RF Low Noise Amplifier Technology Landscape Grows More Diverse

Editorial: Terahertz Update

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Pulse Profiling Power Sensor; Receiver: Wide Frequency Range

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Pulse Profiling RF Power Sensor

LadyBug Technologies’ newly updated LB480A includes both internal and external triggering as a standard feature. The sensor’s flexible triggering features give users the ability to make time gated measurements on pulsed signals. The advanced triggering features have many other uses, as well.

External TTL triggering can be used to synchronize measurements of signals that are near the noise floor, making it possible to visualize them using the pulse profiling display. Internal trigger level and trigger polarity are user settable as required. LadyBug offers a complete line of USB power sensors with frequency coverage from 9 kHz to 40 GHz. LadyBug sensors are first-tier NIST traceable and offer patented No-Zero No-Cal technology.

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SIR-4100 ELINT/MASINT Receiver Up to 40 GHz

The SIR-4000 uses the latest DSP technologies to meet the specific needs of the end user. Elcom recognized that in today’s real time threat environment, one size does not fit all.

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22: Feature Article

RF Low Noise Amplifier Technology Landscape Grows More Diverse

By Tim Galla

RF low noise amplifiers (LNAs) fabricated with solid state technology have been in use for several decades. The early transition to solid state was pioneered with germanium, has subsequently transitioned to silicon, and has now expanded to include a wide range of compound III-V semiconductors and new carbon-based materials.

The rapid adoption and advancement of LNA technologies is largely due to the growth and diversification of RF applications, and the specific requirements for these new and varying use cases. These requirements include the recent focus of greater linearity demands that complex modulation schemes for 5G applications pose on receivers at millimeter-wave frequencies, large-scale deployments of automotive radar, adoption of beam steering/antenna arrays, and advancements in low-probability-of-detection/low-probability-of-intercept (LPD/LPI) and high survivability radars.

Evolving from the early germanium transistors, modern low noise amplifiers (LNAs) are fabricated using compound semiconductors with heterojunctions and even new carbon materials. The effort and advancement in LNA device technology is driven by a growing need for LNAs with specific performance parameter improvements for the many, and growing, receiver and signal chain applications seen today.
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Terahertz Update

Tom Perkins
Senior Technical Editor

The Terahertz (THz) spectrum between the International Telecommunication Union designated 100 and 30,000 GHz occupies the frequency range between millimeter-waves and infrared lightwaves. More practically, the range might be thought of as between 300 GHz and 10 THz.

An obvious benefit of exploiting these submillimeter-wave frequencies is the wide bandwidth available which supports very high data rates (many gigabits per second) not possible at lower operating frequencies. Also, unlike x-rays and UV rays, the energy of terahertz waves is too low to break chemical bonds such as stripping electrons from atoms, meaning less likelihood of damaging living tissue. This makes the frequencies quite attractive for medical uses and security scanning.

But there are many challenges. Problems to overcome are comparable in some ways to those posed by emerging microwave techniques going back seven or eight decades ago. THz-related issues needing more understanding or mitigation include signal generation (stimulus) and capture (reception), active and passive components, interconnections, free space loss, atmospheric losses, power measurement, attenuation in most solids (with exception of some fabrics, paper, and plastics), instrumentation, test methods, antenna patterns and test equipment. Like the very early days of shortwaves and subsequently, fledgling microwaves, THz frequencies are presently mostly unregulated by the FCC and other spectrum regulatory agencies worldwide. That will likely change as wireless spectrum is an economic engine.

Unique Properties

Many materials that are opaque to visible light are transparent to terahertz radiation including textiles, plastics, paper, and cardboard. Certain materials have a unique “fingerprint” at terahertz frequencies due to molecular emission and absorption that occurs. Terahertz waves are already being used for some surveillance (scan for concealed weapons in airports), inspection, security applications, line-of-sight (LOS) and non-line-of-sight (NLOS) reflective data links. The IEEE Microwave Theory and Techniques Society has been publishing Transactions on Terahertz Science and Technology since year 2011.

Experiments at Brown University

Under a temporary FCC experimental license issued in 2017 for outdoor wireless data links, Brown University, Providence, RI, has performed both indoor and outdoor LOS and NLOS tests to learn more about practical THz capabilities. The participants, led by Professor of Engineering Dr. Daniel Mittleman, used frequencies of 100, 200, 300 and 400 GHz at data rates of 1 Gbit/sec at various humidity levels between 60 and 100% (perhaps easily
experienced in the Rhode Island climate. Humidity has very adverse attenuation effects on THz waves.

Indoor over-the-air reflection tests at Brown included a painted cinderblock wall, the same wall with metal foil added, and a smooth metal plate to distinguish between losses due to surface absorption and scattering. The results were characterized by bit error rate (BER), a realistic and practical figure of merit for communications mediums. Their findings are that the effect of scattering from a rough surface is significantly smaller than absorption effects. The absorption losses increase somewhat with frequency, approximately doubling from 100 to 400 GHz.

It was concluded that specular (highly reflective) NLOS paths are practical for indoor THz links up to 400 GHz due to acceptable path losses. In addition to a 2-meter indoor fixed distance they varied incident/reflection angles and operated over longer distances, e.g. 30 meters with a 26 cm² foil target, and including double reflections from different surfaces on the same link path. Results were quite consistent and surprisingly robust.

