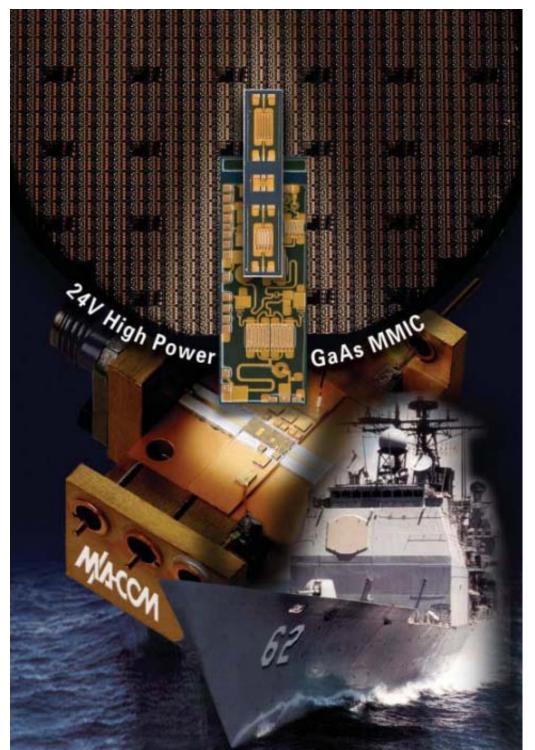






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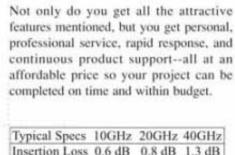


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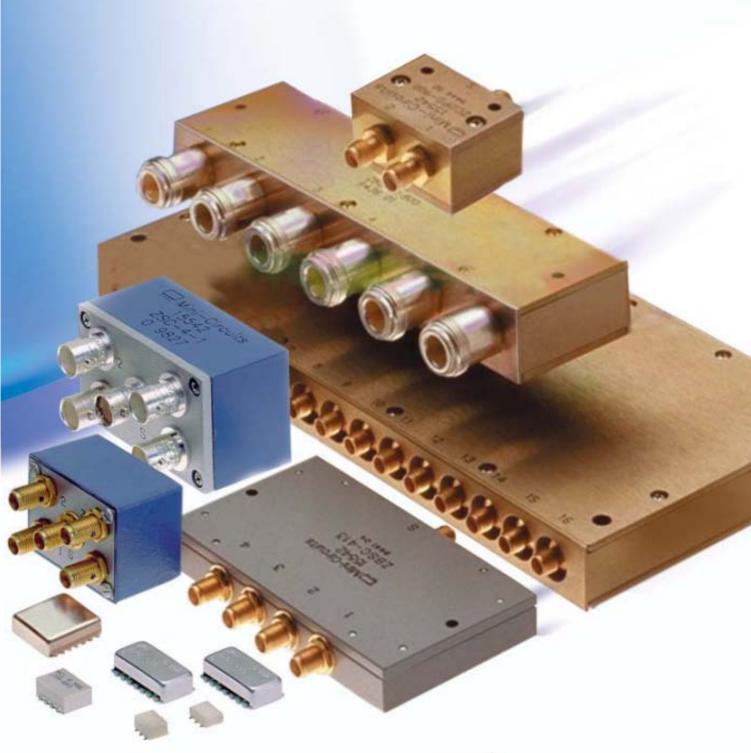
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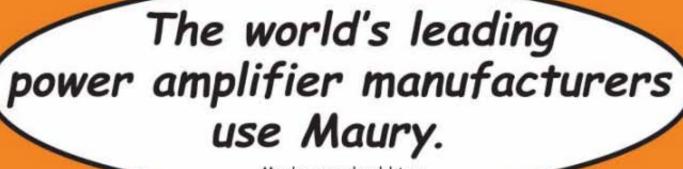
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Cover art courtesy of M/A-COM Inc.

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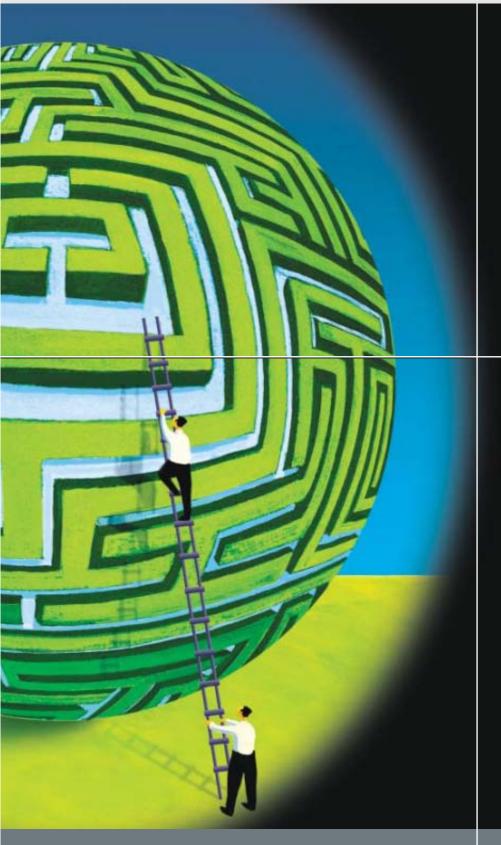
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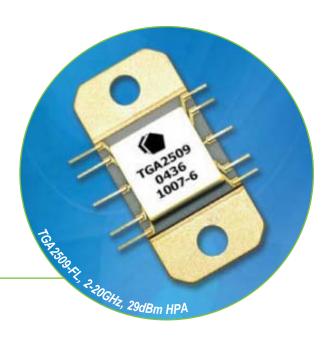


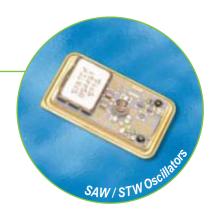
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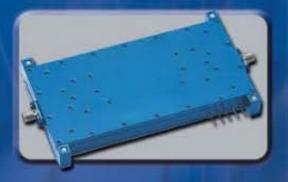




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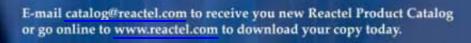
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International Symposium on Advanced Radio Technologies (ISART) March 1-3, 2005 Boulder, CO

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International Conference on Device Packaging March 13-16, 2005 Scottsdale, AZ

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CTIA Wireless 2005 March 14-16, 2005 New Orleans, LA

This event focuses on bringing together the enterprise industry with the consumer and vertical markets to exchange ideas, create partnerships and collaborate to further advance wireless telecommunications. This global event draws attendees from dozens of different industries in more than 80 countries around the world, serving every aspect of wireless providers, users, developers, buyers and manufacturers. For more information, visit www. ctiawireless.com.

RF & Hyper Europe 2005 March 22-24, 2005 Paris. France

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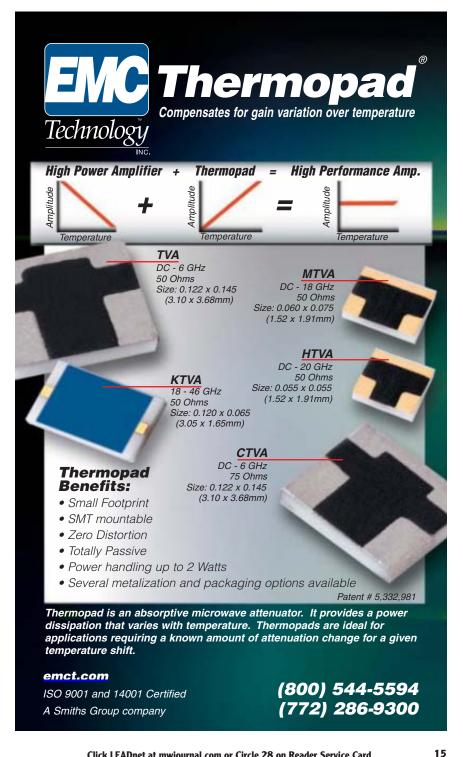
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S8W2	S8W5	N8W5	8	±0.60
S9W2	S9W5	N9W5	9	±0.60
S10W2	S10W5	N10W5	10	±0.60
S12W2	S12W5	N12W5	12	±0.60
S15W2	S15W5	N15W5	15	±0.60
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IEEE MTT-S International Microwave Symposium and Exhibition June 12–17, 2005 Long Beach, CA

This symposium will serve as the centerpiece of Microwave Week 2005. Topics: research, development and application of RF and microwave theory and techniques. In addition to IMS2005, a microwave exhibition, a historical exhibit, the RFIC symposium and the ARFTG conference will be held during Microwave Week 2005. The technical sessions will run Tuesday through Thursday of Microwave Week. Workshops will be held Sunday through Tuesday, and the ARFTG Microwave Measurements Conference will be held on Thursday and Friday. For more information, visit www.ims2005.org. For exhibition information, contact Kristen Dednah, Horizon House Publications, 685 Canton St., Norwood, MA 02062 (781) 769-9750 or e-mail: kdednah@mwjournal.com.

Wireless Communications Association 2005 June 28-July 1, 2005 Washington, DC

This 18th annual event will convene 2000 broadband wireless executives from 40 nations, and feature 200 speakers and 75 exhibitors who will showcase product solutions from 2 to 90 GHz, as well as FSO and SDR solutions For more information, visit www.wcai.com or contact Tim Sheetz at (202) 452-7823 or e-mail: tim@wcai.com.

European Microwave Week 2005 October 3-7, 2005 Paris, France

European Microwave Week 2005 (EuMW) features four major conferences, a three-day commercial exhibition that attracts international players, alongside technical workshops and short courses. GAAS 2005 - The 13th Gallium Arsenide and other Compound Semiconductors Application Symposium (October 3–4); **ECWT 2005** – The European Conference on Wireless Technology (October 3–4); **EuMC 2005** – The 35th European Microwave Conference (October 4-6); EuRAD **2005** – The 2nd European Radar Conference (October 6-7); and the European Microwave Exhibition (October 4–6). For all four conferences the Call for Papers is February 25, 2005. To submit a summary or for more information on the event, visit www.eumw2005.com.

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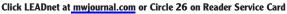
COMING EVENTS

MTT Wireless
January 15–20, 2006
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This inaugural symposium will encompass a combination of events all geared to wireless systems and technologies. A three-day exhibition will take place the same week as three technical conferences. The centerpiece of the week is the *IEEE Radio and Wireless Symposium* (RWS), which continues the evolution of

the successful Radio and Wireless Conference. Also participating are the established Topical Meeting on Silicon Monolithic Integrated Circuits in RF Systems (SiRF) and the IEEE Topical Workshop on Power Amplifiers for Wireless Communications (PA Workshop). For more information, visit www.mttwireless.org. Companies interested in the exhibition, or in sponsorships should contact Kristen Dednah at (781) 769-9750. Technical attendees and perspective authors should contact Fred Schindler at (978) 670-9230

















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- **Dates:** May 9–13, 2005
- **Contact:** Carilyn Clements, IEE, +44 (0) 1438 765631, fax: +44 (0) 1438 767305 or e-mail: <u>cclements@</u> iee.org.uk.

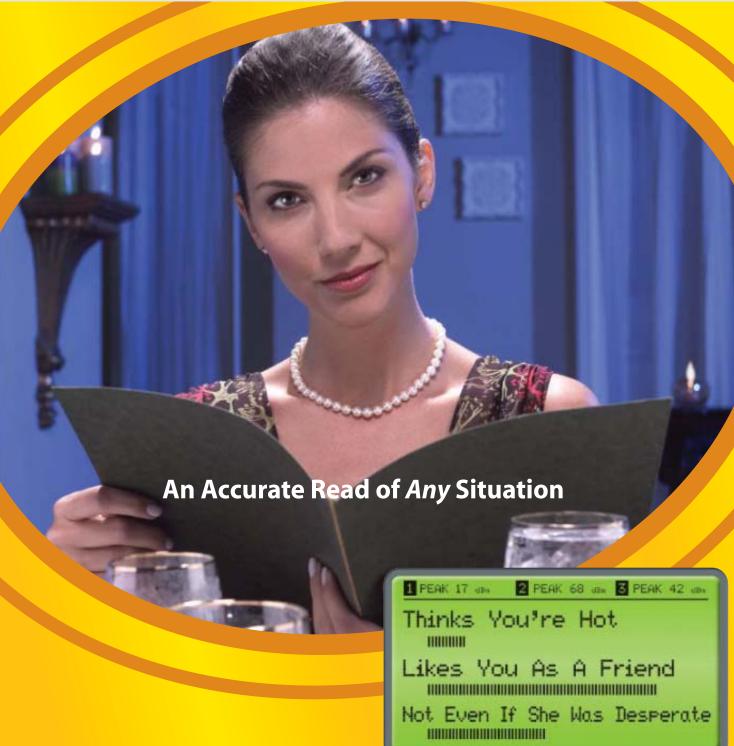
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REMOTE SENSING THROUGH SATELLITES: A TUTORIAL REVIEW

Remote sensing is a multi-disciplinary activity that deals with the inventory, monitoring and assessment of natural resources, following the analysis of data obtained through observations from a remote platform. This technology, under development since the early 1960s, has shown great promise in improving the information collection re-

The use of satellites as platforms for remote sensing has added another dimension to remote sensing.

garding the world's weather, environment and natural resources. The use of satellites as platforms for remote sensing has added another dimension to remote sensing. Satellites allow coverage of large areas at a time and repetitive coverage at predetermined intervals under similar

sun illumination conditions using sun-synchronous orbits. This article describes the whole process of remote sensing, remote sensing satellites, sensors and various elements involved in space and ground segments. Special attention has been given to the configuration of the remote sensing satellites and ground station systems, and, wherever applicable, a comparison has been made with communication satellites systems.

REMOTE SENSING PROCESS

Remote sensing is the technique of deducing information about an object, area or phenomenon through the analysis of data acquired by a sensor device that is not in physical contact with the sensed target. This definition is restricted to measurements made in different spectral regions of the interactions between the targets and electromagnetic (EM) radiations (such as light, heat and radio waves).

A fundamental property of an EM wave is that its velocity and wavelength change when it propagates through media of different densities. Its interaction with matter may, therefore, change the property of the incident wave, namely intensity, direction, wavelength, polarization and phase. The science of remote sensing records these changes and uses them to interpret the characteristics of the matter. The end-to-end process of remote sensing can be explained by the following stages/sequences: (1) a source of electromagnetic energy (sun/self emission), (2) transmission of energy from the source to the surface of the

[Continued on page 24]

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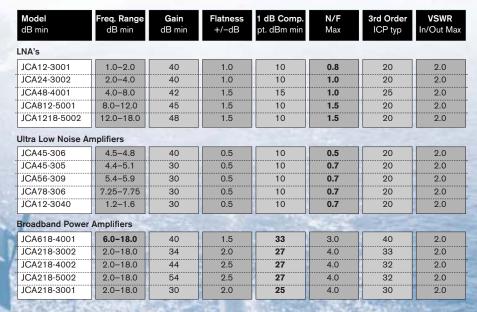


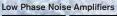
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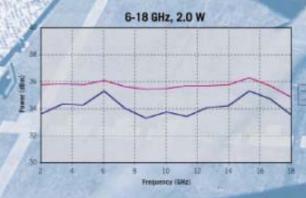




	Carrier Offset	C, X-Band (-dBc/Hz)	Ku-Band (-dBc/Hz)
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1	10 kHz	153	150
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earth, wherein it also undergoes absorption and scattering during passage through the atmosphere, (3) interaction of electromagnetic radiations with the earth's surface (reflection, scattering, absorption and re-emission), (4) transmission of the reflected/scattered/emitted energy from the objects/features of earth's surface to the remote sensors mounted onboard (with appropriate modifications due to atmospheric effects), (5) sensor data output in digital electrical signal form, (6) modulation and transmission of the data (now called satellite payload data) to earth. (7) data acquisition through an earth station tracking receive antenna, (8) data demodulation and archival/recording in different media such as high density digital recorders, hard disks, digital cassette recorders, etc., (9) generation of products by processing of the data to different levels of accuracy employing various corrections and (10) interpretation of the data and its presentation into usable form such as floppies, maps, cartridges, discs, etc.

REMOTE SENSING PHYSICS

The information from an object to the sensor is propagated by EM waves through the atmosphere at the velocity of light, directly through free space as well as indirectly by reflection, scattering and re-radiation. The interaction of EM waves with natural surfaces and the atmosphere is strongly dependent on the frequency of the waves. Remote sensing by satellites involves atmospheric degradation from the entire atmospheric column. Thus, the characteristics of the atmosphere significantly determine the effective use of the electromagnetic spectrum for remote sensing. Although the electromagnetic spectrum is infinitely wide and spans the entire region ranging from the longest wavelengths of radio waves to the shortest wavelengths corresponding to gamma rays, most of the regions cannot be used for remote sensing owing to certain practical limitations. X-rays and most of the ultraviolet radiations are rendered unusable by atmospheric attenuation (complete absorption by the ozone layer in the upper atmosphere), while at lower frequencies, the ionosphere reflects the radiations totally. Therefore, the spectral regions (also called atmospheric windows) in which the atmosphere is transparent or offers very little attenuation only can be used for remote sensing. Such windows fall in ultraviolet (0.3 to 0.4 μ m), visible (0.4 to 0.75 μ m), near infrared (0.77 to 1.34 µm), mid-infrared $(1.55 \text{ to } 2.44 \mu \text{m})$, thermal-infrared $(3.5 \text{ to } 5 \mu\text{m}, 8 \text{ to } 12.5 \mu\text{m} \text{ and } 17 \text{ to})$ 22 µm) and microwave (2 to 1000 mm) regions of the electromagnetic

spectral bands (other than the previously mentioned low attenuation atmospheric windows) offer severe attenuation/absorption due to the presence of water vapor (H_2O) , oxygen (O_2) , ozone (O_3) , carbon dioxide (CO_2) and aerosols in the atmosphere. *Figure 1* depicts the generalized absorption spectrum of the earth's atmosphere.

Many earth surface materials respond in various distinctive ways (have different spectral reflectance characteristics) when illuminated by different regions of the electromagnetic spectrum. Moreover, within any limited region of the spectrum, a particular material exhibits a diagnostic spectral radiance pattern, which is generally different from that of another material. Thus, every individual substance or class of related substances has its own specific spectral signatures (ability to respond to an EM wave) or spectral response curve. Each class of substances shows some dominant signature or pattern by which members of that class can be identified. For example, vegetation may reflect only 10 to 15 percent in the green portion of the spectrum, and as much as 40 to 60 percent in the near infrared. Similarly, water and soil may have different reflection characteristics. However, spectral reflectance characteristics under certain conditions may be the same for some objects (water and wet black soil, for example). In such cases separation of objects based on a single band/wavelength would be difficult. Under these conditions, another portion of the electromagnetic spectrum that provides distinct separation is used. This approach to remote sensing is called multispectral mode study of the objects and involves either measurements of the spectral signatures over one or more regions of the spectrum or sampling of the radiation intensities as single values integrated through specific intervals or wavelength bands. The Multi Spectral Scanner (MSS), Thematic Mapper (TM) and Linear Imaging Self Scanning Sensor (LISS) are some examples of the sensors used in satellites for sensing the radiances of the earth surface in distinct spectral bandwidths.

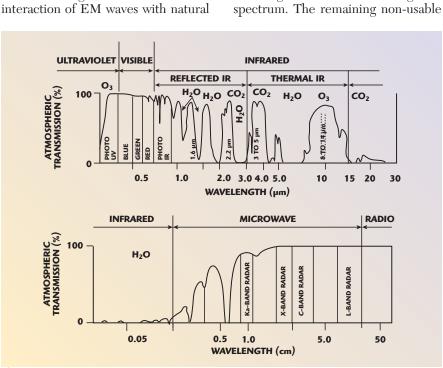


Fig. 1 Generalized absorption spectrum of the earth's atmosphere.

[Continued on page 26]

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Number	(MHz)	(dBm)	(dBm)	(dB)	Figure (dB)	Channel Power (ACPR)	Bias (V/mA)	Style
AH110	50-2000	+23	+39	20.5	5.0	13 (-45 dBc)	8/100	SOT-89
AH114	60-2500	+24	+41	19.0	5.0	17 (-45 dBc)	5/150	SOT-89
AH115	1800-2300	+28	+44	14.0	5.0	22.5 (-45 dBc)	5/250	50IC-8
AH116	800-1000	+28	+42	17.0	7.0	23 (-45 dBc)	5/250	SOT-89
AH118	60-2500	+24	+41	20.5	4.0	17 (-45 dBc)	5/160	SOT-89
AH215	400-2300	+31	+46	17.0	7.0	25.5 (-45 dBc)	5/450	50IC-8
AH312	400-2300	+33	+51	18.0	8.0	27 (-45 dBc)	5/800	50IC-8



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REMOTE SENSING SENSORS

Remote sensing sensors can be grouped into two major categories — passive sensors and active sensors. Sensors that detect natural radiation, either emitted by or reflected from the earth's surface, are called passive sensors. Thus, in a passive sensing system, there is no control over the source of electromagnetic radiation. Examples of passive remote sensing sensors are photographic cameras,

multispectral scanners, etc. The sensors that have their own source of electromagnetic radiation for illuminating the objects are called active sensors. Examples of active sensors are synthetic aperture radar and side looking airborne radar. The active remote sensors work in the microwave region of the electromagnetic spectrum and do not need the sun's illumination. They have the capability to perform remote sensing even in the

presence of persistent cloud cover or any other obstruction and, therefore, are useful for obtaining remote sensing information in a peninsular region, coastal zones and valleys.

REMOTE SENSING SATELLITES

Remote sensing of earth resources can be done using either airborne or space-based platforms. Commercially available aircrafts, modified to house the remote sensing equipment, are mostly used as remote sensing platforms to obtain photographs. Since the altitude of aircrafts can be altered by choice, images of different scales (from 1:5000 to 1:25000) can be tailored for specific applications. There is also flexibility for changing the sensing system for different requirements. However, apart from being expensive, the swath width (area on the earth surface over which an independent measurement can be made by the sensor, that is the distance covered across the track) offered by the aircraft remote sensing is also less due to the lower altitude of the aircrafts. Besides, aircraft do not have accessibility to difficult terrains and cannot fly in bad weather conditions. Space-based platforms that use remote sensing satellites as a means to carry remote sensing equipment/sensors are, therefore, more popular in carrying out earth observations.

Remote sensing satellites are characterized by being in near polar, near circular, sun synchronous and low earth orbit, unlike communication satellites, which are placed in equatorial, elliptical and geosynchronous earth orbit at approximately 36,000 km altitude. The purpose of placing satellites in polar orbit is to take advantage of the earth's rotation on its axis, to bring new segments (or sectors) of the earth under the view of the satellite, provided the period of the satellite orbit is small compared to the rotational period of the earth (24 hours). Therefore, repetitive global coverage is possible when the remote sensing satellites are placed in sun-synchronous polar orbits of 700 to 1000 km altitude (which in effect determines the orbital period of the satellite) with an orbital period of roughly 100 to 120 minutes. A sunsynchronous orbit means that the

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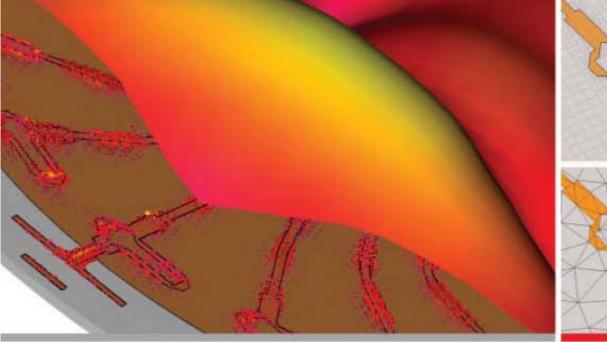
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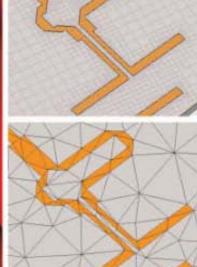
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plane of the orbit maintains a fixed orientation with respect to the sun. The orbit plane rotates at the same rate as the mean rate of the earth around the sun (that is 0.9856°/day). Thus, the satellite passes over a particular latitude approximately at the same local time. Hence, the image of any given point on the globe is always acquired at approximately the same local solar time of day. This is advantageous from a remote sensing point

of view, as it ensures that the sun elevation angle is roughly the same on each satellite pass. As a general rule, a local equator crossing time of 10:30 a.m. emerges as statistically the best from the point of view of obtaining coverage with minimum cloud and haze. A remote sensing satellite, therefore, enables the study of natural resources in various seasons under the same illumination conditions. The satellite returns to its original orbital

trace after every fixed interval time (the IRS-1C satellite repetitive cycle is 24 days with an orbital period of 101 minutes), thus enabling the repeated collection of data in the same plane at the same local time.

The Indian Space Research Organization (ISRO) is responsible, in India, for building and launching remote sensing satellites indigenously. The satellites are launched on a polar orbit by a Polar Satellite Launch Vehicle (PSLV) from the Shriharikota range (also known as the Satish Dhavan Space Centre) in Andhra Pradesh. IRS-1C/1D, IRS-P3/P4 and IRS-P6 are some of the current major Indian operational remote sensing satellites in orbit. The various constituents of the network, required for the operation of a typical remote sensing satellite mission, can be seen in Figure 2, which depicts the overview of the IRS-1C mission and includes different segments of the network in India and abroad along with the individual functions they

SPACE SEGMENT

The spacecraft mainframe and the associated electronics mounted onboard the satellite constitute the space segment of a typical remote sensing satellite mission. It carries out various functions, including imaging the earth in all the required spectral bands, formatting the payload sensor data and transmitting to ground stations (some advanced generation of satellites like Indian Remote Sensing satellites IRS-1C and ID also provide data acquired outside the visibility region of any ground station through an onboard tape recorder; the recorded data is downlinked to the receive earth station during night passes), providing the necessary power for the mainframe and payload subsystems, providing the attitude stability required for imaging, providing housekeeping information for monitoring the satellite health and accepting telecommands to control the spacecraft. The specifications of a typical space segment of a remote sensing satellite can be obtained from Table 1. The specifications of the IRS-1C space segment are shown in **Table 2**.

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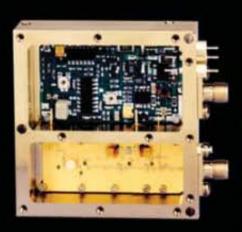
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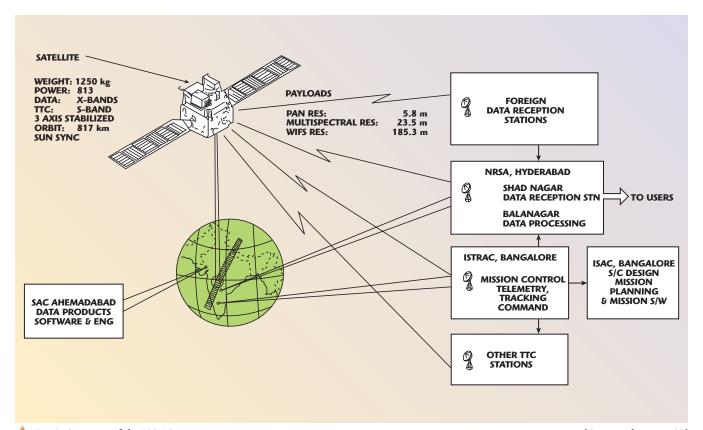


Fig. 2 Overview of the IRS 1C mission.

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MCA1-85L	4	2800-8500	6.0	35	9.45
MCA1-12GL	4	3800-12000	6.5	38	11.95
MCA1-24	7	300-2400	6.1	40	5.95
MCA1-42	7	1000-4200	6.1	35	6.95
MCA1-60	7	1600-6000	6.2	30	7.95
MCA1-85	7	2800-8500	5.6	38	8.95
MCA1-12G	7	3800-12000	6.2	38	10.95
MCA1-24I H	10	300-2400	6.5	40	6.45
MCA1-42LH	10	1000-4200	6.0	38	7.45
MCA1-60LH	10	1700-6000	6.3	30	8.45
MCA1-80LH	10	2800-8000	5.9	35	9.95
MCA1-24MH	13	300-2400	6.1	40	6.95
MCA1-42MH	13	1000-4200	6.2	35	7.95
MCA1-60MH	13	1600-6000	6.4	27	8.95
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TABLE I				
MAJOR SPECIFICATIONS OF A TYPICAL REMOTE SENSING SATELLITE RECEIVE EARTH STATION				
Frequency (MHz)	X-band: 8025–8400; S-band: 2200–2300			
Antenna	10 m diameter parabolic main reflector 1.5 m diameter hyperbolic subreflector			
Feed	Cassegrain composite S- and X-band feed in single channel monopulse mode configuration			
Polarization	RHCP/LHCP, configurable			
Axial ratio (dB)	X-band: 2; S-band: 1.5			
G/T (dB/K)	X-band: 31; S-band: 20			
Pedestal type	Elevation-over-Azimuth			
Antenna travel (°)	El: –5 to ±185; Az: ±360			
Drive type	dual motor drive for each axis with torque bias arrangement to eliminate gear backlash			
Max velocity (°/sec)	Az: 22; El: 10			
Max acceleration (°/sec²)	Az: 5; El: 1			
Servo bandwidth (Hz)	narrowband-mode: 0.5; wideband-mode: 0.85			
Locked rotor frequency (Hz)	4.2			
Tracking accuracy (°)	0.01			
IF frequency (MHz)	X-band: 375; S-band: 70			
Down converter	3-channel synthesized			
Demodulators	configurable for BPSK/UQPSK/QPSK mode with variable data rates up to 300 Mbps			
Data recorder	high density digital tape recorders (HDTR)/Digital Audio Tape/Digital Cassette Recorders (DCRS)/RAIDS			
Timing system	time accuracy: 1 μs time code (output): IRIG-A/IRIG-B (selectable) stability: better than 1×10^{-11}			

The structure of the IRS-1C spacecraft, shown in Fig**ure** 3, has been followed to explain the constitution of the typical space segment. The structure is divided into two major parts, that is, the main and payload platforms. The main platform consists of the major mainframe subsystem packages, solar panels, sun sensors, payload data transmission antenna and TTC antenna, while the payload platform accommodates the remote sensing sensors (PAN, LISS-III and WiFS cameras of IRS-1C satellite). In addition, it also accommodates earth sensors and star sensors. Some advanced satellites have a payload steering mechanism (PSM) that enables the tilting of the sensors in the direction of the pitch axis to facilitate the view of a given area more than once within one cycle of satellite passes and to obtain three-dimensional images of the earth (the PAN camera of IRS-1C can be tilted/steered in steps up to an angle of ±26° so that the maximum wait period to view a given area is only five days). A photograph of the PAN camera is shown in *Figure 4*.

