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APRIL 2014

HIGH FREQUENCY ELECTRONICS

COAXIAL TRANSFORMER POWER AMPLIFIER SPICE SIMULATION

IN THIS ISSUE:

Land Mobile/Public Safety Radio PA Revolution

Featured Products

New Products

Ideas for today's engineers: Analog · Digital · RF · Microwave · mm-wave · Lightwave

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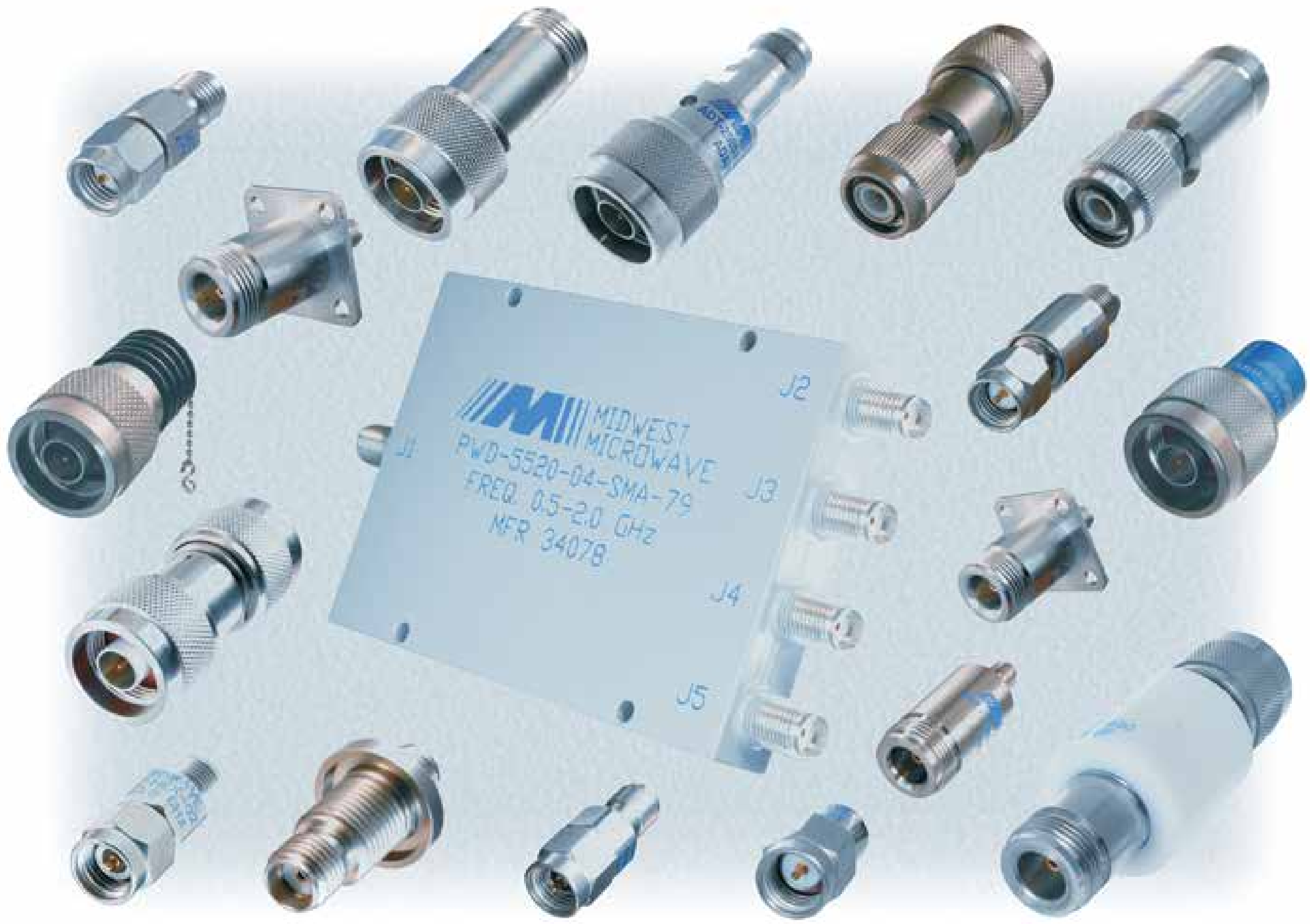

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Adapters
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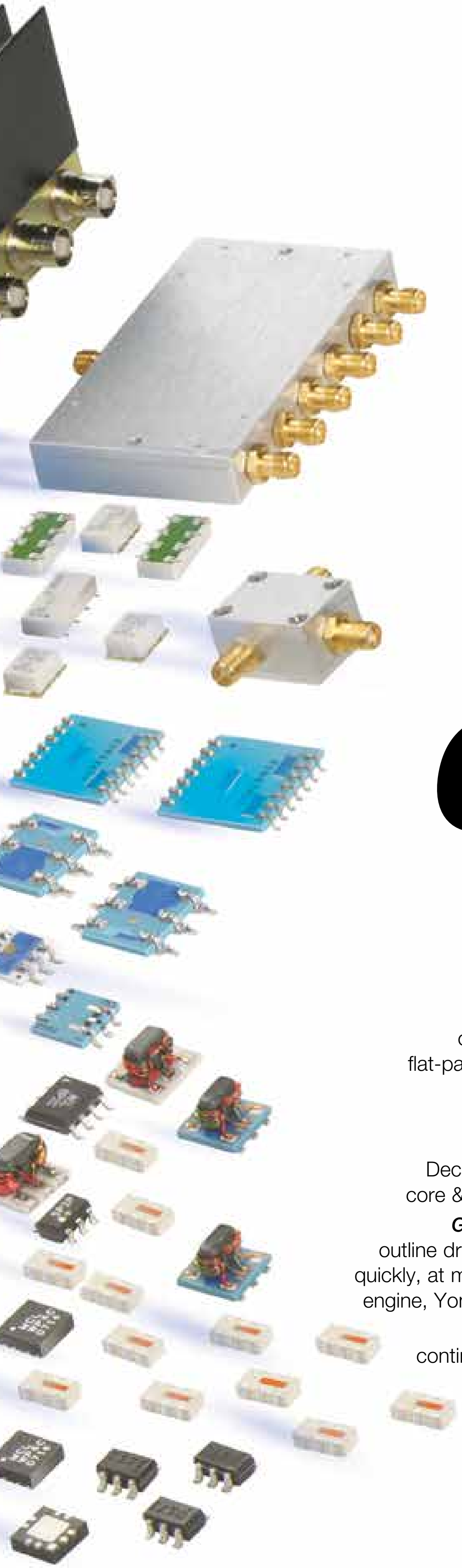

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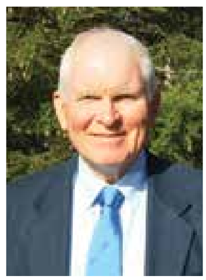

One of the recurring complaints I hear from a few of my "mature" experienced friends and colleagues involves the lack of accessibility to simulation, analysis, and design software. This generally occurs among those who are self-employed consultants or folks working for small companies. Project managers often expect engineers to not only have access to multiple tools, but flexibility with various solvers to find the best model and answers to challenging problems. The problem seems to focus primarily on affordability. Secondarily, there is one of maintenance, both staying current with the latest software versions and having sufficient computer resources.

Before discussing further, I want to say that there are many wonderful tools that have been developed at great expense and their availability has greatly enhanced our field of endeavor and shortened turn-around time from conceptual design to end product. Several of these software companies are loyal advertisers with *High Frequency Electronics.* They also often provide good technical articles and we greatly appreciate their involvement and contributions. So this column is in no way a commentary about them, but rather an observation of a very specific, but not uncommon, conundrum.

Freeware

Many vendors do their best to make introductory, test copies, or short-term "freeware" available in order to provide designers with training software, often complemented with classes "coming to your city." Even events such as Panel Sessions at symposiums can bring out pros and cons of competing software programs. This all helps, but can be a teaser, because the software cost for a license or "key" can be many thousands of dollars. In addition, there is often a yearly maintenance or upgrade fee that in itself might cost more than the self-employed engineer could possibly afford. So the independent consultant, while often quite experienced with lots of practical knowledge, may be left behind or even discriminated against because he or she doesn't have $50K to $100K worth of CAD software readily available.

So what can be done to mitigate this problem? I don't have a simple answer or eloquent solution. First of all, there may be more free stuff out there than one realizes. There are a number of publications, books, handbooks and on-line free or almost-free programs that can attack specific problems in electromagnetics, circuit design, propagation, antenna design, linearization, systems engineering and even program planning. Also, one can often examine the original works of well-respected pioneers in certain disciplines, from which much of the design criteria emanates. A good example of this would be the late Dr. Arthur Oliner, known for work with "leaky waves," among other topics.

Amazing Simulations

There are even programs out there that allow for amazing simulations that can be had for free. An example of a program I've used lately is one that calculates antenna Height Above Average Terrain (HAAT). One can select few or many radial directions. It seems quite accurate. Another allows simulation of a radar's performance at almost any coordinates in the civilized world. There are many filter design and antenna design/pattern/analysis programs. There's a multitude of thermal analysis programs that can be used to simulate the heat dissipation challenges of developing high power Gallium Nitride (GaN) amplifiers. Some of these programs do require a bit of ingenuity and resourcefulness, but the clarity and accuracy of the outcomes can be amazing. Just be careful when searching out programs. Most are reliable, but be vigilant and don't be afraid to give proper credit to sources. One overview of electromagnetic simulation programs can be found at:

http://en.wikipedia.org/wiki/EM_simulation_software

Discounts?

Software companies might consider making their products available at a discount to members of the engineering community who meet certain criteria, in much the same way as they cater to institutions of higher learning to encourage training with their products. I'm sure this is a difficult challenge, not least of which is the possibility of fraud and abuse. But consider the fact that these veteran engineers have considerable influence on their peers and the customers for whom they perform services. So the PR value of making software more readily available may result in enhanced sales.

IMS Right Around the Corner

IMS 2014 will be upon us before we know it. This year's event, to be held in Tampa, Fla., promises much to look forward to, including an impressive technical program as well as balmy weather in a great venue. If you haven't made your arrangements already, now is the time to act. More info available at http://ims2014.mtt.org/.

HFE

Conferences

2014 IEEE MTT-S International Wireless Power Transfer (WPTC 2014)
8 - 9 May 2014
Jeju, Korea
http://www.wptc2014.org/

2014 IEEE MTT-S International Conference on Numerical Electromagnetic Modeling and Optimization for RF, Microwave and Terahertz Applications (NEMO 2014)
14 - 16 May 2014
Pavia, Italy
http://nemo-ieee.org

2014 IEEE International Microwave Symposium (IMS2014)
1 - 6 June 2014
Tampa, Florida, USA
http://ims2014.mtt.org/

2014 IEEE Radio Frequency Circuits Symposium (RFIC 2014)
1 - 3 June 2014
Tampa, Florida, USA
http://rfic-ieee.org/

2014 IEEE Wireless and Microwave Technology Conference (WAMICON 2014)
6 June 2014
Tampa, Florida, USA
http://www.wamicon.org/

83rd ARFTG Microwave Measurement Conference
6 June 2014
Tampa, Florida, USA
http://www.arftg.org/

2014 IEEE MTT-S International Symposium on Radio-Frequency Integration Technology (RFIT 2014)
27 - 30 August 2014
Heifi, Huangshan, China
http://www.rfit2014.org
Call for Papers: http://www.rfit2014.org/RFIT2014CFP.pdf
Paper Submission Deadline: 11 June 2014

2014 IEEE International Conference on Ultra-Wideband (ICUWB 2014)
1 - 3 September 2014
Paris, France
http://www.icuwb2014.org

2014 IEEE Conference on Electrical Performance of Electrical Packaging and Systems (EPEPS 2014)
26 - 29 October 2014
Portland, Oregon
http://epeps.ece.illinois.edu

2014 IEEE MTT-S International Microwave and RF Conference (IMaRC)
15 - 17 December 2014
Bangalore, India
http://www.imarc-ieee.org
Call for Papers: http://www.imarc-ieee.org/images/IMARC2014_CFP.pdf
Paper Submission Deadline: 15 August 2014

2015 IEEE MTT-S Radio Wireless Week (RWW 2015)
25 - 28 January 2015
San Diego, California, USA
http://www.radiowirelessweek.org/

Radio Wireless Week consists of five co-located topical conferences:
RWS: IEEE Radio and Wireless Symposium
PAWR: IEEE Topical Meeting on Power Amplifiers for Wireless and Radio Applications
SiRF: IEEE Topical Meeting on Silicon Monolithic Integrated Circuits in RF Systems
BioWireleSS: IEEE Topical Conference on Biomedical Wireless Technologies, Networks, and Sensing Systems
WiSNet: IEEE Topical Meeting on Wireless Sensors and Sensor Networks

Company-Sponsored Training & Tools

Analog Devices
Training, tutorials and seminars.
http://www.analog.com/en/training-tutorials-seminars/resources/index.html

AWR
On-site and online training, and open training courses on design software.
http://web.awrcorp.com/Usa/News--Events/Events/Training/

National Instruments
LabVIEW Core 1
Online
http://sine.ni.com/tacs/app/fp/p/ap/ov/pg/1/
LabVIEW Core 2
Online
http://sine.ni.com/tacs/app/fp/p/ap/ov/pg/1/
Object-Oriented Design and Programming in LabVIEW
Online
http://sine.ni.com/tacs/app/fp/p/ap/ov/pg/1/
Free, online LabVIEW training for students and teachers.
http://sine.ni.com/nievents/app/results/p/country/us/type/webcasts/

Call for Papers

October 19 – 22, 2014
2014 IEEE Compound Semiconductor Integrated Circuit Symposium (CSISC)
La Jolla, Calif.
Abstract submission deadline: May 2, 2014
Final submission deadline: July 25, 2014
Notification of acceptance date: June 13, 2014
http://www.csics.org/


RoHS
E1
E2
E3
E4

Military Communications Market Seen Reaching $30 Billion by 2022

An increasing emphasis on data-centric communications and providing net-centric capabilities will drive the military communications market with a move towards higher frequencies to meet the growing demand for spectrum. The Strategy Analytics Advanced Defense Systems (ADS) service series of forecasts outline global defense expenditure trends segmented on a regional basis before breaking out the expected spend on military communications incorporating systems, hardware, support and related services across the land, air, naval and space domains.

- The introduction of new satellite communication platforms, such as the US-based AEHF and MUOS systems, in conjunction with an increased and continuing emphasis on network centric and data orientated communications capabilities will drive demand for military satellite communications.
- Shipborne communications spending will be characterized by demand for multiple radio systems.
- Fast-jet platforms will represent the mainstay for the airborne radio market while the emerging UAV market will represent the fastest growth sector.
- Terrestrial radio volumes will be dominated by handheld systems while the emphasis on maintaining net-centric communications through to the tactical edge will drive VSAT terminal shipments.

"Managing bandwidth in increasingly congested spectrum will be a key challenge in meeting future demands for data-centric military communications," observed Asif Anwar, Director of the ADS service. "This is leading to the use of higher frequencies, particularly evident in the military satellite communications segment with adoption of Ka-band."

"Other common themes across the military communications sector include a move towards multi-mode and multi-band radio solutions," added Eric Higham, North American Director for ADS.

—Strategy Analytics
strategyanalytics.com

LTE and AP Markets Driving RF Power Amplifier Equipment and RF Power Semiconductor Device Sales

Asian wireless infrastructure deployments, led by China, continue to be the main driver for the RF power amplifier and RF power semiconductor market in 2013 and beyond.

Despite an off year in 2012 the market for RF power amplifiers grew at a single-digit rate while RF power semiconductors grew at a double-digit clip in 2013. ABI Research sees this trend continuing.

According to research director Lance Wilson, "For the foreseeable future the Asia-Pacific region, particularly China, will dominate this market and remain the most important region and focus for high power RF amplifiers and RF power devices for wireless infrastructure."

LTE and the emerging TD-LTE air interfaces will be the technology engines of growth for the next five years. Another important breakthrough will be that gallium nitride (GaN) devices will start to impact the device segment. "Although silicon LDMOS is by far the technology leader in this market," says Wilson, "GaN devices captured meaningful share in 2013 and will increasingly do so for the next several years."

The continuing overall need for wireless data remains an important driver for the overall market for RF Power amplifier equipment and RF power semiconductor devices.

—ABI Research
abiresearch.com

Global EW Spending To Exceed $9B Through 2022

Global spending on RF-based Electronic Warfare (EW) systems is forecast to grow to over $9.3 billion through 2022. While troop withdrawals from theatres such as Iraq and Afghanistan are causing a short-term decline in the number of land-based Electronic Warfare equipment for Electronic Attack (EA) capabilities such as jammers, the general trends towards asymmetric warfare and the use of IEDs will continue to proliferate, leading to continued demand for land-based EW systems: The Strategy Analytics Advanced Defense Systems (ADS) service forecast model, "Land-based EW (EA) and Components Forecast 2012-2022," details global expenditure for EW equipment with future demand segmented in terms of form factors, power outputs and frequency trends.

- Land-based EW (EA) equipment remains focused on jamming communications frequencies with the emphasis increasingly on providing capabilities that can cover as much of the spectrum as possible.
- System design to selective and reactive jamming capabilities, moving beyond jammers that simply barrage the environment with signals that can also potentially block friendly communications.
- Future systems will also look to offer multimode capabilities that merge C-IED (Counter Improvised Explosive Device) and communications jamming.

