Vol. 49 • No. 7

July 2006

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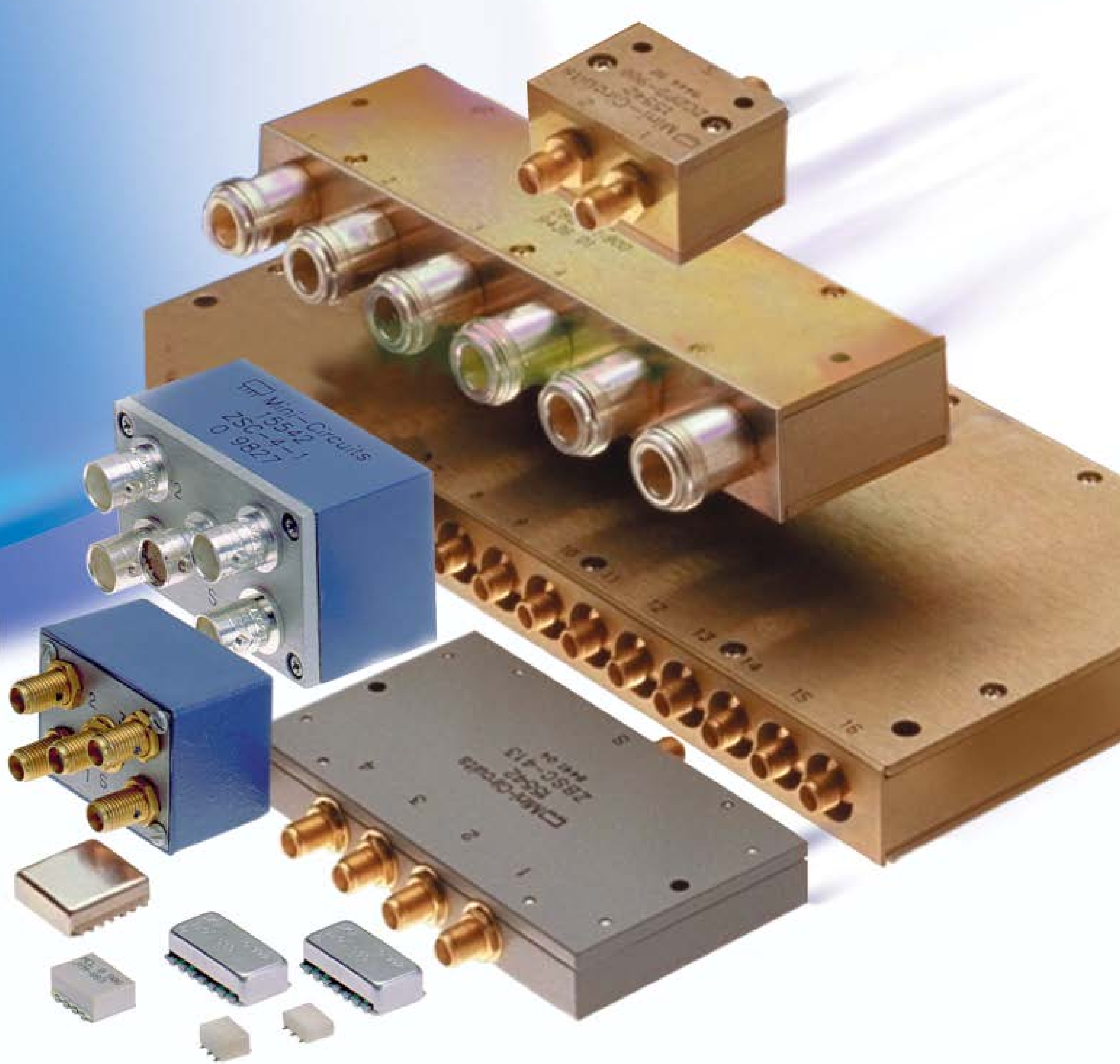



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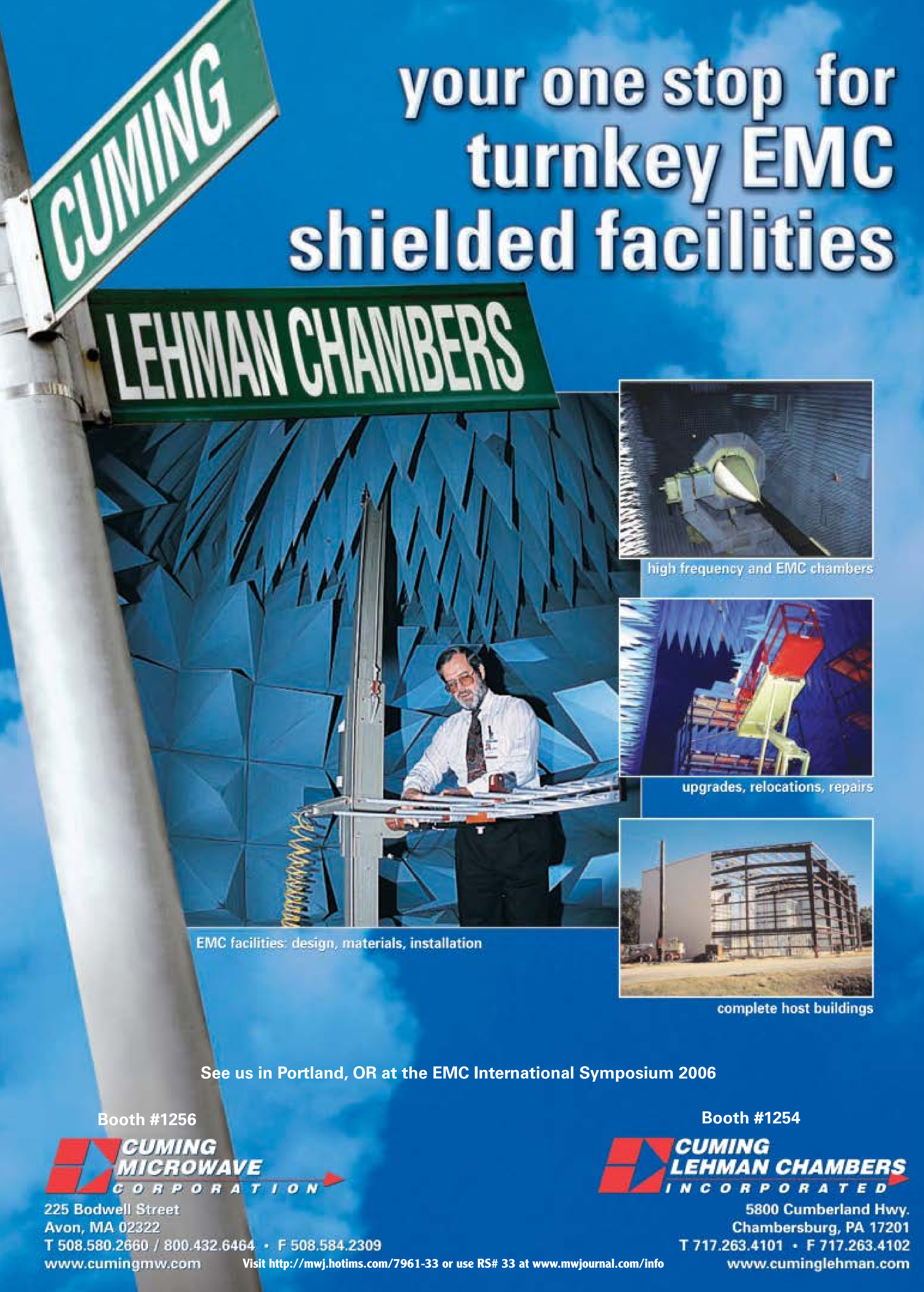
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JULY 2006 VOL. 49 • NO. 7

# FEATURES

## COVER FEATURE



## SPECIAL REPORTS



## TECHNICAL FEATURES



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## TUTORIAL



# DEPARTMENTS



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# Ask Harlan

"Ask Harlan," a technical question and answer session with Harlan Howe, Jr., an industry veteran and long-time *Microwave Journal* editor, has been a regular part of our web site (www.mwjournal.com) for almost two years now. In an effort to better combine the editorial content of our magazine with our newly developed and retooled on-line presence, we have decided to develop Harlan's RF and microwave engineering advice into a monthly feature.

**How it works:** Harlan has selected one question from his "Ask Harlan" column to be featured in the magazine. Please visit www.mwjournal.com/askharlan to provide an answer to this month's featured question (see below). Harlan will be monitoring the responses and will ultimately choose the best answer to the question. Although all of the responses to the featured question will be posted on our web site, we plan to publish the winning answer in the September issue. All responses must be submitted by **August 6, 2006**, to be eligible for the participation of the July question.

The winning response will win a free book from Artech House, along with an "I Asked Harlan!" t-shirt. In addition, everyone who submits a legitimate response will be sent an "I Asked Harlan!" t-shirt.

## *May Question and Winning Response*

**The May question was submitted by Verne Reynolds:**

Dear Harlan,

My wife wants to know if she is endangered by radiation from our stove-top kitchen microwave. When cooking, her face may only be a foot away from the microwave, for minutes at a time. Is she in any danger? Are there any long-term effects we should be concerned with?

**The winning response to the May question is from John Osepchuk of Full Spectrum Consulting:**

1. She is in no danger. 2. There are no long-term effects to be worried about. These conclusions are supported by the following: 1) The typical microwave oven leakage with food in the oven is about 0.1 mW/cm$^2$ at 5 cm from the oven. 2) Federal regulations limit this leakage to 5 mW/cm$^2$ at 5 cm. 3) Even if leakage (emission) is at 5 mW/cm$^2$, the intensity drops off at one foot to at most 0.5 mE/cm$^2$, which is well below the safe exposure limit for the general public in the just-issued IEEE C95.1-2005 Standard, which in itself incorporates a very large safety factor much greater than 10 against harm. The C95.1 limit is 1 mW/cm$^2$ but this is a whole-body average and also averaged over any 30 minutes. 4) Note that at the FDA limit the oven is leaking (radiating) the order of 1 W of microwave power. This is much smaller than the microwave diathermy power of up to and even greater than 125 W, applied to millions of patients, at various places including the head, for beneficial purposes. This power is also comparable to the power (up to 0.6 W) radiated from cell phones, which are held to the head whereas the microwave oven is not brought close to the head. 5) Historically, electrophobia, based on poor-quality research, has caused fear of microwave ovens, police radar, VDTs, power lines and now cell phones and wireless base stations. Over time all of these fears have been judged baseless by scientists, the government and the general public.

**Harlan's response:**

She should not worry. Safety standards for human exposure to non-ionizing radiation such as RF and microwaves have been well established. They have been published in the ANSI-C-95 standard, which is available from IEEE. All ovens are tested for compliance and have a good safety margin. In addition, the door seals are microwave choke designs and do not rely on gasket contact, so even if they get dirty, the door is still sealed. When I was still working as an engineer, I tested the ovens in our company cafeterias at the request of the human resources department. They all passed with safety margins of 5 to 10 times.

## *This Month's Question of the Month*

*(answer on-line at www.mwjournal.com/askharlan)*

**Jayesh Nath from Harris Corp. has submitted this month's question:**

Dear Harlan,

What is the proper usage of diplexer and duplexer?

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| SIM-14+ | +7 | 3700-10000 | DC-4000 | 6.7 | 38 | 16 | +16 | 8.95 |
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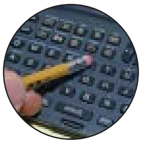



### CALL FOR PAPERS

7th Topical Meeting on Silicon Monolithic Integrated Circuits in RF Systems (SiRF 2007)
*by July 28, 2006*

IEEE Radar Conference 2007
*by August 18, 2006*

IEEE Topical Workshop on Power Amplifiers for Wireless Communications (PA Workshop)
*by October 2, 2006*

## AUGUST

**NIWEEK 2006**
*August 8–10, 2006 • Austin, TX*
www.ni.com/niweek

**IEEE INTERNATIONAL SYMPOSIUM ON ELECTROMAGNETIC COMPATIBILITY (EMC 2006)**
*August 14–18, 2006 • Portland, OR*
www.emc2006.org

**18TH ANNUAL INTERNATIONAL MILITARY & AEROSPACE/AVIONICS COTS CONFERENCE, EXHIBITION AND SEMINARS**
*August 22–24, 2006 • Santa Clara, CA*
http://cotsconference.home.att.net

## SEPTEMBER

**ANTENNA SYSTEMS CO-LOCATED WITH SHORT-RANGE WIRELESS 2006**
*September 6–7, 2006 • Vienna, VA*
www.antennasonline.com

**EUROPEAN MICROWAVE WEEK 2006 (EUMW 2006)**
*September 10–15, 2006 • Manchester, UK*
www.eumw2006.com

**JOINT 31ST INTERNATIONAL CONFERENCE ON INFRARED AND MILLIMETER-WAVES AND 14TH INTERNATIONAL CONFERENCE ON TERAHERTZ ELECTRONICS (IRMMW-THZ 2006)**
*September 18–22, 2006 • Shanghai, China*
www.sitp.ac.cn/irmmw-thz2006

**IEEE INTERNATIONAL CONFERENCE ON ULTRA-WIDEBAND (ICUWB 2006)**
*September 24–27, 2006 • Waltham, MA*
www.icuwb2006.org

## OCTOBER

**28TH ANNUAL SYMPOSIUM OF THE ANTENNA MEASUREMENT TECHNIQUES ASSOCIATION (AMTA 2006)**
*October 22–27, 2006 • Austin, TX*
www.amta.org

## NOVEMBER

**ELECTRONICA 2006**
*November 14–17, 2006 • Munich, Germany*
www.electronica.de

**MM-WAVE PRODUCTS AND TECHNOLOGIES**
*November 16, 2006 • Savoy Place, London*
www.iee.org/events/mmwave.cfm

## JANUARY

**IEEE TOPICAL WORKSHOP ON POWER AMPLIFIERS FOR WIRELESS COMMUNICATIONS (PA WORKSHOP)**
*January 8–9, 2007 • Long Beach, CA*
http://paworkshop.ucsd.edu

**IEEE RADIO AND WIRELESS SYMPOSIUM (RWS 2007)**
*January 9–11, 2007 • Long Beach, CA*
www.radiowireless.org

**7TH TOPICAL MEETING ON SILICON MONOLITHIC INTEGRATED CIRCUITS IN RF SYSTEMS (SIRF 2007)**
*January 10–12, 2007 • Long Beach, CA*
www.ece.wisc.edu/sirf07

## APRIL

**IEEE RADAR CONFERENCE 2007**
*April 17–20, 2007 • Boston, MA*
www.radar2007.org

# Workshops & Courses

## Sonnet Training Class

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■ **Site:** For location information, please visit url.
■ **Dates:** For date information, please visit url.
■ **Contact:** Yun Chase, Sonnet Software Inc., 100 Elwood Davis Road, North Syracuse, NY 13212 (315) 453-3096 or e-mail: chase@sonnetsoftware.com.

## High Speed PCB, System Design and Use of Simulation Tools

■ **Topics:** This course will cover the entire process involved in designing and fabricating high speed PCBs. It begins with the fundamentals of electromagnetic fields and the behavior of transmission lines that are the basis for all high speed signaling. From there it examines all aspects of high speed design leading to the development of a robust set of PCB design rules. For more information, visit www.unex.berkeley.edu.
■ **Site:** Redwood City, CA
■ **Date:** August 21, 2006
■ **Contact:** UC Berkeley Extension, 1995 University Avenue, Berkeley, CA 94720 (510) 642-4151 or e-mail: course@unex.berkeley.edu.

## On-line Course – Introduction to Electronics

■ **Topics:** Based upon the two-day Overview of Electronics course, this new on-line course will introduce the basic ideas behind electronic circuits. The course will consist of 10 units each of which will involve three to five hours of study. The course is designed to act both as an introductory course and a refresher course, and will highlight how electronic systems work and how they are made. For more information, visit www.conted.ox.ac.uk.
■ **Site:** On-line course.
■ **Date:** September 1, 2006
■ **Contact:** University of Oxford Continuing Education, 1 Wellington Square, Oxford, OX1 2 JA UK + 44 1865 270360 or e-mail: electronics@conted.ox.ac.uk.

## "Connect" – CST Workshop Series 2006

■ **Topics:** This introductory workshop will be led by Mohan Jayawardene and Ralf Ehmann during EuMW. It is free of charge and will present CST's "Connected" approach to 3D EM simulation. It will provide modern 3D EM simulation tools that offer benefits such as shorter and more cost-effective development cycles through automatic optimization and parameter studies.
■ **Site:** Manchester, UK
■ **Date:** September 13, 2006
■ **Contact:** For more information, visit www.cst.com.

## Far-field, Anechoic Chamber, Compact and Near-field Antenna Measurements

■ **Topics:** This course presents the state-of-the-art in antenna measurements, including far-field, anechoic chamber, compact and near-field measurements. The course also includes range evaluation and compensation techniques and microwave holography. For more information, visit www.pe.gatech.edu.
■ **Site:** Atlanta, GA
■ **Dates:** November 6–10, 2006
■ **Contact:** Georgia Institute of Technology, Professional Education, PO Box 93686, Atlanta, GA 30377 (404) 385-3500.

## The Entrepreneurial Engineer

■ **Topics:** This short course is an efficient and memorable introduction to the personal, interpersonal, business and organizational skills necessary to help engineers of applied science and mathematics perform at high levels in today's increasingly opportunistic organizations and enterprises. For more information, visit http://online.engr.uiuc.edu/shortcourses/tee/index.html.
■ **Site:** Archived on-line course.
■ **Dates:** Archived on-line for anytime viewing.
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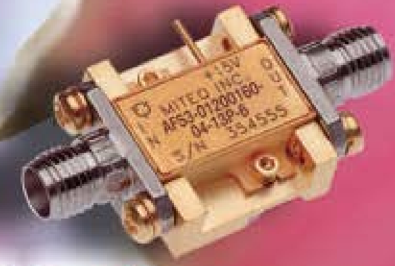

| Model Number | Frequency Range (GHz) | Gain (Min./Max.) (dB) | Gain Flatness (±dB, Max.) | Noise Figure (dB, Max.) | VSWR Input (Max.) | VSWR Output (Max.) | Output Power @ 1 dB Comp. (dBm, Min.) | Nom. DC Power (+15 V, mA) |
|---|---|---|---|---|---|---|---|---|
| **TEMPERATURE COMPENSATED AMPLIFIERS** | | | | | | | | |
| 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 |
| AFS2-04000800-15-TC-2 | 4–8 | 17–22 | 1.00 | 1.5 | 2.0:1 | 2.0:1 | +5 | 100 |
| AFS3-04000800-12-TC-4 | 4–8 | 25–30 | 1.00 | 1.2 | 2.0:1 | 2.0:1 | +8 | 100 |
| AFS2-02000800-30-TC-2 | 2–8 | 14–19 | 1.50 | 3.0 | 2.0:1 | 2.0:1 | +5 | 100 |
| 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 | 100 |
| 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-6 | 12–18 | 22–26 | 1.00 | 3.0 | 2.0:1 | 2.0:1 | +8 | 150 |
| AFS4-06001800-35-TC-6 | 6–18 | 22–26 | 1.00 | 3.5 | 2.0:1 | 2.0:1 | +8 | 150 |
| AFS6-06001800-35-TC-6 | 6–18 | 30–34 | 1.00 | 3.5 | 2.0:1 | 2.0:1 | +8 | 200 |
| AFS4-02001800-45-TC-6 | 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.) | Nom. DC Power (+15 V, mA) |
|---|---|---|---|---|---|---|---|---|
| **HIGHER POWER AMPLIFIERS** | | | | | | | | |
| AFS3-00050100-15-27P-6 | 0.05–1 | 36 | 1.50 | 1.5* | 2.0:1 | 2.5:1 | +27 | 300 |
| AFS3-00100100-15-27P-6 | 0.1–1 | 33 | 2.00 | 1.5 | 2.0:1 | 2.5:1 | +27 | 300 |
| AFS3-00100200-20-27P-6 | 0.1–2 | 34 | 1.50 | 2.0 | 2.0:1 | 2.0:1 | +27** | 300 |
| AFS3-00100300-20-23P-6 | 0.1–3 | 28 | 1.50 | 2.0 | 2.0:1 | 2.0:1 | +23 | 275 |
| AFS3-00100400-25-20P-4 | 0.1–4 | 24 | 1.50 | 2.5 | 2.0:1 | 2.0:1 | +20 | 250 |
| AFS4-00100600-24-20P-4 | 0.1–6 | 30 | 1.50 | 2.4 | 2.0:1 | 2.0:1 | +20 | 300 |
| AFS4-00100800-26-20P-4 | 0.1–8 | 30 | 1.50 | 2.6 | 2.0:1 | 2.0:1 | +20 | 300 |
| AFS4-00101200-35-20P-4 | 0.1–12 | 27 | 2.00 | 3.5 | 2.0:1 | 2.0:1 | +20 | 300 |
| AFS4-00501800-40-20P-6 | 0.5–18*** | 25 | 2.75 | 4.0 | 2.5:1 | 2.2:1 | +20 | 350 |
| AFS3-01000200-18-27P-6 | 1–2 | 32 | 1.50 | 1.8 | 2.0:1 | 2.0:1 | +27 | 350 |
| AFS4-02000400-20-25P-6 | 2–4 | 36 | 1.50 | 2.0 | 2.0:1 | 2.0:1 | +25 | 275 |

* Noise figure degrades below 100 MHz. Please consult MITEQ 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) |
|---|---|---|---|---|---|---|---|---|
| **MODERATE BAND AMPLIFIERS** | | | | | | | | |
| 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 | 1.2–1.6 | 40 | 0.50 | 0.50 | 1.5:1 | 1.5:1 | +13 | 150 |
| AFS3-01400170-06-13P-6 | 1.4–1.7 | 40 | 0.50 | 0.60 | 1.5:1 | 1.5:1 | +13 | 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 | 1.5–2.5 | 38 | 1.00 | 0.60 | 1.8:1 | 1.8:1 | +13 | 150 |
| AFS3-01700190-06-13P-6 | 1.7–1.9 | 38 | 0.50 | 0.60 | 1.5:1 | 1.5:1 | +13 | 150 |
| AFS3-01800220-06-13P-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 | 2.3–2.7 | 36 | 0.50 | 0.60 | 1.5:1 | 1.5:1 | +13 | 150 |
| AFS3-02700290-06-13P-6 | 2.7–2.9 | 32 | 0.50 | 0.60 | 1.5:1 | 1.5:1 | +13 | 150 |
| AFS3-02900310-06-13P-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 | 3.4–4.2 | 40 | 0.50 | 1.00 | 1.5:1 | 1.5:1 | +13 | 200 |
| AFS3-04400510-07-S-4 | 4.4–5.1 | 30 | 0.50 | 0.70 | 1.5:1 | 1.5:1 | +10 | 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 | 5.4–5.9 | 30 | 0.50 | 0.70 | 1.5:1 | 1.5:1 | +10 | 100 |
| AFS3-05800670-07-S-4 | 5.8–6.7 | 30 | 0.50 | 0.70 | 1.5:1 | 1.5:1 | +10 | 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 | 8.5–9.6 | 32 | 0.75 | 0.80 | 1.5:1 | 1.5:1 | +10 | 125 |
| AFS3-09001100-09-S-4 | 9–11 | 26 | 0.50 | 0.90 | 1.5:1 | 1.5:1 | +10 | 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 | 32 | 0.75 | 0.90 | 1.5:1 | 1.5:1 | +10 | 125 |
| AFS4-11701220-09-5P-4 | 11.7–12.2 | 32 | 0.75 | 0.90 | 1.5:1 | 1.5:1 | +10 | 125 |
| AFS2-12201280-14-5P-2 | 12.2–12.8 | 14 | 0.75 | 1.40 | 1.4:1 | 1.5:1 | +5 | 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 | 12.7–13.3 | 30 | 0.75 | 1.50 | 1.5:1 | 1.5:1 | +10 | 175 |
| AFS4-13201400-16-10P-4 | 13.2–14 | 30 | 0.75 | 1.60 | 1.5:1 | 1.5:1 | +10 | 175 |
| AFS4-14001450-15-10P-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 |
| **OCTAVE BAND AMPLIFIERS** | | | | | | | | |
| AFS3-00120025-09-10P-4 | 0.12–.25 | 38 | 0.50 | 0.9 | 2.0:1 | 2.0:1 | +10 | 125 |
| AFS3-00250050-08-10P-4 | 0.25–0.5 | 38 | 0.50 | 0.8 | 2.0:1 | 2.0:1 | +10 | 125 |
| AFS3-00500100-06-10P-6 | 0.5–1 | 38 | 0.75 | 0.6 | 2.0:1 | 1.5:1 | +10 | 150 |
| AFS3-01000200-05-10P-6 | 1–2 | 38 | 1.00 | 0.5 | 2.0:1 | 2.0:1 | +10 | 150 |
| AFS3-01200240-06-10P-6 | 1.2–2.4 | 34 | 1.00 | 0.6 | 2.0:1 | 2.0:1 | +10 | 150 |
| AFS3-02000400-06-10P-4 | 2–4 | 32 | 1.00 | 0.6 | 2.0:1 | 2.0:1 | +10 | 125 |
| AFS3-02600520-10-10P-4 | 2.6–5.2 | 28 | 1.00 | 1.0 | 2.0:1 | 2.0:1 | +10 | 125 |
| AFS3-04000800-07-10P-4 | 4–8 | 28 | 1.00 | 0.7 | 2.0:1 | 2.0:1 | +10 | 125 |
| AFS3-08001200-09-10P-4 | 8–12 | 26 | 1.00 | 0.9 | 2.0:1 | 2.0:1 | +10 | 125 |
| AFS3-08001600-15-8P-4 | 8–16 | 28 | 1.00 | 1.5 | 2.0:1 | 2.0:1 | +8 | 100 |
| AFS4-12001800-18-10P-4 | 12–18 | 28 | 1.50 | 1.8 | 2.0:1 | 2.0:1 | +10 | 125 |
| AFS4-12002400-30-10P-4 | 12–24 | 24 | 2.00 | 3.0 | 2.0:1 | 2.0:1 | +10 | 85 |
| AFS3-18002650-30-8P-4 | 18–26.5 | 18 | 1.75 | 3.0 | 2.2:1 | 2.2:1 | +8 | 125 |
| **MULTIOCTAVE BAND AMPLIFIERS** | | | | | | | | |
| AFS3-00300140-09-10P-4 | 0.3–1.4 | 38 | 1.00 | 0.9 | 2.0:1 | 2.0:1 | +10 | 125 |
| AFS2-00400350-12-10P-4 | 0.4–3.5 | 22 | 1.50 | 1.2 | 2.0:1 | 2.0:1 | +10 | 80 |
| AFS3-00500200-08-15P-4 | 0.5–2 | 38 | 1.00 | 0.8 | 2.0:1 | 2.0:1 | +15 | 125 |
| AFS3-01000400-10-10P-4 | 1–4 | 30 | 1.50 | 1.0 | 2.0:1 | 2.0:1 | +10 | 125 |
| AFS3-02000800-09-10P-4 | 2–8 | 26 | 1.00 | 1.0 | 2.0:1 | 2.0:1 | +10 | 125 |
| AFS4-02001800-23-10P-4 | 2–18 | 25 | 2.00 | 2.3 | 2.0:1 | 2.0:1 | +10 | 175 |
| AFS4-06001800-22-10P-4 | 6–18 | 25 | 2.00 | 2.2 | 2.0:1 | 2.0:1 | +10 | 125 |
| AFS4-08001800-22-10P-4 | 8–18 | 28 | 2.00 | 2.2 | 2.0:1 | 2.0:1 | +10 | 125 |
| **ULTRA WIDEBAND AMPLIFIERS** | | | | | | | | |
| AFS3-00100100-09-10P-4 | 0.1–1 | 38 | 1.00 | 0.9 | 2.0:1 | 2.0:1 | +10 | 125 |
| AFS3-00100200-10-15P-4 | 0.1–2 | 38 | 1.00 | 1.0 | 2.0:1 | 2.0:1 | +15 | 150 |
| AFS1-00040200-12-10P-4 | 0.04–2 | 15 | 1.50 | 1.2 | 2.0:1 | 2.0:1 | +10 | 50 |
| AFS3-00100300-12-10P-4 | 0.1–3 | 32 | 1.00 | 1.2 | 2.0:1 | 2.0:1 | +10 | 125 |
| AFS3-00100400-13-10P-4 | 0.1–4 | 28 | 1.00 | 1.3 | 2.0:1 | 2.0:1 | +10 | 125 |
| AFS3-00100600-13-10P-4 | 0.1–6 | 28 | 1.25 | 1.3 | 2.0:1 | 2.0:1 | +10 | 125 |
| AFS3-00100800-14-10P-4 | 0.1–8 | 28 | 1.50 | 1.4 | 2.0:1 | 2.0:1 | +10 | 125 |
| AFS4-00101200-22-10P-4 | 0.1–12 | 30 | 1.50 | 2.2 | 2.0:1 | 2.0:1 | +10 | 150 |
| AFS4-00101400-23-10P-4 | 0.1–14 | 24 | 2.00 | 2.3 | 2.5:1 | 2.5:1 | +10 | 200 |
| AFS4-00101800-25-S-4 | 0.1–18 | 25 | 2.00 | 2.5 | 2.5:1 | 2.5:1 | +10 | 175 |
| AFS4-00102000-30-10P-4 | 0.1–20 | 20 | 2.50 | 3.0 | 2.5:1 | 2.5:1 | +10 | 125 |
| AFS4-00102650-42-8P-4 | 0.1–26.5 | 22 | 2.50 | 4.2 | 2.5:1 | 2.5:1 | +8 | 135 |

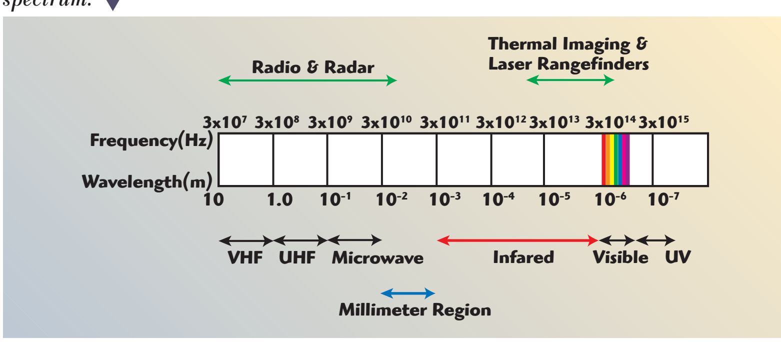
Note: Noise figure increases below 500 MHz in bands greater than 0.1-10 GHz.

# Millimeter-wave Applications: From Satellite Communications to Security Systems

The first thing to consider is, why millimeter-waves? First, there are many advantages associated with increasing the operating frequency for a majority of already well developed applications, including the potential for increased available bandwidth, and the improved resolution and directivity which can be obtained for a given antenna aperture. This can mean smaller, lightweight systems offering increased transmission capacity in the case of communication systems or improved resolution for radar or imaging systems. In the latter case, millimeter and/or sub-mm systems are often mandated to achieve useful resolution for image recognition, or identify explosive materials by their spectroscopic signatures.

Additionally, there are unique features associated with the transmission properties of the atmosphere in the millimeter spectrum region, generally accepted to mean wavelengths between 1 and 10 mm or the band of frequencies covering 30 to 300 GHz. ***Figure 1*** places the mm-band relative to other electromagnetic radiation and, as an example, ***Figure 2*** shows the effective zenith atmospheric transmission in dB/km for typical conditions at sea level and a height of 4 km. The impact of the 60 and 120 GHz $O_2$ lines and multiple resonances of the $H_2O$ molecule can be seen.

*Fig. 1 Millimeter-wave region of the electromagnetic spectrum.*



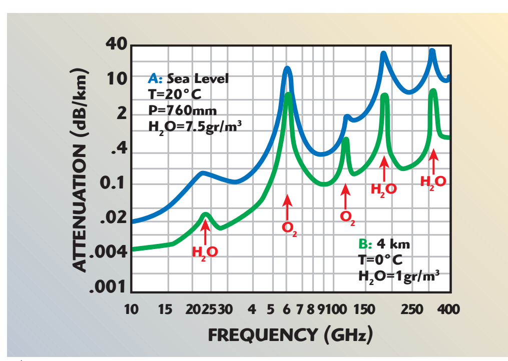




*Fig. 2 Atmospheric attenuation within the millimeter-wave spectrum.*

David R. Vizard
*Farran Technology Ltd.*
*Ballincollig, Co. Cork, Ireland*

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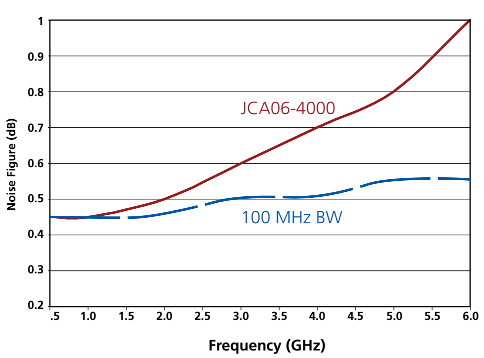
### Noise Figure Capability




- ***Narrowband noise figure < 0.5 dB***
- ***Broadband noise figure < 1.0 dB***
- ***Unconditionally stable***
- ***2 to 4 weeks delivery***
- ***ISO9001 and AS9100 certified***

| Model | Frequency GHz | Gain dB Min | Noise Figure dB Max | Gain Flatness +/- dB Max | P1dB dBm Min | VSWR In/Out Max | DC Current +15v, mA |
|---|---|---|---|---|---|---|---|
| **LNAs** | | | | | | | |
| **JCA01-3041** | 0.50 to 0.60 | 40 | **0.5** | 1.00 | 15 | 2.0:1 | 250 |
| **JCA01-3042** | 0.60 to 0.70 | 40 | **0.5** | 1.00 | 15 | 2.0:1 | 250 |
| **JCA01-3043** | 0.70 to 0.80 | 40 | **0.5** | 1.00 | 15 | 2.0:1 | 250 |
| **JCA01-3044** | 0.80 to 0.90 | 40 | **0.5** | 1.00 | 15 | 2.0:1 | 250 |
| **JCA01-2034** | 0.80 to 0.90 | 30 | **0.5** | 1.00 | 10 | 2.0:1 | 200 |
| **JCA01-2035** | 0.90 to 1.00 | 30 | **0.5** | 1.00 | 10 | 2.0:1 | 200 |
| **JCA01-3045** | 0.90 to 1.00 | 40 | **0.5** | 1.00 | 15 | 2.0:1 | 250 |
| **JCA01-2001** | 0.50 to 1.00 | 30 | **0.9** | 2.00 | 10 | 2.0:1 | 200 |
| **JCA12-2000** | 1.00 to 2.00 | 30 | **0.9** | 1.50 | 10 | 2.0:1 | 200 |
| **JCA12-3000** | 1.00 to 2.00 | 40 | **0.9** | 1.50 | 15 | 2.0:1 | 250 |
| **JCA12-4000** | 1.00 to 2.00 | 50 | **0.9** | 1.50 | 15 | 2.0:1 | 300 |
| **JCA14-3001** | 1.00 to 4.00 | 40 | **0.9** | 2.00 | 15 | 2.5:1 | 250 |
| **JCA14-2001** | 1.00 to 4.00 | 30 | **0.9** | 2.00 | 10 | 2.5:1 | 200 |
| **JCA14-4001** | 1.00 to 4.00 | 50 | **0.9** | 2.00 | 15 | 2.5:1 | 300 |
| **JCA24-2000** | 2.00 to 4.00 | 30 | **0.9** | 1.50 | 10 | 2.0:1 | 200 |
| **JCA24-3000** | 2.00 to 4.00 | 40 | **0.9** | 1.50 | 15 | 2.0:1 | 250 |
| **JCA24-4000** | 2.00 to 4.00 | 50 | **0.9** | 1.50 | 15 | 2.0:1 | 300 |
| **JCA06-4000** | 0.50 to 6.00 | 30 | **1.2** | 2.00 | 10 | 2.5:1 | 300 |
| **JCA26-2001** | 2.00 to 6.00 | 30 | **1.2** | 2.00 | 10 | 2.0:1 | 200 |
| **JCA26-3001** | 2.00 to 6.00 | 40 | **1.2** | 2.00 | 15 | 2.0:1 | 250 |
| **JCA26-4001** | 2.00 to 6.00 | 50 | **1.2** | 2.00 | 15 | 2.0:1 | 300 |

**OPTIONS**

| | | |
|---|---|---|
| Variable Gain Control | TTL Switching | Temperature Compensation |
| Input/Output Isolators | Waveguide Interface | Detector Output |
| Input Limiters | Phase Tracking | Gain Matching |
| Limiting Amplifiers | Low Phase Noise | Hermetic Packages |
| Environmental Screening | K-Connectors | Bias-T Output |

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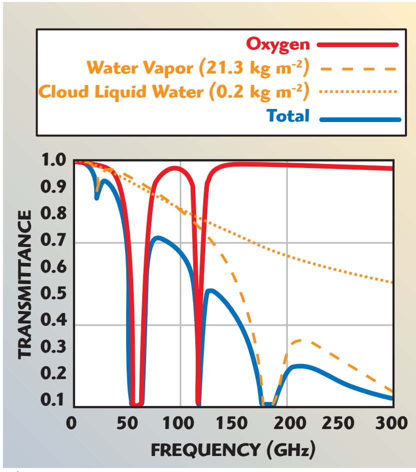



▲ *Fig. 3 Atmospheric transmission in the 30 to 300 GHz region (dotted line, oxygen contribution; dash-dotted line, water contribution).*[16]

▲ *Fig. 4 Millimeter-wave high capacity transceiver (courtesy of Proxim Wireless).*

Such specific and unique resonances allow the remote sensing of atmospheric gases in the Earth and planetary atmospheres, for example, and the identification of potential threat materials in security applications. The high attenuation of the 60 GHz $O_2$ allows high density unlicensed communication and covert systems.