The thermal control system maintains the temperature of different subsystems within specified limits using

TABLE II MAJOR SPECIFICATIONS OF SPACE SEGMENT OF IRS-1C					
Туре	three axis, body stabilized remote sensing satellite				
Orbit	polar, sun synchronous, 817 km altitude with equatorial crossing time of 10:30 AM, in descending node				
Repetivity	341 orbits/24 days				
Revisit capability	5 days				
Thermal Control					
Temperature (°C)	20±3 for payload; 2±2 for batteries and 0 to 40 for electronics package				
Data Handling					
Data rate (Mbps) Modulation Frequency (MHz) Power (W)	PAN LISS-III 84.903 42.4515 QPSK QPSK 8150 8350 40 40				
Beacon frequency (MHz)	8255				
Power					
Solar array power generation capacity	813 W at EOL				
Batteries	2 batteries of 21 AH each				
Telemetry, Tracking and Command					
(A) Telemetry data (bps)	real time: 512 dwell: 512 playback (storage 1): 6400 star sensor (storage 2): 6400				
Subcarrier (kHz)	real time: 25.6 dwell/playback/star sensor: 128				
Modulation	PCM/PSK/PM				
Storage (housekeeping) (MB)	capacity: 2.75 data type: sampled (1:5) or continuous				
Storage (star sensor) (kB)	capacity: 512 data type: raw				
(B) Telecommand	no. of on/off commands: 704 no. of data commands: 50 command bit rate: 100 bps				
Modulation	PCM/FSK/FM/PM				
FSK carrier for ONE (kHz) FSK carrier for ZERO (kHz)	5.555 3.125				
No. of time tag commands	255 per decoder				
Probability of erroneous command execution	1.8×10^{-42}				
Probability of command rejection	0.98×10^{-13}				
Transponder	uplink frequency: 2028.78 MHz down frequency: 2203.2 MHz turn around ratio: 240/221 S-band tone ranging: max tone 100 kHz two way Doppler				

heaters and temperature controllers apart from other passive elements such as paints, multi-layer insulation blan-

[Continued on page 34]

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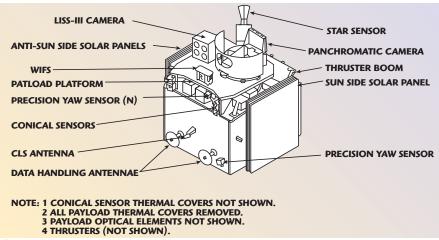


Fig. 3 Isometric view of the IRS-1C spacecraft (stowed mode).

kets and optical solar reflectors. The power requirements are met by deployable sun-side and anti-sun-side solar panels. Batteries are also provided to supply power during an eclipse.

The Telemetry and Telecommand (TTC) subsystem is configured to work at S-band. The telemetry system collects the housekeeping data from each subsystem, and then formats and modulates it on the subcarrier. The IRS-1C satellite has two formats, dwell and normal. The recorded telemetry data of the onboard tape recorder is played back and transmitted to earth at 6.4 kbps using the dwell mode, whereas the normal mode telemetry data is transmitted at

Fig. 4 The PAN camera.

X-BAND TX
LISS III (M)

X-BAND TX
LISS III (R)

X-BAND TX
PAN (R)

X-BAND TX
PAN (M)

X-BAND TX
PAN (M)

X-BAND TX
PAN (M)

📤 Fig. 5 Schematic diagram of the RF data handling system.

512 kbps. The telemetry system also houses another storage facility for recording raw star sensor data. The normal and dwell mode or star sensor telemetry data are phase-shift keying (PSK) modulated on different subcarriers.

The telecommand system employs a shortened B-C-H code for command reception. The telecommand supports autocommanding for autodeployment and safemode operations. It also controls the operation of the payload and data handling systems and configures it for various operational modes. The Attitude and Orbit Control System (AOCS) is used to achieve stabilization of the satellite (three-axis body stabilization in IRS-1C) in a sun-synchronous orbit, using actuators, reaction wheels, magnetic torquers and thrusters. The attitude control electronics package generates control signals for these actuators depending upon the attitude errors sensed by earth sensors, gyros and sun sensors.

As already stated, the remote sensors are placed on the payload platform of the spacecraft. The payload data handling system basically consists of a baseband system and an RF sys-

tem. The baseband system consists of control circuits, oscillators, formatters, randomizers and modulation interfaces. The RF system contains the local oscillators, modulators, power amplifiers (usually TWTAs) and anten-

na systems. Data formatting and multiplexing of different sensors data is done by the baseband data handling system. For example, in the IRS-1C, the data handling system parallels the data from all four ports of each of the three charged coupled devices (CCD) arrays of the PAN payload, which is multiplexed and formatted in two serial PCM streams, PAN-I and PAN-Q, each with a data rate of 42.4515 Mbps. Similarly, the LISS-III formatter accepts digital data from the LISS-III payload in three bands, the SWIR payload in one band and the WiFS payload data in two bands, and then multiplexes and formats them into a single PCM stream of 42.4515 Mbps. The data handling system also provides the selected data of each sensor to the onboard tape recorder for recording. The data during playback is received from the tape recorder and fed to the modulator after performing differential encoding on it.

The serial data from the baseband system is fed to the RF system to modulate (BPSK, QPSK or UQPSK) and transmit the data to ground, either at S- or X-band carrier frequencies. If the data from two different sensors has to be transmitted at different data rates, then an unbalanced quadrature phase-shift keying (UQPSK) modulation scheme is used. Similarly, while binary phase shift keying (BPSK) modulation is used for lower data rate transmission, using an S-band carrier, the higher data rates payload signals are carried by either QPSK or UQPSK modulated X-band carriers. The modulated output, followed by a power amplifier (traveling wave tube amplifier), is applied to the transmit antenna.

The transmit antennae, one each for S- and X-band, are shaped beam antennae, the gain pattern of which is shaped in such a way that an approximately constant flux density is maintained at the aperture of the earth station receive antenna. Beam shaping is essential to equalize the very large variation in path loss.

Some data handling systems also transmit an X-band beacon signal for helping the receive ground stations to track the satellite accurately. *Figure* 5 shows the block schematic of a typical RF data handling system of a remote sensing satellite.

[Continued on page 36]

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Fig. 6 The ISTRAC Spacecraft Control Center.

GROUND SEGMENT

The main functions of the ground segment can be listed as telemetry, tracking and command (TTC), mission control, data reception, data products generation, and dissemination. TTC activities, like in any other satellite mission, include satellite housekeeping data reception and recording, and spacecraft commanding and tracking. Tracking involves the measurement of range and range rate of the satellite with reference to a known source, which in turn determines its position and velocity and, hence, is essential for spacecraft orbit determination and ephemeris generation. Similarly, other mission-related functions such as network coordination

and control, scheduling spacecraft operations, orbit, attitude determination and control, and establishment of communication links between concerned ground segment elements, etc., are known as the mission control activities. The Mission Control Center is shown in Figure 6. Reception and recording of payload data is carried out by the receive ground stations. Generation and distribution of different types of data products described earlier, data quality evaluation, archival and payload programming depending on a user's requirement are also carried out by the ground segment.

REMOTE SENSING SATELLITE RECEIVE GROUND STATION

A receive earth station performs the following functions to meet the data reception requirements in real time that includes acquiring the satellite when it rises in the visibility circle (at about 2° elevation angle of the antenna), tracking the satellite accurately using both Sand X-band carriers by extracting the tracking information and thereafter driving the servo system and antenna, and receiving, demodulating and recording the digital sensor data in real time with desirable quality.

A major functional difference between a remote sensing satellite receive ground station and a communication satellite ground station arises due to the lower altitude of the remote sensing satellites as compared to the geostationary satellites resulting in very high velocity in orbit. Due to the high relative velocities between the satellite and the ground station, the earth station receive antenna has to move in azimuth and elevation with very high velocity (of the order of 15° to 20°/sec) and acceleration (in the order of 5° to 10°/sec²) to keep itself in the line of sight with the satellite for the entire duration of the satellite pass. This tracking require-[Continued on page 38]

[Communa on page 99

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irs					Sroadband I	Vicrowave	Broadband Microwave Power Amplifiers	Fiers	
+7	2.0:1	190	L0104-43	1 - 4	42.5	17.8	41.5	45	14
+10	1.8:1	150	L0204-44	2-4	44	25	42.5	45	14
+10	1.8:1	150	L0206-40	2-6	40	10	38.5	40	8.5
+5	2.5:1	09	L0218-30	2 - 18	30	_	29	30	က
8+	2.2:1	100	L0408-43	4-8	43	20	41.5	45	17
∞ +	2.2:1	170	L0618-43	6 - 18	43	20	41.5	45	22
8+	2.5:1	200	L0812-44	8 - 12	44	22	42	45	22
fiers			L1218-43	12 - 18	43	20	41.5	45	22
+23*	2.0:1	480							
+33	1.8:1	1500			Millimeter	-Wave Por	Millimeter-Wave Power Amplifiers	10	
+33	2.0:1	2000	L1826-34	18 - 26	34	2.5	33	35	4

ах	min	(In/Out)	@ +12/+15VDC		(GHz)	(dBm)	(w)	(dBm)	(dB)	@ +12V
olifiers					В	roadband I	Microwave	Broadband Microwave Power Amplifiers	plifiers	
.3*	+7	2.0:1	190	L0104-43	1 - 4	42.5	17.8	41.5	45	41
1.2	+10	1.8:1	150	L0204-44	2-4	44	25	42.5	45	14
1.5	+10	1.8:1	150	L0206-40	2-6	40	10	38.5	40	8.5
2.2	+2	2.5:1	09	L0218-30	2 - 18	30	_	29	30	က
2.7	8+	2.2:1	100	L0408-43	4 - 8	43	20	41.5	45	17
3.5*	8+	2.2:1	170	L0618-43	6 - 18	43	20	41.5	45	22
2.8	φ	2.5:1	200	L0812-44	8 - 12	44	22	42	45	22
mplifiers	S			L1218-43	12 - 18	43	20	41.5	45	22
3.2*	+23*	2.0:1	480							
9	+33	1.8:1	1500			Millimeter	-Wave Po	Millimeter-Wave Power Amplifiers	ers	
5.5	+33	2.0:1	2000	L1826-34	18 - 26	34	2.5	33	35	4
4	+25	2.0:1	450	L1840-27	18 - 40	27	0.5	26	30	2
4	+33	2.0:1	1850	L2632-37	26 - 32	37	2	36	38	10
				L2640-27	26 - 40	27	0.5	26	30	2
pillers		3	7	L2630-37	26.5 - 30.5	37	2	36	38	10
7.7	+10		150	L2732-35	27 - 32	35	2.8	33	35	9
υ.	100 4	1.0.1	130	L3040-30	30 - 40	30	-	29	35	4
0.	01.+		061	L3236-36	32 - 36	36	4	35	40	12
Phase	Phase noise (dBc/Hz) at offset	Bc/Hz) a	t offset	L3640-36	36 - 40	36	4	35	40	10
OHz	1KHz	10KHz	100KHz			High-Powe	er Rack M	High-Power Rack Mount Amplifiers	ïers	

5.5

±2.0

28 30 32 35

2.0 - 18.0

6.0 - 18.0

AML618P3502-2W

±2.5 ±2.5 +2.5

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±2.25

12.0 - 26.5

0.01 - 6.0

2.0 - 6.0

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2.0 - 8.0

16

2.0 - 18.04.0 - 12.00.5 - 18.00.1 - 26.5

AML0518L1601-LN

AML218L0901 AML412L3002

AML0126L2202

AML1226L3301

1.5

±0.75

24 24 24 24

14.0 - 14.517.0 - 18.0

AML1414L2401 AML1718L2401

AML23L2801

2.8 - 3.1

±0.75

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)				
Model	Frequency (GHz)	Psat (dBm)	Psat (W)	P1dB (dBm)	Pac (kW)	Height (in)
C071077-52	7.1 - 7.7	52.5	170	51.5	1.8	10.25
C090105-50	9 - 10.5	20	100	49	_	8.75
C140145-50	14 - 14.5	50.5	110	49.5	2	10.25
C1416-46	14 - 16	46	40	45	0.35	5.25
C1820-43	18 - 20	43	20	41.5	0.25	5.25
C2326-40	23 - 26	40	10	39	0.25	5.25
C2630-40	26.5 - 30.5	40	10	39	0.25	5.25
C3236-40	32 - 36	40	10	39	0.25	5.25
C3640-39	36 - 40	39	∞	38	0.24	5.25
		1		1		

-164.5 -168 -178

> -165 -160

-165

-155

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Gain (dB)

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-157.5 -153.5

-152.5 -145.5 -150

18 28 20 15

15

2.0 - 6.0

2.0 - 6.0

AML26PN1201

-159

-154

17

8.5 - 11.08.5 - 11.08.5 - 11.0

AML811PN0908 AML811PN1808 AML811PN1508

100Hz

Gain Output Power

-167



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32 28 30

23 33 33

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4.0 - 8.0

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Part Number





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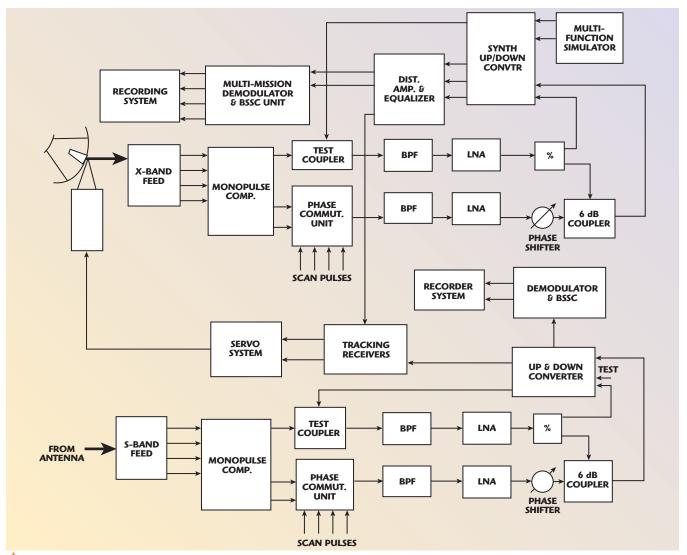


Fig. 7 Block diagram of a remote sensing satellite ground station.

ment of the remote sensing satellite earth station antenna poses severe constraints in the design of several systems apart from the servo and drive systems. Additionally, the lower beam width of the antenna at X-band frequencies, coupled with high Doppler offset frequencies and rates, necessitates the need for a unique design for tracking and data reception systems. The whole operation of the tracking and data reception is a real time operation and has to be carried out very carefully in a planned manner during the complete satellite pass (of about 1 to 15 minutes duration, depending on the satellite location with respect to the earth station). The reliability of all the subsystems involved has to be very high (typically 99 percent) and the system cannot afford any data loss during this period as once the data is lost, the earth station will have to wait for the satellite to appear

on the same path once again in its next cycle (24 days, in the case of IRS-1C) for transmitting the images of the same area. Contrary to communication satellite ground stations, however, remote sensing satellite ground stations do not need any transmit system (high power amplifiers and up-converter systems).

The configuration of a typical remote sensing satellite receive ground station is briefly described with reference to the block diagram in *Figure* 7. The main subsystems of the earth station include the antenna, feed and front-end subsystem, the RF/IF subsystem, the servo subsystem and tracking pedestal, and the data archival subsystem.

The antenna, feed and front-end subsystem receives the signals from the satellite at X-band (8.025 to 8.400 GHz) and S-band (2.2 to 2.3 GHz) simultaneously. The shaped or conven-

tional parabolic antenna of 6 to 10 m diameter is used, depending on the G/T (typically 29 to 31 dB/K) and antenna-efficiency requirement of the earth station. The elevation (El)-overazimuth (Az) mount is the one used by the majority of large earth stations since this type of mount is cost effective and easy to install for large antennae and involves simpler balancing about the axis. Special provisions to track the overhead passes must be made to receive data without any break due to a cone-of-silence appearing overhead (the cone-of-silence is the zone where satellite tracking is impossible due to infinite velocity and acceleration requirements of the antenna). Another type of mount, called an X-Y mount, is basically an unbalanced mount and is more complicated to install. However, smaller antenna [Continued on page 40]

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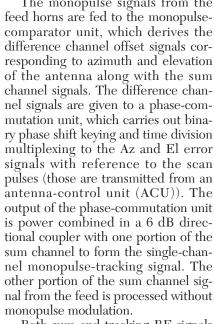
systems (about 6 m diameter) use this type of mount as it facilitates the cone-of-silence to appear at the horizon rather than in overhead zones, and the requirement of velocity and acceleration on the drive system are less demanding for tracking a moving satellite. The antenna remains fully steerable between 0° to 365° in azimuth and 0° to 180° in elevation.

The feed is the dual-band (X- and S-band) single-channel monopulse

tracking-feed mounted in Cassegrain configuration to derive the tracking error signals for driving the antenna in a direction to nullify this error. The antenna is shown in Figure 8. Other types of tracking feeds such as a conical scan feed and sequential lobing feed are not used due to the complex motion of the antenna involved, the additional servo-system requirements to move feed, the inability to follow the amplitude fluctuations resulting from the continuous changing of the cross section of the target, poorer signal-to-noise ratio and poorer tracking

The monopulse signals from the

Both sum and tracking RF signals are fed to the RF/IF subsystem, which consists of a synthesized signal up/down-converter unit that converts different input RF frequencies to corresponding IF frequencies, all centered at 375 MHz (70 MHz in the S-band chain), through synthesizing the local oscillators. The down-converted sum and tracking signals at the IF center frequency on each carrier are brought down to the control room where the difference channel signal is fed to a tracking receiver. The tracking receiver detects the tracking monopulse modulation synchronously and feeds the DC error signals corresponding to azimuth and elevation antenna offset angles to the servo subsystem consisting of the ACU. The tracking pedestal is an elevation-

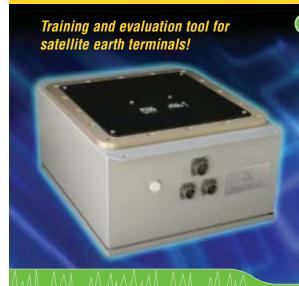




📤 Fig. 8 Dual-band, single-channel monopulse tracking-feed antenna.

[Continued on page 42]

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USSP0175*	169 to 181	0.4 to 2.2	14	-100	0.5 ± 2.5	-10	<0.1	<1	3.0	12	0 to 70
V560TF03	400 to 800	0 to 12	45	-100	6.5 ± 5.5	-15	<6	<2	5.0	19	-10 to 70
CLV1635A	1600 to 1670	0.5 to 4.5	34	-110	2.5 ± 2.5	-15	<1	<1	5.0	20	-40 to 85
USSP2400	2400 to 2485	0.5 to 2.5	120	-83	-1 ± 3	-15	<13	<38	2.7	8	-40 to 85
SMV3590A	3490 to 3690	0.5 to 2.5	210	-89	3 ± 3	-20	<7	<10	2.8	12	-10 to 75
SMV5530A	5430 to 5630	0.5 to 4.5	150	-86	0 ± 2	-25	<4	<3	5.0	27	-35 to 85
CRO6000Z*	5990 to 6010	0.5 to 4.5	18	-108	4 ± 2	-18	<0.5	<2	5.0	122	-40 to 85
CRO6835Z	6834 to 6835	0.5 to 4.5	18	-102	3 ± 3	-18	<0.5	<2	5.0	123	-40 to 85
PLL Part Number	Frequency (MHz)	Step Size (kHz)	Output Power (dBm)	Ø _N @ 10KHz (dBc/Hz)	Ø _N @ 100KHz F (dBc/Hz)	2nd Harmonic (dBc)	Ref Sup (dBc)	Lock Time (msec)	Vcc (Vdc)	lcc (mA)	Operating Temp (°C)
PCA0300A	275 to 325	100	4 ± 3	-101	-122	-7	-65	5	5.0	18	-40 to 85
PCA1292A	1292 to 1298	1000	0 ± 2	-105	-125	-15	-70	1.4	5.0	35	-40 to 85
PSA1780A	1780 to 1840	50	3 ± 2	-106	-127	-15	-65	5	5.0	40	-40 to 85
PSA1905A	1875 to 1935	100	1.5 ± 3.5	-106	-127	-10	-65	6	5.0	40	-30 to 85
PSA2200C*	2160 to 2222	1000	0 ± 3	-108	-130	-15	-70	2	5.0	35	-40 to 70
PSA2960C*	2955 to 2965	125	0 ± 2	-116	-133	-15	-70	1	5.0	30	-40 to 85
PSA3550A	3545 to 3555	1000	0 ± 3	-107	-126	-15	-70	2	5.0	35	-40 to 85
PSA4937A	4880 to 4920	1000	4 ± 2	-86	-103	-25	-70	0.5	5.0	38	-40 to 85

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DC motors, gear boxes, break assembly, synchros and limit switch packages mounted in it. The ACU processes the DC error signals and feeds them to the pedestal drive DC motors through $D\vec{C}$ power amplifiers. The DC motors drive the gear system and antenna in such a way that the antenna tracks the satellite in line of sight with the required accuracies.

The corresponding IF data signals received in the sum channel are fed

to the data demodulators and bit-synchronizers, which are the part of the RF/IF subsystem. The data demodulators/bit-synchronizers are designed with multifunction capabilities to receive data from any input modulation comprised of BPSK, QPSK or UQPSK. This enables the demodulators to be compatible for multi-mission operations facilitating only plugin augmentation in the bit-synchronizer unit and no change in the other units of the earth station is required in order to receive data from any new satellite planned. To test the end-toend performance of the receive chain in the local loop before a satellite pass, a simulator that simulates satellite-transmitted spectrum at variable data rates with different modulation schemes of BPSK/QPSK/UQPSK is used to inject the up-converted testsignal into the front-end LNA amplifier, through a 30 dB test-coupler.

The synchronized data and clock streams from the demodulator/bitsynchronizer unit are given to the data archival subsystem, which consists of high density digital data recorders, a frame synchronizer, timing system and real-time browsing system along with high speed computers required for ancillary data extraction and quick look monitoring. The ancillary data is generated using the telemetry data transmitted along with the tracking signal from the satellite at S-band and the state vector information, and transferred to the data processing station for further

Though the technology for the development of these ground station systems has been well established, continuous technology updating is still being carried out regularly to lessen the complexity and cost of the ground station. Today, the ground stations are automatically operated and controlled remotely through station control computers. Mission specific ground station system design has been replaced with multi-mission compatible system design, which facilitates minimum augmentation for data reception from future satellites.

product generation.

CONCLUSION

Several advances in remote sensing technology have been made to study the continuously changing global environment and resources in a more effective manner. Continued research and development efforts to bring out the latest state-of-the-art technologies in the field have resulted in several remote sensing satellites being launched regularly and more and more countries effectively utilize this technology for various applications. Remote sensing is an important part of the Indian Space Programme. In order to make remote sensing opera-

[Continued on page 44]

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tional in India, a National Natural Re-Management System (NNRMS) is being implemented under the aegis of the Planning Commission within the Department of Space (DOS) as the nodal agency. Several remote sensing application projects, which fall in major disciplines like agriculture, land use, water resources, forestry, geology, marine resources and environment, are being implemented by DOS in collaboration with the user agencies. The Indian Remote Sensing Satellite Programme has a provision to launch a series of satellites every two to three years to provide continuity of data to Indian users. The first in the series, IRS-1A, was launched in March 1988 and was later joined by IRS-1B in August 1991. Several satellites with advanced capabilities in terms of resolution, sensor steering and onboard recording facilities have been launched subsequently. The Indian Space Programme has acquired the latest stateof-the-art capabilities in development and establishment of satellite-based operational remote sensing applica-

tion systems to keep pace with the space programs of other countries.

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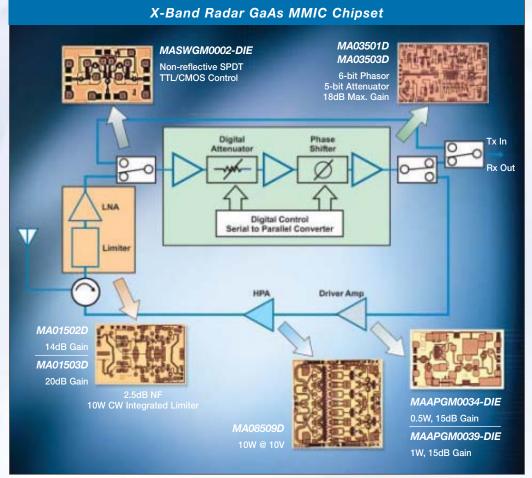




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	TEI	MPERATU	RE COMPI	ENSATED	AMPLII	FIERS		
AFS3-01000200-15-TC-6	1-2	36-40	1.00	1.5	2.0:1	2.0:1	+5	125
AFS2-02000400-15-TC-6	2-4	22-26	1.00	1.5	2.0:1	2.0:1	+5	125
AFS3-02000400-15-TC-6	2-4	26-30	1.00	1.5	2.0:1	2.0:1	+5	125
AFS2-04000800-20-TC-2	4-8	17-22	1.00	2.0	2.0:1	2.0:1	+5	70
AFS3-04000800-18-TC-4	4-8	25-30	1.00	1.8	2.0:1	2.0:1	+8	100
AFS2-02000800-40-TC-2	2-8	14-19	1.50	4.0	2.0:1	2.0:1	+5	70
AFS3-02000800-30-TC-4	2-8	22-27	1.50	3.0	2.0:1	2.2:1	+8	150
AFS2-08001200-30-TC-2	8-12	12-16	1.00	3.0	2.0:1	2.0:1	+5	70
AFS3-08001200-22-TC-4	8-12	24-28	1.00	2.2	2.0:1	2.0:1	+8	100
AFS4-12001800-30-TC-8	12-18	22-26	1.00	3.0	2.0:1	2.0:1	+8	250
AFS4-06001800-35-TC-8	6–18	22-26	1.00	3.5	2.0:1	2.0:1	+8	250
AFS6-06001800-35-TC-8	6–18	30-34	1.00	3.5	2.0:1	2.0:1	+8	400
AFS4-02001800-45-TC-5	2–18	18-24	1.50	4.5	2.2:1	2.2:1	+8	120

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Model Number	Frequency Range (GHz)	Gain (Min./Max.) (dB)	Gain Flatness (±dB, Max.)	Noise Figure (dB, Max.)	VSWR Input (Max.)	VSWR Output (Max.)	Output Power @ 1 dB Comp. (dBm, Min.)	DC Power
		HIGHE	R POWER	AMPLIFIE	RS			
AFS3-00050100-25-27P-6	0.05-1	36	1.50	2.5*	2.0:1	2.5:1	+27	300
AFS3-00100100-25-27P-6	0.1-1	33	2.00	2.5	2.0:1	2.5:1	+27	300
AFS3-00100200-25-27P-6	0.1-2	34	1.50	2.5	2.0:1	2.5:1	+27**	275
AFS3-00100300-25-23P-6	0.1-3	28	1.50	2.5	2.0:1	2.5:1	+23	275
AFS3-00100400-26-20P-4	0.1-4	24	1.50	2.6	2.0:1	2.0:1	+20	250
AFS4-00100600-25-20P-4	0.1-6	30	1.50	2.5	2.0:1	2.0:1	+20	300
AFS4-00100800-28-20P-4	0.1-8	30	1.50	2.8	2.0:1	2.0:1	+20	300
AFS4-00101200-40-20P-4	0.1-12	27	2.00	4.0	2.0:1	2.0:1	+20	300
AFS4-00501800-60-20P-6	0.5-18***	25	2.75	6.0	2.5:1	2.2:1	+20	350
AFS3-01000200-25-27P-6	1–2	32	1.50	2.5	2.0:1	2.0:1	+27	350
AFS4-02000400-30-25P-6	2–4	34	1.50	3.0	2.0:1	2.0:1	+25	250

