ignored in this analysis and all device pairs considered to be without mismatches. Then the drain current of each transistor can be represented as a power-series expression, with a gated-source voltage provided by transistors. For simplicity, the output current, i_{out+} of the left half-circuit composed of transistors M1 and M1a is considered first. The drain currents of those two transistors can



4. This chip layout is based on a commercial 0.18-μm silicon CMOS mixed-signal/RF process.



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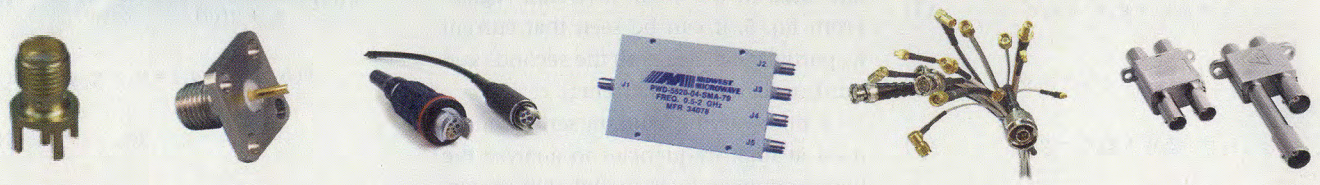

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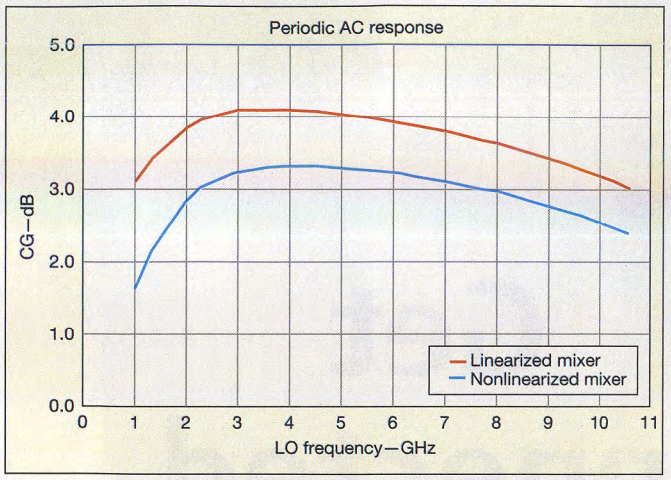
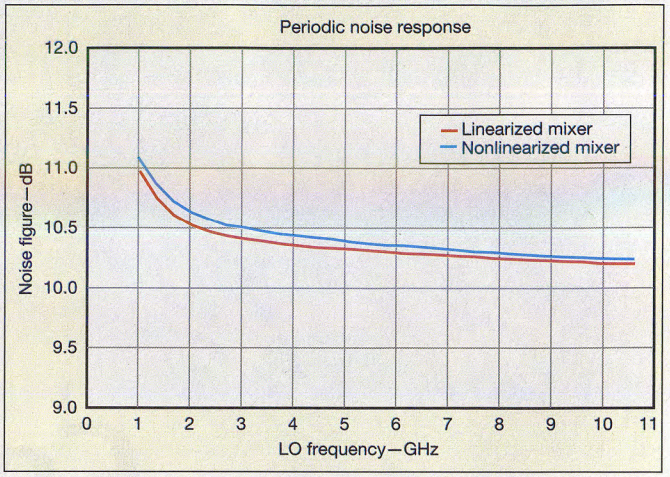


5. These traces show the simulated conversion gain of the upconversion mixer, with and without linearization.



6. These plots show the simulated noise figure of the upconversion mixer, with and without linearization.

be modeled as Eqs. 1-4:

$$i_1 = g_1 v_1 + g_2 v_1^2 + g_3 v_1^3 \quad (1)$$

$$i_{1a} = g_{a1} v_4 + g_{a2} v_4^2 + g_{a3} v_4^3 \quad (2)$$

$$i_2 = -g_1 v_1 + g_2 v_1^2 - g_3 v_1^3 \quad (3)$$

$$v_4 = -i_2 R_{ON} = a v_1 + b v_1^2 + c v_1^3 \quad (4)$$

where:

R_{ON} = the switch on resistance of the switch pair;

$a = R_{ON} g_1$;

$b = R^{ON} g^2$; and

$c = R^{ON} g^3$;

The two nonlinear currents i_1 and i_{1a} add at node v_3, yielding output current i_{out+}:

$$i_{out+} = i_1 + i_{1a} = (g_1 + a g_{a1}) v_1 + (g_2 + a^2 g_{a2} + b g_{a1}) v_1^2 + (g_3 + c g_{a1} + 2ab g_{a2} + a^3 g_{a3}) v_1^3 \quad (5)$$

The third-order derivative g_3 in Eq. 1 is a dominant source of third-order intermodulation distortion, which limits the linearity of a mixer. To improve the linearity, g_3 should be minimized without reducing the fundamental transconductance, g_1. The differential transistor pair M1 and M2 is biased in strong inversion, which has a negative third-order derivative g_3. Therefore, the third-order nonlinearity provided by the cross-coupling post-distortion canceller FET should be positive, which requires biasing FETs M1a and M2a in the weak inversion region. From Eq. 5, it can be seen that current i_{1a} partially cancels both the second- and third-order terms of current i_1.

A time-varying Volterra series can be used at high frequencies to analyze the high-frequency inter-modulation performance of the proposed mixer. The mixer's distortion is induced by the switching and transconductance stages. Reference 12 provides a detailed analysis of the intermodulation distortion of the switching pairs. The effectiveness of the applied linearization is determined mainly by the transconductance stage. For simplicity in this analysis of the mixer, distortion due to the switch pairs has been neglected. The parasitic capacitance and resistance of two auxiliary transistors, except the gate-source capacitance, have also been ignored in the analysis. **Figure 3** shows a version of the mixer schematic diagram for use in high-frequency distortion analysis. This is limited to a third-order analysis, assuming a weakly nonlinear circuit. The expression for IIP3 is given by a Volterra series analysis as follows[13]:

$$IIP3 = \frac{1}{6R_s \cdot |H(\omega)| \cdot |A_1(\omega)|^3 \cdot |\varepsilon(\Delta\omega, \omega_1 + \omega_2)|} \quad (6)$$

where:

$$H(\omega) = \frac{1 + j w C_{gs}(R_s + R_p) + j\omega C_{gd} R_s}{g_1' - j\omega C_{gd}[1 + R_p(g_1' + j\omega C_{gs})]} \quad (7)$$

$$A_1(\omega) = \frac{1}{g_1' + g(\omega)} \cdot \frac{1 + j\omega C_{gd} Z_1(\omega)}{Z_2(\omega)} \quad (8)$$

$$\varepsilon(\Delta\omega, \omega_1 + \omega_2) = g_3' - g_{OB} \quad (9)$$

$$g_1' = g_1 - a g_{a1} \quad (10)$$

$$g_3' = g_3 - c g_{a1} - 2ab g_{a2} - a^3 g_{a3} \quad (11)$$

$$g_{OB} = \frac{2(g_2')^2}{3}\left[\frac{2}{g_1' + g(\Delta\omega)} + \frac{1}{g_1' + g(\omega_1 + \omega_2)}\right] \quad (12)$$

$$g_2' = g_2 + b g_{a1} + a^2 g_{a2} \quad (13)$$

$$g(\omega) = \frac{1 + j\omega C_{gd}[R_s + Z_1(\omega)] + j\omega C_{gs}[R_s + Z_2(\omega)]}{Z_2(\omega)} \quad (14)$$

$$Z_1(\omega) = \frac{1}{j\omega C_{db}} // \{[(Z_M + Z_L) // \frac{1}{j\omega C_{gsa}}] + R_a\} \quad (15)$$

See Eqs. 16 and 17, p. 57.

where:

Z_M = the equivalent impedance of the switch transistor and

Z_L = the equivalent impedance of the load.

Equations 9 through 16 imply that the mixer's linearity (IIP3 or OIP3) is determined by g_1', g_3', and g_{OB}. Parameter g_{OB} represents the combined effect of the second-order nonlinearity generating the second-order intermodulation product,

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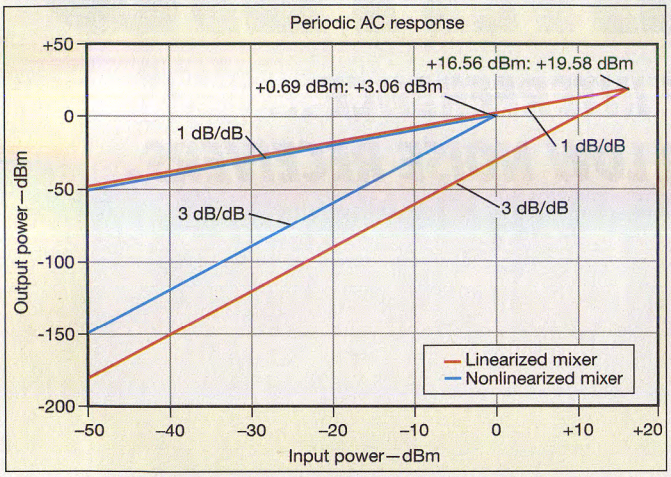
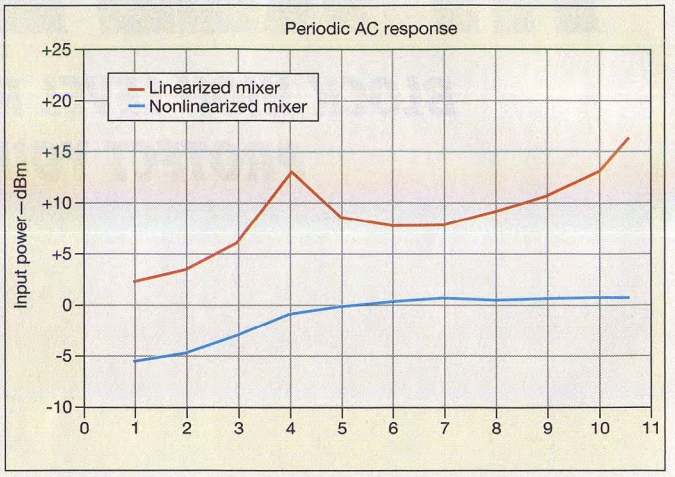


7. These curves show the simulated IIP3 versus RF output, where the RF output is fixed at 10.61 GHz.



8. These curves plot the simulated IIP3 of the upconversion mixer across the full RF range, with and without linearization.

which is then mixed with the fundamental tones, yielding the third-order products.[13] This self-interaction is due to the multiple feedback in the circuit mainly by the gate-drain capacitance.[13]

From Eqs. 12-15 it can be shown that the values of $|H(\omega)|$, $|A_1(\omega)|$, and $|\varepsilon(\Delta\omega, \omega_1 + \omega_2)|$ decrease when the cross-coupling post-distortion technique is implemented in the Gilbert-cell mixer. For this reason, the proposed mixer achieves higher linearity than a double-balanced mixer using a traditional current-bleeding technique. The analysis for the proposed mixer can be confirmed by simulation results shown in **Figs. 7 and 8**.

Noise at the output of the upconversion mixer is caused mainly by the channel thermal noise and the flicker noise of the transconductance stage, and the thermal noise generated in the switching pair and the load.

Because the noise from a transistor is proportional to its transconductance, the noise contribution from the auxiliary transistor is very small and can be neglected in an analysis. The noise figure of the proposed upconversion mixer can be calculated by Eq. 17[14]:

See Eq. 17, next column.

where the quantities α, c, G, and G^2 are evaluated with the bias current of each switch pair and symbols γ_1 and γ_5 represent noise factor γ for transistors M1 and M5, respectively. Parameter K is a coefficient used in the analysis.

Computer simulations on the upconversion mixer were performed with the aid of the Cadence Spectre program from Cadence Design Systems (www.cadence.com) and using the CHRT 0.18-µm mixed-signal/RF CMOS process from Singapore's Chartered Semiconductor Manufacturing Ltd. **Figure 4** shows a layout of the upconversion mixer, which occupies an area of 0.75 × 0.5 mm.

It was evaluated with local-oscillator (LO) input power of +1 dBm, intermediate-frequency (IF) input power of –30 dBm, with the IF fixed at 10 MHz and the LO frequency swept from 1.0 to 10/.6 GHz. The simulated conversion gain was found to be within ±0.5 dB of 3.5 dB, as shown in **Fig. 5**. For the noise figure shown in **Fig. 6**, the IF was also fixed at 10 MHz and the LO frequency swept from 1.0 to 10/.6 GHz, with the simulated results showing noise figure of better than 10 dB across most of the frequency range.

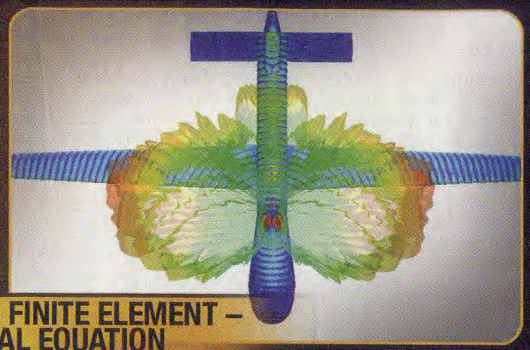
Figure 7 shows simulated IIP3 versus RF output frequency. At 10.61 GHz, the simulated IIP3 performance is +16.56 dBm. For **Fig. 8**, the IIP3 is shown across the full RF range, with the LO frequency swept from 1.0 to 10.6 GHz. The table summarizes the performance of the proposed upconversion mixer,

$$Z_2(\omega) = R_p + j\omega C_{gd}[R_s R_P + R_s Z_1(\omega) + R_p Z_1(\omega)] \quad (16)$$

$$NF = \frac{\alpha}{c^2} + \frac{2\left(\gamma_1 + \gamma_{g1} g_{m1} + \frac{K}{\alpha f g_{m1}^2}\right) g_{m1}\alpha + 4\gamma_5 \overline{G} + 4\gamma_{g5}\overline{G^2} + \frac{1}{R_L}}{c^2 g_{m3}^2 R_5} \quad (17)$$

Comparing recent developments in upconversion mixers

Reference	This work	2	3	4	5
Bandwidth GHz)	1.0 to 10.6	3.1 to 5.0	1.0 to 11.0	3.1 to 5.0	6.0 to 8.0
Noise figure (dB)	10.2 to 11.1	8.4	N/A	12.0 to 13.0	7.0
Gain (dB)	3.0 to 4.0	3.8	-6.0	6.5	0.03
IIP3 (dBm)	+2.5 to +16.56	-7.6	12.0	11.6 to 13.8	N/A
Supply (V)	1.2	1.5	1.8	1.0	1.8
Power (mW)	5.0	1.95	25.0	11.0	4.2
Size (mm)	0.75 x 5.00	0.6 x 0.6	0.5 x 0.6	0.86 x 0.6	0.64 x 0.64



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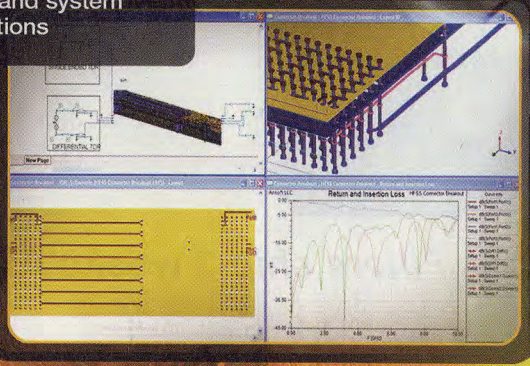

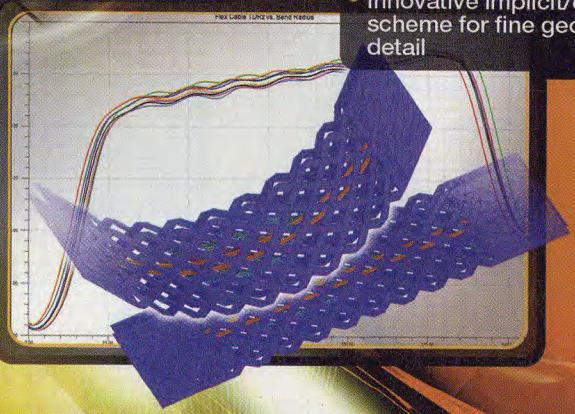

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comparing it to other reported mixers. The mixer proposed here achieves higher linearity than these other mixers, with lower operating voltage.

In summary, the simulations for an upconversion mixer based on a commercial 0.18-µm CMOS process show good results when applying a post-linearization technique to enhance linearity at low voltage levels. The mixer, which draws only 5 mW power from a +1.2-VDC supply achieves peak IIP3 of +16.56 dBm while also providing conversion gain of 3.5 dB. It is designed for use from 1.0 to 10.6 GHz and is suitable for multiple-standard wireless and UWB communications applications. MWRF

ACKNOWLEDGMENTS

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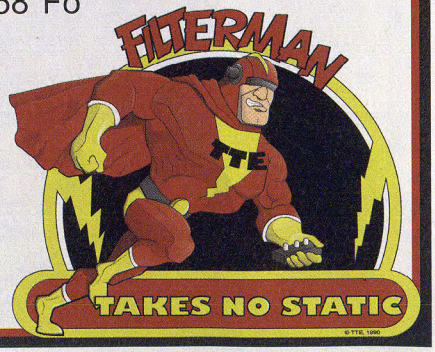

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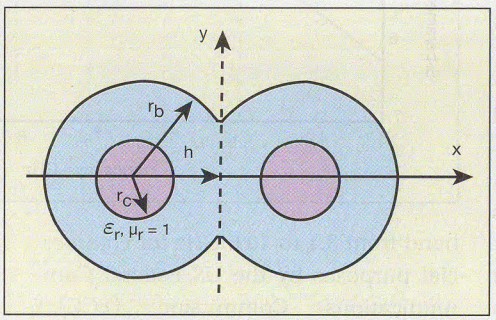
Create UWB Filters With Coaxial Cables

With the aid of a commercial EM simulator, sliced coaxial cables can be used to design and fabricate a bandpass filter with performance suitable for high-power UWB communications applications.

ULTRAWIDEBAND (UWB) communications offers great promise for voice, video, and high-data-rate transmissions, although key components will be needed for such systems. One of those components is the bandpass filter. Although traditional bandpass filters are designed and fabricated in planar form, it is also possible to create a UWB version using coaxial cables and coupled structures. The design approach is straightforward and the filter design can be readily analyzed by means of commercial electromagnetic (EM) simulation software.



1. This is a cross-sectional view of the coupled line with sliced coaxial cables used to form the UWB bandpass filter.

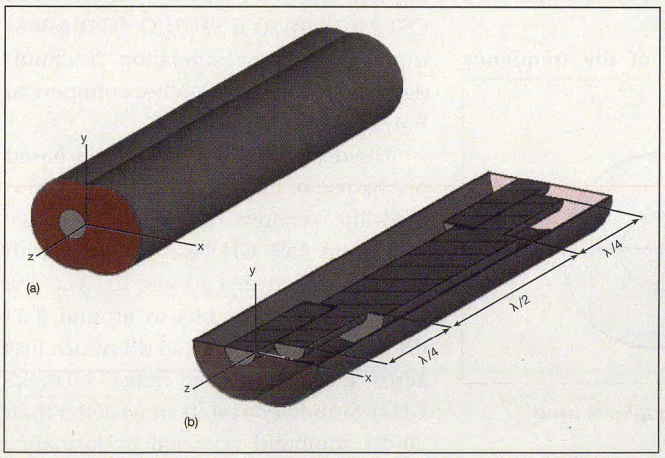
Coaxial cables, of course, vary widely in electrical and mechanical properties, with some cables capable of excellent phase stability with temperature and flexure and some being more sensitive to variations in amplitude and phase performance with temperature. The use of coaxial cable for constructing a bandpass filter requires an understanding of the mechanical requirements for an antenna as well as the electrical charactertics of the cable, such as the power-handling capabilities and the relative dielectric constant, in order to achieve a desired characteristic impedance for the filter.