"The move towards wideband capabilities coupled with portability requirements have driven a move towards solid-state solutions with gallium nitride (GaN) technology firmly entrenched as an enabling technology for land-based EW systems," noted Asif Anwar, Director of the ADS service. "The overall component market for Land-based EW (EA) equipment will grow at a CAGR of 6.4 percent through 2022."

—Strategy Analytics
strategyanalytics.com

Why Coilcraft wirewound chip inductors are your #1 choice

Higher Q Compared to non-wirewounds, our chip inductors usually have Qs that are 50 to 150% higher.

Lower DCR Put up to 3 times more current through our chip inductors thanks to their low DC resistance.

Higher SRF The solenoid winding of our inductors gives them a much higher SRF than multilayer parts.

Tighter tolerance Precision manufacturing lets us consistently make parts with ±2% inductance tolerance. Many popular values also come in ±1%.

Better support With our engineer-friendly web site, interactive design tools and generous free samples, Coilcraft is just plain easier to do business with.

Visit **www.coilcraft.com** for information on all our high performance wirewound inductors.

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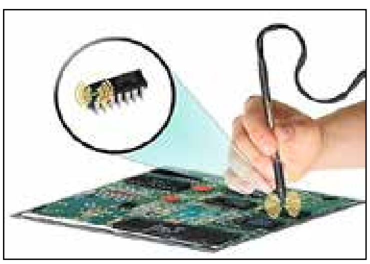
WWW.COILCRAFT.COM

High-energy lasers (HEL) have the potential to benefit a variety of military missions, particularly as weapons or as high-bandwidth communications devices. However, the massive size, weight and power requirements (SWaP) of legacy laser systems limit their use on many military platforms. Recently, **DARPA**'s Excalibur program successfully developed and employed a **21-element optical phased array** (OPA) with each array element driven by fiber laser amplifiers. This low power array was used to precisely hit a target 7 kilometers—more than 4 miles away. The OPA used in these experiments consisted of three identical clusters of seven tightly packed fiber lasers, with each cluster only 10 centimeters across. "The success of this real-world test provides evidence of how far OPA lasers could surpass legacy lasers with conventional optics," said **Joseph Mangano,** DARPA program manager.



Used and non-authentic **counterfeit electronic components** are widespread throughout the defense supply chain; over the past two years alone, more than one million suspect parts have been associated with known supply chain compromises. The problem is pervasive, with both expensive and inexpensive electronic parts being targeted. A new **DARPA** program seeks to develop a tool to verify, without disrupting or harming the system, the trustworthiness of a protected electronic component. **The DARPA Supply Chain Hardware Integrity for Electronics Defense (SHIELD) program** seeks proposals to develop a small (100 micron x 100 micron) component, or dielet, that authenticates the provenance of electronics components. Proposed dielets should contain a full encryption engine, sensors to detect tampering and would readily affix to today's electronic components such as microchips.

Bell-Boeing Joint Project Office, Amarillo, Texas, is being awarded a $76,100,722 modification to the previously awarded V-22 fixed-price-incentive-fee lot 17-21 multi-year contract (N00019-12-C-2001). This modification exercises an option for the manufacture and delivery of one **CV-22 tiltrotor aircraft** for the U.S. Air Force.

Lockheed Martin Corp., Lockheed Martin Aeronautics Co., Fort Worth, Texas, is being awarded a not-to-exceed $7,696,166 undefinitized modification to the previously awarded low rate initial production lot 6 advanced acquisition contract (N00019-11-C-0083) for the **F-35 Lightning II Joint Strike Fighter** aircraft. This modification provides for the procurement of non-recurring sustainment activities for the government of the **United Kingdom**, to include procurement of site activation planning efforts for Royal Air Force Marham.

Teledyne Microelectronic Technologies is celebrating its **50th anniversary**. For half a century, TMT's Los Angeles facility served as the manufacturing center for multi-chip modules and advanced microelectronics packaging solutions for the aerospace, defense, medical and industrial markets. In 2013, TMT moved its production facility to **Lewisburg, Tenn.**, where it is poised for the next half century of innovation and service to meet customers' requirements.

AWR Corp. announced the availability of a free excerpt of the new eBook from **Professor Francesco Fornetti**, ***Conquer Radio Frequency*** *– A Multimedia Conceptual Guide to RF and Microwave Engineering.* The excerpt includes select Explore RF instructional video tutorials done using AWR's Microwave Office® circuit design software. The download is offered as part of AWR's **Professors in Partnership**, a unique program specifically designed to provide engineering students, faculty, and graduates with access to ongoing microwave and RF educational content that enhances and promotes the use of AWR software solutions through e-books, textbooks, and videos.

LadyBug Technologies, manufacturers of patented no-zero no-cal before use USB RF Power Sensors, is pleased to announce new representatives for Nevada. Northern Nevada is served by **Jay Stone Associates** and Southern Nevada is represented by **ACETEC**, Inc. Both firms are established LadyBug partner representatives with extensive experience in RF and microwave technology.

SAGE
18 to 140 GHz

IKE Micro announced completion of its in-house **air cavity array packaging capability**. The line includes automatic 01005/0201 SMT placement, die attach from wafer and waffle pack, wedge wire/ribbon and ball bonding, coil attachment, lid marking, lid attachment, and dicing of array assemblies. “As operating frequencies continue to increase, IKE felt the need to invest in the infrastructure to support the build-to-print manufacturing needs for US-based semiconductor packaging companies. We are providing efficient multi-up packaging solutions for NPI and low/mid volume LGA package orders,” said President and owner **Scott MacKenzie**.

ParkerVision, a developer and marketer of semiconductor technology solutions for wireless applications, announced that its patent portfolio once again ranked among the **Top 25 companies** in The Patent Board’s Telecom and Communications Industry scorecard, published by ***The Wall Street Journal.*** ParkerVision ranked in the top 25 for the overall measure of **technology strength** and, for the fourth consecutive reporting period, earned the highest score among the top 50 companies in terms of 5-year cumulative science strength.

Rosenberger has been successfully qualified by ESA for the supply of SMA, RPC 2.92, TNC and SMP connector series. That means that Rosenberger is a qualified supplier forESA (**European Space Agency**) space projects. Rosenberger is now an ESCC Qualified Manufacturer (European Space Components Coordination) and fulfills the extremely high requirements to suppliers of space industries.

Pasternack Enterprises appointed Ms. **Penny Cotner** as the new Vice President of Sales & Service. She spent the last 20 years of her career at Wyle Electronics and Arrow Electronics where she was most recently Director of Sales Operations. Ms. Cotner was responsible for driving numerous important initiatives at Arrow in the areas segmentation analysis and strategy development, technical sales training, technical sales, and web strategy and implementation as well as leading cross-functional teams across the Arrow organization. Her education includes a B.S.E.E. and an M.B.A.

RFMD announced it has signed a $9.7 million agreement with the Manufacturing and Industrial Technologies Directorate within **the Air Force Research Laboratory (AFRL)** to transfer and produce a **0.14 micron Gallium Nitride (GaN) monolithic microwave integrated circuit (MMIC) technology.** The technology will be scaled to 6-inch diameter wafers using RFMD’s industry-leading 6-inch GaN-on-Silicon Carbide (SiC) manufacturing line. “Through this Air Force contract we have the opportunity to establish the industry’s first 6-inch millimeter wave GaN-on-SiC process technology, allowing RFMD to expand our technology capabilities beyond 100GHz,” said **Gorden Cook,** general manager of RFMD Power Broadband.

Hittite Microwave Corp. announced that it has entered into a definitive agreement to buy substantially all the assets of the **Keragis Corp.,** a provider of extremely high power, wideband amplifier modules, located in San Diego, CA. The purchase price was not disclosed.

FEATURED PRODUCTS

Sensor Heads

Model SRU Series ranging sensor heads are designed for long range distance detection where sensitivity is essential. They are used for moving targets (where the Doppler shift is presented) distance detection. The single channel versions are used for speed and distance sensing only while dual channel versions are offered for speed, distance and direction sensing.

Ducommun
ducommun.com

Phase Shifter

PMI Model No. PS-360-DC-3 OPTION 618-15D is an 8-Bit, Digitally Controlled, 360 Degree phase shifter operating over the 6.0 to 18.0 GHz frequency range. It has a typical insertion loss of 10 dB and a VWSR of 2.0:1 max. Phase accuracy is ±5.2° with PM/AM as low as ±0.8 dB and carrier suppression of 26 dB typically.

Planar Monolithics Industries
pmi-rf.com

CRO

The CVCO55CXT-6000-6075 Coaxial Resonator Oscillator (CRO) is a coaxial-based VCO with an internal proprietary frequency doubler. The CVCO55CXT family's frequency doubling, 2X fundamental technology reaches new performance levels of lower phase noise and much lower harmonics over the competition, while achieving lower current consumption in the process.

Crystek
crystek.com

Switch

RLC Electronics' 11 and 12-Position Coaxial Switch line provides proven reliability, long life and outstanding electrical performance. The switch also features extremely low insertion loss and VSWR over the entire DC-18 GHz range, while maintaining high isolation. The switch can be provided in latching self-cutoff or pulse latching mode.

RLC Electronics
rlcelectronics.com

Circulator

Raditek's Latest 300 Watt, WR112 Waveguide Circulator, RADC-7.0-8.5-WR112-300WR-1-b. This circulator has low insertion loss (0.2dB) and 20dB of isolation. Reverse power options of 2, 3 or 300 Watts. WR112 / UER 84 waveguide interface type.

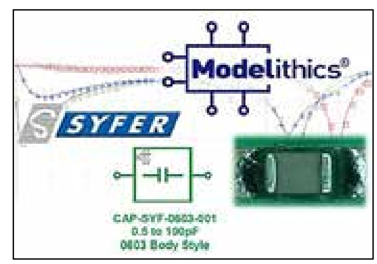
Raditek
raditek.com

Oscillator

RFMW announced application and sales support for high frequency oscillators and VCXOs to 1500 MHz.

These quartz-based, differential and PECL oscillators are targeted to networking and storage applications where fast delivery and high performance are required. Sunny Electronics' SPP-53 VCXO provides excellent phase noise (122dBc @ 10KHz) and less than 1pSec phase jitter performance.

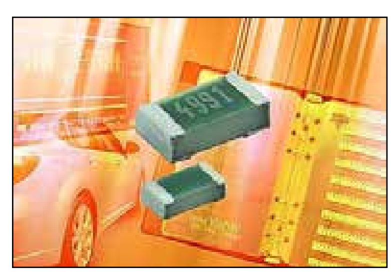
RFMW
rfmw.com



Capacitor Model

Modelithics welcomed Syfer as a strategic Modelithics Vender Partner (MVP). Together, Syfer and Modelithics have developed a Microwave Global Model™ for Syfer's 0603 case size High Q Ultra-Low ESR capacitor family. The model is substrate-, part-value-, and pad-scalable, plus orientation selectable.

Modelithics
modelithics.com

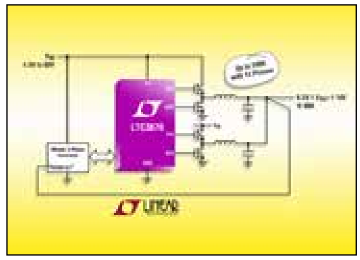


Resistor Kits

Vishay Intertechnology announced that the company is now offering laboratory sample kits of its high-stability thin film chip resistors. The TNPW0402 e3 (LTW0402 e3 96/4) and TNPW0603 e3 (LTW0603 e3 96/4) kits aid engineers in proto-

typing and speed time to market in a wide range of electronic systems.

Vishay Intertechnology
vishay.com



Phase Extender

Linear Technology introduced the LTC3870, a dual phase synchronous step-down slave controller that can generate currents up to 240A when paired with a companion master controller by extending the phase count in multiphase applications. Compatible master controllers include the LTC3880 and LTC3883 digital power system management controllers.

Linear Technology
linear.com

Product Guide

The 2013-2014 RFMD Product Selection Guide provides specifications for more than 750 products including more than 50 recently released products targeting multiple end-market applications. The 60-page guide allows customers to cross-reference and search products using end-market application diagrams. The guide lists products servicing more than 15 end-market segments.

RFMD
rfmd.com

Multipliers

Luff Research models MX-21 and MX-22 frequency multipliers offer excellent performance to 32 GHz. The output power is +13 dBm (mini-

mum) and the harmonics and subharmonics are down -20 dBc (typical). These are ruggedly packaged, connectorized, system ready components operating on single +5 Vdc (150 mA) supply. They offer excellent performance at very low prices.

Luff Research
luffresearch.com

Directional Coupler

VidaRF offers a new directional coupler Model: VDC-75160A6 frequency range from 7.5 - 16 GHz. Available in 6, 10, 20 or 30 dB coupling, 50 watts power handling with SMA connectors, operating temp -55 to 85 C. Sealed and painted to meet IP65 standards.

VidaRF
vidarf.com

VCO

The DRO series Voltage Controlled Oscillator is a fundamental, narrowband signal source utilizing a high-Q dielectric resonator for optimal phase noise performance. The DRO VCO solution is currently being offered for frequencies operating within 7 to 14 GHz. This customizable, ultra-low noise oscillator series is available with both electri-

cal tuning and mechanical tuning for fine frequency precision.

Z-Communications
zcomm.com

Test Set

Model STG-12-S1 is an E band noise figure and gain test set, including a high performance solid-state E

band noise source (STZ-12-I1) and a full waveguide band down converter (STC-20-12-S1). It extends the noise and gain measurement capacity from 10.0 to 15.0 GHz to the frequency range of 60 to 90 GHz. The down converter requires a +10 dBm LO signal in the frequency range of 10.0 to 15.0 GHz.

SAGE Millimeter
sagemillimeter.com

Attenuator

Mini-Circuits' RCDAT-6000-90 is a general purpose programmable RF attenuator supporting frequencies from 1 to 6000 MHz with attenuation from 0 to 90 dB in 0.25 dB steps. Its unique design maintains linear attenuation change per dB, even at the highest attenuation settings. It is controlled via USB or Ethernet-TCP/IP connections and supports both HTTP and Telnet network protocols.

Mini-Circuits
minicircuits.com

Amplifier

Mini-Circuits' CMA-5043+ is a E-PHEMT based Ultra-Low Noise MMIC Amplifier operating from 50 MHz to 4 GHz with a unique combination of low noise and high IP3, making it ideal for sensitive high dynamic range receiver applications. This design operates on +3 to +5V supply at only 33 mA at 3V and 56mA at +5V, is internally matched to 50 ohms.

Mini-Circuits
minicircuits.com

Turn USB Power Sensors into

Smart RF POWER METERS

from -35 up to +20 dBm 9 kHz to 8 GHz

• ***True RMS model now available!*** • *Lightning-fast measurement, as quick as 10 ms**
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- *Power Data Analysis Software*
- *SMA Adaptor (50Ω only)*
- *USB Cable*

** Measurement speed as fast as 10 ms with PWR 8 FS. All other models as fast as 30 ms.*

† See datasheets for an extensive list of compatible software.

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Land Mobile/Public Safety Radio PA Revolution

By Raymond A. Baker, Walter H. Nagy, David W. Runton, Robert A. Sadler

The power amplifier is often the key to achieving design goals.

Public Safety Radio – A Brief History

Mobile wireless communication for public safety was first realized in the 1920s with vacuum tube radios that consumed the entire back seat of a vehicle. Over time, the technology became more practical with improvements in size, cost, and reliability. Transistors brought reduced size and higher efficiency enabling even smaller portable, handheld, radio platforms. At the same time, operational frequencies steadily increased, from HF through VHF, UHF, and up to 800 MHz. New allocations at 700 MHz and access to public networks at 900 MHz are further expanding this communication solution.