- * Noise figure degrades below 100 MHz. Please consult factory for details.
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Model Number	Frequency Range (GHz)	Gain (Min.) (dB)	Gain Flatness (±dB)	Noise Figure (dB, Max.)	VSWR Input (Max.)	VSWR Output (Max.)	Output Power @ 1 dB Comp. (dBm, Min.)	Nom. DC Power (+15 V, mA)
		MODE	RATE BAN	ID AMPLIFI	ERS			
AFS2-00700080-06-10P-6	0.7-0.8	28	0.50	0.60	1.5:1	1.5:1	+10	90
AFS2-00800100-05-10P-6	0.8-1	30	0.50	0.50	1.5:1	1.5:1	+10	90
AFS3-01200160-05-13P-6 AFS3-01400170-06-13P-6	1.2–1.6 1.4–1.7	40 40	0.50 0.50	0.50 0.60	1.5:1 1.5:1	1.5:1 1.5:1	+13 +13	150 150
AFS3-01500180-06-13P-6	1.5-1.8	40	0.50	0.60	1.5:1	1.5:1	+13	150
AFS3-01500250-06-13P-6 AFS3-01700190-06-13P-6	1.5–2.5 1.7–1.9	38 38	1.00 0.50	0.60 0.60	1.8:1 1.5:1	1.8:1 1.5:1	+13 +13	150 150
AFS3-01700190-06-13P-6	1.8-2.2	38	0.50	0.60	1.5:1	1.5:1	+13	150
AFS3-02200230-06-13P-4	2.2-2.3	38	0.50	0.60	1.5:1	1.5:1	+13	150
AFS3-02300270-06-13P-6 AFS3-02700290-06-13P-6	2.3–2.7 2.7–2.9	36 32	0.50 0.50	0.60 0.60	1.5:1 1.5:1	1.5:1 1.5:1	+13 +13	150 150
AFS3-02700290-06-13F-6	2.9-3.1	32	0.50	0.60	1.5:1	1.5:1	+13	150
AFS3-03100350-06-10P-4	3.1-3.5	29	0.50	0.60	1.5:1	1.5:1	+10	150
AFS4-03400420-10-13P-6 AFS3-04400510-07-S-4	3.4-4.2 4.4-5.1	40 30	0.50 0.50	1.00 0.70	1.5:1 1.5:1	1.5:1 1.5:1	+13 +10	200 100
AFS3-04500480-07-S-4	4.5–4.8	30	0.50	0.70	1.5:1	1.5:1	+10	100
AFS3-05200600-07-10P-4	5.2-6	30	0.50	0.70	1.5:1	1.5:1	+10	100
AFS3-05400590-07-S-4 AFS3-05800670-07-S-4	5.4–5.9 5.8–6.7	30 30	0.50 0.50	0.70 0.70	1.5:1 1.5:1	1.5:1 1.5:1	+10 +10	100 100
AFS3-07250775-06-10P-4	7.25-7.75	30	0.50	0.60	1.5:1	1.5:1	+10	100
AFS3-07900840-07-S-4	7.9–8.4	30	0.50	0.70	1.5:1	1.5:1	+10	100
AFS4-08500960-08-S-4 AFS3-09001100-09-S-4	8.5–9.6 9–11	32 26	0.75 0.50	0.80 0.90	1.5:1 1.5:1	1.5:1 1.5:1	+10 +10	125 100
AFS4-09001100-09-S-4	9–11	32	0.75	0.90	1.5:1	1.5:1	+10	125
AFS4-10951175-09-S-4	10.95–11.75 11.7–12.2	32	0.75	0.90	1.5:1	1.5:1	+10	125
AFS4-11701220-09-5P-4 AFS2-12201280-14-5P-2	12.2–12.8	32 14	0.75 0.75	0.90 1.40	1.5:1 1.4:1	1.5:1 1.5:1	+10 +5	125 80
AFS4-12201280-13-12P-4	12.2-12.8	25	1.50	1.30	2.0:1	2.0:1	+12	200
AFS4-12701330-15-10P-4 AFS4-13201400-16-10P-4	12.7–13.3 13.2–14	30 30	0.75 0.75	1.50 1.60	1.5:1 1.5:1	1.5:1 1.5:1	+10 +10	175 175
AFS4-13201400-10-10F-4	14–14.5	30	0.75	1.50	1.5:1	1.5:1	+10	175
AFS4-20202120-25-8P-4	20.2-21.2	24	1.00	2.50	1.5:1	1.5:1	+8	175
AFS4-21202400-28-10P-4	21.2–24	23	1.00	2.80	2.0:1	2.0:1	+10	100
		OC	TAVE BAN	D AMPLIFII	ERS			
AFS3-00120025-09-10P-4	0.1225	38	0.50	0.9	2.0:1	2.0:1	+10	125
AFS3-00250050-08-10P-4	0.25-0.5	38 38	0.50 0.50	0.9 0.8	2.0:1 2.0:1	2.0:1	+10	125
		38	0.50	0.9	2.0:1			
AFS3-00250050-08-10P-4 AFS3-00500100-06-10P-6 AFS3-01000200-05-10P-6 AFS3-01200240-06-10P-6	0.25-0.5 0.5-1 1-2 1.2-2.4	38 38 38 38 34	0.50 0.50 0.75 1.00 1.00	0.9 0.8 0.6 0.5	2.0:1 2.0:1 2.0:1 2.0:1 2.0:1	2.0:1 1.5:1 2.0:1 2.0:1	+10 +10 +10 +10	125 150 150 150
AFS3-00250050-08-10P-4 AFS3-00500100-06-10P-6 AFS3-01000200-05-10P-6 AFS3-01200240-06-10P-6 AFS3-02000400-06-10P-4	0.25-0.5 0.5-1 1-2 1.2-2.4 2-4	38 38 38 38 34 32	0.50 0.50 0.75 1.00 1.00	0.9 0.8 0.6 0.5 0.6	2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1	2.0:1 1.5:1 2.0:1 2.0:1 2.0:1	+10 +10 +10 +10 +10	125 150 150 150 150
AFS3-00250050-08-10P-4 AFS3-00500100-06-10P-6 AFS3-01000200-05-10P-6 AFS3-01200240-06-10P-6	0.25-0.5 0.5-1 1-2 1.2-2.4 2-4 2.6-5.2 4-8	38 38 38 38 34	0.50 0.50 0.75 1.00 1.00	0.9 0.8 0.6 0.5	2.0:1 2.0:1 2.0:1 2.0:1 2.0:1	2.0:1 1.5:1 2.0:1 2.0:1	+10 +10 +10 +10	125 150 150 150
AFS3-00250050-08-10P-4 AFS3-00500100-06-10P-6 AFS3-01000200-05-10P-6 AFS3-01200240-06-10P-6 AFS3-02000400-06-10P-4 AFS3-02600520-10-10P-4 AFS3-04000800-07-10P-4 AFS3-08001200-09-10P-4	0.25-0.5 0.5-1 1-2 1.2-2.4 2-4 2.6-5.2 4-8 8-12	38 38 38 38 34 32 28 28 28	0.50 0.50 0.75 1.00 1.00 1.00 1.00 1.00	0.9 0.8 0.6 0.5 0.6 0.6 1.0	2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1	2.0:1 1.5:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1	+10 +10 +10 +10 +10 +10 +10 +10	125 150 150 150 125 125 125 125
AFS3-00250050-08-10P-4 AFS3-00500100-06-10P-6 AFS3-01000200-05-10P-6 AFS3-01200240-06-10P-6 AFS3-02600520-10-10P-4 AFS3-02600520-10-10P-4 AFS3-08001200-09-10P-4 AFS3-08001200-09-10P-4	0.25-0.5 0.5-1 1-2 1.2-2.4 2-4 2.6-5.2 4-8 8-12 8-16	38 38 38 38 34 32 28 28 28 26 28	0.50 0.50 0.75 1.00 1.00 1.00 1.00 1.00	0.9 0.8 0.6 0.5 0.6 0.6 1.0 0.7 0.9	2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1	2.0:1 1.5:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1	+10 +10 +10 +10 +10 +10 +10 +10 +10 +8	125 150 150 150 150 125 125 125 125 100
AFS3-00250050-08-10P-4 AFS3-00500100-06-10P-6 AFS3-01000200-05-10P-6 AFS3-01200240-06-10P-6 AFS3-02000400-06-10P-4 AFS3-02600520-10-10P-4 AFS3-04000800-07-10P-4 AFS3-08001200-09-10P-4 AFS3-08001600-15-8P-4 AFS4-12001800-18-10P-4 AFS4-12001800-18-10P-4	0.25-0.5 0.5-1 1-2 1.2-2.4 2-4 2.6-5.2 4-8 8-12 8-16 12-18 12-24	38 38 38 34 32 28 28 26 28 28 24	0.50 0.50 0.75 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.50 2.00	0.9 0.8 0.6 0.5 0.6 0.6 1.0 0.7 0.9 1.5 1.8 3.0	2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1	2.0:1 1.5:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1	+10 +10 +10 +10 +10 +10 +10 +10 +8 +10 +10	125 150 150 150 125 125 125 125 100 125
AFS3-00250050-08-10P-4 AFS3-010500100-06-10P-6 AFS3-01200240-06-10P-6 AFS3-01200240-06-10P-4 AFS3-02600520-10-10P-4 AFS3-04000800-07-10P-4 AFS3-08001200-09-10P-4 AFS3-08001600-15-8P-4 AFS4-12001800-18-10P-4	0.25-0.5 0.5-1 1-2 1.2-2.4 2.6-5.2 4-8 8-12 8-16 12-18	38 38 38 34 32 28 28 26 28 28 24	0.50 0.50 0.75 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.50 2.00 1.75	0.9 0.8 0.6 0.5 0.6 0.6 1.0 0.7 0.9 1.5 1.8 3.0	2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1	2.0:1 1.5:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1	+10 +10 +10 +10 +10 +10 +10 +10 +8 +10	125 150 150 150 125 125 125 125 125 100
AFS3-00250050-08-10P-4 AFS3-00500100-06-10P-6 AFS3-01000200-05-10P-6 AFS3-01200240-06-10P-6 AFS3-02000400-06-10P-4 AFS3-02600520-10-10P-4 AFS3-04000800-07-10P-4 AFS3-08001200-09-10P-4 AFS3-08001600-15-8P-4 AFS4-12001800-18-10P-4 AFS4-12001800-18-10P-4	0.25-0.5 0.5-1 1-2 1.2-2.4 2-4 2.6-5.2 4-8 8-12 8-16 12-18 12-24	38 38 38 34 32 28 28 26 28 28 24	0.50 0.50 0.75 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.50 2.00 1.75	0.9 0.8 0.6 0.5 0.6 0.6 1.0 0.7 0.9 1.5 1.8 3.0	2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1	2.0:1 1.5:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1	+10 +10 +10 +10 +10 +10 +10 +10 +8 +10 +10	125 150 150 150 125 125 125 125 100 125
AFS3-00250050-08-10P-4 AFS3-01000200-05-10P-6 AFS3-01200240-06-10P-6 AFS3-01200240-06-10P-4 AFS3-02600520-10-10P-4 AFS3-04000800-07-10P-4 AFS3-08001200-09-10P-4 AFS3-08001200-09-10P-4 AFS3-18001200-09-10P-4 AFS3-18002650-30-8P-4 AFS3-18002650-30-8P-4	0.25-0.5 0.5-1 1-2 1.2-2.4 2-4 2.6-5.2 4-8 8-12 8-16 12-18 12-24 18-26.5	38 38 38 38 34 32 28 26 28 28 24 18	0.50 0.50 0.75 1.00 1.00 1.00 1.00 1.00 1.00 1.50 2.00 1.75 CTAVE B	0.9 0.8 0.6 0.5 0.6 0.6 1.0 0.7 0.9 1.5 1.8 3.0 3.0 AND AMPL	2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1	2.0:1 1.5:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1	+10 +10 +10 +10 +10 +10 +10 +10 +8 +10 +8	125 150 150 150 125 125 125 125 100 125 85 125
AFS3-00250050-08-10P-4 AFS3-01000100-06-10P-6 AFS3-01200240-06-10P-6 AFS3-01200240-06-10P-4 AFS3-02000400-06-10P-4 AFS3-02600520-10-10P-4 AFS3-08001200-09-10P-4 AFS3-08001600-15-8P-4 AFS4-12001800-18-10P-4 AFS4-12002400-30-10P-4 AFS3-18002650-30-8P-4 AFS3-00300140-09-10P-4 AFS2-00400350-12-10P-4	0.25-0.5 0.5-1 1-2 1.2-2.4 2-4 2.6-5.2 4-8 8-12 8-16 12-18 12-24 18-26.5 0.3-1.4 0.4-3.5	38 38 38 38 34 32 28 28 26 28 24 18 MULTIC	0.50 0.50 0.75 1.00 1.00 1.00 1.00 1.00 1.00 1.50 2.00 1.75 DCTAVE B	0.9 0.8 0.6 0.5 0.6 0.6 1.0 0.7 0.9 1.5 1.8 3.0 3.0 AND AMPL 0.9 1.2	2.0:1 2.0:1	2.0:1 1.5:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1	+10 +10 +10 +10 +10 +10 +10 +10 +8 +10 +10 +8	125 150 150 150 125 125 125 125 100 125 85 125
AFS3-00250050-08-10P-4 AFS3-01000200-05-10P-6 AFS3-01200240-06-10P-6 AFS3-01200240-06-10P-4 AFS3-02600520-10-10P-4 AFS3-04000800-07-10P-4 AFS3-08001200-09-10P-4 AFS3-08001200-09-10P-4 AFS3-18001200-09-10P-4 AFS3-18002650-30-8P-4 AFS3-18002650-30-8P-4	0.25-0.5 0.5-1 1-2 1.2-2.4 2-4 2.6-5.2 4-8 8-12 8-16 12-18 12-24 18-26.5	38 38 38 38 34 32 28 26 28 28 24 18	0.50 0.50 0.75 1.00 1.00 1.00 1.00 1.00 1.00 1.50 2.00 1.75 CTAVE B	0.9 0.8 0.6 0.5 0.6 0.6 1.0 0.7 0.9 1.5 1.8 3.0 3.0 AND AMPL	2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1	2.0:1 1.5:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1 2.0:1	+10 +10 +10 +10 +10 +10 +10 +10 +8 +10 +8	125 150 150 150 125 125 125 125 100 125 85 125
AFS3-00250050-08-10P-4 AFS3-01000200-05-10P-6 AFS3-01200240-06-10P-6 AFS3-01200240-06-10P-6 AFS3-02600520-10-10P-4 AFS3-08600520-10-10P-4 AFS3-08001200-09-10P-4 AFS3-08001200-09-10P-4 AFS4-12001800-18-10P-4 AFS4-12002400-30-10P-4 AFS3-08001600-15-8P-4 AFS3-01000400-10-10P-4 AFS3-01000400-10-10P-4 AFS3-01000400-10-10P-4 AFS3-01000400-10-10P-4 AFS3-01000400-10-10P-4	0.25-0.5 0.5-1 1-2 1.2-2.4 2-4 2.6-5.2 4-8 8-12 8-16 12-18 12-24 18-26.5 0.3-1.4 0.4-3.5 0.5-2 1-4 2-8	38 38 38 38 34 32 28 28 26 28 24 18 MULTIO 38 22 38 30 26	0.50 0.50 0.75 1.00 1.00 1.00 1.00 1.00 1.50 2.00 1.75 DCTAVE B 1.00 1.50 1.00	0.9 0.8 0.6 0.5 0.6 0.6 1.0 0.7 0.9 1.5 1.8 3.0 3.0 AND AMPL 0.9 1.2 0.8 1.0 1.0	2.0:1 2.0:1	2.0:1 1.5:1 2.0:1	+10 +10 +10 +10 +10 +10 +10 +10 +10 +10	125 150 150 150 125 125 125 125 100 125 85 125
AFS3-00250050-08-10P-4 AFS3-01000200-05-10P-6 AFS3-01200240-06-10P-6 AFS3-01200240-06-10P-6 AFS3-02000400-06-10P-4 AFS3-02600520-10-10P-4 AFS3-08001200-09-10P-4 AFS3-08001600-15-8P-4 AFS4-12001800-18-10P-4 AFS3-18002650-30-8P-4 AFS3-00300140-09-10P-4 AFS3-00500200-08-15P-4 AFS3-01000400-10-10P-4 AFS3-01000400-10-10P-4 AFS3-02008800-09-10P-4 AFS3-02008800-09-10P-4	0.25-0.5 0.5-1 1-2 1.2-2.4 2-4 2.6-5.2 4-8 8-12 8-16 12-18 12-24 18-26.5 0.3-1.4 0.4-3.5 0.5-2 1-4 2-8 2-18	38 38 38 38 34 32 28 28 26 28 24 18 MULTIC 38 22 38 30 26 25	0.50 0.50 0.75 1.00 1.00 1.00 1.00 1.00 1.00 1.50 2.00 1.75 DCTAVE B 1.00 1.50 1.00 1.50 1.00	0.9 0.8 0.6 0.5 0.6 1.0 0.7 0.9 1.8 3.0 3.0 AND AMPL 0.9 1.2 0.8 1.0 1.0 2.3	2.0:1 2.0:1	2.0:1 1.5:1 2.0:1	+10 +10 +10 +10 +10 +10 +10 +10 +10 +8 +10 +10 +8 +110 +15 +10 +15 +10 +10 +10 +10 +10 +10 +10 +10 +10 +10	125 150 150 150 125 125 125 125 100 125 85 125 125 80 125 125 125
AFS3-00250050-08-10P-4 AFS3-01000200-05-10P-6 AFS3-01200240-06-10P-6 AFS3-01200240-06-10P-6 AFS3-02600520-10-10P-4 AFS3-08600520-10-10P-4 AFS3-08001200-09-10P-4 AFS3-08001200-09-10P-4 AFS4-12001800-18-10P-4 AFS4-12002400-30-10P-4 AFS3-08001600-15-8P-4 AFS3-01000400-10-10P-4 AFS3-01000400-10-10P-4 AFS3-01000400-10-10P-4 AFS3-01000400-10-10P-4 AFS3-01000400-10-10P-4	0.25-0.5 0.5-1 1-2 1.2-2.4 2-4 2.6-5.2 4-8 8-12 8-16 12-18 12-24 18-26.5 0.3-1.4 0.4-3.5 0.5-2 1-4 2-8	38 38 38 38 34 32 28 28 26 28 24 18 MULTIO 38 22 38 30 26	0.50 0.50 0.75 1.00 1.00 1.00 1.00 1.00 1.50 2.00 1.75 DCTAVE B 1.00 1.50 1.00	0.9 0.8 0.6 0.5 0.6 0.6 1.0 0.7 0.9 1.5 1.8 3.0 3.0 AND AMPL 0.9 1.2 0.8 1.0 1.0	2.0:1 2.0:1	2.0:1 1.5:1 2.0:1	+10 +10 +10 +10 +10 +10 +10 +10 +10 +10	125 150 150 150 125 125 125 125 100 125 85 125
AFS3-00250050-08-10P-4 AFS3-01000200-05-10P-6 AFS3-01200240-06-10P-6 AFS3-01200240-06-10P-6 AFS3-02000400-06-10P-4 AFS3-02600520-10-10P-4 AFS3-08001200-09-10P-4 AFS3-08001200-09-10P-4 AFS3-18001200-09-10P-4 AFS3-18002650-30-8P-4 AFS3-18002650-30-8P-4 AFS3-03001400-09-10P-4 AFS3-00500200-08-15P-4 AFS3-01000400-10-10P-4 AFS3-02000800-09-10P-4 AFS3-02000800-09-10P-4 AFS3-02001800-23-10P-4 AFS4-02001800-23-10P-4	0.25-0.5 0.5-1 1-2 1.2-2.4 2-4 2.6-5.2 4-8 8-12 8-16 12-18 12-24 18-26.5 0.3-1.4 0.4-3.5 0.5-2 1-4 2-8 2-18 6-18	38 38 38 38 34 32 28 28 28 28 24 18 MULTIO 38 30 26 25 25 28	0.50 0.50 0.75 1.00 1.00 1.00 1.00 1.00 1.50 2.00 1.75 DCTAVE B 1.00 1.50 1.00 1.50 1.00 1.50 1.00 1.50 1.00 1.50 1.00 1.50 1.00 1.50 1.00 1.50 1.00 1.50 1.00 1.50 1.00 1.50 1.00 1.50 1.00 1.50 1.00 1.50 1.00 1.50 1.00 1.50 1.00 1.50 1.00 1.50 1.00 1.50	0.9 0.8 0.6 0.5 0.6 0.6 1.0 0.7 0.9 1.5 1.8 3.0 3.0 AND AMPL 0.9 1.2 0.8 1.0 1.0 2.3 2.2 2.2	2.0:1 2.0:1	2.0:1 1.5:1 2.0:1	+10 +10 +10 +10 +10 +10 +10 +10 +8 +10 +10 +8 +10 +10 +110 +1	125 150 150 150 125 125 125 125 100 125 85 125 125 80 125 125 125 125
AFS3-00250050-08-10P-4 AFS3-01000200-05-10P-6 AFS3-01200240-06-10P-6 AFS3-01200240-06-10P-6 AFS3-02000400-06-10P-4 AFS3-02600520-10-10P-4 AFS3-08001200-09-10P-4 AFS3-08001200-09-10P-4 AFS4-12001800-18-10P-4 AFS4-12002400-30-10P-4 AFS3-08001600-15-8P-4 AFS3-08001600-18-10P-4 AFS3-08001800-20-10P-4 AFS3-01000400-10-10P-4 AFS3-01000400-10-10P-4 AFS3-01000400-10-10P-4 AFS3-01000400-10-10P-4 AFS3-01000400-10-10P-4 AFS4-06001800-22-10P-4 AFS4-06001800-22-10P-4	0.25-0.5 0.5-1 1-2 1.2-2.4 2-4 2.6-5.2 4-8 8-12 8-16 12-18 12-24 18-26.5 0.3-1.4 0.4-3.5 0.5-2 1-4 2-8 2-18 6-18 8-18	38 38 38 38 32 28 28 26 28 24 18 MULTIO 38 22 38 30 26 25 25 28	0.50 0.50 0.75 1.00 1.00 1.00 1.00 1.00 1.50 2.00 1.75 CCTAVE B 1.00 1.50 1.00 2.00 2.00 2.00 A WIDEBA	0.9 0.8 0.6 0.5 0.6 0.6 0.7 0.9 1.5 1.8 3.0 3.0 AND AMPL 0.9 1.2 0.8 1.0 1.0 2.3 2.2 2.2	2.0:1 2.0:1	2.0:1 1.5:1 2.0:1	+10 +10 +10 +10 +10 +10 +10 +10 +8 +10 +10 +10 +110 +1	125 150 150 150 125 125 125 125 125 125 125 125 125 125
AFS3-00250050-08-10P-4 AFS3-01000200-05-10P-6 AFS3-01200240-06-10P-6 AFS3-01200240-06-10P-6 AFS3-02000400-06-10P-4 AFS3-02600520-10-10P-4 AFS3-08001200-09-10P-4 AFS3-08001200-09-10P-4 AFS3-18001200-09-10P-4 AFS3-18002650-30-8P-4 AFS3-18002650-30-8P-4 AFS3-03001400-09-10P-4 AFS3-00500200-08-15P-4 AFS3-01000400-10-10P-4 AFS3-02000800-09-10P-4 AFS3-02000800-09-10P-4 AFS3-02001800-23-10P-4 AFS4-02001800-23-10P-4	0.25-0.5 0.5-1 1-2 1.2-2.4 2-4 2.6-5.2 4-8 8-12 8-16 12-18 12-24 18-26.5 0.3-1.4 0.4-3.5 0.5-2 1-4 2-8 2-18 6-18	38 38 38 38 34 32 28 28 28 28 24 18 MULTIO 38 30 26 25 25 28	0.50 0.50 0.75 1.00 1.00 1.00 1.00 1.00 1.50 2.00 1.75 DCTAVE B 1.00 1.50 1.00 1.50 1.00 1.50 1.00 1.50 1.00 1.50 1.00 1.50 1.00 1.50 1.00 1.50 1.00 1.50 1.00 1.50 1.00 1.50 1.00 1.50 1.00 1.50 1.00 1.50 1.00 1.50 1.00 1.50 1.00 1.50 1.00 1.50 1.00 1.50	0.9 0.8 0.6 0.5 0.6 0.6 1.0 0.7 0.9 1.5 1.8 3.0 3.0 AND AMPL 0.9 1.2 0.8 1.0 1.0 2.3 2.2 2.2	2.0:1 2.0:1	2.0:1 1.5:1 2.0:1	+10 +10 +10 +10 +10 +10 +10 +10 +8 +10 +10 +8 +10 +10 +110 +1	125 150 150 150 125 125 125 125 100 125 85 125 125 80 125 125 125 125
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Note: Noise figure increases below 500 MHz in bands greater than 0.1-10 GHz.

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FAA and Raytheon Agree to a \$204 M **Contract** Modification to **Provide Full LPV**

•he Federal Aviation Administration and Raytheon have completed negotiations on a contract modification for the Wide Area Augmentation System (WAAS) to deploy what is termed "Full Lateral Precision with Vertical Guidance (LPV) Performance." This modification restructures

existing contract scope and does not increase contract value. During the next four years, incremental improvements will be made to the fielded system to expand benefits to users across North America.

WAAS is a nationwide network of reference, master and uplink stations that augment the Global Positioning System satellite constellation to provide the improved accuracy, integrity and availability required for civil aviation and other safety-of-life applications. WAAS is the FAA's next-generation satellite-based navigation system. It was commissioned by the FAA in July 2003 and has been in continuous operational use since that time.

LPV approach availability has exceeded 95 percent across more than 98 percent of the lower 48 states. WAAS conforms to the Satellite Based Augmentation System standards published by ICAO (International Civil Aviation Organization), providing worldwide interoperability of satellite navigation systems. Under the contract modification, approach and landing guidance availability will increase to more than 99 percent across much of the North American continent, improving safety and efficiency for pilots.

"The contract modification marks another milestone in the continuing satellite navigation partnership between Raytheon and the FAA. We are pleased to have been part of the FAA's success in achieving WAAS initial operational capability in 2003, and we look forward to continuing this relationship as WAAS evolves into a seamless, high availability, satellite-based navigation system throughout North America," said Bob Eckel, vice president of Air Traffic Management Systems at Raytheon. Work began this summer with the installation of four WAAS Reference Stations (WRS) in Kotzebue, Bethel, Barrow and Fairbanks, Alaska. These four new stations join the three existing stations in the state at Cold Bay, Anchorage and Juno. Together, they will support LPV coverage over most of the state and become an integral part of the Capstone program, which is substantially improving safety in the aviation-dependant 49^{th} state.

The full LPV performance contract modification will enhance the WAAS integrity algorithms for increased approach availability during weather disturbances as well as during normal conditions. This is of particular importance on the US west coast and during periods of increased solar flare activity. Full LPV performance will also increase the capacity, redundancy and security of the WAAS terrestrial communications backbone and add new Geostationary Earth Orbit (GEO) satellites into the system, which are critical to providing reliable, redundant GEO coverage to all users throughout North America. The FAA and NavCanada recently announced a bilateral agreement

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to install four reference stations in Winnipeg, Goose Bay, Gander and Iqaluit. The four sites will increase and expand LPV availability throughout much of Canada and the northern United States. John Crichton, NavCanada's president and CEO, sees this as a way to avoid "the cost of developing duplicate systems," and to limit the need to invest in more ground-based ILS approach facilities.

The FAA and the Mexican government are also planning to install five WRS in Mexico at Puerto Vallarta, La Paz, Mexico City, Meridia and Tapalucha. These sites will increase and expand LPV approach availability in Mexico and the American southwest in the same manner as the Canadian sites.

Northrop Grumman Continues Advanced **EHF Payload** Successes

■orthrop Grumman has demonstrated technology for the Advanced Extremely High Frequency (EHF) payload that will greatly improve warfighters' access to military satellite communications while increasing the range of missions the system can support on the ground, at

sea and in the air. The company will provide the Advanced EHF payload to Lockheed Martin, prime contractor for the Advanced EHF system.

Northrop Grumman's Space Technology sector has completed electrical testing of the uplink phased array antenna, which receives signals from ground terminals. One of the new technologies developed for the Advanced EHF payload, the antenna directs radio frequency beams electronically rather than by moving reflectors mechanically. This allows one array to do the job of many reflectors, giving the flexibility to point-on-demand in fractions of a second, greatly improving warfighter access. It is also the first phased array for space application that operates at 44 GHz. Another new technology is the use of an advanced semiconductor material, indium phosphide (InP), for some of the antenna's more than 10,000 monolithic microwave integrated circuits. InP ensures excellent low noise, or clear signal, performance.

"With these successful electrical tests, we have shown that electronic beam steering can support a wider range of missions with fewer antennas," said Clayton Kau, Northrop Grumman Space Technology vice president and manager of the Advanced EHF payload program. "The tests also demonstrate that we are on track to deliver the first flight payload in April 2006." With the more compact phased array, the Advanced EHF system can process greater amounts of information. It will deliver 10 times greater total capacity and channel data rates six times higher than that of Milstar II communication satellites. Advanced EHF is the successor to the Milstar system. The highly directional antenna additionally reduces the possibility of jamming and intercept by enemies, assuring secure, reliable communications between command and control units wherever they operate.

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Lockheed Martin Space Systems, Sunnyvale, CA, is currently under contract to provide the first two Advanced EHF satellites and command and control system. In April, Lockheed Martin successfully completed the system critical design review phase of the program on schedule and is now into the production phase. The MILSATCOM Joint Program Office, located at the Space and Missile Center, Los Angeles Air Force Base, CA, is the contract manager and lead agency for the Advanced EHF program.

Harris Corp. Awarded \$275 M **Mission Support** Contract for FAA FTI Program

arris Corp. announced that it has been awarded a \$275 M contract modification by the Federal Aviation Administration (FAA) to incorporate the agency's Mission Support Services data function into the FAA Telecommunications Infrastructure (FTI) program, bringing the total

estimated value of the program for Harris to \$2.2 B by 2017. "We are excited that the FAA has opted to include its Mission Support traffic as part of the FTI program," said Al Dukes, president, Civil Programs business unit, Harris Government Communication Systems Division

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(GCSD). "Harris is very pleased to be teamed with the FAA in putting an infrastructure in place that meets the agency's unique telecommunications services and security requirements, which are critical to the FAA's role in managing air traffic."

The FTI program, originally awarded to Harris in July 2002, is improving operational functions at more than 5000 FAA facilities nationwide while reducing operating costs, enhancing network security and improving telecommunications service performance, reliability and quality. Harris is also replacing more than 35,000 circuits, upgrading switching and routing services, improving network monitoring and control, implementing a state-of-the-art security system and providing network engineering services. The Harris team is already working to consolidate the Leased Interfacility NAS Communications System, Data Multiplexing Network, Bandwidth Manager and the National Aviation Data Interchange Network into FTI. "The Harris FTI team is committed to fulfilling its collective mission of providing the most efficient and reliable telecommunications solution to the FAA," said John O'Sullivan, FTI program VP, Harris GCSD. "The comprehensive telecommunications and IT experience provided by our teammates, coupled with Harris expertise in highly reliable, secure communications systems integration and management, will help to insure that FTI requirements are met or surpassed over the life of the program."





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Elcoteq Proposes Conversion Into a European Company

Inder new European rules, Elcoteq Network Corp.'s board of directors is proposing that the company be converted into a European Company (Societas Europaea, SE). The move by the manufacturer of electronics for communications technology is in response to the Act

on the European Company, which came into force in Finland in October. The SE form of company will allow a single corporate structure throughout the 28 countries of the European Economic Area (EEA) instead of having several separate subsidiary legal entities as at present.

In Elcoteq's case the new form of company will be achieved by conversion, the company's name changing to Elcoteq Network SE. The board of directors has drawn up a conversion plan and a report, both of which will be registered and announced in the manner required by Finnish law. It is expected that the most probable date for conversion will be in the spring of 2005. As an SE, Elcoteq will be able to merge its subsidiaries in different countries with the parent company, which will reduce the amount of central administration necessary. It also believes the SE form of company will have a positive effect on its image and will thus support its business operations.

Commenting on the initiative the company's president and CEO said, "Elcoteq wishes to be among the first companies to exploit the benefits of conversion into a European Company. This will support our reputation as a pioneer and global operating company, as well as creating greater international visibility both in Europe and elsewhere in the world. While respecting its Finnish roots, the company wishes to forge a clear European identity for itself."

> **Japanese** Deployment of CDMA2000 1X on 2 GHz Network

otorola has announced that it has begun deployment of its CDMA2000 1X solution on a 2 GHz network for KDDI, a carrier for 3G cellular phone services in Japan. The new packetbased 2 GHz network will allow the carrier to leverage additional bandwidth while offering the opportunity to

provide more advanced feature enhancements to deliver new services to its customers.

"This commercial deployment in Japan of CDMA2000 1X in the 2 GHz band underlines our commitment and leadership in developing CDMA2000 1X technology," said Simon Leung, senior vice president, Motorola Inc. and general manager for its infrastructure business in the Asia Pacific region. "We look forward to deepening our 15 year relationship with KDDI through well-designed wireless solutions that will help them capture additional revenue and meet emerging customer needs."

to Merge

lobal Communication Technology Corp. (GCT), the Taiwan-based GaAs MMIC foundry service provider, will merge with one of its major competitors, WIN Semiconductors Corp. (WIN). The shareholders meetings of the two companies met separately to approve the definitive merger

Richard Mumford, European Editor

agreement and confirm an equity swap at a 1:1.6 ratio (1.6 shares of WIN for every 1 share of GCT).

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WIN and Global

The merger has considerable synergy as both companies bring complementary business and technology strengths that will enhance foundry service offerings. The combination of expertise and facilities should enable the merged entity to reduce cost, integrate resources, optimise operation scale and enlarge its market in the GaAs MMIC segment. The merged company will maintain two sites of 6-inch GaAs fabs to provide more technological options and surety of supply to customers.

Alcatel Graduates Towards Cambodian Scholarships

n an effort to reduce the digital divide, Alcatel is granting scholarships to top students at the Institute Technology Cambodia (ITC) in Phnom Penh, Cambodia. Additionally, the company will organise a series of telecom training programs to enhance the telecom knowledge of the students at ITC.

The agreement is for Alcatel to grant scholarships to 28 top students at the Institute who achieved academic excellence over the past year. The scholarships will be used to cover their tuition fee for one year. The program, to be run for the next three years, will help Cambodia train professionals to foster the local telecom market development.

In addition to the scholarship, in November, Alcatel began training programs on a broad range of topics related to telecommunications in the format of regular seminars, with company experts from within and outside Asia as instructors. The aim is to equip the students with practical knowledge to equip them for starting their professional career.

Commenting on the initiative, Mr. Pok Than, secretary of state of the Ministry of Education, Youth and Sports of Cambodia and president of the Administration Board for the Institute Technology Cambodia, said, "Cambodia is in the position of competing with other countries in the region to ambitiously stay at the forefront in the technology development area. To create such sustainable competitiveness of the country, the government is aware of the importance of education and developing many programs. The scholarship opens the opportunities for capable students to learn new technologies as they wish, further sharpening their thoughts for the country's development in the future."

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DTI AIMs for RFID Centres

As part of the UK Department of Trade and Industry's (DTI) effort to encourage the establishment of a network of specialist radio frequency identification (RFID) technology centres around the country and also to play a key European role, it has invited AIM UK, the independent industry associ-

ation representing RFID, bar coding and other automatic identification technologies, to lead the initiative.

Its role will be to develop the overall strategic plan for the development of the centres and determine the centralised services and deliverables that will be provided by the lead centre that will initially be housed at the AIM headquarters in Halifax, West Yorkshire, and sponsored by Yorkshire Forward. It will offer advice to companies on next generation technology for real time data tracking.

Plans are also progressing for the establishment of the European Centre of Excellence for AIDC, which will also be sponsored by Yorkshire Forward and AIM, and ultimately house the National RFID Centre. The plan has been initiated to take advantage of the global annual market for RFID systems that was approximately \$1 B in 2002 with Europe accounting for around 40 percent of

INTERNATIONAL REPORT

the market and the UK around 25 percent of the European figure.

Nokia to Expand
GSM/EDGE Network
in Ecuador

Inder a \$77 M agreement Nokia is expanding and modernising PORTA'S GSM/EDGE network in Ecuador. To fulfill the agreement Nokia will supply a complete range of GSM/EDGE infrastructure equipment and services to enable the operator to further expand and modernise

its network. Deliveries are ongoing and the network is expected to be operational by the end of 2004.