Although they differ from traditional planar circuits, coupled sliced coaxial cables are high-frequency transmission lines that can support a variety of compact circuits, including directional couplers and RF/microwave power dividers. For example, they have been used to build a microwave directional coupler.[1] This kind of coupler has excellent performance in terms of high directivity, low VSWR, good isolation, excellent electromagnetic-interference (EMI) shielding, and high power-handling capability. Furthermore, since it is based on commercial semi-rigid coaxial cables and eliminates a mechanical housing, it is low in cost.[2,3]

Figure 1 shows the cross-section of a coupled line with sliced coaxial cables. The cable is assumed to be lossless with an inner conductor of radius r_c and an outer conductor of radius r_b. Dielectric material with relative dielectric constant ε_r fills the inside of the cable. A portion of each cable is cut out and two cut cables are used to form a coupled line (**Fig. 2**). The cut depth, u, as represented by h on the cross-sectional diagram can be found by the following equation:

$$u = \cos^{-1}(h/r_b)/\cos^{-1}(r_c)/r_b)$$

In ref. 4, a numerical tool under the FreeFEM (www.FreeFEM.org) environment[5] was used to analyze the electromagnetic (EM) parameters for sliced coaxial cables. This numeri-



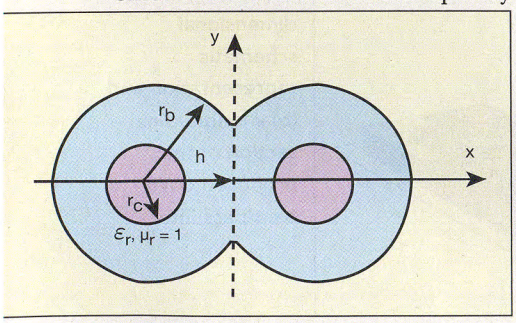
2. These views depict (a) a three-dimensional schematic representation and (b) a longitudinal section of the proposed UWB bandpass filter.

Although they differ from traditional planar circuits, coupled sliced coaxial cables are high-frequency transmission lines that can support a variety of compact circuits, including directional couplers and power dividers.

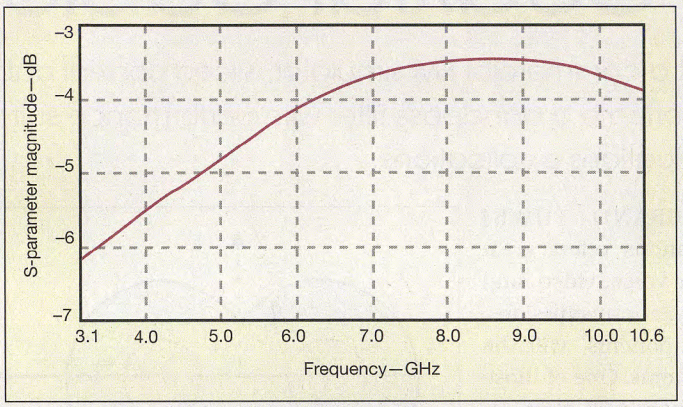
cal tool can be easily adapted to study any other transverse-electromagnetic (TEM) or quasi-TEM structures.[6] Also, the authors proposed rigorous analytical expressions for the primary parameters, including the inductance (L) and capacitance (C) matrices and the impedances of the even and odd modes for sliced coaxial cables, Z_{0e} and Z_{0o}, respectively.[7]

The analytical expressions—deduced from rigorous analyses by means of finite-element-method (FEM) and method-of-moments (MoM) approaches under the FreeFEM and LINPAR[8] environments, respectively—are convenient for all coupled sliced coaxial cables with a wide range of cut depths and outer-to-inner conductor radius ratios between 1.4 and 15. The authors proposed other analytical expressions[9] to calculate the dimensions of sliced coaxial cables used to form compact microwave couplers at the characteristic impedances of 50 and 75 Ω typically used for low-loss transmissions in RF/microwave and cable-television (CATV) systems, respectively. Using these analytical expressions, an analysis can be readily implemented in modern commercial CAE software tools for the design of microwave and wireless components.

Since the release of the frequency band from 3.1 to 10.6 GHz for commercial purposes by the US Federal Communications Commission (FCC),[10] UWB technology has sparked a great deal of interest for its potential in that band. Compact bandpass filters are essential components for UWB systems, but so far only planar structures have been reported for use in low power applications.[11-15] As an alternative approach, the authors propose a novel and a simple compact UWB bandpass filter using sliced coaxial cables, convenient for high power applications requiring a small filter footprint. The filter can be easily designed and fabricated using the Transient Solver[16] contained in CST MICROWAVE STUDIO® (CST MWS) from Computer Simulation Technology (www.cst.com) or other commercial EM software.



3. This sliced coaxial coupler is used to build the UWB filter.



4. This curve reveals the effect of the frequency on the coupling coefficient of the coupler of Fig.3.

The design of the UWB filter is based on the use of impedance steps and coupled-line sections. A center frequency of around 6.85 GHz was selected, with bandwidth between 3.1 and 10 GHz. The insertion loss amounts to around 0.33 dB with better than 11.25 dB return loss across a wide frequency range (4.0 to 9.5 GHz). Simulated results show better than 20-dB stopband rejection performance to 12.5 GHz. For this bandpass filter with center frequency of 6.85 GHz and with a substrate with relative dielectric constant, ε_r, of 2.03, the sliced coaxial-cable filter is extremely compact, measuring only 6 × 8.04 × 33.4 mm.

Figures 2(a) and 2(b) show a three-dimensional (3D) schematic representation and longitudinal section, respectively, of the proposed UWB bandpass filter, assuming 50-Ω external feed lines. The filter structure includes an isolated sliced coaxial cable in the middle and a coupled line with sliced coaxial cables at the two ends.[17] To achieve the UWB passband, the three sections of this filter are arranged with lengths of one-quarter, one-half, and one-quarter wavelength (λ/4, λ/2, and λ/4) as indicated in **Fig. 2(b)**.

As part of this study on UWB coaxial-cable bandpass filters, the authors examined the design of an UWB filter with characteristic impedance of 50 Ω having an inner conductor of radius r_c = 1 mm, outer conductor of radius r_b = 3 mm, and relative dielectric constant of ε_r = 2.03. The cut depth, u, was varied from 0.90 to 0.99 to achieve a coupling coefficient of less than 5 dB for the sliced coaxial coupler **(Fig. 3)**.

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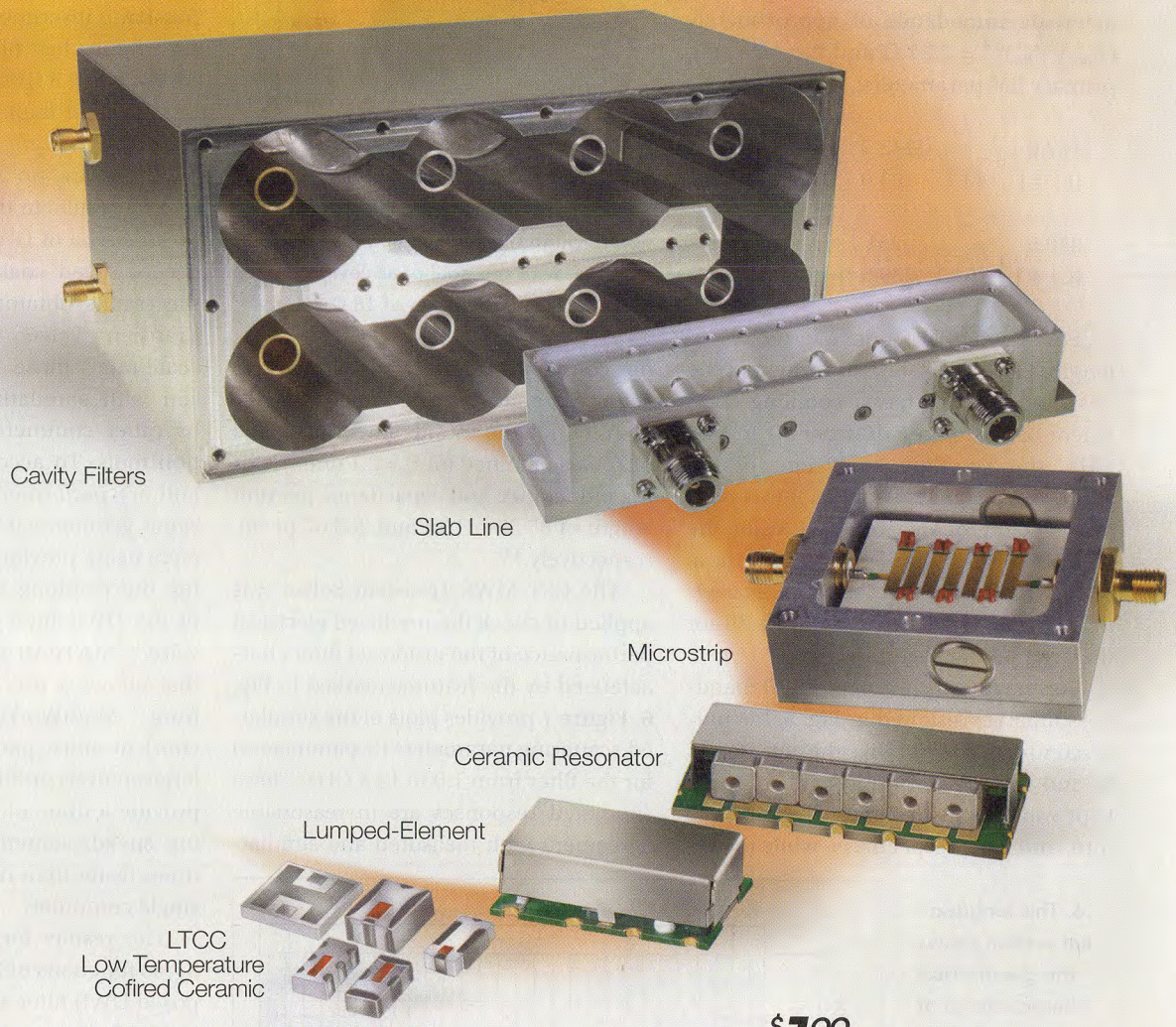

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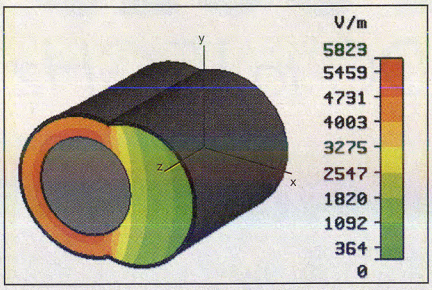
Building upon previous works based on FEM analysis, a coupling coefficient of 2 dB was obtained for a coaxial cable cut depth, h, of 1.02 mm. It yielded a characteristic impedance of approximately $(Z_{0e} \times Z_{0o})^{0.5} = 23.4\ \Omega$ and the following primary EM parameters:

$$[L] = \begin{bmatrix} 182.0 & 143.7 \\ 143.7 & 182.0 \end{bmatrix} \text{ (nH/m)}$$

$$[C] = \begin{bmatrix} 330.5 & -261.1 \\ -261.1 & 330.5 \end{bmatrix} \text{ (pF/m)}$$

For a length of one quarter wavelength, i.e., $l = \lambda/4$, and to verify that the designed coupler has a coupling coefficient of less than 5 dB from 3.1 to 10.6 GHz, the coupling coefficient of the sliced coaxial coupler of **Fig. 3** was plotted versus frequency in **Fig. 4**, using the CST MWS Transient Solver. From these results, it appears that the coupling coefficient varies between 3.4 to 6.15 dB for that frequency range.

For the middle line of the UWB bandpass filter represented in **Fig. 5**, the outer conductor radius, r_b, the cut depth, h, and the dielectric constant, ε_r, were kept constant, with values of 3 mm, 1.02 mm, and 2.03, respectively, while the inner conductor radius, r_c, was varied to achieve a characteristic impedance, Z_0, of 18 Ω, for the middle line. This value of Z_0 was obtained for $r_c = 2.1$ mm, yielding inductance and capacitance per unit length of 85.55 nH/m and 263.67 pF/m, respectively.[4,6]



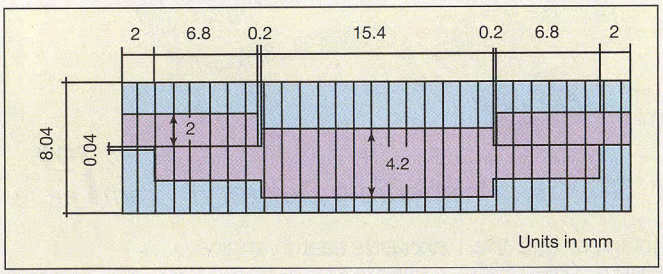
5. The middle line of the proposed UWB bandpass filter shows the energy distribution through the surrounding dielectric material, with the goal of achieving a characteristic impedance of 18 Ω.

The CST MWS Transient Solver was applied to check the predicted electrical performance of the proposed filter characterized by the features marked in **Fig. 6. Figure 7** provides plots of the simulated scattering parameters (S-parameters) for the filter from 1.0 to 12.5 GHz. These simulated responses are in reasonable agreement with measured and simulated results of planar bandpass filter structures. They also meet the requirements for high-power UWB applications per the FCC. The simulated results indicate passband insertion loss of about 0.33 dB with return loss of better than 11.25 dB from 4.0 to 9.5 GHz. The stopband rejection is better than 20 dB for frequencies to 12.5 GHz.

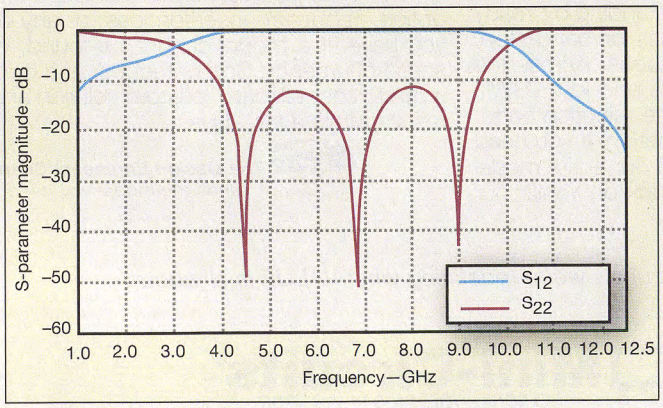
There are no numerical or experimental results in the scientific literature for this type of UWB filter based on the use of sliced coaxial cables. To check the results obtained by the CST MWS Transient Solver, it was necessary to "calibrate" those results by comparison with simulation results generated by other commercial software simulation tools. To accomplish this task, the authors performed simulations for the same geometrical and physical parameters using previous works and estimating the resulting scattering parameters of the UWB filter using MATPAR software.[18] MATPAR is a software package that allows a use of MATLAB software from MathWorks (www.mathworks.com) to enlist paralallel computers for large analysis problems. Such extensions provide a dramatic increase in processing speed, sometimes as much as 30 times faster than running MATLAB on a single computer.

The results for coefficients S_{11} and S_{12} as functions of frequency for the proposed UWB filter structure are provided in **Fig. 8. Figures 7 and 8** show that the responses obtained by the two numerical models (the CST and MATPAR software simulations) are in a good agreement. Although this comparison of simulations from two different software programs is not as valid as comparing the modeled simulation results to the measured results obtained from the analysis of a prototype filter, it does indicate that the basic design parameters for the filter are sound and should yield actual performance that is relatively close to either of the simulated performance plots.

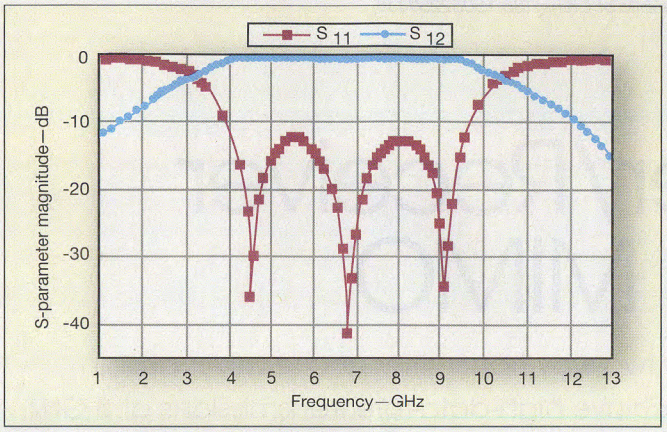
In summary, sliced coaxial cables can be used to form a wideband bandpass filter capable of handling high power levels



6. This longitudinal section shows the geometrical characteristics of the designed UWB bandpass filter.



7. These plots show how simulation software can help in the study of an UWB bandpass filter using sliced coaxial cables.



8. These scattering parameters of the designed UWB BPF were obtained using commercial math analysis software.

in a relatively small footprint. The filter, which measures just 6.00 x 8.04 x 33.40 mm, was fabricated by means of impedance steps and coupled-line sections. It was designed with the aid of the CST Transient Solver software, although other commercial EM simulation software programs can also be used with similar success. The compact bandpass filter features a broad bandwidth ranging from 3.1 to 10.0 GHz with better than 11.25 dB return loss and about 0.33 dB insertion loss over a large portion of its total passband. The design is inherently low in cost due to its humble material requirements and realtively simple to fabricate once dimensions are calculated. MWRF

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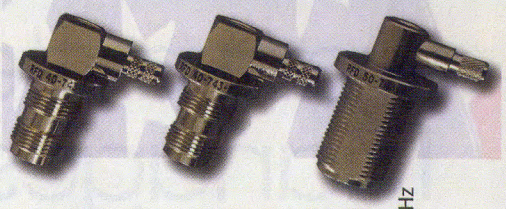

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RG 142	#	#	#	#	–
RG 223	#	#	#	#	–
Sig 195*	#	#	#	#	–
Sig 240*	Δ	Δ	Δ	Δ	–
LMR 195*	#	#	#	#	–
LMR 240*	Δ	Δ	Δ	Δ	–
HP 450	–	–	–	–	#
HP 500	–	–	–	–	#
LA 190	–	–	–	–	Δ
LA 290	–	–	–	–	Δ
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RFD 191	–	–	–	–	Δ
RFD 290	–	–	–	–	Δ

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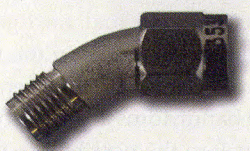

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Transmitter/Receiver Manages MIMO

This high-performance, low-cost two-way transmitter and receiver design employs MIMO techniques to achieve high-data-rate transmissions at 8 GHz.

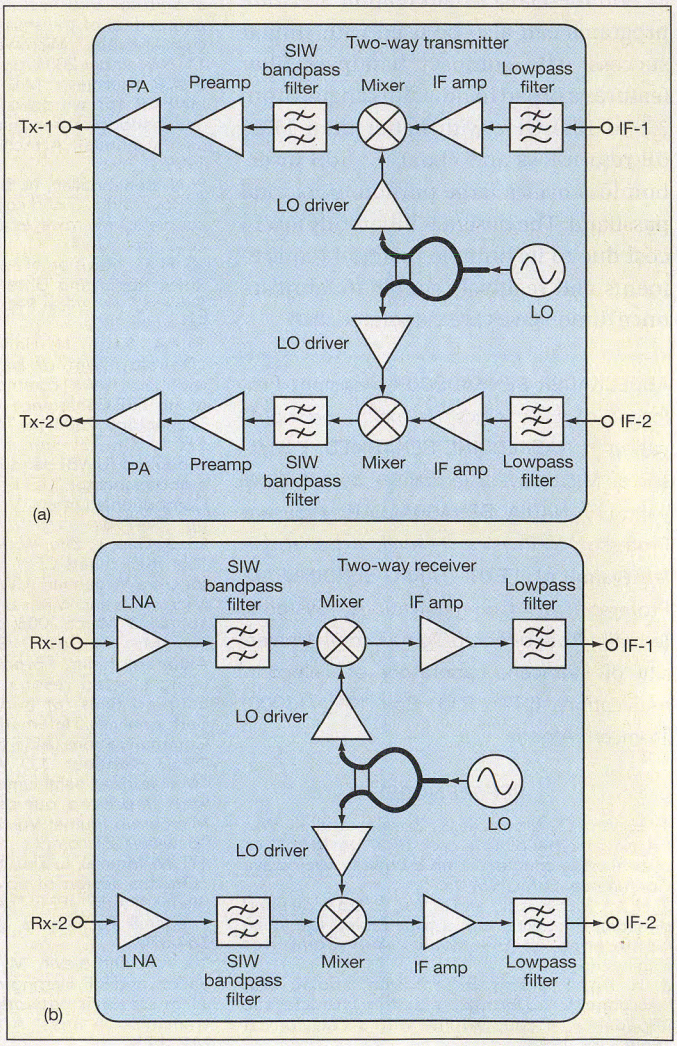
FAST DATA transfers usually require large bandwidths. But the use of multiple-input, multiple-output (MIMO) antenna techniques can also boost data rates for available bandwidths, as shown with this high-performance two-way transmitter and receiver design operating with a 100-MHz bandwidth at 8.05 GHz. It boasts excellent performance, with a receiver noise figure of 2.7 dB and transmitter output power of +17 dBm at 8.05 GHz and associated third-order intermodulation (IM3) level of –41.4 dBc. In addition, the MIMO-based system achieves measured error-vector-magnitude (EVM) performance of 9.07% for an 83.3-MSymbol/s quadrature-phase-shift-keying (QPSK) signal and 6.24% for an 83.3-MSymbol/s 16-state quadrature-amplitude-modulated (16QAM) signal.