Penetration of dust, smoke and fog can be achieved in the so-called 'window' frequencies where atmospheric attenuation is least and maximum range can be achieved. The window frequencies are best illustrated in ***Figure 3***, which shows linear transmission at zenith with the contributions due to atmospheric gases and liquid water for a mid-latitude location. In the medical field terahertz (THz or sub-millimeter-wave) diagnostic tools use organo-metallic molecular signatures, which act as tracers for research in cancer bearing cell structures, and mm-wave 'skin imaging' passive scanners are under study for non-invasive, skin cancer diagnosis.

## MM-WAVE APPLICATIONS

Having outlined the background, consider the sectors in which millimeter-waves are being utilized. Of course, in a short article it is difficult to do justice to such a wide-ranging subject and apologies to the many researchers and manufacturers addressing topics that are too numerous to mention here.

An area to highlight is terrestrial and satellite communication systems and mm-wave ground-based communications. Cellular telephone and data link infrastructure is by far the largest commercial application of mm-wave systems. These use so-called 'backhaul' to provide wireless line of sight interconnections of the nodes in the system. In this way a radio network can be rolled out, to a large extent independent of existing infrastructure and is attractive for use in developing countries for that reason. A wide variety of manufacturers compete in the microwave/mm-wave radio market with the most common high capacity mm-wave radios using frequencies near 38 GHz.[1]

For even higher capacity still, frequencies in the 50 to 60 GHz band may be used at shorter ranges, for 'hot spots' and 'last mile' such as airports, railway stations and temporary set ups for broadcasting or special events. Companies such as Proxim Wireless[2] offer high capacity point-to-point fiber-compatible radio systems for ranges of 0.25 to 1 km, operating in the unlicensed 57 to 64 GHz frequency band, as shown in ***Figure 4***. Data rates depend on the modulation complexity and cover 125 Mbps to 1.25 Gbps. Standard interfaces such as OC3 (155 Mbps) and OC12 (622 Mbps) are used to interface point-to-point wireless networks.

Depending on the network, a mix of frequencies can be chosen in order to trade-off the required capacity, range and infrastructure cost. Although more sophisticated modulation formats have dramatically extended the capacity of a given link, the demand for further increases in bandwidth ensures a strong growth market for existing radios and also newly developing E-band radio-link products. E-band refers to the recent FCC licensed frequencies in the 71 to 86 GHz bands, which allow 1 to 10 Gbps wireless link operation over several miles. Applications include forming a bridge to fiber networks, and providing a backhaul channel for mobile and fixed wireless networks. Emerging E-band developments rely on the recent investments, improvements in performance and cost of suitable mm-wave integrated circuits.[3]

An additional factor in the emergence of commercially viable systems is the availability of suitable very high precision, low cost antennas. Higher gain is required for the greater ranges and is normally provided by precision parabolic reflectors. Companies such as Radiowaves Inc. have pioneered the manufacture and test of such higher frequency antenna solutions for digital radios. Precision antenna surface and feed position tolerances are required to generate tight patterns at mm-wavelengths, together with sophisticated antenna test ranges.[4]

## MILLIMETER-WAVE SATELLITE COMMUNICATIONS

To some extent, the deployment and development of mm-wave satellite communications systems mirrors those of ground-based systems. Highest volume applications involve the use of Ka-band (26.5 to 40 GHz) SATCOM terminals, which, in fact, use frequencies around 20 and 30 GHz for downlink and uplink, respectively. Conventionally the satellite transmits at the higher link frequency to take advantage of the easier deployment of the smaller sized antenna required for the same gain. The challenge for commercial ground terminal manufacturers is the integration of the MMIC device technologies into a high volume commercial application. This is largely a matter of quasi-automated production engineering, and design for production methodologies. An excellent reference paper describing the technology involved is that of R. Alm.[5]

There is every reason to believe the use of higher frequencies will be commercially successful, given the service providers investment in Ka-band satellites, and the experience of current mass market product manufacturing, enabling successful direct broadcasting of TV in frequencies at Ku-band (10 to 14 GHz).

Additionally, given the importance of secure global communications for defence applications, higher data rate

satellite systems have been deployed and are under development, some of which rely on frequency uplinks at around 44 GHz. An example is the US MILSTAR satellite network,[6] which has been operational since 1994 and is being substantially upgraded (MILSTAR II, shown in ***Figure 5***) to provide higher data rates (up to 1.5 Mbps for 192 channels), anti-jamming and inter-satellite cross links at 60 GHz. The most recent satellite in the constellation was launched in 2003.

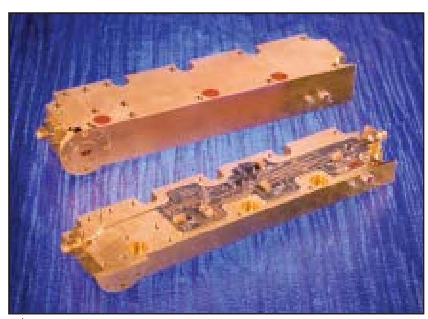
Developments continue with MILSTAR ground terminals focussing on the use of high performance multiple frequency mm-wave converters and antenna systems including the manufacturing technologies required to guarantee a high level of reliability and lower cost using automated production methods (see, for example, a typical converter in ***Figure 6***).

## SCIENTIFIC APPLICATIONS OF MM-WAVES

This subject is too vast to cover here, so just two examples are mentioned, where the contribution from mm-wave systems has been especially significant and developments rapidly evolving. First, millimeter-wave radio-astronomy has become a significant area of research over the last 30 years, since the first detection of molecular species with resonances in the mm-wave spectrum were discovered in extra-galactic molecular clouds. Today, ground-based millimeter and sub-millimeter instruments of increasing sophistication are being used as shared tools for the scientific community. Notable for its sheer scale is the Atacama Large Millimeter Array (ALMA), under construction in a high altitude desert site in Northern Chile.[7]

This millimeter and sub-millimeter radiotelescope is an interferometer consisting of 64 individual 12 m diameter dish antennas, each a wavelength coverage of 0.35 to 10 mm. Resolution will reach 10 milliarcseconds, an order of magnitude better than the Hubble Space Telescope, and it will be an imaging instrument. Scientific goals will be to investigate the cool universe that is radiation

▲ *Fig. 5 MILSTAR II (courtesy of NASA-JPL).*

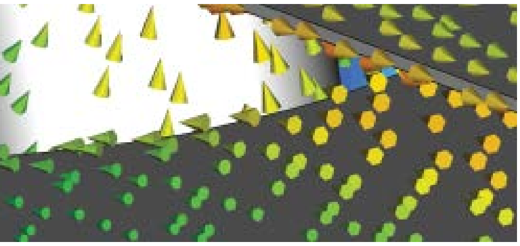


▲ *Fig. 6 44 GHz MMIC upconverter module (courtesy of Farran Technology Ltd.).*







from materials at temperatures from 3 to 100 K, which give rise to spectral signatures in the sub-mm wavelength regions. This will allow the study of molecular gas and dust that forms building blocks for stars, planetary systems and galaxies.

Radio astronomy has historically driven technological developments in receivers, antennas and spectrometers at higher frequencies as the quest for more performance continues. Multi-channel imaging has become important in order to use the observation time effectively and this is driving the development of electronically scanned array sensors with expected spin-offs into other application areas.

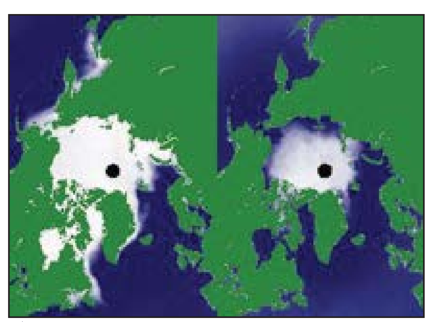
Also of note is millimeter-wave remote sensing, particularly satellite-borne remote sensing of the Earth's atmosphere at millimeter wavelengths, which provides valuable information by global mapping from space. Atmospheric sounding is generally carried out by payloads covering frequencies of interest from around 10 to 183 GHz, designed to measure black body emission from the earth or planetary systems. Multi-spectral mm-wave radiometers have been carried on early satellites pioneered by NOAA-NASA in the 1980s. Such payloads normally are launched with and complement those used for operational meteorological instruments using multispectral infrared and optical imaging. Because land, water, air and ice have differing brightness temperatures, these features can be separated and in some cases uniquely identified.[8] ***Figure 7*** illustrates winter/summer ice pack coverage by microwave remote sensing.

Additionally, temperature sounding of the atmosphere can be provided by use of the properties of the 60 GHz oxygen resonances, and water vapour by means of measuring spectroscopic profiles. The spatial resolution tends to be low (commonly kilometers from spacecraft) and somewhat restricted by the available antenna aperture.

New developments aim at improving the scope in terms of the number of atmospheric constituents detected by increasing the range of frequencies detected, and by providing increased static coverage with geosynchronous satellites. One challenge in this regard with respect to geosynchronous spacecraft for earth imaging is the large antenna size (circa 2 to 3 m diameter) required for reasonable resolution, and the difficulty in scanning this large antenna to provide the required Earth ground coverage. Potentially, mechanical scanners of the type employed by mm-wave passive imagers (discussed later) may be a solution.

## MILLIMETER-WAVE RADARS

Largely developed from defence radar systems, commercial automo-



▲ *Fig. 7 Ice pack coverage winter/summer from satellite by remote sensing.*

tive radar systems using mm-wave sensors are now a reality. Initially based on Gunn diode technologies, it is becoming one of the main application areas for GaAs MMICs. Commercially available forward looking radar systems at 77 GHz allow detection at ranges up to about 200 m. These are marketed as autonomous cruise control (ACC) radars.[9]

To extend this functionality further requires significant improvements in performance (real time classification of targets with insignificant false alarm rates, for example). Despite this current limitation there is a strong market and competition among foundry providers to work with system designers and integrators.[10] Most mm-wave foundries are working with the radar architects to fulfil the needs of the user, who ultimately is the automotive manufacturer. It is not usually cost effective to provide an 'add-on' package because of the high integration cost, so these radars need to be 'designed in.'

GaAs technology promises a full solution to the mm-wave requirements but improvements are still needed (for example, in developing production level designs that do not rely on 'post production' tuning). At 77 GHz packaging is still challenging although MMIC manufacturers such as UMS have made considerable headway with multi-chip packaged approaches.

Another area that requires further development is the provision of suitable VCO solutions for FMCW radars. Initial 0.25 µm PHEMT VCOs have been replaced with HBT designs that offer better low frequency phase noise performance and higher cut-off frequencies using a 0.15 µm process; typically a creditable –85 dBc/Hz at 100 kHz offset can be achieved. As with most system related developments the challenge is to find the optimum combination of functionality and manufacturing cost that will support market growth.

## AIRPORT RADARS

New developments aimed at improving safety following a number of high profile runway accidents (Concorde, Paris 2000 and Milan 2001) are making use of millimeter-wave radar technology. First, radar short-range sensors (~1 km) are radars placed on runway traffic aprons at strategic way points. This is a derivative of conventional approaches that illuminate the complete airport area with a single, high power downward looking radar.[11] The advantages of this 'cellular' approach is that it can offer the possibility of automated collision warnings due to the reduced clutter and lower probability of false alarm. In addition, the lower power required for such sensors allows the possibility of significantly

▲ *Fig. 8 Farran Technology 77 GHz MMIC-based radar sensor module.*

lower cost volume sensor production.[12] Farran Technology manufactures a range of MMIC-based custom radar products, an example of which is shown in ***Figure 8***.

Second, mm-wave foreign object detection radars for airport runway use have been successfully trialled[13] and promise an increased level of safety by ensuring that operational runway debris is detected automatically using multiple millimeter-wave radar sensors. The radars can scan single or multiple runways and relay identified debris locations to a central user display. Automatic localised detection to within a few metres of a small object such as a metal bolt has been demonstrated under all weather conditions day or night. The radar developed by QinetiQ, UK, makes use of the high resolution available from a 1 m mm-wave antenna and the range provided by operating in a 'window' frequency of the mm-wave spectrum. Careful placement and calibration of the radars are required, however, in order to achieve full coverage and minimize local terrain effects.

## SECURITY APPLICATIONS

The potential of mm-wave imaging systems to view concealed weapons or explosives has been the subject of intensive recent developments, responding to the security needs of airports and other establishments. Conceptually the mm-wave 'camera' is not new, having been prototyped by companies such as Millitech and others — notably TRW (now NGST[10]) — in the mid 1980s. However, market 'pull,' advances in mm-wave MMIC production technology, and new system architectures including mechanically scanned optics have spurred the latest developments.

Both passive and active technologies are in use, over a range of (loosely) mm-wave frequencies ranging from 24 to 140 GHz. At these wavelengths, fully populated or 'staring' arrays similar to current multi-pixel optical digital cameras are simply not feasible due to the high cost of individual receiver channels. Thus, the majority of systems use some form of mechanical scanning techniques to form an image from a reduced subset of receiver channels. The major cost element for such systems still tends to be the mm-wave front-end components or arrays. Lower frequency systems can be more cost effective due to the reduced device and packaging costs. However, a larger number of elements and active illumination is generally required to make up for the reduced resolution that is contingent upon the choice of frequency.

Advantages of higher operating frequencies include superior resolution for a given aperture size, enabling completely passive configurations with the requisite performance. Farran Technology has developed low cost advanced amplifier designs and arrays to support low noise imager systems. Advanced optical scanning techniques, such as those applied by the company's patented designs, allow passive linear scans by a low cost multi-channel array to generate distortion-free mm-wave images at video frame rates (~10 Hz). This passive imaging camera (shown

in **Figure 9**) is now manufactured by Smiths Detection,[14] a division of Smiths Group plc. Given the sensitivity of the marketplace to the illumination of persons with millimeter-wave or any other radiation, there may be some advantages to this approach.

## ENABLING TECHNOLOGIES

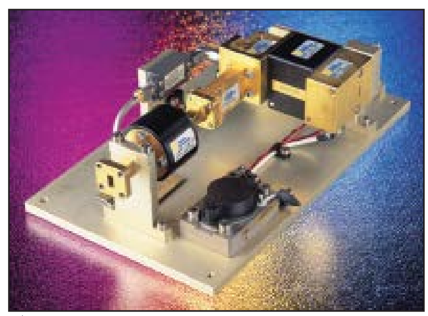
It is probably already clear from the foregoing that key enabling technologies remain to further develop low cost high performance mm-wave MMIC devices, including device packaging techniques and the associated volume production methods. Of some interest in this trend towards lower cost is the potential impact of the reducing geometries and thus increased operating frequencies of CMOS circuits.

Although not designed specifically for analog mm-wave applications, there is potential for considerably lower cost CMOS finding its way into mm-wave applications.[15] Also, considering the discrete device approaches of the late 1980s (see, for example, **Figures 10** and **11**) and today's integrated circuit design equivalents, it is clear that technology has come a long way toward higher levels of integration, reduced size, weight and volume. Such developments allow for the use of increased complexity in demanding high reliability applications including commercial, space and defence markets, and ultimately lower costs for the application of mm-wave technologies in general.

## CONCLUSION

The diversity of uses for the spectral region is what mainly characterises mm-wave applications. A few dominate where the commercial requirements have enabled significant investment in the technology area and there is no reason to suppose the future will

▲ *Fig. 9 Millimeter-wave passive imaging camera for portal security.*[17]



▲ *Fig. 10 Farran's single-channel Ka-band downconverter with discrete waveguide components (approx. 125 x 250 x 75 mm) circa 1990.*

▲ *Fig. 11 Farran's five-channel 35 GHz transceiver MMIC module with integrated PLDRO (75 x 125 x 25 mm).*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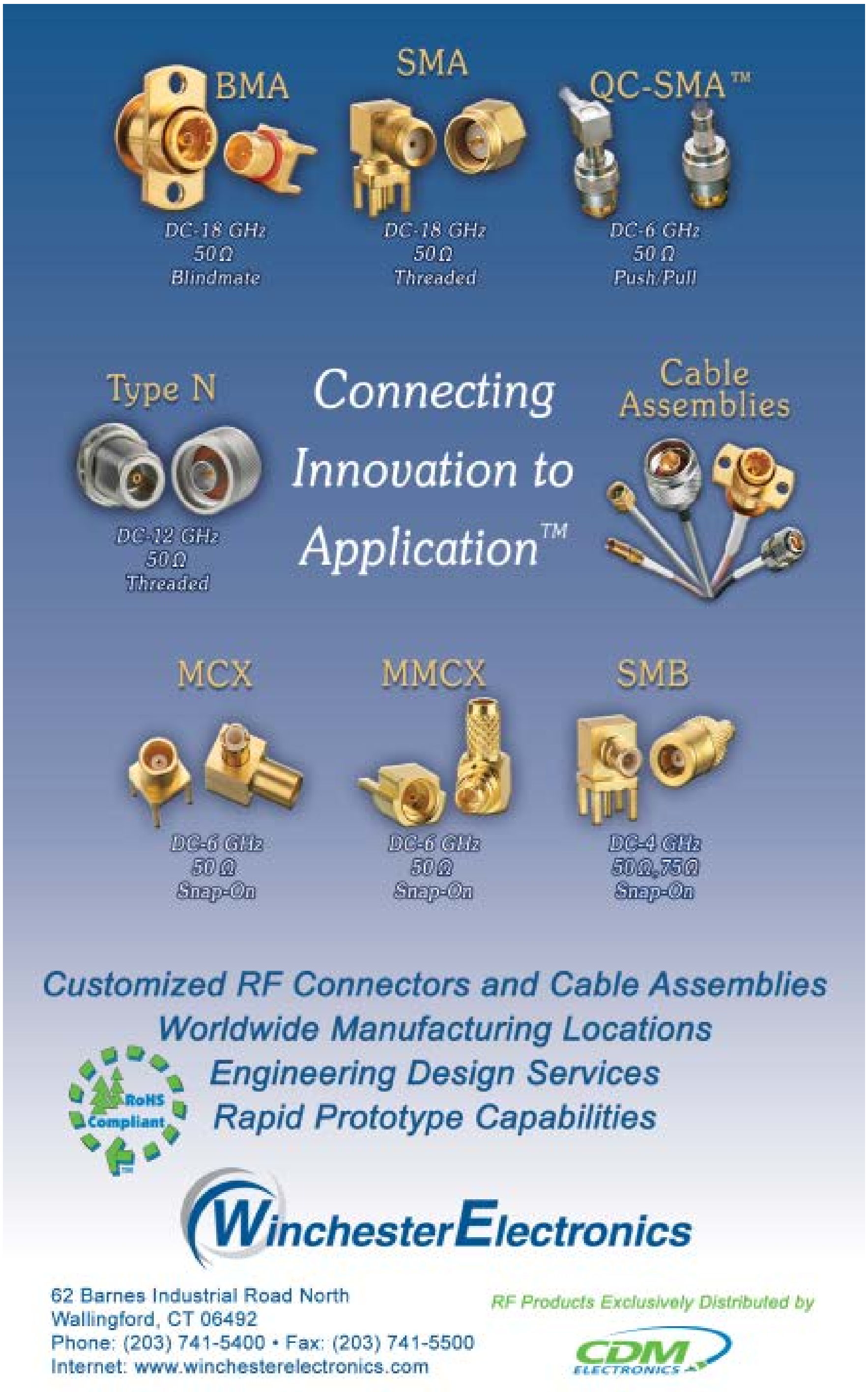
be any different. The need for enhanced security or safety systems offers a significant and worthwhile challenge to the engineering of suitable passive or active mm-wave imaging systems either as standalone devices or in some situations as part of a suite of multiple detection strategies.

As demand for bandwidth increases the used radio communication spectrum looks certain to extend to upwards of 100 GHz, releasing products as spin-offs and reducing cost for new applications. Concomitant demand for power will drive increased developments in new semiconductor technologies areas such as gallium nitride, while demand for smaller devices and more efficient packaging will no doubt encourage the use of mm-wave MEMS. Emerging spectroscopic applications will require sensitive THz-based systems, and thus developments in new quantum sources and detectors will become important. As imaging sensors lower in cost, the deployment of electronically scanned systems in security, satellite systems and a host of civil applications will increase. Millimeter-wave applications have, by default, their particular niche areas that are propelled into the mainstream on commercial imperatives and it appears likely to remain so in the foreseeable future. ■

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**David R. Vizard** *obtained his BSc degree in electronics from UMIST, UK, in 1968. He first worked for Marconi Communication Systems, UK, developing high linearity receiver front-ends. Later he joined the Radio Research Station, Ditton Park, where he initially researched mm-wave solar astronomy and low noise receiver technologies for astronomy and space borne applications. From 1978 he worked at the UK's Science Research Council Rutherford Laboratories, Oxford, UK, in the role of group leader of the Millimeter-Wave Technology Division. In 1986, he took the role of technical manager at Farran Technology Ltd. Currently he holds a senior management position as director of technical sales, and over the years has published a wide range of papers related to developments in the millimeter-wave area. He currently directs Farran's product development in numerous areas including passive imaging, space flight radiometers, millimeter-wave frequency extenders and EVS application radars using FMCW technologies among others.*

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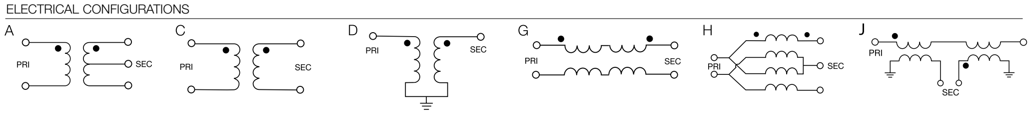



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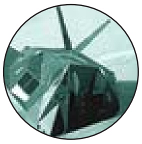



## Lockheed Martin Successfully Tests Entire THAAD Weapon System

Lockheed Martin and the US Missile Defense Agency (MDA) successfully conducted an integrated Terminal High Altitude Area Defense (THAAD) flight test at White Sands Missile Range (WSMR), NM. This is the first developmental flight test to engage the entire THAAD system, including the THAAD interceptor, launcher, radar and fire control system. Specific test objectives included demonstrating all major elements of the THAAD weapon system during engagement of a virtual target: interceptor launch and control; kill vehicle control in response to in-flight up-links; seeker operation; and radar acquisition, track and in-flight communications with the interceptor. All test objectives were achieved. "We achieved a major milestone by successfully testing all of the elements of the THAAD system and proving the system's capability," said Tom McGrath, program manager and vice president for THAAD at Lockheed Martin. "The THAAD flight demonstrations will continue to grow in difficulty and we are eager to press forward. We are confident that the successful completion of these tests will yield a system we will be proud to turn over to our warfighters." US Army soldiers from Fort Bliss' 6th Brigade participated in the test, with two soldiers conducting radar operations, two soldiers assisting contractors at the launcher and one soldier assisting contractors at the THAAD fire control and communications. This is the second successful THAAD developmental flight test conducted since flight testing resumed for the program in November 2005. Three more tests are scheduled to occur at WSMR before THAAD testing moves to the Pacific Missile Range facility in Hawaii. The THAAD interceptor uses hit-to-kill technology to destroy targets and is the only weapon system that engages threat ballistic missiles at both endo- and exo-atmospheric altitudes. A key element of the nation's Ballistic Missile Defense System (BMDS), THAAD is a Missile Defense Agency program, with the program office located in Huntsville, AL. The agency is developing a BMDS to defend the United States, its deployed forces, friends and allies against ballistic missiles of all ranges and in all phases of flight.

## Raytheon's Cobra Judy Program Completes Hardware Design Review

Raytheon Co., with its principal teammate Northrop Grumman, successfully completed a Cobra Judy Replacement (CJR) Mission Equipment (ME) Program Hardware Design Review (CDR). The intensive CDR event took place during five days, concluding with the S-band radar design presentation to the US Navy, with a close out review. Successful completion of the CJR ME program CDR demonstrated to the Navy that the X- and S-band hardware design are complete and ready for construction. The successful CDR sets the stage for the next major program milestone: the post-CDR in-process review this spring. "The CJR Program will provide customers with next-generation integrated solutions for critical data collection challenges," said Pete Franklin, vice president, Raytheon Integrated Defense Systems (IDS) Missile Defense. "It will save the government money by leveraging Raytheon's knowledge across programs and our 30-plus years of experience in radar technology." The CJR ME program is an integrated, surveillance and ballistic missile data collection radar system to support US treaty monitoring activities. Its dual-band radar suite consists of X- and S-band phased array sensors and other mission equipment.

## Northrop Grumman Receives Contract to Upgrade Air Traffic Control Radars

Northrop Grumman Corp. has been selected by the Federal Aviation Administration (FAA) to modify transmitters on 135 ASR-9 air traffic control radars. This will provide cost-effective enhancements in performance and operational availability, while reducing operation and maintenance costs. "Every major airport in America has an ASR-9 radar built by Northrop Grumman," said Tom Chrzanowski, director of FAA Air Traffic Management Systems at Northrop Grumman's Electronic Systems sector. "All told, these radars enable air traffic controllers to monitor the arrival and departure of over 90 percent of all domestic air traffic and provide important air surveillance information over major metropolitan areas for homeland security and defense. The transmitter modification will simplify the process by which the ASR-9 generates a tracking pulse. The modification will reduce potential outages and costs, while providing a modular framework for potential future enhancements. Minimizing present radar operational costs will help enable the transition toward the next-generation air traffic control system. We are pleased to continue our legacy of providing cost-effective solutions in support of the FAA's National Airspace System." This $40 M award is the latest in the FAA's multi-phase, ASR-9 sustainment program, intended to extend the service life of the ASR-9 through 2025. Prior service phases involved weather and processing system upgrades, a detailed service life extension study, development of a proof-of-concept system, and validation of specific antenna and transmitter modifications. The program is administered by the FAA's Air Traffic Organization. Northrop Grumman has over thirty years experience in the design, production and support of more than 400 ground-based surveillance radar systems for the FAA. These key National Airspace System elements support enroute, terminal and airport operations

# DEFENSE NEWS

and provide critical surveillance information to the departments of Homeland Security and Defense for homeland security purposes.

## Raytheon Technology Shows Promise in Extracting Oil from Shale

Shale reserves, estimated at more than two trillion barrels in the US, are a potential source of oil that now may be economically unlocked thanks to technology developed by Raytheon and its partner CF Technologies. Raytheon's Integrated Defense Systems (IDS) business RF energy, combined with critical fluid CF technology, shows promise for efficiently extracting oil from shale. "Raytheon is an expert in RF technology," said Lee Silvestre, director of Mission Innovation at Raytheon IDS. "What makes this effort a breakthrough is that similar RF technology that we have been applying in core defense products has demonstrated applications in the energy crisis." Historically, the lack of an economical and environmentally friendly way for extracting oil from shale has kept it from being a significant energy source. Raytheon IDS and its partner, CF Technologies, located in Hyde Park, MA, have struck upon a solution that could solve both the economic and environmental roadblocks. "We have partnered with CF Technologies, a company expert in critical fluids processes," said Silvestre. "We are now talking with energy companies to license our unique, patent pending, technological approach." Combining RF and CF technologies provides a revolutionary way for recovering oil from shale reserves worldwide, according to John Moses, president of CF Technologies. Based on laboratory results and analysis, the oil produced is a light product, comparable to kerosene, that can be produced by the unique process with high extraction efficiency. "We took a system approach to the energy problem," said John Cogliandro, Raytheon IDS chief engineer for the project. "Oil companies are under pressure to be more efficient in how they extract energy sources from the ground. Using our RF-CF technique provides a viable response to these pressures." In addition to producing more oil from shale formations, some companies may consider it an option for improving return from existing reserves that have been marginal, including heavy oils, tar sands and spent wells. The development of this technology continues while outside experts are considering its ramifications. ■

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## Microsystems Investment is a Plus

INTEGRAMplus, a three year, €6.5 M programme funded by the European Commission and aimed at reducing the costs and risks associated with designing, prototyping and manufacturing integrated Microsystems, has been launched. The new project will be co-ordinated by the UK's QinetiQ, the company that also led the programme's successful forerunner, INTEGRAM, which focused on silicon sensors and electronics. As well as QinetiQ, this new project will also draw on the complementary expertise and facilities of 10 partners from seven different European countries.

The programme will adopt a multi-technology approach and will initially focus on integrating silicon-based MEMS components with polymer backplanes and platforms. Three proof-of-concept demonstrator components will be developed and will include a bio-diagnostics sensor based on customer requirements.

The ultimate goal of INTEGRAMplus is to stimulate take-up of micro and nanotechnologies (MNT) by end users by providing flexible design and prototyping services with a route to manufacture. With its unique combination of pan-European capabilities and supported by an extensive network of supply chain partners, the programme aims to provide European industry with a world-leading facility to stimulate take-up and accelerate time-to-market of smart mixed-technology components and products. Design for manufacturing principles, based on state-of-the-art simulation tools, will be used to reduce risk via virtual manufacturing design studies.

Welcoming the programme's launch, Marcel Hugen, project officer for the European Commission, sponsor of the programme, said, "Micro and nanotechnologies are increasingly being exploited across a wide range of markets with many European companies and institutions demonstrating world-class capabilities. INTEGRAMplus will be a flagship EC project, combining the expertise of its partners for the benefit of European industry, from design and proof of concept, to manufacturing and system integration. This will ensure the continuation of the well known Europractice Initiative in the domain of micro and nanosystems."

## TIPS for NATO

The TIPS industries — EADS, Galileo Avionica, General Dynamics Canada, Indra, Northrop Grumman and Thales — have established a joint venture company to respond to a request for a proposal from NATO for the Alliance Ground Surveillance programme. A contract for the design and development (D&D) phase is expected from NATO later this year. The joint venture company, AGS Industries GmbH, will be the prime contractor for the programme.

The NATO AGS system will provide situational awareness through a shared common ground picture that will be available to NATO and national decision makers. The TIPS mixed fleet of manned and unmanned platforms will provide the Alliance with a core component for the NATO Response Force, providing a critical capability designed to meet its Intelligence, Surveillance and Reconnaissance (ISR) and Command and Control (C2) requirements for the $21^{st}$ century. The mixed fleet solution will also support a variety of new mission requirements for NATO including nation building, homeland security and humanitarian relief.

Speaking on behalf of the TIPS industries, Johann Heitzmann, president and chief executive officer of EADS Military Air Systems, said, "We are very satisfied that we have established the AGS Industries GmbH. The joint venture demonstrates the participating companies' commitment to integration and cooperation, and has helped us establish a united approach towards our NATO customer."

## TRL Technology Invests in Future

In order to develop and focus its business and as an investment for the future TRL Technology Ltd., the wholly-owned subsidiary of TRL Electronics plc, has reorganised its operations and opened a new high technology manufacturing facility. The company, which produces innovative leading edge radio and satellite communications systems, is now organised into three principal business divisions — Surveillance Systems (formerly the Government Communications and the Defence Systems divisions), Defence Electronics (previously the Technology & Innovation division), and Electronic Security, complemented by Operations, Customer Support and Quality Assurance.

The new purpose-equipped 20,000 ft$^2$ manufacturing facility, which also houses the company's Customer Support and Quality Assurance Centre, is part of an investment programme of more than £1.8 M. It is the latest addition to a number of secure sites that the company operates near Tewkesbury, UK.

Martin Somers, the company's director of manufacturing, commented, "This new facility represents an extremely important step for TRL Technology. It provides us with a high tech medium volume production capability to support the state of the art designs being developed by our specialist business divisions. These cover a wide range of advanced defence electronics, satellite monitoring and commercial solutions, as well as manufacture for a number of ongoing contracts with the UK MoD, the US DoD and other government agencies around the world."

## Nokia Commits to China

As a sign of its commitment to the Chinese market Nokia has selected the Beijing Economic-technological Development Area (BDA) as the location for its Nokia China Campus. It will be the company's headquarters for its activities in the Greater China Area. It will also be the headquarters for its R&D centres and mobile phone manufacturing base and is scheduled to open in the later part of 2007.

On completion the world-class campus will host over 1500 staff from R&D, sales and marketing operations, pre-production, logistics, sourcing and manufacturing operations. Eventually, the aim is for more than 2000 Nokia employees to be based in this new hub.

Jorma Ollila, chairman and CEO of Nokia, stated, "For us it will integrate all parts of our operations in one location, providing unique opportunities for exchange of information and ideas, as well as for very effective operations across all of Nokia and with our partners. For Xingwang Park and BDA it means the kick-off of a new phase of development, going from being a primarily manufacturing based area to being a true world class end-to-end business park."

## ESA and Avanti Get European Coverage

The European Space Agency (ESA) and Avanti Screenmedia Group plc have signed a contract for the implementation of the Highly Flexible Satellite (HYLAS), a hybrid Ka-band/Ku-band satellite with European coverage. The contract between the two companies covers support for the development of the most innovative elements of this new system. The supplier of the HYLAS Satellite is EADS Astrium Ltd. and ESA's contribution is €34 M of a total estimated project cost of €120 M.

With a launch mass of around 2100 kg and beginning-of-life power of 3.5 kW, HYLAS is a moderately sized satellite that allows the scalable introduction of new enhanced services with limited technical and financial risk. By using high gain Ka-band spot beams, it is possible to provide up to eight simultaneously active spots, a capacity equivalent to more than 40 conventional 33 MHz transponders.

Giuseppe Viriglio, director of European Union and Industry Programmes for ESA, commented, "HYLAS will play an important role in demonstrating the advanced technological capabilities of European space companies, which are truly competitive on a global scale." ■

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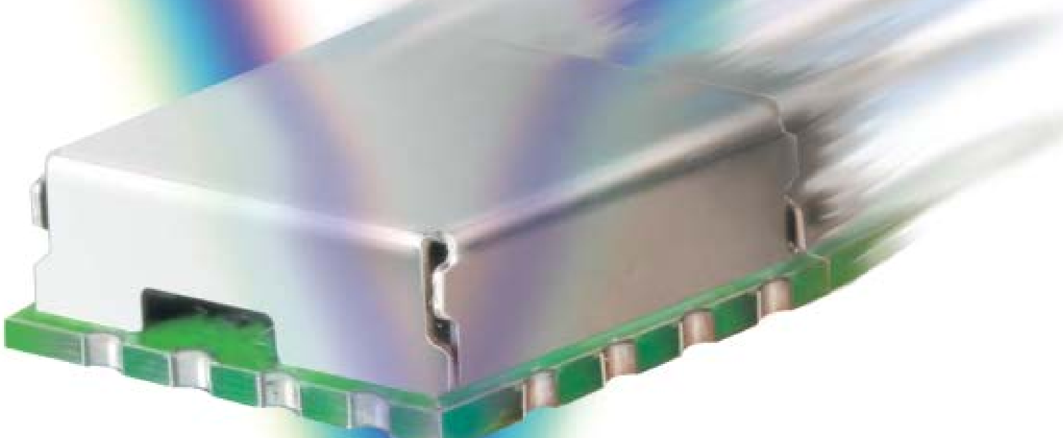

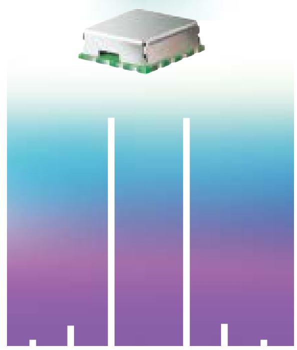

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***U.S. Patent Number 6,807,407***

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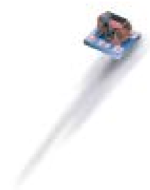
***RF/IF MICROWAVE COMPONENTS***

412 Rev Org

# WORLD'S SMALLEST
# 2WAY-0° SPLITTERS

*5 to 2500MHz...Immediate Delivery*



$1.69 *from* each (qty.1000)

Measuring only 0.15" square, Mini-Circuits tiny SBTC power splitters are also the ***world's lowest priced*** 2way-0° splitters operating within the 5 to 2500MHz band. But that's not all! Patented technology provides outstanding performance features including ***low insertion loss*** down to 0.3dB typical, excellent 0.2dB amplitude and 1degree phase unbalance (typ), and ***superior temperature stability***.