The technology that Nokia and PORTA have introduced to Ecuador is one of the most advanced GSM/EDGE based networks in the Americas. As part of the offering, Nokia will supply its GSM/EDGE core and radio-access network infrastructure. In addition to the network equipment, the company will provide expansions to the Nokia NetAct™ network and service management system, network planning, installation and project management service for efficient network ramp-up, as well as radio network optimisation for enhancing network quality. ■

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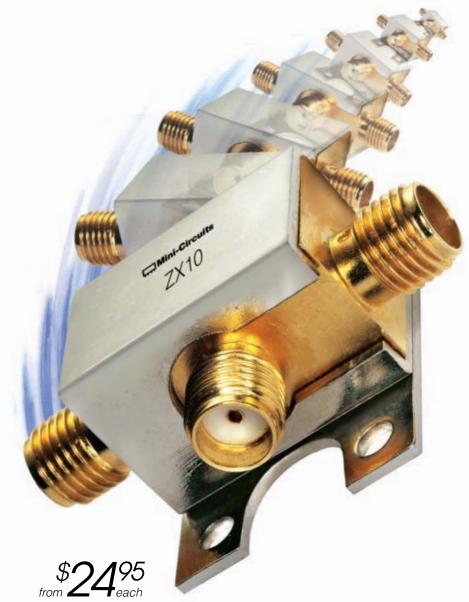


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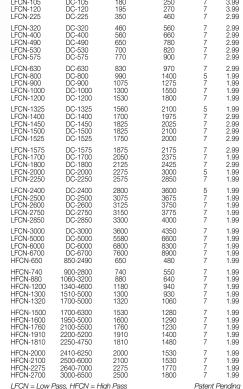
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ZigBee Alliance **Continues Strong** Growth

•he ZigBee Alliance, an association of companies working together to enable wirelessly networked monitoring and control products based on an open global standard, announced 16 new member companies have joined, bringing its membership to more than 100 companies.

New member companies include: Cisco Systems Inc.; Control4; ELDAT Gesellschaft für Electronik und Datentechnik mbH; Exegin Technologies Ltd.; France Telecom R&D LLC; Golden Power Manufacturing Inc.; MaxStream Inc.; Niko N.V.; Novar Controls; Orange Logic; SDSystem Co. Inc.; Shinko Electric Industries Co. Ltd.; Smarthome Inc.; Telematics Wireless Ltd.; TenXTechnology Inc.; and Yamatake Corp.

The ZigBee Alliance has more than doubled its membership in the last year. Its membership base now represents an astounding 22 countries on four continents, signifying the worldwide interest in ZigBee. All Alliance members will continue to participate in ongoing interoperability testing to insure their products are ready to take advantage of the specification once it is completed. Most recently, the ZigBee Alliance concluded another successful interoperability testing event in Denver. "The tremendous level of interest expressed by so many global leaders across a broad range of markets underscores the need for wirelessly networked monitoring and control products based on an open global standard," said Bob Heile, chairman of the ZigBee Alliance. "As our membership continues to expand, so does our potential to deliver innovative applications based on ZigBee. ZigBee's newest members will join in the market roll-out of the initial specification, working to deliver a global interoperable standard for the advancement of easily deployable, low cost, low power, wireless communication products."

Illustrating its growing momentum, the ZigBee Alliance had a significant presence at the Wireless Connectivity (WiCon) Americas, on November 9–10, 2004, in Santa Clara, CA. The ZigBee Alliance hosted a press and analyst reception, was on hand to discuss advances in the wireless market and hosted a ZigBee Pavilion to showcase ZigBee-ready products from Airbee, CompXs, Ember, Freescale Semiconductor, Millenial Net, Motorola, OKI and ZMD. Also at WiCon, ZigBee chairman, Bob Heile, was joined by Jon Adams of Freescale Semiconductor, chairman of ZigBee's Interoperability Working Group, Pat Kinney of Kinney Consulting, secretary of the Alliance, and Venkat Bahl of Ember Corp., vice chairman of the Alliance, to lead sessions on where ZigBee fits in the short range wireless market, offer a tutorial on the IEEE 802.15.4 global standard, reflect on key market requirements for sensors and controls, and preview future applications, markets and protocols.

ZigBee is the only standards-based technology designed to address the unique needs of low cost, low power, wireless sensor networks for remote monitoring, home

COMMERCIAL MARKET

control and building automation network applications in the industrial and consumer markets. Companies who want to have input on developing the ZigBee specification and create ZigBee products can join by visiting: www.zigbee.org/en/join/.

> Wi-Fi Versus **ABI Research Considers Their Future**

iMAX enthusiasts sometimes claim that it will "kill" Wi-Fi. Nothing could be further from the truth, according to current studies from ABI Research. Phil Solis, senior analyst for wireless connectivity, notes that Intel, the most aggressive of WiMAX IC vendors, expects to have chipsets

ready for sale to laptop makers in mid-2006. Intel will probably be the first to market, followed by Fujitsu Semiconductors and Wavesat Inc.

That means, says Solis, that it will be several years before WiMAX gains any real traction in the 802.16e market (802.16e is the mobile version of WiMAX that will allow for portability and mobility). "We are not looking at WiMAX even starting to compete against Wi-Fi until 2007, when it will turn up in a few laptops. By then, Wi-Fi penetration in laptops will be almost universal."

Before WiMAX chips appear in computers, customer premises equipment (CPE) receivers will be able to get signals from local transmitters. But that still leaves the rest of the devices in a corporate or home network unconnected. And putting WiMAX chips, with their high power consumption, in PDAs or phones will be more difficult, and occur later, than putting them in a laptop. A combined scenario — WiMAX to the building, then Wi-Fi for the interior network — should get the best of both worlds.

IEEE Begins Work on WRAN Standard

Over-the-air broadcast TV channels are separated by unused frequencies. This "white space" in the broadcast spectrum varies with the channels present in a locale and creates opportunities for other applications. As a step in putting these unused channels to practical use, the

IEEE has started work on a standard to enable the deployment of wireless regional area networks using the unused TV channels, while not interfering with the licensed services now operating in the TV bands.

The new project, IEEE P802.22,TM "Standard for Wireless Regional Area Networks (WRAN) — Specific Requirements — Part 22: Cognitive Wireless RAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications: Policies and Procedures for Operation in TV Bands," will specify a cognitive air interface for fixed,

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point-to-point, wireless regional area networks that operate on unused channels in the VHF/UHF TV bands between 54 and 862 MHz.

"Signals at these frequencies can propagate 40 km or more from a well-sited base station, depending on the terrain," said Carl R. Stevenson, interim chair of the IEEE P802.22 working group. "This is ideal spectrum for deploying regional networks to provide broadband services in sparsely populated areas, where vacant channels are available. Our goal is to equal or exceed the quality of DSL or cable modem services, and to be able to provide that service in areas where wireline service is economically infeasible, due to the distance between potential users. This standard will enable the creation of interoperable IEEE 802 WRAN products. It has generated a great deal of interest from wireless Internet service providers, community networking organizations, government bodies and other parties." Protocols in the standard will ensure that this new service does not cause harmful interference to the licensed incumbent services in the TV broadcast bands. The standard will provide for broadband systems that choose portions of the spectrum by sensing that frequencies are unoccupied.

In the US, the Federal Communications Commission has issued a Notice of Proposed Rule Making to open the 54–698 MHz portion of the TV for unlicensed usage. IEEE 802.22 will enable compliance to these rules once

COMMERCIAL MARKET

they are finalized. "The standard, which will work with existing 802 architectures, will give IEEE 802.11 $^{\mbox{\tiny TM}}$ wireless local areas networks in outlying areas a fatter pipe for receiving and transmitting data," says Stevenson. "It will complement IEEE 802.16TM metropolitan area networks, which do not include cognitive radio functions for sharing TV spectrum. The concepts underlying this standard are attractive to both developed and undeveloped countries having little wireline infrastructure. By extending out to 40 km or more, most regional area networks should have enough potential subscribers within their coverage areas to make them viable ventures."

The formation of the IEEE 802.22 Working Group has involved broad participation from those in the TV broadcast sector and the pubic safety community who are licensed users of the target spectrum, as well as from chip vendors, wireless equipment suppliers and even other countries having large, relatively sparsely populated areas. "I am pleased to see the ongoing endorsement and support of IEEE 802 Local and Metropolitan Standards Committee by our participant and the data communication industry as evidenced by the many new standards development projects brought to 802 such as this one," said Paul Nikolich, chair of IEEE 802. "I expect the new 802.22 project to substantially improve the utilization of the scarce RF spectrum resources." IEEE P802.22 is sponsored by the IEEE Computer Society.

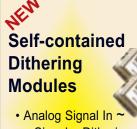
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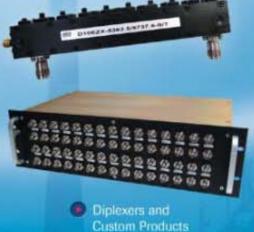






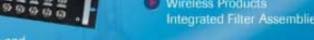
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INDUSTRY NEWS

- Teledyne Technologies Inc. and Celeritek Inc. jointly announced that Teledyne, through its subsidiary Teledyne Wireless Inc., has completed the acquisition of Celeritek's defense electronics business for \$33 M in cash. Celeritek's shareholders approved the asset sale at the company's annual meeting.
- Wireless Telecom Group Inc. (WTT) announced that it has entered into a definitive agreement to acquire all of the outstanding capital stock of privately held Willtek Communications GmbH from the venture capital arm of the international investment group Investcorp and Willtek's chief executive officer, Cyrille Damany, in exchange for \$7 M in cash and 8,000,000 shares of WTT common stock (the "Purchase Price"), and the assumption of certain liabilities and obligations valued at \$4.8 M. As a result of the proposed acquisition, Willtek will become a whollyowned subsidiary of WTT.
- M-tron Industries Inc. has completed the transactions to purchase Piezo Technology Inc., Orlando, FL. The two companies plan to integrate their operations under a single business management and operations group. To reflect this and to maintain the brand awareness of each company, the companies will be conducting business under the new name MtronPTI.
- PCTEL Inc. announced that it has entered into an agreement to acquire selected assets associated with Andrew Corp.'s mobile antenna business. The company has agreed to pay \$10 M in cash for the selected assets. The acquisition is part of PCTEL's continuing plan to solidify a position within high growth wireless communications markets.
- UltraSource Inc., a supplier of custom thin film devices, announced the acquisition of the custom thin film circuit manufacturing unit from MicroMetrics Inc., a semiconductor device manufacturer. The acquisition strengthens UltraSource's position in the custom design and manufacturing of thin film circuits and related services. In addition to all inventory and backlog, UltraSource will be acquiring several pieces of state-of-the-art thin film manufacturing equipment.
- **Cuming Microwave Corp.**, Avon, MA, announced that it has purchased **Lehman Chambers**, Chambersburg, PA. Lehman Chambers specializes in anechoic RF shielded chamber facilities for both high frequency and EMC related testing on a turnkey engineering through construction basis, and has completed over 1400 major projects across North America. Cuming's complementary absorber materials have been used routinely in all of Lehman's structures, making this venture a natural combination of cost-effectiveness and efficiency.
- The **Littlefuse** Electronics Business unit has announced a restructuring and consolidation of its North

AROUND THE CIRCUIT

American distribution network to better serve customers and add value to its line of circuit protection solutions. As part of the company's strategy to provide circuit protection solutions, the company has appointed its distributor partners. The new distributor line-up is expected to optimize the company's distribution structure as well as accelerate demand creation and design-in activity for Littlefuse circuit protection solutions.

- Kulicke & Soffa Industries Inc. announced the opening of its new state-of-the-art probe card manufacturing facility located in Hsin Chu, Taiwan. This facility offers a floor size of over 2400 square meters and has full manufacturing capability for all types of enhanced cantilever probe cards.
- Channel Microwave East, a specialist in filters, diplexers and combiners, announced that the company has moved to a new location. The company is now located at 502 McCormick Drive, Suite C, Glen Burnie, MD 21061 (410) 863-0026, fax (410) 863-0029 or e-mail: bmcdorman@channelmicrowave.com.
- Toshiba America Electronic Components Inc. announced that the company has moved its North American headquarters to new facilities. The North American headquarters is located at 19900 MacArthur Blvd., Suite 400, Irvine, CA 92612 (949) 623-2900, fax (949) 474-1330.
- Centellax Inc. announced that the company has doubled its laboratory and production test facilities at the company's Santa Rosa, CA headquarters. The expansion is intended to accommodate a growing internal demand for production test and quality assurance functions at the company, due to an increase in orders.
- Applied Wave Research Inc. (AWR®) announced that Silicon Laboratories Inc. has adopted AWR's Microwave Office® and Visual System Simulator™ design suites. Silicon Laboratories' applications teams will utilize the software to simulate radio frequency integrated circuit chips and modules.
- The US Air Force announced that M2 Global Technology Ltd. has been selected to participate in its manufacturing technical assistance production program (MTAPP). The MTAPP was established by the Secretary of the Air Force in 1997 to assist in increasing and enhancing the competitiveness of small manufacturing firms in support of the Air Force, Department of Defense and their prime contractors.
- **The LXI Consortium** announced that **Keithley Instruments Inc.** will join the recently formed standards organization. LAN extensions for instrumentation (LXI) is a next-generation, LAN-based modular platform standard for automated test systems.

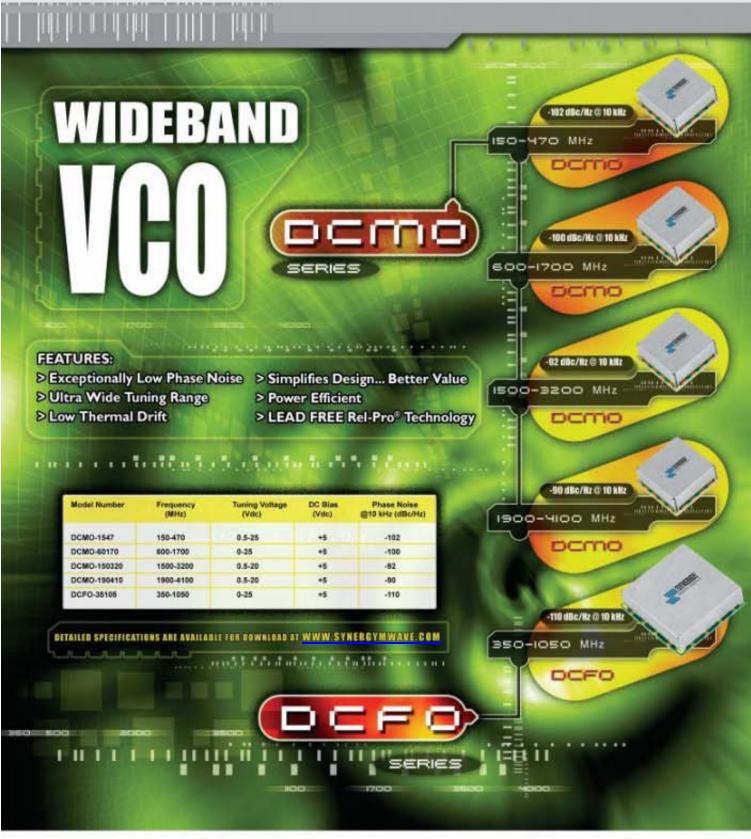
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- Laser Diode Inc. (LDI®) has been awarded certification to the ISO 9001:2000 standard. Lloyd's Register Quality Assurance issued this certification, stating that the LDI quality management system for the design and manufacture of opto-electronic devices has been assessed and approved against the quality management system standard ISO 9001:2000.
- Microwave Solutions Inc. announced that the US Patent and Trademark office has officially certified and registered the company logo and name.

CONTRACTS

- **EMS Technologies Inc.** announced that it has been selected by **Honeywell** and **Thales Avionics** as the supplier of high speed data satellite communications products for their new HS-720 high speed data system. Under the terms of a seven-year agreement, EMS will develop custom avionics products, which will complement the Honeywell/Thales MCS-4000/7000 satellite communications systems. Over the next five years, the forecasted value of this agreement is over \$50 M.
- Agile Materials and Technologies Inc. announced that the United States Army awarded the company a \$5 M, 30-month contract to produce phase shifters for use in phased array antennas, key elements of mobile battlefield communications networks. Agile's patented barium strontium titanate technology allows the company to provide the components at a fraction of the traditional cost.
- HRL Laboratories LLC has been awarded a \$1.9 M 18-month phase 1 contract from the Microsystems Technology Office of the Defense Advanced Research Projects Agency (DARPA) to develop inexpensive passive millimeter-wave imaging arrays. The award is under the "Microantenna Arrays: Technology and Applications" program.
- **Symmetricom** announced that the company has been awarded a five-year Federal Supply Contract by the US **General Services Administration** (GSA) for instruments and laboratory equipment.

FINANCIAL NEWS

- Crane Co. reports sales of \$477.3 M for the third quarter ended September 30, 2004, compared to \$425.3 M for the same period in 2003. Net loss for the quarter was \$205.2 M (\$3.48/per share), compared to a net income of \$28.1 M (\$0.47/per share) for the third quarter of last year.
- RF Micro Devices Inc. reports sales of \$149.1 M for the second quarter of fiscal 2005 ended September 30, 2004, compared to \$163.5 M for the same period in 2004. Net loss for the quarter was \$6.7 M (\$0.04/per diluted share), compared to a net income of \$10.6 M (\$0.05/per diluted share) for the second quarter of last year.

- **AMIS Holdings Inc.** (AMIS) reports sales of \$131.2 M for the third quarter ended September 25, 2004, compared to \$117.4 M for the same period in 2003. Net income for the quarter was \$16.2 M (\$0.19/per diluted share), compared to a net income of \$9.2 M (\$0.12/per diluted share) for the third quarter of last year.
- WJ Communications Inc. reports sales of \$8.9 M for the third quarter ended September 26, 2004, compared to \$6.9 M for the same period in 2003. Net income for the quarter was \$1.2 M (\$0.02/per diluted common share), compared to a net loss of \$3.3 M (\$0.06/per common share) for the third quarter of last year.
- Stratex Networks Inc. reports sales of \$43.6 M for the second quarter of fiscal 2005 ended September 30, 2004, compared to \$36.9 M for the same period in 2004. Net loss for the quarter was \$6.8 M (\$0.08/per share), compared to a net loss of \$7 M (\$0.08/per share) for the second quarter of last year.
- Ansoft Corp. has entered into a \$30 M one-year secured credit facility with PNC Bank, National Association. The revolving facility replaces the company's previous credit facility terminated during the first quarter. The new facility will be used primarily for general corporate purposes. In related news, the company announced that its board of directors voted to amend its existing common stock repurchase program to permit the company to acquire an additional 1,000,000 shares of its common stock. Under the original program approved in 1998 and amended in 2002, the company has purchased approximately 1,800,000 of the 2,000,000 shares authorized for repurchase.
- Peregrine Semiconductor Corp. announced that it has closed an oversubscribed \$17.6 M round of series C financing led by Ridgewood Capital and Palisades Ventures.
- An investor group led by Francisco Partners and Shah Capital Partners announced the completion of the acquisition of the business of **C-MAC MicroTechnology** from **Solectron Corp.** The investor group provides C-MAC with the financial support to drive its future growth plans.

NEW MARKET ENTRIES

- **C9 Networks**, a provider of communications solutions for small- to mid-sized operators, announced the availability of the C9 C3000, an entirely new line of cable modem termination systems (CMTS). The advanced CMTS supports both wired and wireless services with an easy to control management system built right into the box. This next-generation headend is an ideal solution for network integrators or operators looking to differentiate and extend their services by adding secure wireless capabilities to their existing offerings.
- Richardson Electronics announced its entrance into the RFID market. Richardson's expertise in engineering design, strategic alliances and technology infrastructure

[Continued on page 64]









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makes RFID a natural extension of its current capabilities. As a first RFID offering, Richardson has signed a strategic partnership with WJ Communications Inc., to represent the global sales channel for its new multi-protocol MPR 5000 and MPR 6000 RFID reader cards.

- Isotec Corp., a manufacturer of RF connectors in Korea, announced that the company has opened a sales office in San Jose, CA. This location will offer RF/microwave connectors and cable assemblies for the US market. The company is located at 111 North Market Street, Suite 616, San Jose, CA 95113. The company can be reached at (408) 351-3450, fax (408) 351-3540, e-mail: isotec@unitel.co.kr or visit <u>www.isoconnector.com</u>.
- Wireless Valley Communications announced its entry into the rapidly developing Chinese market via a strategic alliance with Cornes Dodwell Ltd., a Far East trading company with significant technology distribution operations in Japan and China. The partnership is built around China's demand for in-building wireless voice networks. Cornes Dodwell will be using and selling Wireless Valley's full suite of products.

PERSONNEL

■ Unity Wireless Corp. announced that **Victor Halpert** has been named to the company's board of directors. Robert Singer, a director of Unity Wireless since April 2000, stepped down from the board to open the position for Halpert. Halpert brings nearly 15 years of financial and accounting experience to the company's board of directors.



■ CoorsTek Inc. formally announced the promotion of Derek C. Johnson to president and COO. Johnson will oversee all of the company's 12 manufacturing facilities located in North America, Europe and Asia. Johnson's 20 year career with the company began when he joined the Scotland operations in February 1984.



■ Cris Emson moves to Aurora, IL, to hold the position of vice president of

Vector Fields Inc. He takes with him specialized knowledge of all the company's software, particularly on high frequency applications using the CONCERTO pack-



▲ Alex Michaelides

age. Emson joined Vector Fields Ltd. in 1988 from the Rutherford Appleton

[Continued on page 66]









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AROUND THE CIRCUIT

Laboratory. In related news, the company announced the promotion of **Alex Michaelides** to applications manager. His experience includes customer support, where he specialized in electromagnetics and the development of application oriented software.



■ Trilithic welcomed Randy Estep to the company as vice president of operations. Estep brings over 25 years of experience from ComSonics Inc., Harrisonburg, VA, and Hughes Network Systems, Germantown, MD.

Centellax Inc. announced the appointment of James

Hudspeth as vice president of operations. In his new position, Hudspeth will oversee and direct all aspects of the company's plant management, including manufacturing, materials allocation, production engineering, program management and purchasing. He brings nearly 30



years of high technology operations management experience to this position. Prior to Centellax he served as VP, manufacturing optical systems at Vitesse Semiconductor.

■ Eagleware Corp. announced that **Charlie Miller** has joined the company as vice president of marketing and that Miller has opened an Eagleware office in Silicon Valley. Miller has over 25 years of experience in the EDA space. He has worked with the company as a member of the board of directors for nearly five years. The new office is located at 560 South Winchester Blvd., Suite 500, San Jose, CA 95128. Miller joins the company from Aptix, where he was vice president of sales and marketing.



- Aeroflex/Metelics announced that Peter Sahjani has been appointed director of marketing and business development focusing on InGap HBT/ PHEMT amplifier products for the wireless infrastructure telecom market. Prior to joining Metelics, Sahjani held several key technical and senior management positions at M/A-COM, Loral, Filtronic Solid State, Agilent and most recently at EiC Corp.
- Pascall Electronics, part of the Intelek group, announced the appointment of **Chris Hood** as senior sales engineer. Hood joins the team with over 20 years experience in sales in the aerospace, defense and communications industry having worked for ELS Defence Ltd. and FR Aviation.

[Continued on page 68]









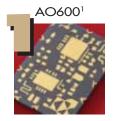
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AROUND THE CIRCUIT



■ Lorch Microwave announced that **Gary Maczis** has joined the company's engineering team. Formerly with K&L Microwave, Maczis brings more than 20 years experience in the design of miniature RF and microwave filter products.

▲ Gary Maczis

iTerra Communications LLC announced the appointment of **Eugene Brannock** as director of business de-

velopment for the company's microwave monolithic integrated circuit products and MMIC-based modules. His responsibilities include overall management of the company's MMIC product line. Before joining iTerra, Brannock was executive vice president of Eudyna USA (formerly Fujitsu Compound Semiconductor Inc.).



Link Microtek has appointed **Jeff Hinsley** to the new position of instrument sales engineer. He will take responsibility for the UK and Ireland. The appointment follows the company's decision to reorganize its sales force into three groups specializing in instruments, components and high volume surface-mount products. Hinsley joins Link from Ansoft, where he was involved in the development and pro-

motion of circuit and finite-element simulation tools, as well as managing key accounts in the wireless sector.

REP APPOINTMENTS

- RF Logic LLC announced the appointment of Dehron as its exclusive representative in the country of Israel. Dehron is a firm with over 20 years of experience in this market.
- Micro-Ant Inc., Fall River, MA, a provider of the design, development and manufacturing of antennas, has appointed RF Associates Inc., Topsfield, MA, to provide technical representation to the company's new and existing customer relationships within the New England region. RF Associates can be reached at (978) 887-9762 or visit www.rfassociates-ne.com.
- Planar Electronics Technology has appointed several new sales representatives. Eastern Tech Corp. will cover MD, DC and VA, and can be reached at (410) 715-2100 or e-mail: johns@eastern-tech.com. Data Marketing Associates will be responsible for TX, OK, AR and LA and can be contacted at (972) 661-0300. J-Square Marketing Inc. will handle NY, NJ and CT. The company can be contacted at (516) 935-3200 or e-mail: alfordj@jsquare.com. EBA Microwave will cover southern CA and can be contacted at (949) 496-7533 or e-mail: elbell@surfside.net. Atem S.A. will be responsible for France and can be reached at 011-33 (0) 1-6934-9203 or e-mail: atem.tb@wanadoo.fr. SpanTech Microwave

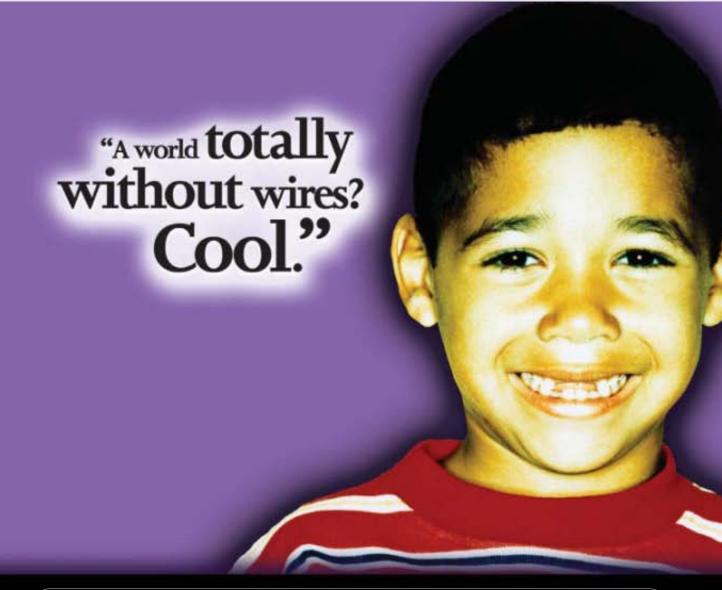
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Technology S.A. will handle Spain and Portugal. The company can be reached at 011-34-95-241-7024 or e-mail: info@spantech-mt.com.

- MI Technologies announced it has selected Compomill Nordic Components AB, Upplands Väsby, Sweden, to represent the company's line of RF and microwave test and measurement products to customers in Sweden, Finland, Denmark, Norway, Estonia, Latvia and Lithuania.
- **Trompeter** has announced that Interstate Connecting Components (ICC), Moorestown, NJ, with offices in Virginia Beach, VA, and Denver, CO, has been signed as an authorized distributor of the company's products. Orders and RFQs can be placed through the ICC Web site at www.connecticc.com or by phone at (800) 795-7689.
- Praxsym Inc. announced the appointment of Castle **Rock Microwave** as its representative for the new PM-2458 wireless broadband power meter. The PM-2458 is a handheld VSWR meter for the license exempt 2.4, 5.3 and 5.8 GHz bands. Castle Rock is taking sales and distribution inquiries at (303) 362-6836 or e-mail: brett@ castlerockmicrowave.com.
- **XMA** Corp. and First Source Inc. announced the signing of a distribution agreement. Under terms of the agreement, First Source will distribute XMA's full line of standard RF and microwave components.
- Agilent Technologies Inc. named Microlease and Rosenkranz as authorized user-equipment resellers in Europe for the Agilent Advantage Assurance program. The program gives European engineers and purchasing agents the option to buy used company equipment that has been evaluated, fully calibrated and guaranteed by Agilent to meet original performance specifications.
- **ANADIGICS Inc.** announced that the company has appointed Takachiho Koheki Co. Ltd., Tokyo, Japan, as a distributor for the country of Japan.

WEB SITES

- Comarco Wireless Test Solutions announced that the company's Web site now offers secure comprehensive support for its worldwide customer base. This new site, www.comarco.com, offers many novel features and is the vehicle for providing this support.
- Flomerics announced ready-to-run thermal models for Philips' power semiconductors available to designers via the SmartParts3D Web site (<u>www.smartparts3d.com</u>). Design engineers can now instantly download complex, calibrated thermal models of power semiconductor packages from Philips to incorporate in Flotherm thermal simulations.

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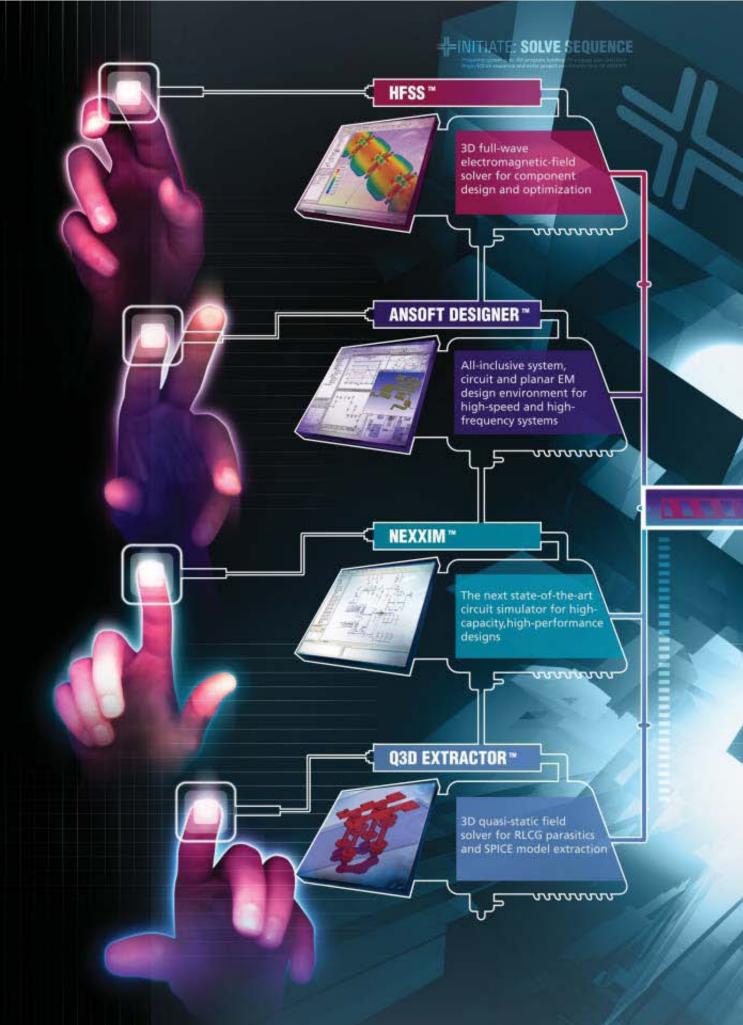
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HIGH PERFORMANCE WIDEBAND MSAG GAIN BLOCK/DRIVER AMPLIFIER MMICS USING MLP TECHNOLOGY

The multi-level plating (MLP) process has been used to develop a family of wideband, low noise, generic gain block and driver amplifier MMICs operating up to 20 GHz. MLP implementation provides significant performance improvements over standard MMIC processing techniques, especially with regards to bandwidth and gain. This article discusses salient features of the MLP process, including test data for multilayer microstrip lines, spiral inductors, 3 dB couplers and MLP-based MMIC amplifiers. The design approach and test data for several broadband MMICs, including a low noise amplifier, a single-bias gain block, and 0.25 W and 0.7 W driver amplifiers, are also described.

ideband, low noise, generic gain block and driver amplifier MMICs have been developed using many different device technologies including MESFET, HBT and PHEMT. Among these, PHEMT-based MMIC technologies have achieved superior performance due to inherent device high frequency operation capability. In order to achieve superior performance similar to PHEMT technologies, multifunction self-aligned gate (MSAG®)-based MMICs are implemented using a multi-level plating (MLP) process. MLP utilizes multiple low dielectric constant polyimide and thick metallization layers atop the base GaAs. Designing with MLP allows for lower loss transmission lines or matching networks, 1-3 higher

frequency operation and increased flexibility in the development of higher power components.