Expectations are high for fast data access in both fixed and mobile wireless applications. According to the International Telecommunications Union (ITU), fourth-generation (4G) wireless communications networks should support data rates to 1 Gb/s for low-mobility applications and 100 Mb/s for high-mobility applications.[1] To meet these requirements, advanced technologies are needed, including high-level modulation schemes, orthogonal frequency division multiplexing (OFDM), and MIMO techniques, and the channel bandwidth should be at least 100 MHz.[2-5] However, most existing communications standards employ no more than 20 MHz bandwidth.[6] The most desirable RF/microwave bandwidths, below 6 GHz, are already well occupied, so that next-generation wireless applications are expected to operate in the next higher-frequency available bands from 6 to 15 GHz,[7] where continuous multiple 100-MHz channel bandwidths are available.

To explore the possibilities for high-data-rate wireless communications in that 6-to-15-GHz band, a two-way transmitter and receiver for use with MIMO wireless techniques at 8.05 GHz were designed and implemented.

Figures 1(a) and (b) show block diagrams of the two-way MIMO transmitter and receiver, respectively. The subsystems employ a classic superheterodyne transceiver architecture. The center frequency of the transmitting and receiving IF signal is set at 850 MHz, with a bandwidth of 100 MHz. The required RF specifications for the transmitter and receiver are listed in **Tables 1(a) and (b),** respectively.

For the two-way transmitter and receiver, the local oscillator (LO) is comprised of a phase-lock-loop (PLL) frequency synthesizer. To meet the high linearity requirement listed in **Table 1(a)**,



1. These block diagrams show (a) the two-way transmitter and (b) the two-way RF receiver.



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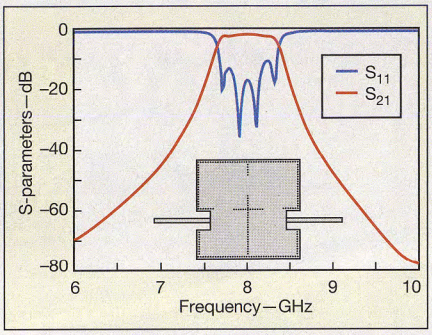
IF/RF MICROWAVE COMPONENTS

a passive mixer, which requires +17 dBm LO drive power, is used for the receiver, and an LO drive amplifier is used with each mixer. To meet the conversion gain requirement of the two-way transmitter, an intermediate-frequency (IF) amplifier and two RF power amplifiers cascaded together are also used.

For the two-way receiver, a low-noise amplifier (LNA) with adequate gain helps meet the noise-figure requirements for the downconversion signal chain listed in **Table 1(b)**. Following downconversion, a low-noise IF amplifier is added to provide suitable conversion gain, and to minimize the impact of the following stage on the noise figure of the receiver.

System-level simulations were carried out for the RF transmitter and receiver using Advanced Design System (ADS) software from Agilent Technologies (www.agilent.com). All the RF bandpass filters in the two-way transmitter and receiver were based on substrate-integrated-waveguide (SIW) techniques,[8-10] for suppressing image signals, LO signals, and other interference. The SIW filters are low in cost and compatible with standard printed-circuit-board (PCB) fabrication methods. The SIW filters are designed and simulated with the help of the full-wave High-Frequency Structure Simulator (HFSS) electromagnetic (EM) simulation software from Ansoft Corp. (www.ansys.com). Simulation results are shown in **Fig. 2**.



2. These simulation results show the performance of a SIW bandpass filter, such as those used in the two-way transmitter and receiver.

Table 1(a): Specifications for the two-way transmitter

Parameter	Specification
Operating band	8.0 to 8.1 GHz
Channel bandwidth	100 MHz
Conversion gain	≥22 dB
Gain flatness	≤2.5 dB
Amplitude unbalance	≤1 dB
Transmit third-order intermodulation (at +17-dBm output power)	≤–40 dBc

Table 1(b): Specifications for the two-way receiver

Parameter	Specification
Operating band	8.0 to 8.1 GHz
Channel bandwidth	100 MHz
Conversion gain	≥26 dB
Gain flatness	≤2.5 dB
Amplitude unbalance	≤1 dB
Noise figure	≤3 dB

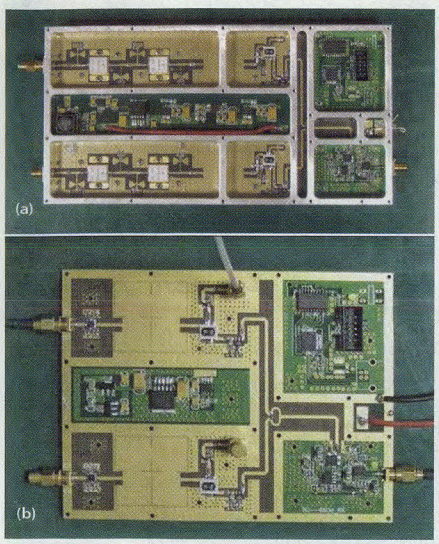


Following the simulations, the two-way RF transmitter and receiver designs were fabricated and integrated on PCBs. A frequency-control module was also included, to control the PLL frequency. **Figure 3** shows photographs of the fabricated prototypes.

The measured performance of the two-way transmitter and receiver (RF = 8.0 to 8.1 GHz, LO = 7.2 GHz, IF = 800 to 900 MHz) includes the output power of the transmitter (when the IF input power = –5 dBm), the conversion gain of the receiver, and the IM3 product of the transmitter (when the output power = +17 dBm). Detailed measured results are listed in the **Tables 2(a) and (b)**.

To measure the overall performance of the transmitter and receiver as a communications system, a test system consisting

of the prototype transmitter and receiver was constructed to measure the EVM performance. **Figure 4** shows a schematic diagram for the EVM measurement setup. The frequency-conversion plan was: RF = 8.0 to 8.1 GHz, LO = 7.2 GHz, IF = 800 to 900 MHz. In the test setup, a model SMBV100A vector signal generator from Rohde & Schwarz (www.rohde-schwarz.com) was modulated with in-phase/quadrature (I/Q) signal generated by an N8241A arbitrary waveform generator (AWG) from Agilent Technologies.



3. These prototype circuits show (a) the two-way transmitter and (b) the two-way receiver.

The modulated IF signal is first upconverted by the transmitter, then sent through an appropriate attenuator (to simulate path loss), and then downconverted by the receiver. The resultant IF signal is demodulated and analyzed by a model 89600 vector signal analyzer (VSA) from Agi-

Table 2(a): RF measurement results for the two-way transmitter

Parameter	Specification
Center frequency	8.05 GHz
Conversion gain	24.6 dB
Gain flatness	1.8 dB
Amplitude unbalance	0.3 dB
Transmit third-order intermodulation (at +17-dBm output power)	–41.4 dBc

Table 2(b): Specifications for the two-way receiver

Parameter	Specification
IF center frequency	850 MHz
Conversion gain	28.6 dB
Gain flatness	0.6 dB
Amplitude unbalance	0.8 dB
Noise figure	2.7 dB

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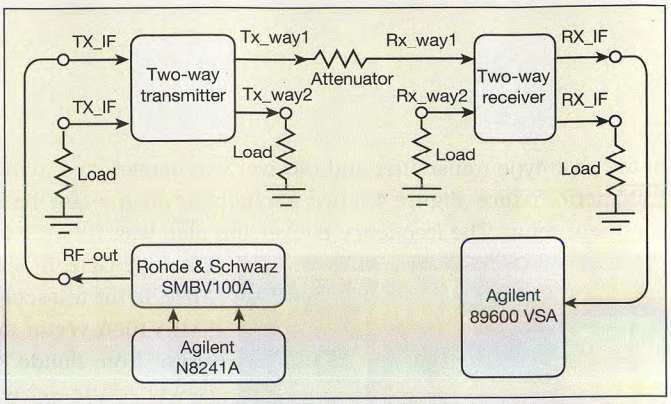
lent Technologies to determine the EVM. During the measurement process, several baseband signals with different modulation types and symbol rates were applied.

Figure 5 shows measured EVM results for a 20-MSymbol/s baseband signal applied with modulation of (a) QPSK, (b) 16QAM, and (c) 256-state quadrature amplitude modulation (256QAM). Under those three modulation conditions, the measured EVM values were 2.02%, 1.16%, and 1.06%, respectively. To test the wideband performance of the transmitter and receiver, an 83.3-MSymbol/s (with occupied bandwidth of 92.5 MHz) baseband signal was applied with the following modulation formats: (a) QPSK and (b) 16QAM, with resulting EVM of 9.07% and 6.24%, respectively. The measured EVM results are shown in **Fig. 6.** The measured results show that the two-way MIMO communication system can support high spectrum efficiency and high data rate communications with low EVM.

In summary, low-cost, high-performance two-way transmitter and receiver designs were developed for use at 8.05 GHz. They support high data rates over a 100-MHz bandwidth using MIMO techniques. Measurements reveal low EVM for reliable high-data-rate performance with high spectral efficiency. MWRF



4. This diagram shows key instruments in the EVM test setup.

ACKNOWLEDGMENTS

This work was supported in part by the NSFC under Grant No. 60921063, and in part by the National Science and Technology Major Project of China under grants No. 2010ZX030007-02-01 and 2011ZX03004-003.

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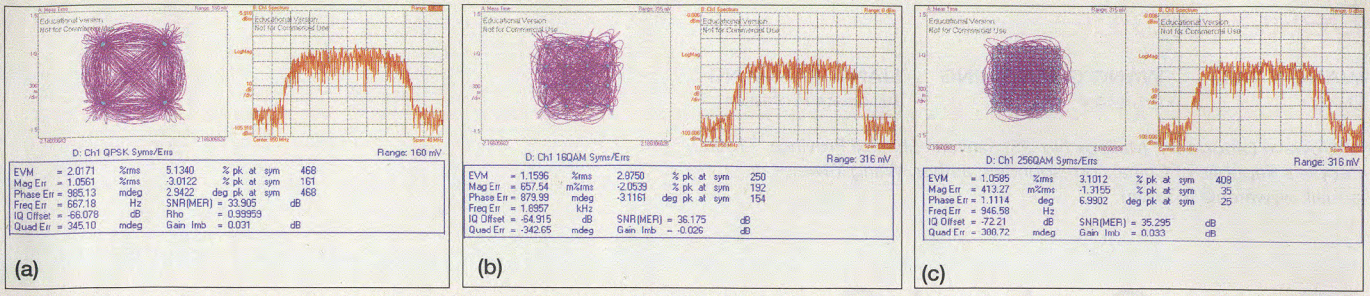
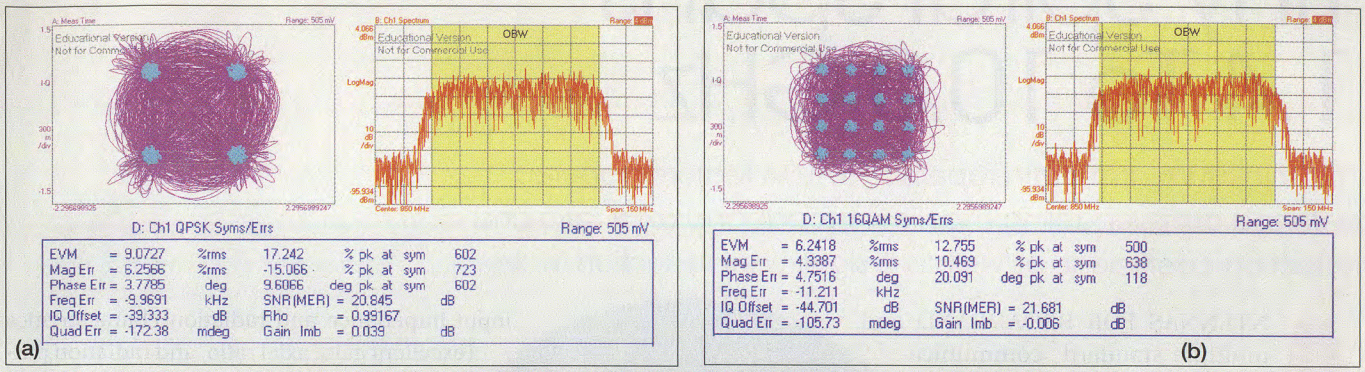


5. Test system EVM was measured with 20-MSymbols/s signals with the following modulation: (a) QPSK, (b) 16QAM, and (c) 256QAM.



6. The experimental system EVM was measured with 83.3 MSymbols/s and baseband signals with: (a) QPSK and (b) 16QAM.

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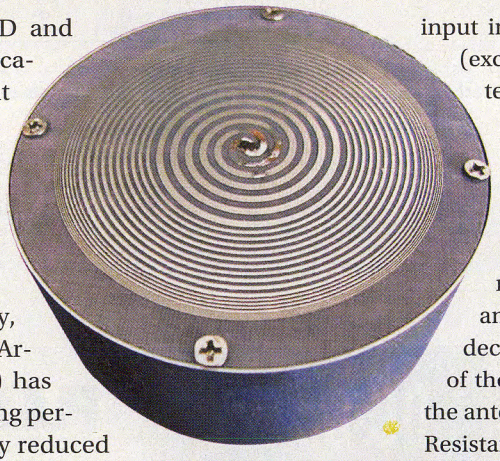
Tiny Spiral Spans 1.4 To 10.0 GHz

This miniature arm-width-tapered ATARSA features tapered antenna arms, enabling excellent broadband axial ratio and reflection coefficient, as well as a significant reduction in size.

ANTENNAS FOR BROADBAND and multiple-standard communications must provide excellent performance in a small area. While a spiral antenna can provide consistent radiation patterns, the size reduction is often a problem, since the antenna's design is related to the physical wavelengths of the operating frequencies. Fortunately, a miniaturized arm-width-tapered Archimedean spiral antenna (ATARSA) has been designed that delivers outstanding performance in a size that is dramatically reduced compared to conventional spiral antennas.



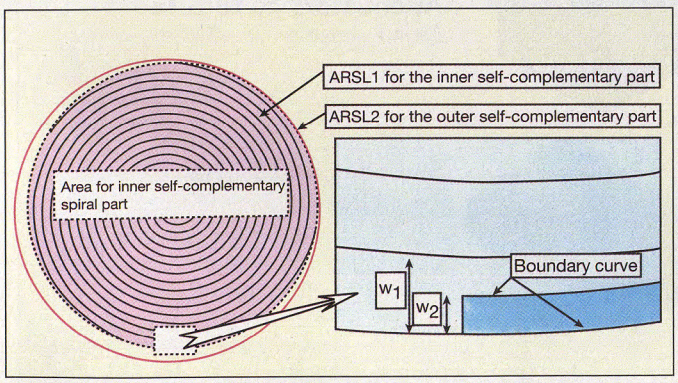
1. This photograph shows a prototype of the ATARSA.

The arms of the antenna are tapered to maintain self-complementarity, helping to achieve that good performance in a small size. Comparing the results of computer simulations and measurements (which agree closely), the ATARSA offers reflection coefficient and axial ratio of –10 dB and 3 dB, respectively, from 1.4 to 10.0 GHz. It features a 73.1% reduction in area compared to a typical Archimedean spiral antenna designed for the same frequency band.

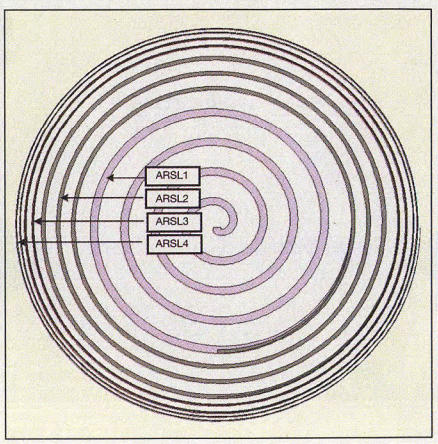
Spiral antennas have long been appreciated for their stable input impedance and radiation characteristics (excellent gain, axial ratio, and radiation patterns) over several octaves. The tradeoff has been their large size when designed for low-frequency operation. As a result, a variety of techniques have been developed to reduce the size of a spiral antenna. One of the most efficient methods is to add loads to the ends of the antenna.[1-10] Reactance loading can greatly decrease the phase velocity along the arms of the antenna, helping to reduce the size of the antenna by 50%.[1]

Resistance loading[2,3] and the use of microwave absorber materials[4-6] have also been used for size reductions in spiral antennas, but they weaken the current at the ends of the antenna arms—helping to achieve lower-frequency operation in a smaller antenna size, but with a sacrifice in gain performance. Tapered spiral lines have been used, as detailed in refs. 7-10, in order to improve the low-frequency response of a spiral antenna by reflecting the current from the ends of the antenna arms. As ref. 7 explains, making a tapered line thinner and with more windings on a fixed radius helps to miniaturize a spiral antenna with enhanced performance at low frequencies.

Up until now, tapered spiral lines have been applied mainly to the ends of equiangular spi-



2. This schematic diagram shows the basic construction of the ATARSA with its precisely defined spiral curves.



3. The ATARSA's width tapered antenna arm can be modeled with these parameters.



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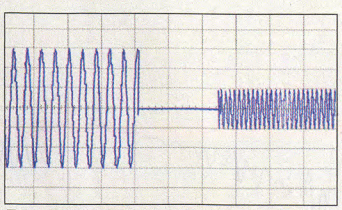
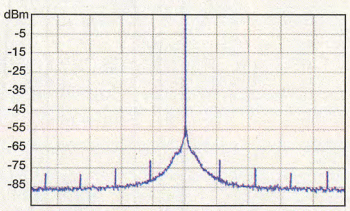


Frequency and power hopping.



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ral antennas rather than Archimedean spiral antennas (ARSAs)[8-10] in attempts to achieve size reductions. The tapered lines have typically degraded or destroyed the self-complementarity of the antennas, limiting the amount of impedance matching possible at the cost of low-frequency performance.

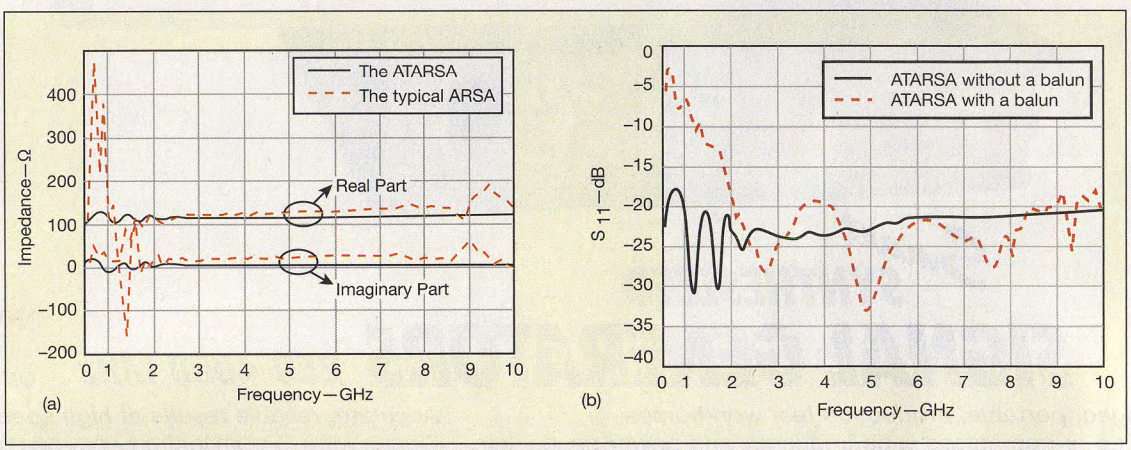
To overcome these limitations, a new method was developed for tapering the arms of an ARSA while also preserving the self-complementarity of the design. **Figure 1** shows an ATARSA, designed for an operating frequency range of 1.58 to 10.00 GHz; it has an outer diameter of only 53 mm. The small size is achieved by a combination of thin tapers and increased number of windings. The antenna is backed by an absorber-loaded cavity to enhance its unidirectional operation. This eliminates back-side radiation without decreasing the frequency band of operation, although at some loss of efficiency. An exponentially tapered microstrip balun is employed as a balanced feed for the antenna.

When an ATARSA is designed, the self-complementarity of an ARSA is maintained in a transition area **(Fig. 2)**. Archimedean spiral curves are defined by the function $r = r_0 + a\phi$ where r_0 is the original radius of the spiral line, a is the spiral constant, and ϕ is the winding angle (derived from the starting angle, ϕ_{st} and the ending angle, ϕ_{end}). The width of the Archimedean spiral lines must be $a\pi/2$ when a two-arm self-complementary ARSA is built.