In the United States, public safety frequency allocations include the following specific bands (see Figure 1):

These bands are often collated into the following bands:

- 25 – 50 MHz
- 136 – 174 MHz
- 220 – 222 MHz
- 380 – 520 MHz
- 763 – 870 MHz

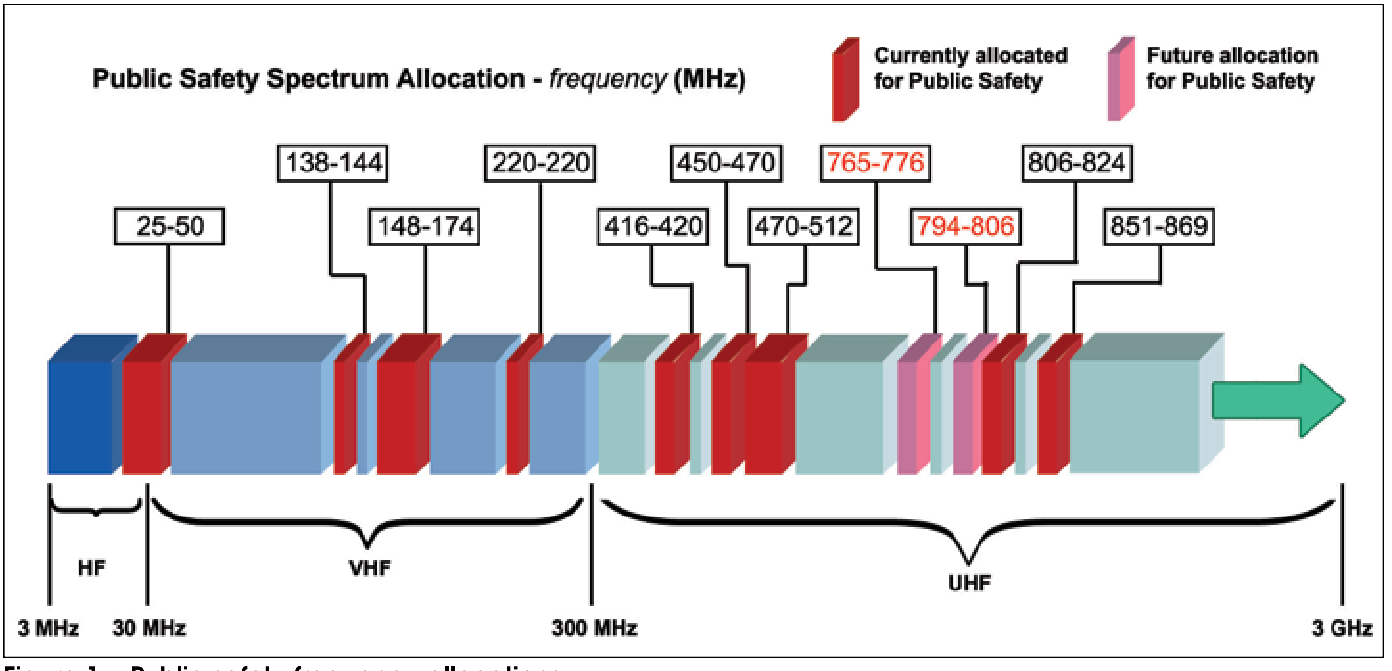

Figure 1 • Public safety frequency allocations.

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LZY-22+	0.1-200	43	16	32	1495	1470
ZHL-5W-1	5-500	44	8	11	995	970
• ZHL-100W-GAN+	20-500	42	79	100	2395	2320
• ZHL-50W-52	50-500	50	40	63	1395	1320
• ZHL-100W-52	50-500	50	63	79	1995	1920
LZY-1+	20-512	43	37	50	1995	1895
• ZHL-20W-13+	20-1000	50	13	20	1395	1320
• ZHL-20W-13SW+	20-1000	50	13	20	1445	1370
LZY-2+	500-1000	46	32	38	1995	1895
NEW ZHL-100W-13+	800-1000	50	79	100	2195	2095
ZHL-5W-2G+	800-2000	45	5	6	995	945
ZHL-10W-2G	800-2000	43	10	13	1295	1220
ZHL-30W-252+	700-2500	50	25	40	2995	2920
ZHL-30W-262+	2300-2550	50	20	32	1995	1920
ZHL-16W-43+	1800-4000	45	13	16	1595	1545
ZVE-3W-83+	2000-8000	36	2	3	1295	1220
ZVE-3W-183+	5900-18000	35	2	3	1295	1220

Listed performance data typical, see minicircuits.com for more details.

** To order **without** heat sink, add **X** suffix to model number (example: LZY-22X+).*

• Protected under U.S. Patent 7,348,854

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Although FM (frequency modulation) was the primary protocol for trunking radios throughout the 1980s, digital modes were added in the 1990s allowing for voice, data, and encryption using M-FSK or GMSK modulation. North American users generally use the APCO P25 standard, while in Europe the standard is TETRA. Eventually systems will migrate towards the LTE (Long Term Evolution) standard for the 700 MHz band enabling wideband data and additional interoperability with public networks at 900 MHz.

Despite radio standard evolution, interoperability with older modulation formats/services remains a requirement, and the incorporation of these frequencies and standards into a single radio system poses a serious design challenge. The most simplistic solution is to stack multiple single narrowband radios, but this compromises size and cost. A more ideal solution would be to implement a single broadband radio, but this places several restrictions on the designer requiring multi-band, multi-mode operation without compromising cost, size, or efficiency, which is a significant challenge.

Because the RF power amplifier dominates overall radio power consumption, the amplifier is often the key to achieving the design goals. The advent of Gallium Nitride (GaN) technology opens a practical path to next generation, flexible, future-proof, frequency agile architectures for both handheld and mobile radios.

Wideband Architecture and LPFs

Power amplifier design for land mobile applications begins with a few fundamental requirements.

- Output Power
- Modulation Format and Linearity
- Efficiency
- Bandwidth
- Harmonic Suppression

Several basic block diagrams are shown below outlining design options to address these requirements.

Considering only the transmit portion, the simplest solution is the conventional narrow or single band PA (power amplifier) chain of Figure 2.

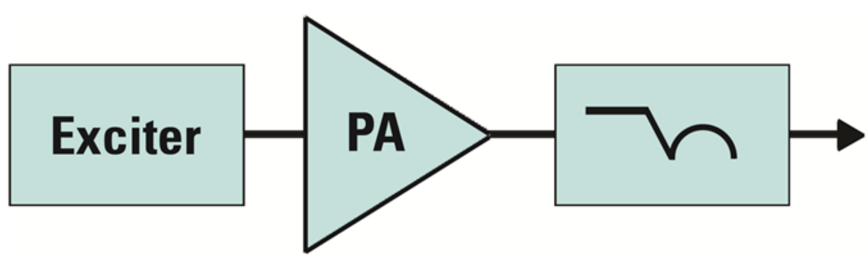
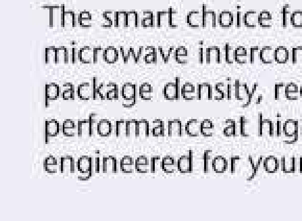


Figure 2 • Single band power amplifier chain.

To optimize power amplifier efficiency, RF PA's are typically designed to operate at or near saturation. Harmonic content represents a significant challenge for the PA design since regulations prohibit out of band emissions. Second and third harmonic levels may rise, reaching -15 to -10dBc and placing a difficult burden on the low pass filter. This filter is typically designed with five or more poles to reduce output harmonic levels below -60dBc (or more) to meet emission specifications.



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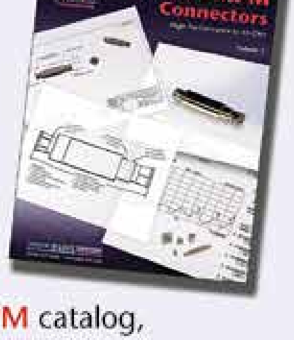

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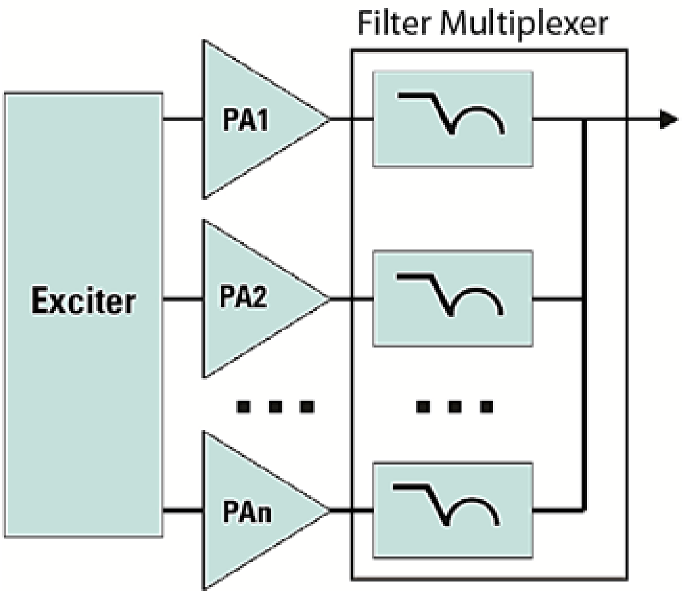

Figure 3 • A multiband implementation with conventional narrowband amplifiers using silicon or LDMOS devices.

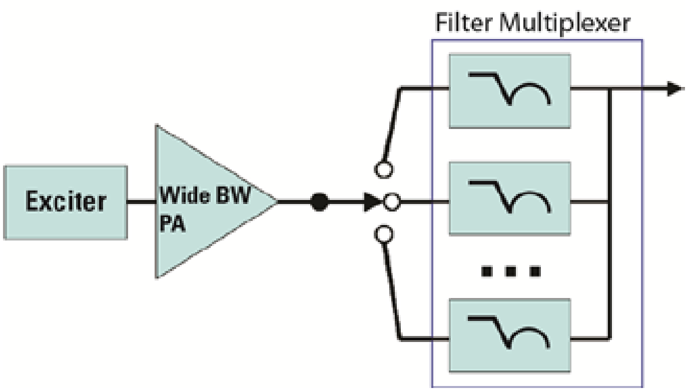

Figure 4 • A single wideband amplifier and a low loss switch could consolidate the multiple amplifiers of Figure 3 into the concept shown.

Operation across two or more bands has historically required separate amplifiers and an assembly of low pass filters and an n-plexer. Figure 3 shows a multiband implementation with conventional narrowband amplifiers using silicon or LDMOS devices.

This approach necessarily requires wide gaps between adjacent bands to relax filter requirements that drive cost and insertion loss. In addition to harmonic attenuation, the filter-multiplexer must isolate each power amplifier filter chain from those of every other band. This configuration works well for two band radios such as 150 MHz/450 MHz or 450 MHz/800 MHz where band edges are separated by many multiples of the passband, keeping filter orders reasonable. Figure 3 shows an implementation with low-pass filters, but in practice some of these may be band-pass, with or without stopband zeros. Filter design for this application presents a host of choices and tradeoffs.

Conceptually, a single wideband amplifier and a low loss switch could consolidate the multiple amplifiers of Figure 3 into the concept shown in Figure 4. A switch, whether FET based or PIN, offers lower cost than a complete band specific amplifier chain and consumes less circuit board area. On the other hand, the amplifier must offer higher power and efficiency to offset increased insertion loss of the switch. Figure 4 also requires guard bands, i.e. gaps in the frequency coverage to ensure deselected filters don't load the operating path and interfere with PA performance.

Figure 5 shows a single amplifier solution that offers continuous frequency operation. Switches at both the filter bank input and output isolate all but the desired channel. This allows for filter design to be less rigorous since pass-bands may have a slight overlap. Compared to Figure 4, however, this configuration doubles the switch insertion loss. This may be, at least, partially overcome by the elimination of the multiplexer requirement and lower overall filter insertion loss.

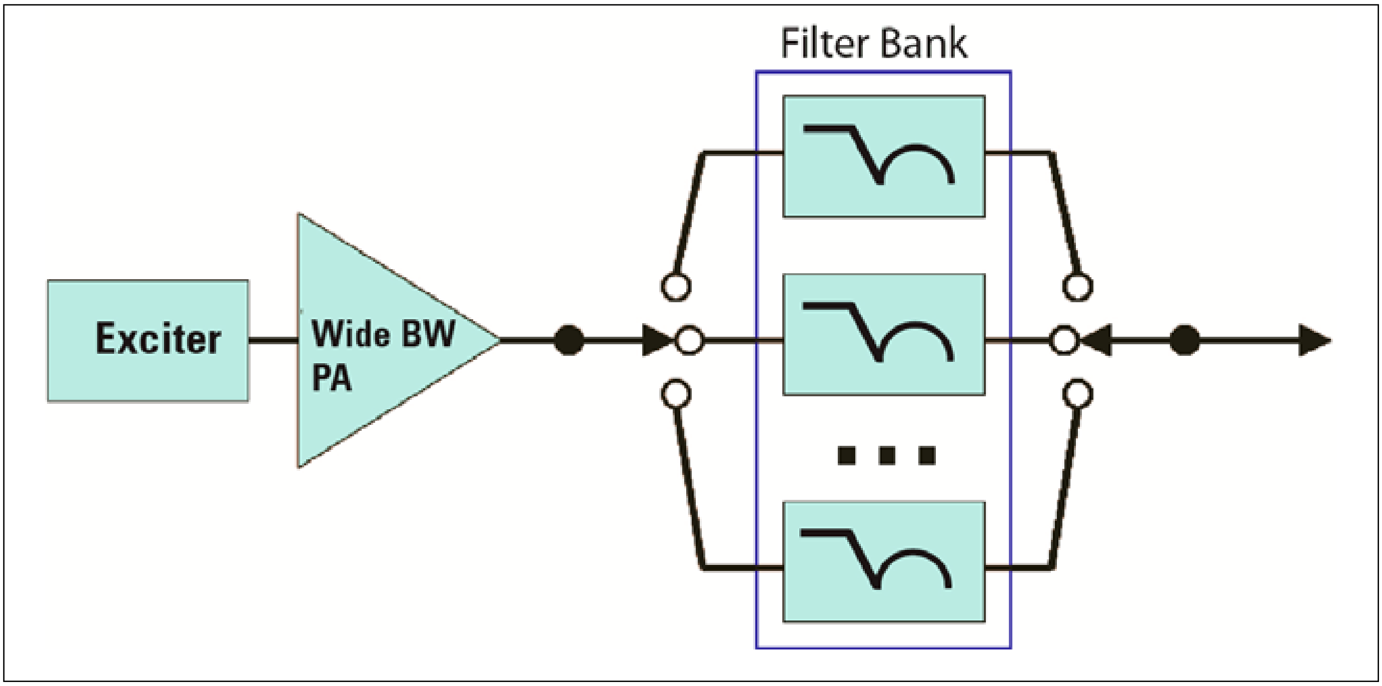

Figure 5 • A single amplifier solution that offers continuous frequency operation.

On the output side, harmonic content from the switch must remain below regulatory levels, under all operating conditions. In the past, this function required mechanical or a conservatively designed PIN diode matrix. New SOI based FET switches can now meet this requirement for handheld radio power levels (up to 10W), and with continued advancements, the technology may eventually support 50W vehicle based power levels as well. [1]

Because Land Mobile Radio (LMR) frequency allocations have large gaps between the lower bands, the multi-band architecture shown in Figure 4 is a realistic approach. Figure 5 is the best solution for mobile military applications or other products that require continuous coverage.

PA Refresher

The wideband power amplifiers suggested in Figures 4 and 5 is a significant design challenge for conventional low voltage silicon and LDMOS amplifiers. Consider the operating conditions in a typical radio. Whether handheld or mobile, the amplifier typically draws power directly from the handheld or vehicle battery.

The theoretical natural load impedance for a Class AB power amplifier, ignoring saturation or knee effects, is given by the familiar maximum power load-line equation:

$$P \approx \frac{V^2}{2R_L}$$

A typical handheld radio designed for 5W from a 7.2V battery yields a load resistance of 5.1 ohms. A higher power mobile radio designed for 50W operating from a typical 13.6V supply requires a 1.8 ohm load. Both of these are very low impedances requiring high Q networks to achieve a 50 ohm match.

Generally, the ability to match a transistor over a desired bandwidth is limited by two fundamental quantities.

- The transformation ratio, i.e. the ratio of the load R from 50 ohms
- The device Q, related to the transistor's input and output resistance and capacitance

Higher operating voltage is the only way to reduce the transformation ratio in these examples. As the battery voltages are fixed by practical considerations, in order to increase the operating voltage of the transistor the addition of a high efficiency DC-DC boost converter is required.

The DC-DC boost converter eases the design challenge. Using the same equations, 5W from a 22V supply yields a load R of 48 ohms for the handheld PA, and 50W from a 50V supply yields a load R of 25 ohms for the mobile case (exactly 2:1 from 50 ohms). At these frequencies, ferrite loaded broadband transformers can implement low integer impedance ratios like 2:1 or 4:1. Higher operating voltage and broadband transformers can be used to mitigate the transformation ratio limitation and enable wide operating bandwidth.

GaN: Solving Problems

Despite the above simplification, RF power transistors also have parasitic reactances, such as shunt capacitances like C_{GS} and C_{DS}, which can't be ignored. With these additions, Q becomes a limiting factor as frequencies approach 1 GHz. GaN solves both problems as it offers high power density devices operating to 48V with intrinsic capacitances that are a fraction of comparable power LDMOS devices.

Although the usual high efficiency PA architectures of Class-D, E, F, etc. offer very high efficiency, these techniques are usually narrowband and highly non-linear. A class-AB GaN based amplifier can routinely attain 60% to 70% CW efficiency while retaining some linearity. Public safety networks use a variety of waveforms but most are constant or near constant envelope like FM, MSK, PM, or PSK. Future requirements for LTE or other high peak-to-average ratio (PAR), high linearity wireless waveforms, can be satisfied by pairing a reasonably linear Class-AB amplifier with baseband digital pre-distortion or other linearity correction technique [2].