At the M/A-COM facility in Roanoke, VA, the MSAG MESFET process^{4–9} is being used to develop low cost, high volume, high performance and highly reliable multifunction monolithic ICs for commercial and military applications. Because of its versatility in integrating low noise, power and high speed large-scale integration (LSI) functions on a single chip, the process has been named the

[Continued on page 76]

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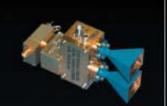
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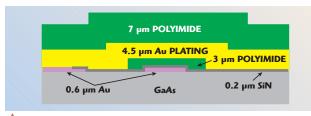


Fig. 1 Standard "Process 5" wafer cross-section.

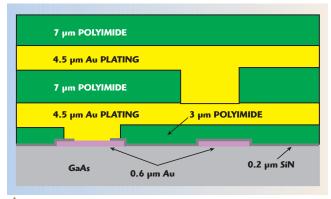


Fig. 2 Multi-level plating (MLP) process wafer cross-section.

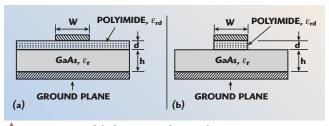


Fig. 3 Two modified microstrip line configurations.

multifunction self-aligned gate process. The MSAG process eliminates the need for a gate recess, the single most important yield and reproducibility-limiting step. As each device type, which may include EFET, DFET, Schottky diode/limiter, low noise FET, switching FET, power FET and n' implants, is optimized for its respective function, it requires an additional mask. The MSAG process is available as a standard foundry service to outside users.

MULTI-LEVEL PLATING PROCESS

Figures 1 and 2 show stylized cross-section views of standard and MLP-processed GaAs wafers. A common design rule, set for core structures and common GaAs processing techniques, except for the MLP-unique elements, allows for simplified design, layout and processing.

There are two key differences between the standard and MLP-processed MMICs. The first is the addition of a second, 7 μ m thick, low dielectric constant polyimide layer; the second difference is the addition of a second thick, 4.5 μ m, gold metallization layer. These two additions provide the MLP advantages.

With the additional polyimide layer, a designer has the flexibility to locate transmission lines, known as multilayer microstrip lines, on polyimide up to $10~\mu m$ thick. The impedance of such lines can be increased by 40 to 60 percent — as compared to standard lines on the given base substrate. The high impedance capability of MLP is well

IADLE I
MEASURED CHARACTERISTICS OF MULTILAYER MICROSTRIP LINES WHEN GaAs SUBSTRATE THICKNESS IS 75 μm

Polyimide	Microstrip	Ζ ₀	E _{re}	α (dB/cm)
Thickness (µm)	Width (µm)	(Ω)		@ 20 GHz
0	20	69.0	7.58	1.07
	50	50.0	8.26	0.83
	100	35.8	8.58	0.70
	150	28.1	9.15	0.61
3	20	81.0	5.32	0.85
	50	57.0	6.22	0.68
	100	41.0	7.10	0.55
	150	32.0	7.47	0.48
7	20	92.0	4.38	0.69
	50	64.1	5.08	0.50
	100	45.0	5.93	0.41
	150	35.5	6.45	0.37
14	20	105.0	3.70	0.55
	50	75.0	4.26	0.40
	100	53.0	4.90	0.35
	150	42.0	5.43	0.30

suited for implementing low loss matching networks and improving the bandwidth of passive components.

The additional thick metallization layer offers benefits as well, mostly in the area of DC current routing/high power design and extending the usage of passive components to lower frequencies. Most straightforwardly, the designer now has the flexibility to use 9 μ m thick transmission lines. Current handling for such lines is 20 mA/ μ m.

A second benefit of the additional thick metal layer is the option to create high current structures, such as spiral inductors. Previously, spiral inductors have been current limited, based on the width of the thin metallization underpass to access the center of the spiral, typically 2 mA/ μ m... as compared to 10 mA/ μ m for 4.5 μ m thick lines. With MLP, a spiral inductor can be fabricated with 4.5 μ m thick spirals and 4.5 μ m thick underpasses.

The configuration of the multilayer microstrip line is shown in *Figure* 3, where ε_r and ε_{rd} are the relative dielectric constants of the GaAs substrate and polyimide buffer layer, respectively, and h and d are their respective thicknesses. The thickness of the polyimide could be between 5 and 25 µm. However, the MLP process only allows polyimide thicknesses of 3, 7 and 10 µm. The microstrip conductor W has an approximate thickness of 4.5 um. Typical dielectric constant values for GaAs and polyimide are 12.9 and 3.2, respectively. Measured results for the multilayer microstrip structure are summarized in **Table 1**. As an example of the reduced loss characteristics of MLP, on a bare $75 \mu m$ GaAs substrate, a 50 Ω line is about 50 µm wide, whereas with a 10 µm polyimide layer atop the base GaAs, it is approximately 90 µm wide. The losses are 0.83 and 0.41 dB/cm, respectively, a 50 percent reduction for the 50 Ω line on polyimide. Further improvement may be obtained by etching away the surrounding polyimide, so that more of the microstrip is surrounded by air. This configuration is also compatible with multi-level plating MMIC fabrication processes.

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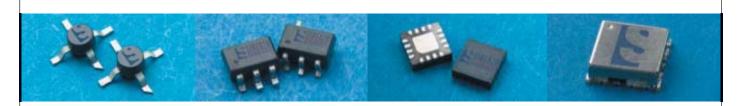
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A family of 6.7 nH inductors was also characterized, and their figure of merit indexes (FMI) is compared in *Table 2*. FMI is defined as

$$FMI = \frac{Qf_{res}}{Inductor Area}$$
 (1)

where

 $f_{res} = self$ -resonance frequency

The inductors selected are a standard inductor with thin metal underpass, a MLP multilayer inductor with 9 μ m thick spiral metallization and a

	*						
TABLE II							
6.7 nH IND	ARISON O JCTORS FO F MERIT II	OR BEST					
Parameter	Standard Inductor	Multi- layer Inducto	3D Inductor				
$f_{res}\left(GHz\right)$	5.0	6.4	4.43				
Q	22.0	33.0	28.5				
Area (mm ²)	0.193	0.193	0.084				
FMI (GHz/mm ²)	5.7	10.9	15.03				

3-D inductor. The Q values are obtained at the maximum Q frequency. It is easily noted that the 3-D structure has the best FMI. This is because of its reduced area. A trade-off of this inductor type is that it has the lowest resonance frequency due to higher inter-level capacitances. The Q factor for the 3-D inductor is about 23 percent higher than for the standard inductor but about 16 percent lower than for the multilayer inductor using thick metallization. The FMI for the 3-D inductor is about 2.6 times larger than for the standard inductor.

A final example of the benefits of MLP is a broadband 3 dB coupler, which is required in many microwave

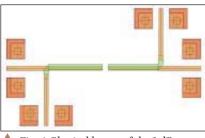
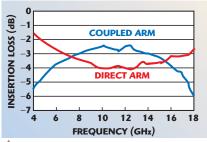


Fig. 4 Physical layout of the 3 dB asymmetric broad side coupler.

applications. MLP is also suitable to realize tight directional couplers on GaAs substrates. A 3 dB asymmetric broadside coupler was developed using the MLP process on a 75 μ m thick GaAs substrate. *Figure 4* shows the top-sectional view of the broadband coupler, which operates over the 7 to 15 GHz frequency range. The physical length of the coupler is 3000 μ m. The bottom and top conductor line widths are 40 and 60 μ m, respectively, resulting in a lower dissipated loss than for a Lange coupler on GaAs. As shown in *Figure 5*, the measured insertion loss



▲ Fig. 5 Measured performance of the 3 dB coupler.

[Continued on page 80]

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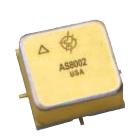




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Mod	del	Freq. Range (MHz)	Small Signal Gain (dB) Typ.	Noise Figure (dB) Typ.	Power Output at 1dB Comp. (dBm) Typ.	Intercept Point 3rd/2nd (dBm) Typ.	D. Volts Nom.	C. mA Typ.
AC	688	50-600	21.0	0.7	21.0	32/44	5	85
AC	1286	650-1200	31.0	1.0	12.0	23/35	15	62
AC	1088	100-1000	18.0	1.1	20.0	30/42	5	85
AC	3556	3000-3600	20.5	1.2	12.5	25/42	5	45
AP	1588	1200-1600	25.0	1.4	24.5	35/58	15	145
AP	1053	10-1000	11.0	1.5	26.0	39/58	15	100
AS	4221	1000-4200	13.0	1.8	14.0	26/42	15	40
AC	2 205	100-2200	12.0	1.9	13.5	28/48	5	50
AC	2 554	1000-2500	25.0	1.9	15.5	26/45	5	72
AC	22 08	200-2200	19.0	2.0	18.0	28/34	8	50
AS	50 02	300-5000	21.0	2.2	16.0	25/32	15	88
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in the coupled and direct ports are 3.3 \pm 0.5 dB and 3.5 \pm 0.5 dB, respectively. The measured return loss was better than 18 dB.

The MLP process results in improved performance in MMIC passive components including couplers, filters, dividers/combiners and transformers, and also allows the realization of new MMIC components including thin film microstrip, multi-level inductors, tight couplers and baluns.

DISTRIBUTED AMPLIFIERS USING THE MLP PROCESS

At the circuit level, improvements in performance can be achieved using very high impedance lines (microstrip lines on 10 µm polyimide) in the gate and drain equivalent transmission lines of a distributed amplifier, using low loss matching networks at the output of a power amplifier, using high current carrying capacity inductors in matching networks and using 9 µm thick conductors instead of 4.5 µm thick conductors having twice the width. An approximate expression for the small-signal gain of a distributed

amplifier is given by¹⁰

$$G \cong \frac{g_{\rm m}^2 n^2 Z_0}{4} \left[1 - \alpha_{\rm g} \ell_{\rm g} \frac{n}{2} \right]^2$$
 (2)

n = number of FETs

 $\begin{array}{l} g_m = transconductance~per~FET \\ Z_0 = characteristic~impedance~of~the \end{array}$ gate line

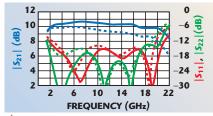
 α_g = attenuation constant of the gate

 $\ell_{\rm g}$ = length of gate line per unit cell

In this expression, a constant characteristic impedance and a constant unit line length have been assumed. Also, the drain line losses are neglected. Equation 2 shows that, for higher gain, one needs higher Z_0 and lower α_g . As previously shown, MLP provides both these features.

As an example of the performance benefit MLP provides for wideband MMICs, *Figure 6* shows the predicted performance of a pair of 2 to 20 GHz distributed amplifiers, one designed using standard Process 5 techniques and the other implemented in MLP. As is easily noted, approximately 1.5 dB additional gain is provided by the MLP design at 20 GHz. Thus, MLP can be used to either increase gain for a given bandwidth, or provide additional bandwidth for a given amount of gain.

In the following, examples of distributed amplifiers developed using MSAG FET with the MLP process are described. In these MMICs, the gate and drain microstrip conductors are on a 10 µm thick polyimide layer atop the GaAs substrate. The circuits were designed using small-signal models for the FET devices and matched to 50Ω at the input and output.



📤 Fig. 6 Predicted performance of a 2 to 20 GHz distributed amplifier using a standard "Process 5" (dashed lines) and MLP (solid lines) processing.

[Continued on page 82]





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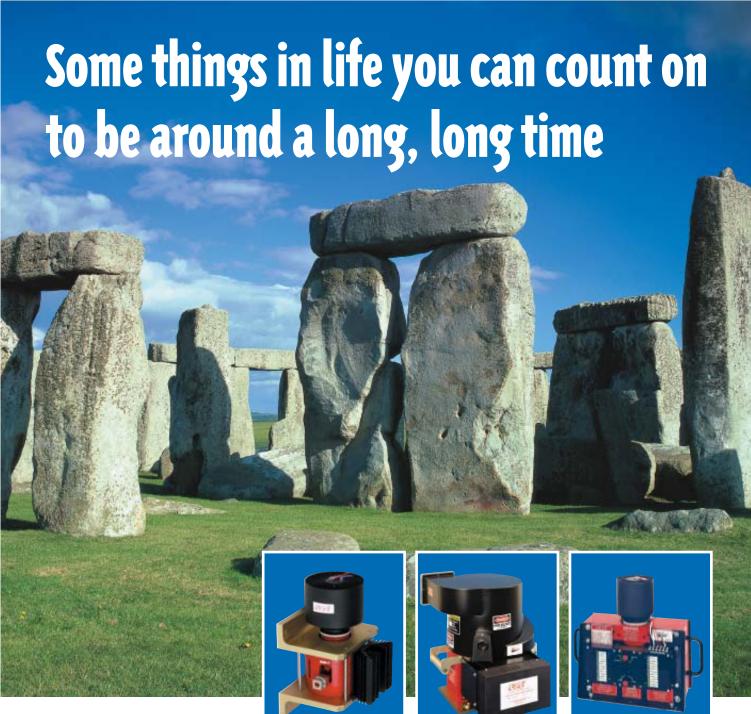


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2 to 20 GHz Distributed LNA (Self-biased)

Figure 7 shows the physical layout of a 2 to 20 GHz distributed LNA, incorporating six 150 μ m 5N (low noise) FETs. The circuit was designed for low

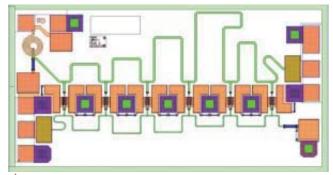


Fig. 7 Layout of a 2 to 20 GHz self-biased distributed LNA.

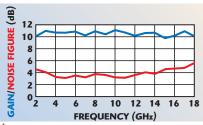


Fig. 8 Measured gain and noise figure of self-biased 2 to 20 GHz distributed LNA.

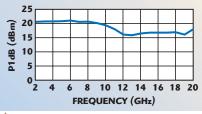


Fig. 9 Measured P1dB of self-biased 2 to 20 GHz distributed LNA.

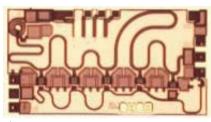
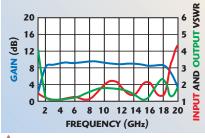


Fig. 10 A 2 to 18 GHz self-biased distributed driver amplifier.



 \blacktriangle Fig. 11 Small-signal gain, and input and output VSWR at $V_D = 5$ V of the distributed amplifier driver.

noise figure and high gain using a low noise FET model. A single supply operation is provided through the use of on-chip self-biasing networks. The value of the resistor between the source of the device and ground is selected to

bias the device at $0.25~I_{DSS}$ to provide a trade-off between minimum noise figure and high P1dB. The drain supply voltage is 5~V. The chip size is $3 \times 1.6~mm$.

Figures 8 and 9 show the measured LNA gain and noise figure, and P1dB, respectively. The current under drive in-

creases from 75 mA at the Q-point to about 110 mA at the PldB compression point. The measured return loss was better than 10 dB over the 2 to 20 GHz frequency range.

2 to 18 GHz Distributed Amplifier Driver (Self-biased)

Figure 10 shows the physical layout of a distributed driver amplifier (DA), designed for the 2 to 18 GHz frequency band. It is comprised of five 5N FETs, each having a 300 µm gate periphery. The circuit was designed for high P1dB and high gain while providing a good match to 50Ω at the input and output. A single supply operation is provided through the use of on-chip self-biasing networks. The nominal drain supply voltage is 5 V; however, on-chip voltage drop resistors allow variable supply voltage from 5 to 8 V. The chip size is 3×1.7 mm. **Figure 11** shows the measured gain and return loss; Figure 12 demonstrates the saturated power at different drain biases.

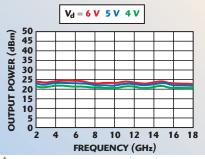


Fig. 12 Saturated output power of the distributed amplifier driver as a function of frequency and drain voltage.

[Continued on page 84]







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Gali — S66 Gali — 3 Gali — 6F Gali — 4F	DC-3000 DC-3000 DC-4000 DC-4000	22 22.4 12.1 14.3	2.8 12.5 15.8 15.3	2.7 3.5 4.5 4.0	18 25 35.5 32	136 127 93 93	16 35 50 50	3.5 3.3 4.8 4.4	.99 .99 1.29 1.29
Gali	DC-4000 DC-4000 DC-4000 DC-2000	18.0 20.4 21.9 22.9	15.9 15.7 15.0 15.5	3.5 3.5 3.3 2.7	32 31.5 28.5 32	78 103 100 85	50 50 50 50	4.4 4.3 4.3 4.4	1.29 1.29 1.29 1.29
Gali Gali 4 Gali 51 Gali 51 Gali 74	DC-4000 DC-4000 DC-4000 DC-4000 DC-1000	12.2 14.4 18.1 20.6 25.1	18.2 17.5 18.0 18.0 19.2	4.5 4.0 3.5 3.5 2.5	35.5 34 35 35 38	93 93 78 103 120	70 65 65 65 80	5.0 4.6 4.5 4.4 4.8	1.49 1.49 1.49 1.49 2.35

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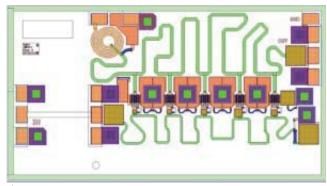
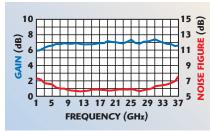


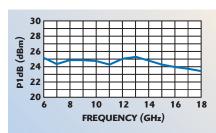
Fig. 13 Layout of a 2 to 18 GHz distributed power amplifier.

2 to 18 GHz Distributed Power Amplifier

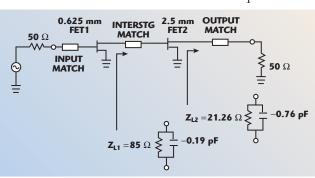
This is another DA, designed for higher power level. It uses the same approach as discussed previously. This topology employs five 300 μ m 5A (power) FETs biased at 8 V. The physical layout of this circuit is shown in *Figure 13*. The MMIC is oversized at 3.0 \times 1.7 mm due to the limitations of being in a development mask. In a production mask, the final



▲ Fig. 14 Measured gain and noise figure of the 2 to 18 GHz distributed power amplifier.



▲ Fig. 15 Measured P1dB of the 2 to 18 GHz distributed power amplifier.



▲ Fig. 16 Schematic of a two-stage driver amplifier.

chip size would be 2.3×1.4 mm. Figures 14 and 15 show the measured gain and noise figure, and output P1dB, respectively.

2 TO 8 GHz DRIVER AMPLIFIER

Another useful feature of MLP is to create high current

inductors for broadband and compact designs.¹¹ In this section, a broadband 0.7 W driver amplifier developed using MLP inductors is discussed.

Traditionally, a driver amplifier is designed based on the loadline method. $^{12-15}$ The design of the two-stage broadband MMIC driver amplifier was based on a design methodology using small-signal, nonlinear FET models and loadpull data obtained at the operating bias point. The operating point of the amplifier was selected for class-AB operation (0.30 I_{DSS}) of the device in order to obtain the best compromise of power output, gain, PAE, linearity and variable power supply operation over the 2 to 8 GHz frequency range.

In this design, the loadline technique is used initially to optimize the circuit parameters. The optimum load impedances Z_{L1} and Z_{L2} at the drain of the first and second stage FETs, necessary to realize the maximum output power and PAE, are shown in **Figure 16**. Then, the design is simulated using the nonlinear model to calculate the power compression of each stage and the output power and PAE as a function of input power. Since it is very difficult to optimize the matching networks to the required load impedances over wide

bandwidths, using nonlinear models, the above design process is repeated so that an optimum solution for simultaneous match to the load impedances at the drain of each FET and best gain, power and PAE are achieved.

[Continued on page 86]







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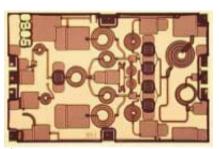
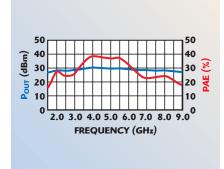


Fig. 17 A 2 to 8 GHz, 0.7 W driver amplifier.



ightharpoonup Fig. 18 P_{out} and PAE of the 2 to 8 GHz driver amplifier at $V_D = 8$ V $P_{IN} = 18$ dBm.

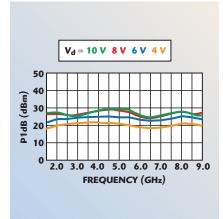
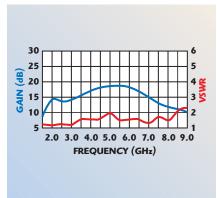


Fig. 19 P1dB of the 2 to 8 GHz driver amplifier as a function of drain voltage.



ightharpoonup Fig. 20 Small-signal gain and input VSWR of the 2 to 8 GHz driver amplifier at $V_D = 8$ V.

The input stage, which has a limited gain compensation network, was designed for good input match as well as for maximum power transfer at the high frequency end. The interstage matching network was designed to provide a flat gain response and deliver enough power to the output stage FETs for achieving overall maximum output power and PAE. The output matching elements were selected to provide an optimum load match with minimum insertion loss, since efficiency and output power are reduced to a great extent by a passive loss. Both stages, as well as the complete amplifier, were designed to be unconditionally stable over 3 to 10 V drain power supply voltage and 0.25 to 0.50 I_{dss} drain current. Experience has shown that for MSAG FETs, standard even-mode (K > 1) and oddmode stability analyses are adequate to avoid microwave oscillations. However, under large-signal condition and pulsed operation, it is necessary to use worst-case K-factors greater than 1 when S-parameter data is used for various bias conditions from $V_{ds} = 3V$, $0.50 I_{dss}$ to $V_{ds} = 10V$, $0.25 I_{dss}$. This approximately replicates the envelope a full cycle of the input signal experiences during the large signal and pulsed operation. It was found that imposing a K > 2.0 condition, for V_{ds} = 10V and $0.25 I_{dss}$ small-signal S-parameters, is about what is necessary to ensure K > 1 under all conditions.

Figure 17 shows the photograph of the two-stage 0.7 W power output driver amplifier. The chip size is 3×2 mm.

Typical CW measured P_{out} and PAE for MMIC chips on Cu-W carriers at $V_{DS} = 8V$ and $P_{in} = 18$ dBm are shown in *Figure 18*. The amplifier has greater than 28.5 dBm power output and better than 24 percent PAE over the 2 to 8 GHz frequency range. *Figure 19* depicts P1dB power levels at various drain voltages. The variations of small-signal gain and input VSWR as a function of frequency are shown in *Figure 20*. The input VSWR is better than 2:1 over the 1.5 to 8.4 GHz range.

CONCLUSION

A family of wideband, low noise, generic gain block and driver amplifi-

[Continued on page 88]



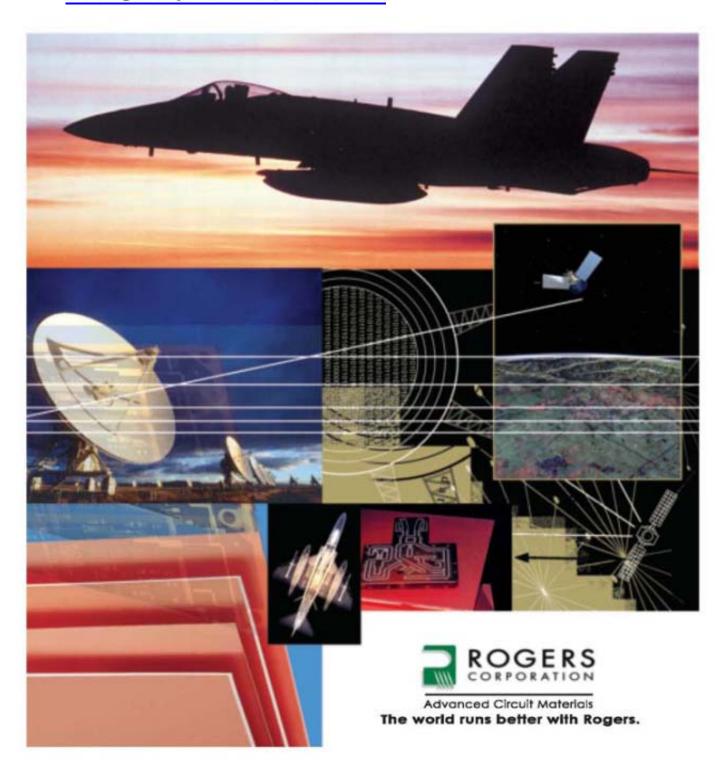






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er MMICs for commercial and military applications has been developed. Using MLP processing, higher performance and higher frequency operation are achieved.

ACKNOWLEDGMENT

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In a typical multi-carrier power amplifier (MCPA) application, it is well known that good amplitude matching and good phase matching are required for greater reduction of intermodulation distortion (IMD) or for better harmonic rejection within the CDMA spectral mask. To solve the mismatching problem, it is desirable to accurately measure the output power or to provide accurate feedback for amplitude control. In order to accurately measure the power level, a logarithmic amplifier has been used as an RF power detector that converts the RF power level to a voltage. 1–3

Previous work on semiconductor RF detectors has led to improved linearity performance.^{2,3} Recently, more efforts have been directed to the compensation of the nonlinearity of semiconductor detector ICs. They have focused on the voltage drift caused by temperature changes or the voltage variation according to the crest factor in a modulated system. An additional requirement is a wide dynamic range, which stems from the average envelope

power characteristics of the CDMA signal. Some attractive RF detector ICs have recently become available.

In order to realize a cost-effective MCPA, the nonlinearity of a logarithmic amplifier is by itself of no interest. In preference to the problem of nonlinearity, an effective powersaving control is required. Although the detection voltage of a logarithmic amplifier can be changed because of the dynamic range or temperature variation, there are few issues for linearity because of the compensation factor provided by manufacturers. It is important to define an accurate offset voltage according to the condition of the input signals.

In this article, when each CDMA carrier is randomly located within the transmission frequency band, the variation of output voltage of

[Continued on page 92]

SANG HYUN PARK Chung-Ang University Seoul, Korea







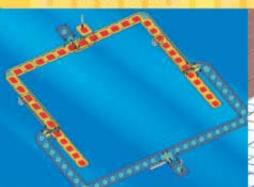


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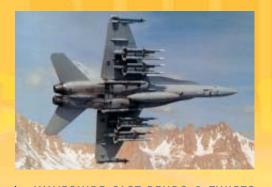


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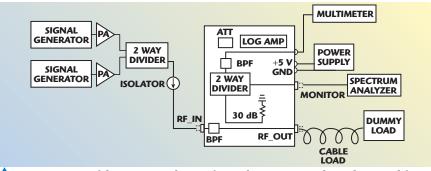
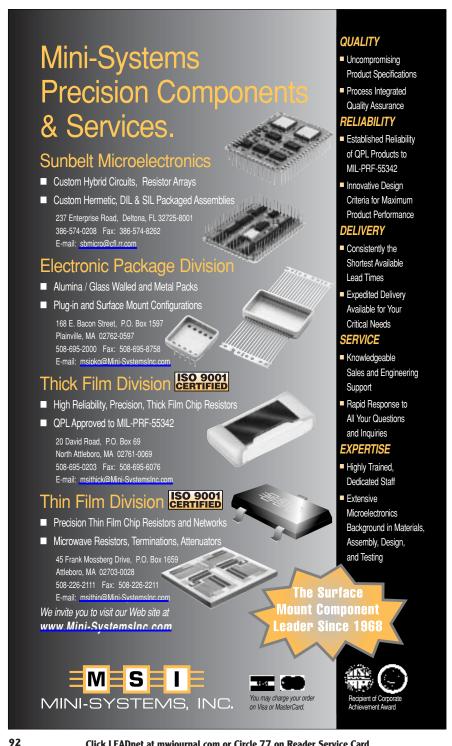


Fig. 1 Diagram of the experimental set-up for RF detection using a logarithmic amplifier.



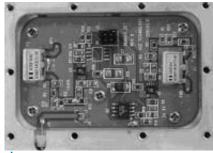


Fig. 2 The RF power detector manufactured with a logarithmic amplifier.

the detector IC is described. In the field, CDMA service carriers have been placed with some frequency space between them. In a rural area, CDMA carriers, allocated within an odd channel number, have sometimes been used. This work, based on experiments, shows the variations in the output voltage of a logarithmic detector for two or three CDMA carriers with the same total transmitted power as a function of their frequency separation.

EXPERIMENTS

In this task, an AD8314 IC, made by Analog Devices, was used and the experimental configuration is illustrated in Figure 1. Figure 2 shows the manufactured RF power detector. Although the specification for its input is in dBm, a logarithmic amplifier fundamentally responds to voltage and not to current. A direct consequence of this characteristic is that input signals of equal RMS power but different crest factors produce different results at the logarithmic amplifier's output.4-6 For more accurate measurements, a directional coupler, a bandpass filter (BPF), a splitter and a power detector were used. The operating center frequency was 1.75 GHz and the bandwidth of the CDMA carrier was 1.23 MHz. A signal generator and a power amplifier for each CDMA carrier should be used because any nonlinearities and harmonics in power detection could have a significant impact on the accuracy of the measurement. The BPF was necessary to minimize the effect of any extra-injected out of the band signal. The cable and dummy load were used to reduce the reflected RF power from the terminal. The injected signal was decoupled by 30 dB and divided into monitoring and detection paths. The power and frequency of the input signal were monitored with a spectrum analyzer.

[Continued on page 94]











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The output voltage of the detected RF power was measured with a digital multimeter with a 0.001 V sensitivity.

TEST RESULTS

To determine the linear dynamic range of this work, the output voltage of the detector as a function of input RF power was measured, as shown in *Figure 3*. The reference voltage of this detector was 0.755 V and the slope was 0.03 V/dB. In *Figure 4*, CDMA carri-

ers with the same total power, 25 dBm, were applied to the RF detector and there was no frequency separation between them. As the number of CDMA carriers was increased, the output voltage increased. The voltage difference between one carrier and five carriers was 0.022 V.

When two CDMA carriers with different frequency spacing are applied, the resulting output voltage of the detector is shown in *Figure 5*. When the

total power of the two CDMA carriers was 25 dBm, the detected voltage for two CDMA carriers was higher by

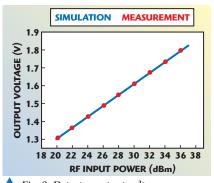


Fig. 3 Detector output voltage as a function of input power.

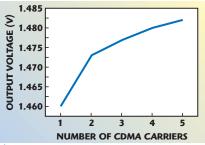
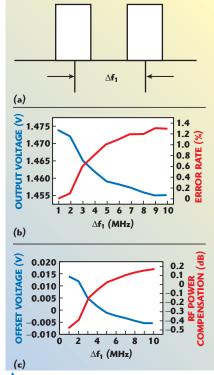


Fig. 4 Power detector output voltage as a function of the number of CDMA carriers.



A Fig. 5 Experimental results for two CDMA carriers; (a) frequency separation between carriers, (b) detector output voltage as a function of Δf₁, and (c) offset voltage and RF compensation compared to a single CDMA carrier.