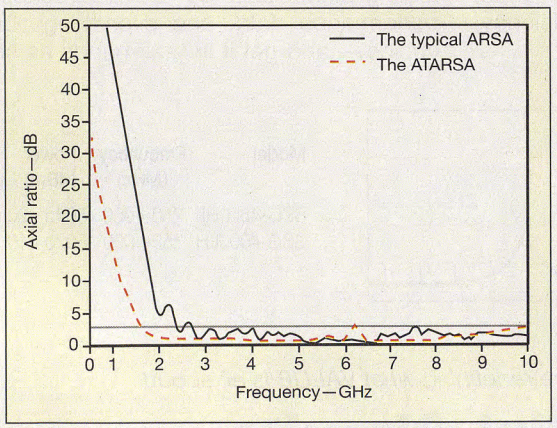
In **Fig. 2**, the inner area is fully filled without any overlap by duplicating a self-complementary Archimedean spiral line (called ARSL1) at every 90-deg. rotation. The second self-complementary Archimedean spiral line, ARSL2, begins at the ϕ_{end} of ARSL1. Its outer boundary curve is flush with that of the inner area and its inner boundary curve is flush with the outer boundary curve of the inner winding area after a 90-deg. winding. In this way, it can fill the outer area. The width of ARSL2 (w_2) is smaller than the width of ARSL1 (w_1), so the arm width is tapered and the self-complementary structure of the ATARSA is preserved.

The miniature ATARSA was modeled by understanding its mechanical construction. Its antenna arms consisted of ARSLs with four different widths **(Fig. 3)**. If these four ARSL "subantennas" are considered as ARSL1, ARSL2, ARSL3, and ARSL4, then ARSL1 was formed with four windings with width of 1 mm, ARSL2 was constructed with three windings 0.5 mm wide, ARSL3 with two windings each 0.25 mm wide, and ARSL4 with two windings each 0.125 mm wide. There were 11 windings in the antenna aperture, the outer diameter of which is 53 mm. To achieve good matching behavior, the original radius of ARSL1 was chosed as 1 mm. The ATARSA was fabricated from a circular substrate with relative dielectric constant of 4.3 in the z direction at 10 GHz and thickness of 1 mm.

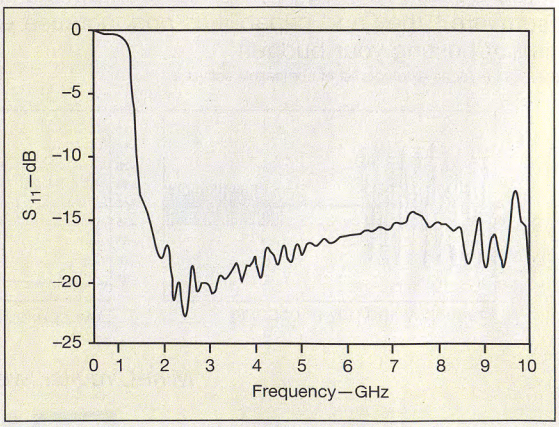
Continued on p. 73.



4. These plots reveal (a) the impedances of the ATARSA and a typical ARSA and (b) the S_{11} behavior of the ATARSA with and without a balun.

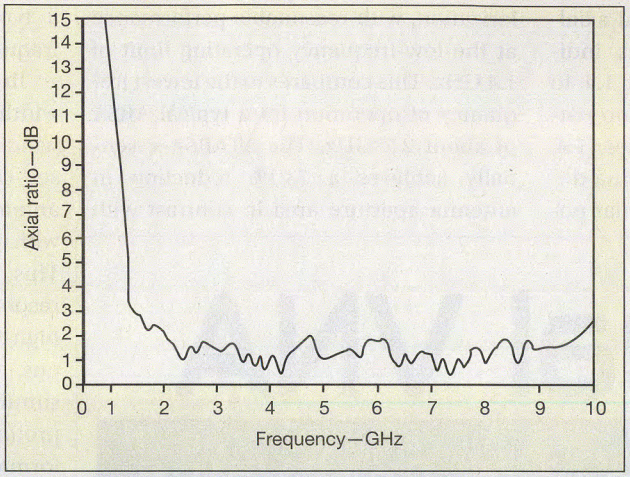


5. These plots compare the axial ratios of the ATARSA with a typical ARSA.



6. The measured S_{11} performance of the ATARSA is plotted here.

The characteristic impedance of a two-arm ATARSA simulated alone is shown in **Fig. 4(a)**, together with the characteristic impedance of a typical self-complementary ARSA with arm width and outer diameter of are 1 mm and 53 mm, respectively. According to basic ARSA design principles, the wavelength of the lowest frequency of operation will be determined by the formula $C \geq 1.5\lambda$, where C is the circumference of the antenna aperture and λ is the wavelength of the lowest operating frequency. By this formula, the lowest frequency of operation for the miniature ATARSA is 2.7 GHz. But from **Fig. 4**, it is possible to find that real and imaginary parts of the ATARSA's impedance change more gradually over frequency than those of an ARSA. The imaginary part of the ATARSA's impedance changes more approximately to zero, likely because of the better self-complementary structure of the ATARSA than the ARSA. As a result, the ATARSA provides excellent reflection coefficient characteristics with impedance chose for 100Ω across the full operating band **[Fig. 4(b)]**. An exponentially tapered microstrip balun was used as the feed for the ATARSA. **Figure 4(b)** shows the simulated results for S_{11} when the ATARSA is fed by that balun, with S_{11} better than –10 dB from 1.3 to 10.0 GHz.



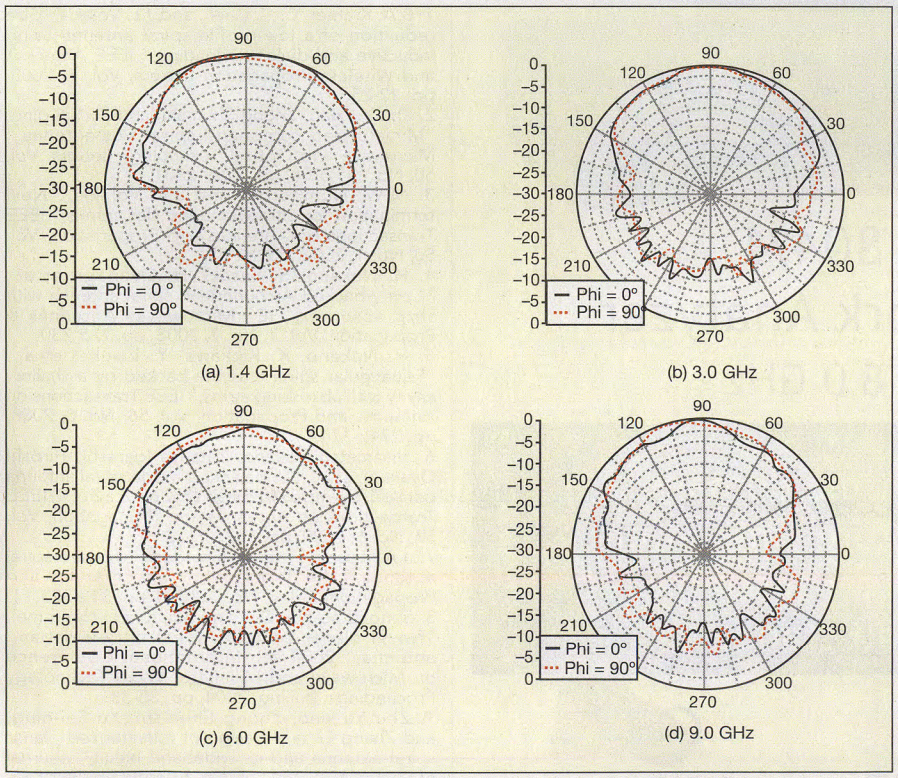
7. The measured axial ratio of the ATARSA is shown here.

The performance of the spiral antenna was evaluated by simulating and measuring its axial ratio, a parameter that assigns a value to the ratio of an antenna's electric field strength in its two major axes. For an antenna with radiating field that is perpendicular to the direction of propagation, the electric field magnitude is generally reprsented by an ellipse which can be characterized by the axial ratio. An antenna's polarization can be linear, circular, or elliptical where, in the first two cases, a plot of the antenna's electric field appears as a straight line or a circle, respectively. The polarization in turn can be characterized as rotating in a clockwise direction, and being designated as right-hand polarization, or rotating in a counterclockwise direction, and being called left-hand polarization.

Figure 5 offers another comparison between the axial-ratio performance of a typical ARSA and the novel ATARSA. The ATARSA shows excellent performance in terms of circular polarization. According to the simulations of axial ratio, the ATARSA works well with circularly polarized signals in the frequency range from 1.4 to 10.0 GHz.

For the prototype, the ATARSA was etched onto a 1-mm-thick, copper-laminated dielectric substrate with permittivity of 4.3. The antenna was backed by a cavity full of microwave absorber material to improve directivity. Measurements were performed with a commercial microwave vector network analyzer (VNA), with results shown in **Fig. 6**. The measured results show good antenna performance from 1.4 to 10.0 GHz, correlating well with the simulated results.

Figure 7 shows the axial ratio of the ATARSA in the main direction of radiation. The plot reveals the excellent broadband characteristics of the antenna. The VNA-measured results, while not exactly matching the simulated data



8. These plots show radiation patterns at several frequencies: (a) 1.4 GHz, (b) 3.0 GHz, (c) 6.0 GHz, (d) 9.0 GHz.

of **Fig. 5,** do track the broadband axial-ratio behavior of the simulations, indicating stable performance from 1.4 to 10.0 GHz. **Figure 8** shows radiation patterns for four different frequencies (1.4, 3.0, 6.0, and 9.0 GHz). The antenna design appears to do well with circular polarization, with reasonable performance at the low-frequency operating limit of 1.4 GHz. This compares to the lowest frequency of operation for a typical ARSA of about 2.7 GHz. The ATARSA essentially achieves a 73.1% reduction in antenna aperture area in contrast with a typical ARSA working in the same frequency band.

In conclusion, by tapering the arm width of the antenna along an increasing winding angle, it was possible to design a self-complementary Archimedean spiral antenna with miniature dimensions but with good low-frequency performance. This difficult-to-achieve low-frequency response combines with the antenna's high-frequency capability for a continuous, wideband radiation pattern. The simulations and measurements of a prototype ATARSA shows excellent performance from 1.4 to 10.0 GHz, with significantly more effective miniaturization than reported in refs. 8-10.

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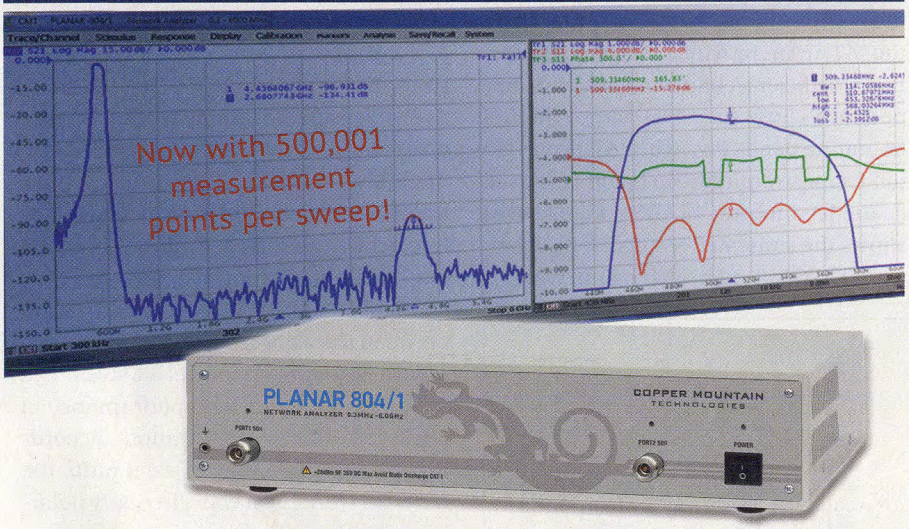

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The authors would like to thank the support from National Natural Science Foundation of China under Grant No. 60971118. Thanks are also due to the reviewers for their valuable comments. MWRF

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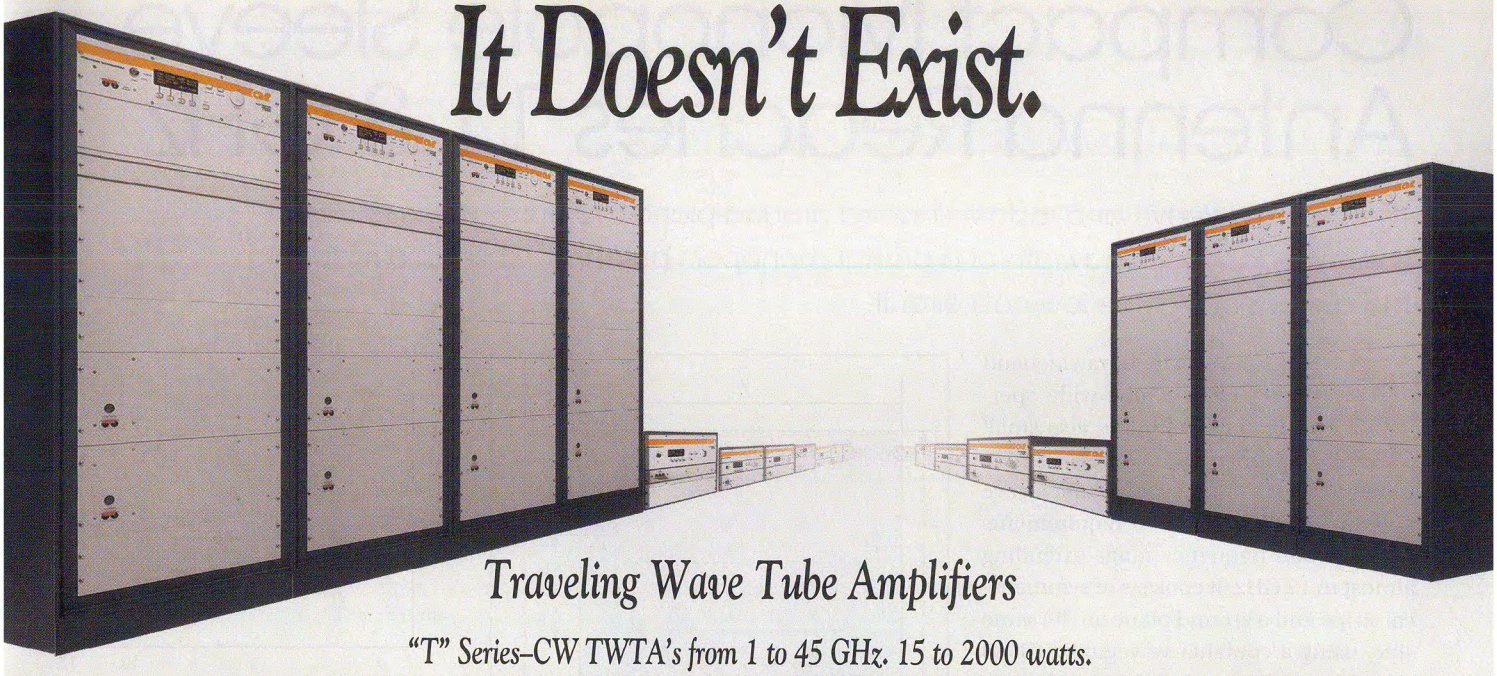

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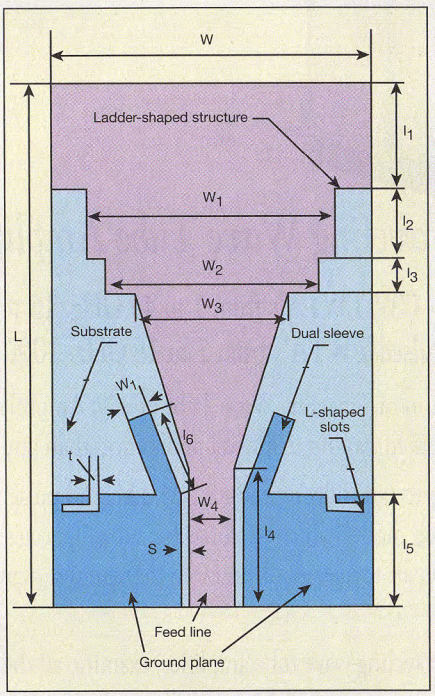
The use of a sleeve and ladder-shaped ground-plane structures helps to widen the impedance bandwidth of a planar monopole antenna, while also reducing the dimensions of the low-cost circuit.

ANTENNAS FOR ultrawideband (UWB) must exhibit wide operating bandwidth, but also small size for use in a variety of electronic devices. A monopole planar sleeve antenna may meet those requirements with a broad frequency range extending almost to 12 GHz. It consists of symmetrical strips and a ground plane on the same side, using a coplanar-waveguide (CPW) structure on low-cost FR-4 dielectric substrate material with relative dielectric constant of 2.95 and thickness of 1.6 mm. This antenna is suitable for worldwide interoperability for microwave access (WiMAX) applications.

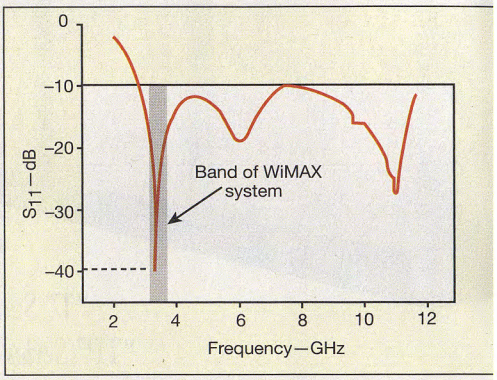
Numerous types of antennas have been proposed for UWB applications.[1,2] Among the various types of UWB antenna designs proposed, the planar monopole antenna is particularly promising: It can provide uniform radiation fields and be integrated seamlessly with other electronic devices.[3,4]

Ground-plane effects play strong roles in the characteristics of a planar monopole antenna, including its impedance bandwidth and radiation pattern. The dual-sleeve tuning technique has been successfully applied to create antennas with wideband characteristic impedance,[5] while the technique of forming slots on the ground plane has been adopted for use in many kinds of antennas.[6-9]

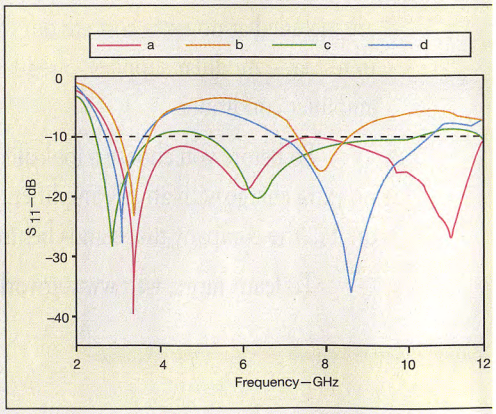
The proposed planar monopole sleeve antenna exhibits the desired return-loss characteristics for UWB communications. Its 10-dB bandwidth covers the UWB spectrum from 3.1 to 10.6 GHz and more, provided by using a trapezoid conductor and L-shaped slots in the ground plane. The use of such a structure enhances the impedance bandwidth.[10]



1. This diagram shows the geometry of the proposed printed planar monopole antenna.

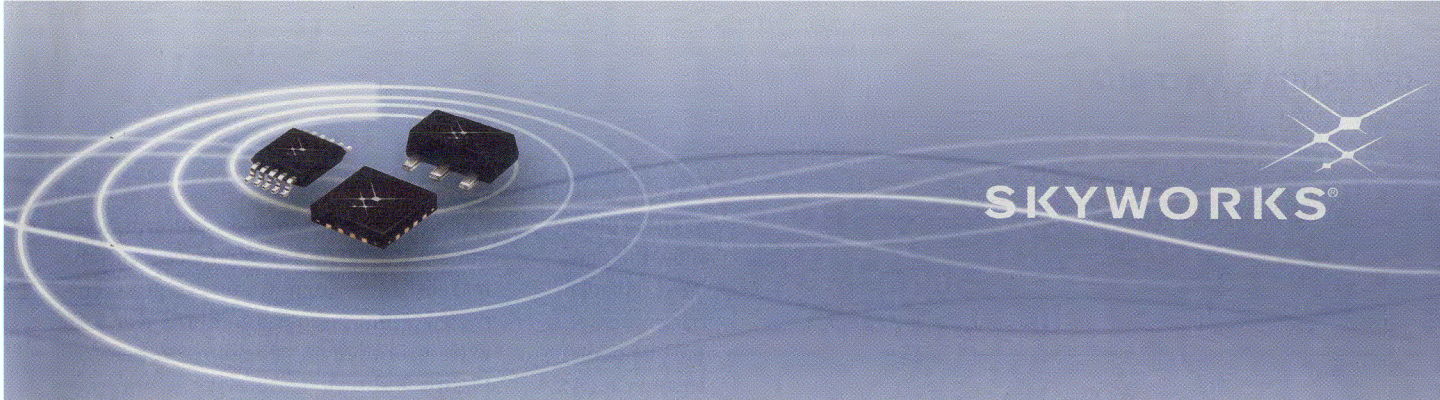


2. This plot shows the S_{11} behavior of the monopole antenna as simulated by the HFSS EM software.



3. These plots show S_{11} responses for different antenna structures, as simulated by the HFSS EM software: (a) the monopole antenna with the sleeve and ladder-shaped structure, (b) the monopole antenna with just the ladder-shaped structure, (c) the monopole antenna with just the sleeve, and (d) just the monopole antenna without the two structures.