Collecting these arguments, the ideal wideband LMR amplifier would have the following characteristics:

- High efficiency with correctable linearity
- Constant gain and power across the band
- High voltage operation – 28V to 48V to simplify the wideband match
- Low intrinsic capacitance for low Q at the highest operating frequency
- Rugged and low cost

The Handheld Mobile Radio

- Consider a typical handheld radio PA design requirement:
- Battery packs of 4.5-12V, usually around 2Amp-Hours
- Moderate output power, 1W to 10W at the PA, 1-8W at the antenna
- RF power control for battery conservation, -6 dB to -10 dB reduction typical
- ALC to maintain constant output power
- High PA efficiency to extend operating time, reduce battery size and weight
- 50 ohm load impedance but must tolerate moderate VSWR from broadband antennas
- Small area and volume, low cost

With a boost converter the PA supply voltage becomes somewhat arbitrary, but what is the optimum voltage? As shown earlier, 22V was ideal for a 5W power level, con-

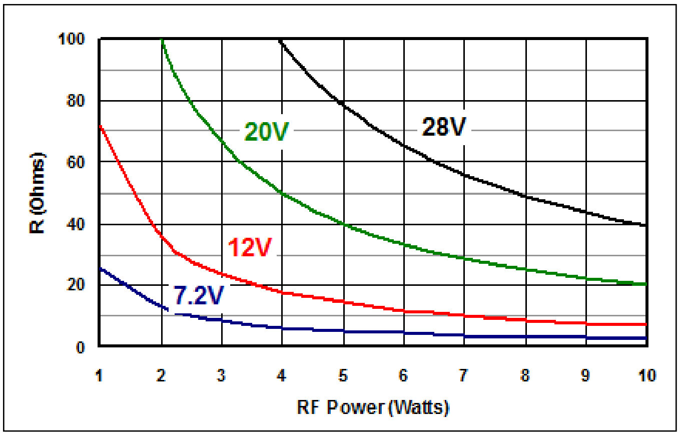

Figure 6 • Plot of output power versus load resistance.

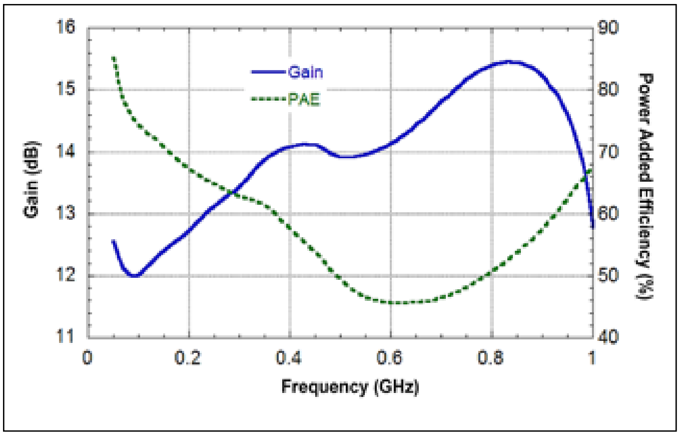

Figure 7 • Broadband performance of the NPA1006 at 41dBm (12.5W) output power with power added efficiency (PAE) ranging from 50 to 85 percent.

firmed by the Figure 6 plot of output power versus load resistance. The 5W and 50 ohm intersection occurs around 22V.

For the highest power handheld radios the 28V curve intersects 50 ohms at 8W. Adding headroom in the boost converter to 32V, a nominal 28V design can deliver up to 10W into 50 ohms. Tracing the 50 ohm termination line, the output ranges from 1W to 10W as the supply voltage varies from 10V to 32V. This approximate 3:1 voltage ratio delivers a 10:1 power ratio as expected.

As a contrast, Figure 6 also shows the load impedance versus output power using a typical 7.2V battery pack. The target impedance is very low, providing the justification for classic handheld power amplifier modules being inherently narrow/single band.

The Handheld Solution – the NPA1006

The NPA1006 is a new integrated GaN power amplifier that offers 10W minimum from a 28V supply continuously from 20MHz to 1GHz. The package is a low profile overmolded plastic 6 x 5 x 1mm surface mount (SMT) package well suited to the space limitations of a handheld product. External support circuitry is minimal requiring only a few passive lumped elements on the output to improve the high frequency performance and proper depletion-mode GaN transistor biasing [3].

The NPA1006 includes an internal input matching network providing a near 50 ohm input impedance. The output of the PA is unmatched, but even so a simple matching network provides a broadband match to 50 ohms. Combining high operating voltage and low intrinsic capacitance, the transistor works well natively from low to mid band for both large and small signal conditions. At high frequencies the simple external match of the applications circuit maintains good power and efficiency through 1GHz. The external output match can also be optimized for narrower band performance if desired (such as VHF/UHF or UHF/800 MHz only).

In theory, these external chip components could be integrated into the NPA1006 but the losses, particularly of the inductor, would be higher and it would also increase the module cost. Figure 7 shows the broadband performance of the NPA1006 at 41dBm (12.5W) output power with power added efficiency (PAE) ranging from 50 to 85 percent.

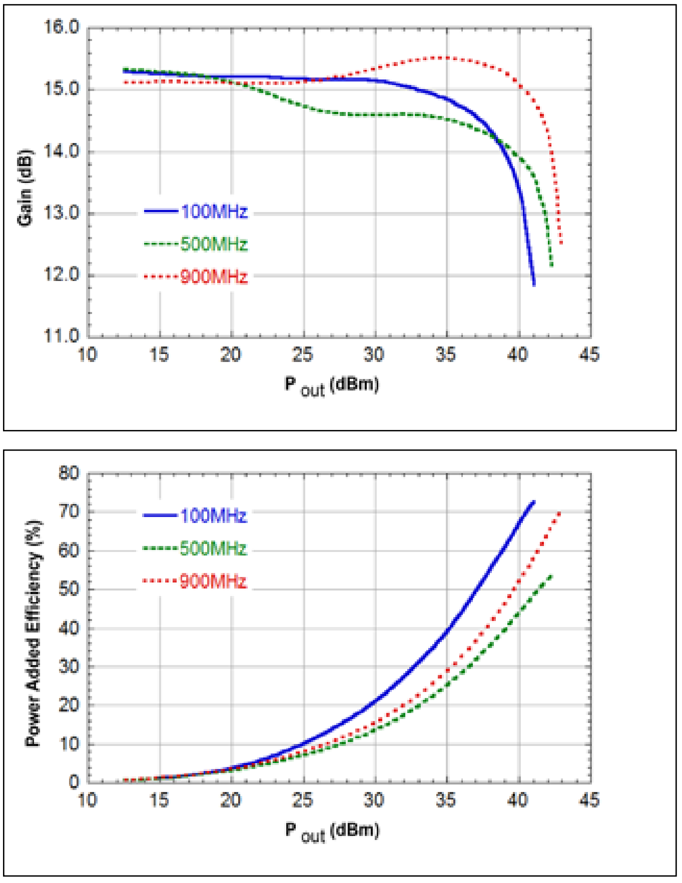

Figure 8 • Gain and PAE versus output power.

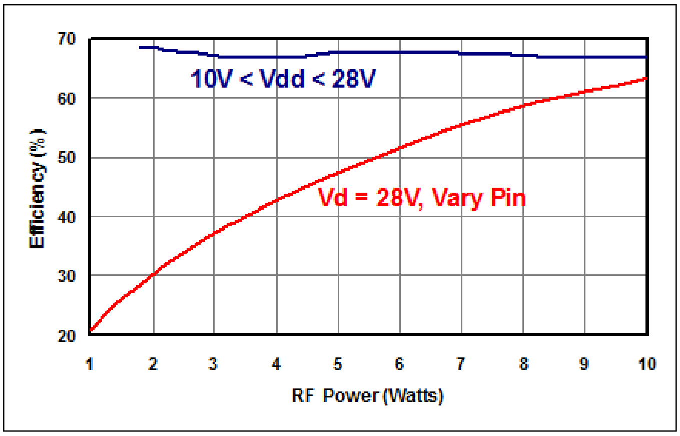

Figure 9 • This figure contrasts these two approaches with the NPA1006 operating at 100 MHz.

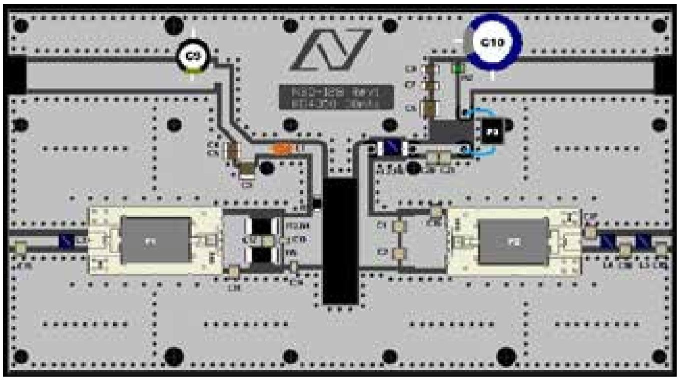

Figure 10. The layout of a broadband LMR mobile PA reference design that operates from 100 MHz through 1 GHz.

Figure 8 shows both gain and PAE versus output power. These plots show that although the NPA1006 can operate at 12.5W output power across the band of interest, the actual saturated power and therefore peak efficiency varies across that band.

Targeting peak efficiency will provide the longest battery life for a portable radio. Unlike the battery only configuration, the battery plus DC-DC converter configuration can throttle the amplifier voltage up or down as needed. For every combination of frequency, desired output power, and load VSWR there is an optimum supply voltage for best efficiency. The efficiency difference between the conventional case, using power control by reducing input drive, and the proposed configuration, which adjusts both the input drive and the supply voltage, can be significant. Figure 9 contrasts these two approaches with the NPA1006 operating at 100 MHz.

By reducing both the drive and the supply voltage the efficiency remains well above 60% from under 2W to more than 10W as seen in the upper curve. Using drive reduction alone the lower red curve reveals that the efficiency falls rapidly at low power levels. A variable supply voltage, intelligently controlled, can reduce or counter the effect of these factors while maintaining maximum performance.

Thermally, the NPA1006 is an optimized device with a low 4.6°C/W thermal resistance (R_{JC}). Proper control of the thermal path from the backside of the device through the underlying PCB via array to the heat sink requires careful design for optimal thermal transfer [4].

The Vehicle Mobile Radio

Vehicle mounted radios face a different set of challenges.

- 13.6VDC nominal vehicle supply, subject to large swings and transients
- Efficiency critical to reduce heat dissipation, not conserve energy
- Higher power levels: >50W output at VHF/UHF, to 35W at 700-900 MHz typical
- Wide operating temperature range, -30C to +50C typical
- Nominal 50 ohm load impedance, but potentially poor antenna VSWR

Unlike the handheld case, higher power levels and reduced size restrictions favor a discrete transistor PA solution. As with the case of the handheld, however, we must also consider the optimum operating voltage. To deliver 50W at the antenna port with the functional diagram of Figure 3, the amplifier must provide an additional 1 - 2 dB to compensate for the switch and filter losses, or nominally about 80W. The ideal voltage for 80W into 50 ohms is 90V, well above the current RF GaN technology limit of 50V. But 80W and a 48V supply yields a load R of 14.4 ohms, nearly a 1:4 from 50 ohms. With broadband ferrite loaded transformers this is a realizable solution.

NPT2022 LMR Mobile Power Amplifier Reference Design

Figure 10 shows the layout of a broadband LMR mobile PA reference design that operates from 100MHz through 1GHz. The design uses the NPT2022, a new 100W, 48V GaN HEMT in the TO272-2 plastic package. This is the largest CW capable plastic packaged GaN device on the market today. The plastic package technology drops the pricing of a 100W GaN on Si device by about half and provides a cost reduction roadmap that can challenge LDMOS pricing in high volumes. Thermally, the JEDEC standard outline, TO272-2, offers better performance than the same die in a conventional, and expensive, air cavity metal flange. Thermal resistance (R_{JC}) is 1.3 C/W.

With a nominal 48V supply, the design delivers more than 80W across the entire band with well-behaved gain and good input and output return loss. A parallel R-C

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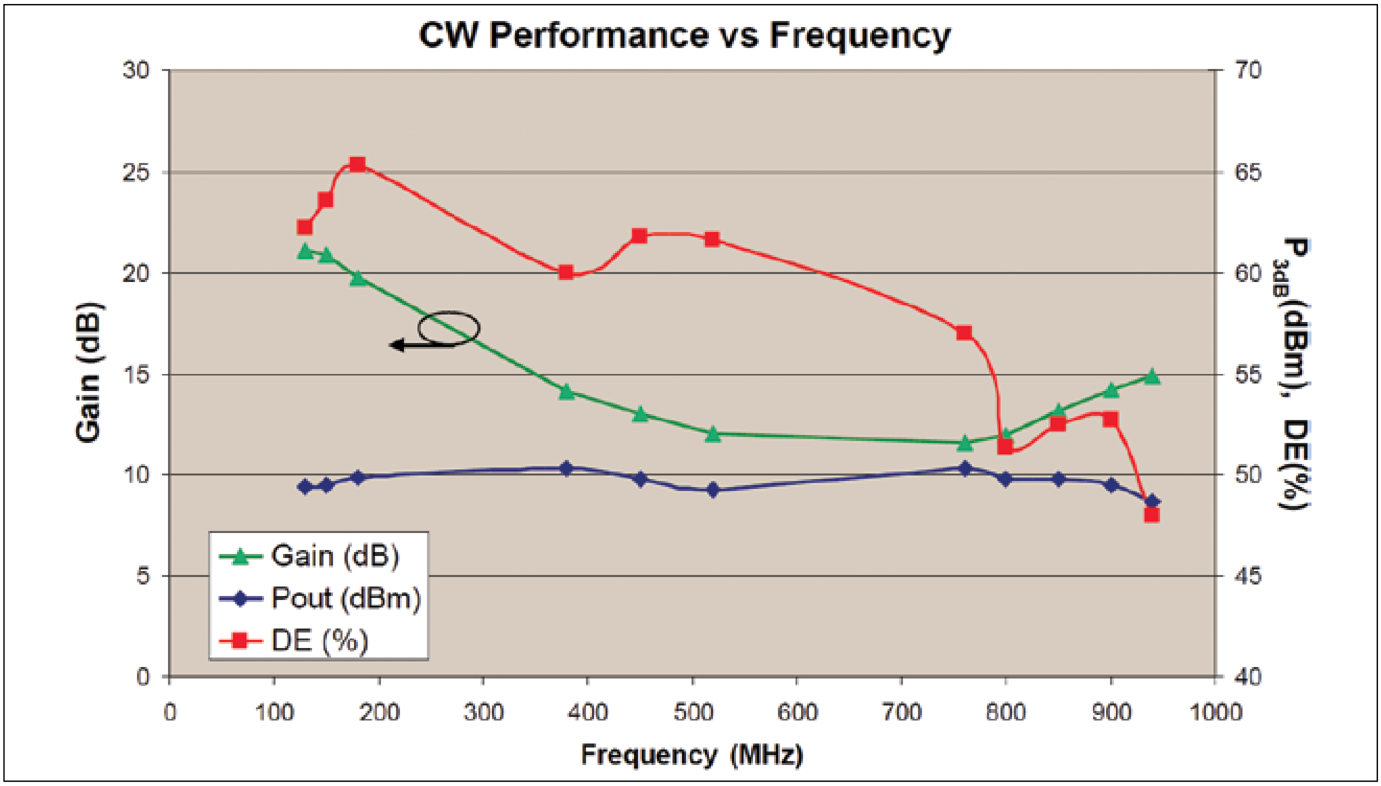

Figure 11. Performance of this design over 100 MHz to just below 1 GHz.

network at the input adds low frequency loss that both reduces gain and improves stability.

The three key components are the two 4:1 ferrite loaded transformers at the input and output and the 100W, 48V plastic GaN HEMT. The board shown uses a custom SMT transformer, but conventional coax plus binocular core construction works equally well.

Figure 11 shows the performance of this design over 100 MHz to just below 1 GHz.

Output power is at or above 80W with a worst-case efficiency just below 50%.

Regulatory limits set lower maximum power levels for the upper UHF bands, requiring power backoff at the higher frequencies. Analogous to the earlier handheld discussion, power control using a combination of reduced drive and supply voltage will maintain high efficiency over the operating envelope. This lightens the thermal load at 800 MHz where the ferrite transformers tend to become lossier. The backoff from a typical 50W to 35W output is 1.5 dB, requiring a DC supply range of 40V to 48V.

Summary

The next generation of LMR radios must support both legacy and LTE modulation and frequency bands. While it is possible to continue to expand capability through stacked system blocks, the more efficient method takes advantage of software defined radio advances combined with broadband GaN based power amplifiers. These new systems provide ultimate flexibility supported by simplistic transceiver architectures. Radios based on these design platforms are both cost effective and configurable for land mobile radio standards deployed worldwide today while being adaptable for the standards of tomorrow.

For more information on these reference designs, please contact Nitronex Applications, applications@nitronex.com.

About the Authors:

Raymond A. Baker, Walter H. Nagy, David W. Runton and Robert A. Sadler are with Nitronex, LLC.

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[1] *"AN18 – RF Switch Performance Advantages of UltraCMOS™ Technology over GaAs Technology,"* www.psemi.com.

[2] Runton D, Zavosh, F, Thron, C, *"Digital Predistortion Linearizes RF PA's"*, Microwaves & RF, August 2000.

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[4] *"GaN Essentials™: AN-012: Thermal Considerations for GaN Technology,"* www.nitronex.com.

Coaxial Transformer Power Amplifier SPICE Simulation

By Andre Adrian

SPICE simulation of a 600W output power, linear mode class B power amplifier.

Introduction

Sometimes, the better is the enemy of the good. This article shows that a coaxial transformer [1] or a coaxial cable transformer [2] can be better than a transformer or an autotransformer within a radio frequency power amplifier. Presented is the SPICE simulation of a 600W output power, linear mode class B power amplifier for the frequency range 1.8 MHz to 50 MHz (wave length 160m to 6m).