[Continued on page 96]

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AMF-5B-040080-60-30P	4-8	33	1.5	6	30	2:1	1400
AMF-5B-040080-70-33P	4-8	33	2	7	33	2:1	2200
AMF-6B-040080-60-33P-2	4–8	40	2	6	33	2:1	2400
AMF-5B-080120-80-30P	8-12	24	1.5	8	30	2:1	1650
AMF-6B-080120-70-30P	8-12	30	1.5	7	30	2:1	1800
AMF-6B-080120-50-33P	8-12	33	1.5	5	33	2:1	2000
AMF-5B-080120-50-35P	8-12	35	2	5	35	2:1	2800
AMF-5B-060130-50-35P	6-13	35	2	5	35	2:1	2800
AMF-8B-060180-60-30P-2	6-18	31	2.5	6	30	2:1	2000
AMF-6B-060180-60-33P	6–18	35	2.5	8	33	2.2:1	2800
AMF-8B-080180-60-30P	8-18	31	2	6	30	2:1	2000
AMF-6B-080180-80-33P	8–18	35	2.5	8	33	2:1	2800
AMF-5B-120180-60-28P	12-18	18	2	6	28	2:1	1600
AMF-6B-120180-50-28P	12-18	24	2	5	28	2:1	1700
AMF-8B-120180-60-30P	12-18	33	2	6	30	2:1	2000
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0.014 V than for a single CDMA carrier with the same RF power. As the channel spacing was increased, the output voltage of the detector decreased. When the output voltage is normalized to the output with 1 MHz space, the error rate is increased by 1.3 percent. If the output voltage is normalized to the output for one CDMA carrier, the offset voltage is also decreased. However, when the channel space is close to 10 MHz, the slope of change in the offset

voltage is much decreased. The maximum voltage difference over 10 MHz is 0.02 V. At this point, the difference in power level can be calculated at a rate of 0.03 V/dB. When two CDMA channels were located with some frequency separation, the maximum voltage was increased by 46 percent compared with the slope of the detector. The rate of difference in detection voltage over 10 MHz was limited to 67 percent. Therefore, the calculated RF power mea-

sured through the power detector should be compensated by a maximum of 0.7 dB, compared with that of a single CDMA carrier.

In a similar manner, the experimental results for three CDMA carriers with different frequency spacings are shown in **Figure 6**. When the separation between the first and second carriers is Δf_1 and the separation between the second and third carriers is Δf_2 , the detection voltage for three CDMA carriers was higher by 0.018 V than for a single CDMA carrier with the same power. Also, this value was higher by 0.04 V compared with that of two CDMA tones. As Δf_1 and Δf_2 in-



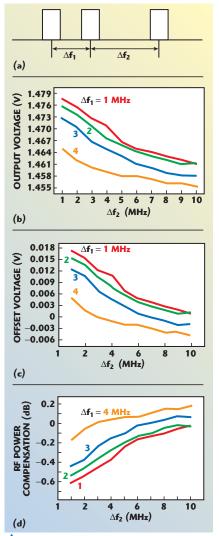


Fig. 6 Experimental results for three CDMA carriers; (a) frequency separation between carriers, (b) output voltage of the detector, (c) offset voltage as a function of frequency separations compared to a single carrier, and (d) RF compensation as a function of frequency separations compared to a single carrier.

[Continued on page 99]

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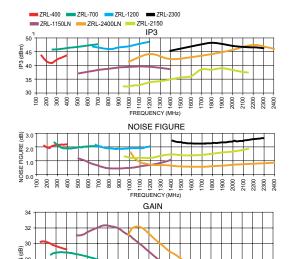






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ZRL-2150	950-2150	25	1.5	33	22.0	119.95
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creased, the detection voltage was decreased. The decrease for three CDMA carriers, as a function of frequency spacing, was similar to that for two CDMA carriers. When three CDMA channels were spaced by some frequency, the maximum voltage was shifted higher by 60 percent compared with the slope of the detector. However, the offset voltage for three CDMA carriers was the same as that for two CDMA carriers when the frequency separation was more than 10 MHz.

In this article, the effect of multi-channel RF signals, in the Korea PCS band, detected with a logarithmic amplifier, is reported. When two CDMA carriers are applied, the detected voltage was higher by 0.014 V compared with the detected voltage for a single CDMA carrier, but decreased as the channel spacing increased. The difference in detected voltage between the 1 MHz and the 10 MHz separation was approximately 0.02 V with respect to a slope of the logarithmic amplifier of 0.03 V/dB; the maximum error in RF power detection was 0.65 dB. In the experiments with three CDMA carriers, the detected voltage was higher by 0.0 18 V compared with the detected voltage of a single CDMA carrier; however, it was decreased in the same manner as in the case of two CDMA carriers.

CONCLUSION

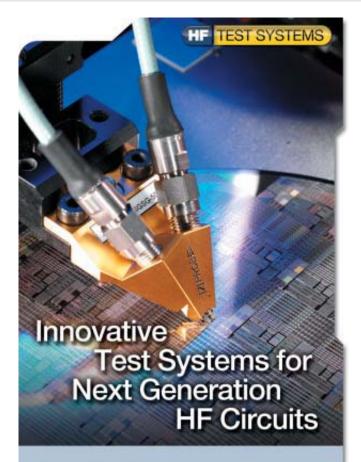
When the RF powers for multi-carriers are detected, the experiments show that there are offset voltages according to the frequency spacings. Even though the transmitted power is the same, as the number of signals is increasing, the detected voltage increases. However, as the frequency spacing becomes wider, the detected voltage of multi-carriers decreases. When the channel spacing is larger than 5 MHz, the effective detected voltage for CDMA multi-carriers shows a vertical shift in the transfer function. However, the slope of the detected voltage as a function of channel spacing is not affected. For the accurate power-control of CDMA power amplifiers, a compensated, offset voltage should be used.

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APPLICATION NOTE

A WIDEBAND MMIC-BASED FEEDBACK OSCILLATOR

Classic feedback oscillators have often been favored because of their low phase noise performance and wide frequency tuning characteristics. This article covers the basic theory of feedback oscillators, and shows how the addition of a vector modulator in the feedback path results in an extremely versatile circuit configuration. The implementation of this system on a single MMIC is described and is shown to offer unparalleled flexibility in terms of oscillation frequency, phase noise and tuning range.

he requirement for increased data rates in modern radio systems has led to higher order modulation schemes which, in turn, demand oscillators with lower phase noise. Meanwhile, manufacturers must also deliver low cost solutions covering many different frequency bands. These two criteria have generally been incompatible, since an improvement in phase noise usually occurs at the expense of tuning range. As a result, manufacturers frequently incorporate many different oscillator parts into their radio systems.

An oscillator that combines good phase noise performance with flexibility and wide

tuning range is therefore highly desirable. The classic feedback oscillator lends itself to meeting these requirements, while an MMIC-based implementation results in a low cost solution incorporating ancillary circuits such as buffer amplifiers, a prescaler and a frequency doubler.

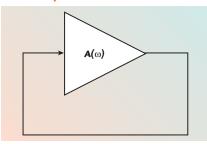
THEORY OF OPERATION

Figure 1 is a diagram showing a simple feedback oscillator. This circuit will oscillate if there is a positive loop gain at a frequency where the open loop phase shift is a multiple of 2π . Oscillations will grow at that frequency until gain compression in the feedback amplifier reduces the loop gain to unity.

It is difficult to predetermine the oscillation frequency of the system accurately due to uncertainties in the loop phase shift. The insertion phase of the amplifier will vary according to manufacturing tolerances, temperature and supply voltage. In addition, at high frequencies, transitions and interconnects can significantly alter the loop delay. In order to cope with these uncertainties some means of phase control in the feedback path are incorporated [Continued on page 102]

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Fig. 1 Simple feedback oscillator.



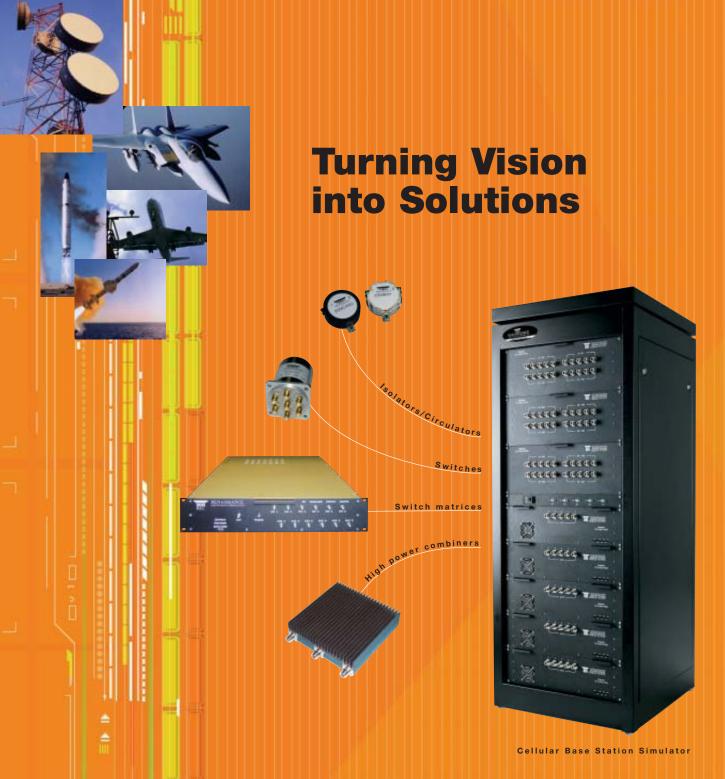
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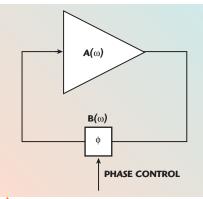


Fig. 2 Simple feedback oscillator with delay control.

to allow frequency tuning. *Figure 2* shows the same simple feedback oscillator with a controllable phase shift in the feedback path.

If the amplifier is broadband, then there may be more than one frequency at which the oscillation criteria are satisfied, giving rise to unwanted oscillation modes and spurious output signals. To eliminate these unwanted oscillations, a filter can be placed in the feedback path. The filter reduces the open loop gain of the oscillator

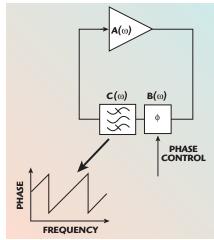


Fig. 3 Simple feedback oscillator with a filter in the feedback path.

for signals outside the passband. It is generally chosen such that there is always just one frequency at which the oscillation conditions are met. *Figure* 3 shows the same feedback oscillator with a controllable phase shift in the feedback path and with the addition of a bandpass filter.

The addition of the filter has a beneficial effect on the phase noise of the oscillator by increasing the slope of phase shift versus frequency. A larger phase versus frequency slope will cause the loop to be less susceptible to perturbations in phase. Various noise sources (principally thermal, shot and flicker noise) act on the loop phase and result in modulation of the output phase or frequency. The filter's phase versus frequency response, or Q-factor, decreases the sensitivity of the oscillator loop to these noise sources and hence improves the resulting phase noise.

The Q-factor of the filter is typically much higher than the feedback amplifier, and increases with the number of stages in the filter. The phase noise in a feedback oscillator can be calculated according to^{2,3}

$$L(f_{\rm m}) = \frac{FkTG}{8Q^2P} \left(\frac{f_{\rm r}}{f_{\rm m}}\right)^2 \tag{1}$$

This expression demonstrates the importance of maximizing Q and the power in the loop P, while keeping the amplifier noise figure F to a minimum.

[Continued on page 104]

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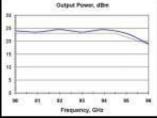
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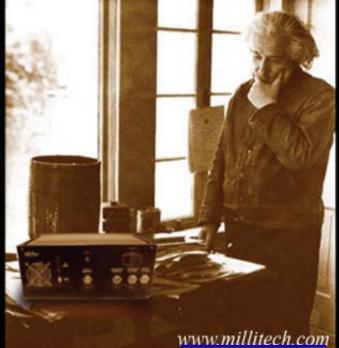
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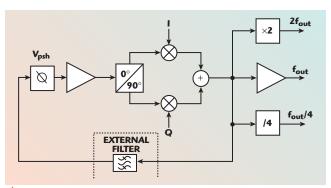








APPLICATION NOTE



▲ Fig. 4 Block diagram of the feedback oscillator MMIC.

CIRCUIT IMPLEMENTATION

One of the problems associated with feedback oscillators is the control of the loop phase. The amplifier, phase-shifter and filter must be designed to ensure that the loop phase is $n \cdot 2\pi$ at the desired oscillation frequency. A versatile design that can be used with many different filters is difficult because the insertion phase of different filters will not be the same. There are also practical limits to the phase variation that can be achieved in a conventional phase-shifter; a large phase variation is undesirable due to the high oscillator voltage

control coefficient (Kvco) it entails (this can be detrimental to phase noise and phase-locked loop (PLL) dynamics).

In this patented implementation^{4,5} the simple feedback oscillator approach has been extended by adding a four-quadrant vector modulator in the

feedback path. This allows the designer to control the loop phase over a full 360°; hence, the same circuit can be used with many different feedback filters regardless of phase shift. In addition, the increased phase variation that is available increases the oscillator tuning range without resulting in an impractical $K_{\rm vco}$.

Analog control of the vector modulator inputs is generally not practical so the I and Q control signals are generated in digital-to-analog converters (DAC) or digital potentiometers. An analog fine phase adjustment is incorporated to allow interpolation between vector modulator settings and to phase-lock the oscillator in a synthesizer.

In order to maximize the range of applications for this circuit, it has been designed to cover the widest possible bandwidth. In this case, acceptable circuit performance is achieved over one octave (6 to 12 GHz), and, with the on-chip frequency doubler, the circuit can be configured as a low phase noise signal source at any frequency between 6 and 24 GHz.

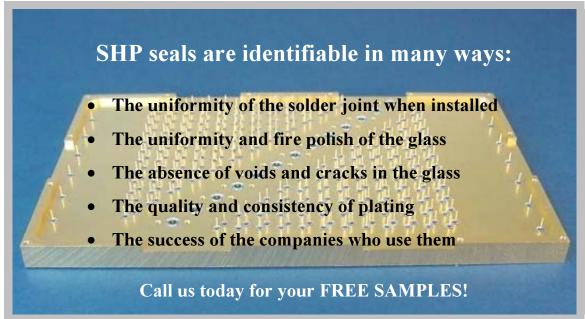
This novel feedback oscillator concept has been implemented in a commercial GaAs HBT process on a single highly integrated MMIC. HBT technology was chosen due to its combination of good RF performance at reasonable cost, and its low flicker (1/f) noise corner frequency compared to a HEMT processes. This is important since many modulation schemes require good phase noise performance at low frequency offsets such as 10 to 100 kHz. *Figure 4* shows a diagram of the

[Continued on page 106]



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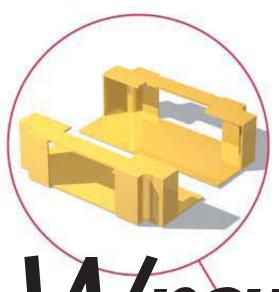


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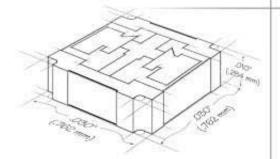
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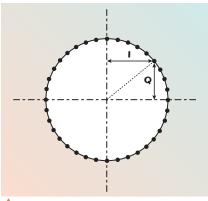


Fig. 5 Example of coarse phase delay settings.

major circuit blocks inside the MMIC. The feedback filter may be implemented on-chip, or, for increased flexibility, a number of external filters may be used to address many different applications with the same circuit design.

FEEDBACK FILTER

As shown, a filter is used to close the feedback path and determines the tuning range and phase noise of the oscillator. Thus far, the filter has been implemented both as a coupledline structure and lumped-element filter on GaAs, but a variety of other technologies could be used, including:

- Dielectric resonator
- Microstrip on ceramic or soft substrate
- Waveguide
- Cavity

The choice of filter will determine the oscillation frequency, phase noise performance and tuning range of the system. The high performance and broad bandwidth of the oscillator MMIC allows the loop designer a great deal of freedom in optimizing these parameters through careful choice of both filter and operating point.

COARSE PHASE ADJUSTMENT

A four-quadrant vector modulator is used to implement a coarse phase adjustment. This circuit allows 360° of adjustment. By providing 360° of phase rotation, the VCO can be made to oscillate at any point where the gain of the active circuit exceeds the insertion loss of the filter. This leads

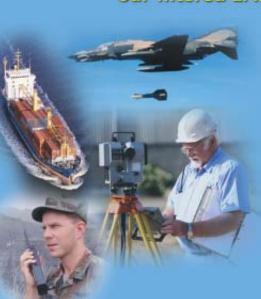
to a highly flexible architecture, since the absolute insertion phase of the filter at a desired oscillation frequency is not important.

The circuit is implemented as a pair of double-balanced Gilbert cell multipliers with frequency compensation. Balanced quadrature input signals are supplied by a Lange coupler followed by differential amplifiers. These circuits dominate the noise figure of the feedback circuit.

Figure 5 shows an example of how quantized phase adjustment over 360° of phase delay may be set using the vector modulator. For constant loop gain operation the vector modulator requires I and Q control signals that conform to cosine/sine functions. The magnitude of the I and Q signals can be adjusted to control the vector modulator gain, and thus optimize the loop gain to suit the chosen filter. Loop gain must be sufficient to ensure start-up, but not so large that gain compression degrades the phase noise performance.

[Continued on page 110]

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	QH6213	2 - 30	1200	0.3	1.25:1	± 5	25
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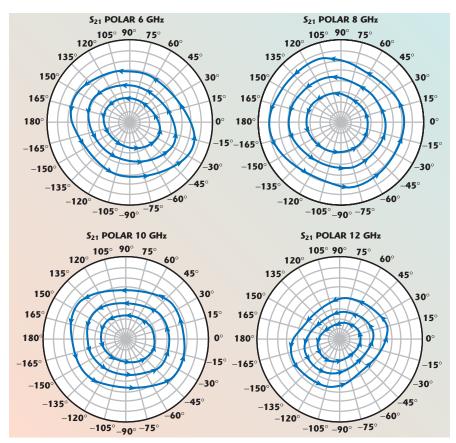
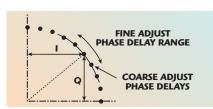


Fig. 6 Vector modulator phase characteristics at three scaling factor settings.



📤 Fig. 7 Fine adjust phase delay range

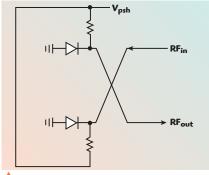


Fig. 8 Fine phase adjustment circuit.

Figure 6 shows plots of typical quantized phase delays from the vector modulator for three scaling factor settings. Small phase and amplitude errors (as

seen in the slight non-circularity of these plots) arise due to the limited bandwidth of the quadrature Lange coupler and unavoidable asymmetries within the vector modula-

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FINE PHASE ADJUSTMENT

The fine phase adjustment is an analog input signal used to interpolate between coarse phase settings (see Figure 7) and allow phase-locking of the oscillator in a synthesizer. There are many ways of implementing the fine phase adjustment. The first implementation is shown in *Figure 8* and uses a Lange coupler with controlled reflective terminations, 6,7 in this case two arrays of varactor diodes. The insertion phase of the Lange coupler is controlled by varying the reactance presented by the diode terminations.

A planned future implementation adds the analog control signal to the quantized I and Q control signals using a pair of two-quadrant multipliers to maintain the sense of analog control and removing the need for an extra phase shifter, thus improving the thermal noise figure and overall phase noise.

It is important that the fine phase adjustment range covers the widest gap that can occur between coarse phase adjustment points. This is necessary to avoid dead spots in the tuning range of the oscillator — points that can never be reached by the fine/coarse phase tuning.

The maximum phase variation in the fine phase adjustment will determine the minimum number of bits required to control the vector modulator. Some allowance must also be made for non-idealities in the vector modulator, manufac-

[Continued on page 112]

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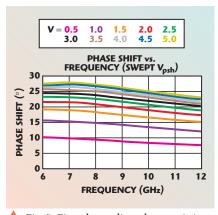


Fig. 9 Fine phase adjust characteristics.

turing tolerances, temperature effects, etc. *Figure* **9** shows the tuning characteristics of the fine phase adjustment.

PRESCALER

To lock the feedback oscillator to a stable reference, a frequency divider is implemented on the MMIC and a port with the divided output frequency is provided. The divide ratio is 4 and the output power is approximately 0 dBm, allowing this circuit to interface directly to standard PLL ICs.

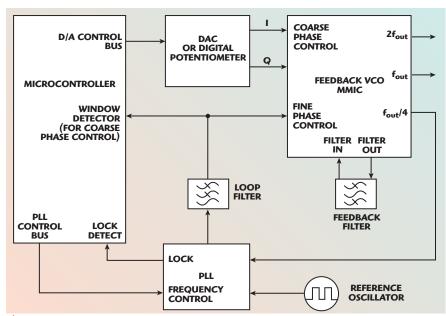


Fig. 10 Synthesized implementation.

DOUBLER

The feedback oscillator MMIC also contains a frequency doubler circuit. The circuit is thus capable of generating output signals over two full octaves.

SYNTHESIZED FEEDBACK OSCILLATOR IMPLEMENTATION

Figure 10 shows a block diagram of a synthesized oscillator using the feedback oscillator MMIC. The microcon-[Continued on page 114]





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troller programs the PLL IC and sets the coarse phase adjustment according to sine/cosine lookup tables. If the PLL is out of lock and the desired output frequency is outside the range of the fine phase adjustment, then a window detector forces the coarse phase control to step through phase settings until lock is achieved.

The coarse phase control lines are low pass filtered with a cutoff frequency lower than the PLL loop bandwidth. In this way phase-lock can be maintained as coarse phase stepping occurs as required to compensate for temperature changes or to change frequency.

OSCILLATOR MEASUREMENTS

The circuit has been evaluated using three different filters with different bandwidths and circuit structures:

• A 7 GHz coaxial resonator filter with a 40 MHz bandwidth

- A 7 GHz coupled-line filter on GaAs substrate with an 800 MHz bandwidth
- A 7 GHz lumped-element filter on a GaAs substrate using metal-insulator-metal (MIM) capacitors and microstrip inductors with a 3 GHz bandwidth

The sharpness of the phase-delay versus frequency characteristic of the filter sets the phase noise of the oscillator. This characteristic can be traded-off with the filter bandwidth. which sets the tuning range of the oscillator. Figure 11 shows the measured phase noise of the MMIC implementation using the three filters previously described. A straight line extrapolation has been used to determine the anticipated phase noise with other filter bandwidths.

The measured phase noise versus frequency offset for this circuit using the coupled-line filter (with > 800 MHz tuning range) is shown in Figure 12 for a carrier frequency of 6.672 GHz. The circuit has been phase-locked using the on-chip prescaler and a commercial synthesizer IC with a loop bandwidth of 5 kHz. The phase noise slope is 20 dB per decade above 100 kHz, indicating that flicker noise does not contribute to phase noise at offsets > 100 kHz.

The octave bandwidth of the feedback VCO MMIC means that a very



Fig. 11 Phase noise (at 100 kHz offset) vs. tuning range, using an external three-section filter.

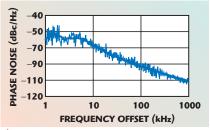


Fig. 12 Measured phase noise of feedback oscillator with 7 GHz coupled-line filter (800 MHz tuning range).

[Continued on page 116]

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wide tuning range is possible. Measurements were made with a 3 GHz bandwidth lumped-element filter centered at 7 GHz. The filter response is shown in Figure 13 and the resulting tuning characteristic in Figure 14. The tuning range exceeds 40 percent while the buffered output power is +7 to +10 dBm. Future versions of this MMIC will improve the output power flatness.

CONCLUSION

Feedback oscillators are known to offer a good combination of low phase noise and wide tuning range; however, limited phase shift control can make the circuit inflexible. Designers have often been reluctant to use this architecture due to difficulties in predicting the loop phase shift with sufficient accuracy. The feedback oscillator has been shown to be highly suitable for a

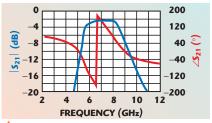


Fig. 13 Measured response of 3 GHz bandwidth filter.

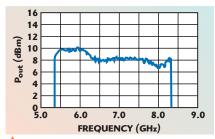


Fig. 14 Measured tuning range and output power of the feedback VCO with 3 GHz bandwidth filter.

MMIC implementation, and, when combined with a vector modulator in the feedback path, the result is a highly versatile oscillator circuit.

Integration of the oscillator with a prescaler allows this circuit to interface directly with commercial synthesizer ICs, while a frequency doubler extends the potential output signal range to cover two octaves.

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Patent information: Original - International Application No. PCT/AU01/00997 filed on 14 August 2001. US application was published on 22 January 2004 as publication number US-2004-0012452-A1. Japanese reference is 2002-520397 (13 Feb 2003). European application reference is 01957635.4.

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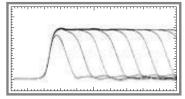
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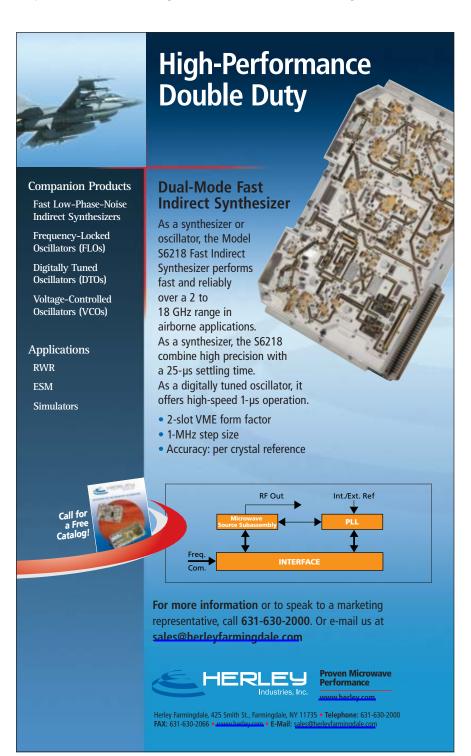
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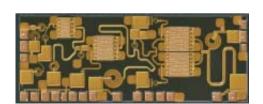


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COVER FEATURE



HIGH VOLTAGE, LOW COST FETS FOR HPA MMIC APPLICATIONS

/A-COM is a longtime supplier to the military, Navy, Army and Air Force of GaAs MMICs, employed in active phased array radars. To date, the company's GaAs process of choice has been its Multifunction Self-aligned Gate (MSAGTM) process. MSAG features selective ion implantation with noncontacting stepper lithography to provide a combination of excellent FET performance, very flexible circuit functionality, outstanding reliability and low manufacturing cost. Having been in continuous production since 1986, MSAG is a mature and well-characterized process.

The MSAG power FET produces 0.8 W/mm power density at 65 percent power-added efficiency (PAE) while operating at 14 GHz and 10 V drain voltage. Using this process, the company supplies some of the highest power GaAs MMICs available. The practical power limit for a MSAG high power amplifier (HPA) is set by the ability to implement an efficient load line matching circuit for a given amount of FET gate periphery. The load line impedance is approximately proportional to voltage, therefore, the matching problem is simplified at higher voltages for higher power applications.

Sometime ago, the Navy identified a need for more MMIC power than could be achieved using a 10 V GaAs process. This need is a part of the drive toward developing wide band-gap semiconductors, which are capable of operating at much higher voltages, with better thermal characteristics than 10 V GaAs-based devices.

M/A-COM has been engaged for several years in exploring higher operating voltages in GaAs, using derivatives of the MSAG process. For the past 18 months, the company has been under contract to ONR/MDA (N00014-020C-0453, \$1.8 M) to develop and demonstrate the practicality of high voltage MSAG (HVMSAG™) devices for S-band HPA MMICs.

HVMSAG developments on the ONR/MDA program have been very positive and are leading now to the development of high voltage HPAs for commercial applications. The work is protected under M/A-COM's US Patent 6,005,267, issued December 21, 1999, covering a MES/MIS FET with Split-gate RF Input, and US Patent 6,559,513 B1, issued May 6, 2003, for a Field Plate MESFET.

Although there is no doubt that wide bandgap semiconductors offer advantages in terms of power density compared to GaAs, the hallmark of the HVMSAG process is that no new infrastructure development is required. HVM-SAG is manufactured on a mature process line, thus the manufacturing cost is low and the reliability outstanding.

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ightharpoonup Fig. 1 HVMSAG CW 468 μ m FET power density performance at V_d = 25 V and 3.5 GHz.

Fig. 2 HVMSAG CW 468 μ m FET PAE performance at $V_d = 25$ V and 3.5 GHz.

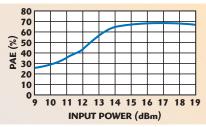
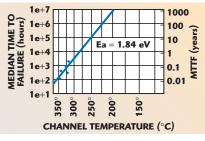


Fig. 3 Arrhenius plot of HVMSAG RF life test results at 28 V operation.



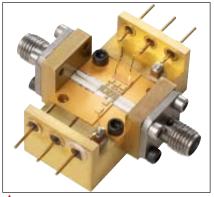
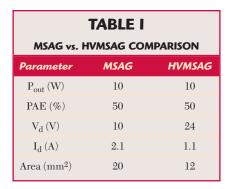
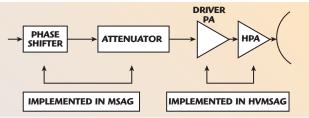


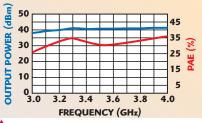
Fig. 4 A HVMSAG HPA mounted to a test fixture.

The HVMSAG process is designed to operate at 24 V. The S-band power density of a typical HVMSAG FET at 3.5 GHz under CW conditions is approximately 1.5 W/mm and its PAE is 65 percent, as shown in *Figures 1* and 2, respectively. Accelerated operational life testing results shown in the Arrhenius plot of *Figure 3* reveal outstanding thermal robustness with an MTTF of more than 106 hours at 150°C channel temperature. The actu-



▼ Fig. 5 An active phased array transmit element.





igspace Fig. 6 Output power and PAE of a 10 W S-band 24 V GaAs MMIC driver amplifier at $P_{in}=15~dBm$.

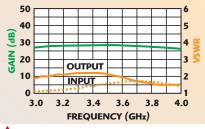


Fig. 7 Small-signal gain and input/output VSWR of the 10 W S-band driver amplifier.

al channel temperature depends on the HPA design and chip environment. HVMSAG is available on either 50 or 75 μm substrate thicknesses. Obviously, more care in thermal design is required when operating at 24 V versus 10 V but reliable operation of HVMSAG HPAs of much higher power than using 10 V GaAs processes is achievable. **Figure 4** shows an HVMSAG HPA mounted in a test fixture.

While leveraging a transistor topology that is fabricated using the proven MSAG process, the HVMSAG high voltage FET device has been developed to provide higher power density at higher drain voltages, while main-

taining all the cost, reliability and repeatability inherent in MSAG MMIC-based solutions. *Table 1* compares the capability of both the MSAG and HVMSAG processes for high power S-band amplifiers. The greater power density and higher voltage of the HVMSAG process reduces chip size, lowering costs in high volume production, and halves the DC current, reducing the amount of copper in the system bus networks.

The outstanding power performance of the HVMSAG process has positioned M/A-COM as a leading contender for the Navy's next generation S-band active phased array radars. In addition,

many commercial and defense applications could benefit from this breakthrough development. HVMSAG devices are capable of more output power per area of GaAs. The resulting FETs permit the manufacture of more compact MMICs with a lower cost per watt. The resulting load line has a higher impedance for a given power and is easier to match. The new devices also simplify bias circuitry.

Figure 5 shows a typical phased array transmit element that utilizes MSAG and HVMSAG devices. The average power and PAE of the threestage driver amplifier are shown in Figure 6. This part was eutecticly mounted in a connectorized fixture and tested at 25 percent duty cycle with a drain bias of 24 V. No matching external to the MMIC was applied in achieving these results. The small-signal gain, and input and output return losses of a single amplifier are shown in *Figure 7*. The IC has better than 2 dB gain flatness over a 28 percent bandwidth and excellent input VSWR. The output VSWR is as expected for a power matched appli-

MMICs such as these should find use in multiple defense and commercial applications. Additional information may be obtained by contacting the company.