Figure 1 shows a layout for the proposed antenna. It consists of a trapezoid and a ladder-shaped patch fed by a 50-Ω transmission line. L-shaped slots are cut from the edge of the ground plane and a 4.7-mm-long sleeve is attached to each side of the ground plane. Two patches



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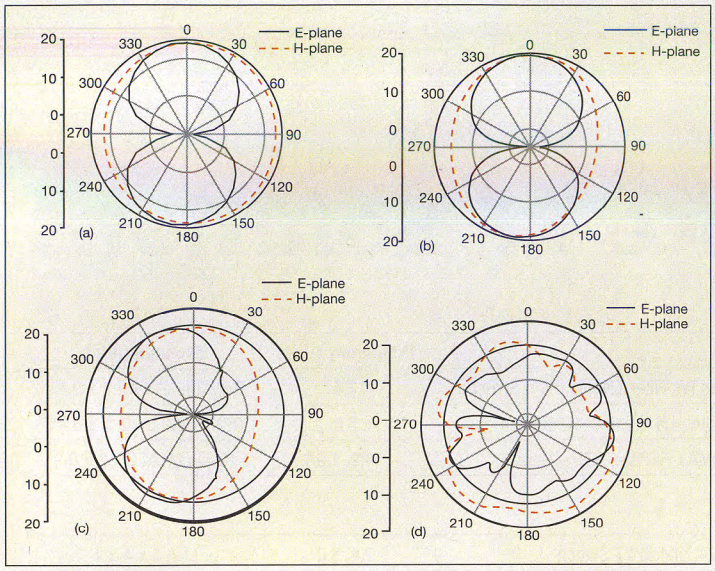


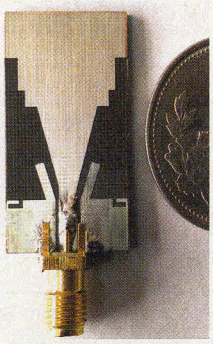
4. These plots show the simulated radiation patterns of the monopole antenna at (a) 3.4 GHz, (b) 6.0 GHz, (c) 8.0 GHz, and (d) 10.0 GHz.

form a 38.5-deg. angle. The trapezoidal structure improves the impedance bandwidth. The lower-frequency resonant point can be adjusted by changing the size of the ladder-shaped patch; the higher-frequency resonant point links tightly to the dual-sleeve structure to broaden the impedance bandwidth. To achieve a compact structure, the slots on the ground plane are chosen to be L-shaped configurations.

The antenna is printed on a standard, low-cost FR-4 copper-clad substrate with thickness of 1.6 mm and relative permittivity of 2.95. The overall size of the antenna is 32 x 20 x 1.6 mm. Its performance and behavior were analyzed with the aid of the Ansoft High-Frequency Structure Simulator (HFSS) software (www.ansys.com).

Figure 2 shows the simulated reflection coefficient (dB) as a function of frequency (GHz). The 10-dB bandwidth reaches from 2.39 GHz to 11.8 GHz, meeting the UWB application. Also, the reflection coefficient from 3.3 to 3.7 GHz (for WiMAX applications) is better than –17.5 dB. At 3.39 GHz, it reaches nearly –40 dB.

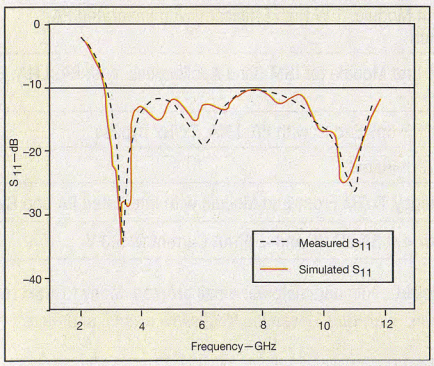
Figure 3 shows the effects of the ladder-shaped conductor and the sleeve on the monopole antenna's reflection-coefficient performance. As can be seen from the curves of **Figs. 3(b) and 3(d)**, the lower resonant frequency has been adjusted to 3.39 GHz by the use of the ladder-shaped conductor. **Figures 3(c) and 3(d)** show how the sleeve tuning method produces a new higher resonant frequency, while also expanding the impedance bandwidth.



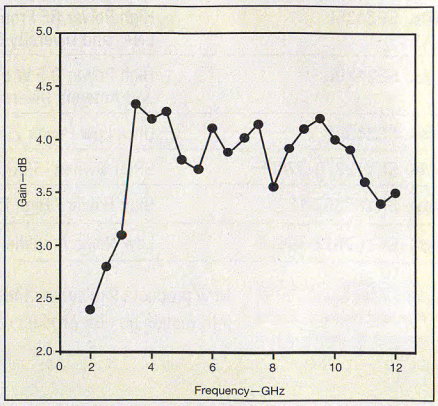
5. This photograph shows the prototype monopole antenna, fabricated on FR-4 substrate.

The far-field radiation patterns in the x-y E and H planes were computed at four frequency points: 3.4, 5.0, 8.0, and 10.0 GHz. **Figure 4** shows that nearly omnidirectional radiation patterns were obtained at all four frequencies. With the increase in frequency, however, the symmetry of the radiation patterns was lost, with pronounced sidelobes appearing. **Figure 5** shows a prototype of the proposed antenna; its dimensions are listed in the **table**. Measurements of return loss agree well with the simulations provided in **Fig. 6**. **Figure 7** shows that the measured peak antenna gain as a function of frequency varied approximately from 2.4 to 4.4 dBi.

In conclusion, the use of the sleeve and ladder-shaped structures can help shrink the dimensions of a planar monopole antenna while also providing the wide impedance bandwidth needed for UWB communications applications. MWRF



6. These plots compare the simulated and measured S_{11} responses for the planar monopole antenna.



7. This plot shows the measured gain of the compact planar monopole antenna.

ACKNOWLEDGMENTS

The authors would like to thank the National Natural Science Foundation of China for its support under Grant No. 60971118. The authors also thank the reviewers of this article for their invaluable comments.

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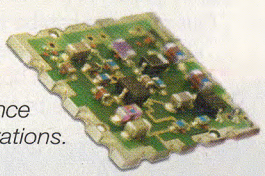

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Dimensions of the proposed antenna

Parameter	Value (in mm)
W	20
L	32
S	0.5
T	0.5
w_L	1.3
w_1	15.5
w_2	13.8
w_3	9.4
w_4	3.6
w_t	2
l_1	6
l_2	4
l_3	2
l_4	8
l_5	6.5
l_6	4.7

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DCMO514-5	50 -140	0.5 - 24	+5 @ 29 mA	-110
DCMO616-5	65 -160	0.5 - 24	+5 @ 28 mA	-108
DCMO1027	100 -270	0.5 - 24	+5 - 12 @ 20 mA	-112
DCMO1129	110 -330	0.5 - 24	+5 - 12 @ 22 mA	-112
DCMO1545	150 -450	0.5 - 24	+5 - 12 @ 22 mA	-108
DCMO1857	180 -560	0.5 - 24	+5 - 12 @ 26 mA	-108
DCYR2060-5	200 -600	0.5 - 28	+5 @ 60 mA	-119
DCMO2260-5	220 -600	0.5 - 24	+5 @ 28 mA	-108
DCMO2476	240 -760	0.5 - 24	+5 - 12 @ 27 mA	-108
DCMO2550-12	250 -500	0.5 - 20	+12 @ 30 mA	-112
DCYR3097-5	300 -970	0.5 - 28	+5 @ 38 mA	-112
DCMO3288-5	320 -880	0.5 - 24	+5 @ 21 mA	-109
DCMO3288-12	320 -880	0.5 - 24	+12 @ 32 mA	-105
DCFO35105-5	350 -1050	0.5 - 25	+5 @ 53 mA	-110
DCMO40110-5	400 -1100	0.5 - 24	+5 @ 37 mA	-103
DCMO40110-8	400 -1100	0.5 - 24	+8 @ 39 mA	-104
DCMO40110-12	400 -1100	0.5 - 24	+12 @ 38 mA	-105
DCMO50120-5	500 -1200	0.5 - 24	+5 @ 37 mA	-102
DCMO50120-12	500 -1200	0.5 - 24	+12 @ 28 mA	-103
DCYR50125-10	500 -1250	0.5 - 24	+10 @ 37 mA	-110
DCMO60170-5	600 -1700	0.5 - 25	+5 @ 35 mA	-100
DCMO60170-12	600 -1700	0.5 - 24	+12 @ 29 mA	-102
DCMO80210-5	800 -2100	0.5 - 24	+5 @ 28 mA	-96
DCMO80210-10	800 -2100	0.5 - 24	+10 @ 25 mA	-100
DCMO90220-5	900 -2200	0.5 - 24	+5 @ 28 mA	-98
DCMO90220-12	900 -2200	0.5 - 24	+12 @ 29 mA	-99
DCMO92200-12	925 -2000	0.5 - 18	+12 @ 35 mA	-101
DCMO100230-5	1000 -2300	0.5 - 24	+5 @ 35 mA	-98
DCMO100230-12	1000 -2300	0.5 - 24	+12 @ 33 mA	-101
DCYS100200-12	1000 -2000	0.5 - 28	+12 @ 33 mA	-105
DCMO110250-5	1100 -2500	0.5 - 28	+5 @ 25 mA	-100
DCMO110250-8	1100 -2500	0.5 - 28	+8 @ 30 mA	-102
DCMO130275-5	1300 -2750	0.5 - 24	+5 @ 20 mA	-93
DCMO135270-8	1350 -2700	0.5 - 20	+8 @ 36 mA	-93
DCMO150318-10	1500 -3100	0.5 - 22	+10 @ 32 mA	-96
DCMO150318-5	1500 -3200	0.5 - 20	+5 @ 24 mA	-93
DCMO150320-5	1500 -3200	0.5 - 18	+5 @ 33 mA	-92
DCYS160360-5	1600 -3600	0.5 - 20	+5 @ 47 mA	-94
DCMO170340-3	1700 -3400	0.5 - 20	+3.5 @ 18 mA	-85
DCMO170345-5	1700 -3450	0.5 - 16	+5 @ 43 mA	-88
DCMO172332-5	1720 -3320	0.5 - 24	+5 @ 22 mA	-94
DCMO190410-5	1900 -4100	0.5 - 18	+5 @ 45 mA	-90
DCMO200420-5	2000 -4200	0.5 - 17	+5 @ 50 mA	-89
DCYS200400-5	2000 -4000	0.5 - 16	+5 @ 45 mA	-90
DCYS200400P-5	2000 -3900	0.5 - 22	+5 @ 50 mA	-95
DCMO250512-5	2500 -5125	0.5 - 14	+5 @ 51 mA	-76
DCYS250500-5	2500 -5000	0.5 - 14	+5 @ 45 mA	-78
DCYS250510-5	2500 -5100	0.5 - 16	+5 @ 45 mA	-78
DCYS275550-5	2750 -5550	0.5 - 22	+5 @ 43 mA	-77
DCYS300600-5	3000 -6000	0.3 - 17	+5 @ 43 mA	-77

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CONQUER PHASE NOISE AND JITTER IN FREQUENCY STANDARDS

TO MEASURE A signal's noise level, phase noise or jitter can be used. The choice depends largely on the application, although jitter can be calculated from phase noise if the phase-noise characteristic is known. In a five-page white paper titled, "Designing for Exceptional Phase Noise and Jitter Performance in Precision GPS Frequency Standards," Precision Time and Frequency, Inc. provides a concise overview of the steps and considerations needed to design a high-performance, low-noise, precision-frequency standard.

The first step is to select the right crystal oscillator. A "good" oven-controlled crystal oscillator (OCXO) will have a phase-noise characteristic of at least –125 dBc/Hz at 10 Hz offset from a 10-MHz carrier. At higher offsets, phase noise will generally fall linearly to a noise floor of less than –160 dBc/Hz at 10 kHz offset from a 10-MHz carrier. In evaluating phase-noise specifications, it is critical to keep in mind the carrier frequency at which the measurement is quoted, as there is a direct mathematical relationship between carrier frequency and measured phase noise.

Precise Time and Frequency, Inc., 50L Audubon Rd., Wakefield, MA 01880; (781) 245-9090, FAX: (781) 245-9099, www.ptfinc.com.

The next task is to preserve the attained low phase noise when buffering and distributing. In addition to filtering the power supply at the input to the printed-circuit board (PCB), filtering should be placed at the supply pins to the buffer amplifiers. When it comes to amplifying and distributing low-phase-noise RF signals, current feedback amplifiers are sufficient. However, the layout must be correct to ensure desired performance. For this application, bandwidth limiting is required. Capacitance to ground at the inputs and outputs also must be minimized as much as possible to avoid instability. With these tips, the white paper provides a solid foundation for designers working in this segment.

GET A SOLID GRASP OF IEEE 802.11ad



WIRELESS LOCAL-AREA NETWORKING (WLAN) was birthed to support computers in the home and office as well as on the road. Today, however, the usage models have moved far beyond such basic functionality. They now incorporate wireless display, high-definition-television (HDTV) distribution, rapid upload/download, backhaul, outdoor campus/auditorium, and the manufacturing floor. Two new IEEE project groups have emerged to provide very high-throughput capabilities: Working Groups TGac (focused on IEEE 802.11ac) and TGad (proposing IEEE 802.11ad). The standard that is the focus of the latter is detailed at length in a newly available application note from Agilent Technologies titled, "Wireless LAN at 60 GHz—IEEE 802.11ad Explained."

The 28-page application note explains that IEEE 802.11ad is being jointly proposed by its working group and the Wireless Gigabit Alliance (WiGig; http://wirelessgigabitalliance.org). The goal of the standard, which is expected to be finalized by the end of this year, is to provide throughput to 7 Gb/s using roughly 2 GHz of spectrum at 60 GHz over a short range. All of the IEEE 802.11 standards are tasked with backward compatibility. Thus, IEEE 802.11ac and 802.11ad are compatible at the medium-access-control (MAC) or data-link layer. They differ only in their physical-layer (PHY) characteristics. As a result, devices could have three radios: a 2.4-GHz radio for general use, which may suffer from interference; a 5-GHz radio for more robust, higher-speed applications; and a 60-GHz radio for ultra-high speed within a room. Session switching between all three radios would be supported.

Agilent Technologies, Inc., 5301 Stevens Creek Blvd., Santa Clara, CA 95051; (408) 345-8886, FAX: (408) 345-8474, www.agilent.com.

The application note provides in-depth information on various facets of the standard. For example, a discussion of the choice of 60 GHz explains that transmission at that frequency covers less distance for a given power. For the most part, this is due to the increased free-space path loss (68 dB over 1 m at 60 GHz, which is 21.6 dB worse than at 5 GHz). It is compounded by propagation losses through materials and human-body shadowing (losses from, say, 3 to 30+ dB).

Another concern raised about the 60-GHz band is the range limitation caused by the substantial RF absorption peak, which is due to a resonance of atmospheric oxygen molecules. Yet this absorption effect only begins to grow significant beyond 100 m. As a result, it does not impact low-power transmissions. With IEEE 802.11ad, it is considered an advantage that low-power transmissions will not propagate very far. In addition to reducing the likelihood of co-channel interference, such limited propagation increases the possible frequency re-use density.

Among other benefits are reduced opportunities for protected content to be stolen by eavesdropping on nearby transmissions; the emergence of low-cost microwave-component fabrication techniques; and the fact that high path loss can be mitigated by increasing antenna gain. In-depth information also is provided on topics like a regulatory overview, the standard's PHY, and testing. By covering so many aspects surrounding IEEE 802.11ad, the note succeeds in addressing both the requirements and challenges of supporting today's unwired world.

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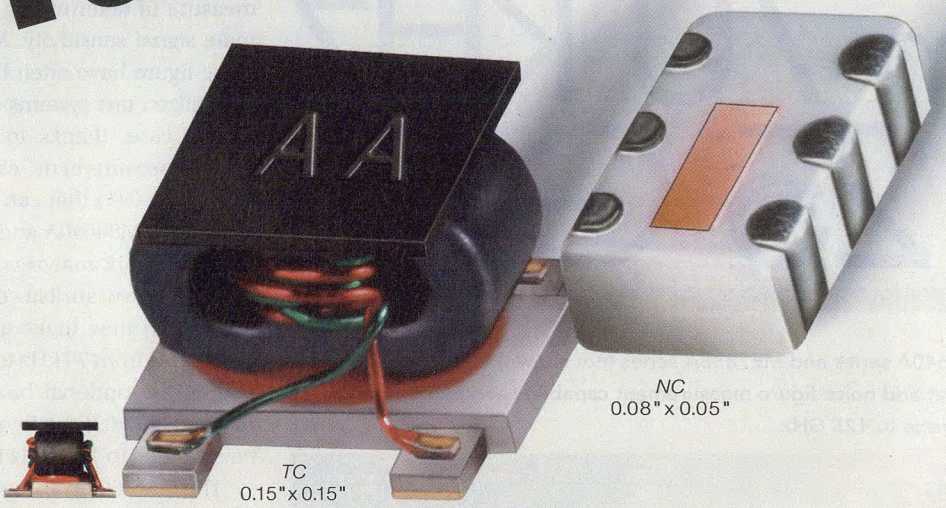

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VNAs Measure Noise From 70 kHz to 125 GHz

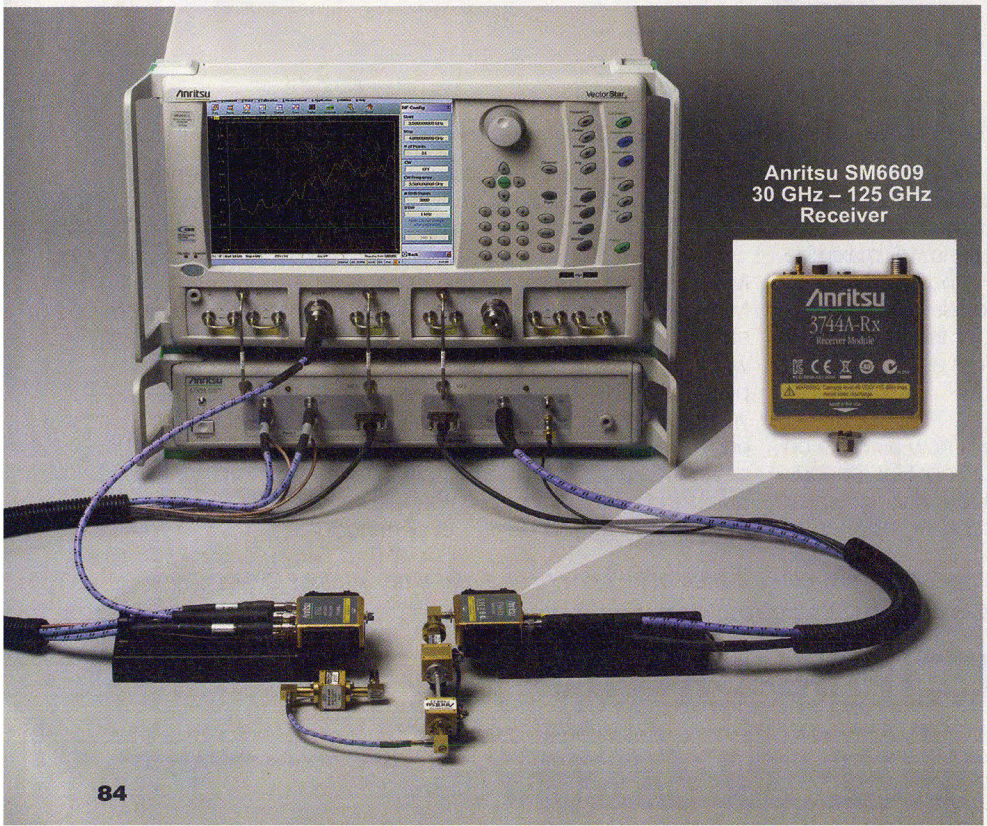
Two new options arm an established line of microwave vector network analyzers for making accurate noise figure measurements, along with the capability to make those measurements up to 125 GHz.