Pads are solder plated, and connections are assembly welded for high temperature reflow reliability. As demand for smaller gets bigger, blow away the competition with Mini-Circuits space saving, ***money saving*** SBTC power splitters.

CUSTOM PRODUCT NEEDS...*Let Our Experience Work For You.*

| Model | Freq. (MHz) | Z | Price $ea. (Qty. 25) |
|---|---|---|---|
| SBTC-2-10+ | 5-1000 | 50Ω | 2.49 |
| SBTC-2-20+ | 200-2000 | 50Ω | 3.49 |
| SBTC-2-25+ | 1000-2500 | 50Ω | 3.49 |
| SBTC-2-10-75+ | 10-1000 | 75Ω | 3.49 |
| SBTC-2-15-75+ | 500-1500 | 75Ω | 3.49 |
| SBTC-2-10-5075+ | 50-1000 | 50/75Ω | 3.49 |
| SBTC-2-10-7550+ | 5-1000 | 50/75Ω | 3.49 |

***U.S. Patent No. 6,963,255***

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***RF/IF MICROWAVE COMPONENTS***

354 Rev E

## IEEE 802.19™ to Standardize Coexistence of Wireless Methods

The IEEE 802.19™ Wireless Coexistence Technical Advisory Group (TAG) has begun development of a recommended practice on methods for assessing the coexistence of wireless networks. This document will define recommended wireless coexistence metrics and the methods for computing them, as well as various wireless coexistence scenarios. "Industry continues to develop new standards and specifications for wireless networks that operate in the same frequency bands as other wireless networks," said Paul Nokolich, chair of the IEEE 802 (R) Local Area and Metropolitan Area Network Standards Committee. "IEEE 802, for instance, has multiple working groups developing wireless networks standards for systems that share frequency bands. The recommended practice to be created by the IEEE 802.19 TAG will help IEEE 802 working groups and the rest of the industry assess the performance of new wireless technologies and those now deployed in shared frequency bands." Steve Shellhammer, chair of the 802.19 Technical Advisory Group, adds that "The IEEE 802.19 TAG continues its work to meet the evolving needs of the public and industry. This project addresses the call for standardized methods to evaluate how effectively wireless networks coexist." The document to be developed by the TAG, IEEE 802.19, "Recommended Practice for Information Technology – Telecommunications and Information Exchange Between Systems – Local and Metropolitan Networks – Specific Requirements – Part 19: Methods for Assessing Coexistence of Wireless Networks," is expected to be published in 2008.

## RFID Big Picture

Radio Frequency Identification – RFID – is a technology of many uses. In one form or another, it is found in fields as varied as supply chain logistics, aerospace and defense, automotive, border security, life sciences and pharmaceuticals, retail and transportation. Although many reports published by ABI Research and other analysts address specific vertical markets and RFID applications, their diversity has often made it difficult for investors, governments, integration service providers, end-users, developers and others to grasp the bigger picture and to understand the landscape of this rapidly growing collection of markets. That gap has now been filled by a new ABI Research study, "RFID Annual Market Overview: Vertical Market and Application Market Overview for Tags, Readers, Software and Services." It provides a high level, but still detailed examination of RFID technologies, applications and addressable vertical markets by region, and is intended to give readers a general outline of the broad RFID market. According to Erik Michielsen, director, RFID and Ubiquitous Network Research, "RFID shows nuances across technologies, but also identifies the relevant applications for them and how vertical markets are building use-cases for them within application and business process environments." The research also highlights the differences between low growth RFID applications, such as access control, animal tracking and vehicle immobilization, and high growth applications, such as personal identification documents, contactless point-of-sale and item-level RFID tracking. "The study includes a number of vendor profiles," adds Michielsen, "and it is worth pointing out that they are not intended to be any kind of 'Top 30' list; rather, they have been chosen to reflect the wide range of specializations, company sizes and global locations that characterize the massive RFID ecosystem."

## Taiwan, China Leading Strong Asian Semiconductor Manufacturing Growth

After the 300 mm wafer fabrication went online in 2004, the semiconductor manufacturing capacity in Asia has continually grown, especially in Taiwan, and growth will continue for the next several years, reports In-Stat. With Taiwan building up foundry capacity, it has become the highest fabrication density area, says the high tech market research firm. "Capacity in China will also grow rapidly over the next several years," says Prakash Vaswani, In-Stat analyst. "Price advantages and emerging domestic fabrication-less companies will allow China's local foundries to survive."

*Recent research by In-Stat found the following:*

- Due to outsourcing trends catching up with IDM, dedicated foundry companies are benefiting from outsourcing orders both from IC design houses and IDMs.
- Because of 300 mm wafer fabrication's capital risk and a more competitive industry environment, alliance and mergers will become a common phenomenon in this industry.
- TSMC and UMC are the leading foundries in Asia and will account for over 50 percent of Asian capacity through 2009.

The research, "Semiconductor Manufacturing Capacity by Countries in Asia, 2006," covers the Asian semiconductor manufacturing industry and includes capex and capacity by key accounts from 2004 to 2008, with the forecast segmented further by major geographic region. This research identifies and quantifies industry development within each major geographic region and recommends strategies for vendors to take advantage of these opportunities. It also discusses East Asia IDMs, foundry and DRAM vendor development. This research is part of In-Stat's Asia Semiconductor and Manufacturing Service, which tracks semiconductor consumption by application and by country. This service forecasts application segments in crucial Asian markets, including China, India, Japan, Korea and Taiwan.

## MEMS in Mobile Handsets Will Top $1 B by 2010

MEMS consumption in mobile handsets reached $157 M in 2005 and by 2010, consumption will exceed $1 B, reports In-Stat. In addition to the microphones and bulk acoustic resonators that have dominated the MEMS market to date, there are emerging opportunities for inertial sensors (principally accelerometers) and several types of RF components including band/mode switches, matching elements (such as digital varactors) and oscillators, says the high tech market research firm. "Although high volume MEMS, such as microphones and bulk acoustic resonators, are cost competitive, there are no near-term opportunities for other types of MEMS to break into the mobile handset market based on price advantage," says Frank Dickson. "Longer term, displays, fuel cells and other types of MEMS devices could also develop a price advantage. However, suppliers of these devices may find a quicker path to profit in other markets that have less demanding cost and size requirements."

*Recent research by In-Stat found the following:*

- Mobile handsets, which are the largest single product market for semiconductors outside the personal computer (PC) market, are also a major opportunity for MEMS component suppliers.
- MEMS mode/band switches and digital tuning will first appear in mobile handsets in 2007, followed by MEMS-based oscillators in the following year.
- In the microphone area, continued growth is foreseen based upon an increasing demand for ultra thin handsets, as well as continuing price declines.

The research, "MEMS – Making Their Mark in Mobile Handsets," covers the intersection of mobile handsets and MEMS. It includes forecasts of MEMS handset components through 2010. It also analyses key issues, including: How will current MEMS applications grow? Where and why can MEMS devices replace other types of components? What new features can MEMS enable? What are MEMS limitations? This research is part of In-Stat's Emerging Semiconductor Chips and Applications Service, which focuses on the new or changing critical semiconductor applications and technologies that could change the dynamics of the semiconductor industry and drive future demand. Specifically, this service provides reports covering the hot applications, emerging semiconductor chips and selected high growth areas. The editorial calendar for this service changes throughout the year according to changes in the market, new technologies and customer requested topics. ■



## INDUSTRY NEWS

■ **Ducommun Inc.** announced that its Ducommun Technologies Inc. (DTI) subsidiary has acquired the capital stock of **WiseWave Technologies Inc.**, a privately held company based in Torrance, CA. WiseWave is a manufacturer of custom microwave and millimeter-wave products for both aerospace and non-aerospace applications. WiseWave's sales for the last twelve months were approximately $4.4 M. Terms of the transaction were not disclosed. The principal shareholders, Yonghui Shu and Xiaoxin Gu, will remain with the business. Following the acquisition the WiseWave business will be integrated with DTI's Carson, CA microwave business.

■ **Aeroflex** announced that an agreement has been reached with **Kenwood USA** for providing advanced P25 testing solutions to Kenwood dealers. Under this program, Kenwood dealers will be able to lease the Aeroflex 2975 Advanced P25 radio test system at special discount rates. The 2975 will be used in the installation, test and alignment of P25 and other radio systems currently fielded and in development from Kenwood.

■ **TTP Communications plc** and **Analog Devices Inc.** (ADI) announced that TTPCom's subsidiary, TTPCom Ltd., has reached an agreement with ADI — its long time collaborator in the development of silicon and software for cellular phones — under which TTPCom will transfer to ADI intellectual property, engineering resources and related assets associated with the support and customization of TTPCom GSM/GPRS/EDGE modem software specifically for use on ADI products. The agreement grants ADI the right to directly distribute TTPCom's modem software for use on ADI SoftFone baseband products and provides development rights for AJAR, TTPCom's advanced applications platform. This agreement is designed to simplify wireless device development for customers by consolidating the resources involved in the licensing and customization of SoftFone-based hardware and software at one company, ADI.

■ **Agilent Technologies Inc.** announced a reorganization of its electronic measurements group, merging the company's operations support systems group with two other existing businesses within EMG. David Churchill, Agilent's vice president and general manager of the Design Validation Division, will head the new business unit, named Network and Digital Solutions. Before joining Agilent in 2005, Churchill was the senior vice president and general manager, communications and video business unit, at Tektronix.

■ **Vishay Intertechnology Inc.** announced that its group of five Vishay-owned and independent Precision Centers is available to serve the needs of design engineers, purchasing agents and others looking for small quantities of Vishay ultra-high-precision Bulk Metal® foil resistors. The Precision Centers located in Malvern, PA; Sterling, MA; Houston, TX; St. Paul, MN; and Ontario, CA use standard Vishay-approved manufacturing procedures. The facilities provide delivery in up to three days, do not have any minimum-order requirements and will provide resistors at any tolerance available within published resistance ranges.

■ **Nu Horizons Electronics Corp.**, a global distributor of advanced technology active components and system solutions, continues to focus its efforts on expanding the organization's Asia Pacific operations by adding technical and sales support in Nanjing and Chengdu, China. In addition, over recent months, the company has established new or upgraded facilities in Beijing, Shanghai, Wuhan, Hong Kong, Seoul, Bangkok and Bangalore.

■ **Pendulum Instruments** has further expanded its international activities. The company has its headquarters in Stockholm, Sweden, with subsidiaries in Oakland, CA and also St. Petersburg, Russia. International sales are performed via some 80 distributors around the world. The company has established a new office in Beijing, China, to support the company's distributors in China and identify opportunities within the Chinese market. The office is located at Pendulum Instruments, China, Room 540A, No. 6 Xi Zhi Men Wai Da jie, Xi Cheng District, Beijing 100044, PRC, China +86 683 11 857 or e-mail: rong.zheng@pendulum-instruments.cn.

■ **Elcoteq SE**, a global provider of electronics manufacturing services for the communications technology industry, announced its move to new facilities in Manaus, Brazil and Juarez, Mexico. Relocating to these new premises enhances the manufacturing and office space and enables Elcoteq to provide state of the art services to its present and future customers in the Americas. The company's other sites in the Americas are located in Monterrey, Mexico and in Texas.

■ **Aperto Networks** announced a strategic alliance with **Allied Telesis** to sell Aperto Networks' carrier-grade PacketMAX™ solutions, starting with the 2.5 GHz product supply for the Japanese market.

■ **RF Monolithics Inc.** announced that it has begun shipping evaluation kits for its recently announced TRC101, TXC100, TXC101, TXC102 and RXC101 single chip, feature rich, transceiver, transmitters and receiver IC products. The evaluation boards, available in various frequencies, are designed to serve as standalone platforms and allow for complete evaluation of the RFICs without the need to develop code for a microcontroller.

■ **Circuit Components Inc.** (CCI) announced that the company's line of Rigid/Bus® board stiffeners are RoHS compliant. RoHS compliance takes effect this month and will require all manufacturers of electronic and electrical equipment sold in Europe to be in compliance with the EU's Restriction of Hazardous Substances Directive that mandates reduction of six hazardous substances.

Secret Unveiled.

TOP SECRET:

Code Name: "GALAXY"

Objective: Utilize space-age technology to combine rugged construction and low cost.

The Product: SGM "GALAXY" Series

## SGM "GALAXY" Series

- 0.25 to 18 Ghz
- Multi-Octave Bandwidth
- Low Conversion Loss
- *SYNSTRIP®* Multi-Layer Technology
- Lead Free - RoHS Compliant
- Patent Pending REL-PRO® Technology


RoHS COMPLIANT

| Model # | Frequency (MHz) LO/RF | Frequency (MHz) IF | Isolation (dB) [ Typ/Min ] LO/RF | Isolation (dB) [ Typ/Min ] LO/IF | Isolation (dB) [ Typ/Min ] RF/IF | Conversion Loss (dB) [ Typ/Max ] | LO Power (dBm) [ Nom ] | Input IP3 (dBm) [ Typ ] |
|---|---|---|---|---|---|---|---|---|
| **SGM Series** | | | | | | | | |
| SGM-2-7 | 250 - 3250 | DC - 700 | 30/15 | 10/5 | 30/15 | 6.5/8.5 | 7 | +10 |
| SGM-2-13 | 250 - 3250 | DC - 700 | 30/15 | 10/5 | 30/15 | 6.5/8.5 | 13 | +16 |
| SGM-2-17 | 250 - 3250 | DC - 700 | 30/15 | 10/5 | 30/15 | 6.5/8.5 | 17 | +20 |
| SGM-3-7 | 1350 - 7000 | DC - 2000 | 25/10 | 20/8 | 20/10 | 7/9.5 | 7 | +8 |
| SGM-3-13 | 1350 - 7000 | DC - 2000 | 25/10 | 20/8 | 20/10 | 7/9.5 | 13 | +14 |
| SGM-3-13 | 1350 - 7000 | DC - 2000 | 25/10 | 20/8 | 20/10 | 7/9.5 | 17 | +18 |

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■ **Lexycom Technologies Inc.**, a manufacturer of software defined radios, announced it has implemented the necessary internal and external process changes to ensure a smooth and seamless transition into being RoHS compliant.

■ **picoChip** and **Airspan Networks** announced complete WiMAX Forum certification of Airspan's MacroMAX basestation for the 3.5 GHz FDD profile. The MacroMAX is powered by picoChip's software upgradeable architecture, as are Airspan's HiperMAX and MicroMAX-SDR basestation models, which are expected to achieve certified status during 2006. All three products can support both 256 OFDM and SOFDMA PHYs.

■ **Teledyne Relays** has been recognized as one of the Top Preferred Suppliers for 2006 by **Rockwell Collins**. Teledyne Relays, a producer of switching products, was cited for performance in meeting delivery schedules and product quality. The company was also recognized for design and engineering support and the teamwork demonstrated with Rockwell Collins.

■ **Evans Capacitor Co.** has been awarded a US Chamber of Commerce Small Business Blue Ribbon award. Evans Capacitor developed and now manufactures advanced capacitors for aerospace and defense applications. This award, sponsored by AIG, was designed to honor businesses that showed excellence in a variety of selection criteria, including financial performance and business history, staff training and motivation, community involvement, customer service and business planning.

■ **Printed Circuits Corp.**, a specialist in design, fabrication, assembly, box build, repair and testing of printed circuit boards in prototype to production quantities, announced its facility has received SDB/8a certification from SBA.

## CONTRACTS

■ **Herley Industries Inc.** announced that it has received a \$2 M contract award to provide the avionics for an advanced domestic target program. This contract represents a follow-on order to **Micro Systems Inc.**, Herley's Center of Excellence for all command and control systems.

■ **Planar Electronics Technology** (PET) has won a \$1.4 M production contract for an Airborne Military Surveillance RF Distribution Subsystem. This production contact was awarded by a prime US Government Contractor that PET has been working with on the design and development of this subsystem.

■ **EMS SATCOM**, a division of EMS Technologies Inc., reports that **Bombardier Aerospace** has selected the company's eNfusion™ AMT-3800 high gain antenna as an approved factory option of its ultra long range Global™ Express XRS and super large Bombardier Global 5000™ business jets. The AMT-3800 antenna joins the company's AMT-50 tail-mounted high gain antenna as an option available to aircraft purchasers.

■ **Andrew Corp.** has won a strategic exclusive development and production contract from **L-3 Communications–Narda Satellite Networks** for a new 3.9 meter flyaway tactical satellite earth station antenna. The award is the first for Andrew's new military satellite communications product line.

■ **CSR plc** announced that it has chosen **Anritsu**'s MT8852B EDR test set for integration into its "Bluetooth Characterization Systems" for automated testing of standard rate and EDR Bluetooth devices. The MT8852B Bluetooth EDR test set fully implements v2.0 standard test mode signaling. This will expedite the test and verification of new designs from CSR.

■ **Tektronix Inc.**, a worldwide provider of test, measurement and monitoring instrumentation, announced that **Sony Corp.** has adopted Tektronix Real-Time Spectrum Analyzers (RTSA) and RFID analysis software developed for measuring and analyzing communication conditions between a reader/writer and an IC card equipped with Sony FeliCa contactless IC card technology. This combination of application specific software and Tektronix Real-Time Spectrum Analyzers has helped Sony to quickly measure and troubleshoot communication conditions, and create consistent and reproducible results.

## FINANCIAL NEWS

■ **Silicon Laboratories Inc.** reports sales of \$114.5 M for the first quarter of 2006, compared to \$104.8 M for the same period in 2005. Net income for the quarter was \$11 M (\$0.19/per diluted share), compared to a net income of \$17.4 M (\$0.31/per diluted share) for the first quarter of last year.

■ **ANADIGICS Inc.** reports sales of \$35.7 M for the first quarter of 2006 ended April 1, 2006, compared to \$21.8 M for the same period in 2005. Net loss for the quarter was \$4.6 M (\$0.12/per share), compared to a net loss of \$11.5 M (\$0.34/per share) for the first quarter of last year.

■ **Ansoft Corp.** reports sales of \$24.7 M for the fourth quarter of fiscal 2006 ended April 30, 2006, compared to \$21.7 M for the same period in 2005. Net income for the quarter was \$8.3 M (\$0.32/per diluted share), compared to a net income of \$4.7 M (\$0.18/per diluted share) for the fourth quarter of last year.

■ **WJ Communications Inc.** reports sales of \$12.3 M for the first quarter of 2006 ended April 2, 2006, compared to \$7.8 M for the same period in 2005. Net loss for the quarter was \$2.4 M (\$0.04/per share), compared to a net loss of \$7.7 M (\$0.12/per share) for the first quarter of last year.

■ **Merrimac Industries Inc.** reports sales of \$6.2 M for the first quarter of 2006 ended April 1, 2006, compared to \$7.3 M for the same period in 2005. Net loss for the quarter was \$441,000 (\$0.14/per share), compared to a net income of \$84,000 (\$0.03/per share) for the first quarter of last year.

■ **Superconductor Technologies Inc.** reports sales of \$4.8 M for the first quarter ended April 1, 2006, com-

pared to $4.4 M for the same period in 2005. Net loss for the first quarter was $3.2 M ($0.26/per diluted share), compared to a net loss of $5.5 M ($0.51/per diluted share) for the first quarter of last year.

## NEW MARKET ENTRY

■ **Fairchild Semiconductor** marks its entrance into the high performance amplifier market with five operational amplifiers (op amps). The 210 MHz FHP3x50 and the 50 MHz FHP3x30 families allow designers to target a broad range of high definition (HD) and standard definition (SD) video applications including set-top boxes, digital TVs and audio/video amplifiers. These two product families were developed with Fairchild's new proprietary "BCP6T" technology. Fairchild's high performance op amps allow video designers to achieve their dual objectives of delivering good amplifier performance and maintaining low power consumption.

## PERSONNEL

■ ARRIS announced the appointment of **Charles Cheevers** to the role of CTO, Europe. Cheevers will also continue in his role as vice president of engineering for the ARRIS Cadant® C3™ CMTS and Keystone™ D5™ DMTS products and as general manager of the ARRIS R&D Center in Cork, Ireland. The addition of the European CTO role to Cheevers' responsibilities, coupled with the company's large technology presence in Europe, will increase the company's ability to serve the needs of European MSOs in cable technology.


▲ *Alistair Manley*

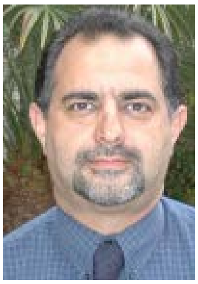
■ SiGe Semiconductor announced that **Alistair Manley** has been promoted from senior director of marketing to vice president, partner development. Leveraging over 34 years experience in business development, marketing and sales, Manley will manage worldwide development and communication activities for the company's strategic reference design partners.


▲ *Linda Wood*

■ Crane Aerospace & Electronics, a segment of Crane Co., has appointed **Linda Wood** as electronics group vice president of human resources. In this capacity, Wood will lead the intellectual capital process and all human resource functions for the electronics group. She will be located in Redmond, WA. Wood joined the company in 1996 as manager of employee benefits and payroll for ELDEC, one of the brands which comprise Crane Aerospace & Electronics. In 2002, she was promoted to the position of director of compensation and benefits for Crane Co.

▲ Paul Jeffs

■ **Paul Jeffs** has been appointed to the role of director of European field marketing for Anritsu. He will lead the marketing operation in Europe, the Middle East and Africa for all the company's test and measurement and service assurance products, across all markets. These include: wireless, wired and IP equipment vendors, and network operators in both the fixed-line and wireless sectors. Jeff's role will be to promote the end-to-end solutions that include the company's traditional test and measurement tools and the service assurance solutions historically offered by NetTest.



▲ Amir Saket

■ Sabritec has welcomed **Amir Saket** as the company's director of operations. In this position, Saket is responsible for developing and maintaining manufacturing business plans that support customer requirements. He will ensure that objectives for product delivery, production costs and quality requirements are met. Saket will drive lean initiatives in operations and will champion various continuous improvement projects. He has over 18 years experience in all facets of connector operations. In related news, **Fredrik Thorell** has joined the company as applications engineer. In this position, Thorell will act as the liaison between the customer and engineering department. He will provide commercial and technical product support and recommend appropriate application specific interconnect solutions to the US and European markets. Prior to joining Sabritec, Thorell had worked as a components and design engineer for connectors, back shells, cables and fiber optic interconnects, and was the technical advisor to production, purchasing, design and planning.

▲ Fredrik Thorell

■ Kyocera America Inc. announced several promotions. **Steve Bowen**, formerly executive account manager, has been promoted to district sales manager for the newly established Phoenix District Sales Office, responsible for managing the office's sales activities and personnel. **Tony Soldano**, formerly executive account manager, has been promoted to district sales manager for the newly established East Fishkill sales office, responsible for managing the office's sales activities and personnel. **Antonio Pagkalinawan**, formerly sales engineer, has been promoted to district sales manager of the New Jersey District, responsible for managing the office's sales activities and personnel. **Josh Castleberry**, formerly sales engineer, has been promoted to sales product manager for electro-optical products, responsible for EO sales in the US. **Keith Fujii**, formerly layer division program manager, has been promoted to layer division design manager.

**Nancy Platon**, formerly senior staff accountant, has been promoted to manager of accounts payable and general ledger. **Richard Sabo**, formerly junior accountant, has been promoted to staff accountant and assumed the additional responsibilities of import administration.

■ MICA Microwave has appointed **Dennis Deck** as the company's sales and marketing manager. Deck will manage the company's sales team and have direct responsibility for western states regional sales, and far eastern region, which includes China, India, Japan and Singapore. He has over 20 years of experience in the microwave industry, which includes a sales history specializing in microwave components.

## REP APPOINTMENTS

■ **Aeroflex/Weinschel Inc.** announced that it has signed an exclusive agreement with **Cain-Sweet Co.** to expand the company's territory as a manufacturers representative to now include Canada. Cain-Sweet has represented Aeroflex/Weinschel in the Pacific Northwest and has offices in Vancouver, Calgary, Toronto, Ottawa, Montreal, Portland and Seattle.

■ **MITEQ Inc.**, a supplier of RF and microwave components, has appointed **MHz Marketing Inc.**, Laurel, MD, as its exclusive sales representative in Virginia, Maryland, eastern Pennsylvania and southern New Jersey. MHz Marketing can be reached at (301) 317-5001.

■ **Pulse**,® a Technitrol company, announced that the company has expanded its sales channels in North America, including Canada, Mexico and Puerto Rico through its distributor **Digi-Key**. Pulse products can be purchased directly from Digi-Key and are featured in its print and online catalog. Digi-Key can fulfill the prototype and production needs for both Pulse's and Digi-Key's widespread customer bases.

## WEB SITE

■ **Keithley Instruments Inc.** has co-developed and sponsored a Nanotechnology Test Weblog, or Blog, designed exclusively for engineers and researchers dealing with electrical testing issues in the field of nanotechnology and MEMS. The Nanotest Weblog keeps visitors abreast of the latest news in the nanotechnology and MEMS industry through frequent posts of technical and business developments. The weblog is coordinated by *Nanotech Briefs* magazine and can be accessed directly at www.nanotestblog.com.

# Broadband Amplifiers by AML Communications

To Order Call: (805)388-1345 ext. 203

| Model | Frequency (GHz) | Gain (dB) | Flatness (dB) max | NF (dB) max | P1dB (dBm) min | VSWR (In/Out) | DC Current @ +12/+15VDC |
|---|---|---|---|---|---|---|---|
| **Broadband Low Noise Amplifiers** | | | | | | | |
| AML016L2802 | 0.1 – 6.0 | 28 | ±1.25 | 1.3* | +7 | 2.0:1 | 190 |
| AML48L3001 | 4.0 – 8.0 | 30 | ±1.0 | 1.2 | +10 | 1.8:1 | 150 |
| AML412L3002 | 4.0 – 12.0 | 30 | ±1.5 | 1.5 | +10 | 1.8:1 | 150 |
| AML218L0901 | 2.0 – 18.0 | 9 | ±1.0 | 2.2 | +5 | 2.5:1 | 60 |
| AML0518L1601-LN | 0.5 – 18.0 | 16 | ±1.0 | 2.7 | +8 | 2.2:1 | 100 |
| AML0126L2202 | 0.1 – 26.5 | 22 | ±2.25 | 3.5* | +8 | 2.2:1 | 170 |
| AML1226L3301 | 12.0 – 26.5 | 33 | ±2.0 | 2.8 | +8 | 2.5:1 | 200 |
| **Broadband Medium Power Amplifiers** | | | | | | | |
| AML0016P2001 | 0.01 – 6.0 | 21 | ±1.25 | 3.2* | +23* | 2.0:1 | 480 |
| AML26P3001-2W | 2.0 – 6.0 | 28 | ±2.5 | 6 | +33 | 1.8:1 | 1500 |
| AML28P3002-2W | 2.0 – 8.0 | 30 | ±2.0 | 5.5 | +33 | 2.0:1 | 2000 |
| AML218P3203 | 2.0 – 18.0 | 32 | ±2.5 | 4 | +25 | 2.0:1 | 450 |
| AML618P3502-2W | 6.0 – 18.0 | 35 | ±2.5 | 4 | +33 | 2.0:1 | 1850 |
| **Narrow Band Low Noise Amplifiers** | | | | | | | |
| AML23L2801 | 2.8 – 3.1 | 28 | ±0.75 | 0.7 | +10 | 1.8:1 | 150 |
| AML1414L2401 | 14.0 – 14.5 | 24 | ±0.75 | 1.5 | +10 | 1.5:1 | 130 |
| AML1718L2401 | 17.0 – 18.0 | 24 | ±0.75 | 1.6 | +10 | 1.8:1 | 150 |

## Low Phase Noise Amplifiers

| Part Number | Frequency (GHz) | Gain (dB) | Output Power (dBm) | Phase noise (dBc/Hz) at offset 100Hz | 1KHz | 10KHz | 100KHz |
|---|---|---|---|---|---|---|---|
| AML811PN0908 | 8.5 – 11.0 | 9 | 17 | -154 | -159 | -167 | -170 |
| AML811PN1808 | 8.5 – 11.0 | 18 | 18 | -152.5 | -157.5 | -165.5 | -168 |
| AML811PN1508 | 8.5 – 11.0 | 15 | 28 | -145.5 | -153.5 | -158.5 | -164.5 |
| AML26PN0904 | 2.0 – 6.0 | 9 | 20 | -150 | -165 | -165 | -178 |
| AML26PN1201 | 2.0 – 6.0 | 11 | 15 | -155 | -160 | -160 | -175 |

## High Dynamic Range Amplifiers

| Part Number | Frequency (MHz) | Gain (dB) | P1dB (dBm) | OIP3 (dBm) | DC |
|---|---|---|---|---|---|
| AR01003251X | 2 – 32 | 21 | 32 | 52 | +28V @ 470mA |
| AFL30040125 | 50 – 500 | 23 | 28 | 53 | +28V @ 700mA |
| BP60070024X | 20 – 2000 | 32 | 30 | 43 | +15V @ 1100mA |

*Above 500MHz.

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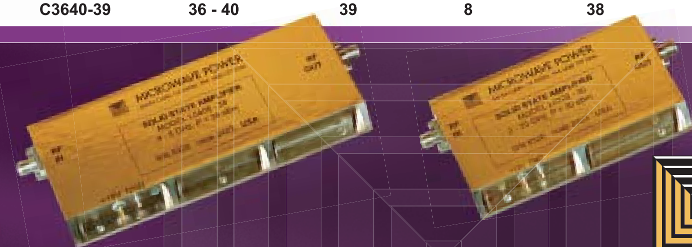
| Model | Frequency (GHz) | Psat (dBm) | Psat (W) | P1dB (dBm) | Gain (dB) | DC Current(A) @ +12V or +15V |
|---|---|---|---|---|---|---|
| **Broadband Microwave Power Amplifiers** | | | | | | |
| L0104-43 | 1 - 4 | 42.5 | 17.8 | 41.5 | 45 | 14 |
| L0204-44 | 2 - 4 | 44 | 25 | 42.5 | 45 | 14 |
| L0206-40 | 2 - 6 | 40 | 10 | 38.5 | 40 | 8.5 |
| L0208-41 | 2 - 8 | 41 | 12 | 40 | 40 | 17 |
| L0218-32 | 2 - 18 | 32 | 1.4 | 31 | 35 | 5 |
| L0408-43 | 4 - 8 | 43 | 20 | 41.5 | 45 | 17 |
| L0618-43 | 6 - 18 | 43 | 20 | 41.5 | 45 | 22 |
| L0812-46 | 8 - 12 | 46 | 40 | 45 | 45 | 28 |
| **Millimeter-Wave Power Amplifiers** | | | | | | |
| L1826-34 | 18 - 26 | 34 | 2.5 | 33 | 35 | 4 |
| L1840-27 | 18 - 40 | 27 | 0.5 | 26 | 30 | 2 |
| L2240-28 | 22 - 40 | 28.5 | 0.7 | 27 | 30 | 3 |
| L2630-39 | 26 - 30 | 39 | 8.0 | 38 | 40 | 15 |
| L2632-37 | 26 - 32 | 37 | 5.0 | 36 | 38 | 10 |
| L2640-31 | 26 - 40 | 31 | 1.2 | 30 | 30 | 5 |
| L3040-33 | 30 - 40 | 33 | 2.0 | 32 | 33 | 9 |
| L3337-36 | 33 - 37 | 36 | 4.0 | 35 | 40 | 12 |
| L3640-36 | 36 - 40 | 36 | 4.0 | 35 | 40 | 10 |

## High-Power Rack Mount Amplifiers

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

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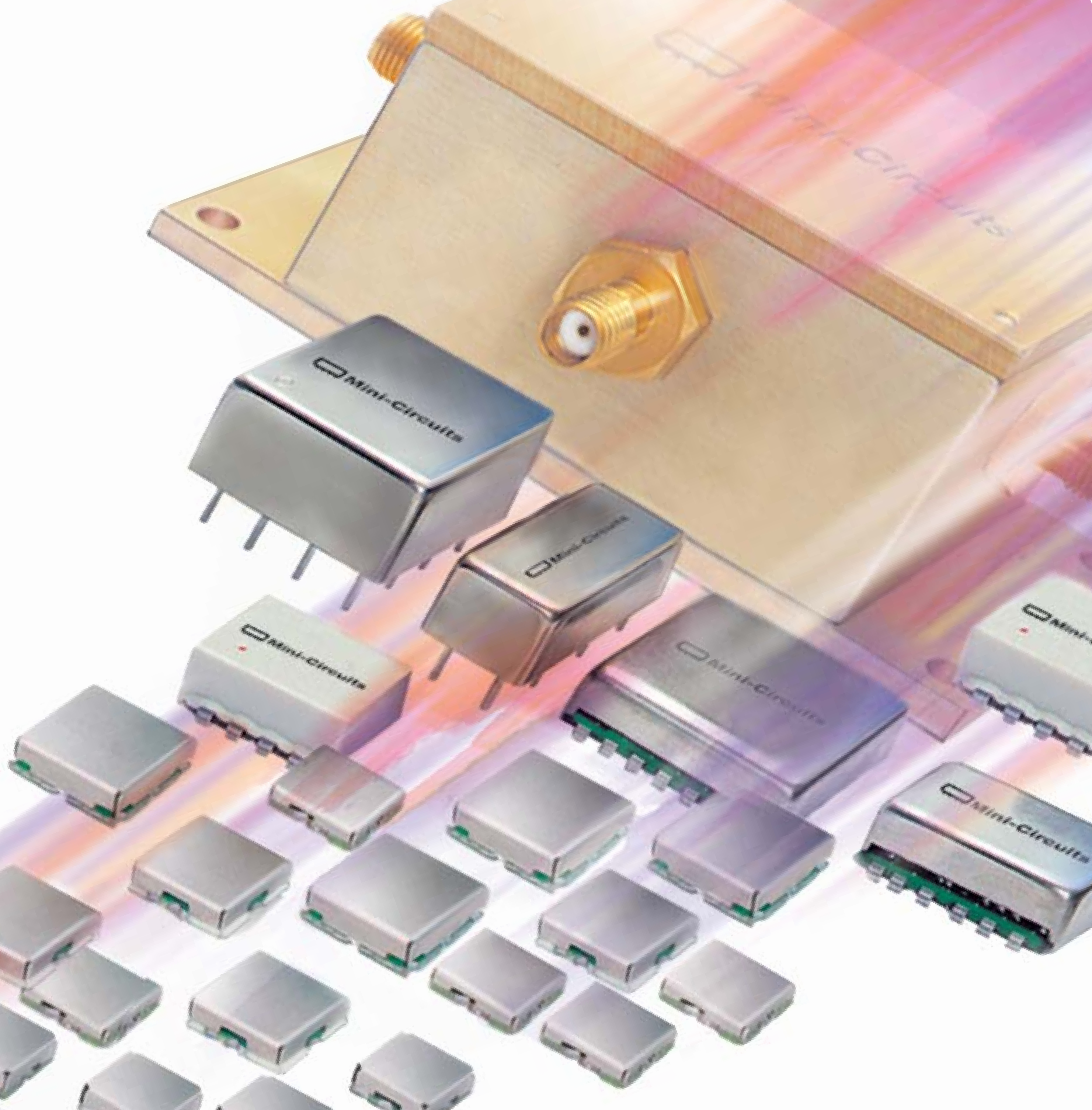


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402 Rev A

# TECHNIQUES OF RFID SYSTEMS: ARCHITECTURES AND APPLICATIONS

*From its first use in World War II, to differentiate between enemy and friendly aircraft, RFID has come to an era where it is used as an important identification tool, providing added security and conveniences in our daily lives. Its components and features are still being researched and integrated in existing systems to create a marketable and potential new system.[1,2] The main purpose of this article is to highlight and discuss the various RFID systems that are being implemented or under development. The advances, approaches and improvements in the designs will be examined and, if possible, compared with one another. Recommendations for future study are also outlined. This review serves as a comparative study and reference, beneficial for RFID researchers for future implementation of the technology.*