A coaxial transformer is a transmission line transformer (TLT) that uses a ferrite core to improve the lower cut-off frequency of the TLT [3]. The amp works with lossy matching (dissipative equalizer). Ballast resistors are used to dissipate reflected energy within the amplifier. A transmission line and an inductance together simulate a coaxial transformer. SPICE tables are used to model the complex permeability of the ferrite core [4]. The loaded TLT works as common mode suppression (CMS) choke and as a building block for power splitter and 180° hybrid. The push-pull amplifier circuit uses an ordinary 50V, 150W RF MOSFET like MRF151 or SD2931-10. Two amp modules are combined, because one pair of MRF151 can only deliver 300W output power. The bias voltage supply uses a complementary emitter follower to create a low impedance bias voltage. To reduce electromagnetic interference (EMI), a 5th order Butterworth low-pass filter is placed between amp and antenna. The component values for this filter are calculated within SPICE.

Amplifier Overview

Figure 1 presents the amplifier. The PA uses a supply voltage Vdd of 50V direct current for the RF MOSFETs. The voltage regulator VR1 generates the bias voltage from a 13.8V supply voltage Vbb. The power splitter PS1 separates the RF input signal Vin into two signals with 0° phase difference. R1 to R4 “repair” the impedance mismatch of PS1, for details see below. The two power amplifier modules PA1 and PA2 provide the action. PS2 combines the two output signals. The low-pass filter LP1 “cleans” the output signal from harmonics.

Bias Voltage Supply

Figure 2 shows the complementary emitter follower voltage regulator. The resistor R1 and the zener diode D1 together deliver a stable voltage of 8.2 volts. R2 and R4 work as voltage divider with high impedance. The components D2, R3, D3 keep the voltage between base of Q1 and base of Q2 at a constant value. The transistors operate in class AB with a little quiescent current of 40mA. The output voltage Vout can be set between 1 and 7 volt. This circuit fulfills the task of current source and current sink. The feedback loop of the voltage regulator lies within the transistors, between base and emitter. See reference [5] for the important topic of MOSFET thermal runaway and for a simpler bias voltage supply circuit.

Balun

The common mode suppression (CMS) choke or the balun was patented in 1932 by Felix Gerth. He explained the construction and function as: “In line E is inserted a coil arrangement L that consists of two interwound coils, which are wound in the same direction and are closely

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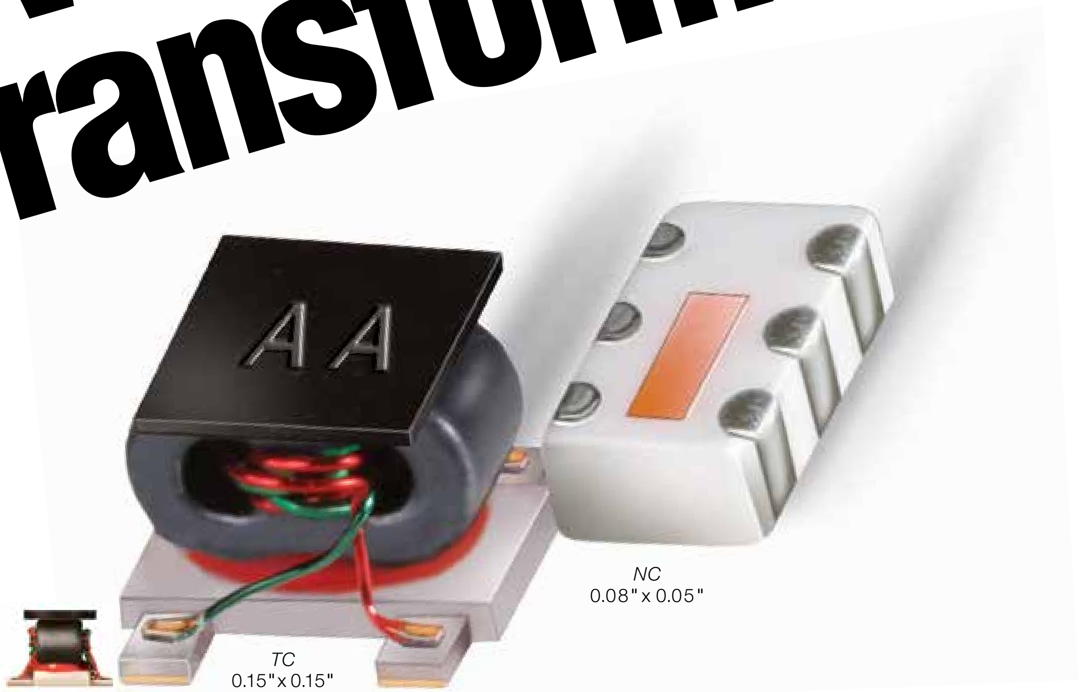
Wideband Transformers



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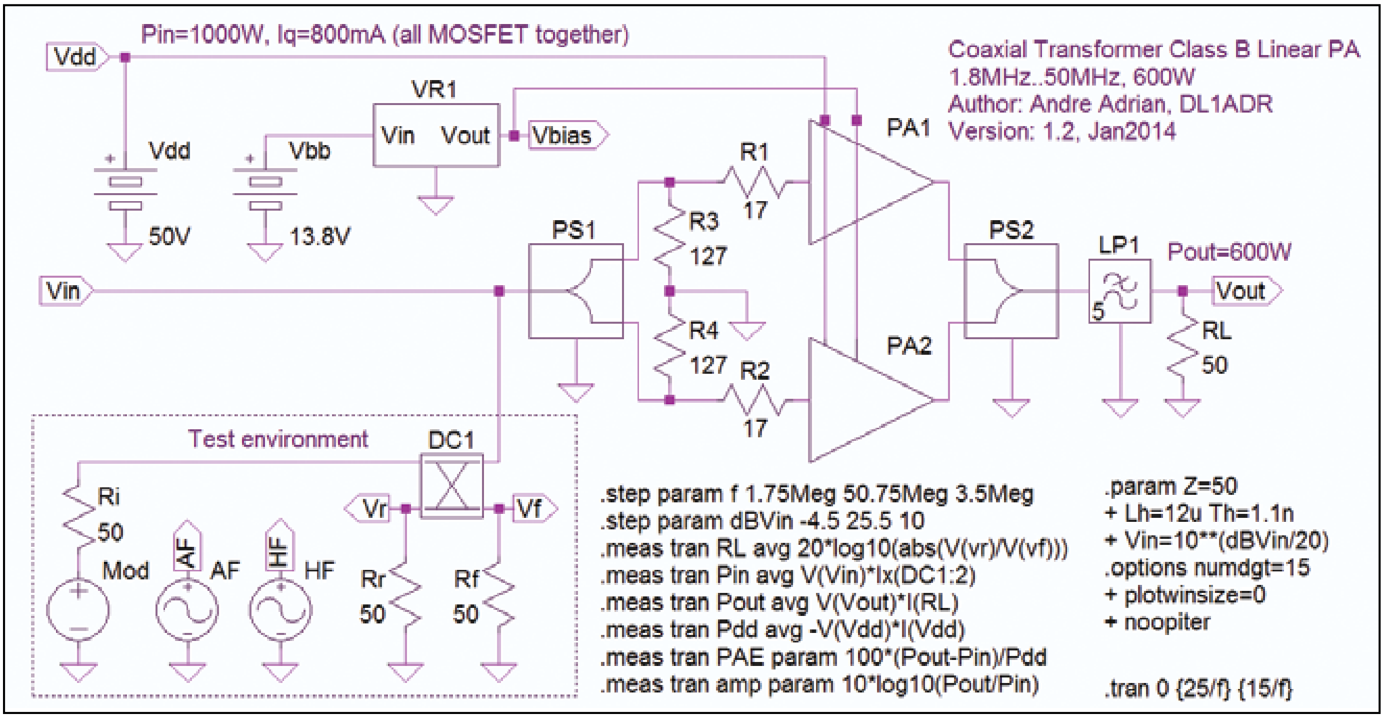

Figure 1 • Coaxial transformer power amplifier overview.

coupled together. One of these coils is inserted in each of the two conductors of the line E. The inductances of these coils neutralize one another for the counter-phasal currents coming from the transmitter so that in this desired direction the power can flow unhindered. With the co-phasal currents induced by the radiation of the antenna A, however, the inductances are added, so that the currents find a resistance which does not permit them to flow" [8]. The choice of words today is differential, odd or

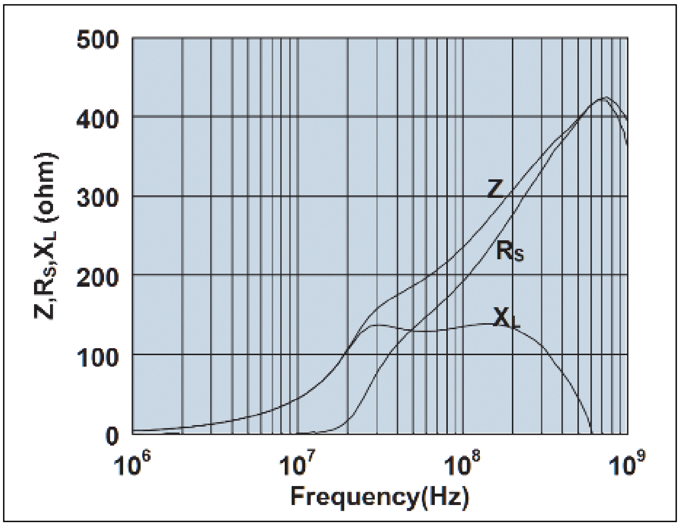

Chart 1 • Round cable core 2661540002 characteristics (Copyright Fair-Rite).

normal mode for counter-phasal and common or even mode for co-phasal.

The differential mode suppression (DMS) choke uses the same components as a CMS choke. Just the wiring is different. In figure 5, BA1 and BA7 are baluns and BA4 is a DMS choke.

The inductance controls the low frequency behavior of the balun and the length of the coaxial cable controls the high frequency performance. The delay-time of the 50Ω baluns is 1.1ns and the inductance is 12µH. The length of the coaxial cable is calculated from the velocity of propagation and the delay-time. A cable with solid polyethylene dielectric has a wave propagation speed of 66% of the speed of light. The cable length is 22cm or 8.6in. The 25Ω baluns have half the inductance, half the delay-time and half the cable length. All baluns in this circuit use ferrite material 61.

Coaxial Transformer SPICE Model

The coaxial transformer is a special version of the balun. A low frequency model is given in [3]. Figure 3 shows the SPICE model of the author. A lossless transmission line (TLINE) replaces the ideal 1: 1 transformer that is used in [3]. The inductance of the ferrite core only influences the outer conductor of the coaxial cable. A series resistor simulates the resistive losses of the magnetic material.

The ferrite material that is used for the coaxial transformer has frequency dependent properties. Chart 1 shows for the Fair-Rite round cable core 2661540002 the

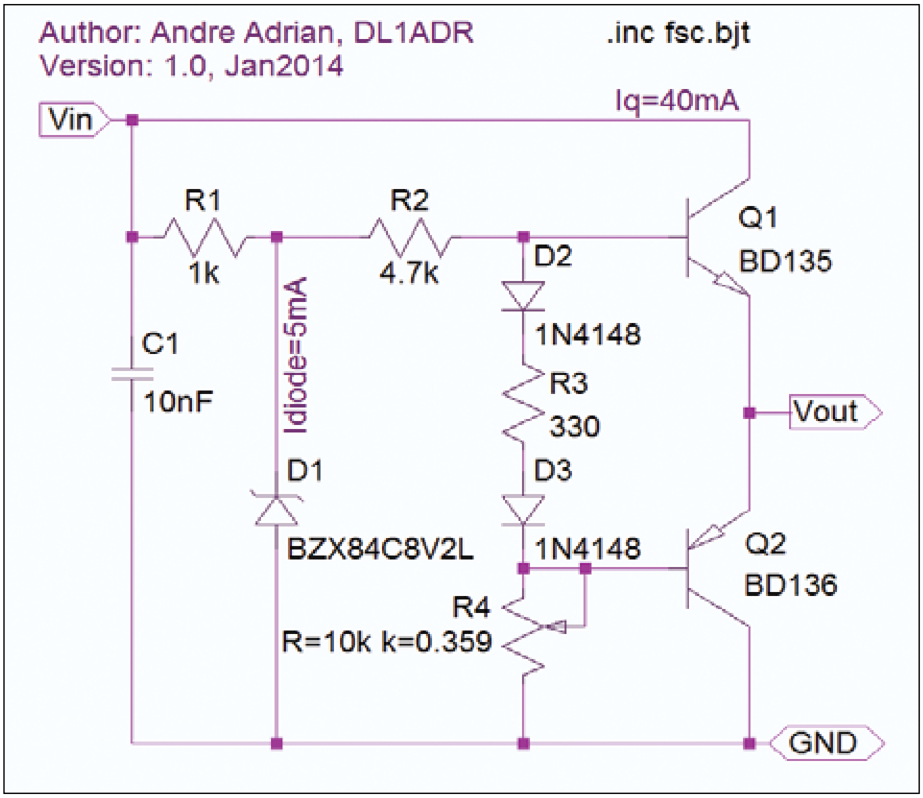

Figure 2 • Bias voltage supply.

frequency dependent behavior of reactance, resistance and impedance. Up to a frequency of 25MHz the cause for the impedance Z lies in the reactance X_L. At 50MHz, reactance and series resistance R_S have the same influence on the impedance. Above 600MHz the impedance cause is solely the resistance of the ferrite material. In an ideal inductance, the voltage follows the current with 90° phase difference. The ferrite material 61 behaves this way at frequencies below 25MHz. At 50MHz is the phase difference between the voltage and the current 45°. The equivalent circuit is then a series RL network.

The ferrite suppliers present this information normally as complex permeability μ_s, see chart 2. The real part μ_s' or μ_{s1} describes the frequency dependent reactance, the imagery part μ_s" or μ_{s2} describes the frequency dependent resistance (ferrite core losses). The reactance and the resistance are calculated with the formulas that are presented in [4]. L_0 is the "air core" inductance, the inductance without any ferrite core.

$$\omega = 2 \cdot \pi \cdot f \qquad X_L = \omega \cdot \mu_{s1} \cdot L_0 \qquad R_s = \omega \cdot \mu_{s2} \cdot L_0$$

The author uses within SPICE the following definition of the inductance: "The inductance L is defined for the initial permeability μ_i". The air core inductance and the frequency dependent inductance and resistance are computed as:

$$L_0 = \frac{L}{\mu_i} \qquad L(\omega) = \mu_{s1} \cdot L_0 \qquad R_s(\omega) = \omega \cdot \mu_{s2} \cdot L_0$$

The quality factor Q and the impedance Z of the inductance is computed with X_L and R_s or the complex permeability:

$$Q = \frac{X_L}{R_s} \qquad Z = \sqrt{X_L^2 + R_s^2} \qquad Z = \omega \cdot L_0 \cdot \sqrt{\mu_{s1}^2 + \mu_{s2}^2}$$

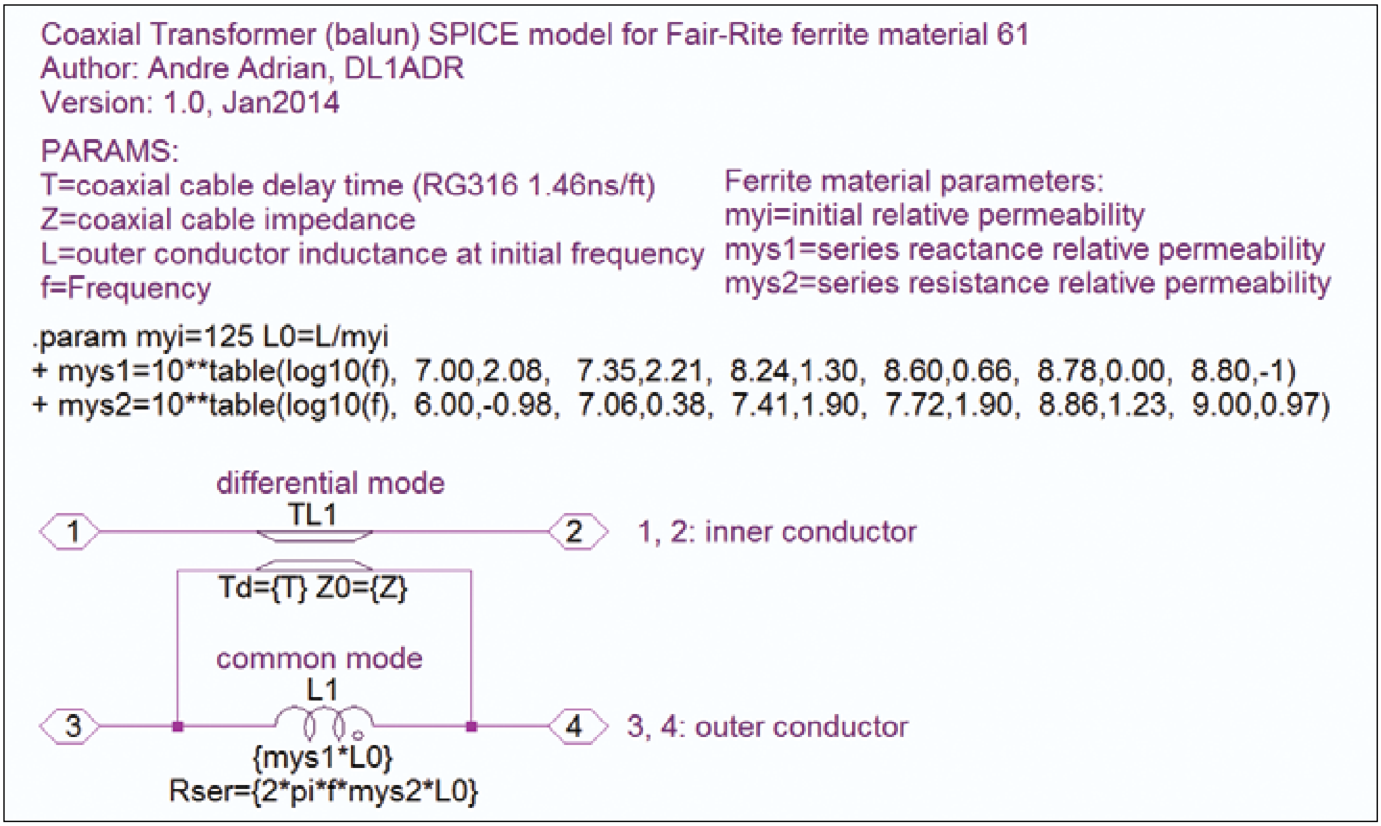

Figure 3. Coaxial transformer SPICE model.