NOISE FIGURE IS A PARAMETER well-known to receiver designers, and a key measure of determining a receiver's ultimate signal sensitivity. Measurements of noise figure have often been reserved for specialized test systems. But this needn't be the case, thanks to the new noise-figure measurement capability (option MS-4640A-041) that can be built into the VectorStar MS4640A and ME7838A series vector network analyzers (VNAs) from Anritsu Co. (www.anritsu.com). These workhorses can now make noise-figure measurements from 70 kHz to 70 GHz. And by adding the optional broadband receiver (model SM6609) the frequency range can be extended to 125 GHz **(Fig. 1)**.

The SM6609 broadband receiver equips an ME7838A VNA for continuous broadband frequency coverage from 70 kHz to 125 GHz via a small-dimensioned coaxial connector. Back in 1983, Anritsu (then Wiltron Co.) introduced the K-connector with 2.92-mm dimensions for frequency coverage to 40 GHz, in support of its line of scalar network analyzers. Over the years, the firm's Bill Oldfield has been instrumental in developing smaller coaxial connector configurations for higher-frequency use. The 1-mm connector, for example, is specified to 110 GHz, but can operate up to 125 GHz. Anritsu plans to support the new architecture with coaxial as well as waveguide adapters for those making noise-figure measurements on waveguide DUTs.

The new millimeter-wave noise-figure measurement systems are suitable for both research and production tasks, with

1. The VectorStar MS4640A series and ME7838A series (not shown) VNAs are eligible for two new options that add noise-figure measurement capability and extend the coaxial frequency coverage to 125 GHz.



S-parameter measurement speed of 55 ms for 201 data points using an intermediate-frequency (IF) bandwidth of 10 kHz. They offer noise-figure measurement resolution of < 0.1 dB, backed by calibration and measurement stability of 0.1 dB over 24 h. The system dynamic range for S-parameter measurements is 108 dB at 65 GHz and 107 dB at 110 GHz.

The SM6609 receiver uses the same nonlinear-transmission-line (NLTL) technology employed in the firm's model 3743A VectorStar frequency extension modules (see the September 2011 issue of *Microwaves & RF*, p. 98). The compact size of those frequency-extension units, which are a fraction of the size and weight of conventional frequency-converter modules, enabled ease of positioning on wafer probe stations when making on-wafer measurements. The firm will offer additional optional frequency-conversion modules for waveguide-based millimeter-wave coverage through 750 GHz and beyond for higher-millimeter-wave and quasi-optical measurements.

Noise-figure measurements on the VectorStar MS4640A and ME7838A series VNAs equipped with the optional SM6609 receiver are supported by optional measurement software. The analyzers run under simple graphical user interfaces (GUI) that offer various other active-device measurements related to noise figure—including gain and compression point—as either standard or optional capabilities.

Accurate noise-figure measurements, of course, are aided by some understanding of how these measurements are made and why. Noise figure essentially describes the degradation of a system or component's signal-to-noise ratio (SNR) due to the output noise power (N_o) added by a device under test (DUT), usually an active device such as an amplifier. Measuring the noise figure of the DUT can help determine the impact it will have on a system's SNR.

Noise figure (NF) in decibels can be calculated as a function of noise factor, F:

$$NF = 10\log F$$

where:

$$F = (S_i/N_i)/(S_o/N_o)$$

and:

S_i = the input signal power;

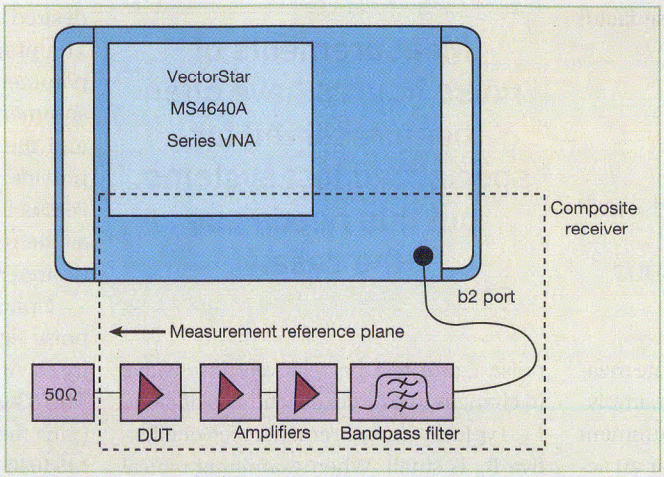
N_i = the input noise power;

S_o = the output signal power; and

N_o = the output noise power.

Over the years, noise-figure measurements have improved due to better understanding of how to make the measurements,[1-6] more sensitive receivers, and more accurate noise-power measurements. Option MS-4640A-041 (which equips a VectorStar MS4640A or ME7838A VNA) and a model SM6609 receiver (with noise-figure capability through 70 to 125 GHz) incorporates many of these noise-figure advances, including the use of the cold-source measurement method rather than the hot-cold or Y-factor measurement approach.

The Y-factor (hot-cold) measurement technique uses a noise source capable of producing a low-temperature (cold) noise power (N_c) and a hot noise power (N_h). Such a noise source is the Input Noise Signal in **Fig. 2**. The Y factor is simply the ratio of hot to cold noise powers, $Y = N_h/N_c$.[2] The Y factor was useful for a quick calculation of noise figure using Eq. 1:



2. This block diagram shows a simple representation of the VNA-based noise figure measurement system.

$$F = [(T_h/T_c) - 1]/(Y - 1) \quad (1)$$

where:

T_h = the equivalent hot temperature of the noise source; and

T_c = the equivalent cold temperature of the noise source, which is often assumed to be equal to 290 K per IEEE definition.

By making noise-figure measurements of the receiver alone, and then the receiver with the device under test (DUT), it is possible to deconvolve the noise figure of the DUT using the Friis equation[1]:

$$F_{DUT} = F_{SYS} - (F_{rcvr} - 1)/G \quad (2)$$

where:

F_{DUT} = the noise factor of the DUT;

F_{SYS} = the noise factor of the whole system (receiver + DUT);

F_{rcvr} = the noise factor of the receiver alone; and

G = the gain of the DUT.

The DUT gain, G, can be measured separately, such as by means of scattering (S) parameters; it can also be determined from the change in measured noise powers during calibration and measurement. The hot-cold noise-figure measurement approach is based totally on ratios and therefore does not require absolute power calibrations. This was important when the available measurement dynamic range over broad bandwidths was limited.

Calibration of the equivalent hot temperture, T_h, for a noise source is difficult and usually left to a handful or qualified laboratories. Another problem with the hot/cold noise-figure measurement approach is related to minimizing impedance match changes when the noise source changes between its hot and cold states.[4] Match changes result in large measurement errors, which can be partially overcome by source correction methods.[3]

The cold-source noise-figure measurement method was developed to eliminate the need for the hot/cold noise source. In

the cold-source method, the noise factor can be found from Eq. 3:

$$F = (kT_0B + N)/(kT_0BG) \quad (3)$$

where:
k = Boltzmann's constant (~1.3807 × 10^{-23} J/°K);
N = the noise power added by the DUT;
G = the gain of the DUT; and
B = the measurement bandwidth.

This method requires an accurate measurement of absolute noise power, implying the need for an effective measurement receiver calibration. It also calls for an accurate measurement of bandwidth which, in the case of using a VNA with a digital IF system, can be readily determined. The bandwidth can also be found when measuring absolute power, provided a noise source is used. Isolating the noise factor of the DUT using this method, the noise contributions of the receiver must be known, which can be performed with only a cold source attached to the receiver's input port. Once receiver noise is known, Eq. 3 can be rewritten as Eq. 4:

$$F = (1/G) + (N_{DUT} + rcvr - N_{rcvr})/kT_0BG \quad (4)$$

This method places great import on gain measurements, with errors in measuring gain or noise power transferred almost on a dB-for-dB basis to the noise-figure results. Again, impedance matching is also important for maintaining good measurement accuracy, and the receiver noise power may be affected by the source impedance. By considering that the response of a DUT can be represented by its minimum noise factor (F_{min}), its resistive noise (R_n, and its optimum impedance (Γ_{opt}),[7] the net noise figure of the DUT can be found from Eq. 5:

$$F = F_{min} + (4R_n|\Gamma_S - \Gamma_{opt}|^2)/[Z_0(1 - |\Gamma_S|^2)|1 + \Gamma_{opt}|^2] \quad (5)$$

where:
Z_0 = the system characteristic impedance.

If R_n is small relative to Z_0, the net noise figure will be relatively insensitive to changes in source reflection coefficient, Γ_S. Typically, measurement receiver effective R_n is small. When examining typical noise circles for a measurement receiver at 50 GHz (not shown), even if the DUT's output port is poorly matched, the effective receiver noise figure only changes by about 0.65 dB from F_{min}. For a DUT with 10-dB gain and 2-dB noise figure, this would only add 0.1-dB uncertainty, and only 0.01-dB uncertainty for a DUT with 20-dB gain and 2-dB noise figure.

Measurements of noise figures have often been reserved for specialized test systems, but this needn't be the case.

A number of factors affect noise-factor measurement uncertainty, $\tilde{F}$, arising from deviations (Δ) that can occur during measurements or calibrations:

$$\tilde{F} = 1 + (G + \Delta G) + (N_{DUT + rcvr} - N_{rcvr}) + (\Delta N_{DUT + rcvr} - \Delta N_{rcvr})](1 + \Delta R)/[kT_0B(G + \Delta G)] \quad (6)$$

Equation 6 does not list all possible uncertainty sources—just the dominant ones. Gain variation (ΔG) is usually associated with S-parameter measurements. Other variations are related to measurements of noise power, including ΔR terms related to a user's power calibration and receiver calibration, and ΔN terms related to impedance match interactions.

To help understand different uncertainty scenarios, the VectorStar Noise Figure Uncertainty Calculator, based on Monte Carlo methods,[8] was created as a companion to the new 125-GHz noise-figure measurement capability. The program runs on an external personal computer (PC) or on the desktop of a VectorStar VNA and is helpful in determining the optimum measurement setup for achieving a desired measurement uncertainty target. The program takes into account receiver parameters, DUT parameter, power measurement parameters, source parameters, and the cold source temperature. It can provide plots of noise figure uncertainty versus frequency and versus gain as well as the receiver gain required to achieve a desired noise-figure uncertainty.

Option MS4640A-041, which adds noise-figure-measurement capability to Anritsu's VectorStar MS4640A and ME7838A series VNAs, is priced at $15,000 (plus the cost of the analyzer). VectorStar MS4640A series VNAs are available in standard frequency ranges from 10 MHz to 20, 40, 50, or 70 GHz (with frequency extension option to 70 kHz), while the ME7838A series VNAs offer single-sweep capability from 70 kHz to 110 GHz through a 1-mm connector.

The SM6609 receiver option extends the overall frequency range of the VNAs to 125 GHz through the same type of 1.0-mm coaxial connector. P&A: $15,000 (noise-figure capability); 8 wks, and $30,250 (SM6609 receiver for 125-GHz coverage); 16 wks. MWRF

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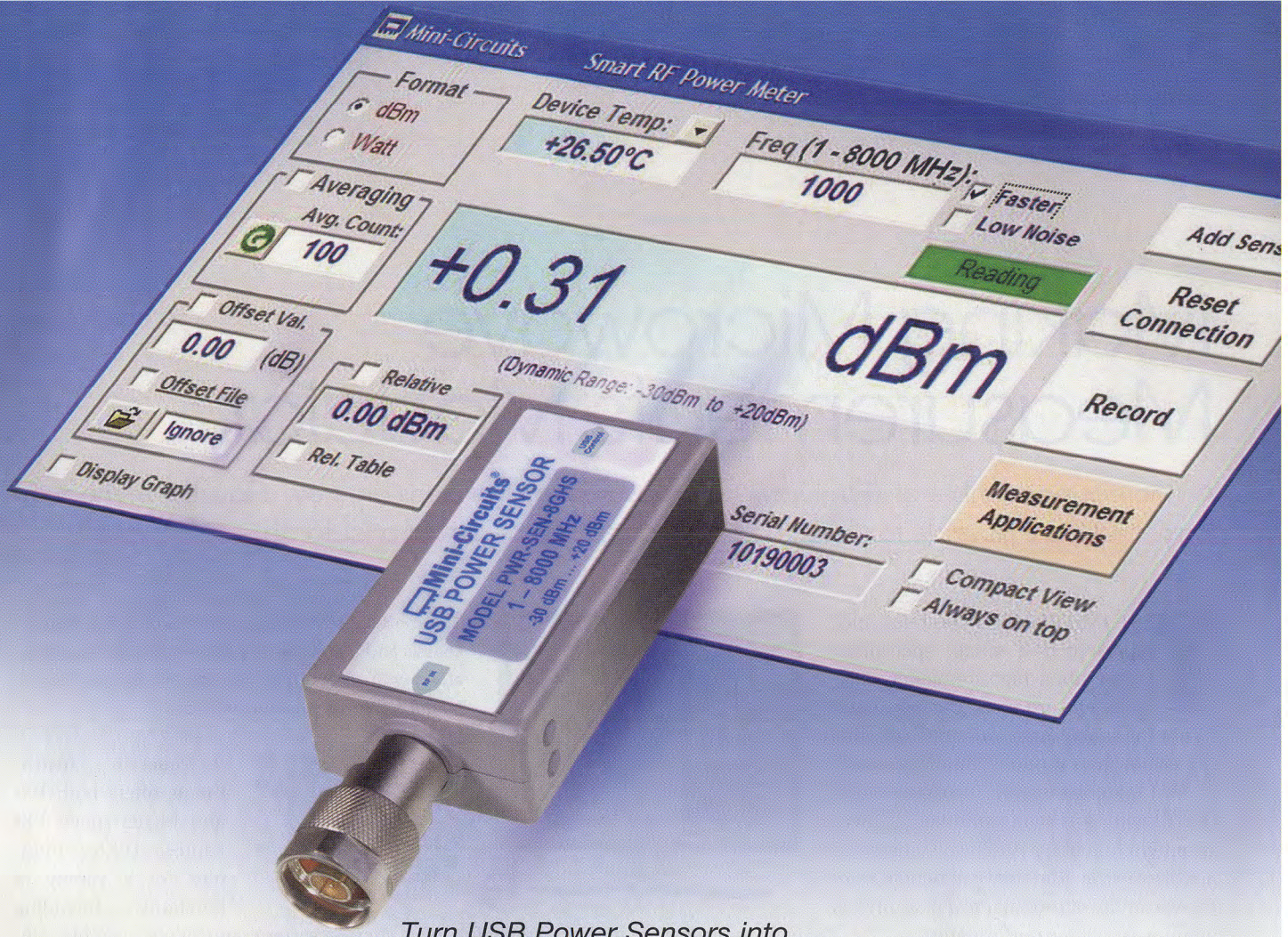

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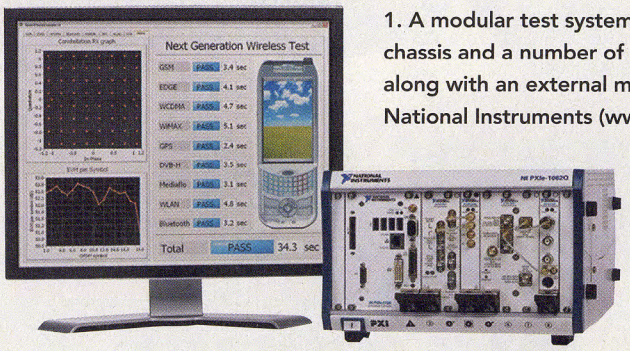
Making Microwave Measurements Modular

An increasing number of RF/microwave measurement functions are now available in modular form, making it possible to shrink the size and reduce the power of automated test systems.

TEST INSTRUMENT modules once represented a small, specialized area among high-frequency measurement products. But more and more manufacturers are now supporting established module standards—such as PCI eXtensions for Instrumentation (PXI)—with a growing number of measurement functions. As a result, engineers are discovering that they can benefit from the versatility of modular test instruments without sacrificing performance.

Since National Instruments (www.ni.com) created the specifications for PXI instrumentation in the late 1990s, the open PXI standard has gained momentum. Much of the credit for this goes to the PXI Systems Alliance industry group (PXISA; www.pxisa.org), now with more than 50 member companies. PXI Instruments use the Peripheral Component Interconnect (PCI) bus together with modular Eurocard mechanical packaging, in contrast to more traditional rack-mount instruments using the General Purpose Interface Bus (GPIB) for control and data communications.

PXI instruments are built into either 3U or 6U Eurocards, where each U is 1.75 in. (44.45 mm) high and represents a rack unit or slot in a mainframe or chassis. Common PXI chassis sizes range from 4 to 18 slots, with some of the slots occupied by essential functions such as power supplies and system controllers. The chassis contains the PXI backplane with the PCI, triggering, and timing buses, and uses a dedicated 10-MHz system reference clock. Because the PXI backplane was defined with a somewhat limited bandwidth of 132 MB/s, the PXI standard evolved into a higher-speed standard (PXI Express) with a backplane bandwidth to 6 GB/s. PXI Express also adopted a higher-speed differential 100-MHz reference clock for enhanced synchronization capabilities, using the differential interface for improved immunity to noise.



1. A modular test system consists of a mainframe chassis and a number of plug-in function modules, along with an external monitor. [Photo courtesy of National Instruments (www.ni.com)]

Software for PXI instruments is managed by the PXI Systems Alliance—with PXI software defining the frameworks for PXI systems, which are based on 32-b Microsoft Windows® operating systems. The software is designed for compatibility with most popular development environments. The goal for all PXI software and hardware is universal interoperability.

Assembling a PXI or other modular measurement system starts with a mainframe/chassis designed to hold the modules. Next, modules are added to define desired measurement functions, such as signal generation and signal analysis. Control functions and measurements results are shown on a computer display screen in a PXI system **(Fig. 1)**.

National Instruments offers both PXI and higher-speed PXI Express (PXIe) modules for a variety of functions, including chassis, system controllers, switches, signal sources, and digitizers/analyzers. Examples include the recently introduced PXI/PXIe-2543 multiplexer, the PXIe-5185/5186 digitizers, and the PXIe-5665 vector signal analyzer (VSA). The PXI/PXI-2543 is a 4 x 1 50-Ω multiplexer for high-density switching applications. It consists of dual single-pole, four-throw (SP4T) FET switches capable of operating from 10 MHz to 6.6 GHz with input power levels to +30 dBm. The insertion loss is typically less than 3.4 dB to 2.4 GHz and typically less than 6.1 dB through 6.6 GHz. VSWR is typically less than 1.50:1 through 2.4 GHz and less than 1.60:1 through 6.6 GHz. The isolation is better than 70 dB through 2.4 GHz and better than 59 dB through 6.6 GHz. Propagation delays are minimized to 1720 ps.