Radio frequency identification (RFID) has become and will continue to be very important in the area of automated identification. With the current emerging RFID technology, it is now possible to have an under-the-skin ATM/credit card or to pay up for a trolley full of goods by pushing across an electronic sensor without unloading them on the counter. Now, retailers such as Wal-Mart, Target, Tesco, Metro and Albertson's are the leading companies in adopting RFID in the retail supply chain. Gillette, Delta Airlines, Prada, Marks & Spencer and dozens of other Fortune 5000 international organizations and major corporations are supporting large-scale pilot projects, deploying RFID technology to support a wide variety of applications within the supply chain and beyond. According to a survey conducted by IBM, the primary initial objective of retailers deploying RFID systems would be to better manage inventories, out-of-stock products and warehouse efficiency. Many retailers are also interested in testing RFID for theft prevention purposes, while manufacturing companies are also examining the transportation and logistics implications of the new technology. Other than applications in the retail markets, terrorist and privacy concern after September 11$^{th}$ urged the US to adopt RFID in passports.[3] The RFID chip

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|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Parent Part ID** | *Min.* | *Max.* | *Min.* | *Max.* | *Max.* | *Typ.* | *Max.* | *Min.* | *Typ.* | *Max.* | *Max.* | *Max.* |
| DBL-0102N305 | .05 | 2.0 | 28.0 | 32.0 | 0.5 | 1.8 | 2.0 | 5.0 | 15.0 | 2.0 | 2.0 | 150 |
| DBS-0102T412 | 0.5 | 2.0 | 29.0 | 35.0 | 1.5 | 3.2 | 3.8 | 12.0 | 22.0 | 2.0 | 2.0 | 250 |
| DBS-0102N318 | 0.5 | 2.0 | 34.0 | 39.0 | 1.0 | 2.0 | 2.2 | 18.0 | 28.0 | 2.0 | 2.0 | 250 |
| DBS-0112N210 | 0.5 | 12.0 | 20.0 | 26.0 | 1.5 | 5.5 | 6.5 | 10.0 | 20.0 | 2.0 | 2.0 | 270 |
| DBS-0208N315 | 2.0 | 8.0 | 30.0 | 35.0 | 1.5 | 2.1 | 2.3 | 15.0 | 25.0 | 2.0 | 2.0 | 200 |
| DBS-0208N320 | 2.0 | 8.0 | 32.0 | 38.0 | 1.5 | 2.5 | 3.0 | 20.0 | 30.0 | 2.0 | 2.0 | 300 |
| DBS-0208N420 | 2.0 | 8.0 | 42.0 | 48.0 | 1.5 | 2.5 | 3.0 | 20.0 | 30.0 | 2.0 | 2.0 | 350 |
| DBS-0208N323 | 2.0 | 8.0 | 32.0 | 38.0 | 1.5 | 2.5 | 3.0 | 23.0 | 33.0 | 2.0 | 2.0 | 350 |
| DBS-0218N320 | 2.0 | 18.0 | 20.0 | 26.0 | 2.0 | 4.5 | 5.0 | 20.0 | 30.0 | 2.0 | 2.0 | 425 |
| DBM-0218N627 | 2.0 | 18.0 | 34.0 | 41.0 | 2.0 | | 6.5 | 27.0 | 35.0 | 2.0 | 2.5 | 1800 Typ |
| DBS-0408N318 | 4.0 | 8.0 | 30.0 | 35.0 | 1.5 | 2.3 | 2.5 | 18.0 | 28.0 | 2.0 | 2.0 | 230 |
| DBS-0411N320 | 4.0 | 11.0 | 26.0 | 30.0 | 1.5 | 4.0 | 4.5 | 20.0 | 30.0 | 2.0 | 2.0 | 250 |
| DBS-0411N630 | 4.0 | 11.0 | 39.0 | 45.0 | 1.5 | | 7.5 | 30.0 | 40.0 | 2.0 | 2.0 | 1250 |
| DBS-0513N215 | 5.0 | 13.0 | 20.0 | 24.0 | 1.5 | 2.2 | 2.5 | 15.0 | 25.0 | 2.0 | 2.0 | 140 |
| DBS-0513N320 | 5.0 | 13.0 | 27.0 | 31.0 | 1.5 | 3.0 | 3.5 | 20.0 | 30.0 | 2.0 | 2.0 | 290 |
| DBS-0612N210 | 6.0 | 12.0 | 20.0 | 24.0 | 1.5 | 2.2 | 2.5 | 10.0 | 20.0 | 2.0 | 2.0 | 150 |
| DBS-0612N320 | 6.0 | 12.0 | 25.0 | 29.0 | 1.5 | 3.5 | 4.0 | 20.0 | 29.0 | 2.0 | 2.0 | 250 |
| DBS-0612N420 | 6.0 | 12.0 | 34.0 | 38.0 | 1.5 | 3.5 | 4.0 | 20.0 | 29.0 | 2.0 | 2.0 | 300 |
| DBL-0618N410 | 6.0 | 18.0 | 28.0 | 33.0 | 1.0 | 2.3 | 2.5 | 10.0 | 20.0 | 2.0 | 2.0 | 150 |
| DBS-0618N315 | 6.0 | 18.0 | 26.0 | 30.0 | 1.5 | 2.7 | 3.0 | 15.0 | 25.0 | 2.0 | 2.0 | 260 |
| DBL-0618T620 | 6.0 | 18.0 | 28.0 | 35.0 | 2.3 | 3.5 | 4.0 | 20.0 | 30.0 | 2.0 | 2.0 | 490 |
| DBL-0618N420 | 6.0 | 18.0 | 30.0 | 34.0 | 1.5 | 2.3 | 2.5 | 20.0 | 30.0 | 2.0 | 2.0 | 370 |
| DBS-0618N520 | 6.0 | 18.0 | 32.0 | 37.0 | 1.5 | 2.7 | 3.0 | 20.0 | 30.0 | 2.0 | 2.0 | 430 |
| DBS-0712N315 | 7.0 | 12.4 | 28.0 | 32.0 | 1.5 | 2.3 | 2.5 | 15.0 | 25.0 | 2.0 | 2.0 | 190 |
| DBS-0712N320 | 7.0 | 12.4 | 22.0 | 26.0 | 1.5 | 2.5 | 3.0 | 20.0 | 30.0 | 2.0 | 2.0 | 260 |
| DBS-0910N420 | 9.0 | 10.0 | 30.0 | 35.0 | 1.0 | | 1.7 | 20.0 | 30.0 | 2.0 | 2.0 | 350 |
| DBS-0910N530 | 9.0 | 10.0 | 30.0 | 40.0 | 0.5 | | 3.0 | 30.0 | 40.0 | 2.0 | 2.0 | 1200 |
| DBS-1218N515 | 12.0 | 18.0 | 32.0 | 37.0 | 1.5 | 2.8 | 3.0 | 15.0 | 25.0 | 2.0 | 2.0 | 310 |
| DBS-1218T718 | 12.0 | 18.0 | 36.0 | 44.0 | 1.5 | 3.7 | 4.0 | 18.0 | 28.0 | 2.0 | 2.0 | 510 |
| NWL-0412N410 | 4.0 | 12.0 | 40.0 | 48.0 | 1.0 | 1.2 | 1.5 | 8.0 | 16.0 | 2.0 | 2.0 | 225 |
| NWM-0218N630 | 2.0 | 18.0 | 45.0 | 52.0 | 2.0 | | 6.5 | 30.0 | 38.0 | 2.0 | 2.0 | 3000 Typ |

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embedded in the passport will make them more secure, and ensure that the bearer is the person who was issued the passport originally. When queried, the chip will deliver the name, address, date and place of birth of the bearer, along with a digital photograph. The information will not be encrypted, but will contain a digital signature certifying the authenticity of the chip. This technology does not work well over long distances, and the readers required for the type of chip chosen for the passports would be fairly difficult to hide, thus making it almost impossible to envision terrorists tracking US citizens as they emerge from customs.

This article first provides an overview of RFID systems and how they work, followed by the history of RFID, a review of recent and future RFID systems, and finally some recommendations for future work in this exciting technology.

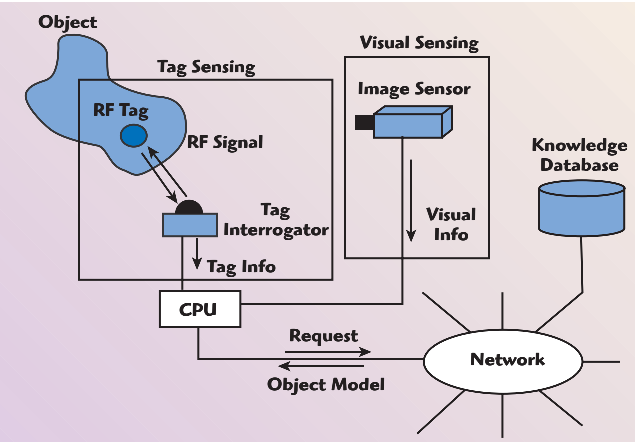
## TIME LINE OF RFID

The combination of radio broadcast technology and radar are associated with the technology lying behind RFID. In 1906, Ernst F.W. Alexanderson first demonstrated continuous wave (CW) radio generation and transmission of radio signals and radar was introduced in 1922.[4] Following the convergence of these two important radio disciplines, RFID was invented in 1948 by Harry Stockman and described in his first paper.[5]

However, the first obvious use of RFID technology can be traced to the British during World War II. Tags were placed on British allies aircraft to distinguish between their own aircrafts returning to base and enemy aircrafts who were invading. The tag produced a signal as the allied aircraft approached the base and if the base received no signal, the aircraft would be known as a 'foe,' meaning that enemy aircraft were approaching. This system was called 'Identify: Friend or Foe' (IFF). A variation of the system is still used today for aviation traffic control.[6]

After the first breakthrough of RFID, in the 1950s, the technology never really picked up until the 1960s to the 1980s. The 1960s saw the development of the theory of RFID and the start of its commercial applications. Commercial companies such as Sensormatic, Checkpoint and Knogo developed Electronic Article Surveillance (EAS) equipment to counter theft. EAS is arguably the first and most widespread commercial use of RFID. These types of systems are '1-bit' inexpensive tags, whereby only the presence or absence of a tag could be detected. At that time, the systems used either microwave or inductive technology.[4] In the late 1960s and early 1970s, RFID was used to track nuclear materials in response to the need for more security and safety surrounding their use.[6] Developmental work on the RFID tagging of equipment and personnel continued to increase in the 1970s. Applications were intended for animal tracking, vehicle tracking and factory automation. Mario Cardullo[7] received the first patent for a passive, read-write RFID tag from the US Patent Office on January 23, 1973. He got the idea for the tag in 1969 after witnessing the flaws in the CARTRAK optical system, an optical reflector system, for the railroad industry. Notable advances in this technology were also being realized at research laboratories and academic institutions such as Los Alamos Scientific Laboratory, Northwestern University and the Microwave Institute Foundation in Sweden. Two companies, Amtech and Identronix Research, started to explore commercial uses of RFID for animal tracking.[6] RFID tags were placed in the backs of dairy cows to allow tracking of the animals' identifications and temperatures. Furthermore, automatic feeding without overfeeding could be accomplished when the animal's unique ID code was obtained from the tag. Railroad companies became interested in RFID after bar code technology failed to successfully track rolling cars in the dirty and unpredictable outdoor environment.

Most of the early RFID research used 900 and 900/1800 MHz frequencies. By 1983, low frequency (LF), medium frequency (MF), very high frequency (VHF), ultra high frequency (UHF) and microwave frequencies were also being utilized.[6] The 1980s became the decade for full implementation of RFID technol-




▲ *Fig. 1 General architecture of the tag-based vision system. (©2002 IEEE)*

ogy.[4] RFID tags were regularly being manufactured by several US and European companies. In 1988, the primary effort in RFID shifted somewhat from new applications to performance improvement, cost reduction and size reduction.

The 1990s were a significant decade for RFID since it saw the wide scale deployment of RFID.[4] This is also the era when questions on standards emerged. A new effort underway was the development of the Texas Instruments Registration and Identification System (TIRIS), used in many automobiles for control of the starting of the vehicle engine. The TIRIS system and others, such as from Mikron — now a part of Philips — developed new uses for dispensing fuel, gaming chips, ski passes, vehicle access and many other applications.

Additional companies in Europe were becoming active in the RFID race as well, including Microdesign, CGA, Alcatel, Bosch and the Philips spin-offs of Combitech, Baumer and Tagmaster. A pan-European standard was needed for tolling applications in Europe, and many of these companies were at work on the CEN (Comité Européen de Normalisation) standard for electronic tolling. Tolling and rail applications were also appearing in many countries, including Australia, China, Hong Kong, Philippines, Argentina, Brazil, Mexico, Canada, Japan, Malaysia, Singapore, Thailand, South Korea, South Africa and several European countries.[4]

## ADVANCEMENT IN RFID SYSTEM DESIGN

This section highlights the most up to date development of RFID systems, produced using the most advanced RF technologies available to date. In 2002, M. Boukraa and S. Ando presented a paper on a machine vision system that uses the RFID tag to identify objects prior to locating them visually.[8] The system is developed for a desktop PC driving the reader and the image sensor (a camera) and is connected to a PC server that manages the object model database. By using the RFID tag to assist in the 3D scene analysis, the central processing unit (CPU) commands the RFID system and retrieves information such as the object's tag ID from the network. The retrieval of a complete model of the detected object is done through a network knowledge database, designed in XML. Tag sensing and visual sensing are then integrated to perform a high level vision task. The shape of the object is stored as 3D homogenous coordinates. ***Figure 1*** shows the general architecture of the system. Generally, the tag-based vision algorithm falls into four main parts: reads tag info and retrieves object model from database; detects lines and edges with Hough transform; extracts a discriminating six-point subset from those featured points; and calibrates the camera and registers the object. This system makes it possible to simplify any object recognition task to a problem of registering the object model to the image. The recognition part is independent of the number of models in the database.

In early 2003, Michelin, the tire maker, adopted the RFID system to track expired and worn out tires, following the enactment of the Transportation Recall Enhancement, Accountability and Documentation (TREAD) Act by the US Congress in 2000. With this system, an RFID tag is embedded in the tires,[9] enabling them to be tracked electronically.

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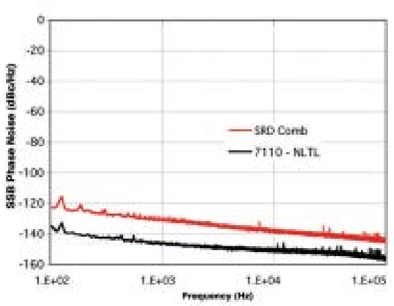


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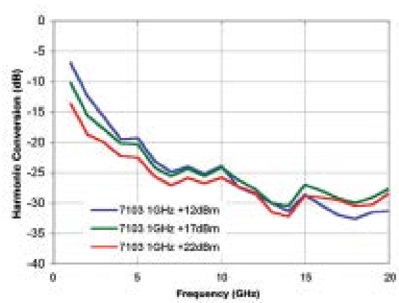


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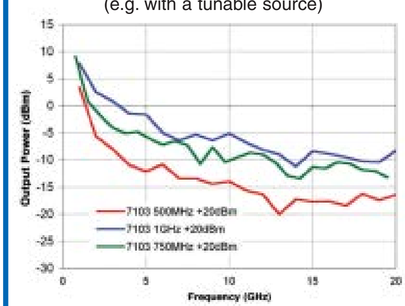


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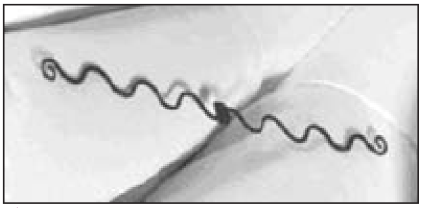


*Fig. 2 Michelin's RFID tag. (©2003 RFID Journal)*

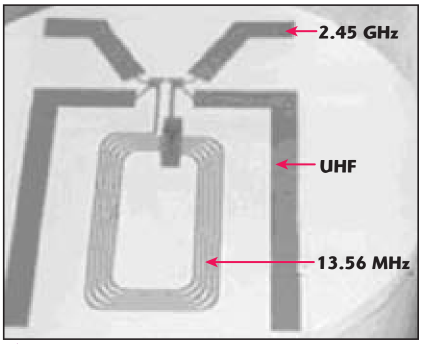


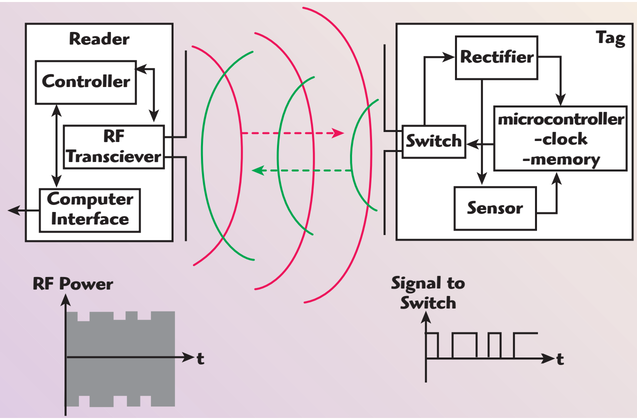

*Fig. 3 MM chip with three antennas. (©2004 RFID Journal)*

***Figure 2*** shows the Michelin's RFID tag. The microchip in the tag holds a unique ID for the tire, which can be associated with the vehicle identification number. The chip can store information about when and where the tire was made, its maximum inflation pressure and size. Information can be updated with a handheld reader. Although other tire makers have demonstrated the ability to read RFID tags embedded in tires, Michelin claims to be the first to meet the Automotive Industry Action Group's B-11 standard for North America, which calls for a read distance of 24 inches. Achieving that range has been a challenge because the rubber makes it harder to read the tag. Michelin took microchips from Fairchild Semiconductor and Philips Semiconductor and designed its own special antenna to boost the read range. The antenna was designed to compensate for the fact that electromagnetic waves travel differently through rubber than through air. The tag that Michelin designed loses only 10 percent of its read range when it is embedded in a tire. The other key issue was to ensure that the rubber bonds carefully to the antenna so that the antenna, which is made of wire, does not break or is dislocated. In order to protect the antenna and to ensure the firmness of the tag in the tire, Michelin developed a proprietary coating to put on the tags before embedding them into the rubber. Besides basic tracking of the tires, the RFID system is also being adopted as pressure and temperature sensors for the tires. These sensors,[9] developed independently by Philips and Texas Instruments, use active tags to measure the vehicle's tire pressure and temperature. Readers are then placed on the dashboard of the vehicle to broadcast the readings to the user. Philips produced such a tag known as a "signal conditioning chip," or P2SC.[10] At regular intervals, the chip will broadcast the temperature and pressure of each tire, either through a warning light or digital readout, displayed on the dashboard. The P2SC chip can withstand shock resistance up to 2000G and temperatures of up to 175°C. The system is designed to work with the receivers used for remote keyless entry. Antennas are installed in each wheel well. The keyless remote entry receiver, which uses rolling ID numbers to match keys to cars, is modified so that it can send out a low frequency signal through the wheel well antennas. The low frequency signal activates the RFID tag either in the tire valve or inside the rim of the tire. The activated tag will then broadcast its rolling ID number at either 315 or 434 MHz, which identifies the tire and its location, as well as data on the temperature and pressure of that tire. Philips does not make the entire active sensor but produces the microchip that will communicate with the wireless remote entry receiver. A system integrator would combine the chip with a pressure and heat sensor made by a third party. The two chips would likely be mounted on a tiny circuit board with a small battery.

Hitachi further worked on its μ-Chip[11] and developed a new version of the μ-Chip by embedding an antenna into the chip.[12] It was announced on September 2, 2003. The new chip cut the cost of the previous tag in half.[13] This newly developed version features an internal antenna, enabling chips to employ the energy of the incoming electromagnetic waves to wirelessly transmit its ID number to a reader. The $0.4 \times 0.4$ mm chip can thus operate entirely on its own without the need of external antennas. The internal antenna is formed using a bump-metalization technology (used to create the electrical contacts of an IC), a process already widely used by semiconductor manufacturers, thus eliminating any need for specialized equipment. The new μ-Chip can be easily embedded in most paper sheets such as bank notes, gift certificates, important documents and business forms, which require a highly sophisticated level of security to prevent counterfeiting and to help in the automation of logistics systems and other business processes. For these purposes, the μ-Chip was used to identify and validate entrance tickets to Expo 2005, held in Aichi, Japan, in March 2005. Other potential application includes embedding them in agricultural products to ensure the safety of food by providing trace detection of ingredients.

The multi-frequency MM chip[14] by Toppan Forms and FEC Inc. is following the trend. Designed in March 2004, the antenna is affixed to the chip to form the tag, as shown in ***Figure 3***. This tag can be read from 2 to 3 mm at a frequency of 2.45 GHz. Additionally, a small "booster antenna" can be added to increase the read distance to 24 to 30 cm and another external antenna can extend the range to about 50 cm. At a frequency of 13.56 MHz, the reading distance ranges from 15 to 20 cm with the booster antenna and from 30 to 40 cm with the external antenna. In the UHF spectrum, the tag can be read up to 1 meter with the booster antenna and up to 5 meters with the external antenna. As such, in order to achieve the maximum read distances at the three common RFID frequencies (13.56 MHz, 868 to 956 MHz and 2.45 GHz), the chip needs to have an on-chip antenna and two other external antennas attached. Each antenna is tuned to work in a frequency range. As mentioned earlier, the tag can be read by Toppan's special reader. Applications using the antenna-embedded MM chip include tagging airline baggage and goods in the supply chain.

A new automobile immobilizer system using three RFID readers[15] has been developed making it three-times harder for prospective thieves to start a car's engine. This new system, named TheftStopper1, was developed and manufactured in January 2005 by C-Chip Technologies, a Montreal security systems provider. TheftStopper1's three RFID readers each have a




▲ *Fig. 4 Block diagram of the RFID biosensor system. (©2003 Auburn University)*

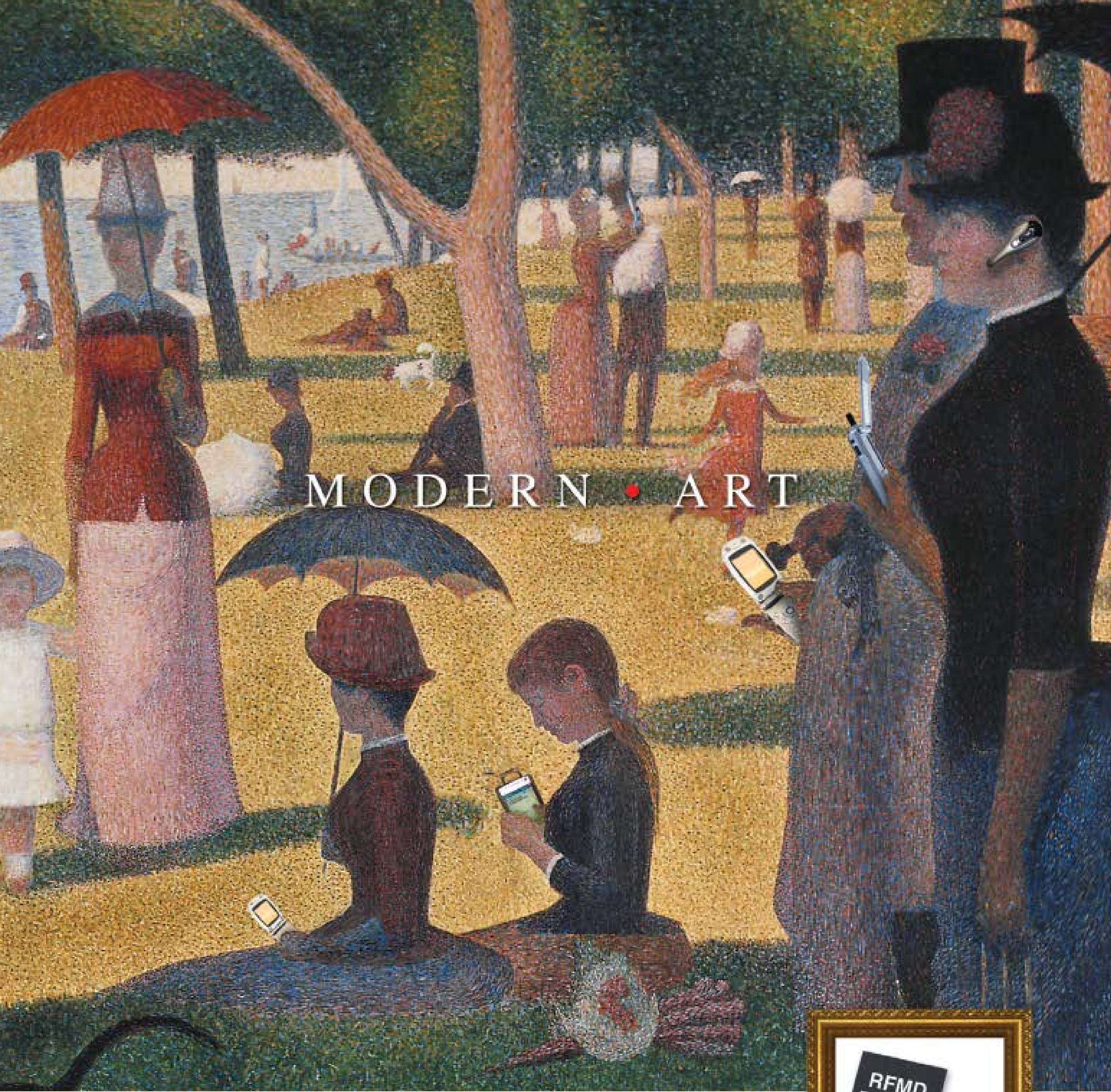
nanowatt microcontroller and relay. One of the RFID readers serves as the starter cutoff or 'mother' unit, which controls the power to the two other control units. The other two units function as power switches and are installed at different parts of the car, such as the fuel pump, ignition circuit, computer or transmission relay. A car will not start unless all three-control units receive a signal from a key fob containing the correct ID code. As the key fob's active tag can transmit its signal over a distance of 20 feet, the mother unit can communicate with the key fob, well before the driver even starts the vehicle, to verify whether the key fob's ID code matches the one programmed in the mother unit. When the driver turns the ignition switch, a second connection is made between the mother unit and the two other units and the engine starts. Without the key fob's tag, none of the three cut-off switches will allow electric current to flow to their respective devices.

The new RFID systems find an increasingly important role in automobile applications. The pressure, temperature tracking of the automobile tires and automobile immobilizer system confirmed this. Furthermore, the introduction of embedded RFID tags is finding applications in important documents, passports and currencies to avoid fraud and to preserve its authenticity. Advanced RF technologies play vital roles in this development.

## POTENTIAL FUTURE IMPLEMENTATIONS

This section highlights the use of advanced RF technologies in future implementations of the RFID system, which are being investigated by several companies.

In 2003, S. Nambi, S. Nyalamadugu and M. Stuart of Auburn University started a project that uses RFID technology, integrated with sensors for detection of pathogens in food.[16] The idea is to keep track of food products from initial production throughout the supply chain thus significantly reducing mortality rate and lost productivity due to food borne bacteria and pathogens like Salmonella and E. Coli. The frequency used is 13.56 MHz. In the initial stages of the project, a passive tag with reduced functionality and merely for detection of temperature was designed. Besides that, a very basic reader with a reading range of 10 cm was built for the system. The antennas for the reader and the tag are multi-turn rectangular loop antennas designed for a resonant frequency of 13.56 MHz, which were modeled using Numerical Electromagnetic Code (NEC) Windows Professional software. The biosensor is to be interfaced to the tag circuit using the microcontroller. The device will use a generic microcontroller with an on-chip memory and also input and output ports. The microcontroller can be software programmed to output a certain bit stream depending on the input that it will receive from the sensor. The program logic can poll the respective ports and detect changes in the input from the sensor. The biosensor will have sensitive biological film coatings that will change their material properties when in contact with the targeted pathogens. ***Figure 4*** shows the pilot RFID biosensor system. When the reader activates the tag, it will start transmitting its identity code for a specific period of time. At the same time, a controller in the reader will decode the identity of the tag. While the tag is sending out the information bits, the sensor in the tag will alarm the micro-





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controller if a set temperature value is exceeded. The controller will then process the information and send a code, which is appropriate for that particular state of the system.

Another innovative implementation of the RFID system can be seen when two companies, Winwatch and Hitachi, teamed up to produce a new RFID product in which an Hitachi µ-Chip is embedded in watches with an antenna to track and authenticate them and avoid counterfeiting. Winwatch is talking Swiss watch companies into employing this RFID system in the near future.

In July 2004, a Swiss company planned to adopt the RFID system in their range of watches to protect them against counterfeiting and to improve consumer services. As Swiss brands such as Cartier, Longines, Piaget and Rolex are often counterfeited, the Swiss company has already patented a way of embedding a tiny RFID tag in the glass crystal of a watch.[17] With the teaming up of Winwatch and Hitachi Europe, Hitachi's µ-Chip with its embedded antenna[12] will be used to track the watches. Each µ-Chip contains a unique serial number that can be associated with a particular watch. When that watch is shipped to a retailer, the retailer can check the authenticity of the watch by checking the serial number with the watch's manufacturer. The numbering system that uses Hitachi's µ-Chip is proprietary. Therefore, companies wanting to use Winwatch's technology for such applications would need to adopt the same proprietary system. Because of the small size of its antenna, the RFID tag can be read only if it is no more than 1 mm from the antenna of the RFID reader. By putting the chip in the watch crystal, tags can be added to the already-manufactured watches, and it is easier to read the tag in the crystal because there is no interference from metal or the body of the person wearing the watch. Winwatch is targeting more Swiss watch companies to employ this RFID system in the near future. Soon, the first interactive Swiss-made wristwatches with RFID tags embedded in the watch glass will be realized. Once implemented in this real retailer market, researchers can look forward to producing watches employing a RFID system that can replace current RFID cards for identification, access control and as a smart card.

So far, RFID systems have been used in pressure and temperature measurements of tires. In yet another breakthrough, Intel plan to adopt RFID in sensor networks to detect heat, light, movement and other environmental factors.[18] Also known as motes, the sensors gather data and transmit it from one node of a network to another, until it reaches a node connected to a computer that can store and analyze the data. Unlike conventional computers, where people have to input most of the data and receive most of the computer's output, this new sensor network will anticipate people's needs and act on their behalf. The widespread deployment of RFID technology is expected to lead to the installation of more robust networks that can cope with the quantity of data that a sensor can generate. RFID tags with integrated temperature sensors are already on the market, and researchers are working on other low cost sensors that can be integrated with RFID tags.

## CONCLUSION

The past three years have been important in the evolution of RFID technology. In 2003, RFID made major strides towards becoming a technology that can be used in open supply chains.[19] However, there is still a lot of work to be done by the Auto-ID Center and the International Organization for Standardization (ISO) to finalize standards. The Electronic Product Code (EPC) has progressed to the point that Wal-Mart, the world's largest retailer, is committed to using it. The Auto-ID Center has handed its research work off to the Auto-ID Labs, which are continuing to do important work. The Cambridge Laboratory, for instance, is working on concepts that could change the way goods are manufactured. The center handed the promotion of the EPC Network to EPCglobal, a joint venture between the Uniform Code Council (UCC) and European Article Number (EAN) International. EPCglobal is set-up to oversee the rollout of RFID standards worldwide.

In 2004, some 60 RFID vendors agreed to support one global protocol,

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EPCglobal Generation 2 protocol.[20] End users have found ways to tag many difficult products so that they can be read reliably when they reach a retailer's warehouse or store. Hardware products are improving at a rapid clip, and software companies are developing new middleware products and applications that can take advantage of real-time data. An infrastructure is being put in place to enable companies to make enough tags, labels and readers to meet demand. ■

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# IN SEARCH OF MAXWELL

Friday the 13th of December 1996 was a lucky day. Daylight, such as it was, found me traveling south from Syracuse on Route 81 in a cold windy rain. I was going to visit an old friend from Cornell, L. Pearce Williams, Professor Emeritus, History of Science and Technology, Cornell University. Pearce was going to loan me his copy of the very rare book, *The Life of James Clerk Maxwell* by Lewis Campbell and William Garnett, published in 1882.

On the way home, I bought a scanner and an extra 2 GByte hard drive, modern miracles of the time. I finished scanning and OCR-ing (Optical Character Recognition) in February 1997. Later, when it became available, I converted the result to Adobe Acrobat .pdf format. This rare book is now available to everyone by visiting my company's web site, www.sonnetsoftware.com, for a free download.

My rendering of the book caught the attention of some key people. One is David Forfar, a trustee of the James Clerk Maxwell Foundation.[1] Another is Capt. (ret.) Duncan Ferguson, owner of Maxwell's life-long home in rural Scotland.[2] They both warmly invited me to visit. Last summer, I was able to accept their kind invitations. This story is about that trip… in search of Maxwell.

## ARRIVAL

On the taxi ride from the airport, I was gently informed that the correct pronunciation of Edinburgh is "Ed-in-burr-ah," with a lightly rolled "rr." And, just for reference, the correct pronunciation of Clerk is the same as we Americans pronounce "Clark." Little known, "Clerk" is not his middle name; it is more accurately part of his last name. Today, we might be tempted to write it as a hyphenated last name (which is exactly what P.G. Tait, a very close friend of Maxwell, always did).

I asked the cab driver if he had ever heard of James Clerk Maxwell, and he said no, but that if he were someone famous, there is undoubtedly a statue for him somewhere around Edinburgh. It turned out that while there are many statues around Edinburgh, Maxwell unfortunately is not among them, at least for now.

During my stay in Scotland I found that perhaps two thirds of those I asked would have no idea who this JCM fellow was. As one of the three greatest physicists of all time, this is a sad situation, but one that we will perhaps discuss another day.

JAMES RAUTIO
*Sonnet Software*
*Liverpool, NY*

## OLD 31

On the first morning, as we (my wife, my son and I) walked from our bed and breakfast, we passed the nearest Maxwell site, "Old 31," 31 Heriot Row (see ***Figure 1***). At 10 years old, Maxwell was sent here to live with his aunt. He attended Edinburgh Academy, about a 20 minute walk downhill to the north. Today, two families live at Old 31. I decided to respect their privacy and did not ring the doorbell, so I have no idea if they realize the significance of their home. Incidentally, the home of Robert Louis Stevenson (*Treasure Island*, *Strange Case of Dr. Jekyll and Mr. Hyde*), born 19 years after Maxwell, is just several doors down the same street.

The daughter of Maxwell's aunt, his cousin Jemima, would become a world-class artist. We are especially fortunate that she made numerous paintings of Maxwell in his youth. Her depiction of young Maxwell arriving at Old 31 on that cold November evening is shown in ***Figure 2***.

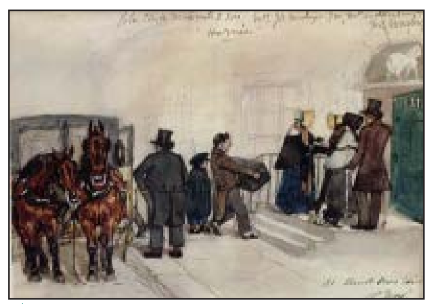


## MAXWELL'S BIRTHPLACE

Down the block and around the corner, we arrive at Maxwell's birthplace, 14 India Street (see ***Figure 3***). We are especially fortunate in that 14 India Street was acquired by the James Clerk Maxwell Foundation[1] (the Foundation's tenant at this location is the International Centre for Mathematical Sciences). When the Foundation was in the process of acquiring 14 India Street, there was resistance from local residents who had no knowledge of Maxwell and his importance. Fortunately, one government official involved in the decision was well aware of Maxwell and came to the rescue.