Hybrid

"The hybrid transformer represents a four-port device having two input ports, one sum port and one difference port. The unique characteristic of the hybrid transformer is its ability, to isolate the two input signal sources" [2]. The hybrid is an evolution of the Guanella 1: 4 balun. The low impedance connection of the 1: 4 balun is called sum-

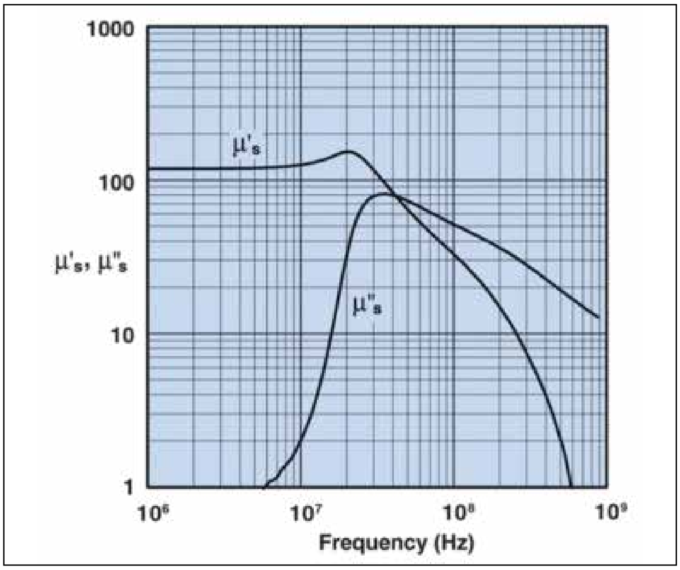

Chart 2 • Ferrite material 61 characteristics (Copyright Fair-Rite).

mary port; the two high impedance connections are called input ports. The 1: 4 balun does have a difference port, but nothing connects here. Clyde Ruthroff informs about an important fact: "In all hybrids in which all four arms are single-ended, it has been found necessary to use two cores in order to get proper magnetizing currents" [9].

The hybrid ports have different impedances. If the coaxial cable has an impedance of Z, the sum port will show an impedance of 2*Z. The difference port has an impedance of Z/2 to ground. The impedance between both input ports is Z/2. The impedance amounts to Z/4 between one input port and the ground. The hybrid uses 25Ω coaxial cable. The sum port impedance is 50Ω, difference port to ground is 12.5Ω and input port to ground is 6.25Ω.

Power Splitter

Figure 4 shows that a power splitter is the combination of a Magic-T hybrid and of a 1: 2.25 line transformer. The Magic-T is the DMS choke BA1 with the additional ballast resistor R1. The transformer circuit bases on "Fig. 34" in a patent from Guanella [10]. The two baluns BA2 and BA3 are wired according to the bootstrap method. The two windings of the BA2 are in series connection, as are the two windings of the BA3. The top coil of the BA3 is parallel to the lower coil of the BA2. The top coil belongs solely to the BA2; the middle coil belongs to the BA2 and the BA3 and the lower coil belongs only to the

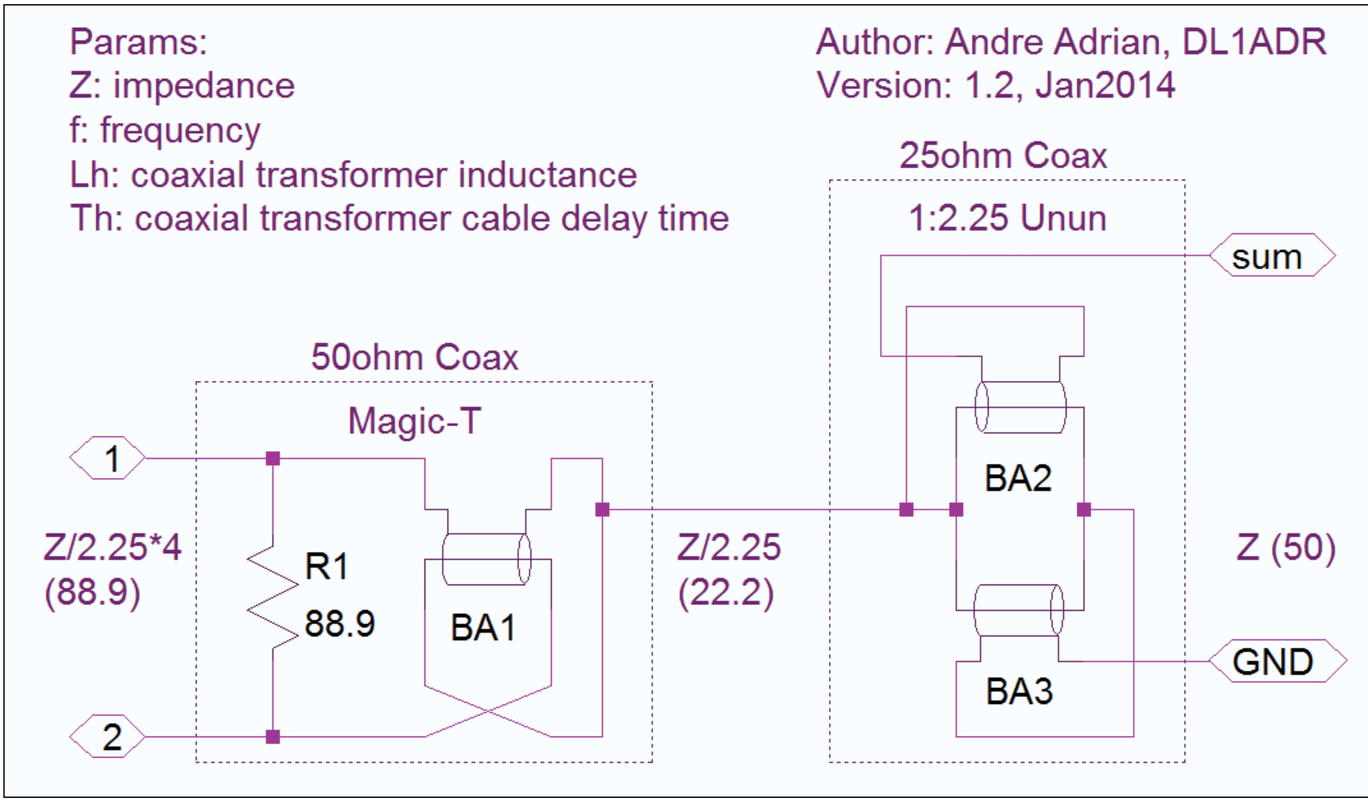

Figure 4 • Coaxial transformer power splitter.

BA3. The low frequency model of this network is an autotransformer with three windings. An autotransformer voltage ratio of 2: 3 gives an impedance ratio of 4: 9. The reciprocal value is 2.25.

The 2.25 ratio power splitter transforms the impedance of 50Ω into two times 44.4Ω. R1, R3 in figure 1 are an L-pad with 44Ω input impedance and 50Ω output impedance for the first amplifier module; as are R2, R4 for the second. They provide a lossy impedance match, because they transform RF energy into thermal energy (heat). BA1 is a 50Ω balun and BA2 and BA3 are 25Ω baluns. For details see the Balun section.

Push-Pull Circuit

Figure 5 displays the push-pull circuit. Here occurs the direct current (DC) to radio frequency (RF) translation. Hybrid BA1 is a common mode rejection choke. The 180° hybrid consists of BA2, BA3 and the ballast resistor R1. The hybrid sum port connects to BA1. The ballast resistor terminates the difference port. If the RF signals at both MOSFET gates are equal in magnitude but opposite in phase, there is no RF-energy at the difference port. The ballast resistor consumes RF-energy that was reflected. The reactance of a MOSFET gate is individual. These different input reactances are the cause of RF energy at the ballast resistor. C1, C2 connect the hybrid 0° and 180° ports with the MOSFET gates.

R4, L1 supplies the bias voltage for MOSFET X1 and R5, L2 supplies it for MOSFET X2. The hybrid input ports are terminated by the RL series networks, too. R4, R5 are the last part of input lossy matching. The gate voltage controls the MOSFET behavior. The RF currents that flow into and out from the MOSFET gate are reactive currents or wattless currents. For a MOSFET gate there is no impedance match. Every impedance match transfers electrical power from low voltage and high current into high voltage and low current.

A reactance input match is possible. L1 compensates the reactance of the gate-source capacitance Cgs within the MOSFET. Both form a LC-circuit with a resonance frequency above the upper cut-off frequency.

The capacitors C3, C4 establish a common RF level for the bias voltage connector, the drain voltage connector and the ground connector. The figure shows that the ground connections of the push-pull circuit come together in one point. There is also a common drain voltage point and a common bias voltage point. The amplifier components placement should be symmetrical; as pictured in the schematics. These guidelines help to build a stable amplifier.

The push-pull circuit uses bridge neutralization as described in [5]. No capacitive coupling should occur between the MOSFET gate and drain. The differential mode suppression (DMS) choke BA4 connects the

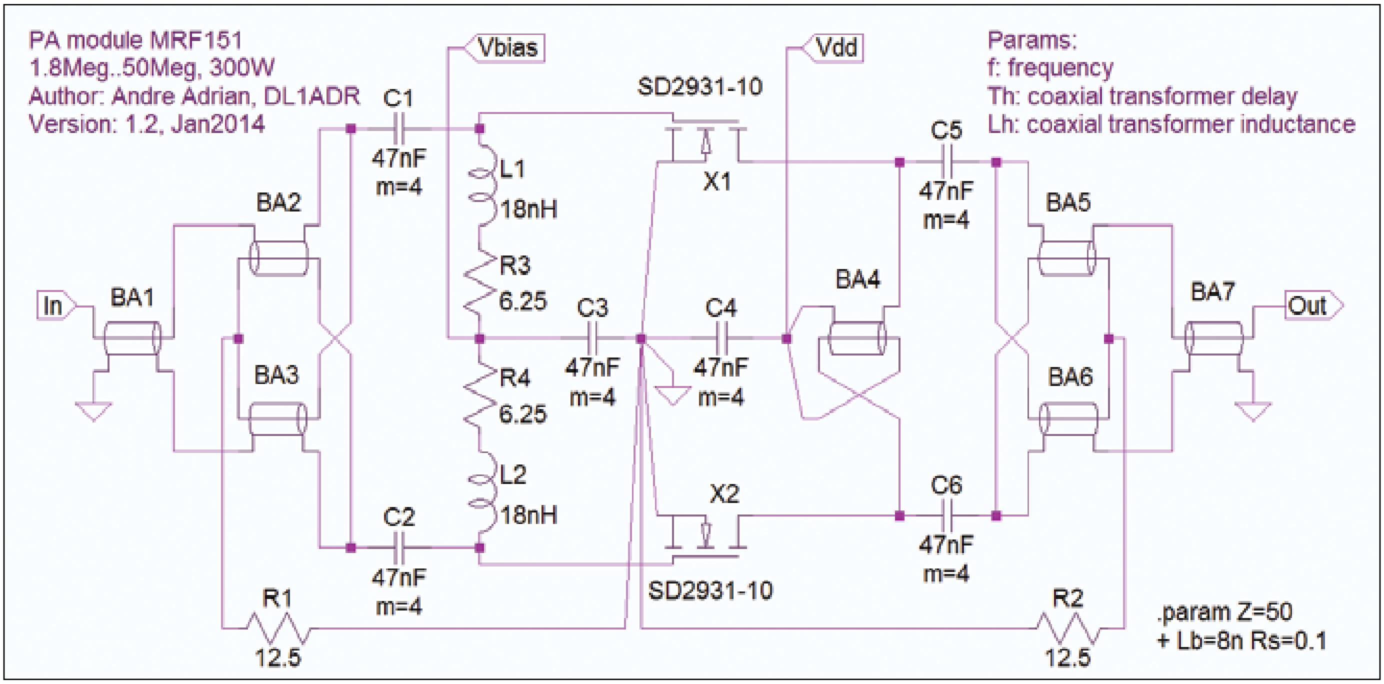

Figure 5 • Coaxial transformer push-pull circuit.

MOSFET drain to the supply voltage. The output section C5, C6, BA5, BA6, R2 and BA7 is similar to the input section. The component values are the same, but the components have a higher power rating. The ballast resistor R2 "destroys" the RF energy that is reflected from the low-pass output filter. The even harmonics of a push-pull amplifier are weak, but the odd harmonics are strong. Look at [6] for a 600W amplifier solution without power splitter. Reference [7] discusses the individual behavior of RF MOSFET in a push-pull circuit.

BA1 and BA7 use 50Ω coaxial cable and BA2 to BA6 use 25Ω coaxial cable. For details see the Balun section. The capacitor C1 is in reality four capacitors in parallel. This is true for C2 to C6, too. The capacitor body creates an inductance. Putting these parasitic inductances in parallel reduces the sum inductance. Every capacitor is, at high frequency, a series LC-circuit and every inductor is a parallel LC-circuit. The RF currents that flow into and out the capacitor connectors are distributed between the parallel capacitors. This current sharing is important for capacitors C4, C5 and C6.

The Low-Pass Filter

The amplifier uses a Butterworth type, 5th order, low-pass filter, see figure 6. Every 5th order filter has a stop-band decline of 30dB per octave. The pass-band return loss can be tuned to a mediocre value for a large frequency range or an excellent value for a small frequency range. This filter is optimized for the small frequency ranges of the ham bands. The formulas to calculate the components values are very simple. The parameter f in the formula is not the upper cut-off frequency; but the upper pass-band frequency for best return loss. The impedance match is perfect at this frequency. The filter inductances produce losses. The SPICE simulation runs with a Q value of 100 for the inductances. The assumed parasitic parallel capacitance of the coils of 2pF improves in fact the stop-band attenuation.

The filter needs two inductances and three capacitors. The spreadsheet table 1 gives the values for some radio amateur bands.

The low-pass formulas start with the well-known reactance formulas of capacity and inductance.

band	f (kHz)	C1 (pF)	L1 (nH)	C2 (pF)	L2 (nH)	C3 (pF)
160m	1800	1769	4423	3539	4423	1769
80m	3700	861	2152	1721	2152	861
40m	7100	449	1121	897	1121	449
20m	14200	224	561	449	561	224
10m	29000	110	275	220	275	110
6m	50000	64	159	127	159	64

Table 1. 5th order Butterworth low-pass filter components values.

$$X_c = \frac{1}{\omega \cdot C} \qquad X_L = \omega \cdot L$$

The line impedance Z is used as reactance at frequency ω, the circular frequency of perfect impedance match. C and L can be calculated now.

$$X_c = Z \qquad X_L = Z \qquad C = \frac{1}{Z \cdot \omega} \qquad L = \frac{Z}{\omega}$$

The following relation is there between the quality factor Q and the series resistance R_s of the inductance.

$$Q = \frac{X_L}{R_S} \qquad Q = \frac{\omega \cdot L}{R_S} \qquad R_S = \frac{\omega \cdot L}{Q}$$

The Q value of 100 gives an attenuation of 0.3dB at the frequency ω. "One decibel is none decibel", as the knights of the RF table like to say.

Test Environment

The test environment is needed to create the power amplifier characteristics charts and to improve the SPICE simulation speed. The three components Mod, AF and HF give the input voltage a specific envelope curve. At simulation start, the input voltage is very small. It grows exponentially up to the intended value. This start-up behavior helps SPICE to settle quickly to a steady state output voltage.