The PXIe-5185 and PXIe-5186 digitizers were co-developed by National Instruments and Tektronix (www.tek.com). The dual-channel PXIe digitizers operate with sampling rates of 6.25 GSamples/s for two channels and 12.50 GSamples/s for one channel, with 8-b vertical resolution. The

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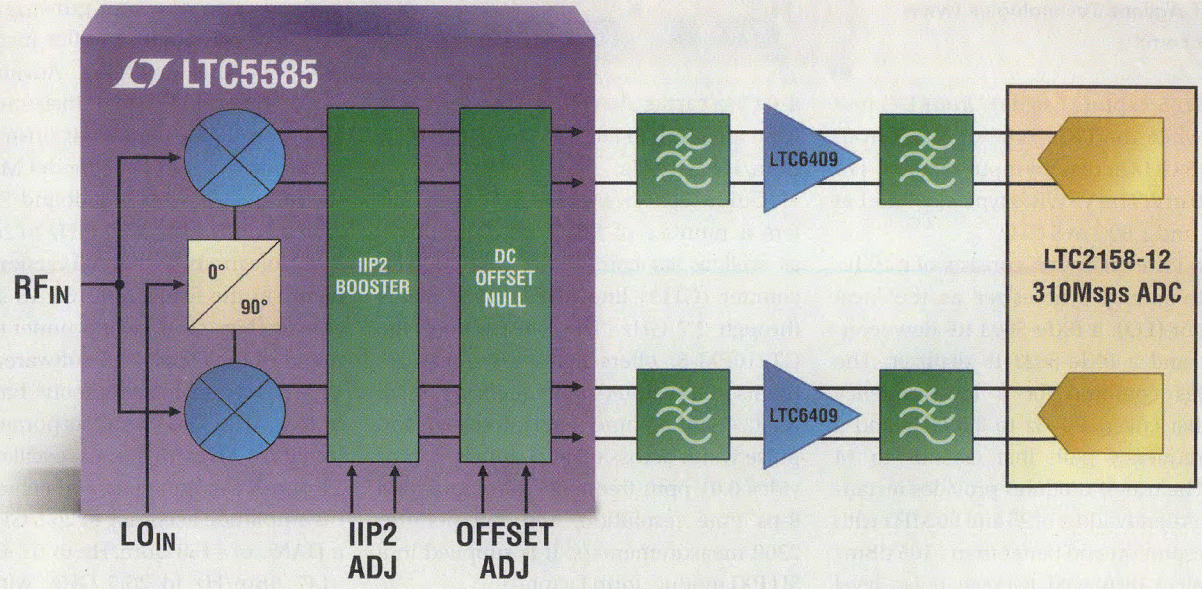

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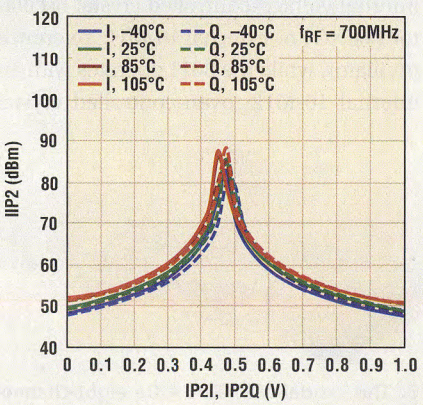
I/Q Demodulation BW	>530MHz	>530MHz
IIP3	31dBm@450MHz	25.7dBm@1.9GHz
Adjustable IIP2	>80dBm	>80dBm
DC Offset Cancellation	Yes	Yes

IIP2 Optimization vs Trim Voltage



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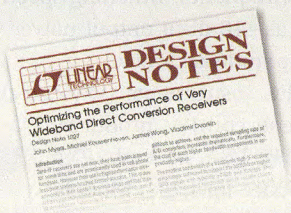

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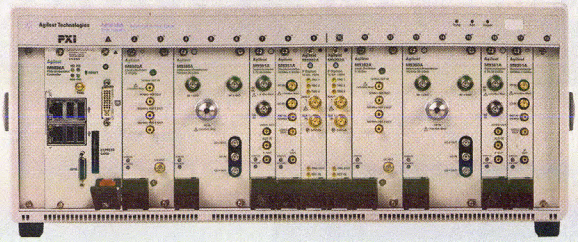


2. This 18-slot PXIe chassis holds the modules that comprise the M9392A dual-channel VSA with bandwidth of 50 MHz to 26.5 GHz. [Photo courtesy of Agilent Technologies (www.agilent.com)]

PXIe-5185 captures signals from DC to 3 GHz, while the PXIe-5186 operates from DC to 5 GHz across an input range of 110 to 1000 mV. The VSWR is typically 1.25:1 at 1 GHz and 1.80:1 at 5 GHz.

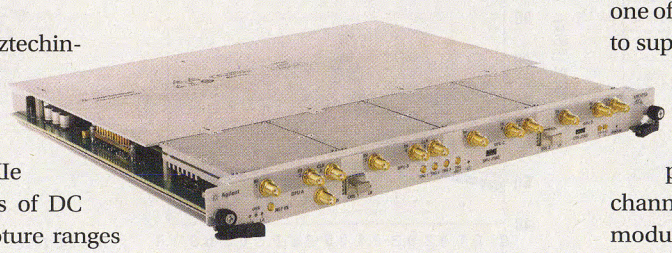
The PXIe-5665 VSA consists of a PXIe-5653 frequency synthesizer as the local oscillator (LO), a PXIe-5603 RF downconverter, and a PXIe-5622 IF digitizer. The modules combine for a low-frequency path that covers 20 Hz to 3.6 GHz and a high-frequency path that extends to 14 GHz. The trio of modules provides instantaneous bandwidths of 25 and 50 MHz with 16-b resolution and better than –165 dBm/Hz typical displayed average noise level (DANL) at 1 GHz. The amplitude accuracy is typically ±0.1 dB with ±0.35 dB typical amplitude flatness within a 20-MHz bandwidth. The typical phase noise is –129 dBc/Hz offset 10 kHz from an 800-MHz carrier.

Phase Matrix (www.phasematrix.com) offers a full line of PXI modular instruments, including tunable preselector filters, frequency downconverters, and microwave LOs, in 3U sizes occupying from one to three slots in a PXI chassis. For example, model PXI-1450B is a two-slot PXI LO module with frequency range of 3 to 9 GHz and 1-Hz tuning resolution. It has 500-µs frequency switching speed and as much as +16 dBm output power with ±2 dB amplitude accuracy.

ZTEC Instruments (www.ztechinstruments.com) produces a 6-GHz VSA in both PXI and PXIe formats. Models ZT 8651 PXI and ZT 8651 PXIe both feature frequency spans of DC to 6 GHz with amplitude capture ranges of –120 to +20 dBm. They operate at 400 MSamples/s with 16-b resolution and use a high-speed FPGA for real-time signal processing. The VSAs provide 1-Hz frequency resolution and phase noise of better than –125 dBc/Hz offset 100 kHz from a 1-GHz carrier. Low-level signals benefit from an 80-dB SFDR and DANL of –163.5 dBm/Hz at 6 GHz.

GuideTech (www.guidetech.com) offers a number of PXI chassis products, as well as its continuous-time-interval-counter (CTIA) line of PXI instruments through 2.7 GHz. The latest model, the GT210PXI-8, offers automatic measurements of time interval, frequency, period, totalize, ratio, time interval delay, and pulse width across eight channels. It provides 0.01 ppm frequency resolution and 8-ps time resolution, and can perform 2300 measurements/s. It is supplied in a 3U PXI module form factor.

Aeroflex (www.aeroflex.com) has developed a variety of PXI instruments, including its models 3010 and 3011 frequency synthesizers, each fitting into single-width 3U PXI cards. They tune from 12.50 to 3.0 GHz with 1-Hz frequency resolution and typical phase noise of –116 dBc/Hz offset 20 kHz from the carrier. The phase noise for both units is –114 dBc/Hz offset 10 kHz from the carrier and typically –140 dBc/Hz offset 1 MHz from the carrier. The 3010 derives its stability from an internal voltage-controlled crystal oscillator (VCXO) or external 10-MHz reference oscillator, while the 3011 operates with an internal 10-MHz oven-controlled crystal oscillator (VOCXO) reference.



3. This model M9703A AXIe eight-channel digitizer shows the similarity with PXI. This single-slot digitizer provides 12-b resolution for an analog bandwidth of DC to 1 GHz. [Photo courtesy of Agilent Technologies (www.agilent.com)]

Agilent Technologies (www.agilent.com) supplies numerous instruments in the PXI format, but is also one of a growing number of companies to offer instruments in the emerging AdvancedTCA Extensions for Instrumentation and Test (AXIe) modular instrumentation standard. Agilent's model M9392A is the industry's most broadband PXIe VSA with a bandwidth of 50 MHz to 26.5 GHz. Available in a two-channel version that fits neatly in the firm's M9018A 18-slot PXIe chassis **(Fig. 2)** and works under the command of the 89600 VSA software, the PXI VSA boasts an instantaneous bandwidth of 250 MHz. The VSA incorporates an internal 10-MHz reference oscillator with ±1 ppm/year aging rate and achieves ±0.5 dB amplitude accuracy to 26.5 GHz. It has a DANL of –158 dBm/Hz to 9.5 GHz and –147 dBm/Hz to 26.5 GHz, with phase noise of –115 dBc/Hz offset 10 kHz from a 10-GHz carrier.

In addition to instruments, Agilent offers chassis products, such as the model M9703A AXIe eight-channel digitizer **(Fig. 3)**. The single-slot 12-b digitizer has an analog bandwidth of DC to 1 GHz and operates at sampling rates to 3.2 GSamples/s. The compact AXIe module includes four Virtex-6 FPGAs from Xilinx (www.xilinx.com) and 4 GB internal memory for robust signal analysis and processing.

The firm is not alone in offering AXIe modules, with companies such as Aeroflex also producing AXIe test equipment products. Guzik (www.guzik.com) is also one of an increasing number of computers to support the newest instrument module format, with its ADC 6000 series of AXIe digitizer modules. With one- to four-channel models with sampling rates to 40 GSamples/s (for one channel) and bandwidths to 13 GHz, these modules offer deep memories for complex signal capture.

Those accustomed to traditional instruments may doubt the capabilities of modular test equipment. Nonetheless, they can provide excellent results while passing test data at high speeds. MWRF

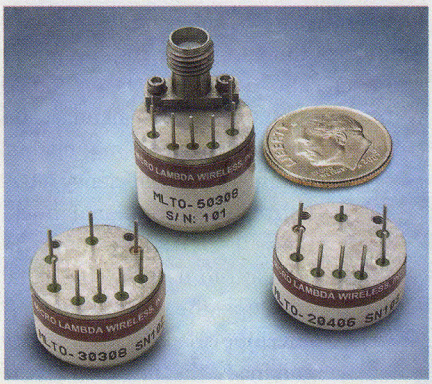
TO-8 YIGs Tune 3 To 13 GHz

These compact microwave oscillators can tune across customer-specified bands with generous output power, featuring low levels of spurious and SSB phase noise.

OSCILLATORS can be built from many different types of resonators. Perhaps one of the most reliable for high-frequency applications is the yttrium-iron-garnet (YIG) sphere, the heart of YIG-tuned oscillators. At one time, such tunable sources were relatively large and heavy. But with new models such as the second-generation MLTO-Series of permanent-magnet YIG oscillators from Micro Lambda Wireless (www.microlambdawireless.com), these microwave oscillators take up no more space than a small coin on a printed-circuit board (PCB). Diminutive oscillators in the MLTO Series are supplied in tiny TO-8 housings and are available in selected tuning ranges from 3 to 13 GHz.

These oscillators can be constructed with pin or coaxial connectors **(see figure)**. They are designed for operating voltages of +8 and –5 VDC and deliver consistent performance across operating (case) temperatures from 0 to +65°C. The oscillator series currently includes models MLTO-50365 for use from 3.0 to 6.5 GHz, MLTO-50409 for use from 4.0 to 9.0 GHz, and MLTO-50613 with a tuning range of 6.5 to 13.0 GHz. Each oscillator has a free-running frequency, which is varied as current is applied to the permanent-magnet resonant cavity with its YIG sphere.

Each model provides at least +10 dBm output power across its tuning range, with worst-case power variations contained within a 3-dB window. Frequency drift over temperature is a maximum of ±25 MHz in the two lower-frequency oscillators and ±20 MHz in the MLTO-50613.



MLTO-Series oscillators can be supplied in 0.875-in.-diameter TO-8 housings with pin or coaxial connectors and operating frequencies to 13 GHz.

MLTO-50365 exhibits harmonics of –12 dBc or better and spurious levels of –70 dBc or better from 3.0 to 6.5 GHz. It has phase noise of –100 dBc/Hz or better offset 10 kHz from the carrier, improving to –128 dBc/Hz or better offset 100 kHz from the carrier, and typically –130 dBc/Hz offset 100 kHz from the carrier. It suffers typical pulling of frequency of a mere 2 MHz into a load with 12-dB return loss, and typical pushing with power supply of 2 MHz/V at +8 VDC.

As with the other oscillators in the series, the MLTO-50365 has a main tuning coil and a frequency-modulation (FM) coil for modulation and phase-locking purposes when used in a frequency synthesizer design. The main coil sensitivity is typically 9 MHz/mA while the FM coil sensitivity is 150 kHz/mA. The MLTO-50365 YIG oscillator draws a maximum of 60 mA from +8 VDC and 20 mA from –5 VDC.

Moving up in frequency, model MLTO-50409 tunes from 4.0 to 9.0 GHz, with harmonic and spurious levels that meet or exceed –12 and –70 dBc, respectively. The phase noise is –100 dBc/Hz or better offset 10 kHz from the carrier and –128 dBc/Hz or better offset 100 kHz from the carrier, with typical phase noise of –130 dBc/Hz offset 100 kHz from the carrier. Frequency pulling is typically 2 MHz into a 12-dB-return-loss load while frequency pushing is typically 2 MHz/V with supply variations centered at +8 VDC. The main tuning coil sensitivity is typically 15 MHz/mA while the FM tuning coil sensitivity is typically 150 kHz/mA. Model MLTO-50409 draws maximum power of 60 mA from a +8-VDC supply and 20 mA from a –5-VDC supply.

The MLTO-5613 operates from 6.5 to 13.0 GHz, with similar tuning characteristics as the others. It also exhibits harmonics of –12 dBc or better and spurious performance of –70 dBc or better. The phase noise is at least –98 dBc/Hz offset 10 kHz from the carrier and at least –123 dBc/Hz offset 100 kHz from the carrier, with typical phase noise of –125 dBc/Hz offset 100 kHz from the carrier. The MLTO-5613 operates on 60 mA at +8 VDC and 15 mA at –5 VDC.

The TO-8 packages are only 0.5 in. tall with 0.675-in. diameter, facilitating attachment to tight spots on PCBs. Extended temperature versions to +85°C are available for all models. P&A: 6 wks. ARO.—*JB*

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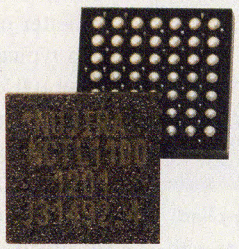
Envelope Tracking Makes Phones Smarter

Using envelope-tracking techniques, the efficiency of the power amplifiers found in cellular telephones can be improved.

POWER AMPLIFIER DESIGNERS supporting wireless communications aim for high efficiency, often through innovative biasing schemes. These schemes typically use only as much energy as needed by the active devices to meet transmit power requirements. Now, however, there is an easier way to boost the power-added efficiency (PAE) of a power amplifier: through the addition of a Coolteq.L envelope-tracking integrated circuit (IC) from Nujira Ltd. (www.nujira.com). The firm's recently announced model NCT-L1100 power-supply-modulator chip closely tracks an amplifier's amplitude or power envelope, dynamically adjusting the supply voltage as needed to consume less power and raise PAE.



Model NCT-L1100 is an envelope-tracking power-supply modulator designed to improve the efficiency of power amplifiers in 3G/4G cellular telephones. The IC is supplied in a low-profile WLCSP housing.

Traditional power amplifiers operate with a fixed voltage supply, working with a wide range of input power levels. The peak-to-average-power ratio (PAPR) of these signals can be large, with optimum efficiency occurring when the power amplifier is operating in compression when driving peak level signals. For lower-level signals, the amplifier is still supplied with a fixed voltage and current, although it may not require as much supply power.

Nujira's Coolteq.L employs the company's envelope-tracking (ET) technology, which tracks the signal envelope of a wireless handset transceiver and dynamically modulates the supply feeding the power amplifier. The technology is embodied within the company's lines of handset and base-station power-supply modulators, offering a high-efficiency alternative to conventional buck-boost DC/DC converters. In addition to tracking the signal envelope, the firm's ISOGAIN™ envelope-shaping technology enhances the linearity of the power amplifier, all the while maintaining its compressed operation for maximum PAE.

The model NCT-L1100 is the first of Nujira's Coolteq.L line of power-supply modulators designed for use in small, portable devices. It can operate with voltage supplies from 2.50 to 5.25 V, such as cellular telephone handsets. It can also handle peak current to 1 A and provide average power levels to 1.2 W in support of efficiency as high as 80%. The integrated circuit (IC) features a wide-bandwidth, three-stage current supply, control, and ripple-elimination circuitry within a low-profile WLCSP housing **(see photo)**, allowing for ease of integration within an RF front end or power-amplifier module.

The Coolteq.L family is suitable for use in third-generation (3G) and fourth-generation (4G) cellular handsets. The firm also offers its Coolteq.h line of power-supply modulators for base-station applications. Power-supply modulators are available for bandwidths of 5, 10, and 20 MHz, in support of all cellular communications Long-Term-Evolution (LTE) frequency bands; they also include fast disable/enable functionality for use in time-division LTE (TD-LTE) systems. Side benefits of the reduction in amplifier power consumption include longer battery operating life and less heat produced by the amplifier within a handheld telephone.

As Nujira's Chief Executive Officer Tim Haynes notes, "The industry consensus is that Envelope Tracking will become the standard PA architecture for the next generation of handsets, because it is the only power optimization technology which delivers high efficiency over the entire spectrum used for 3G and 4G standards. As a result we see the launch of our first commercial chip for mobile handsets as a significant milestone—not just for Nujira, but for the mobile handset sector."

The Coolteq.L model NCT-L1100 uses the industry-standard OpenET analog envelope interface. The IC conforms to Mobile Industry Processor Interface (MIPI) alliance RF front-end (RFFE) specifications to enable a number of different operating modes, including for ET, average power tracking, bypass, and standby. The power-supply modulator, which can supply outputs from 0.5 to 5.0 V with buck-boost capability, is designed for operating temperatures from −40 to +85°C.—*JB*

NUJIRA LTD., Building 1010, Cambourne Business Park, Cambourne, Cambridge CB23 6DP, United Kingdom; (44) 1223-597900, e-mail: info@nujira.com, *www.nujira.com.*

USB Steers Digital Pads



Digital attenuators in the LDA series of compact Lab Brick® products are powered and controlled by a Universal Serial Bus (USB) connection to a laptop or personal computer (PC). These step attenuators are available for use through 6 GHz and are easily programmed to provide fixed attenuation or attenuation ramps, using a simple graphical user interface (GUI). Units range in capability from model LDA-102, which provides 63-dB attenuation in 0.5-dB steps from 0.1 to 1000.0 MHz to model LDA-602, which offers 63-dB attenuation in 0.5-dB steps from 6 to 6000 MHz. The compact units measure just 3.86 x 2.52 x 1.35 in. (98 x 54 x 34 mm) and weigh just 0.5 lb. (0.23 kg). They are supplied with a USB flash drive containing the GUI software and a digital version of the programming guide, along with a 6-ft.-long USB cable. The digital attenuators are compatible with computers running Microsoft Windows™ standard operating systems for personal computers, including Windows 2000, XP, Vista, and 7.

VAUNIX TECHNOLOGY CORP., 242 Neck Rd., Haverhill, MA 01835; (978) 662-7839, FAX: (978) 662-7842, ***www.vaunix.com.***

USB Meter Reads Power To 8 GHz

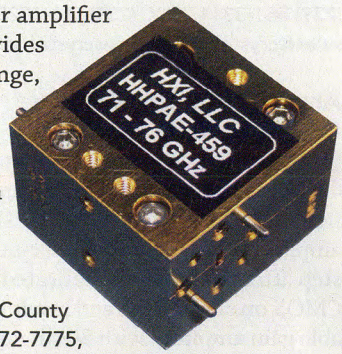
RFMW Ltd. has announced that it is offering applications and sales support for the model TED8000-40 Universal Serial Bus (USB) power sensor from Telemakus (www.telemakus.com). Designed for power measurements from 50 to 8000 MHz, the USB sensor uses a laptop or personal computer (PC) as the control and display; this enables it to replace a full-sized power meter. It can also be used with the company's low-cost USB signal sources to form a cost-effective, USB-controlled microwave scalar network analyzer. The power sensor achieves true root-mean-square (RMS) measurement accuracy over its frequency and power ranges, detecting power levels over a 50-dB dynamic range with 0.5-dB accuracy. No zeroing or cal standards are required for operation as factory calibration data is stored within the on-board flash memory. Installation files for the custom Graphical User Interface (GUI) are also resident in Flash.



RFMW, LTD., 90 Great Oaks Blvd., Ste. 107, San Jose, CA 95119; (408) 414-1450, e-mail: info@rfmw.com, ***www.rfmw.com.***

Amplifier Boosts 71 To 76 GHz

Model HHPAE-459 is a millimeter-wave power amplifier designed for use from 71 to 76 GHz. It provides small-signal gain of 29 dB over that frequency range, with +18-dBm output power at 1-dB compression. Based on monolithic-microwave-integrated-circuit (MMIC) technology, the amplifier operates from a single +6.5-VDC bias supply with an internal voltage regulator and bias sequencer. The amplifier is ideal for transmitters in E-band radio communications systems.