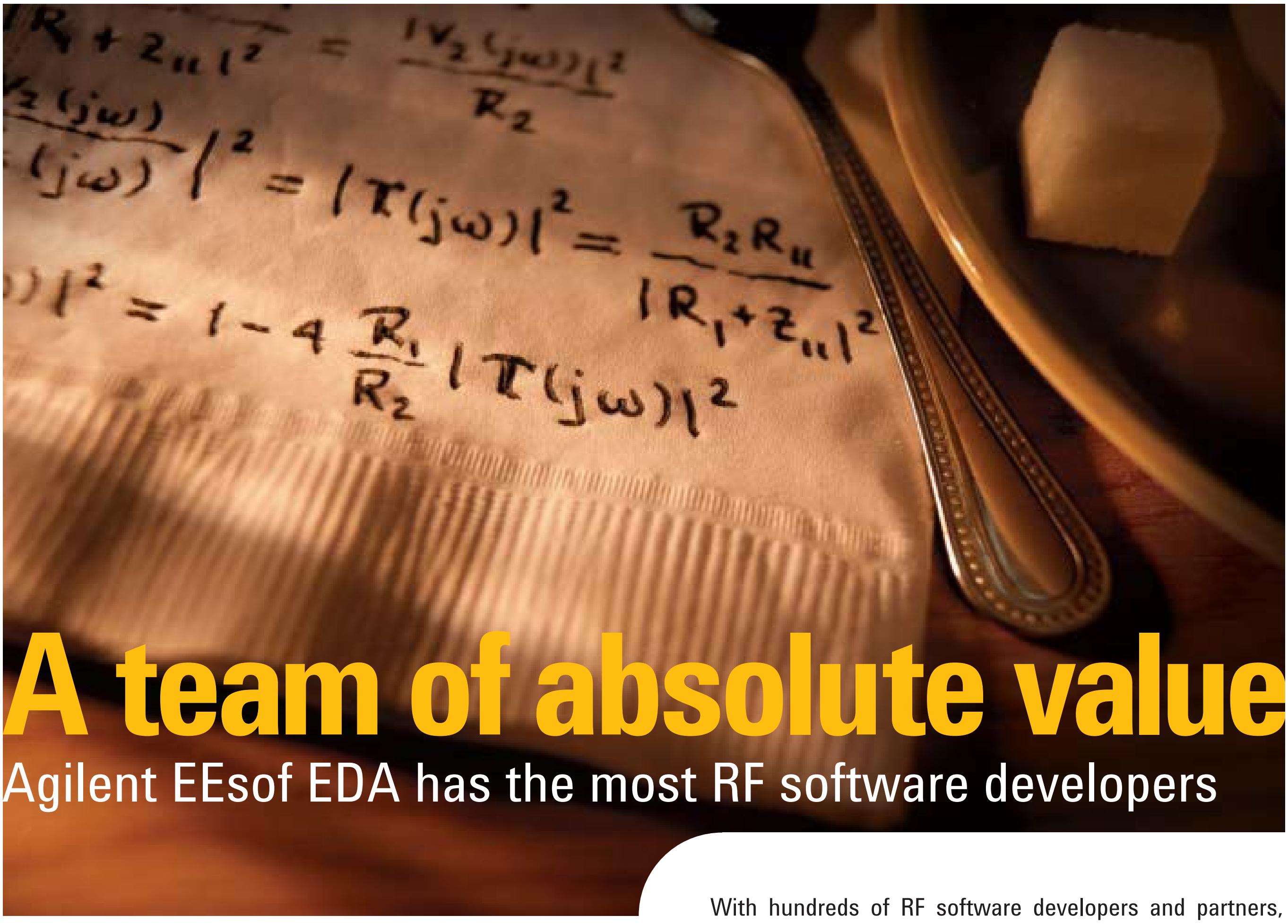
The Foundation maintains a well equipped meeting room on the sec-

▲ *Fig. 1 Maxwell's home while attending Edinburgh Academy.*



▲ *Fig. 2 Watercolor by Maxwell's cousin showing his arrival in Edinburgh (second from left).*

▲ *Fig. 3 Maxwell's birthplace.*

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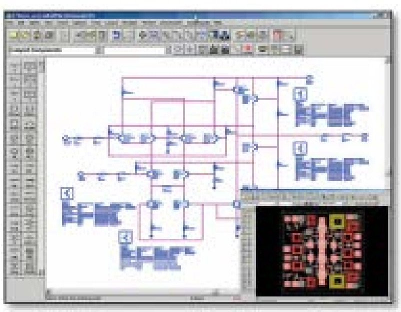

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ond floor. If you have a small meeting in Edinburgh, they would be pleased to hear from you. The room in which Maxwell was most likely born is immediately adjacent to the meeting room.

The first floor is the real treasure. Here the foundation displays an amazing collection of Maxwell artifacts. It is not open on regular hours, but if you contact the Foundation, they are happy to open it on request. This is an absolute must visit site for any Maxwell aficionado. Special thanks to David Ritchie (introduced to me by David Forfar) for hosting me on my visit to the museum.

There is a common misperception that Maxwell did mostly theoretical work and very few experiments. This is not the case, as even a cursory inspection of the Foundation's exhibits shows.

Perhaps the most significant artifact is the apparatus Maxwell used to measure electrostatic and magnetostatic constants, and thus determine the speed of light (see ***Figure 4***). Maxwell joked that the only use he made of light in the experiment was to read the dials on his apparatus.

The value Maxwell calculated (in 1861) for the speed of light is 193,088 miles per second. The best-known mechanical measurement was 195,647 miles per second. These values are so close, it seems that one could consider Maxwell's equations to have been at least partially validated. However, no one really took notice.

First, Maxwell was very modest. He realized his work was "great guns," but he did not actively and publicly promote it as such. Second, Maxwell had 20 equations in 20 variables (he did not have formal use of div and curl), with what we today call magnetic vector potential as primary. Maxwell's equations were simply too complicated. Third, when he published the equations in their complete form (1865), he made no attempt to connect them back to the lord and ruler over all physics at that time, Isaac Newton. There was no mechanical model, no connection to f = ma.

As a result, no one realized the significance of Maxwell's equations until over 20 years after Maxwell's 1865 publication and almost a decade after his death. This is when Hertz independently derived them in their modern form (by applying corrections to the then popular "action at a distance") and went on to experimentally confirm that light is indeed an electromagnetic wave.

The abstract concept of using what came to be known as "fields," with absolutely no connection to Newton and f = ma, revolutionized physics. Maxwell was in fact the inspiration for Einstein and his (field) theories of relativity. Freeing physics from the confining womb of Newtonian me-

▲ *Fig. 4 Apparatus used by Maxwell to determine the speed of light based on electrostatics and magnetostatics.*


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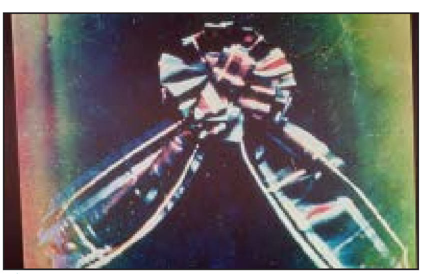
chanics led directly to all the major developments of 20th century physics. It was actually this much more significant but lesser realized accomplishment, and not Maxwell's successful unification of the electric and magnetic forces per se, that was Maxwell's most significant legacy.

Another set of artifacts on display at 14 India Street are the negatives for the first color photograph, shown in ***Figure 5***. Maxwell had used simple experiments while a student at Edinburgh and Cambridge to determine that the three primary colors of light are red, green and blue. So he got the idea to take three photographs through appropriate filters, then simultaneously project them through three projectors, as shown in ***Figure 6***.

There was just one problem, not realized until much later. The colloidal photographic process used at that time had no sensitivity to red. However, there are clearly large amounts of red in the photograph. A little detective work shows that the negative would have been sensitive to ultraviolet and the filter is transparent to ultraviolet. In addition, the red in the pictured ribbon was also reflective to ultraviolet. Maxwell was lucky.

▲ *Fig. 5 Negatives for the first color photograph.*



▲ *Fig. 6 The first color photograph by Maxwell.*

▲ *Fig. 7 Edinburgh Academy.*

## EDINBURGH ACADEMY

A pleasant 20 minute walk north takes us to Edinburgh Academy. On my first visit, there was equipment and people everywhere (see ***Figure 7***). It just happened that the Academy was being used as a movie set for the day and as we were being politely but firmly escorted out by a guard, we were saved by an Academy employee, who then showed us around areas not being used for the movie. We then set up a meeting time with Rob Cowie, Academy Alumni Relations. If you visit, be sure to give Rob a call first.

The Academy was founded as an innovative and leading edge educational institution for its time. Even so, appropriate for this time period, memorization was the principle part of much of Maxwell's education. For example, the Academy boys (and at that time, it was just boys) were expected to be able to conjugate 800 irregular Greek verbs by the age of 12. Maxwell intensely disliked memorization; he called it "muggery." Maxwell performed poorly the first three years. In his second three years there, he found course work that required understanding, rather than just memorization, and he started making the medal lists. (In fact, a number of his medals are on display at the 14 India Street museum.)

Maxwell's first day of classes entailed a small social "adjustment." Maxwell spoke with a "country boy" Corsock accent, he wore clothing that simply did not fit in with the popular "city boy" styles and he was the new kid in class. The result is graphically depicted in a newspaper clipping on display at 14 India Street (see ***Figure 8***). On Maxwell's first day at school, he got beat up.

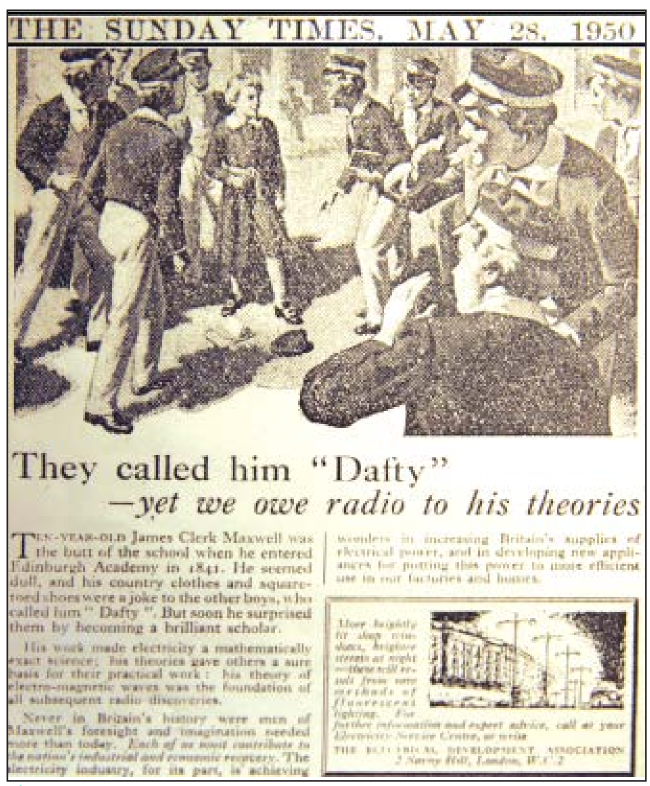
Today Edinburgh Academy is still a leading edge educational institution, as evidenced by its construction (presently underway) of a new state-of-the-art auditorium and laboratory facility to be named for Maxwell. In an appropriate note of irony that Maxwell himself would have appreciated, it is located only a few meters from the likely location of that first day's most memorable experience.

## ON TO GLENLAIR

Maxwell spent most of his time at Glenlair, the family estate in very remote south-western Scotland. We traveled by train for one hour from Edinburgh to Lockerbie, then one more hour by car to Glenlair.

While in Lockerbie, we spent several hours visiting memorials to the victims of the Pan Am 103 disaster, where a terrorist bomb took down a 747 with 288 people including 35 Syracuse University students. I had just finished two years as a visiting professor at SU when that happened. The Maxwell connection: Henrietta Ferguson, the wife of the present owner of Glenlair, spent her Christmas holiday preparing meals for the first responders.

Maxwell's career took him to Edinburgh, Aberdeen, London and Cambridge. However, Maxwell always viewed Glenlair as home and he would return here whenever possible. For ex-



THE SUNDAY TIMES, MAY 28, 1950

They called him "Dafty"
—*yet we owe radio to his theories*

TEN-YEAR-OLD James Clerk Maxwell was the butt of the school when he entered Edinburgh Academy in 1841. He seemed dull, and his country clothes and square-toed shoes were a joke to the other boys, who called him "Dafty". But soon he surprised them by becoming a brilliant scholar.

His work made electricity a mathematically exact science; his theories gave others a sure basis for their practical work: his theory of electro-magnetic waves was the foundation of all subsequent radio discoveries.

Never in Britain's history were men of Maxwell's foresight and imagination needed more than today. *Each of us must contribute to the nation's industrial and economic recovery.* The electricity industry, for its part, is achieving wonders in increasing Britain's supplies of electrical power, and in developing new appliances for putting this power to more efficient use in our factories and homes.

▲ *Fig. 8 Maxwell's first day of school.*

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ample, Maxwell wrote the founding document of modern electromagnetics, his two volume treatise on *Electricity and Magnetism*, at Glenlair House.

Today, Glenlair House itself is in a sorry state, as shown in ***Figure 9***. There was a fire in 1929. The fire trucks came, but they had no water. All the firemen could do was to help carry things out of the house. In spite of attempts to halt the decay, the building is now in danger of being lost forever. The present owner, Capt. Duncan Ferguson, has established a Scottish Trust[2] to oversee a hoped-for stabilization/preservation of the property. Donations are welcome.

The present owner lives in the gardener's cottage nearby. We spent several nights in the nicely restored servant's quarters, now known as Glenlair Lodge, attached to Glenlair House. At night, we listened carefully for Maxwell's ghost, or perhaps even Maxwell's mythical demon opening and closing doors, but we heard nothing. During the visit, we made an appropriate donation to the restoration fund.

This is the place where Maxwell set pen to paper, founded electromagnetics and set the stage for the rest of the 20th century physics. Having worked in electromagnetics for a quarter of a century, I find the emotions of such a visit beyond description. Visiting Glenlair was really a religious pilgrimage.

Notice the small foyer at the main entrance to Glenlair House (center, ***Figure 9***). This was built by Maxwell. I walked through that door (as Maxwell himself undoubtedly did many times), turned right, looked down and pulled back a tarp. A beautiful floor appeared (see ***Figure 10***), with tile colors of white, red, green and blue. These seem like odd colors, until we remember Maxwell's work with the primary colors of light mentioned above. This speculation is my own. I have not seen this point discussed elsewhere.

The Glenlair estate is a peaceful, rural paradise. Abundant wildlife, forest, field, cattle and sheep fill the countryside. I can see Maxwell working through some equations, then going for a walk, talking with some neighbors, then returning to his work. Genius happened here.

The Glenlair duck pond provided an escape for young Maxwell, literally. His mother died tragically when he was eight years old. They then hired a

▲ *Fig. 9 Maxwell's home, Glenlair House, today.*

▲ *Fig. 10 The tile floor in the Glenlair House foyer.*

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tutor. However, the tutor physically mistreated the young boy. One day, he escaped the tutor's punishments by taking to a tub in the pond, much to the amusement of his family.

Maxwell himself said nothing about the mistreatment. However, when one of his aunts discovered what was happening, the tutor was immediately dismissed and it was then that Maxwell was sent to live in Edinburgh at Old 31.

There is no tub here today, so escape is no longer possible, and the ducks are fake. Capt. Ferguson, who restored the pond himself, once had live ducks. However, some animal rights activists released mink on a nearby farm and those mink then ate Glenlair's ducks.

### GRAVESITE

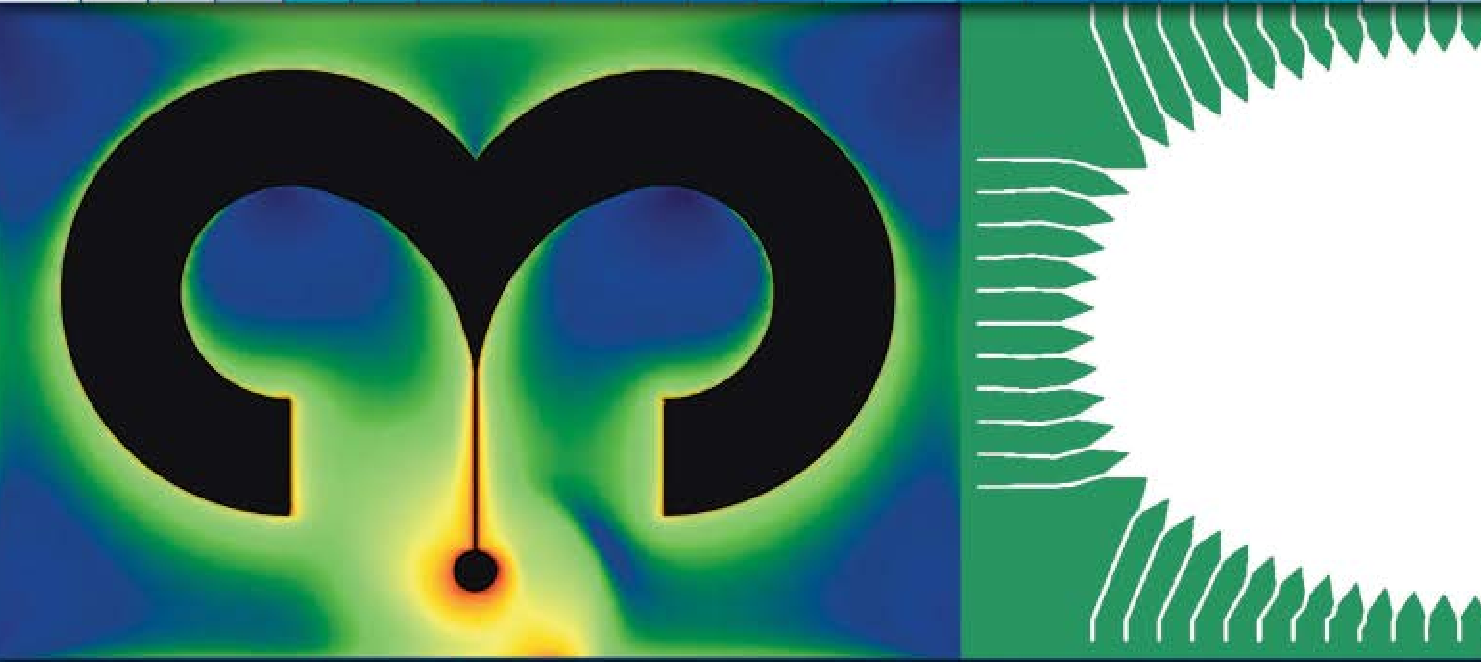
There is a small memorial marker for Maxwell on the floor, next to Newton's, in Westminster Abbey, but Maxwell is not buried there. His final resting place is near Glenlair in the ruins of a very small church built in the 1500s, around the time of Mary Queen of Scots (with whom Maxwell's ancestors had significant interaction) (see ***Figure 11***). There is one marker for all four; his father, his mother, his wife and himself. They are not listed in the order of death, suggesting it was put in place at a later date. In addition, the marker has no birth dates and it has a modern appearance. We do not know who placed the stone, or when.

The gravesite is in the side yard of a much larger church built by Maxwell's father and which is in use today. Inside, the pew that the Maxwell family occupied is all the way to the back on the right. That area is today used for storage.

If you visit the church, be sure to get in touch with Sam Callander. He is caretaker and unofficial historian of the church and lives just down the street. He will be very happy to show you around and also let you enjoy his large collection of Maxwellia. He speaks with a strong Corsock Scottish




▲ *Fig. 11 Maxwell's final resting place.*



### THE LIFE OF JAMES CLERK MAXWELL

*Presented by* James C. Rautio, IEEE/MTT Distinguished Microwave Lecturer

James Clerk Maxwell stands shoulder to shoulder with Newton and Einstein, yet even those of us who have spent decades working with Maxwell's equations are almost totally unfamiliar with his life and times. This presentation, from the viewpoint of a microwave engineer, draws on many sources in providing an understanding of James Maxwell himself. What was Maxwell like as an infant? What was the tragedy at eight years old that profoundly influenced his life? What unique means of transportation did young Maxwell use to escape a cruel tutor? What memorable event occurred on his first day of school? When did he publish his first papers, and what were they about? What did Maxwell have to do with the rings of Saturn? Why did he lose his job as a professor? Why did he have a hard time getting another job? What was his wife like? What is Maxwell's legacy to us? The answers to these questions provide insight into Maxwell the person and add an extra dimension to those four simple equations we have studied ever since. There are no equations in this presentation. The presentation is appropriate for anyone with a general interest in the origins of modern physics. For electronic handouts for the lecture, visit www.sonnetsoftware.com and click on the large "Distinguished Microwave Lecture Series" button at the bottom of the "News" section.

accent, probably very much like Maxwell himself.

## CONCLUSION

Maxwell died at the age of 48 of stomach cancer. This is the same disease that had taken his mother precisely 40 years before. While Maxwell himself was mortal, he launched a never-ending wave that spread throughout all the dimensions of the physics of the 20$^{th}$ century and whose influence will continue to be felt for the centuries to come. In this way, Maxwell is indeed immortal. We all benefit from his having lived, even those of us who haven't the faintest idea who he is. ■

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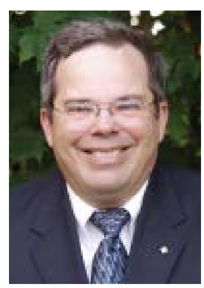
1. http://www.clerkmaxwellfoundation.org/.
2. http://www.glenlair.org.uk/.

**James C. Rautio** *received his BSEE degree from Cornell University in 1978, his MS degree in systems engineering from the University of Pennsylvania in 1982 and his PhD in electrical engineering from Syracuse University in 1986. From 1978 to 1986, he worked for General Electric, first at the Valley Forge Space Division, then at the Syracuse Electronics Laboratory. At this time he developed microwave design and measurement software, and designed microwave circuits on alumina and GaAs. From 1986 to 1988, he was a visiting professor at both Syracuse University and at Cornell University. In 1988, he went full time with Sonnet Software, a company he had founded in 1983. In 1995, Sonnet was listed on the* INC 500 *list of the fastest growing privately held US companies, the first microwave software company ever to be so listed. Today, Sonnet is the leading vendor of 3-D planar high frequency electromagnetic analysis software. He was elected a fellow of the IEEE in 2000 and received the IEEE MTT Microwave Application Award in 2001 and is an adjunct professor at Syracuse University.*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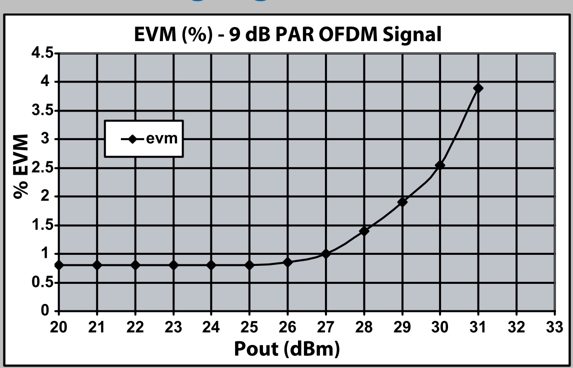


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# A DUAL-PASSBAND WAVEGUIDE FILTER WITH A CANONICAL STRUCTURE FOR KA-BAND SATELLITE APPLICATIONS

*This article presents the implementation techniques for a six-pole, dual-passband waveguide filter with an asymmetric canonical structure for Ka-band satellite applications. An asymmetric canonical structure is chosen, not only to increase the transmission zeros of dual-passband filters, but also to get high isolation between the input and output coupling elements. Very effective nonlinear equations are extracted to obtain the coefficients of a transfer function from the coupling matrix to synthesize a filter network. An appropriate equivalent circuit model for an asymmetric canonical structure is proposed to design a filter. To validate the proposed implementation approach, a six-pole, dual-mode, dual-passband filter for Ka-band satellite applications is realized. Very good agreement between the measured and computed responses is obtained.*

For the effective use of the available frequency spectrums, the channels of conventional communications satellite systems are allocated contiguously in frequency. Each channel is filtered by a channel filter with high frequency selectivity, amplified by a high power amplifier and transmitted to the ground through a single beam. Modern satellite systems often use a complex arrangement of frequency plans and spatial coverage. Such systems may require compact filters with multiple passbands.

Microwave filters for satellite applications generally require the lowest mass possible because of the high launch cost of the payload. Therefore, the techniques of dual-mode elliptic response filters have long been considered to reduce the size and mass for satellite applications.[1] Due to their ease of fabrication and tuning, the in-line type, dual-mode filters, with input and output ports positioned on opposite sides of the structure, have been widely used for satellite applications.[2–4] Holme has realized an in-line type, dual-mode, dual-passband filter with an elliptic response by allow-

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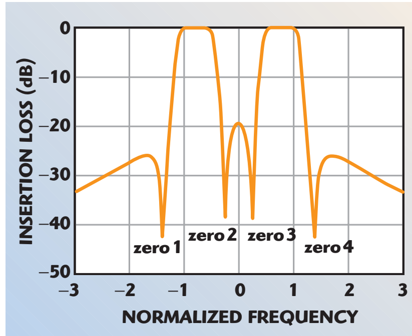


▲ *Fig. 1 Transmission characteristics of a dual passband filter.*

ing transmission zeros to be used to separate the filter into multiple passbands.[5] However, the N-pole, in-line type, dual-mode filter can realize N/2 transmission zeros at the most. Therefore, implementation techniques for the dual-passband filter with a canonical structure are required to increase the number of zeros up to N-2.[6]

This article presents the implementation techniques of a dual-passband filter with an asymmetric canonical structure. An asymmetric canonical structure is chosen not only to increase the transmission zeros of dual-passband filters, but also to get high isolation between input and output coupling elements. Very effective nonlinear equations are extracted to obtain the coefficients of the transfer function from the coupling matrix for synthesizing the six-pole filter with an asymmetric canonical structure. The configuration of the equivalent circuit with lumped elements is proposed and the lumped element values are obtained. To validate the proposed implementation approach, a six-pole, dual-mode, dual-passband filter for satellite applications was fabricated. Very good agreement between the measured and computed responses is obtained.

## DUAL-PASSBAND FILTER TRANSFER FUNCTION

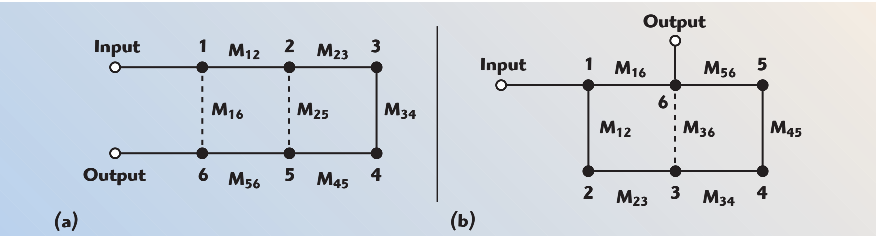
For the single-passband elliptic function filter with high frequency selectivity, all poles are located within the passband and all the zeros are located out-of-band. However, for a dual-passband realization, zeros may be used to split the single passband into two passbands, as shown in ***Figure 1***. Furthermore, two zeros between each passband are indispensable for realizing a dual-passband by splitting a single-passband. The dual-passband, elliptic function filter with high frequency selectivity should therefore be of a configuration that can realize at least four zeros. Generally, N-2 zeros for the N-pole resonator filter are located on the complex frequency(s) if the coupling value between the first and last resonator is nonzero. Poles and zeros are determined after optimization for the desired dual-passband filter response. From the optimized poles and zeros to meet the stringent specification, the transfer function of a symmetrical six-pole filter with four zeros is written with respect to s as

$$t(s) = \frac{1}{\varepsilon}\,\frac{s^4 + a_{z2}s^2 + a_{z0}}{s^6 + a_{p5}s^5 + a_{p4}s^4 + a_{p3}s^3 + a_{p2}s^2 + a_{p1}s + a_{p0}} \qquad (1)$$

where

$\varepsilon$ = ripple factor

In this article, the coefficients of the denominator and numerator polynomials and the ripple factor for the design




▲ *Fig. 2 Signal flow diagrams of a six-pole filter; solid lines = resonator, dashed lines = direct coupling; (a) symmetric canonical structure and (b) asymmetric canonical structure.*

of a dual-passband filter with better than 22 dB return loss in the passband are chosen as $a_{z2} = 1.9531$, $a_{z0} = 0.1182$, $a_{p5} = 1.0961$, $a_{p4} = 2.5333$, $a_{p3} = 1.6303$, $a_{p2} = 1.6228$, $a_{p1} = 0.4296$, $a_{p0} = 0.2144$ and $\varepsilon = 5.1370$, respectively.

## SIX-POLE FILTER COUPLING MATRIX

Due to their ease of fabrication and tuning, the in-line type, dual-mode filters, with the input and output ports positioned on opposite sides of the structure, have been designed widely for satellite applications.[3,4] However, the N-pole, in-line type, dual-mode filter can realize N/2 transmission zeros at the most. It is possible to increase the number of zeros up to N-2 by employing a canonical structure.[5] ***Figure 2*** shows the signal flow diagrams for six-pole symmetric and asymmetric canonical filters. Since the coupling matrix of a symmetric canonical filter is symmetric ($M_{12} = M_{56}$ and $M_{23} = M_{45}$), for most practical cases it can be obtained easily. However, the symmetric canonical filter has a major drawback when it is realized with the dual-mode technique. There is an isolation problem due to the fact that the input and output coupling elements are in the same physical cavity. Therefore, the asymmetric canonical filter is an alternative structure to solve this problem.[7] For an N-pole, lossless resonator filter, the transmission coefficient $S_{21}$ is given as[8]

$$S_{21} = -2jR_T\left[A^{-1}\right]_{N1} \tag{2}$$

where

$R_T$ = input/output-termination resistance

Here [A] is a N-square matrix containing the complex frequency variable s and the frequency-independent coupling coefficients $M_{pq}$

$$[A] = -j\begin{bmatrix} s+jM_{11} & jM_{12} & jM_{13} & \cdots & jM_{1N-1} & jM_{1N} \\ jM_{12} & s+jM_{22} & jM_{23} & \cdots & jM_{2N-1} & jM_{2N} \\ jM_{13} & jM_{23} & s+jM_{33} & \cdots & jM_{3N-1} & jM_{3N} \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ jM_{1N-1} & jM_{2N-1} & jM_{3N-1} & \cdots & s+jM_{N-1N-1} & jM_{N-1N} \\ jM_{1N} & jM_{2N} & jM_{3N} & \cdots & jM_{N-1N} & s+jM_{NN} \end{bmatrix} \tag{3}$$

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| VLF-120 | DC-120 | 195 | 280 | VLF-1575 | DC-1575 | 1875 | 2175 |
| VLF-225 | DC-225 | 350 | 460 | VLF-1700 | DC-1700 | 2050 | 2375 |
| VLF-320 | DC-320 | 460 | 560 | VLF-1800 | DC-1800 | 2125 | 2425 |
| VLF-400 | DC-400 | 560 | 660 | VLF-2250 | DC-2250 | 2575 | 2900 |
| VLF-490 | DC-490 | 650 | 800 | VLF-2500 | DC-2500 | 3075 | 3675 |
| VLF-530 | DC-530 | 700 | 820 | VLF-2600 | DC-2600 | 3125 | 3750 |
| VLF-575 | DC-575 | 770 | 900 | VLF-2750 | DC-2750 | 3150 | 4000 |
| VLF-630 | DC-630 | 830 | 1000 | VLF-2850 | DC-2800 | 3300 | 4000 |
| VLF-800 | DC-800 | 1075 | 1275 | VLF-3000 | DC-3000 | 3600 | 4550 |
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| VHF-1320 | 1400-5000 | 1320 | 1060 | VHF-2700 | 2650-6500 | 2500 | 1800 |
| VHF-1500 | 1600-5500 | 1550 | 1250 | VHF-3800 | 4250-10000 | 3800 | 3200 |
| VHF-1600 | 1650-5000 | 1600 | 1290 | VHF-5500 | 6000-11500 | 5500 | 4500 |
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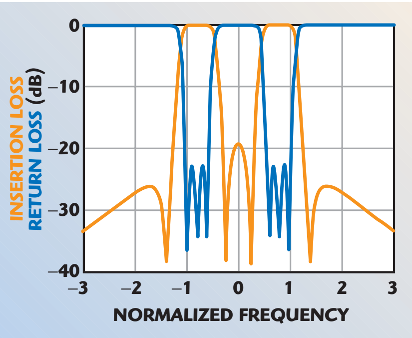



▲ *Fig. 3 Insertion loss and return loss of the six-pole dual passband filter.*

The transmission coefficient (Equation 2) for an N-pole filter can be described as a fractional expression like the transfer function with the denominator and numerator polynomials. The denominator polynomial of Equation 2 is equal to the determinant of [A] with respect to s. The numerator of the transmission coefficient can be obtained from the determinant of the matrix in which the elements of the N$^{th}$ row and the 1$^{st}$ column are removed. The synthesis method of a four-pole filter with two zeros was proposed by solving the nonlinear equations of the relation between the coefficients of the transfer function and the coupling matrix.[9] This method is very useful for a four-pole filter, but any other equations were not provided for an arbitrary structure. By using the well-known algorithm[10] for the computation of the determinant, very effective equations can be derived to obtain the coefficients of the denominator polynomial and the numerator polynomial with respect to s from the coupling matrix and the termination resistance for a six-pole filter with an asymmetric canonical structure. These equations for each coefficient are given as

$$
\begin{aligned}
E_5 &= 2R_T \\
E_4 &= M_{12}^2 + M_{16}^2 + M_{56}^2 + M_{45}^2 + M_{34}^2 + M_{36}^2 + M_{23}^2 + R_T^2 \\
E_3 &= R_T\,(M_{36}^2 + M_{12}^2 + 2M_{45}^2 + 2M_{34}^2 + 2M_{23}^2 + M_{56}^2) \\
E_2 &= M_{12}^2M_{45}^2 + M_{34}^2M_{56}^2 + M_{12}^2M_{56}^2 + M_{12}^2M_{34}^2 + R_T^2M_{23}^2 + \\
&\quad R_T^2M_{34}^2 + M_{12}^2M_{36}^2 + M_{45}^2M_{16}^2 + M_{34}^2M_{16}^2 + M_{23}^2M_{16}^2 + \\
&\quad M_{36}^2M_{45}^2 + M_{23}^2M_{56}^2 + M_{23}^2M_{45}^2 + R_T^2M_{45}^2 - \\
&\quad 2M_{12}M_{23}M_{36}M_{16} - 2M_{34}M_{45}M_{36}M_{56} \\
E_1 &= R_T\,(M_{12}^2M_{45}^2 + M_{12}^2M_{34}^2 + 2M_{23}^2M_{45}^2 + M_{34}^2M_{56}^2 + \\
&\quad M_{36}^2M_{45}^2 + M_{23}^2M_{56}^2 - 2M_{34}M_{45}M_{36}M_{56}) \\
E_0 &= M_{12}^2M_{34}^2M_{56}^2 + M_{12}^2M_{45}^2M_{36}^2 + M_{23}^2M_{45}^2M_{16}^2 + \\
&\quad R_T^2M_{23}^2M_{45}^2 - 2M_{12}^2M_{34}M_{45}M_{36}M_{56} - \\
&\quad 2M_{45}^2M_{12}M_{23}M_{36}M_{16} + 2M_{12}M_{23}M_{34}M_{45}M_{16}M_{56} \\
P_4 &= 2R_T\varepsilon M_{16} \\
P_2 &= 2R_T\varepsilon\,(M_{45}^2M_{16} + M_{34}^2M_{16} + M_{23}^2M_{16} - M_{12}M_{23}M_{36}) \\
P_0 &= 2R_T\varepsilon\,(M_{12}M_{23}M_{34}M_{45}M_{56} - M_{12}M_{23}M_{45}^2M_{36} + \\
&\quad M_{23}^2M_{45}^2M_{16})
\end{aligned}
\tag{4}
$$

The coefficients of the denominator polynomials and the numerator polynomials given by Equation 4 should be equal to the coefficients of the polynomials given by Equation 1. Thus, the goal function, obtained by comparing the coefficients of polynomials, is expressed for optimization as

$$G = \sum_{i=0}^{5} \left|E_i - ap_i\right| + \left|P_4 - 1\right| + \left|P_2 - az_2\right| + \left|P_0 - az_0\right| \quad (5)$$

The gradient optimization method, with the goal function presented in this article, is applied to the filter using commercial mathematical tools such as MathCAD.™ The coupling values obtained by optimization are shown in Equation 6. Note that the coupling matrix has alternating larger and smaller adjacent resonator couplings.[11] ***Figure 3*** shows the frequency response of the transfer function (Equation 1) and coupling matrix ([M]) given by Equation 6. Note that the response of the transfer function and that of the coupling matrix cannot be distinguished. This agreement verifies the presented synthesis method for the presented topology of the resonator filter

$$M = \begin{bmatrix} 0 & 0.8450 & 0 & 0 & 0 & 0.1776 \\ 0.8450 & 0 & 0.4768 & 0 & 0 & 0 \\ 0 & 0.4768 & 0 & 0.7328 & 0 & -0.5199 \\ 0 & 0 & 0.7328 & 0 & 0.0952 & 0 \\ 0 & 0 & 0 & 0.0952 & 0 & 0.6661 \\ 0.1776 & 0 & -0.5199 & 0 & 0.6661 & 0 \end{bmatrix} \quad (6)$$

$R_T = 0.5480$

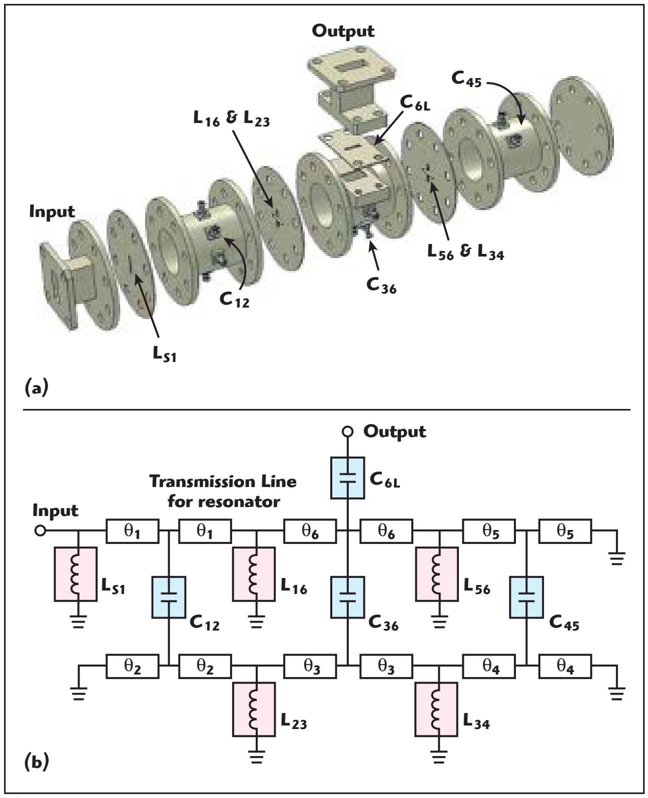



*Fig. 4 Six-pole waveguide filter with asymmetric canonical structure's; (a) configuration and (b) equivalent circuit model.*

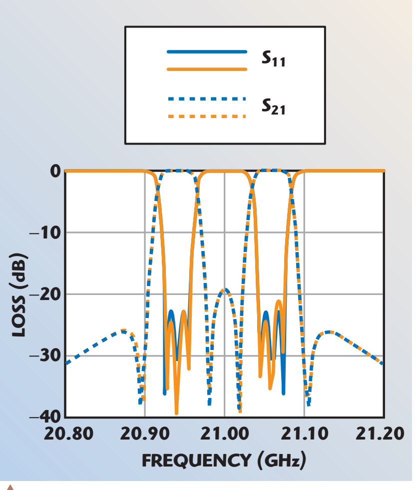
| TABLE I | |
|---|---|
| LUMPED ELEMENT VALUES | |
| $L_{S1}$ (pH) = $C_{6L}$ (pF) | 1.0487 |
| $C_{12}$ (pF) | 0.2157 |
| $L_{23}$ (pH) | 0.1217 |
| $L_{34}$ (pH) | 0.1871 |
| $C_{45}$ (pF) | 0.0243 |
| $L_{56}$ (pH) | 0.1700 |
| $L_{16}$ (pH) | 0.0453 |
| $L_{36}$ (pH) | –0.1327 |

| TABLE II | |
|---|---|
| ELECTRICAL LENGTH OF RESONATOR | |
| $2\theta_1$ | 530.29° |
| $2\theta_2$ | 537.43° |
| $2\theta_3$ | 538.67° |
| $2\theta_4$ | 538.40° |
| $2\theta_5$ | 538.53° |
| $2\theta_6$ | 531.64° |

## SIX-POLE FILTER EQUIVALENT CIRCUIT MODEL

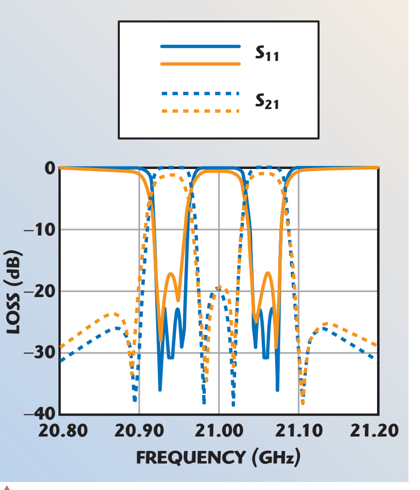
For satellite communication systems that have stringent requirements for low insertion loss and high power capacity, it is usually necessary to implement the filters in waveguide. As shown in ***Figure 4***, a six-pole, dual-passband filter with an asymmetric canonical structure consists of dual-mode, circular waveguide cavities excited in their $TE_{113}$ mode, coupling irises and tuning screws. In each cavity, a screw at a 45° angle from the polarization axes couples the dual modes and tuning screws adjust the resonant frequencies.