DC1 is a Sontheimer-Frederick directional coupler [11]. It determines the return loss together with the resistors Rr and Rf. See figure 7 for the wiring. The inductance

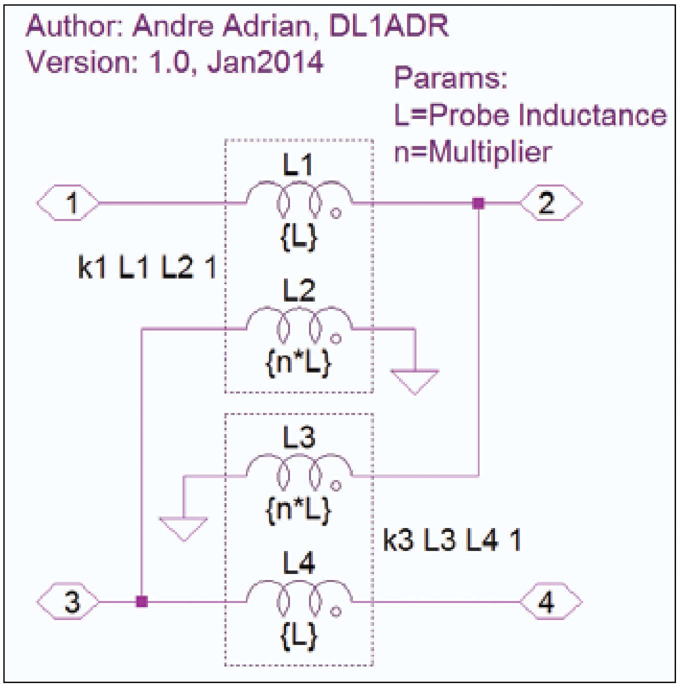

Figure 7 • Sontheimer-Frederick directional coupler.

L1 and L4 are typically a piece of coax cable without jacket and without outer conductor. The inductance L2 and L3 is a winding on a ferrite toroid. A ferrite material 61 toroid FT50-61 fits nicely on a coaxial cable of 5mm diameter.

MOSFET Model

The SPICE simulation results are only as valid as is the MOSFET model. The author uses a model of his own

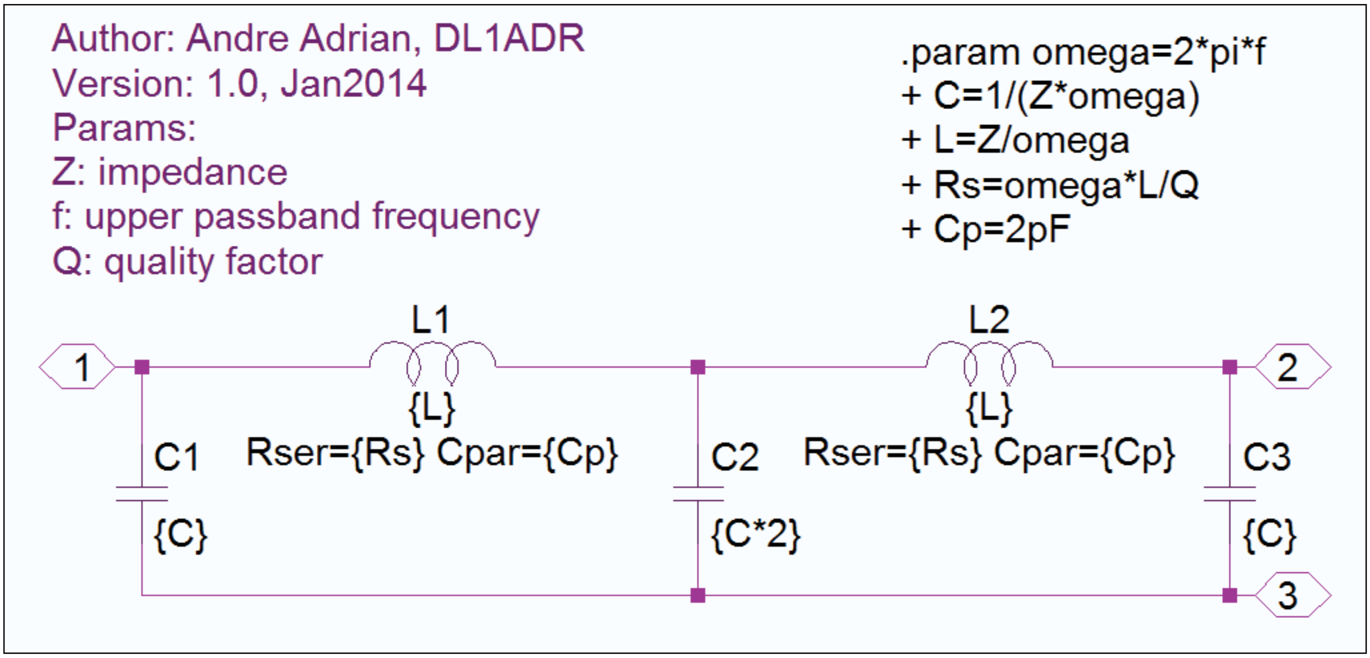

Figure 6 • 5th order, Butterworth, low-pass filter.

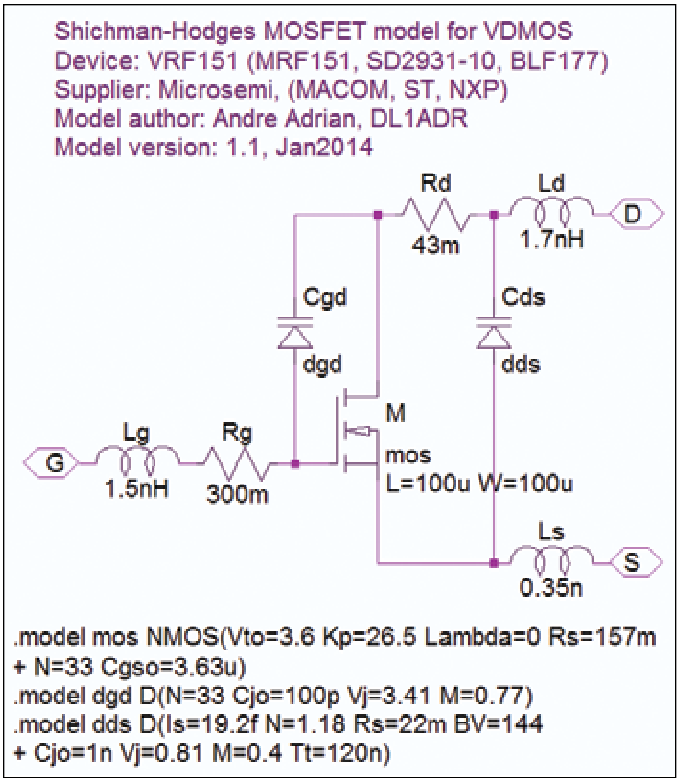

Figure 8 • Vertical RF MOSFET model.

fabrication. SPICE diode circuit elements simulate the voltage dependent capacitances Cgd and Cds. Capacitance Cgs and resistance Rs are part of the NMOS circuit element.

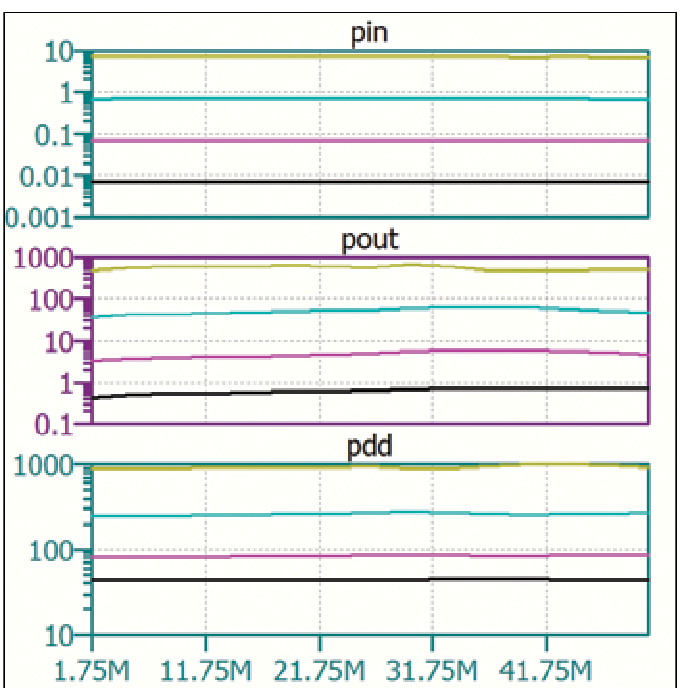

Chart 3 • Amplifier input power (pin), output power (pout), and supply power (pdd).

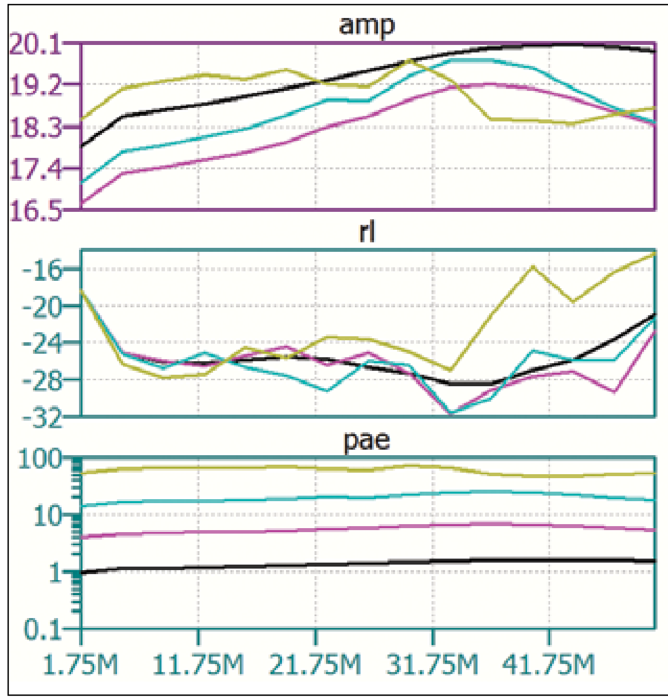

Chart 4 • Amplification (amp) in dB, return loss (rl) in dB and power added efficiency (pae) in %.

Power Amplifier Characteristics

First of all, this power amplifier still needs to be built. The given characteristics are SPICE simulation results. The author assumes that the real thing will behave like the simulation. There is a lot of experience with coaxial transformers since the days of Gerth, Guanella and Ruthroff that support the SPICE results. Chart 3 shows the input power, output power, supply power characteristics for different frequencies and different input levels. The powerful .STEP command of LTSpice makes this chart easily possible.

Chart 4 shows amplification, return loss and power added efficiency (PAE) for the same frequencies and input levels. All in all, the amplifier performance is above average. A peak PAE of 72% is mediocre, compared to the values of class E or F amplifier. But these amplifiers are single frequency amplifiers. It makes no sense to compare apples and oranges.

Chart 5 shows the intermodulation behavior. The two input signals are 14MHz and 14.1Mhz sine waves. The

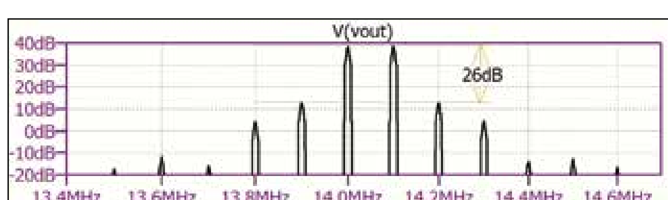

Chart 5 • Intermodulation test results.

LTSpice FFT function shows a 26dB difference between amplified input signals and intermodulation products at full output power.

Conclusions

An amplifier without "real" transformers needs more ferrite cores. But these ferrite cores are smaller. The formulas for ferromagnetic cross sectional area do not apply for baluns. Within a balun, there is no conversion from RF current to a magnetic flux and back to another RF current. The RF current travels as transversal electromagnetic (TEM) waves thru the balun. The input section of the amplifier converts the impedance from 50Ω down to 12.5Ω. This is no input impedance match. It just reduces the influence of the gate source capacitance Cgs of the MOSFET on the frequency response. This amplifier has the strength to become a classic circuit. You design it in SPICE, you build it, and it works.

About the Author

The author started his carrier as an apprentice at Siemens AG. Later he studied computer science. He is also a radio amateur, call sign DL1ADR. Since 1991 he has worked for the German Air Traffic control agency DFS. His e-mail address is andre dot adrian at gmx dot net.

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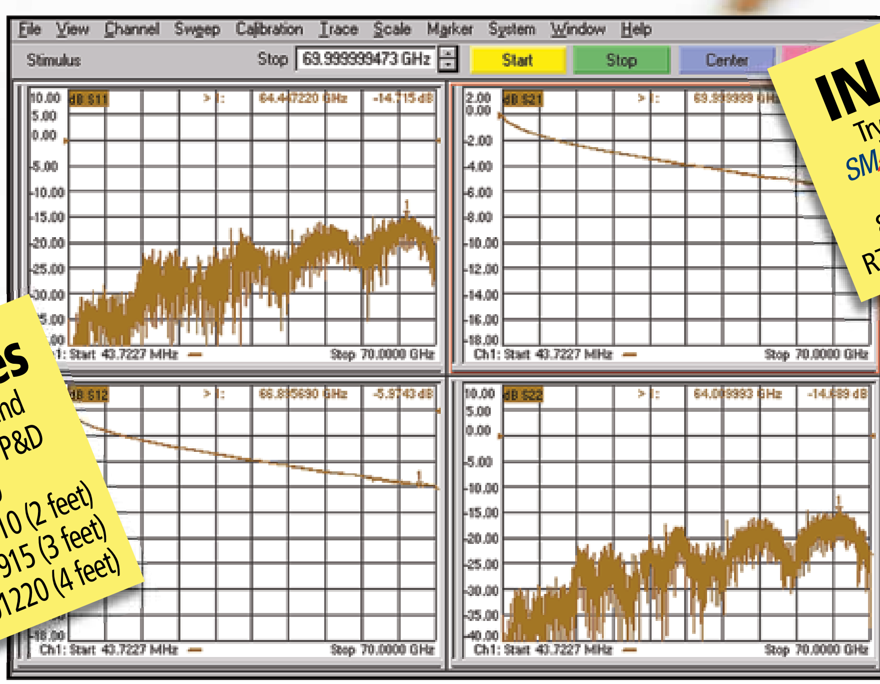

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Adapters

RF Industries provides between series adapters for the 4.1-9.5 (Mini) DIN, 7-16 DIN and N type interfaces. All adapters are manufactured with brass bodies in durable non-tarnish tri-metal (white bronze) plating with a PIM rating of less than or equal to -155 dBc. All low PIM products from RF Industries are 100% PIM tested to assure performance.

RF Industries
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Gauss Meter

Anaheim Scientific released the first product in the new E-Series of Electromagnetic Meters, the E100

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Anaheim Scientific
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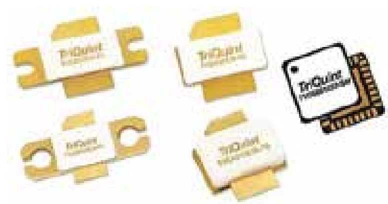
Model AHP1950-21-4036 is a power amplifier offering 40 dB of linear gain and 36 dBm typical output power at 1 dB gain compression point over the frequency range from 17.5 to 21.5 GHz with excellent gain flatness and VSWR. The amplifier has built-in DC voltage regulator and requires a single DC power supply +9~12.0V. The package size of the amplifier is 2.6 × 2.0 × 0.50”.

Wenteq Microwave
wenteq.com



Transistors

Richardson RFPD announced that it is accepting orders for five new discrete GaN transistors from TriQuint. The new discrete gallium nitride (GaN) on silicon carbide (SiC) high-electron-mobility transistors (HEMTs) offer a range of pulsed output power covering 10W to 285W, with operating ranges from DC to 6 GHz.

RichardsonRFPD
richardsonrfpd.com

Capacitor

AVX Corp. announced its new FLC Series medium power AC filtering film capacitors. Exhibiting extremely high dielectric strength in operating temperatures spanning -40°C to +85°C, FLC Series capacitors are comprised of dry, metallized polypropylene encased in a plastic case filled with flame-retardant thermosetting resin, all in accordance with UL 94.

AVX Corp.
avx.com

Driver Amp

Custom MMIC announced a new driver amplifier, the CMD192C5. It is the packaged version of the highly popular CMD192 amplifier that until now had only been available in die form. The CMD192C5 is a wideband GaAs MMIC distributed amplifier that operates from DC to 20 GHz and has a positive gain slope versus frequency.

Custom MMIC
custommmic.com

Adapters

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Meller Optics
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Cables

Mini-Circuits' 50Ω, DC to 12.5 GHz model 141-SMNB-series Hand-Flex coaxial cables are ideal for integrating rack-mounted coaxial components and subassemblies in tight spaces and dense system configurations. N-Type female bulkhead connector at one end is equipped with a nickel-plated brass flange for secure connections to rack mounted equipment.

Mini-Circuits
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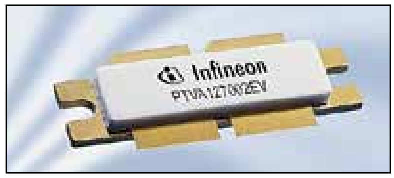
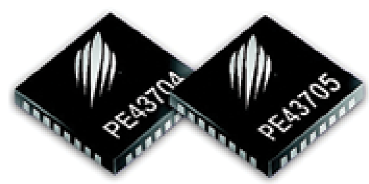


Transistor

Infineon Technologies AG introduced its 700W L-Band RF power transistor featuring the highest-in-industry L-Band output power (700W) available for radar systems operating in the 1200 – 1400 MHz frequency range. By lowering part counts, the new device can reduce system cost and improve reliability while maintaining high ruggedness.