RENAISSANCE ELECTRONICS CORP., 12 Lancaster County Rd., Harvard, MA 01451; (978) 772-7774, FAX: (978) 772-7775, e-mail: sales@rec-usa.com, ***www.rec-usa.com.***

Conductive Foams Shield Cell Phones

Condux Plus™ electrically conductive foams provide excellent electrical conductivity, consistent mechanical properties, and outstanding electromagnetic (EM) shielding capabilities. These attributes enhance conductivity and improve shielding performance in small wireless devices, such as cellular telephones. The materials are available in different thicknesses (0.33, 0.53, and 0.73 mm) to serve a variety of circuit and package configurations. They feature consistent and reliable connectivity while also offering excellent mechanical stability over time and temperature. The typical compression set for 0.021-in.-thick (0.53-mm-thick) Condux Plus foam is only 2.5%. Condux Plus foam can also be used as an electromagnetic-interference (EMI) shielding material, with superb shielding effectiveness (SE) over a wide operating frequency range of 200 MHz to 10 GHz. Condux Plus materials are RoHS and REACH compliant, and will not deform with processing.

ROGERS CORP., One Technology Dr., Rogers, CT 06263; (860) 774-9605, FAX: (860) 779-5509, ***www.rogerscorp.com/hpf.***

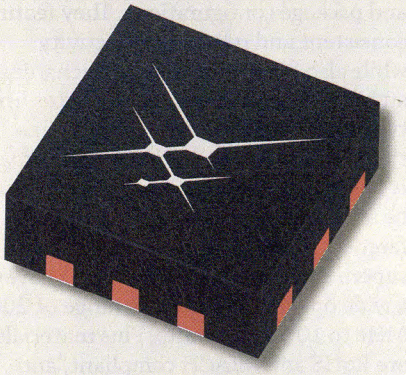
Tiny Caps Feature Tight Tolerances

The Accu-P® line of RF capacitors has been augmented by some of the industry's smallest, tightest-tolerance capacitors available, with subminiature 01005-size chips now available with capacitance values from 0.05 to 2.40 pF. The capacitors, which are ideal for applications at VHF, UHF, and microwave frequencies, boast tolerances to within ±0.01 pF. The capacitors, which are fabricated with high-thermal-conductivity materials, incorporate high-purity electrodes for low effective series resistance (ESR). They achieve high breakdown voltages, high insulation resistance, and low loss at frequencies through 40 GHz. The Accu-P series capacitors are available in standard 01005, 0201, 0402, 0603, 0805, and 1210 chip sizes for use at temperatures from –55 to +125°C. They undergo inspection, test, and quality-control procedures in accordance with ISO9001 and MIL standards.

AVX CORP., One AVX Blvd., Fountain Inn, SC 29644; (864) 967-9304, ***www.avx.com.***

Switch Controls 0.1 To 2.7 GHz

Model SKY13388-465LF is a symmetrical, single-pole, four-throw (SP4T) switch designed for applications from 100 MHz to 2.7 GHz. Built with a silicon-on-insulator (SOI) process, the switch requires only two control lines for operation. The high-performance SP4T switch features typical isolation of better than 30 dB at 1.0 GHz and more than 23 dB at 2.7 GHz. The insertion loss is typically 0.60 dB at 2.2 GHz and 0.65 dB at 2.7 GHz. The switch, which runs on



supplies of +2.5 to +5.5 VDC, is rated for +37 dBm maximum input power. It exhibits an input 1-dB compression point of typically +36 dBm from 0.8 to 2.7 GHz, and an input third-order intercept point of typically +65 dBm. The switch is supplied in a compact quad flat no lead (QFN) housing measuring just 2 x 2 mm.

SKYWORKS SOLUTIONS, INC., 20 Sylvan Rd., Woburn, MA 01801; (781) 376-3000, FAX: (781) 376-3100, e-mail: sales@skyworksinc.com, ***www.skyworksinc.com.***

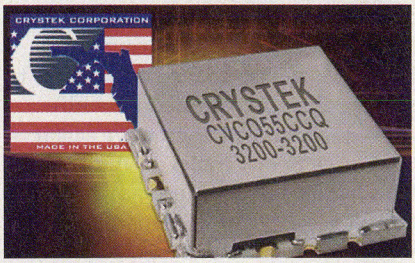
Mod/Demod Unit Spans 20 to 300 MHz

Model CMX973 is a combination of an IF/RF quadrature demodulator and quadrature IF/RF modulator, supplied in a 32-lead VQFN package. It operates from 20 to 300 MHz with in-phase/quadrature (I/Q) receive bandwidth of 10 MHz and I/Q transmit bandwidth of 25 MHz. The demodulator is suitable for superheterodyne architectures with IF frequencies up to 300 MHz and may be used in low IF systems or those converting to baseband. The modulator converts directly from baseband to the desired transmit frequency and features quadrature phase correction to minimize unwanted spectral components. It provides a 0-dBm modulator output level with better than 1-deg. I/Q phase matching and better than 0.5-dB gain matching. It operates from supplies of +3.0 to +3.6 VDC and consumes low current. The circuit, which is controlled by serial bus, is ideal for avionics radios, wireless data terminals, and software-defined radios (SDRs).

CML MICROCIRCUITS, Oval Park, Hatfield Rd., Langford, Maldon, England CM9 6WG; 44 (0)1621 875500, FAX: 44 (0)1621 875600, ***www.cmlmicro.com.***

VCO Maintains 3200 MHz Output

Model CVCO55CCQ-3200-3200 is a voltage-controlled oscillator (VCO) that operates at a center frequency of 3200 MHz. Its frequency is adjusted by a control voltage range of 0.5 to 4.5 V. The oscillator has typical phase noise of –115 dBc/Hz offset 10 kHz from the carrier. It delivers typical output power of +6 dBm with second-harmonic suppression of typically –12 dBc. Pushing and pulling are minimized to 0.3 MHz and 0.1 MHz/V, respectively. The VCO, which is supplied in a 0.5 x 0.5 in. SMD surface-mount package, draws maximum current of 27 mA from a +6-VDC

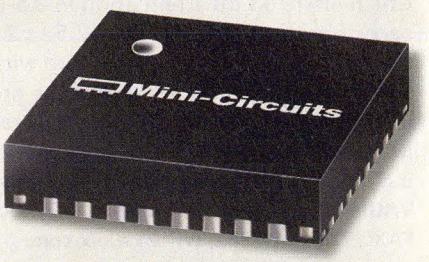


supply. It is ideal for use in digital radios, fixed wireless access, cellular base stations, and in satellite-communications (satcom) systems.

CRYSTEK CORP., 12730 Commonwealth Dr., Ft. Myers, FL 33913; (800) 237-3061, (239) 561-3311, FAX: (239) 561-1025, e-mail: sales@crystek.com, ***www.crystek.com.***

Amp/Attenuator Combo Covers 0.45 To 2.40 GHz

Model DVGA1-242+ is a digitally controlled variable gain amplifier; it combines a high-gain E-PHEMT amplifier with a wide-dynamic-range step attenuator, and is fabricated using CMOS on silicon. The end result is a variable gain amplifier with 30-dB nominal gain at 0-dB attenuation that features a 31.5-dB gain control range from 0.45 to 2.40 GHz. The digitally controlled attenuator includes a 6-b serial interface for fast switching and 0.5-dB step resolution. The attenuation accuracy is typically 0.1 dB. The amplifier achieves +23 dBm output power at 1-dB compression, with an output third-order intercept point of typically +35.2 dBm at 450 MHz and +37 dBm at 2.40 GHz. The amplifier and attenuator combination, which is supplied in a 5 x 5 mm surface-mount MCLP package, runs on supplies of +3 and +5 VDC. It is suitable for cellular communications and Global Positioning



System (GPS) receivers, among many other applications.

MINI-CIRCUITS, P.O. Box 350166, Brooklyn, NY 11235-0003; (718) 934-4500, FAX: (718) 332-4661, ***www.minicircuits.com.***

LNAs Limit Noise In Cellular Stations

A pair of low-noise amplifiers (LNAs) leverage GaAs E-pHEMT technology to achieve low noise figures through 2.7 GHz. Model TQP3M9036 operates from 400 to 1500 MHz with a noise figure of 0.45 dB at 900 MHz and the model TQP3M9037 runs from 1500 to 2700 MHz with a noise figure of 0.40 dB at 1900 MHz. Model TQP3M9036 features 19-dB gain at 900 MHz with +20-dBm output power at 1-dB compression and an output third-order intercept point of +35 dBm. Model TQP3M9037 offers 20-dB gain at 1900 MHz with +21-dBm output power at 1-dB compression and an output third-order intercept point of +36 dBm. Both LNAs include a biasing network that maintains stability over temperature through a current mirror and resistive feedback, and also provides a switching circuit for digital power-down capability. The amplifiers operate on bias voltages from +3 to +5 VDC and are housed in 2 x 2 mm DFN packages.

TRIQUINT SEMICONDUCTOR, INC., 2300 NE Brookwood Pkwy., Hillsboro, OR 97124; (503) 615-9000, FAX: (503) 615-8900, ***www.triquint.com.***

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D		
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F		
Fairview Microwave.	www.fairviewmicrowave.com, email: sales@fairviewmicrowave.com	18
H		
Herotek Inc	www.herotek.com, email: sales@herotek.com	13
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I		
International Manufacturing Services.	www.ims-resistors.com	66
L		
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M		
M/A-COM INC	www.macomtech.com	IFC
Maury Microwave, Inc	www.maurymw.com, email: maury@maurymw.com.	43
Meese Munich	www.electronica.de	68
Mini Circuits/Sci Components	www.minicircuits.com.	12
Mini Circuits/Sci Components	www.minicircuits.com.	23
Mini Circuits/Sci Components	www.minicircuits.com.	41
Mini Circuits/Sci Components	www.minicircuits.com.	55
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Mini Circuits/Sci Components	www.minicircuits.com.	35
Mini Circuits/Sci Components	www.minicircuits.com.	45
Mini Circuits/Sci Components	www.minicircuits.com.	47
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Mini Circuits/Sci Components	www.minicircuits.com.	83
Mini Circuits/Sci Components	www.minicircuits.com.	87
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Mini Circuits/Sci Components	www.minicircuits.com.	30-31
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N		
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R		
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RFMW Ltd.	www.rfmw.com.	6
S		
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Synergy Microwave	www.synergymwave.com, email: sales@synergymwave.com.	81
T		
Tecdia	www.tecdia.com.	16
TTE Incorporated.	www.tte.com	58
W		
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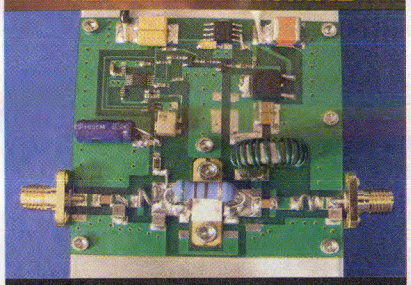

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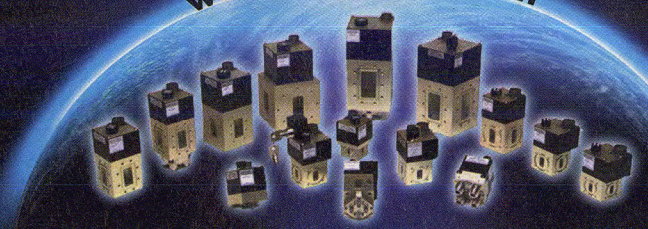

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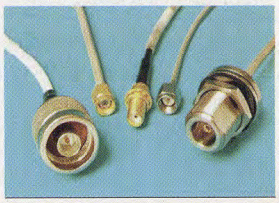

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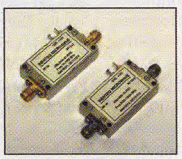

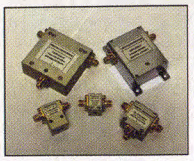

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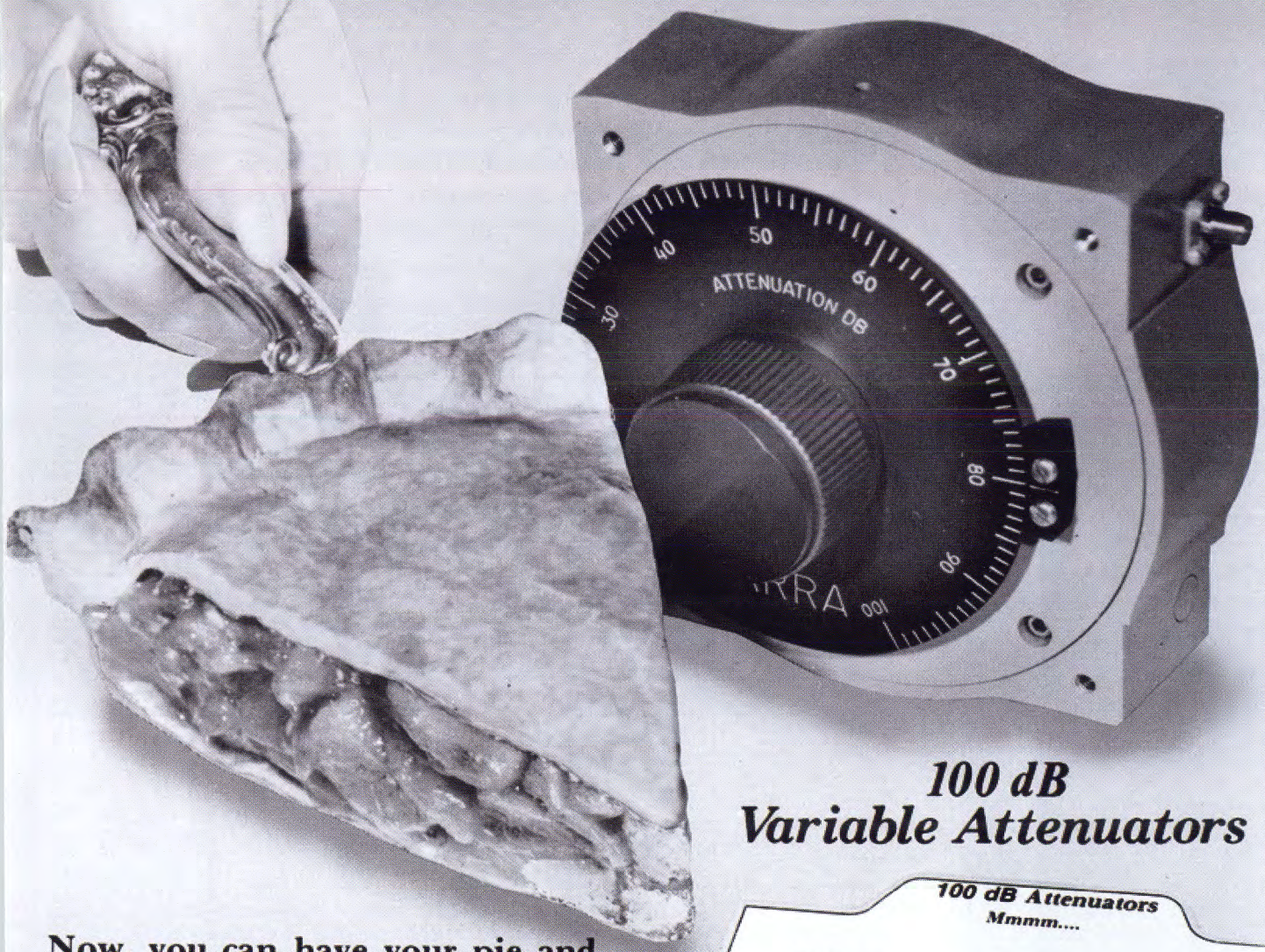

100 dB Variable Attenuators

100 dB Attenuators
Mmmm....

Freq Range	Atten vs Freq dB	Model #
500 - 1000 MHz	1.5	2952 - 100
900 - 1300 MHz	0.75	2-3952 - 100
1000 - 2000 MHz	1.5	3952 - 100X
2000 - 4000 MHz	1.5	4952 - 100 X
4000 - 8000 MHz	1.5	5952 - 100X

Insertion loss - 6 dB
VSWR - 1.5
Power - 15 cw
Temperature -30 to +120 C

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- Extremely high reliability
- Non-contacting movable parts (our special recipe)
- High power version available (up to 200 W)
- Usage will not change calibration
- Attenuation will not vary with temperature
- Excellent phase characteristics
- Type N standard SMA connectors available

Applications include:
•TACAN •DME/IFF •Lab standards •Altimeter
Or any other requirements needing high attenuation and accurate dial reading.

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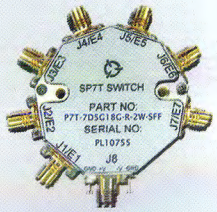
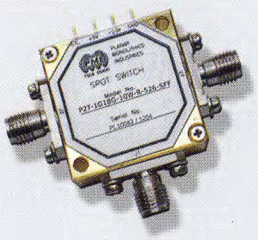
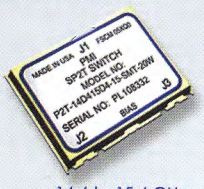


Model Number	Style	Frequency Range (GHz)	Insertion Loss (dB)	Isolation (dB)	Reflective / Absorptive	Switching Speed (nSec)	Operating Input Power	DC Voltage & Current
P1T-0R310R0G-60-R-SFF-20W	SPST	0.3 – 18.0	2.5	60	Reflective	250	20 Watt Peak 7 Watt Average	+5vdc@100mA -12vdc@50mA
P1T-1R0G18R0G-80-R-SFF-75W	SPST	1.0 – 18.0	2.5	80	Reflective	25	75 Watt Peak 2 Watt Average	+5vdc@65mA -12vdc@20mA
P1T-0R5G2R0G-80-R-SFF-LVT-10W	SPST	0.5 – 2.0	1.0	80	Reflective	25	10 Watt Peak 2 Watt CW	+5vdc@50mA -5vdc@5mA
P1T-0R6G1R3G-70-SFF-4W	SPST	0.6 – 1.3	1.5	70	Absorptive	30	4 Watts	+5vdc@100mA -5vdc@100mA
P2T-335M535M-30-R-SFF-20W	SPDT	0.335 – 0.535	0.9	45	Reflective	100	20 Watts	+5vdc@31mA
P2T-1G18G-10-R-528-SFF-HIP10W	SPDT	1.0 – 18.0	3.0	25	Reflective	40	10 Watts	+5vdc@5mA -28vdc@5mA
P2T-0R1G2R0G-40-SFF-100W	SPDT	1.0 – 2.0	1.5	40	Reflective	<1µSec	100 Watts CW	+5vdc@150mA -15vdc@70mA
PEC-9R510R7-100W-SFF-120W	SPDT	9.5 – 10.7	1.5	40	Reflective	400	120 Watts	+5vdc@160mA -28vdc@15mA
P2T-0R5G18G-60-SFF-10W	SPDT	0.5 – 18.0	1.5	60	Reflective	150	10 Watts	+5vdc@100mA -15vdc@75mA
P2T-14D415D4-15-SMT-20W Surface Mount, Driverless	SPDT	14.4 – 15.4	0.5	15	Reflective	50	20 Watts	Bias 50mA
P3T-0R1G2R0G-40-SFF-100W	SP3T	0.1 – 2.0	1.5	40	Reflective	<1µSec	100 Watts CW	+5vdc@150mA -15vdc@70mA
P3T-0R5G18G-70-SFF-200W	SP3T	0.5 – 18.0	3.75	70	Absorptive	100	200 Watts Peak 12 Watts CW	+5vdc@150mA -15vdc@100mA
P4T-2G18G-45-TFF-100W	SP4T	2.0 - 18.0	3.1	45	Reflective	200	100 Watts Peak 1 Watt CW	+5vdc@105mA -15vdc@70mA
P4T-0R1G2R0G-40-SFF-100W	SP4T	0.1 – 2.0	1.5	40	Reflective	<1µSec	100 Watts CW	+5vdc@150mA -15vdc@70mA
P4T-0R1G18G-65-SFF-75W	SP4T	0.1 – 18.0	2.6	65	Reflective	50	75 Watts Peak 1 Watt CW	+5vdc@150mA -15vdc@50mA
P4T-900M1300M-35-SFF-50W	SP4T	0.9 – 1.3	2.0	35	Absorptive	<5µSec	50 Watts	28vdc
P8T-2R37G2R39G-60-SFF-10W	SP8T	2.37 – 2.39	2.5	60	Reflective	<2µSec	10 Watts	+5vdc@500mA -27vdc@10mA
P8T-8G18G-50-SFF-10W	SP8T	8.0 – 18.0	4.0	50	Reflective	75	10 Watts Peak 4 Watts CW	+5vdc@450mA -15vdc@150mA







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