In order to design this filter, an appropriate electrical model of the filter network is needed with frequency-dependant impedance inverters. An electrical model with the same filter configuration is especially practical to estimate the length of each cavity. Input and inter-cavity irises act as shunt inductive discontinuities whose magnitudes are determined by the length of slots. The output iris and the coupling screws can be replaced with capacitors, as shown in the equivalent circuit. In this model, ideal normalized transmission lines (1Ω) are used for resonators as a matter of convenience. A length of three or four half-wavelengths for the cavity is usually chosen to obtain higher unloaded Qs ($Q_u$) and practical coupling coefficients. In this article, three half-wavelength long cavities are chosen. Since the method to determine the lumped element values is already well described in the literature,[12,13] it is not repeated here. When the center frequency of the filter is 21 GHz, with 150 MHz of bandwidth, the final results for the element values and the electrical lengths of the cavities are given in ***Tables 1*** and ***2***. As shown, the electrical length of each cavity has different phases due to the adjacent lumped elements. ***Figure 5*** shows the frequency response of the six-pole filter with an asymmetric canonical structure. The simulated results, using the equivalent circuit model with the lumped element values given in the table, have shown good agreement with results from the ideal impedance inverter.




▲ *Fig. 5 Simulated response of the six-pole filter using ideal impedance inverters (blue) and lumped elements of the equivalent circuit (orange).*

▲ *Fig. 6 Fabricated dual passband waveguide filter.*




▲ *Fig. 7 Simulated (blue) and measured (orange) frequency response of the dual passband filter.*

## FABRICATED SIX-POLE, DUAL-BAND FILTER

The filter is realized using iris coupled cylindrical waveguide cavities operating in the $TE_{113}$ orthogonal degenerate modes for volume and mass reduction. The diameter of the cavities is carefully selected to control the higher order modes and to optimize the $Q_u$, which influences the in-band performances and the losses. In order to determine the length of the cavities, both the electrical lengths given in the table and the added length from the finite iris thickness have to be considered. The filter consists of three circular cavities with small length variations over the temperature range. Each open ended cylindrical cavity was machined from solid Invar 36, a low thermal expansion alloy, which provides a stable RF performance over the specified temperature range. The irises are made from a thin sheet of Invar 36. As shown in ***Figure 6***, the cavities, irises and tuning screws are finished with silver-plating to minimize the insertion losses. Before assembling the filter, the sizes of the input/output and inter-cavity slots must be chosen by measuring the inter-cavity couplings.[14] After the slots are set, the tuning screws and coupling screws must be adjusted. The filter is divided into two short-circuited pieces and screws are adjusted by measuring the phase response of the input reflection coefficient. ***Figure 7*** shows the computed and measured responses of the filter. The measured results of the experimental filter show good agree-

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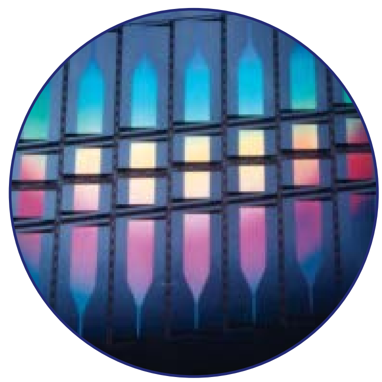

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ment with the theory. The presented filter structure and design techniques can be applied not only to satellite communications systems but also to commercial communications systems.

## CONCLUSION

This article presents the implementation techniques for a Ka-band, dual-passband filter with an asymmetric canonical structure. An asymmetric canonical structure is chosen, not only to increase the transmission zeros of dual-passband filters, but also to get high isolation between input and output coupling elements. Very effective nonlinear equations to obtain the coefficients of a transfer function from the coupling matrix values have been proposed for synthesizing the filter. The configuration of the equivalent circuit with lumped elements has been proposed and the values of lumped elements have been obtained. To validate the proposed implementation approach, a six-pole, dual-mode, dual-passband filter for satellite applications has been fabricated. Very good agreement between the measured and computed responses has been obtained. The presented filter structure and design techniques can be applied not only to satellite communications systems but also to commercial communications systems. ■

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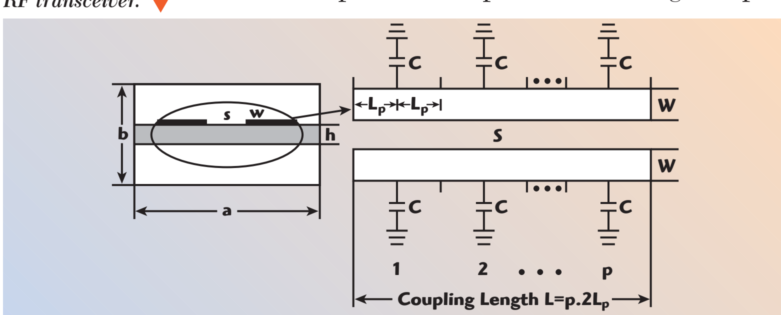
# PERIODICALLY LOADED SSS COUPLED-LINE FILTER FOR SECOND HARMONIC SUPPRESSION

*A suspended substrate stripline (SSS) filter using coupled-lines with periodical capacitive loading is proposed to suppress the second harmonics. The required capacitive loading is achieved by using elevated circular posts in the filter cavity. An example filter at 2.4 GHz has been fabricated to verify the design.*

Rapidly growing wireless systems call for low loss filters with special requirements such as a suppressed second harmonic and a wide stop band region. Although conventional parallel coupled-line filters have many salient features,[1] their spurious response at $2f_o$ make them unsuitable for modern day wireless systems. This spurious response occurs because of the unequal even- and odd-mode phase velocities at $2f_o$. Various techniques have been reported to equalize the phase velocities at $2f_o$ and thereby suppressing the spurious response.[2–8] Using lumped capacitive loading, spurious suppression and miniaturization in parallel coupled-line filters have been reported.[2] Some techniques[3–6] use either stepped impedance resonators, wiggly-coupled-line resonators or mostly rely on choosing the proper dimensions for coupled-lines and substrate suspension heights for equalizing the phase velocities at $2f_o$. Spurious suppression in microstrip line filters has been obtained by using floating grounds.[7] Using periodical non-uniform microstrip coupled-lines, spurious rejection has been achieved.[8]

This article reports another technique that uses coupled-lines with periodically loading capacitances to suppress the second harmonic, $2f_o$. Periodic capacitive loading of a coupled-line section of an SSS filter is shown in ***Figure 1***.

*Fig. 1 Architecture of a 2.4 GHz CMOS single-mixer RF transceiver.*

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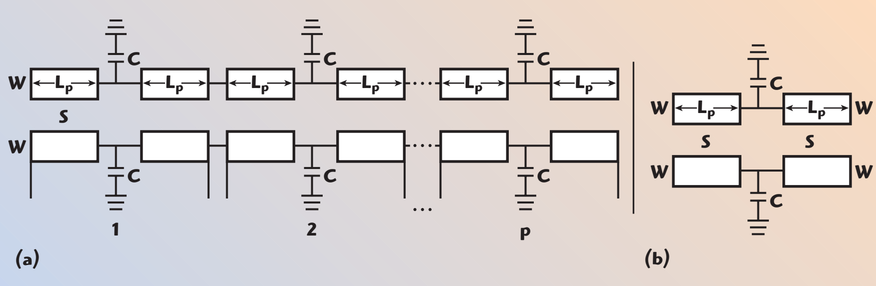



Fig. 2 Coupled-line section with 'p' periodical capacitively loaded cells (a) and a periodical unit cell (b).



***Figure 2*** shows a typical coupled-line section with 'p' periodical cells, each having a length of $2L_p$ and a capacitance placed at the center of the cell. The number of periodically loaded cells 'p' and the values of the capacitors C in each coupled-line section can be properly chosen to achieve the desired harmonic suppression. A circuit simulator such as Ansoft Designer 2.0 can be efficiently used to design filters by treating each periodic cell, as shown in the figure.

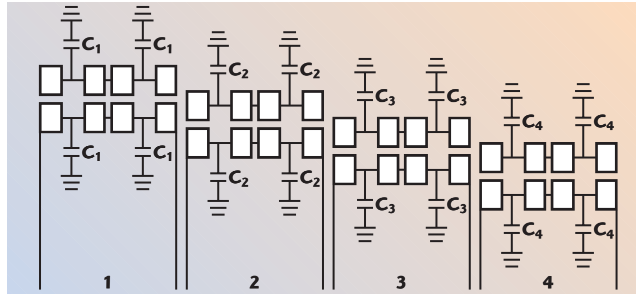
A bandpass filter at 2.4 GHz has been designed to demonstrate the validity of the proposed configuration with the following specifications: $f_o$ = 2.4 GHz, bandwidth = 15 percent, ripple = 0.1 dB and filter order N = 3. Based on the filter specifications, a standard synthesis procedure[5] is used to calculate the required coupling coefficients. The corresponding physical dimensions are given in ***Table 1***. The equivalent circuit of the periodic cell is used along with the synthesized coupled-line dimensions to obtain the required loading capacitance for the suppression of the second harmonic. Ansoft Designer 2.0 was used to simulate the filter shown in ***Figure 3*** with N = 3 and p = 2.

Due to the loading of the capacitances, the filter center frequency may be shifted. This can be corrected by reducing the length of the resonators. The capacitance value varies in each coupled-line section to obtain second harmonic suppression (for fixed 'p,' W and S). After achieving second harmonic suppression, the filter is fine-tuned to get the exact filter center frequency and bandwidth. ***Table 2*** lists the required capacitances in each section. Each section utilizes two periodic cells. Finally, the required low values of lumped capacitances are realized by using circular posts, as shown in ***Figures 4*** and ***5***. The posts' dimensions are given in ***Table 3***. To verify the accuracy of the design procedure, the method of moments-based planar EM simulator IE3D has been used to simulate the entire filter and the results are compared with the ones from the Ansoft Designer in ***Figure 6***.

**TABLE I**

**DESIGN PARAMETERS FOR THE CONVENTIONAL PARALLEL COUPLED-LINE FILTER (W = 2 mm, SS Parameters: a = 17.86 mm, b = 2.58 mm, h = 0.38 mm and $\varepsilon_r$ = 2.17)**

| Coupled Stage N | Coupling Coefficients $K_N$ | $S_N$ (mm) | Coupling Length $L_N$ (mm) |
|---|---|---|---|
| 1 | 0.402 | 0.12 | 28.6 |
| 2 | 0.140 | 0.74 | 28.6 |
| 3 | 0.140 | 0.74 | 28.6 |
| 4 | 0.402 | 0.12 | 28.6 |

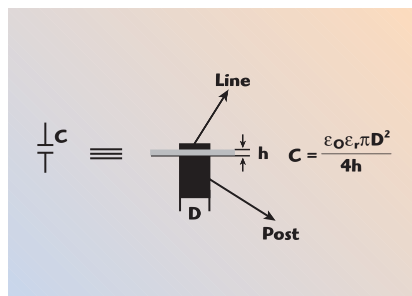



▲ *Fig. 3 Three section (four coupled stages) harmonic suppression filter with p=2.*

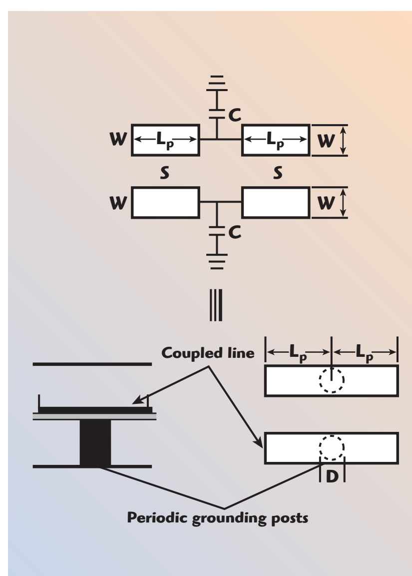
**TABLE II**

**CAPACITANCES NEEDED FOR SECOND HARMONIC SUPPRESSION (p = 2, W = 2 mm)**

| Coupled Stage N | $C_N$ (pF) |
|---|---|
| 1 | 0.14 |
| 2 | 0.12 |
| 3 | 0.12 |
| 4 | 0.14 |




▲ *Fig. 4 Lumped capacitor and its equivalent modes.*




▲ *Fig. 5 Lumped capacitance loading and its equivalent circuit.*



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|---|---|---|---|---|---|
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| LFCN-105 | DC-105 | 180 | 250 | 7 | 3.99 |
| LFCN-120 | DC-120 | 195 | 280 | 7 | 3.99 |
| LFCN-225 | DC-225 | 350 | 460 | 7 | 2.99 |
| LFCN-320 | DC-320 | 460 | 560 | 7 | 2.99 |
| LFCN-400 | DC-400 | 560 | 660 | 7 | 2.99 |
| LFCN-490 | DC-490 | 650 | 800 | 7 | 2.99 |
| LFCN-530 | DC-530 | 700 | 820 | 7 | 2.99 |
| LFCN-575 | DC-575 | 770 | 900 | 7 | 2.99 |
| LFCN-630 | DC-630 | 830 | 1000 | 7 | 2.99 |
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| LFCN-900 | DC-850 | 1075 | 1275 | 7 | 1.99 |
| LFCN-1000 | DC-1000 | 1300 | 1550 | 7 | 1.99 |
| LFCN-1200 | DC-1200 | 1530 | 1865 | 7 | 1.99 |
| LFCN-1325 | DC-1325 | 1560 | 2100 | 5 | 1.99 |
| LFCN-1400 | DC-1400 | 1700 | 2015 | 7 | 2.99 |
| LFCN-1450 | DC-1450 | 1825 | 2025 | 7 | 2.99 |
| LFCN-1500 | DC-1500 | 1825 | 2100 | 7 | 2.99 |
| LFCN-1525 | DC-1525 | 1750 | 2040 | 7 | 2.99 |
| LFCN-1575 | DC-1575 | 1875 | 2175 | 7 | 2.99 |
| LFCN-1700 | DC-1700 | 2050 | 2375 | 7 | 1.99 |
| LFCN-1800 | DC-1800 | 2125 | 2425 | 7 | 2.99 |
| LFCN-2000 | DC-2000 | 2275 | 3000 | 5 | 1.99 |
| LFCN-2250 | DC-2250 | 2575 | 2900 | 7 | 1.99 |
| LFCN-2400 | DC-2400 | 2800 | 3600 | 5 | 1.99 |
| LFCN-2500 | DC-2500 | 3075 | 3675 | 7 | 1.99 |
| LFCN-2600 | DC-2600 | 3125 | 3750 | 7 | 1.99 |
| LFCN-2750 | DC-2750 | 3150 | 4000 | 7 | 1.99 |
| LFCN-2850 | DC-2800 | 3300 | 4000 | 7 | 1.99 |
| LFCN-3000 | DC-3000 | 3600 | 4550 | 7 | 1.99 |
| LFCN-3800 | DC-3900 | 4850 | 6000 | 7 | 2.99 |
| LFCN-4400 | DC-4400 | 5290 | 6700 | 7 | 2.99 |
| LFCN-5000 | DC-5000 | 5580 | 6850 | 7 | 1.99 |
| LFCN-6000 | DC-6000 | 6800 | 8500 | 7 | 1.99 |
| LFCN-6700 | DC-6700 | 7600 | 9300 | 7 | 1.99 |
| HFCN-650 | 850-2490 | 650 | 480 | 7 | 1.99 |
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| HFCN-1760 | 2100-5500 | 1760 | 1230 | 7 | 1.99 |
| HFCN-1910 | 2200-5200 | 1910 | 1400 | 7 | 1.99 |
| HFCN-1810 | 2250-4750 | 1810 | 1480 | 7 | 1.99 |
| HFCN-2000 | 2410-6250 | 2000 | 1530 | 7 | 1.99 |
| HFCN-2100 | 2500-6000 | 2100 | 1530 | 7 | 1.99 |
| HFCN-2275 | 2640-7000 | 2275 | 1770 | 7 | 1.99 |
| HFCN-2700 | 3000-6500 | 2500 | 1800 | 7 | 1.99 |
| ● HFCN-3800 | 4250-10000 | 3800 | 3200 | 5 | 2.49 |
| ● HFCN-5500 | 6000-11500 | 5500 | 4500 | 5 | 2.99 |
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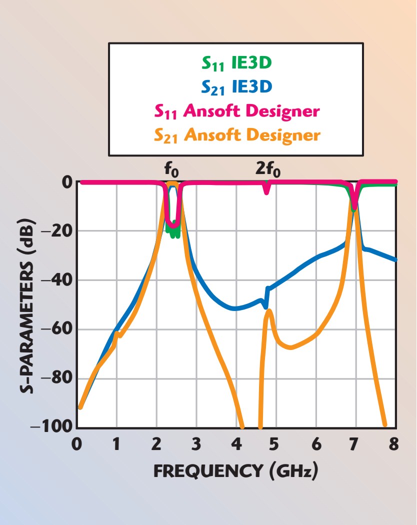
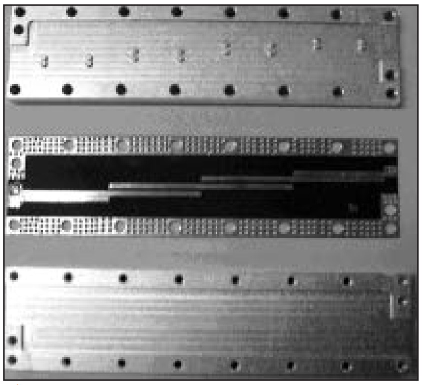
**TABLE III**
**DESIGN PARAMETERS FOR THE FILTER AFTER LOADING POSTS (p=2 and W=2 mm)**

| Coupled Stage N | $D_N$ (mm) | $S_N$ (mm) | Periodical Cell Length (2Lp) (mm) | Coupling Length $L_N$=p.2Lp (mm) |
|---|---|---|---|---|
| 1 | 1.84 | 0.1 | 12.8 | 25.6 |
| 2 | 1.68 | 0.7 | 12.9 | 25.8 |
| 3 | 1.68 | 0.7 | 12.9 | 25.8 |
| 4 | 1.84 | 0.1 | 12.8 | 25.6 |

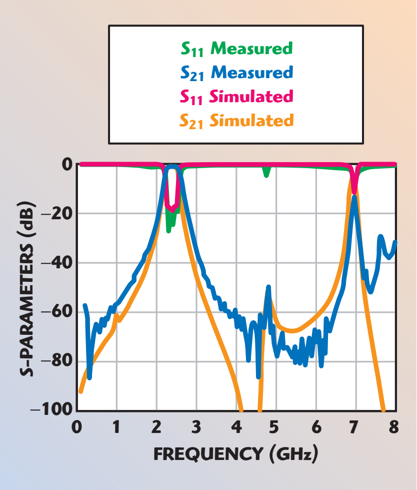





▲ *Fig. 6 Simulated characteristics of the harmonic suppression filter.*



▲ *Fig. 7 Layout of the harmonic suppression filter showing the periodic grounding posts.*




▲ *Fig. 8 Measured results for the harmonic suppression filter.*

## CONCLUSION

***Figure 7*** shows a photograph of the filter, which has periodically elevated posts in the bottom cavity to achieve the desired harmonic sup-

pression. ***Figure 8*** compares the measured results of the fabricated filter against the simulation results. A suppression level better than 50 dB can be observed. The return loss is better than 17 dB and the maximum insertion loss is 0.8 dB. The measured results compare well with the simulation results. This procedure, being simple to implement, offers relaxed dimensions for the coupled-lines and also improves the mechanical rigidity (due to the supporting posts) over conventional SSS filters. ■

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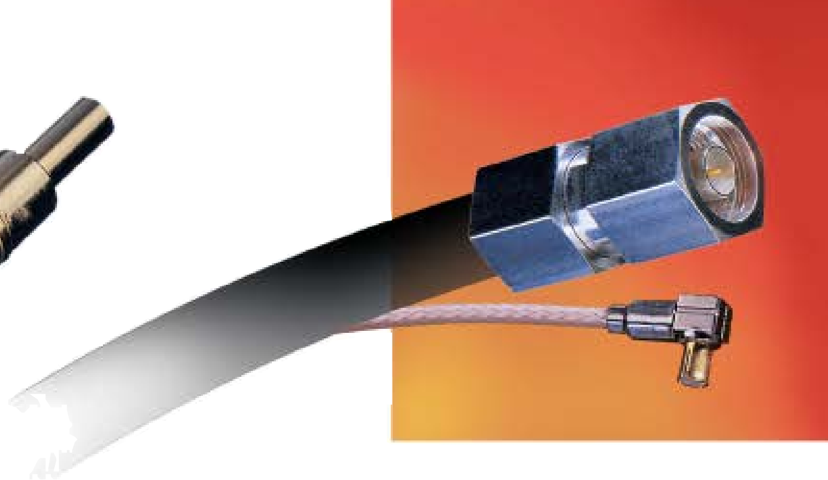

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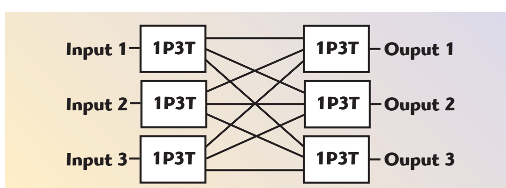
# MATRIX SWITCHES: BLOCKING VERSUS NON-BLOCKING

In the RF and wireless industries, system performance requirements seem to expand almost daily. These systems continue to encompass more and more of today's broad-reaching technologies. Engineers working in this environment are often tasked with designs that must combine and distribute RF signals from multiple input devices while, at the same time, making those signals available via multiple outputs. In many cases, an RF matrix switch can be the solution to this problem. In this article, the three most basic types of matrix switches are explored. The inherent advantages and disadvantages of each of these configurations will also be touched upon.

*In this article, the three most basic types of matrix switches are explored.*

## BLOCKING MATRIX

A blocking matrix switch is built with switches on both the inputs and outputs. Therefore, each input signal can be switched to one individual output port. If an application requires an input to be available to more than one output simultaneously, then a non-blocking matrix becomes necessary. ***Figure 1*** shows the connectivity of a 3 × 3 blocking matrix switch. ***Figure 2*** depicts some of the possible connection states with this type of switch. The two most notable advantages of a blocking matrix switch are insertion loss and isolation. Because the design uses only switches and no power dividers, the insertion loss is relatively low. Using only switches makes it also possible to maintain a very high isolation from input to output. However, one significant disadvantage to this type of design is its cost. RF switches are generally more expensive to produce than RF power dividers.




▲ *Fig. 1 A 3 x 3 blocking matrix switch configuration.*

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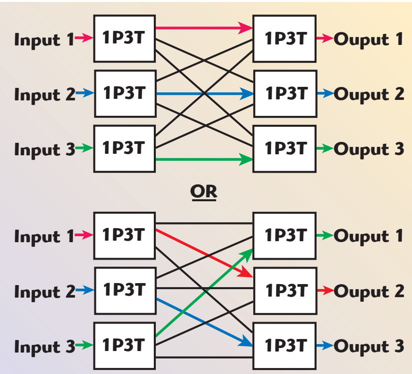
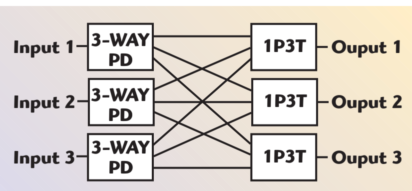
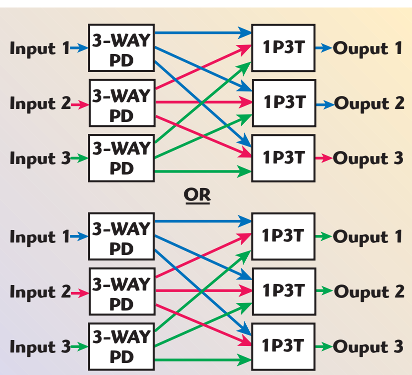


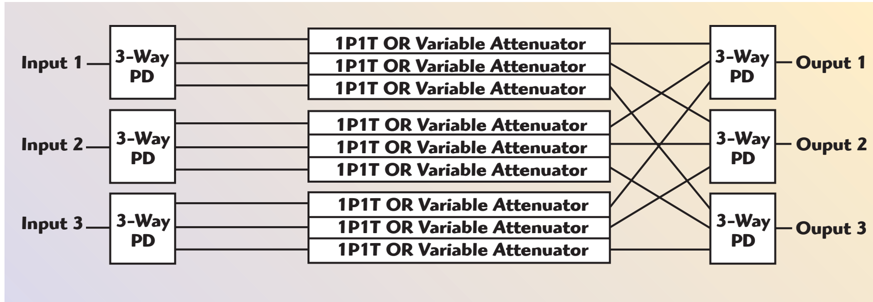

▲ *Fig. 2 Possible connection states for a 3 x 3 blocking matrix switch.*



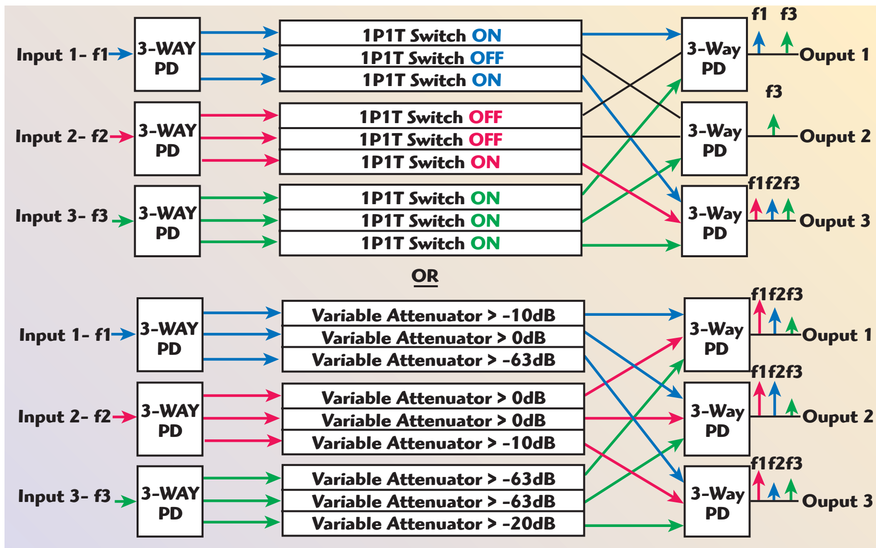

▲ *Fig. 3 Layout of a typical 3 x 3 non-blocking matrix switch.*




▲ *Fig. 4 Some possible connection states of a 3 x 3 non-blocking matrix switch.*




▲ *Fig. 5 Layout of a 3 x 3 extended variation 3 x 3 non-blocking matrix switch.*




▲ *Fig. 6 Possible connections and manipulations with a 3 x 3 extended variation non-blocking matrix switch.*

## NON-BLOCKING MATRIX

A typical non-blocking matrix switch is one that is built with power dividers on the inputs and switches on the outputs. Each input signal is thereby split to all output switches. This means that, in a 4 × 20 non-blocking matrix switch for example, the four input signals could be split to all 20 outputs. This would allow an engineer to select the signal to be seen at each output. Or a user could even have a single input connected to all 20 outputs without even using the other inputs. ***Figure 3*** shows the layout of a typical 3 × 3 non-blocking matrix. ***Figure 4*** depicts some of the possible connection states with this type of switch. The obvious advantage of a non-blocking matrix switch is its greater switching flexibility. However, certain compromises have to be made in order to achieve that increased flexibility. Because it uses power dividers, a matrix like this will have a higher nominal insertion loss. Having a power divider at each input can also have a negative effect on the isolation between channels. In the event that two outputs are switched to receive the same input signal, the isolation between output ports is determined by the isolation of the power divider. Typically this will be approximately 20 dB.

## NON-BLOCKING MATRIX — EXTENDED VARIATION

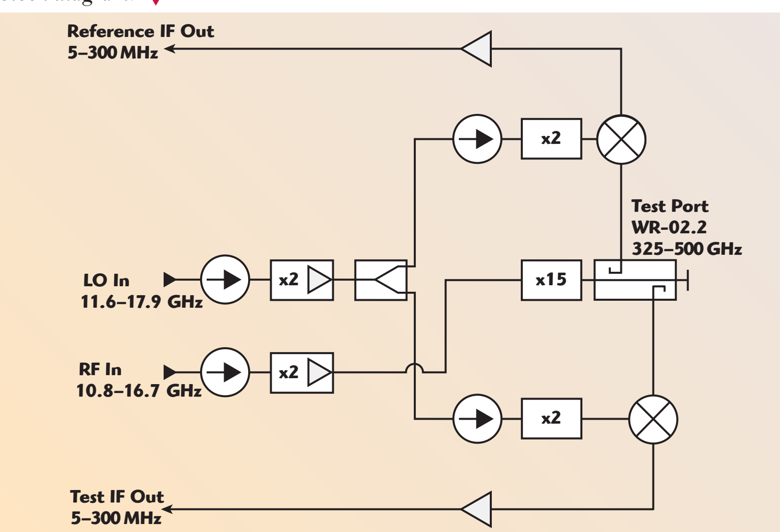
An extended variation of a non-blocking matrix switch is one that is built with power dividers on the inputs and outputs. Depending on the functionality needed, an array of either 1P1T switches or programmable attenuators is placed between the layers of power dividers. This configuration allows for multiple input signals to be available at one output. When the programmable attenuator option is exercised, a user may individually adjust the strength of each signal being received by an output. ***Figure 5*** shows a 3 × 3 extended variation non-blocking matrix. ***Figure 6*** shows some of the connection states and manipulations that are possible with this type of switch. This configuration offers even greater switching flexibility than a standard non-blocking matrix switch and can even be used bi-directionally. Once again, however, this configuration does have its disadvantages. Using twice the number of power dividers results in an even greater nominal insertion loss through the system.

When choosing the right matrix switch design, it is important to have a thorough understanding of the application. Many different variables must also be taken into account, along with the matters of connectivity that were addressed in this article. Everything from RF performance and reliability to control interfaces and programming should be considered before making a decision. ■

# A 325 TO 500 GHz VECTOR NETWORK ANALYZER FREQUENCY EXTENSION SYSTEM

Scientific investigation in the upper millimeter-wave region has long been accomplished using equipment built by the researcher for his specific task. The signal sources used were multipliers driven by either Gunn diode oscillators or backward wave oscillators that were available up through 110 GHz. Signal detection was done with special built narrow band detectors or harmonic mixers. Researchers were often hampered in their investigation due to the narrow band nature of the test equipment.

*Fig. 1 WR-02.2 functional block diagram.*




The most common investigations in the millimeter-wave frequency range are spectral line investigation, molecular particle signature identification and material property characterization. Because of atmosphere effects on millimeter-wave transmission, emerging millimeter-wave applications include communications, transportation, scientific research and homeland security.

Full waveguide bandwidth vector network analysis (VNA) systems capable of measuring absorption, reflectivity and scattering properties through 110 GHz were available in the early 1980s. In the late 1990s, the full waveguide bandwidth capability had gone up to 220 GHz. By 2002, a 220 to 325 GHz vector network analysis system was available. As the 325 GHz waveguide VNA system became available, researchers began to demand higher

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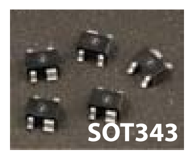


| Part Number | Typical 2 GHz Performance | | | | Typical 12 GHz Performance | | | | VDS (Vdc) | IDSS (mA) |
|---|---|---|---|---|---|---|---|---|---|---|
| | Gain (dB) | P-1 (dBm) | IP3 (dBm) | NF (dB) | Gain (dB) | P-1 (dBm) | IP3 (dBm) | NF (dB) | | |
| **FPD1500DFN** | 18 | 27 | 42 | 1.2 | 7* | 27 | 40 | N/A | 5 | 465 |
| **FPD750DFN** | 20 | 24 | 38 | 0.3 | 11.5* | 24 | 38 | N/A | 5 | 230 |
| **FPD750SOT343** | 18 | 20 | 38 | 0.3 | 8* | 20 | 38 | N/A | 3.3 | 230 |
| **FPD6836SOT343** | 20 | 20 | 32 | 0.5 | 9* | 19 | 32 | 1.2 | 3 | 105 |

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waveguide frequency bands. It is this demand that drove the 500 GHz and above frequency extension module development.