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PRODUCT FEATURE



BASE STATION TEST SET

omprehensive on-site testing of base stations using real-world scenarios, both at initial installation and then during ongoing maintenance, plays a vital role in preventing and solving performance problems before they impact subscribers. Thorough independent testing gives operators greater confidence in the quality of the deployed network. Poorly performing base stations have a significant impact on the quality of service experienced by users of the higher data rate services available on EDGE and 3G networks. Whether this is caused by incorrect installa-

tion, a gradual degradation in performance, or complete failure of a particular module, the end result is that subscribers will suffer poor performance and will be less satisfied with their service provider.

In order to avoid scenarios of this type Aeroflex's RIWS 6413A base station test set has been developed. Its concept is the same as the company's 6113 GSM base station tester, which is used by GSM operators throughout the world. However, the 6413A is aimed at operators' and infrastructure vendors' field technicians installing and maintaining 3G Node Bs. It is designed to allow technicians to perform a complete set of transmitter and receiver measurements that will give confidence that the Node B under test is working correctly, and, if not, to give sufficient information to enable faulty modules to be replaced or repaired. The 6413A will support the measurements shown in **Table 1**, with others to be added on an ongoing basis.

[Continued on page 132]

RACAL INSTRUMENTS WIRELESS
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Slough, UK

TABLE I

THE 6413A TEST SET'S MEASUREMENT CAPABILITY									
Transmitter	Receiver	Functional							
Max output power	reference sensitivity level	Node B reset							
Frequency error	dynamic range	Iub link tests							
Error vector magnitude									
Peak code domain error									
Adjacent channel leakage ratio									
CPICH power accuracy									

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PRODUCT FEATURE



Fig. 1 The front panel display utilizing touch-screen controls.

Mobile phone operators are placing increased emphasis on test equipment that is easy to use and will withstand the rigors of field operation. The 6413A has been designed with this in mind and accordingly incorporates a number of features in both the user interface and technical performance. To make operation as simple and as intuitive as possible, the instrument contains an embedded PC running the Microsoft Windows XP operating system and incorporates a touch-screen display (as shown in *Figure 1*).

A particular feature is the 'one button test' that enables an automated sequence to be set up in advance that can then be run repeatedly at the press of a single on-site button. Other features include the ability to measure power levels up to +46 dBm. This removes the need to use attenuators between the Node B output and the test equipment input, thus reducing the likelihood of expensive repairs as a result of mistakenly overloading the input.

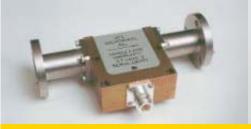
RECEIVER TESTING

Although some base stations incorporate a small amount of built-in test equipment, and there are solutions available for checking transmitter characteristics, an area that is consistently overlooked is the adequate testing of the complete base station receiver path from the RF input to the Iub connection to the Radio Network Controller (RNC).

If the receiver is failing to perform to specification, the operator takes the risk that their subscribers will experience some or all of the following problems:

- An increase in dropped calls at the limits of cells due to poor sensitivity.
- An increase in dropped calls throughout the cell because of poor signal quality.
- The inability to use revenue generating higher data rate services because of poor signal quality.

The ability to make receiver measurements is a key feature and differentiator of the 6413A. Although making receiver measurements sounds straightforward, there is actually considerable complexity involved. *Figure 2* shows the test setup.





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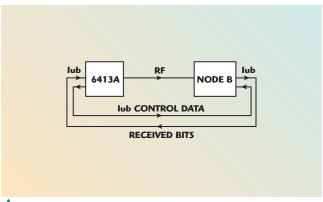


Fig. 2 Receiver measurements test setup.

To make receiver measurements it is necessary to emulate the Radio Network Controller so that the Node B acts as if it is connected to a real network. The 6413A communicates with the Node B via the Iub link, sending it messages to operate in a particular manner. The instrument then generates an uplink DCH channel containing a pseudorandom bit sequence (PRBS). This PRBS is, in turn, transmitted to the tester's RNC emulator via the Iub interface, decoded and the bit error rate (BER) determined. Although this sounds straightforward, there are a number of issues that need to be addressed in the design:

 Whereas many elements of the Iub interface are standardized, there are some elements that are manufacturer, Node B model, or even Node B software version specific.

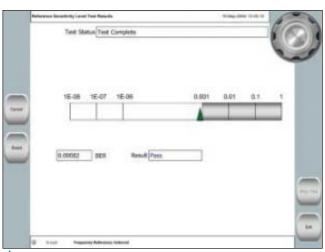


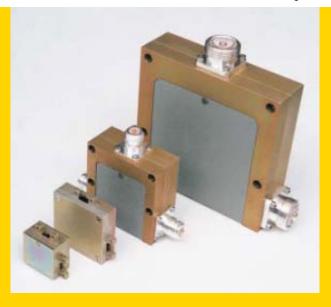
Fig. 3 A typical receiver BER measurement result.

This requires the instrument to have software that can be adapted to all of these conditions.

- The ATM protocols used for the Iub interface are complex to implement and decode so the 6413A incorporates a Network Interface Module to manage the ATM protocols and physical interfaces (E1, T1 and STM-1).
- Decoding of the Iub information to extract the original PRBS from within the DCH.

Figure 3 shows a typical receiver measurement result.

[Continued on page 134]





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PRODUCT FEATURE

FUTURE PROOFING

Today's 3G networks are being rolled out using the R99 version of the 3G standards. However, R5 is likely to appear within the next year, while network operators will continue to operate their GSM networks for some future time. The 6413A makes use of powerful baseband processing and software-defined radio techniques to ensure maximum flexibility and the future ability to add GSM, GPRS, EDGE and FDD R5 with a simple upgrade. In addition, the RF transceiver is designed to cover all GSM and UMTS frequency bands. The Network Interface Module has also been designed to manage the changes in the Iub protocol introduced by R5 as well as the A-bis control requirements for testing GSM base stations.

CONCLUSION

The 6413A has been designed specifically to withstand the rigors of field operation, while at the same time being easy to use and providing full functionality. In particular, the instrument contains an embedded PC running the Microsoft Windows XP operating system, 'one button test' operation and a touch-screen display. The facility for receiver measurement is a key function and by the very nature of its potential applications future proofing has been a primary consideration during its development - through a simple update there is the facility to add GSM, GPRS, EDGE and FDD R5 when required, thus offering the flexibility and practicality that is paramount for such instruments.

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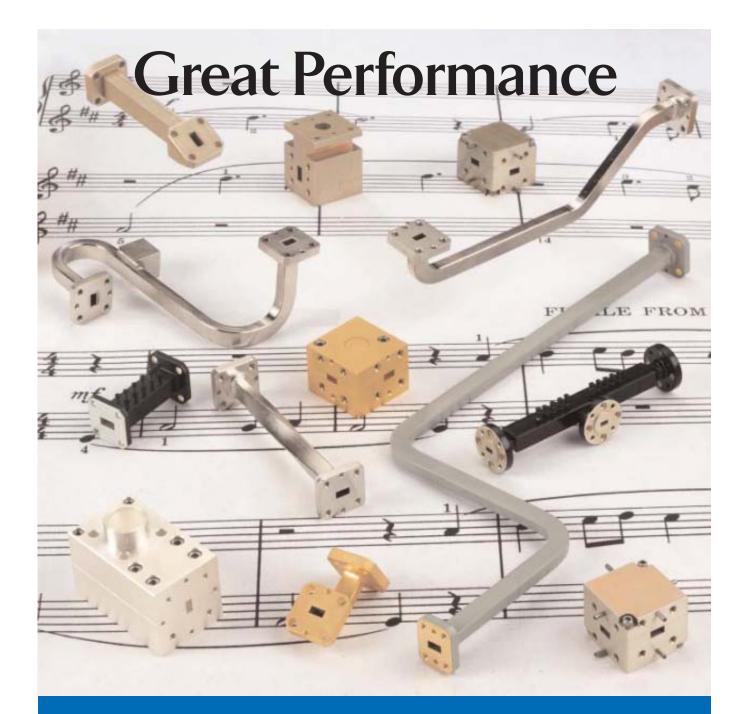


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PRODUCT FEATURE



A MEMS-BASED AMPLIFIED SWITCH FILTER BANK

or more than 15 years, Spectrum SEI Microwave has developed PIN diode and MMIC-based switched filter banks. Recent advancements have made microelectromechanical systems (MEMS)-based RF switches advantageous for particular applications. The model 310-020022-001 is SEI's first MEMS-based switched filter bank.

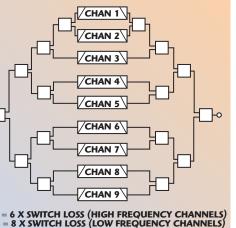
SWITCHING

The company was presented with a need for a 9-channel amplified switched filter bank with the lowest possible current consumption while maintaining high linearity over a multioctave bandwidth. Additionally, the application did not call for continuous switching, as

the filter bank required operation in a particular frequency band for relatively long periods of time. Given these criteria, the most logical switching solution would be some type of latching mechanical relay that does not draw current

The use of conventional latching mechanical RF relays could be quickly eliminated due to two primary shortcomings. With high levels of stray capacitance, a binary tree switch structure would be required to achieve broad bandwidth. The use of a binary tree structure, as shown in Figure 1, leads to high insertion losses as the resulting circuit has a minimum of six switches per path. Conventional relays are also relatively large in size.

The model M1C06-CDK2 RF MEMS switch developed by Magfusion is a miniature latching SPDT relay that has many characteristics that make it an excellent choice for this application. With low insertion loss and low stray capacitance, the MEMS switch offers flexibility in configuration of the switch matrix. Depicted in Figure 2, the final switch



to maintain its state.

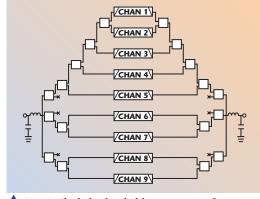


Fig. 2 The hybrid radial-binary tree configuration.

[Continued on page 138]

Spectrum Microwave Delmar, DE

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Fig. 1 A binary tree

structure.









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MMVC57	5.60 – 5.90	10	115	−108 dBc/Hz typ.	24
MMVC62	6.10 – 6.50	10	115	−108 dBc/Hz typ.	25
MMVC72	6.90 – 7.65	15	125	–95 dBc/Hz typ.	15
MMVC88	8.40 – 9.10	12	85	–90 dBc/Hz typ.	15
MMVC99	9.40 – 10.40	10	70	–90 dBc/Hz typ.	15
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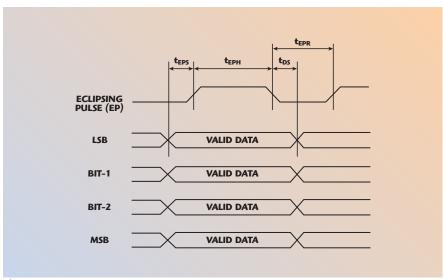








PRODUCT FEATURE



▲ Fig. 3 Logic timing of the eclipsing pulse.

TABLE I TYPICAL PERFORMANCE SPECIFICATIONS								
Parameter Value								
Frequency range (MHz)	20 to 500							
Gain (dB)	15							
Rejection	8-pole response							
VSWR	1.5							
Isolation (dB)	> 80							
Noise figure (dB)	< 5							
Power	8 mA @ 3.3 VDC							
Size (in)	$4.65 \times 3.00 \times 0.40$							

configuration is best described as a hybrid radial-binary tree. The common arm incorporates a low pass structure to absorb the cumulative stray capacitance from the radial portion of the switch matrix. To keep losses low, the five highest frequency bands have only four switches per path. The lower bands can tolerate a higher number of switches per path since the filters and the switches exhibit less loss at lower frequencies.

TECHNICAL CHALLENGES AND SOLUTIONS

The need to minimize power consumption presented challenges throughout the design process. Because it is magnetically self-latching, the M1C06-CDK2 switch eliminates the need to expend energy to maintain a selected switch state. This allows for all logic and control circuitry to be powered down when the user is

not commanding a state change. When the filter bank is in a set-on mode, the channel amplifier is the only device drawing current. To accommodate a logic power-down, an eclipsing pulse is used to initiate a state change. The eclipsing pulse is asserted when the user has established a valid 4-bit TTL control word specifying the desired frequency band. *Figure 3* illustrates the logic timing.

Another useful aspect of the M1C06-CDK2 switch is its ability to withstand hot switching. The device is rated at 100 million cycles for a bias condition of 10 V and 10 mA. This property allowed the amplifiers' supply voltages to be applied to the common arm of the 9-pole input switch matrix and subsequently drawn off the ON arm. As a result, no additional control circuitry was needed to power the channel amplifiers ON and OFF.

Although the MEMS switches do not require power to maintain their switch state, each device typically draws 110 mA for approximately 200 μs to toggle its state. With 18 MEMS switches per filter bank, this switching current could quickly add up to a significant load on the power supply if all switches had to be commanded when a new tuning word was loaded. Several techniques were employed to minimize the switching current. If the existing state of the filter bank is known when the user initiates a change to a new desired state, then it can be determined which MEMS switches require toggling and which

do not. The technique of hot switching the amplifier supply voltage through the MEMS switches, as previously discussed, presented a unique solution to the challenge of storing the existing state without consuming additional current. By sensing which arm of the input switch matrix holds the supply voltage, the existing state could be determined. This information is digitally processed through a complex programmable logic device (CPLD) that determines which MEMS switches must be toggled based on the new desired state.

Capacitive energy storage is also used to minimize the switching current draw required from the power supply. Due to size constraints, an array of discrete tantalum capacitors combines for nearly $4000~\mu F$. Additional energy storage is obtained through the use of power and ground planes formed on inner layers of the PC hoard

The mechanical requirements for this filter bank also presented several design challenges. To accommodate all the necessary control circuitry, a 4layer PC board was used with both top and bottom layers fully populated. Using a total of 18 MEMS switches made it inevitable that several devices would be in close proximity to each other. This close proximity presented an assembly challenge when switches began repelling each other due to their strong magnetic fields. A custom assembly fixture was fabricated to hold the components in place during reflow. It should be noted that the M1C06-CDK2 switch is now available in a magnetically shielded package, which will reduce the observed effects.

PERFORMANCE AND CONSTRUCTION

The model 310-020022-001 is an amplified switch filter bank consisting of nine selectable RF frequency bands covering a range of 20 to 500 MHz. The critical performance parameters for the 310-020022-001 unit are listed in *Table 1*. Small signal gain is 15 dB while drawing just 8 mA typically from a single +3.3 VDC supply. Each of the nine channels exhibits an 8-pole Chebychev filter response. A typical transfer function is

[Continued on page 144]

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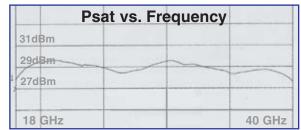
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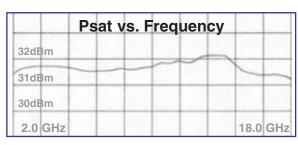












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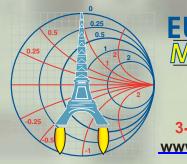






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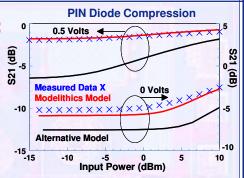




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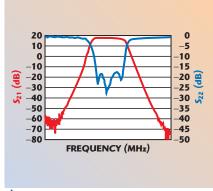
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PRODUCT



🛕 Fig. 4 The switch filter bank's typical transfer function and return loss.

depicted in Figure 4. The unit is designed with a filter-amplifier-filter configuration offering low distortion amplification of the input signal.

The complete assembly is housed in a rugged $4.65" \times 3.00" \times 0.40"$ machined aluminum chassis with a silver plate finish and through-hole mounting. RF connectors are SMP-male, while power and logic signals are externally applied through a 9-pin micro D-sub connector.

CONCLUSION

Although not suitable for continuous switching applications, MEMSbased switch banks offer several advantages over PIN diode versions. A passive version is under development that consumes zero power while operating after the commanded state is reached. In a passive switched filter bank, latching MEMS switches would also provide a fail-safe for operation in case prime power is lost. Another advantage is the linearity of the MEMS over PIN diodes. A passive MEMS-based switch bank is able to handle in excess of 30 dBm, while a PIN diode version with only a 3.3 V supply would be limited to approximately 18 dBm unless DC-DC converters were used.

The 310-020022-001 switch filter bank has begun to tap into the advances in MEMS switches and their applications to RF and microwave systems. This concept could be extended to higher frequencies with various channeling configurations for either passive or active applications.

Spectrum Microwave, Delmar, DE (302) 846-2750, www.specwave.com.

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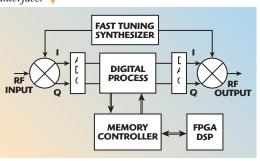
A MIXED-SIGNAL ASIC FOR DIGITAL RF MEMORY APPLICATIONS

igital RF memories (DRFM) are used for the reproduction of complex, coherent signals usually associated with modern pulse compression radars. There are many different implementations of DRFM systems. *Figure 1* displays one particular type, a double sideband, four-bit, phase sampled system with 500 MHz of instantaneous bandwidth.

A custom mixed signal application-specific integrated circuit (ASIC) was designed and fabricated in 0.18 μm CMOS that implements the baseband components of the system including the phase-sampling circuit, digital processing, signal reconstruction and digital-

to-analog outputs.

DRFM baseband processor with LNX digital RF memory and external memory interface.



ASIC DESIGN

A block diagram of the LNX DRFM ASIC is shown in *Figure 2*. A preamplifier stage amplifies, buffers and level shifts the input to facilitate the interface to the digital logic circuitry. The input bandwidth is 250 MHz providing 500 MHz of instantaneous bandwidth using the I and Q inputs. High speed comparators are used to sample the I and Q inputs at up to 640 MHz, while a look-up table is used for error correction and encoding into a four-bit phase value representing 22.5° of resolution. Data is then stored for processing and playback. The signal is reconstructed using the phase data and sine/cosine look-up tables.

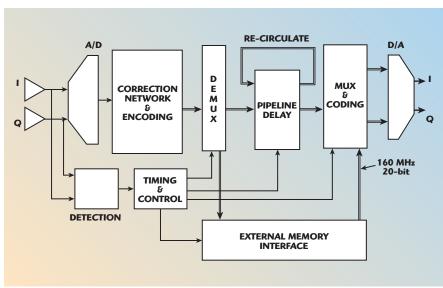
After encoding, the data enters a demultiplexing block where it is distributed over a 20-bit bus that runs at one quarter the sampling rate, facilitating storage in an external memory. Alternatively, the data is fed to the next delay line block. This block implements two functions: it can either delay the digitized signal in fixed increments or it can recirculate the data for head-to-tail reconstruction. Head-to-tail reconstruction or recirculation allows a CW signal to be replayed with the correct phase and frequency characteristics of the

LNX CORP. Salem, NH

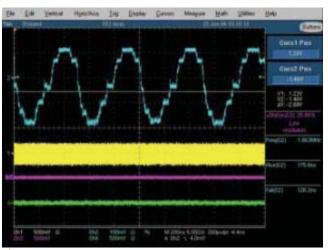
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▲ Fig. 2 Simplified block diagram of the LNX DRFM ASIC.



▲ Fig. 3 Reconstruction of a 2 MHz signal sampled at 730 MHz in recirculate mode.

recorded signal. The minimum throughput time delay is < 25 ns.

The external memory interface operates at 160 MHz and performs the demultiplexing for data storage and playback. Full duplex operation allows signals to be sampled and stored simultaneously with the playback and transmission of a previously stored signal. Data signal levels are 3.3 V CMOS and the clocks are differential LVDS. The ASIC supplies all of the timing and control for external storage. An external memory, FPGA or DSP processing system can be used to store and/or process the recorded waveforms.

The ASIC contains all of the timing necessary to maintain phase coherency for signals that are recirculated. Timing is also provided to external circuitry to maintain the

coherence of recorded signals. The timing circuitry can also be used for range gate pull off (RGPO) in radar jamming applications. In this scenario, the jammer can walk the range gate of the radar off the target.

There are other auxiliary circuits such as a pseudorandom noise (PN) generator and a frequency measurement function. The

PN noise generator can be used to add pseudo-random noise to the output signal. The frequency measurement block can measure the frequency of the input signal with up to 10-bit accuracy using accumulated delta phase measurements; the resolution of the frequency measurement can be automatically adjusted depending on pulse length.

A microprocessor interface is provided for configuration and test. For example, data can be written to, or read from the external memory interface from the microprocessor bus. Status and control registers are also provided.

The back end of the ASIC implements a quadrature modulator. Independent sine/cosine look-up tables convert the four-bit phase values to sine/cosine outputs. Two on-board

digital-to-analog converters convert the look-up table outputs to analog outputs for signal reconstruction and up-conversion. The update rate of the D/A is 640 MHz, consistent with the sampling rate and is capable of driving ± 0.5 V into 50 $\Omega.$

PERFORMANCE

Performance of the new chip met or exceeded all of the requirements. The chip displayed < 5 mV of input offset, with an input bandwidth of > 250 MHz and a clock frequency of > 700 MHz. *Figure 3* shows signal reconstruction and playback of a 2 MHz input signal sampled at 730 MHz. The device is operating in recirculate mode where a sampled pulse is being reconstructed in a head-to-tail fashion, with no phase discontinuity.

Other performance characteristics include four-bit (22.5°) phase resolution and < 25 ns throughput delay, with multiple delay modes, phase and PN noise modulation, 10-bit frequency measurement capability, and multiple target tracking. The ASIC features a 160 MHz external memory interface and a dual-channel, four-bit digital-to-analog converter for signal reconstruction. Power dissipation is 2.5 W and the operating temperature range is -40° to +85°C. The IC is housed in a 240-pin CQFP package.

CONCLUSION

A mixed-signal ASIC has been introduced for digital RF memory applications. The device includes preamplifiers, phase sampling, an external memory interface and signal reconstruction. It is implemented in 0.18 µm CMOS and features an instantaneous input bandwidth of > 500 MHz and phase data sampling at 640 MHz. The ASIC includes all of the timing and control for phase coherent external data storage and signal reconstruction, signal delay and recirculation, pseudo-random noise generation, and frequency measurement. The architecture of the device is particularly aimed at DRFM applications.

LNX Corp., Salem, NH (603) 898-6800, www.lnxcorp.com.

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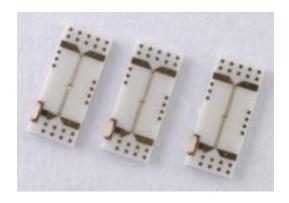
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PRODUCT FEATURE



MULTI-LAYER THIN FILM **INTERCONNECTS**

traSource is a high quality supplier of precision thin film circuit fabrication including custom resistor networks and attenuators, metallized substrates and MEMS fabrication with a focus on using its thin film manufacturing capabilities to supply custom products from prototypes to high volume production. The products range in application from wireless communications, DC to 200 GHz microwave components, fiber optic and laser technology, infrared imaging systems, microwave calibration and test fixtures, and other commercial and military products.

Recently the company has added multi-layer thin film interconnect technology to its list

of capabilities. This new technology is specifically designed for high yield manufacturability and reliability. Multi-layer thin film interconnect technology reduces assembly time and improves yield and manufacturability, while improving performance and repeatability. It increases circuit density while reducing the number of wire bonds, and enables high frequency design with 10-micron lines and spaces. At the same time the process lowers material content and cuts cost.

The Ultra process offered incorporates the deposition of a thin layer of silicon nitride Si₃N₄ as a dielectric layer to facilitate metalinsulator-metal (MIM) layered structures on a substrate, thus making a very robust structure with increased reliability and repeatable performance. The process can be used to create circuit bridges, and realize RF capacitors and high Q inductors.

UltraBridge structures create dense, fully integrated solutions to complex interconnect challenges such as in fabricating Lange couplers and multi-chip modules. It is a cost-effective alternative to air bridges. Figure 1 shows an example of an UltraBridge utilization.

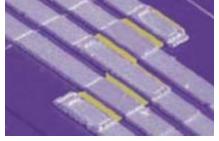
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Fig. 1 An UltraBridge



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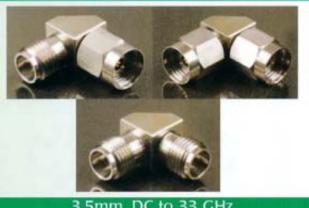




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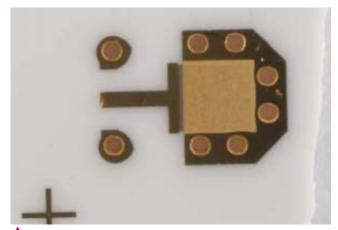


Fig. 2 An example of UltraCapacitors.

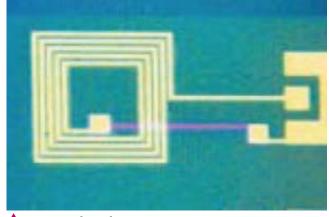


Fig. 3 An UltraInductor structure.

UltraCapacitor structures form integrated capacitors for dense circuit areas. These capacitors are available in values from 2 to 250 pF with tolerances of 10 percent. They are ideal for use in next level integration of passive elements. *Figure 2* shows an example of UltraCapacitors.

UltraInductor structures facilitate high Q spiral inductor designs, thereby reducing large wire bonds and associated parasitic inductances. *Figure 3* demonstrates typical UltraInductor use.

The Ultra process is comprised of a base conductor of TiW/Au and a dielectric of Si_3N_4 with a dielectric constant of 7.8, providing a capacitance density of 0.05 to 0.15 pF/mil². The substrate material is Al_2O_3/AlN .

Ultra process structures are currently being used in everyday products such as wireless communication systems and microwave components. The process offers a robust solution with increased reliability and lower costs.

UltraSource Inc., Hollis, NH (603) 881-7799, www.ultra-source.com.

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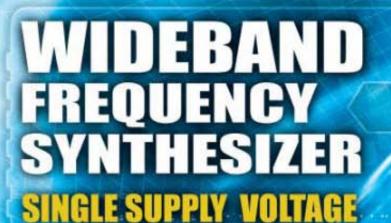
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Filtronic Compound Semiconductors, 10181 Bubb Road, Cupertino, CA 95014

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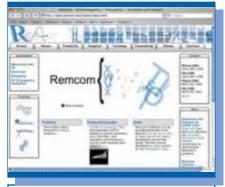


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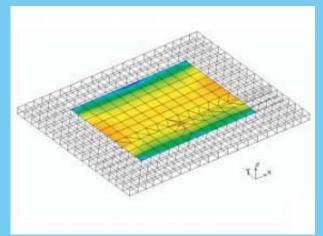
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Zeland Software has been recognized as a leading developer to provide unparalleled high-frequency electromagnetic simulation and design tools for microwave, semiconductor, wireless, and telecom industries, government laboratories, and universities around the world.

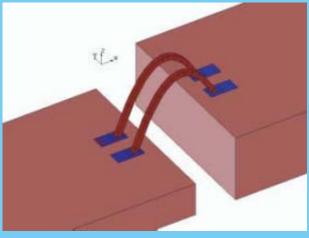
Applications of Zeland's Software include MMICs, RF ICs, LTCC circuits, RF IDs, 3D IC interconnects and packages, high-speed digital circuits, multilayer PCBs, MCMs, HTS circuits and filters, microstrip antennas, wire antennas, conical and cylindrical helix antennas, inverted-F antennas, antennas on finite ground planes, other RF antennas, waveguides, EMC/EMI, biomedical effects of electromagnetic waves, and many more.

We are committed to satisfying our customers with high performance software and quality technical support. We love to discuss design challenges with customers and provide our input. We welcome any feedbacks or tough EM simulation and design problems from customers.

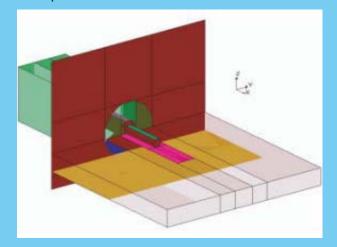
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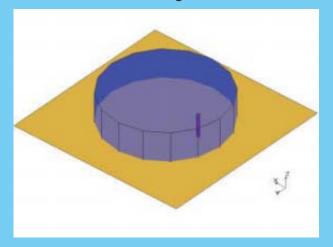
A patch antenna with finite size substrate



Wire bonds in inhomogeneous dielectrics



A coaxial to microstrip transition



A dielectric antenna

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High Reliability Resistive Components

This updated Web site features high reliability thick and thin film resistive components for the surface-mount and hybrid electronic industries. The site highlights a broad range of high quality thin and thick film chip resistors, surface-mount networks and custom circuits. These products are utilized in biomedical, communications, aerospace and defense applications.

State of the Art Inc., 2470 Fox Hill Road, State College, PA 16803-1797

www.resistor.com



Microwave System Solutions

This Web site provides a direct link to the STC Microwave Systems site (click on "microwave systems solutions"). This site offers products for the defense, space and communications industries. A user can choose Arizona for microwave and millimeter-wave components, integrated assemblies and subsystems for frequency generation, management, conversion, conditioning and control electronics. The other option is to choose Olektron for RF and microwave components and subsystems.

STC Microwave Systems, 340 N. Roosevelt Avenue, Chandler, AZ 85226

www. craneaerospace.com



WEB UPDATE

Switching Solutions

This Web site provides easy access to the company's technical service and customer support. The site focuses on providing product and sales channel information to engineers. It offers visitors various ways to communicate with the company, including visitor registration forms, request for quote forms, data sheet request forms, literature request forms, technical support forms, feedback/comment forms, application notes and e-mail.

Teledyne Relays, 12525 Daphne Avenue, Hawthorne, CA 90250

> www. teledynerelays.com



Interconnect Solutions

This updated Web site features the company's complete interconnect product information including high performance wire and cable, cable assemblies and RF/microwave connectors. Markets served include the aerospace, defense electronics, wireless infrastructure, optical telecommunications and test and measurement industries. The site also features new search capabilities by keyword, part number or industry callouts.

Tensolite, 100 Tensolite Drive, St. Augustine, FL 32092



Frequency Control Devices

This Web site offers a whole new look and feel that provides more features with fewer clicks, creating rapid, intuitive and thorough access to the information a user is looking for. With this redesigned site and expanded product offerings, the company is committed to making it easier for customers to do business with them. The site features the company's full line of quartz crystals and oscillators as well as ultrasonic transducers and piezoelectric components offered by the Ultrasound Division.

Valpey Fisher Corp. 75 South Street, Hopkinton, MA 01748

www.valpeyfisher.com



On-line Store

This electronic products on-line store allows purchasing of the company's GORE™ CX4 high performance cable assemblies and the GORE InfiniBand™ cable assemblies. The CX4 high performance cable assemblies, part of the 10-gigabit Ethernet standard, provide good signal fidelity over long distances using the smallest, most flexible cable. The Infini-Band cable assemblies conform to the electrical, mechanical and physical specifications and standards established for interconnects in the InfiniBand I/O architecture.

W.L. Gore & Associates Inc. 402 Vieve's Way, PO Box 2200, Elkton, MD 21922-2200

www. gore.com/electronics

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NEW WAVES: Military & Government Electronics

High Gain Omni Antenna



This high gain omni antenna covers the entire Link16 band, 960 to 1215 MHz. The antenna offers 7 dBi gain that can nearly double the range of a system that is constrained by output power. Receive sensitivity is increased significantly, which is usually the limiting factor for communications with distant airborne platforms. The antenna has a corporate feed structure to ensure that the peak gain remains at the same elevation angle of +1.5 dB at all frequencies. Weight: 1.7 kg.

European Antennas Ltd., Suffolk, UK +44 (0) 1638 731888, www.european-antennas.co.uk.

Circle No. 216

Tunnel Diode Detector

The model DT1826 is a tunnel diode detector that is offered with either negative or positive output polarity. The unit has good temperature stability with flat frequency response. It has fast pulse detecting capability. The maximum flatness is ±1 dB. This detector offers a typical TSS of -47 dBm and is based on 2 MHz video bandwidth and a 2 dB amplifier noise figure. The detector operates at -55° to +100°C. Applications for the detector are fast pulse detection for radar or fiber optic communication.