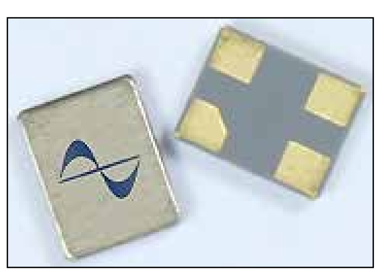
Infineon Technologies AG
infineon.com



Attenuator

Richardson RFPD, Inc. announced design support capabilities for a new high frequency, high power, 7-bit digital step attenuator (DSA) from Peregrine Semiconductor. The PE43705 is the latest addition to this family of DSAs. An integrated digital control interface supports both serial and parallel programming of the attenuation, including the capability to program an initial attenuation state at power-up.

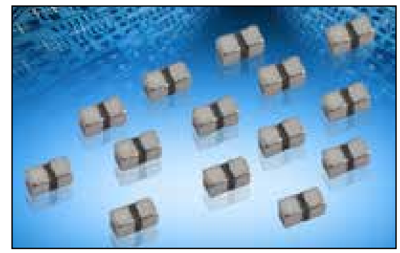
Richardson RFPD
richardsonrfpd.com



TCXO

Precision Devices expanded its TCXO line with new products that target applications where available circuit board space is at a premium or products that require excellent long term precision. These new miniaturized products are ideally suited for all types of applications where small size (down to 2.5 x 2.0 mm) and/or accuracy (to +/-.5ppm or better) is required.

Precision Devices
pdixtal.com



Capacitors

AVX Corp. introduced broadband capacitors designed to address DC blocking from ~16KHz to 40GHz. Exhibiting low insertion loss and excellent return loss, the new capacitors are packaged in a compact 0301 case and are ideal for semiconductor data communications, transmit and receive optical subassemblies, transimpedance amplifiers, and test equipment.

AVX Corp.
avx.com

Attenuator

Mini-Circuits' BW-K20-2W44+ 50Ω, 2W, 20 dB precision fixed attenuator features: DC to 40 GHz; precise attenuation; excellent VSWR, 1.20 typ.; passivated stainless steel connectors. Applications: matching; instrumentation; test set-ups.

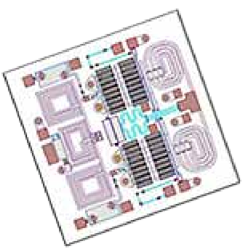
Mini-Circuits
minicircuits.com

Transceiver Module

Model SSC-7737731200-1212-C1 is a compact and cost-effective E band transceiver module operating in the frequency range of 76 to 78 GHz.

The module is designed and fabricated for emerging automotive ACC radar applications. It can be used as FMCW transceiver for speed and distance measurements or Radar target simulators for testing.

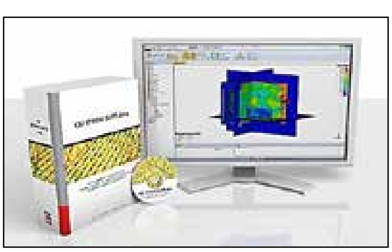
SAGE Millimeter
sagemillimeter.com



Amplifier

Triquint's TGA2216 is a wideband cascode amplifier fabricated on TriQuint's production 0.25um GaN on SiC process. The cascode configuration offers exceptional wideband performance as well as supporting 48V operation. It operates from 0.1 - 3.0 GHz and provides 12W of saturated output power with 14 dB of large signal gain and greater than 40% power-added efficiency.

TriQuint Semiconductor
triquint.com



EM Simulation Software

CST announced the 2014 version of the electromagnetic simulation tool, CST STUDIO SUITE®. The latest edition has been developed to improve the performance of the solvers and increase the capabilities for hybrid simulation without compromising on usability. CST STUDIO SUITE comprises a range of electromagnetic simulation tools for high frequency, low frequency, charged particle and multiphysics applications.

CST
cst.com

Power Amp

Richardson RFPD announced a 2500–6000 MHz, 100W solid state high power amplifier from Empower RF Systems. The 1191/BBM-5K8CKT is guaranteed to deliver 100W minimum output power and related RF performance under all specified temperature and environmental conditions. Typical power output is 125W.

Richardson RFPD
richardsonrfpd.com

Diode

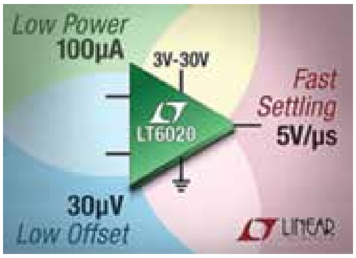
RFMW announced design and sales support for Skyworks SMV2026 series of hyperabrupt tuning varactor diodes. The SMV2026-079LF is offered in the SC-79 package while a smaller, SOD-882 package if available for space constrained layouts. Low series resistance of 0.5 ohm at 5V typifies this Skyworks varactor series and enables low phase noise in wideband VCO designs.

RFMW
rfmw.com

Digitizer

Agilent Technologies introduced next-generation real-time peak detection as one of the additional functionalities for its PCIe high-speed digitizers, starting with the U5303A 12 bit digitizer. These functionalities address application needs such as high-speed medical imaging, LIDAR laser ranging, environmental monitoring, analytical, and non-destructive testing.

Agilent Technologies
agilent.com



Op Amp

The LT6020 is a dual 3V to 30V fast settling operational amplifier, featuring 30µV maximum input offset voltage and 0.5µV/°C max VOS drift. While supply current is only 100µA maximum per amplifier, proprietary slew enhancement circuitry provides fast clean output step response. The LT6020 settles to 0.0015% in less than 15µs regardless of whether the output step is 5V or 25V.

Linear Technology
linear.com

Product Showcase

Oscilloscope

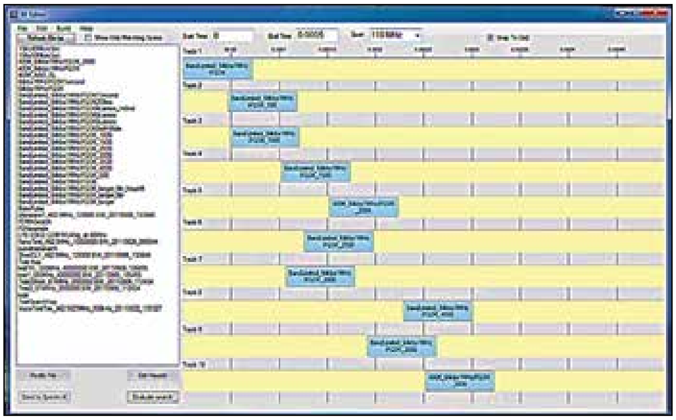
Tektronix introduced the TBS1000B-EDU and TBS1000B series of 2-channel oscilloscopes. Featuring enhancements such as a high-resolution 7-inch display, dual channel frequency counter and 34 automated measurements, the new instruments represent value entry-level oscilloscopes for students and teachers and support a wide range of general commercial applications including basic research and development.

Tektronix
tektronix.com

SATCOM Trio

Designed for ultra-lightweight applications such as Airborne and “ManPack” Portable Terminals, TMS’s Ka SOTM Trio consists of a wide-band solid state power amplifier (SSPA), a Low Noise Block Downconverter (LNB), and a Block Upconverter (BUC). Both the LNB and BUC can be electronically switched between commercial and military Ka-bands. The products are hermetically-sealed for harsh environments and extremely power-efficient for battery-powered applications.

Teledyne Microwave Solutions
teledynemicrowave.com



Editing Software

X-COM Systems introduced Version 3.0 of its RF Editor graphical signal editing software. RF Editor is the only commercially-available software that offers comprehensive editing capability for waveforms and waveform segments that have been captured over the air, offloaded from a signal analyzer, or created in programs such as MATLAB. It allows users to easily manipulate I&Q data files for RF signals of any length.

X-COM Systems
xcomsystems.com

BERT

Tektronix unveiled the industry's first fully integrated 40 Gb/s Programmable Pattern Generator (PPG). This 40 Gb/s PPG, along with the previously announced 40 Gb/s Programmable Error Detector now comprise a complete 40 Gb/s BERT solution. With 200 fs Random Jitter (RJ) and 8 ps risetime performance, it delivers the performance and signal quality critical for serial data testing at 40 Gb/s.

Tektronix
tektronix.com

Cable Assemblies

Fairview Microwave introduced a line of low loss test cables using LL335i and LL142 coax. Rated to 18 GHz, these new low loss cable assemblies are ideal for test environments where a rugged, phase stable cable assembly is required. Fairview Microwave's new LL335i and LL142 cables allow for higher power transmission because the resulting higher temperatures do not have a negative effect on the cable due to the thermal stability of the PTFE tape dielectric.

Fairview Microwave
fairviewmicrowave.com

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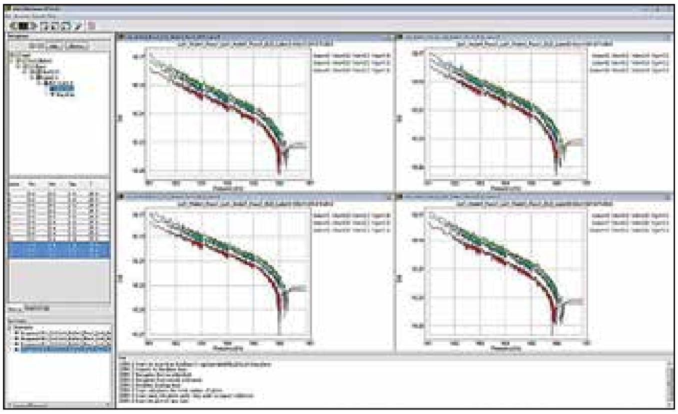
tim@highfrequencyelectronics.com



tNoise Analyzer

Agilent Technologies introduced the Agilent EEsof EDA E4727A Advanced Low-Frequency Noise Analyzer—a next-generation hardware and software system for measurement and analysis of flicker noise and random telegraph noise (RTN). Flicker noise has long been considered a critical characteristic of electronic devices. It significantly affects performance of active mixers, voltage-controlled oscillators, frequency dividers, op amps and comparators.

Agilent Technologies
agilent.com

mm-Wave Synthesizers

Micro Lambda Wireless announced the production release of a new series of low noise frequency synthesizers covering up to 33 GHz. Standard models include MLSP-1829 covering 18 to 29 GHz and MLSP-2333 covering 23 to 33 GHz. Step sizes are programmable from 1 kHz and up using 5 wire SPI or standard USB control. Units are available with internal crystal reference, external crystal reference or both.

Micro Lambda Wireless
microlambdawireless.com

Multiplier

Model SFA-713863410-12KF-S1 is a 71GHz to 86GHz X4 active multiplier designed for E-Band Communications and automotive radar applications. The active multiplier converts 17.75 to 21.5 GHz/+5 dBm input signal to deliver 71 to 86 GHz frequency band with a typical +10 dBm output power. The spurious and harmonic suppressions of the multiplier are 60 dBc 20 dBc or better, respectively.

SAGE Millimeter
sagemillimeter.com

Right Angle Adapters

Do you have the Right Angle in Quality, Performance and Reliability? SGMC Microwave does! SGMC Microwave has an extensive line of 2.4mm, 2.92mm, 3.5mm, and SMA Precision Right Angle In-Series and Between-Series adapters suited for your application needs. Please visit our website or contact us direct to find out more about our Precision Right Angle Coaxial Connectors.

SGMC Microwave
sgmcmicrowave.com

Network Monitoring System

Agilent Technologies announced a significant enhancement to its Passive Network Monitoring System for converged telecommunication networks across 2G, 2.5G, 3G and now 4G LTE technologies. The ystem offers a highly scalable monitoring and processing portfolio that effectively processes both voice and data completely independent of telecom network elements.

Agilent Technologies
agilent.com

Power Splitters

Pulse Electronics introduced a line of power splitters for its PIMinator low passive intermodulation (PIM) indoor distributed antenna system (iDAS) family. When there are multiple antennas in a building, the signals need to be split between the antennas. Pulse's power splitters are designed to work with its PIMinator line of antennas to ensure a PIM spec of -155 dBc at 2x20 watts. Low PIM is the key to the performance of DAS systems because PIM reduces or degrades base station performance.

Pulse Electronics Corp.
pulseelectronics.com

RF Module

Comtech PST introduced a high power density solid state RF module. The GaN-based 6-18GHz RF amplifier's highly integrated design is ideal for use in communication, electronic warfare, and radar transmitter systems where space, cooling, and power are limited.

Comtech PST
comtechpst.com

Relay

RelComm Technologies is offering a high power handling, high performance 1P8T relay configured with 'N' type connectors and RF performance to 1 GHz. Power rating is 1200 W continuous over the operating temperature range of -25°C - +70°C. The relay measures 3.75"sq. and is less than 3" tall. It is fitted with a standard DB25P header for ease of installation and is fully RoHS compliant.

RelComm Technologies
relcommtech.com

Switch

JSW2-63DR+ is a medium-power reflective, 50Ω, 10 to 6000 MHz SPDT RF switch, with reflective short on output ports in the OFF state. Made using a Silicon-on-Insulator process, it provides very high IP3 (55 dBm typ.). This switch also has a built-in CMOS driver and negative voltage generator, all packaged in a tiny 2x2mm package, enabling it to operate over wideband and fit into tight spaces.

Mini-Circuits
minicircuits.com

X-Band Amps

Pasternack Enterprises introduced a family of coaxial X band high gain power amplifiers. These RF amplifiers are typically used as driver amplifiers or high power output amplifiers in a wide variety of commercial, industrial and military applications including telecom infrastructure, test instrumentation, fixed microwave backhaul, radar systems, communication systems, satellite communications and commercial avionics.

Pasternack Enterprises
pasternack.com

Combination Analyzer

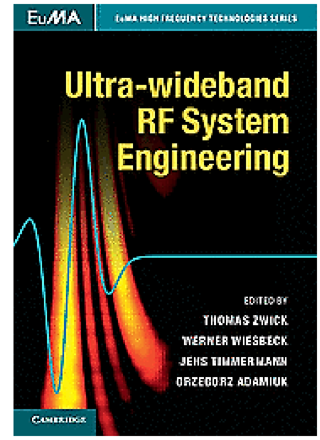
FieldFox handheld combination analyzers offer an easier solution than benchtop instruments, with the accuracy and functionality required for performing precision radar system performance validation. The combination analyzer solution includes: an analyzer that functions as a basic cable and antenna analyzer with spectrum and vector network analysis capabilities; A built-in power meter and vector voltmeter; and more.

Agilent Technologies
agilent.com

Book Review

Ultra-wideband RF System Engineering

Edited by: Thomas Zwick, Werner Wiesbeck, Jens Timmermann, Grzegorz Adamiuk



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Reviewed by Tom Perkins, HFE Senior Technical Editor

Ultra-wideband (UWB) as defined by the earliest man-made electromagnetic waves consisted of the energy created in a controlled fashion by spark gap transmitters which might be compared to the natural energy generated randomly by lightning discharges. Ultra-wideband manmade signals were banned in the 1920s. Vacuum tube technology had made narrowband "cw" possible. But in 1992 a conference was organized to address ultra-wideband, short pulse electromagnetics. Early research topics focused on ground penetration radar. Subsequent activity by an emerging ultra-wideband community has resulted in significant progress which has been reported in conferences and journals. This book represents much of the progress that has been made in the past 20 years, enabled by great advances in hardware technology as well as techniques.

The text concentrates on the frequency range of 1 to 10 GHz (30 to 3 cm wavelength). Within that constraint a number of applications are considered, including mine detection, 3D imaging and medical applications. System behavior in both the frequency domain and time domain are examined. Even if the reader has no intentions of employing such technology, the insight conveyed in looking at these "extreme" cases may import new understanding to RF system issues being addressed. Manipulation and optimization of pulse shapes is addressed in Chapter 2. This subject becomes quite fascinating and useful. A great deal of the content is devoted to ultra-wideband antennas. This information is useful not only to the instantaneous UWB systems developer, but also to folks needing frequency agility in narrow-band systems where space and weight are constrained.

A later chapter describes various monolithic integrated circuit schemes for UWB transceivers. Cross-correlation detection techniques are described along with conventional low-noise amplifiers and power amplifiers. Performance parameters of an IEEE 802.15.4a compliant single chip transceiver are described. Finally applications are briefly discussed. The many references open doors to much more information. This UWB topic deserves close attention by researchers and entrepreneurs in our field in the years to come. There will undoubtedly be numerous practical applications for this not-so-new technology.

—Tom Perkins
Senior Technical Editor

50 MHz to 26.5 GHz

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Mini-Circuits' New AVM-273HP+ wideband, 13 dB gain, unconditionally stable microwave amplifier supports applications from 13 to 26.5 GHz with 0.5W power handling! Gain flatness of ±1.0 dB and 58 dB isolation make this tiny unit an outstanding buffer amplifier in P2P radios, military EW and radar, DBS, VSAT, and more! Its integrated application circuit provides reverse voltage protection, voltage sequencing, and current stabilization, all in one tiny package!

The AVA-183A+ delivers excellent gain flatness (±1.0 dB) from 5 to 18 GHz with 38 dB isolation, and 19 dBm power handling. It is unconditionally stable and an ideal LO driver amplifier. Internal DC blocks, bias tee, and microwave coupling capacitor simplify external circuits, minimizing your design time.

The PHA-1+ + uses E-PHEMT technology to offer ultra-high dynamic range, low noise, and excellent IP3 performance, making it ideal for LTE and TD-SCDMA. Good input and output return loss across almost 7 octaves extend its use to CATV, wireless LANs, and base station infrastructure.

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