The development of the 325 to 500 GHz VNA frequency extension modules presented here represents the highest frequency possible where sub-harmonic contamination suppression can be achieved while using 20 GHz synthesizers. Using practical multiplier schemes to reach the next band above 500 GHz is impacted by the sub-harmonic contamination inside the bandpass of the waveguide to the degree that it is not filterable.

## THE WR-02.2 FREQUENCY EXTENSION MODULE ARCHITECTURE

***Figure 1*** depicts the WR-02.2 frequency extension module architecture. This architecture is in alignment with using the 20 GHz synthesizer for the LO and RF input — above 20 GHz the synthesizer uses a ×2 and/or ×3 multiplier to extend the synthesizer frequency coverage with phase noise degradation at 20log(n), offering no advantages over the integrated multipler/amplifier in the millimeter-wave frequency extension module.

The RF input frequency is amplified and multiplied to a total multiplication factor of 30 to reach the 325 to 500 GHz frequency range. An input isolator is added to the RF doubler/amplifier input to diminish amplitude fluctuation from the RF cable and connection interface mismatch. The doubler/amplifier output signal drives the ×15 multiplier chain to produce the output frequency at the WR-02.2 frequency band. The ×15 multiplier chain, selected during the initial design stage, optimizes for the least in-band sub-harmonic contamination with realizable filtering. A lower RF multiplication factor multiplier chain, using a combination of ×2 or ×3, would avoid much in-band sub-harmonic contamination but this would require inter-stage amplification. An amplifier at W-band or higher is commercially scarce and not without its own problems; furthermore, the complicity of the multiplier chain would increase. This ×15 multiplier chain achieves an average –32 dBm output power as measured with a calorimeter.

The LO input frequency is amplified and multiplied to a net multiplication factor of four before the millimeter-wave harmonic mixer LO input. An input isolator is located at the LO doubler/amplifier input to mitigate amplitude fluctuation due to LO cable and interface mismatch. The doubler/amplifier output signal is split equally to drive the next doubler chain that energizes the LO port of the millimeter-wave reference and test harmonic mixer. To optimize the match between the splitter and the doubler, an isolator is placed at the doubler input port. The doubler generates +10 dBm minimum output power at the WR-15 frequency band, more than sufficient RF power to properly bias the millimeter-wave harmonic mixer. The simplicity of this LO chain topology has proven in the lower millimeter-wave frequency



  

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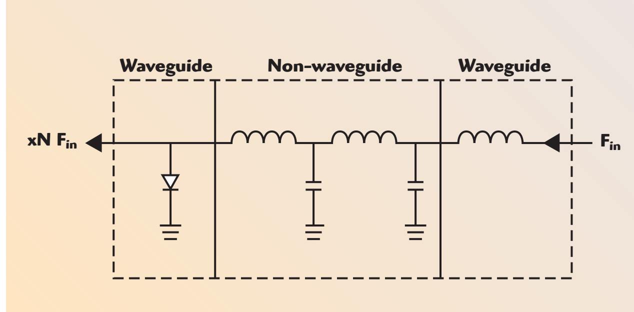
bands that the inherent LO phase coherence offers the optimal high level noise performance response.

The 325 to 500 GHz frequencies are coupled through a 10 dB coupler to the millimeter-wave harmonic mixer RF input. The millimeter-wave harmonic mixer IF output has been optimized for the output frequency range of 5 to 300 MHz. A > 50 dB gain multi-stage IF amplifier boosts the peak IF output to –13 dBm. –13 dBm power output is selected to prevent saturation to the vector network analyzer internal IF chain and simultaneously maximizes the vector network analysis system dynamic range. Depending on the millimeter-wave vector network analysis system used, the –13 dBm IF output power may have to be reduced to prevent saturation to the millimeter test set controller.

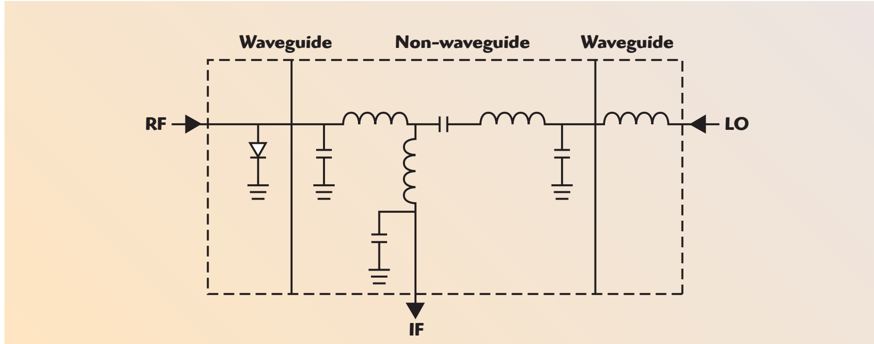



▲ *Fig. 2 Simplified multiplier schematic.*

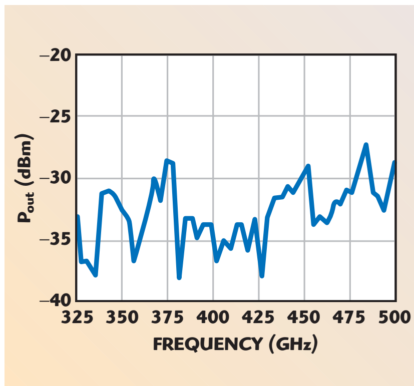
## MILLIMETER-WAVE COMPONENT DESIGN

The WR-02.2 component design can be divided into two challenging areas: 3D EM analysis with devices embedded in and out of the waveguide structure and machining realization of those millimeter-wave components. The challenges in designing millimeter-wave multipliers (see ***Figure 2***) and mixers (see ***Figure 3***) using commercial software packages such as HFSS from Ansoft and Agilent have been the absence of good, accurate model simulations to seamlessly simulate designs with devices and circuit embedded inside the waveguide and circuits outside of the waveguide. Henceforth, multiplier and mixer design becomes a piecemeal design encompassing simulations, assumptions, experience and a lot of experimentations. Electromagnetic-field simulation establishes the baseline for the best planar circuit material (softboard or ceramic) to be used in the waveguide frequency band of interest and provides detailed analysis of passive circuits outside of the waveguide channel. Passive components such as a coupler, with performance strongly tied to mechanical dimensions, has had good correlation between simulation and measured results. The WR-02.2 10 dB coupler was analyzed intensively with HFSS.

The next challenge is to be able to realize those millimeter-wave components through precision machining. Surface finish and mechanical interface are critical due to the small size of the wavelength in this frequency band. The best commercially available milling machine is taxed to the limit to produce the surface finish




▲ *Fig. 3 Simplified mixer schematic.*




▲ *Fig. 4 WR-02.2 ×15 multiplier chain output power.*

and mechanical tolerance required for the WR-02.2 components.

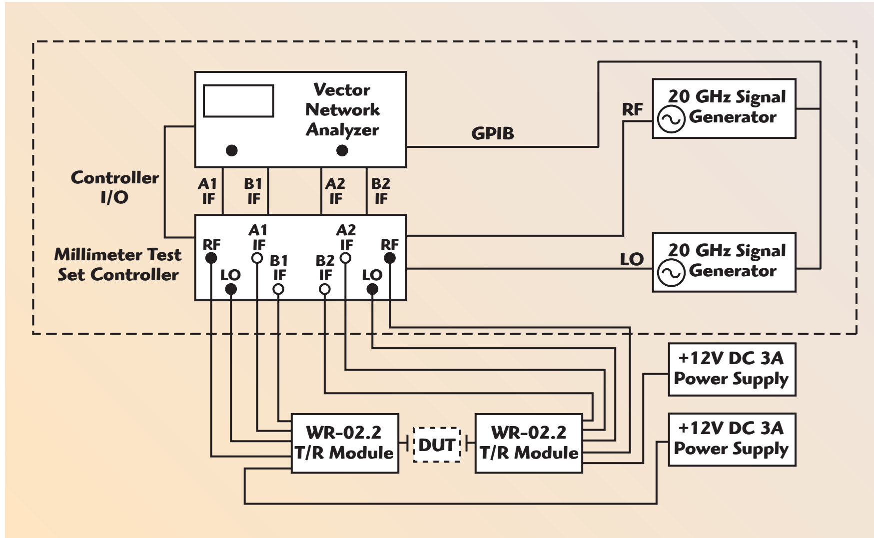
T-6061 aluminum was chosen for the WR-02.2 dual directional coupler because of its low thermal expansion properties and ease of machining. The waveguide channels are 0.022 × 0.011 inches and any growth in the dimensions of the waveguide or its length due to temperature change can potentially destroy the efficacy of a calibration. Tooling to produce this coupler with the proper surface finish and accuracy requires extremely small endmills with spindle speeds in excess of 12,000 rpm. Because of the coupler's intricacy and the finishing quality, machinist skill becomes one of the most important aspects in manufacturing this component.

## RESULTS AND DISCUSSION

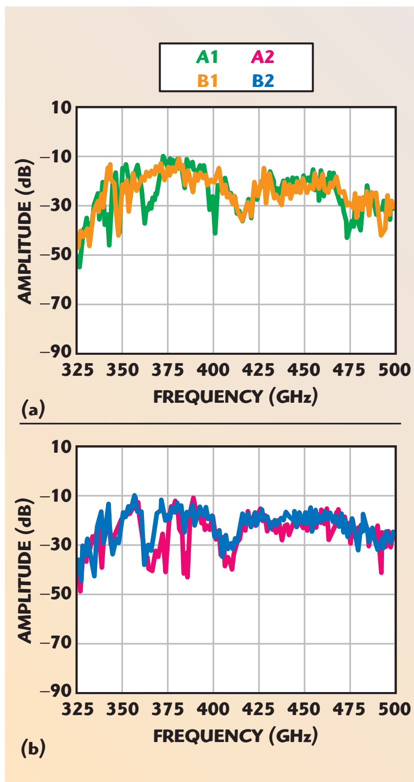
***Figure 4*** shows a typical WR-02.2 multiplier chain output power. A calorimeter is used in measuring the WR-02.2 output power. A 310 GHz high pass filter is inserted at the WR-02.2 multiplier chain output to suppress sub-harmonic power contribution. The sub-harmonic power contamination is the result of the high harmonic number multiplier used. Design work to improve output power and to alleviate the sub-harmonic contamination problem is ongoing. A stand-alone mixer test system at these frequencies is not available. Therefore, mixers are tuned and optimized in the WR-02.2 frequency extension module.

***Figure 5*** shows the complete WR-02.2 "two-port" VNA measurement system. The data taken uses the Agilent 8510/85105A millimeter-wave vector network analyzer system due to its availability at the time of the test and the good phase noise characteristic of the 8362x synthesizers. However, a millimeter-wave vector network analyzer system such as the Agilent PNA/N5260A with two external low phase noise option synthesizers or the Anritsu ME7808, 37347D/3738A can be used with the WR-02.2 frequency extension modules. The millimeter module configuration equation is set for an RF frequency multiplication factor of 30, an LO frequency multiplication of 28, an IF frequency range of 20 MHz and a sweep frequency range between 325 to 500 GHz.

***Figure 6*** depicts the reference and test port mixer raw response of two different WR-02.2 frequency extension modules. Ignoring the few discrepant points, the overall reference and test mixer raw responses track each other closely across the frequency band. Moreover, the vector network analysis system is able to discern the RF path sub-harmonic contamination — indicating a good calibration is attainable. The system dynamic range plot, depicted in ***Figure 7***, exemplifies an outstanding achievement for this frequency range. With new filtering hardware in the RF path, it is anticipated that the raw mixer responses may be




▲ *Fig. 5 Millimeter-wave vector network analysis system configuration.*

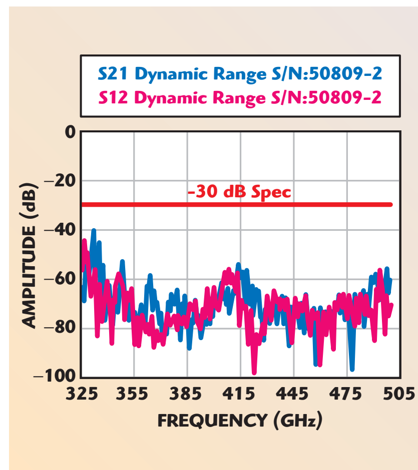



▲ *Fig. 6 WR-02.2 reference and test mixer raw response of two different extension modules.*

smoother across the frequency band and possibly improve the overall system dynamic range.

## CONCLUSION

A viable and compact WR-02.2 millimeter-wave frequency extension transmission/reflection module for use with a vector network analyzer has been described. The WR-02.2 module extends the microwave vector network analyzer two-port S-parameter measurement capabilities to the 500 GHz frequency range. More importantly, the WR-02.2 T/R modules are "plug & play" when used in a millimeter-wave vector network analysis system such as Agilent's PNA/N5260A, 8510/85105A and Anritsu's ME7808, 37347D/3738A. Planned improvements to the WR-02.2 frequency extension module will allow the module to test active devices without restrictions.




▲ *Fig. 7 System dynamic range.*

Note: This material was presented at the 66th ARFTG Conference in Washington, DC in December 2005 and published by ARFTG at that time.

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**TABLE I**

**HYRELEX TYPICAL VALUES**

| | TF-260 | | TF-290 |
|---|---|---|---|
| Dielectric constant @10 GHz | 2.60 | | 2.90 |
| Dissipation factor @10 GHz | 0.0020 | | 0.0028 |
| Moisture absorption (%) | | < 0.02 | |
| Dielectric breakdown (kV) | | > 60 | |
| Volume resistivity (Mohm/cm) | | $10^7$ | |
| Surface resistivity (Mohm) | | $10^7$ | |
| Arc resistance (seconds) | | > 180 | |
| Flexural strength (MD) (psi) | > 23,000 | | > 35,000 |
| Flexural strength (CD) (psi) | > 20,000 | | > 30,000 |
| Peel strength (1 oz. VLP) (lbs/linear inch) | | 7 | |
| Thermal conductivity (W/m/K) | | 0.20 | |
| CTE (x-y) (ppm/°C) | | 9–12 | |
| CTE (z) (%) | 3 | | 2 |
| Flammability rating | | V-0 | |

All reported values are typical and should not be used for specification purposes. In all instances, the user shall determine suitability in any given application.

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| DCMO Series | | | | |
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| DCMO1027 | 100 to 270 | 0 to 24 | -112 | +5 to +12 |
| DCMO1129 | 110 to 290 | 0.5 to 24 | -112 | +5 to +12 |
| DCMO1545 | 150 to 450 | 0.5 to 24 | -108 | +5 to +12 |
| DCMO1857 | 180 to 570 | 0.5 to 24 | -108 | +5 to +12 |
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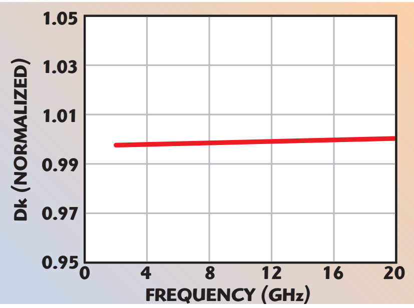
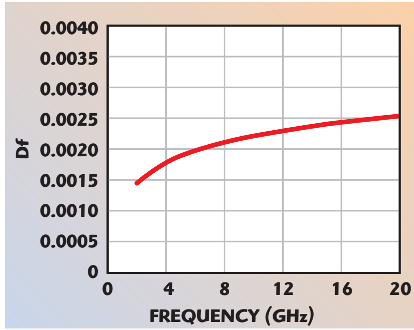
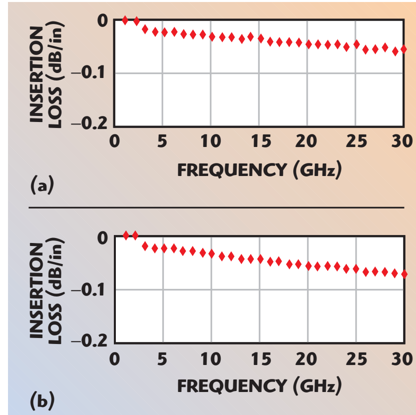



▲ *Fig. 1 Normalized dielectric constant vs. frequency.*




▲ *Fig. 2 Dissipation factor vs. frequency.*




▲ *Fig. 3 Insertion loss vs. frequency; (a) TF-260 and (b) TF-290.*

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***Figures 1*** and ***2*** show the HyRelex material's dielectric constant (Dk) and dissipation factor (Df) performance over the DC to 20 GHz frequency range. ***Figure 3*** shows insertion loss vs. frequency for the TF-260 and TF-290 materials.

Applications for HyRelex include double-sided, multilayer and rigid flex circuits used in high frequency telecommunications, avionics, medical, automotive, military and consumer electronics. A Certificate of Conformance containing lot-specific data accompanies each shipment. Additional information may be obtained from the company's web site.

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| SMXE50-S2 | 10KHz-2.0GHz | 50 |
| SMXE50-S3 | 10KHz-3.0GHz | 50 |
| SMXE100-S2 | 10KHz-2.0GHz | 100 |
| CMX5005 | 10KHz-1.0GHz | 500 |
| CMX100010 | 10KHz-1.0GHz | 1000 |
| CMX200020 | 10KHz-1.0GHz | 2000 |
| ST81-10 | 1.0GHz-8.0GHz | 10 |
| ST81-25 | 1.0GHz-8.0GHz | 25 |
| ST81-50 | 1.0GHz-8.0GHz | 50 |
| ST81-100 | 1.0GHz-8.0GHz | 100 |
| ST181-10 | 1.0GHz-18.0GHz | 10 |
| ST181-25 | 1.0GHz-18.0GHz | 25 |
| ST181-50 | 1.0GHz-18.0GHz | 50 |
| ST101-100-50 | 1.0GHz-10.0GHz | 100/50 |
| TD122-25 | 2.0GHz-12.0GHz | 25 |
| TD122-50 | 2.0GHz-12.0GHz | 50 |
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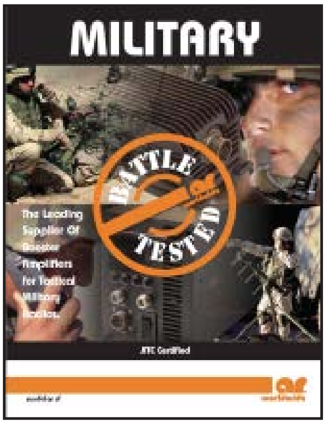


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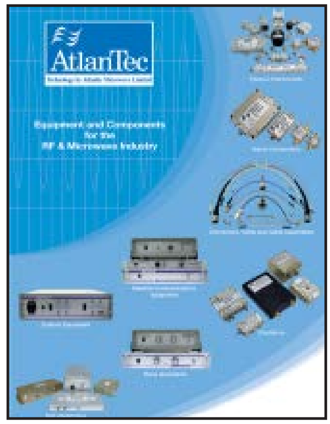


## Product Guide

From attenuators and amplifiers through connectors, couplers, isolators, mixers and power dividers to VCOs and zero bias Schottky detectors, this guide comprehensively describes the company's AtlanTec brand named products. It gives full technical specifications, drawings and photographs of all the components and equipment for the RF and microwave industries under the headings: satellite communications equipment, broadband noise generators, oscillators, active components, passive components and cable, connectors and cable assemblies.

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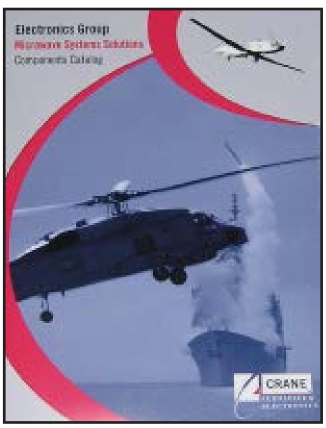


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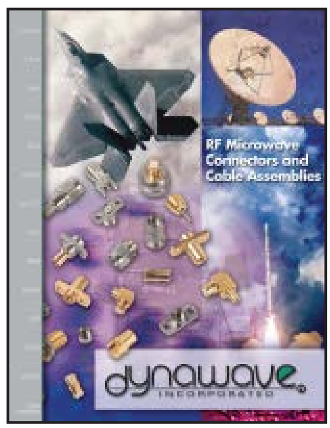
**Crane Aerospace & Electronics, Electronics Group,**
**Microwave Systems Solutions,**
**Chandler, AZ (480) 961-6269, www.craneae.com.**

***RS No. 312***

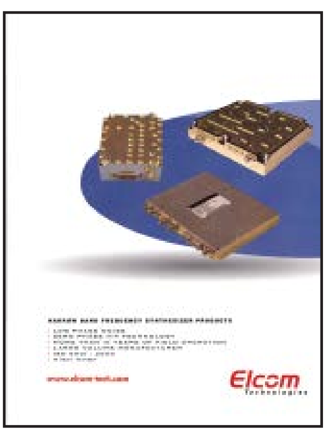



## Product Catalog

This catalog details the company's capabilities in the design and manufacture of RF microwave connectors and cable assemblies. The company is a provider of high quality, standard and special RF and microwave connectors, adapters, blindmate interconnecting components and cable assemblies for use in military applications and commercial microwave, RF and wireless industry components. Information of quote requests, ordering information and product warranty are also provided.

**Dynawave Inc.,**
**Haverhill, MA (978) 469-0555, www.dynawave.com.**

***RS No. 313***

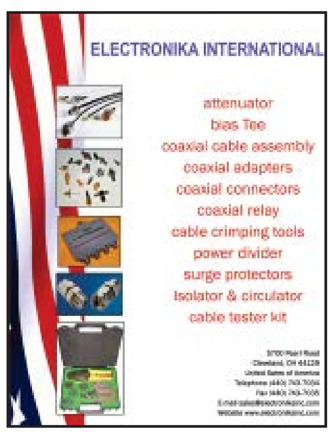



## Product Brochure

This brochure highlights the company's narrowband frequency synthesizer products. Featured products include the MFS, DFS and WMFS series that offer reliable integrated system synthesizers. Also highlighted are the SPDRO, SFDRO and PSDRO series products that offer phase noise efficiency with broad performance features. The products are targeted for applications such as radar systems, EW, instrumentation, digital radio, military, fiber optics and SATCOM.

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

***RS No. 314***

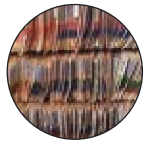


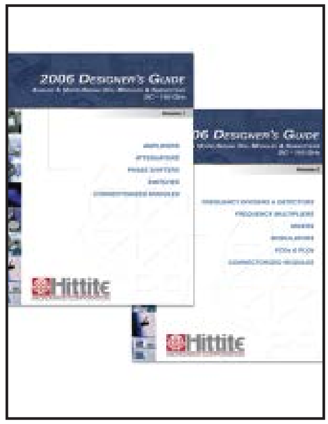

## RF and Microwave Component Catalog

This 120-page catalog contains the company's coaxial cable assemblies, attenuators, adapters, power dividers, bias tees, coaxial switches, isolators/circulators, and adapters and attenuator testing kits. These are standard off the shelf products up to 18 GHz, with specifications and drawings listed in the catalog. This catalog is handy for design engineers and buyers who are looking for product specifications and pricing for new development.

**Electronika International Inc.,**
**Cleveland, OH (440) 743-7034, www.electronikainc.com.**

***RS No. 315***



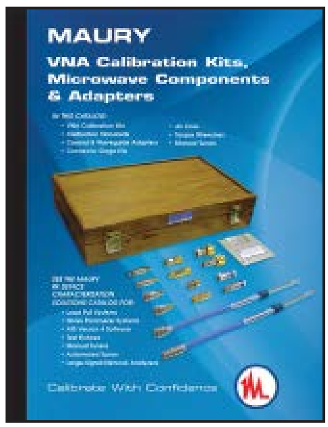



## Designer's Guide

The 11th edition Designer's Guide catalog for 2006 includes full specifications for 398 components, 80 new RFIC and MMIC product data sheets, quality/reliability, application and packaging/layout information. New for 2006 is a two volume catalog format: Volume 1 – Amplifiers and Control Devices; Volume 2 – Frequency Generation, Mixers and Modulators. To request a 2006 catalog two volume set, visit www.hittite.com and select the "Submit Inquiry" button.

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

***RS No. 316***




## Cal Kits, Components and Adapters

This 160-page catalog covers the entire precision VNA calibration kit line and the components that make up these kits. It also includes connector gage kits, air lines, torque wrenches and manual tuners, plus an extensive section on precision coaxial and waveguide adapters. Detailed specifications are given for every product along with general information about VNA calibration methodologies, standard waveguide flange specifications, and useful facts that are relevant to the test and measurement industry.

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

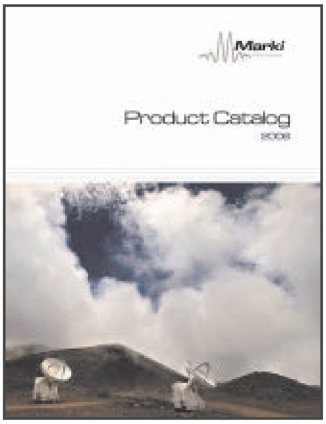
***RS No. 318***


## Short Form Catalog/CD-ROM

This updated short-form catalog and product catalog on CD-ROM includes new product highlights, updated data sheets with more comprehensive information and measurement curves, RoHS Program information, application notes, company and facility overviews, ordering information and a complete listing of international sales representative and distribution networks. In addition, the CD-ROM is hyperlinked to the company's web site to facilitate the collection of additional information.

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

***RS No. 320***

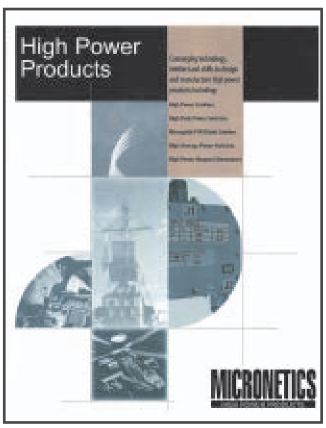



### Product Catalog

This redesigned catalog features the company's standard product data sheets and useful application notes. Standard products include RF/microwave mixers, doublers, multipliers and specialty components up to 65 GHz. Outline drawings, including information about new surface-mount packaging technology and performance specifications are provided for each component. E-mail: mixers@markimicrowave.com to request a copy.

**Marki Microwave,**
**Morgan Hill, CA (408) 778-4200, www.markimicrowave.com.**

***RS No. 317***




### Product Brochure

This brochure highlights the company's high power PIN diode control devices in frequencies ranging from 20 MHz to 18 GHz and power levels up to 10 kW peak and 1200 W CW. These switches, limiters and high power assemblies have accumulated years of reliable field proven performance in both defense and commercial applications.

**Micronetics High Power Products,**
**Hudson, NH (603) 883-2900, www.micronetics.com.**

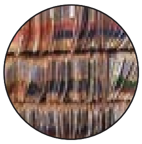
***RS No. 319***


### Amplifier Catalog

This 34-page catalog highlights the company's complete bipolar amplifier line up to 3 GHz. The catalog features low noise, medium power, wideband, MRI, cellular/PCN and INMARSAT bands. Typical amplifier performance curves are shown, including outline drawings and explanation of specification definitions.

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

***RS No. 321***



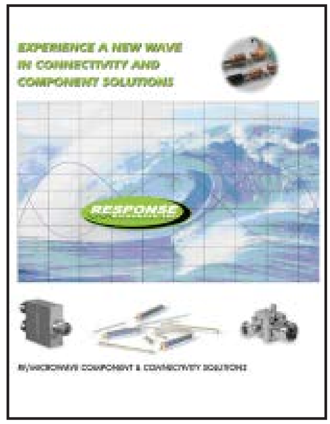



## Active and Passive Catalog

This comprehensive 190-page catalog details the company's full line of products, from passive components such as filters and isolators to active components such as broadband low noise amplifiers and space qualified channel amplifiers. The company designs, develops and manufactures these products to serve a variety of domestic and international markets including defense, wireless and satellite communications. Product outline drawings, specifications and performance graphs are included for most products.

**Narda Microwave-West,**
**Folsom, CA (916) 351-4500, www.nardamicrowave.com.**

***RS No. 322***

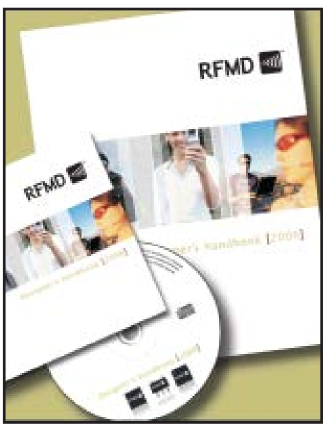



## Products and Capabilities Brochure

This 24-page brochure provides an overview of corporate capabilities and selection tables of the company's passive component and connectivity product offering that operates from DC to 40 GHz. The guide offers application notes on its *HYBRIDLINE* series of drop-in quad hybrids and couplers, and also provides a comprehensive outline to the company's web site and enhances available data sheets and application notes.

**Response Microwave Inc.,**
**Framingham, MA (978) 456-9184, www.responsemicrowave.com.**

***RS No. 323***




## Designer's Handbook

This Designer's Handbook outlines the company's broad product portfolio of RF systems and solutions for applications that drive mobile communications. Includes technical data on RFMD's power amplifiers, front-end modules, transceivers, SoCs and other integrated components for mobile handset, cellular base station, Bluetooth,® WLAN and GPS applications – all backed by RFMD's commitment to service, technical support and quality.

**RFMD,®**
**Greensboro, NC (336) 678-5570, www.rfmd.com.**

***RS No. 324***


## New Products Catalog

This current edition of the company's new products catalog features products from the coaxial switch range with the inclusion of the six-pole 26.5 GHz CCR-58, Smith Charts for the CCR-33 18 GHz switch and the RF522 10 GHz relay, and a microwave switch selection guide. New products from the industrial solid-state range include the HIPak series data and a selection guide, with revised data for the 30 and 100 amp DC solid-state relays. Revised data for five miniature plastic relays from the military solid-state range are also included.

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

***RS No. 325***


## CD-ROM Product Catalog

The 11th edition of this CD-ROM includes several new and updated brochures and catalogs including the newest edition of the LMR® Wireless Products Catalog with the latest updates to the LMR product line. This CD-ROM features an easy-to-use menu for navigation within each catalog. Also included are "how-to" installation videos to assist users of LMR low loss coaxial cable products and two handy calculators for determining both coaxial cable attenuation and conversion of VSWR-to-return loss.

**Times Microwave Systems,**
**Wallingford, CT (203) 949-8400, www.timesmicrowave.com.**

***RS No. 326***


## Selection Guide

The CORCOM product guide allows for selection and application of EMI and RFI filtering devices. Included in the guide is detailed information on RFI power line filters, power entry modules, DC filters and signal line filtering products. In addition to extensive product information, the guide also includes detailed, easy-to-use selection charts to assist designers in the product selection process. The flow-chart style of the selection chart allows engineers to quickly determine the most suitable product for specific applications and parameters.

**Tyco Electronics Corp.,**
**Harrisburg, PA (800) 522-6752, www.tycoelectronics.com.**

***RS No. 327***

# Do you know what your customers want?

According to CTIA data, **Enterprise end-users** are hungry for more anytime anywhere access–looking for customizable and off-the-shelf solutions that can save their company money and maximize efficiency.

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**www.ctia.org/wirelessIT06**

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*The Next Generation of Wireless Data*

## Space/Flight Qualified Low Noise Amplifiers

These low noise amplifiers are designed, manufactured, tested and screened to be extremely reliable and rugged for space or flight applications. Screening options include MIL-STD-883 and MIL-PRF-38534. In addition to the testing and standards that go into these amps, the company also provides complete documentation, total quality, dedicated project management, status reporting and customer service. Applications include space communications, satellite applications, flight systems and R&D or Hi-Rel applications that require high Mean-Time-Between-Failure numbers (as high as one million hours). Custom designs are available including low cost options to meet a budget or level of necessity.

***AmpliTech Inc.,***
***Hauppauge, NY (631) 435-0603,***
***www.amplitechinc.com.***

**RS No. 216**

## Precision Noise Measurement System

The AU3000 series precision noise measurement system (PNMS) provides digitally-controlled, electronic and mechanical tuner-based test systems for small-signal characterization of semiconductor devices for the RF, microwave and millimeter-wave industry. The fast, precision electronic tuner offers over 1000 tuning states up to 18 GHz and the mechanical tuners have over one million states (up to 110 GHz). Other features include system integration expertise in providing automated, turn-key and customizable on-wafer and fixture systems, optional Auriga synthetic instruments and total system hardware control.

***Auriga Measurement Systems LLC,***
***Lowell, MA (978) 441-1117,***
***www.auriga-ms.com.***

**RS No. 217**

## Frequency Extender

This ELFE frequency extender can be used with a variety of receivers and operates from 18 to 40 GHz. A dedicated RF input operates from 0.5 to 18 GHz. When the extended range is not selected on the ELFE, the 0.5 to 18 GHz signal is routed through the unit to the accompanying microwave tuner or receiver. A separate RF input accepts 18 to 40 GHz, which is converted to the 2 to 18 GHz range for the accompanying tuner or receiver. The 0.5 to 18 GHz RF pass-through feature along with the down-conversion of 18 to 40 GHz band allows the ELFE to operate with other manufacturers' equipment of limited frequency coverage while providing full 0.5 to 40 GHz performance.

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

**RS No. 251**

## MMIC Regenerative Divider

The model HMC447LC3 is a low noise 10 to 26 GHz divide-by-4 regenerative divider that utilizes GaAs HBT technology. This versatile divider accepts input power levels from –15 to +10 dBm and exhibits a low SSB phase noise of –150 dBc/Hz at 100 kHz offset. The HMC447LC3 delivers consistent output power of –4 dBm, operates from a single +5 V supply and requires no external components, making it ideal for use in high frequency phase-locked loops and in local oscillator distribution applications. The HMC447LC3 is housed in a RoHS compliant, 3 ×3 mm leadless SMT package with an exposed ground paddle.


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

**RS No. 218**

## E-band Millimeter-wave Antenna


The HPCPE-80RS Discriminator antenna is designed for the new E-band millimeter-wave band that covers the allocation from 71 to 86 GHz. This antenna provides 44 dBi of gain, has an excellent front-to-back ratio of 64 dB and meets all FCC regulations for the E-band.

***Radio Waves Inc.,***
***N. Billerica, MA (978) 459-8800,***
***www.radiowavesinc.com.***

**RS No. 219**

## Drop-in Isolators

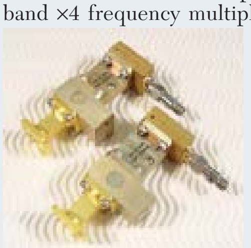
The R series of drop-in isolators was designed in response to the exploding market for Ku- and X-band. These flange-mount drop-in isolators are ideal for military, SATCOM, space, intelligence and air surveillance radar systems. Covering frequencies from 7.2 to 8.4 GHz, 9.5 to 10.5 GHz, 12.7 to 14.5 GHz and 14 to 15.5 GHz, these temperature stable devices offer a typical loss of < 0.4 dB, and return loss and isolation of > 20 dB in an industry standard footprint. Price: $24.95. Delivery: in stock.

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

**RS No. 220**

## Ka-band ×4 Frequency Multiplier

The model 32-4XF is a space-qualified, Ka-band ×4 frequency multiplier. The assembly multiplies a coaxial 8 GHz input up to a 32 GHz output in WR-28. A combination high pass/low pass filter is used to reject unwanted harmonics by 60 dB minimum. The final output passes through an isolator with 20 dB of isolation. With a typical conversion loss of 18 dB, output power is 0 to +5 dBm depending on the input power. These models are environmentally tested for vibration, pyro shock, thermal vacuum and electrically tested from –40° to +85°C. This model, 32-4XF, is presently on board the Mars Reconnaissance Orbiter and will be on the Kepler Mission scheduled to be launched in October 2008.