Herotek Inc., San Jose, CA (408) 941-8399, www.herotek.com.

Circle No. 217

300 MHz to 6 GHz Mixer

The MCA1 series is a broadband, highly reliable low temperature cofired ceramic (LTCC)



frequency mixer. With level 7, 10, and 13 (LO) models available for 300 MHz to 6 GHz designs, these double balanced mixers have insertion down to 6 dB typ-

ical, isolation up to 40 dB typical and are built with all circuitry hermetically embedded inside the ceramic to realize good temperature stability, repeatability and a compact 0.07" profile. These mixers are ideal for the government's COTS program and commercial applications. Price: \$5.95 (10).

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

Circle No. 220

Lumped Component Filter



The model 9LB10-5/QX1-N/N is a lumped component filter designed for customers who have low frequency, high power requirements where low insertion loss is a must. This unit is versatile and works well in military and commercial environments. This filter offers < 2 dB insertion loss across 100 percent of passband. Other specifications include > 90 dB stopbands, 2.0 VSWR and 50 W CW power. Size: $6.0" \times 1.5" \times 1.5"$ with type N connectors.

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

Circle No. 218

AlGaAs Flip Chip Diode

The model MA4AGFCP910 is an AlGaAs flip chip diode designed for a variety of broadband (0.1 to 50 GHz) multi-throw switch and switched-phase shifter circuits, including those commonly found in electronic countermeasure, radar and high speed instrumentation systems. These devices provide significant circuit tuning advantages due to the ultra low Ct-5 (< 21fF@ 20 mA) and smaller Ls (0.5 nH). The MA4AGFCP910 provides a 0.4 dB insertion loss at 15 mA with 8 dB of isolation at 0 V at 50 GHz in a single series diode configuration. Price: \$2.00 (100,000).

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

Circle No. 219

Filtered Low Noise Amplifiers

These filtered low noise amplifiers (LNA) feature a robust housing that allows for greater



corrosion resistance and more effective shielding. The LNAs offer a low noise figure of typically 1.5 dB and are designed for L1 and L1/L2 GPS applications re-

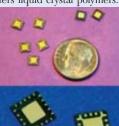
quiring precision and high reliability. Both the L1 and L1/L2 series of LNAs feature 3-pole ceramic filters that select only desired GPS signals as the low noise gain stage of each maintains the receiving system's sensitivity. These LNAs are ideal for civilian applications such as surveying, radio and television, shipping and military uses.

Spectrum Microwave, Delmar, DE (302) 846-2750, www.spectrumwave.com.

Circle No. 224

Air Cavity QFN Packaging

This near hermetic air cavity QFN packaging offers liquid crystal polymers. This packaging fea-

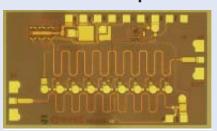


tures precise molding, high moisture resistance (MSL1), near zero outgassing of < 10 ppm and good electricals for high frequency (low ε). The packaging is environmental friendly, JEDEC MO220 pad com-

pliant and has low NRE customization. NovaPack Technologies SARL, Trappes, France +33 (0) 1 30 68 62 90, www.novapacktech.com.

Circle No. 221

Ultra-wideband Amplifier



The model CGY2160UH is an amplifier that offers a bandwidth of 1.5 to 45 GHz and provides a high gain of 15 dB. This MMIC has a midband noise figure of 2.5 dB, delivers 18 dBm of PldB at 20 GHz and 15 dBm at 40 GHz and has a compression point up to 45 GHz. The power consumption is 500 mW and requires no external biasing networks. Good input and output matching to 50 Ω is achieved and unconditional stability is guaranteed over the entire frequency, biasing and temperature range. Typical applications are for electronic warfare systems, radar and countermeasures, instrumentation and as a general-purpose wideband gain block.

OMMIC, Limeil-Brevannes, France

+33 (0) 1 45 10 67 31, www.ommic.com.

Circle No. 222

Flange-mount Drop-in Isolator

This K-series of flange-mount drop-in isolators features up to 30 percent bandwidth in the 4 to



18 GHz range. These isolators are ideal for military and space applications and are made of steel housings that are gold plated for better RF perfor-

mance. This temperature stable device has typical loss of < 0.4 dB and VSWR and isolation of 20 dB. Sizes: $0.375" \times 0.620" \times 0.18"$ and $0.350" \times 0.475" \times 0.18"$

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

Circle No. 223









Traveling Wave Tube

The model TH 4064 is a traveling wave tube (TWT) that has recently been added to the mini-tube family. This tube has been developed for



Thales Electron Devices, Paris, France +33 (0) 1 30 70 35 00, www.thalesgroup.com/electrondevices.

operation in the 6 to 18 GHz waveband and is especially designed to meet data transmission requirements for unmanned aerial vehicles, including both downlinks and uplinks. This helix-type mini-TWT covers the C, X and Ku frequency bands and delivers 150 W of continuous power, with large bandwidth of 250 MHz, in a small, lightweight package.

Circle No. 225

■ Coaxial Cable Assemblies

The HELI-FOIL are flexible, high power interconnect and jumper cables for military/aero-space and commercial/telecom applications. These



cable assemblies provide good insertion loss performance and cover the frequency range of DC to 18 GHz. The cables are low loss, ultra stable and are especially suited for high ambient temperature environments in both field and laboratory conditions. These assemblies feature passivated stainless steel connectors with most

popular interface types available.

Times Microwave Systems,

Wallingford, CT (203) 949-8400, www.timesmicrowave.com.

Circle No. 226

SAW Filter

This SAW filter is designed for use in a global navigation satellite system. Insertion loss for these filters is below $2\ dB$ and stopband attenuation



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is higher than 40 dB. Outstanding filter parameters are a low ripple of 0.3 dB in passband and a low VSWR of 1.8. The devices can be used in balanced or unbalanced operations and are supplied in a

ceramic SMD package. Sizes: $3.0 \times 3.0 \times 1.2$ mm and $2.5 \times 2.0 \times 0.9$ mm.

VECTRON International Telefilter, Teltow, Germany +49 (0) 3328-478417, www.vectron.com.

Circle No. 227

[Continued on page 160]

[Commuea on page 1



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NEW PRODUCTS

COMPONENTS

■ Lumped Element Diplexer

The model DP-1149 is a lumped construction diplexer. The low frequency port has $\leq 1~\mathrm{dB}$



insertion loss from DC to 600 MHz, and the high frequency port has ≤ 1 dB insertion loss from 1000 to 3000 MHz. Isola-

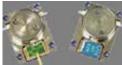
tion over the opposite passband is ≥ 60 dB for both paths. VSWR is ≤ 1.7 within the respective passbands. Power handling capability is specified at 10 W. Size: $1.6"\times 1.3"\times 0.5"$.

RLC Electronics Inc., Mount Kisco, NY (914) 241-1334, www.rlcelectronics.com.

Circle No. 235

■ Drop-in Isolators

These drop-in isolators operate in the 2110 to 2170 MHz band and are designed for universal



mobile telecommunications systems. Both units operate over the temperature range of -20° to 85°C

and offer a frequency range of 2.09 to 2.19 GHz, an insertion loss of 0.22 dB, isolation of -26 dB

and return loss of $-26~\mathrm{dB}$. Part number 994-039038-044 has a 70 W non-beryllium oxide termination. Part number 994-039038-046 has a 70 W non-beryllium oxide termination configured as a $-20~\mathrm{dB}$ attenuator for monitoring the output port.

M2 Global Technology Ltd., San Antonio, TX (210) 561-4800, www.m2global.com.

Circle No. 233

1P2T RF Switch

The model 50S-1313 is a 1P2T, failsafe RF switch. The model offers a frequency range of



DC to 18 GHz with a maximum insertion loss of 0.35 dB and a minimum isolation of 60 dB. This switch is suitable for a number of OEM and integration applications. The 50S-1313 is avail-

able from stock with SMA connectors and a +12 V supply. Size: $2.02" \times 1.34" \times 0.52"$. Weight: 2.5 ounces.

JFW Industries Inc., Indianapolis, IN (317) 887-1340, www.jfwindustries.com.

Circle No. 231

Surface-mount Relay

The series RF522 relay is a compact, DPDT, surface-mount latching device that is charac-



terized up to 10 GHz. The series RF522 is rated from DC to 10 GHz over a temperature range of 55° to +85°C. It is

available in two coil voltages of 5 and 12 VDC and features a 50 Ω characteristic impedance. The RF522 package employs lead-free construction and is sealed against moisture and contamination. Size: $0.709" \times 0.709" \times 0.335"$.

Teledyne Relays, Hawthorne, CA (323) 777-0077, www.teledynerelays.com.

Circle No. 238

Cable Assemblies

These Storm FlexTM 086 cable assemblies offer a durable 0.096" diameter with consistent per-



formance in flexure, VSWR, phase and insertion loss change. Storm Flex 086 construction and materials minimize the common problem of breakage behind the connector,

providing improved pull strength. Connector retention is 40 lbs (minimum) straight pull; 15 lbs (minimum) right angle pull.

Storm Products – Microwave, Woodridge, IL (630) 754-3300, www.stormproducts.com/microwave.

Circle No. 236

[Continued on page 162]

ANTENNA DESIGN ENGINEER

At Garmin, our hands-on approach to engineering means you can be part of a team that develops and tests real products. Our GPS navigation and communication products are used by pilots, hikers, bikers, boaters, fishing enthusiasts and travelers. Our continued growth and success have created an outstanding opportunity for an experienced RF Antenna Design Engineer.

Responsibilities will include designing and testing X-band pulse radar components including antenna arrays, waveguide rotary joints, filters terminations and circulators, low noise amplifiers and down converters, L-band antennas, XM radio receiver applications, and supporting Garmin project engineers in the implementation of antennas into products through testing and optimization.

Requirements for this position include a PhD in Electrical or Computer Engineering, Physics or a related field and a minimum of 5 years experience or a Bachelor's Degree in Electrical or Computer Engineering or Physics with a minimum GPA of 3.0 plus a minimum of 10 years antenna design experience in wireless, radar, and microwave communications.

If you're willing to dream big and work hard, take a look at Garmin. We offer an excellent compensation and benefits package and a friendly team environment. Great location too, in beautiful Johnson County, a Kansas City suburb which offers affordable housing, excellent schools, and plenty of opportunity for recreational and cultural pursuits. Forward your resume with salary requirements to:



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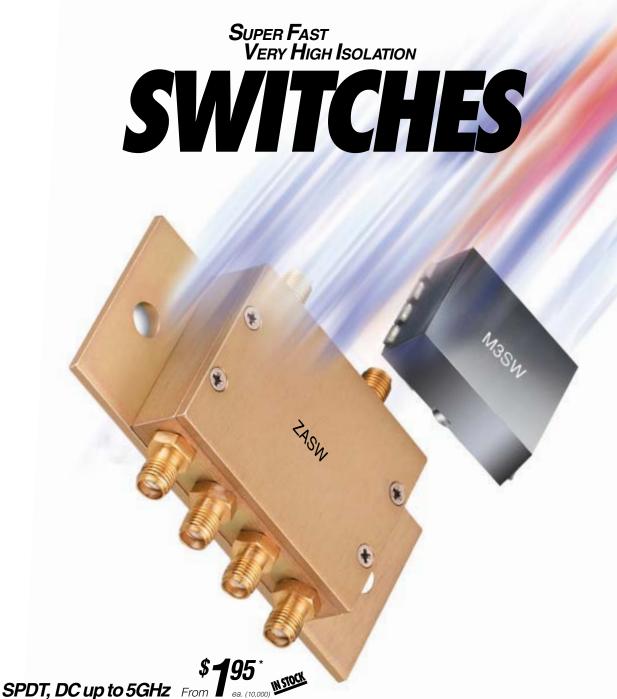
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Mini-Circuits wideband SPDT switches offer very high isolation up to 90dB at 1GHz, built-in TTL driver with blazing fast 10nsec switching speed, and the ability to withstand severe operating temperatures. But that's not all! Reflective and absorptive models are available to suit your design requirements; M3SW's 3x3mm MCLPTM surface mount package with exposed metal bottom for excellent grounding and heat dissipation and ZASW's tough built coaxial design with SMA-F connectors. No matter which model you choose, you'll get strong performance and rugged reliability at a price that crushes the competition. So look no further. You'll find just the right switch for your commercial, industrial, or military application right here at Mini-Circuits!

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	SPECIFICATIONS (@ 1GHz)						
	Model	Freq. (GHz)	In-Out Isol. dB(typ)	Ins. Loss dB(typ)	1dB Comp. dBm(typ)	Price \$ea (Qty. 10)	
	M3SW-2-50DR M3SWA-2-50DR	DC-4.5 DC-4.5	60 65	0.7 0.7	25 25	4.95 * 4.95 *	
	ZASW-2-50DR ZASWA-2-50DR	DC-5 DC-5	90 90	1.7 1.7	20 20	(Qty.1-9) 89.95 89.95	
•	Supply voltage +5V, -5V. TTL control. Switching time 10nsec (typ). • Reflective • Absorptive				3x3mm Mini-Circuits Low Profile (MCLF		

Detailed Performance Data & Specs Online at: www.minicircuits.com/model





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PRODUCTS

■ Eight-way Power Divider

The model PSS-8-8000/24000-S is an eightway power divider that covers the frequency



range of 8000 to 24000 MHz. This unit provides a 5.5 dB maximum insertion loss and typical isolation is 12 dB. The mechanical package

for this power divider is $2.4" \times 4.4" \times 0.5"$ excluding SMA connectors.

Lorch Microwave, Salisbury, MD (410) 860-5100, www.lorch.com.

Circle No. 232

Double-balanced Mixer

The model SMD-C6000 is an ultra wide bandwidth, surface-mount, IF DC-coupled double-



balanced mixer designed broadband low cost applications. The SMD-C6000 is ideal for applications in ultra wideband frequency conversion, phase detectors, PSK modulators and demodulators. It

requires +10 dBm of local oscillator drive and typically gives interport isolation of better than 70 dB at 10 MHz and 20 dB at 6000 MHz. Size: $0.5" \times 0.375" \times 0.150"$

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

Circle No. 237

AMPLIFIERS

Amplifier Gain Blocks

These InGaP HBT Darlington amplifier gain blocks cover the frequency range from DC up



to 6 GHz. The amplifiers offer OIP3 up to +38 dBm with the P1dB compression ranging from +11 to +20 dBm. The series covers

the gain from 12 to 18 dB measured at 2 GHz. These devices are suitable as general-purpose gain blocks and driver amplifiers for use in present and third generation telecom infrastructure requirement.

Aeroflex/Metelics Inc., Sunnyvale, CA (408) 737-8181, www.aeroflex-metelics.com.

Circle No. 239

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Circle 2

Solid-state Amplifier

The model 500A250 is a broadband, solid-state amplifier that delivers 500 W of power and



covers the frequency range of 100 kHz to 250 MHz. This model joins the "A" series family, which includes the 10,000A250A,

model offers high VSWR tolerance, a digital front panel, remote interface and a class "A" design, which makes it ideal for EMC and RFI testing, as well as calibration of RF transduc-

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

Circle No. 240

InGaP HBT Power Amplifier

The model HMC450OS16G is an 800 to 1000 MHz power amplifier that offers 26 dB of gain,



+40 dBm OIP3 and +28.5 dBm of saturated output power. This model is ideal as a linear driver in BTS and repeater applications. This model operates from a

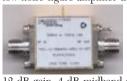
single +5 V supply and offers the same pinout and functionality as the higher band model HMC413QS16G 1.6 to 2.3 GHz power amplifier. Hittite Microwave Corp.,

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

Circle No. 241

Low Noise Figure Amplifier

The model PEC-12-50M40G-4R0-15-SFF is a low noise figure amplifier that has been devel-



oped to provide gain flatness of ±2 dB over the 50 MHz to 40 GHz bandwidth. This amplifier offers

12 dB gain, 4 dB midband noise figure, in/out VSWR of 2.5 and Pout at 1 dB compression of

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MASS

15 dBm. This unit handles RF input power of +17 dBm without damage while operating from +15 VDC at 225 mA.

Planar Electronics Technology, Frederick, MD (301) 662-5019, www.planarelectronicstechnology.com.

Circle No. 242

ANTENNA

Antenna Switch

The model FMS2011 is a single-pole six-throw (SP6T) antenna switch that is ideally suited for low control voltage and high power switching applications. This model is optimized for quad band handset antenna switching applications. This antenna is manufactured using the FCSL propriety 0.5 µm high performance GaAs PHEMT process. This model operates over the DC to 2.5 GHz frequency range. The FMS2011 features include typical insertion loss of 0.5 dB (Tx), 0.8 dB (Rx) and isolation of 45 dB typical (Tx-Rx).

Filtronic Compound Semiconductor Ltd., Durham, UK +44 (0)1325 301111, www.filcs.com.

Circle No. 245

INTEGRATED CIRCUIT

Monolithic Microwave Integrated Circuit

The model 22TX0392 is a gallium arsenide (GaAs) monolithic microwave integrated cir-



cuit (MMIC) subharmonically pumped up-converter. This model integrates an im-

age reject subharmonic anti-parallel diode mixer followed by a balanced two-stage output amplifier and includes an integrated LO buffer amplifier. The image reject mixer eliminates the need for an image bandpass filter after the ouptut amplifier to remove signal power at the image frequency. Using 0.15 micron gate length GaAs pseudomorphic high electron mobility transistor device model technology, this upconverter covers the 21.2 to 23.6 GHz frequency bands. Delivery: six to eight weeks ARO.

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

Circle No. 248

MATERIALS

■ Polymide Laminates

The R/flex CRYSTAL® is a polymide laminate with flexible circuit materials and a transparent epoxy-based adhesive system. Inherent flame retardant performance, good adhesion, dynamic flexibility, low and predictable dimensional change, among other features, make this system ideal for high density circuitry in dynamic or static applications.

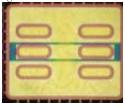
Rogers Corp., Rogers, CT (860) 774-9605, www.rogerscorporation.com.

Circle No. 250

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Ultra-low Loss Package

This MEMpack series of ultra-low loss packages consist of a silicon nitride membrane that



is bonded to a die or wafer, to create a low profile hermetically sealed shell. I/O pads are accessed through sealed ports in the membrane and may be bumped

or wire bonded as with standard dice. Package added loss is under 0.08 dB up to 50 GHz, and less than 0.01 dB over much of that range. The sealing process takes place below 300°C, and uses only metals and ceramics to avoid outgassing.

MicroAssembly Technologies Inc., Richmond, CA (510) 758-2600, www.microassembly.com.

Circle No. 249

PROCESSING **EQUIPMENT**

Laser Structuring System

This ProtoLaser 100 is an easy-to-operate high performance laser structuring system for print-



ed circuit board prototyping that combines milling, drilling and contour routing capabilities of advanced LPKF ProtoMat® PCB plotter. The ProtoLaser 100 is ideal for producing high quality

RF and microwave boards on a variety of materials from FR4 to PTFE-based substrates. Its new laser beam technology isolates the circuits from the copper layer and removes non-contacting copper between them.

LPKF Laser & Electronics AG, Garbsen, Germany +49 (0)5131-7095-0, www.lpkf.de.

Circle No. 251

SOFTWARE

PCB Design Software



The AnsoftLinksTM v3 software streamlines data flow from electronic design automation vendor

[Continued on page 164]

- Pick One -

hich is without?

- **Double cheese** pizza?
- The Sunday crossword?
- Clean Sheets?
- The Red Sox?
- The bold new look of **Microwave** Journal®?







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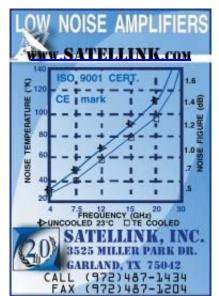
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PRODUCTS

software into the company's products. This latest version features a new translator for Mentor Graphics Expedition and an enhanced link to Cadence Virtuoso® for improved geometry export and solid modeling. With v3, engineers seamlessly transfer an integrated circuit, printed circuit board and package designs into any of the company's high performance electronic products to analyze, verify and optimize electromagnetic-associated performance characteristics.

Ansoft Ĉorp., Pittsburgh, PA (412) 261-3200, www.ansoft.com.

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Software Design Suite

The Microwave Office® 2004 design suite is for next generation radio frequency and microwave circuit designs. The latest version of this design system provides RF and microwave engineers with significant improvements in power and usability to increase design accuracy and shorten design cycle time. Microwave Office 2004 software fully integrates three-dimensional planar electromagnetic simulation with circuit simulation and layout tools, permitting arbitrary physical structures to be embedded within linear and nonlinear circuit simulations. Price: \$8000-\$40,000.

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

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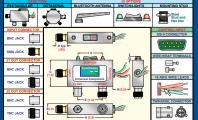
Reduction Solver

CST MICROWAVE STUDIO®'s new model order reduction (MOR) solver is particularly effective for the simulation of highly resonant structures such as filters. This new module complements the existing transient, frequency domain (on Cartesian and tetrahedral grids) and Eigenmode solvers already available in CST MWS. CST GmbH,

Darmstadt, Germany +49 (0) 6151 7303-0, www.cst.com

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The MLSE series of YIG-based wideband synthesizers is ideal as the main local oscillators in



receiving systems, frequency converters and test and measurement equipment. These synthesizers provide 1 Hz frequency resolution over the 2 to 20 GHz and 1 to 22

GHz frequency range. Power levels of +20 and +17 dBm are standard throughout the series. Spurious performance is -60 dBc and full band tuning speed is 13 to 18 mS. Size: $7" \times 5" \times 2"$.

Micro Lambda Wireless Inc., Fremont, CA (510) 770-9221, www.microlambdawireless.com.

Circle No. 256

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Mage



CMags

Rubidium Frequency Standard



The model 8040C is a fully featured and configurable rubidium frequency standard that provides flexible output options in a 1U rack mount package. The 8040C is ideal as a frequency reference in test equipment, communications systems, and timing systems utilized in aerospace and defense applications. As a standalone reference or in combination with a GPS input the 8040C can provide stable reference signals for distribution to multiple test locations.

Symmetricom Inc., San Jose, CA (978) 927-8220, www.symmttm.com.

Circle No. 259

SUBSYSTEM

■ IF Switch Matrix

The model 1411H is a switch matrix that offers wide advanced signal control features for ad-



vanced applications. This unit covers a frequency range of 50 to 250 MHz, and can be configured as small as 64 inputs by 64 outputs up to 128 inputs by 128 outputs. High signal intercept

levels and input-to-input isolations are key attributes of the unit's performance. The unit features a graphical front panel display for control. Communication with the unit can be RS-232 or $10~\rm base~T.$

STC Microwave Systems, Beverly, MA (978) 524-7290, www.craneaerospace.com.

Circle No. 260

TEST EQUIPMENT

Design Tools



These design tools enable RF and baseband engineers working at the physical layer to create, analyze and troubleshoot orthogonal frequency division multiplexing signals specified in the IEEE 802.16-2004 standard, often referred to as WiMAX. The Signal Studio for WiMAX works with the E4438C ESG vector

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signal generator to create modulated WiMAX signals for thorough stimulation of components. Used in conjunction with the E8827A advanced communications model set in ADS 2004, the design tools offer engineers a virtual WiMAX prototyping and system test solution. Agilent Technologies Inc.,

Palo Alto, CA (800) 829-4444, www.agilent.com.

Circle No. 261

Vector Network Analyzers

The 37000D series of Lightning Vector Network Analyzers (VNA) covers four frequency ranges



up to 65 GHz. This D series delivers improved performance, updated interfaces, expanded software application and Ethernet connectivity. These enhanced VNAs

are designed to test active and passive components intended for emerging applications such as high speed wireless networks and Ka-band satellite communications systems during R&D and production.

Anritsu Ltd., Bedfordshire, UK+44 (0) 1582 433433, www.eu.anritsu.com.

Circle No. 262

Power Meter

The model 9000B is a power meter with a diode sensor. This meter operates in a frequen-



cy range of 100 kHz to 40 GHz and a power range of -30 to +20 dBm, usable to -39 dBm. This model offers two auto ranges, an auto zero sensor and operates

from 115 VAC, 230 VAC (optional), +10 to +24 VDC, 500 mA. Delivery: stock to 30 days.

Sunnyvale, CA (408) 734-5999, www.krutar.com.

Krytar,

Circle No. 264

■ Connector Calibration Kits

These coaxial 1.85 mm connector calibration kits perform full two-port calibrations of net-



work analyzers and are capable of making measurements up to 70 GHz. These 1.85 mm calibration kits are available in three types. The 7850A series can per-

form a full two-port calibration to 70 GHz using an offset short calibration method. The 7850B series economy kits can perform a full two-port fixed load calibration to 70 GHz. A single sex male/female version is available. The 7860A series offers a TRM/TRL/LRL full two-port calibration up to 70 GHz.

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

Circle No. 265

- Pick One -

Which one will be here in January?

- The Olympics?
- The Easter Bunny?
 - Mardi Gras?
 - World Peace?
- The bold new look of Microwave Journal®?













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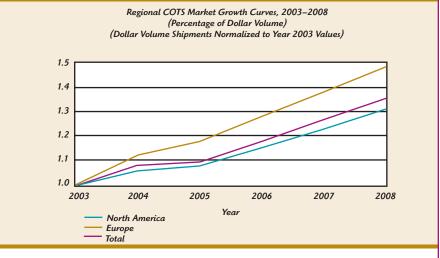
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MICROWAVE METRICS

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- VDC's research indicates that North American and European COTS merchant board, system, OS and SW development tools shipments comprised over \$2.3 B in 2003, with a projected compound annual growth rate (CAGR) of 6.27% over the period 2003–2008.
- Shipments of COTS merchant computer boards to these markets were over US\$
 670 M in 2003. This is expected to grow to US\$ 835 M in 2008.
- Shipments of COTS integrated systems/subsystems accounted for just over US\$
 1.6 B in revenues in 2003, and are projected to grow to almost US\$
 2.2 B in 2008.
- Shipments of embedded OSs/RTOSs and software development tools, combined, comprised over US\$ 120 M in shipments to the COTS market in 2003. This is expected to increase to over US\$ 217 M in 2008.



Source: Venture Development Corp., One Apple Hill Dr., Suite 206, Box 8190, Natick, MA 01760 (www.vdc-corp.com)

US to Buy \$1.7 B of Software-defined Radio Equipment by 2007

The US military is the largest proponent and purchaser of software-defined radio (SDR) equipment. In fact, shipments of SDR equipment to the US military are forecast to reach over \$1.7 B by 2007, according to a new study from Venture Development Corp. This represents a compound annual growth rate of 48.4% between 2003 and 2007.

Most US SDR procurement takes place through the DoD's JTRS program. JTRS was started seven years ago in an effort to coordinate the replacement of approximately 750,000 US military radios with 250,000 to 320,000 software-defined radios.

Unlike previous radio systems, these new SDR radios can interoperate with each other and be upgraded via software to incorporate the latest communications technologies. Since its conception, the program has been expanded to enable interoperability with the British military, NATO and other Allied Forces.

Estimated JTRS Spending Through 2007 Includes (in millions of dollars):

2003: 212.5 2004: 558.4 2005: 533.5 2006: 880.0 2007: 1386.10

Source: Military & Aerospace Electronics, PennWell, 98 Spit Brook Rd., Nashua, NH 03062 (http://mae.pennnet.com/home.cfm)









Next month all the pieces come together.













Ultra-Wideband Radio Technology

Kasimierz Siwiak and Debra McKeown John Wiley & Sons Ltd. 264 pages; \$95 ISBN: 0-470-85931-8

This book is designed to give a basic overview of the subject of ultra-wideband (UWB) technology. It grounds the reader with a brief history, offers an understanding of the current regulations and standards that are being developed, and then presents the workings of the technology. The history of ultra-wideband is introduced in Chapter 1, its first appearance being the early spark-gap

"One advantage of UWB is touted to be its enormous capacity."

mechanisms. The development of a technology is tempered as much by invention and innovation as by regulations, which are explored in Chapter 2: the Regulatory Climate. In Chapter 3: UWB in Standards, the development of some standards activities in which UWB will appear, are traced. Chapter 4: Generating and Transmitting UWB Signals, details the generation of wideband

signals, which requires techniques different from those used with conventional radio signals. In Chapter 5: Radiation of UWB Signals, the concept of finite time imparts interesting characteristics to UWB radiation. The time solution to radiation is presented and shows how wideband signals differ from their narrowband counterparts. Chapter 6: Propagation of UWB Signals, explains how UWB signals interact in the real world in a variety of environments. Receiving UWB signals is not very different from receiving other wireless signals; however, there is an art to receiving signals efficiently and translating them correctly to extract the information conveyed. In Chapter 7: Receiving UWB Signals, the techniques of efficient signal receptions are discussed. One advantage of UWB is touted to be its enormous capacity. Chapter 8: UWB System Limits and Capacity, quantifies the performance of UWB links and shows how the environment and other wireless users have an impact on the amount of information that can be packed on a link. Chapter 9: Applications and Future Directions, explains several ideas that have been proposed for marketing and a couple that are just sparks of thought and are meant to enthuse readers and open minds to the possibilities.

To order this book, contact: John Wiley & Sons Ltd., The Atrium, Southern Gate, Chichester, West Sussex PO19 8SQ UK +44 1243 779777.

THE BOOK END

An Introduction to Microelectromechanical Systems Engineering, Second Edition

Nadim Maluf and Kirt Williams Artech House Inc. 302 pages; \$89, £59 ISBN: 1-58053-590-9

he past few years have witnessed an increasing maturity of the MEMS industry and a rapid introduction of new products addressing applications ranging from biochemical analysis to fiber-optic telecommunications. The market size for MEMS products has doubled in the past five years and is projected to grow at this fast rate for the foreseeable future. In this second edition of the original publication, the authors have revised the original text and added substantial new material, while retaining the style characteristic of an introductory book intended for a broad audience of scientists, engineers, students and business executives. The section on fabrication processes has been expanded by adding new methods and materials. The advantages and limitations of many micromachined structures are covered in more detail. The chapter on commercial structures is now divided into four chapters,

each focusing on a specific application and expanded with appropriate material covering new technical developments and products. Chapter 4 is now specific to automotive and industrial applications, covering traditional products, such as pressure sensors, accelerometers, yaw-rate sensors and new emerging products in

"The market size for MEMS products has doubled in the past five years..."

valving and pumping. Chapter 5 now covers the applications of MEMS in photonics, including displays, optical sensors and new products that are now common in fiberoptic telecommunications. The focus of Chapter 6 is on applications in life sciences, with emphasis on new products and developments specific to biochemical analysis and microfluidics. With the emergence of wireless and RF as a new market for MEMS technology, Chapter 7 describes recent developments and introductions in this promising area. In Chapters 4 to 7, the information on applications and systems that include MEMS products was expanded where appropriate. In Chapter 8, the material on packaging was also expanded to include packaging of optical MEMS products and an entirely new section on reliability and quality assurance was added.

To order this book, contact: Artech House Inc., 685 Canton St., Norwood, MA 02062 (781) 769-9750 ext. 4030; or 46 Gillingham St., London SW1V 1HH UK +44 (0) 207-8750.

Dan Massé

Dan Massé is a member of the Microwave Journal staff.

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MTT Wireless is a combination of events all geared to wireless technologies and systems

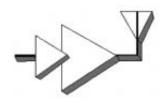


The IEEE Microwave Theory and Techniques (MTT) Society announces the establishment of MTT Wireless, a week-long event encompassing wireless systems and technologies

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The established *Topical Meeting*on Silicon Monolithic Integrated Circuits
in RF Systems (SiRF)
18–20 January 2006



The IEEE Topical Workshop on Power Amplifiers for Wireless Communications (PA Workshop) 16–17 January 2006

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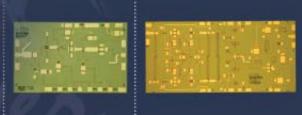












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