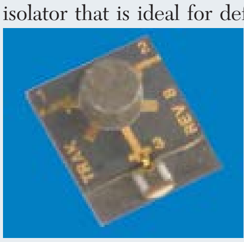


***Spacek Labs Inc.,***
***Santa Barbara, CA (805) 564-4404,***
***www.spaceklabs.com.***

**RS No. 221**

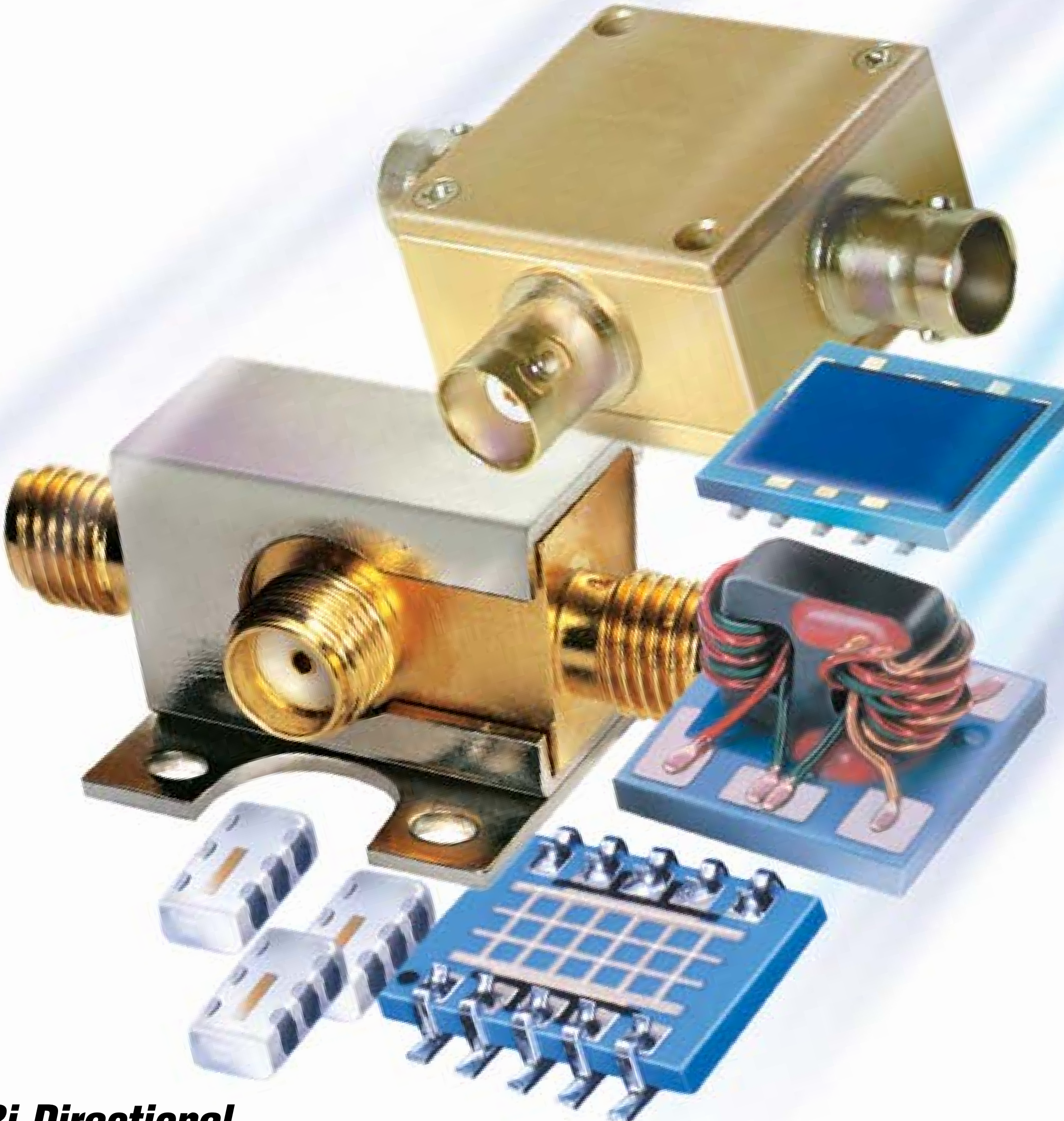
## Ka-band Microstrip Isolator

The model D9A8031 is a Ka-band microstrip isolator that is ideal for defense and space applications. This model operates in Ka-band with typical electrical specifications that include insertion loss < 0.7 dB, operates in a frequency range from 30 to 31 GHz and offers typical isolation of > 18 dB. Additional specifications include an operating temperature of –54° to +85°C. Size: 0.238" × 0.28" × 0.13". Weight: 0.4 grams.



***TRAK Microwave Corp.,***
***Tampa, FL (813) 901-7200,***
***www.trak.com.***

**RS No. 222**



## Directional/Bi-Directional

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Mini-Circuits coupler families offer versatile, low cost solutions for your needs ranging from connectorized versions to the smallest couplers in the world! Choose from 50&75 ohm directional and bi-directional couplers in LTCC packages and rugged connectorized designs with flat coupling ranging from 6-22dB. Mini-Circuits BLUE CELL™ technology offers the world's most highly evolved LTCC technology so you can count on minimal insertion loss and high directivity with models able to handle up to 65W. For today's small design requirements, there's our BDCN series, a 0.12"x0.06" chip. With our LTCC designs, ESD is no longer a problem. For specific specs on all our LTCC couplers, you can visit Mini-Circuits web site and pick the best couplers for your commercial, industrial, and military needs.

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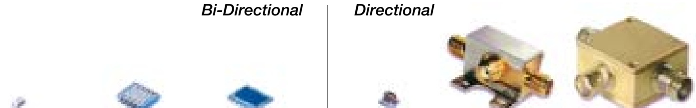
*Detailed Performance Data & Specs Online at*: **www.minicircuits.com/dcoupler.html**

***Bi-Directional*** | ***Directional***



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|---|---|---|---|---|---|
| .12"x.06"x.03" | .25"x.30"x.07" | .30"x.25"x.04" | .15"x.15"x.15" | .74"x.50"x.54" | 1.25"x1.25"x.75" |
| $2.99 ea. (Qty.25) | $5.95 ea. (Qty.25) | from $3.95 ea. (Qty.25) | $1.99 ea. (Qty.25) | $29.95 ea. (Qty.1-9) | $29.95 ea. (Qty.1-9) |

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*See our 244 page RF/IF Designer's Guide in EEM (Electronic Engineers Master)*

# COMPONENTS

## Between Series Coaxial Adapter

The model 5040 is a between series coaxial adapter that operates from DC to 40 GHz.

VSWR maximum is 1.10 from DC to 18 GHz and 1.15 from 18 to 40 GHz. Connector configuration is male to male. This connector's configurations are also offered in: male to female, female to male and female to female. Delivery: stock to 30 days.

***Krytar,***
***Sunnyvale, CA (408) 734-5999,***
***www.krytar.com.***

**RS No. 225**

## Microwave Coaxial Cable

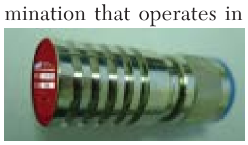
This series of semi-flexible and semi-rigid cables is available in lengths up to 50 ft. Including all the popular outside diameters of 0.034, 0.047, 0.086, 0.141 and 0.250 inches, the collection includes outer conductor materials of copper, aluminum and braided copper/tin composite. Common to all standard types is the characteristic impedance of 50 Ω, PTFE dielectric material and an operating temperature range of –55° to +125°C. The aluminum outer cables are tin plated as standard while copper types come in a choice of plain or tin-plated. Beyond the standard range are a number of options with alternative impedances, FEP jackets, silver plated inner and outer conductors and low loss variants.

***Atlantic Microwave Ltd.,***
***Braintree, UK +44 1376 550220,***
***www.amrf.co.uk.***

**RS No. 223**

## Coaxial Terminations

The model TNM-114 is a Type N coaxial termination that operates in a frequency range



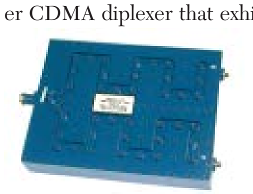
from DC to 2.5 GHz. Also available in SMA models, large volumes of these terminations are kept in stock and priced for quick delivery.

***Microwave Communications Laboratories Inc.,***
***Saint Petersburg, FL (727) 344-6254,***
***www.mcli.com.***

**RS No. 228**

## High Power CDMA Diplexer

The model 2DP-1880/1960-NS1 is a high power CDMA diplexer that exhibits less than 1 dB



of loss in both the Tx passband of 1930 to 1990 MHz and the Rx passband of 1850 to 1910 MHz. Passband-to-passband isolation is greater than 75 dB, VSWR is less than 1.5 at the passbands and power handling is a robust 600 W peak, 60 W average.

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

**RS No. 232**

## RF Attenuators

These RoHS compliant, SMA M/F, 2 W, 662 series attenuators cover all wireless applica-


tions from DC to 6 GHz and are available in attenuation values from 1 to 30 dB in 1 dB increments. Standard attenuation values of 3, 6, 10, 20 and 30 are in stock ready for immediate shipment. Delivery of other values is stock to two weeks ARO. Made in USA.

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

**RS No. 226**

## IF SAW Filter

The TMX U512 IF SAW filter at 140 MHz is designed for 3G and broadband applications. It

offers a bandwidth of 16 MHz minimum at –3 dB (relative bandwidth superior to 10 percent) and is characterized by low ripple (0.5 dB typical) in the passband, sharp filtering function and high rejection (45 dB minimum at ±20 MHz). This filter is ideally suited for base stations and networking equipment, and is RoHS compliant. Prototypes are available in an SMT package of 13.3 × 6.5 × 1.6 mm.

***TEMEX SAS,***
***Sophia-Antipolis, France***
***+33 (0) 4 97 23 30 00, www.temex.com.***

**RS No. 235**

## 4 × 4 Hybrid Combining Network

The CM-84 is a 4 × 4 hybrid combining network designed to meet the needs of the wire-

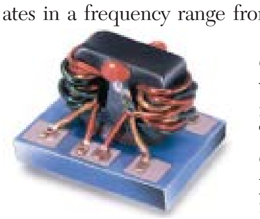
less market for broadband combiners with over 25 dB isolation across the whole band. The CM-84 will combine up to four different wireless signals in the frequency band from 700 to 2700 MHz without mutual interference. This feature of hybrid combiners means that the four inputs can be added together without the use of filters.

***Microlab/FXR,***
***Parsippany, NJ (973) 386-9696,***
***www.microlab.fxr.com.***

**RS No. 227**

## Directional Couplers

This DBTC series of directional couplers operates in a frequency range from 5 to 2000 MHz and features nine different coupling values that range from 9 to 20 dB. These couplers deliver flat coupling over broad multi-octave bandwidths. The 50 and 75 Ω models stand 0.15" square and employ LTCC construction to embed circuits inside the ceramic base thus realizing good temperature stability, repeatability and ruggedness. Patented with additional patent pending. Price: from $1.99 each (25).

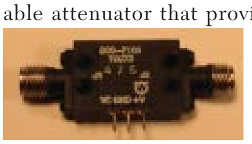


***Mini-Circuits,***
***Brooklyn, NY (718) 934-4500,***
***www.minicircuits.com.***

**RS No. 229**

## Voltage Variable Attenuator

The model 500-F102 is a solid-state voltage variable attenuator that provides 50 dB of dynamic range of (0 to 5 V) over a broad bandwidth of 10 to 18 GHz in an ultra-miniature package (0.75" × 0.53"). Linearization and temperature compensation are included with flat frequency response. Convenient single DC voltage supplied is +15 V. GPO and SMA removable connector options are available, allowing for drop-in applications.



***RH Laboratories,***
***Nashua, NH (603) 459-5900,***
***www.rh-labs.com.***

**RS No. 233**

## Power Dividers/Combiners

These custom high power two-way dividers/combiners are in-phase "Wilkinson" type designs that offer good electrical performance within the band of ±12 percent of any center frequency between 750 to 2400 MHz. These devices can be used as dividers or combiners with 50 W CW per channel for fail-safe applications, where typically one output is for example, the loss of one element in an antenna array. As a divider, it can handle up to 200 W assuming a load VSWR of 1.2 or better.

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

**RS No. 234**

## High Power Fixed Attenuator

The model HFP-5150-8 is a high power fixed attenuator ideal for applications that include high power radar, amplifier test, telecommunication labs and MRI calibration. This series features a frequency range from DC to 8 GHz with an input power rating of 150 W CW. Standard attenuation values are 3, 6, 10, 20, 30 and 40 dB and the VSWR is rated at 1.20 at 4 GHz and 1.30 at 8 GHz. Type N male/female connectors are standard. Delivery: stock to four weeks.

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

**RS No. 237**

# AMPLIFIERS

## Rack-mount Amplifier

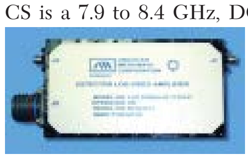
The model SSPA 0.5-3.0-20-RM is a high power rack-mounted, super broadband gallium nitride power amplifier that operates over the 500 to 3000 MHz band. This rack-mounted PA was designed for high power EW jamming applications and broadband communications systems. It is also ideal for test equipment applications that need extremely broad bandwidths with high power, high gain and good linearity. The P1dB is 20 W typical across the band. The saturated output power is typically 30 to 50 W across the band.

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

**RS No. 238**

## Solid-state Detector Log Video Amplifier

The model LVD-709804-50-7193141 option CS is a 7.9 to 8.4 GHz, DC coupled detector log video amplifier for continuous wave applications. It includes an input low pass filter, temperature sensor circuitry, MIL-STD-461E EMI shielding and is environmentally sealed. Supply voltage is +28 V at 225 mA maximum. The unit uses a D38999/20WB5PN connector for power and temperature sensor connections. Size: 4.50" × 2.50" × 1.10".

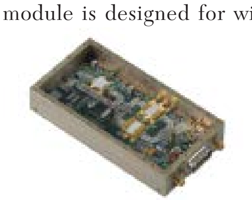


***American Microwave Corp.,***
***Frederick, MD (301) 662-4700,***
***www.americanmicrowavecorp.com.***

**RS No. 239**

## WiMAX Power Amplifier

This solid-state GaAs FET power amplifier module is designed for wireless broadband networks. Model KMS1070M12 operates from 3.65 to 3.85 GHz. This amplifier is a special application version of the company's KMS 1070 and offers similar overall performance but with an EVM of 2 percent. The nominal output power of the module is 20 W (P1dB). In addition to moving the band edge up in frequency the unit's gain is increased to 40 dB overall and high speed RF switching has been incorporated into the amplifier. The RF switching can be used to blank or gate the amplifier input signal with a switching speed of typically 74 nanoseconds. This series of amplifiers can be custom configured.



***AR Worldwide Modular RF,***
***Bothell, WA (425) 485-9000,***
***www.ar-worldwide.com.***

**RS No. 240**

## RF Power Amplifier

The 6000 series of NMR amplifiers feature good performance in terms of efficiency, pulse droop, fast and active noise blanking, and isolation. The combination of quadrature combiners and an active VSWR protection mechanism fully protect the 6000 series amplifiers against VSWR load mismatch. The 6000 series is available in power levels from 100 W to over 1 kW in broadband and band specific applications over the frequency range from 20 MHz to 4 GHz.

***Ophir RF,***
***Los Angeles, CA (310) 306-5556,***
***www.ophirrf.com.***

**RS No. 242**

## 50 W Amplifier

The model 50T4G18 is a traveling wave tube microwave amplifier that more than doubles the power available over the 4.2 to 18 GHz frequency range in one amplifier. This model provides 50 W of CW power and is suitable for RF testing. Previously, model 20T4G18A, with a power output of 20 W, was the highest power offering for this frequency range. If harmonic content is an issue, model 40T4G18 is also available.

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

**RS No. 241**

## GaAs FET Amplifier

The model SM3436-47L is a GaAs FET amplifier designed for 3.5 GHz broadband wireless applications. This unit operates from 3.4 to 3.6 GHz with a P1dB of +47 dBm and an OIP3 of +64 dBm. Small-signal gain is 53 dB with a flatness of ±0.5 dB across the band. Standard features include a single +12 VDC supply, thermal protection with auto reset and over/reverse voltage protection. Size: 7.5" × 3.97" × 0.79". An integral heatsink is also available. This amplifier is also available in lab unit and 19" rack configurations.

***Stealth Microwave Inc.,***
***Trenton, NJ (609) 538-8586,***
***www.stealthmicrowave.com.***

**RS No. 243**

## Two-stage Driver Amplifier

The AH212-EG is a high dynamic range, 1 W, two-stage driver amplifier, housed in a low cost SMT lead-free/green/RoHS-compliant 4 × 5 mm QFN package. The InGaP/GaAs HBT is able to achieve superior performance for various narrowband-tuned application circuits, featuring 26 dB gain, +46 dBm OIP3 and +30 dBm of compressed 1 dB power. This device operates over the 1800 to 2400 MHz frequency band and provides good in-band gain flatness.

***WJ Communications Inc.,***
***San Jose, CA (408) 577-6200,***
***www.wj.com.***

**RS No. 244**

# ANTENNAS

## 2.4 GHz Directional Antennas

These directional P series yagis are available in 6, 9, 12, and 15 dBi gain and offer end-fired re-

liability combined with durable disk-on-rod technology. These rugged, wide bandwidth antennas will deliver clean radiation patterns with high front-to-back ratios, while the tubular radome reduces wind loads and increases strength in harsh environments. These features combined with discreetly colored UV-stabilized radomes reduce the visual impact of the antenna, and offer excellent solutions for moderate to high gain directional requirements at 2.4 GHz. Mounting hardware facilitates uptilt and downtilt orientations.

***Astron Wireless Technologies Inc.,***
***Sterling, VA (703) 450-5517,***
***www.astronwireless.com.***

**RS No. 245**

## Bi-sector Array

This PCS bi-sector array provides operators with the needed flexibility to target network

congestion and supports the roll-out of new mobile data rich services. The bi-sector array is a solution for PCS networks to address capacity and quality challenges found in high capacity macro cell site applications. The PCS bi-sector array provides additional service capacity using the existing site infrastructure at a fraction of the cost of introducing additional sites. Its direct "drop and insert" design reduces deployment time from months to mere hours. In combination with its distinctive aspects for optimizing network capacity, the PCS bi-sector array is a cost-effective solution for addressing network congestion.

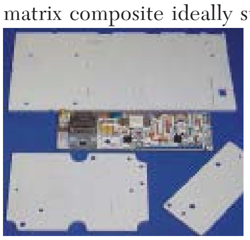
***TenXc Wireless Inc.,***
***Ottawa, Ontario, Canada (613) 591-6696,***
***www.tenxc.com.***

**RS No. 248**

# MATERIAL

## Metal-matrix Composite

The aluminum silicon carbide (AlSiC) is a metal matrix composite ideally suited as a thermal



management material for insulated gate bipolar transistor (IGBT) base plates. These plates can be used in high power traction, power control and fly-by-wire applications, which require thermal performance reliability. The IGBT baseplates are lightweight and offer high strength. The thermal performance reliability AlSiC composites offer is ideal for the production of high reliability military electronics. AlSiC has been tested and meets the requirements of the RoHS directive.

***CPS Corp.,***
***Chartley, MA (508) 222-0614,***
***www.alsic.com.***

**RS No. 249**

# SERVICES

## Value-added Services

In addition to manufacturing cable assemblies, the company also offers value-added services

to these products. The company's equipment provides private labeling and custom marking with bar codes, logos, company name, part numbers or custom requests. This is done in a variety of colors for quick identification. In addition, shrink tubing or wire rap around markers can also be applied.

***RF Industries,***
***San Diego, CA (858) 549-6340,***
***www.rfindustries.com.***

**RS No. 250**



Visit http://mwj.hotims.com/7961-35

# SOURCE

## Wideband Voltage-controlled Oscillator

The model V844ME24-LF is a C-band (3250 to 3700 MHz) voltage-controlled oscillator (VCO) designed for WiMAX applications. This model offers a low phase noise performance of –86 dBc/Hz at 10 kHz offset away from the carrier. This VCO combines linear tuning with good harmonic suppression. It provides an average tuning sensitivity of 165 MHz/V and typical harmonic suppression of –20 dBc. It also guarantees O/P power of 5 dBm ±2 dB over the extended operating temperature range of –40° to 85°C. Size: 0.50" × 0.50" × 0.22". Price: $18.95/VCO (5 pcs. min.). Delivery: stock to four weeks.

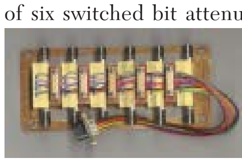

***Z-Communications Inc.,***
***San Diego, CA (858) 621-2700,***
***www.zcomm.com.***

**RS No. 252**

# SUBSYSTEMS

## Switched Bit Attenuator Array

The model SAA-218-6-093-013542 is an array of six switched bit attenuators (AMC model SBA-218-6) that operates in a frequency range from 2 to 18 GHz. This assembly provides switchable RF attenuation for six signal paths. The settings will be selected by six digital control bits. The standard version of this product is epoxy sealed, but the hermetically sealed version is available for more extreme environmental requirements.



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

**RS No. 247**

## Switching Matrices

These matrices incorporate highly repeatable and long-cycle-life relays and switches that cover the spectrum from DC to 33 GHz. The company provides multiple standard and customized switching configurations, from compact four-terminal modules to larger M×N rack assemblies. Each switching matrix incorporates the company's extensive selection of time-tested miniature electromechanical relays and coaxial switches. These components offer ±0.1 dB repeatability, high power up to 2 kW capability, 5M cycles, built-in attenuation/bypass, and 50 and 75 Ω impedance.

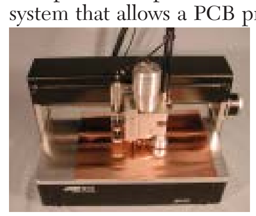
***Teledyne Relays,***
***Hawthorne, CA (800) 284-7007,***
***www.teledynerelays.com.***

**RS No. 236**

# SYSTEM

## Pneumatic Pressure Foot

This pneumatic pressure foot is a precision flat system that allows a PCB professional to make precision depths of cut in a laminate substrate for microwave, RF and digital prototype circuits on the Quick Circuit platform. This system is specifically designed for rapid prototyping applications that require both a precision depth of cut and minimal contact with the material. The pneumatic pressure foot provides pneumatic air cushion for minimal contact during milling, easy to install retrofit kit and fits on any current or new QC 5000, QC 7000 or QC 9000 models. Price: $1,295.00.



***T-Tech Inc.,***
***Norcross, GA (770) 455-0676,***
***www.t-tech.com.***

**RS No. 253**

# TEST EQUIPMENT

## Integrated Microwave Assemblies

Models PTB-50-0R118-6R5-18-120VAC-SFF-DVA and PEC-50-0R118-6R5-18-120VAC-1U-SFF are integrated microwave assemblies packaged in either a 1U 19" rack chassis or a portable test bench housing. The units are high gain amplifiers that operate over a broadband frequency range from 100 MHz to 18 GHz. These units feature integrated digitally controlled attenuators with a resolution of 1 dB increments. The attenuators can be controlled via the external optical encoded knob or via the RS-232 rear panel connector. The actual amount of selected attenuation is displayed on the front panel LCD screen.

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

**RS No. 231**

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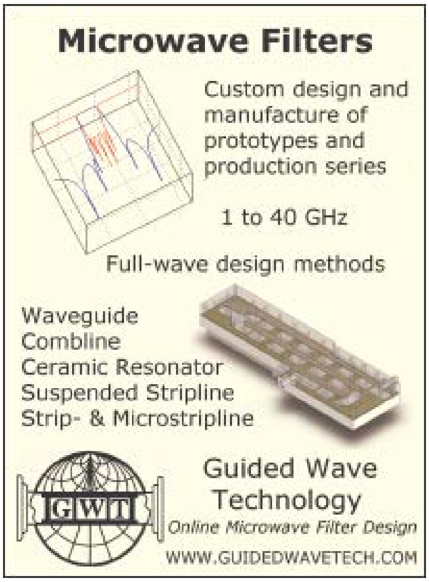


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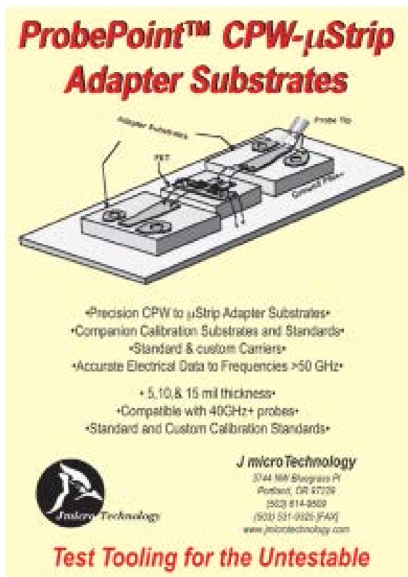


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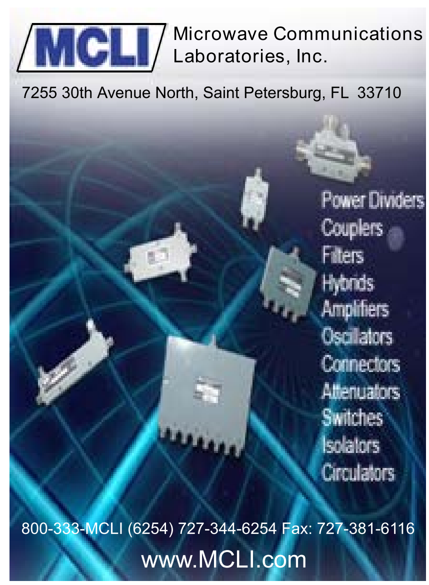


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# CALL FOR PAPERS

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

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

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

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# MICROWAVE METRICS

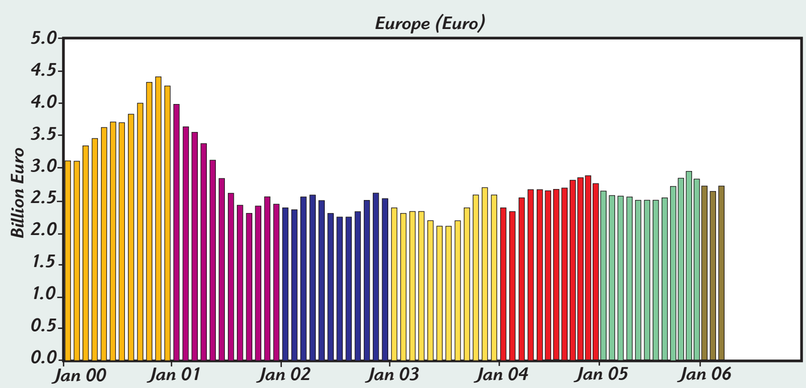
## *European Semiconductor Market*

Semiconductor shipments to Europe showed a moderate sequential decline, in line with the worldwide trend and the seasonal behavior of the first quarter of the year. The overall market performance was for the most part influenced by the decrease in sales of microprocessors, down sequentially from Q4 2005, but also declining in comparison to the first quarter of last year.

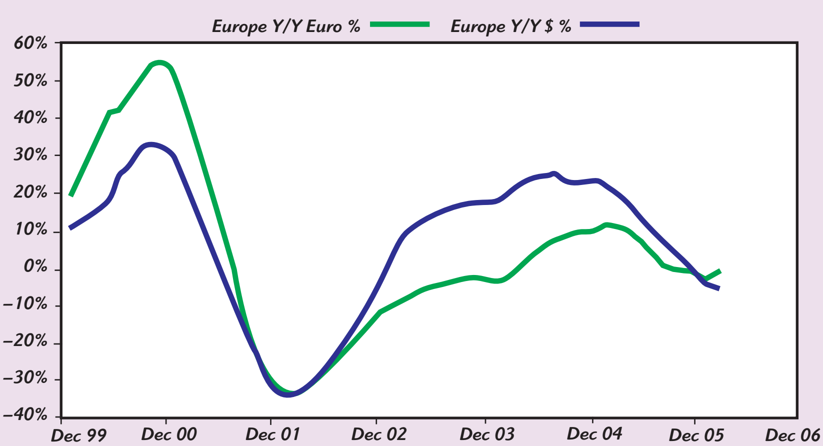
In Europe and other regions flash memory products slowed down in Q1 2006. However, this relative slow down should be viewed against the extremely positive outlook for flash memory over the past year. There was high demand for application specific integrated circuits in this quarter, particularly for the automotive and the consumer sectors. Chips for communication applications reported an overall positive result. A moderate growth was recorded for digital signal processors and DRAM.

European semiconductor sales in March 2005 amounted to US$ 3.240 B according to the World Semiconductor Trade Statistics (WTS), up 4.1% versus the previous month. This corresponds to a 4% decline compared to the same month last year. On a total year basis, semiconductor sales declined in 2006 as well by 4% versus the year 2005.

On a worldwide basis, semiconductor sales in March were US$ 19.697 B, up 2.3% versus the previous month. This results in an increase of 7.3% versus the same month in 2005 and on a year-to-date basis it results as well in a growth rate of 7.3%.




*Monthly European Semiconductor Sales in Billion Euro (3-month-average Data)*




*European Semiconductor Sales Growth in % — Annualized Growth Trend (Y/Y) in Euro and Dollar (12-month-average Data)*

*Source: European Electronic Component Manufacturers Association, Diamant Building–Bd. A. Reyers 80, B1030 Brussels, Belgium (www.eeca.org)*

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## Call for Papers

The IEEE MTT-S International Microwave Symposium 2007 (IMS 2007) will be held in Honolulu, Hawaii, Sunday, June 3 through Friday, June 8, 2007 during Microwave Week 2007. Technical papers describing original work in research, development, and application of RF and microwave theory and techniques are solicited.

**Microwave Week 2007**: The IMS 2007 technical sessions will run from Tuesday through Thursday of Microwave Week. Workshops will be held on Sunday, Monday, and Friday. In addition to IMS 2007, a microwave exhibition, a historical exhibit, the RFIC Symposium (www.rfic2007.org), and the ARFTG Conference (www.arftg.org) will also be held in Honolulu during Microwave Week 2007.

**Electronic Paper Submission**: Technical papers for this symposium must be submitted via the IMS 2007 web site, www.ims2007.org. Complete information on how to submit a paper and register for the conference, as well as other important information, can be found at the IMS 2007 web site.

**Proposals Invited**: Workshop (Tutorial through Expert level), Special Session (Focused and Honorary), and Panel/Rump Session proposals are invited. To suggest topics, or to volunteer to help organize or participate in a Workshop, Special Session or Panel Session, contact the appropriate committee member listed on this page.

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## Electronic Submission Deadlines

| | |
|---|---|
| Proposals for short courses, workshops, panels, and special sessions: | September 1, 2006 |
| Manuscripts for Review: | December 1, 2006 |
| Final Manuscripts: | March 1, 2007 |
| All submissions must be made through the IMS2007 portal: | www.ims2007.org |

**ALL SUBMISSIONS MUST BE IN PDF FORM** — **Hard copies not accepted**

The authors are responsible for formatting. Font embedding must be IEEE Xplore compatible.

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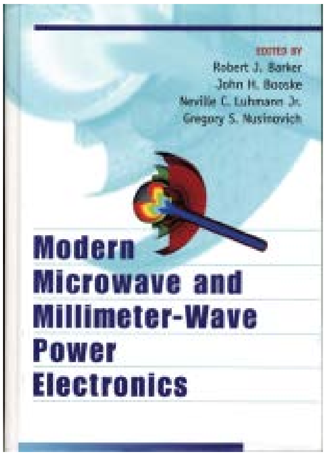
## Modern Microwave and Millimeter-Wave Power Electronics




**Robert J. Barker, John H. Booske, Neville C. Luhmann, Jr. and Gregory S. Nusinovich, Editors**
**Wiley Interscience • 864 pages; $145**
**ISBN: 0-471-68372-8**

The designers of present and future microwave and millimeter-wave power electronics systems need to be aware of the unique and rich characteristics of microwave vacuum electronic devices (MVED). Unfortunately, there exists a glaring lack of vacuum electronics courses in most university curricula. This book seeks to help fill that gap and can be used by conscientious educators to give their graduate students a clearer grasp of the full range of possibilities. The preparation of this text was originally launched as a method to document the fruits of more than 15 years of ongoing MVED basic research that has been sponsored by the US Air Force Office of Scientific Research (AFOSR). The book will familiarize the R&D and academic communities with the capabilities and limitations of MVED and highlight the exciting scientific breakthroughs of the past decade that are dramatically increasing the compactness, efficiency, cost-effectiveness and reliability of this entire class of devices. This comprehensive text explores a wide range of topics: traveling wave tubes, which form the backbone of satellite and airborne communications as well as of military electronic countermeasures systems; micro-fabricated MVEDs and advanced electron beam sources; klystrons, gyro-amplifiers and cross-field devices; "virtual prototyping" of MVEDs via advanced 3-D computational models; high power microwave (HPM) sources; next generation microwave structures and circuits; how to achieve linear amplification; advanced material technologies for MVEDs; and a web site appendix providing a step-by-step walkthrough of a typical MVED design process. Concluding with an in-depth examination of emerging applications and future possibilities for MVEDs, this book ensures that systems designers and engineers understand and utilize the significant potential of this mature, yet continually developing technology.

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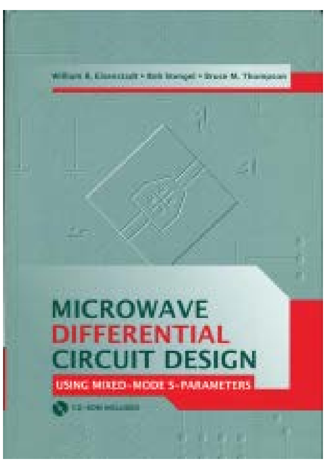
## Microwave Differential Circuit Design




**William R. Eisenstadt, Bob Stengel and Bruce M. Thompson**
**Artech House • 242 pages; $109, £48**
**ISBN: 1-58053-933-5**

Mixed signal/radio frequency (RF) designs with complex digital and analog functionality, called systems-on-a-chip (SoC), are now in production for wireless applications. The topic of differential RF and microwave circuit design is rich in ideas but the results are scattered throughout the literature. Mixed-mode S-parameters can show and separate the differential-mode and the common-mode circuit performance of a four-port RF system. The goals of this book are to present conceptual structure and teach powerful new techniques in the area of differential RF circuit design. It describes the basic mixed-mode S-parameter techniques necessary to perform high frequency differential four-port circuit design. In addition, mixed-mode techniques are used to develop design-related analyses of balanced transmission lines, amplifiers, three-port hybrids and four-terminal coupler designs. Chapter 1 reviews the basic properties of signal integrity, differential circuits and the advantages of differential circuit design, compared to single-ended circuit design. Chapter 2 presents mixed-mode S-parameter theory and examples. Chapter 3 is devoted to balanced transmission line basics. Chapter 4 shows balanced small-signal amplifier theory. Chapter 5 reviews mixed-mode techniques applied to three-port hybrid splitters and combiners. Chapter 6 discusses mixed-mode S-parameters applied to four-terminal components and Chapter 7 concludes with mixed-mode analysis applied to the time domain. The book is accompanied with a CD containing S-parameter design examples and IC technology. It holds a unique, general access, simplified 180-nm SiGe BiCMOS IC technology design kit from Jazz Semiconductor for the Agilent ADS simulator. This software allows readers to design very realistic microwave ICs and explore prepared example circuits and problems from the design chapters in the book.

*To order this book, contact:*
Artech House
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Norwood, MA 02062
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46 Gillingham St.
London SW1V 1HH UK
+44 (0) 207-8750

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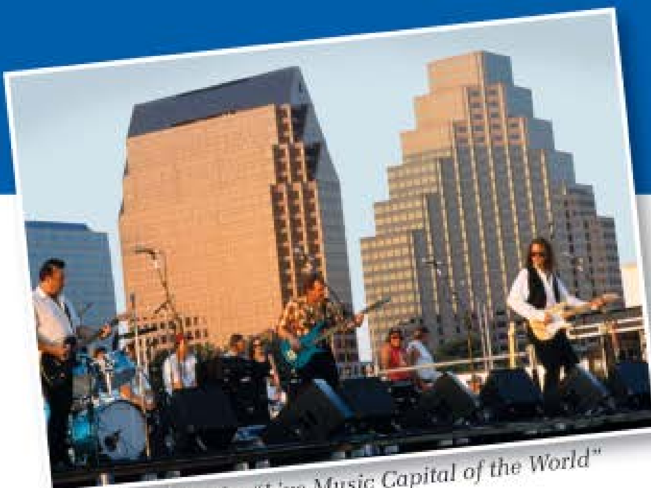

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