In the outdoor tests, the Brown University team set up an experiment that crossed a grassy surface and concrete sidewalk. Temperature, humidity and wind conditions were monitored and recorded. There were many conclusions. Significant ones included that multipath interference, which significantly increases with operating frequency, occurs to a lesser extent over grass than concrete. The reasoning is that the water content in the grass absorbs THz energy. Thus, the surface multipath signals are more attenuated than with the concrete surface. Tech Editor’s Note: The small, moist grass blades at these frequencies could be like radiation absorbent material (RAM) in a natural setting affecting THz waves. I wonder if a low budget THz anechoic chamber could be made with wet AstroTurf?

Dr. Mittleman noted “I think it’s fair to say that most people in the terahertz field would tell you that there would be too much power loss on those bounces, and so non-line-of-sight links are not going to be feasible in terahertz.” Mittleman added, “But our work indicates that the loss is actually quite tolerable in some cases -- quite a bit less than many people would have thought.”

Additional details on the THz research can be found in their paper Channel Performance for Indoor and Outdoor Terahertz Wireless Links in APL Photonics. The work was supported by the National Science Foundation and the W. M. Keck Foundation.
Meetings and Events

2019 IEEE Asia-Pacific Microwave Conference (APMC)
10 - 13 December 2019 | Singapore, Singapore
Field of Interest: Communication, Networking and Broadcast Technologies; Components, Circuits, Devices and Systems; Engineered Materials, Dielectrics and Plasmas; Fields, Waves and Electromagnetics; Photonics and Electrooptics

2019 IEEE MTT-S International Microwave and RF Conference (IMARC)
13 - 15 December 2019 | Mumbai, India
Field of Interest: Communication, Networking and Broadcast Technologies; Components, Circuits, Devices and Systems; Engineered Materials, Dielectrics and Plasmas; Fields, Waves and Electromagnetics; Signal Processing and Analysis

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2020 94th ARFTG Microwave Measurement Symposium (ARFTG)
26 - 29 January 2020 | San Antonio, Texas, USA
Field of Interest: Components, Circuits, Devices and Systems; Fields, Waves and Electromagnetics

2020 IEEE Radio and Wireless Symposium (RWS)
26 - 29 January 2020 | San Antonio, Texas, USA
Field of Interest: Communication, Networking and Broadcast Technologies; Components, Circuits, Devices and Systems; Fields, Waves and Electromagnetics; Signal Processing and Analysis

RF/Wireless Continuing Education

Within each 3 - 5 year period, one-half of an engineer's technical knowledge becomes obsolete. New graduates soon discover that university education provides only the foundation of knowledge that is realistically needed to perform well in the industry. Continued education is a must for survival in today’s competitive market.

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China Will Dominate 5G Deployment Despite Early Lead by the USA and South Korea

According to the latest mobile network forecasts by global tech market advisory firm, ABI Research, 5G is expected to have 12 million connections worldwide by the end of 2019. The number of connections will then skyrocket to 205 million worldwide at the end of 2020, thus starting the golden age of 5G.

The new generation is expected to grow much faster than anticipated and 5G connections are set to overtake 4G connections in 2025. ABI Research expects approximately 3 billion 5G connections in 2025 with 4G declining from its current 3.9 billion to 2.2 billion at the end of the same year.

“Despite the challenges faced by early adopters and the relatively high prices of 5G-capable smartphones in 2019, ABI Research expects 5G to reach the mass market mid-2020, by which time China will start to dominate in terms of connections, and as a result, market interest and technology expertise,” says Dimitris Mavrakis, Research Director at ABI Research. “The infrastructure value chain is maturing, handset vendors are manufacturing mid-tier 5G handsets, and consumers are now discovering higher speeds, better user experiences, and new services, including Cloud Gaming and AR/VR applications. All of these will contribute to the explosion of consumer 5G in 2020.”

ABI Research expects China to dominate 5G deployment after all mobile service providers launched in November 2019 having deployed 5G in 50 cities before launching. Chinese operators are forecasted to have 143 million subscribers at the end of 2020, which will represent an overwhelming 70% of total connections worldwide. In contrast, U.S. operators will reach approximately 28 million in the same year. In 2025, China is expected to have 1.1 billion 5G subscribers and the United States, 318 million. “Globally, ABI Research expects mobile service providers to spend nearly US$1.2 trillion in the next 5 years to build out their networks and will generate nearly US$6.2 trillion in service revenues from the consumer market alone. Although most mobile 5G subscribers will be in China, mobile service provider revenues will still be higher in the United States in 2025, mainly driven by higher subscription prices,” Mavrakis concludes.

—ABI Research
abiresearch.com

Battery Electric Vehicles on the Fast Track to Reach an Installed Base of Over 100 Million by 2029

After decades as a high-cost, low-volume rounding error of global vehicle sales, electric powertrains are now in the ascendancy. Traditional Internal Combustion Engine (ICE) powertrains, diesels, are no longer able to keep pace with the stringent emissions requirements being laid down by governments around the world. These requirements are paving the way for Battery Electric Vehicle (BEV) sales to grow from 1.3% in 2018 to 16.4% in 2029, creating an Electric Vehicle (EV) installed base of over 100 million, forecasts global tech market advisory firm, ABI Research.

“Simultaneously, automakers are seeking to alleviate consumer fears around EV range by rapidly increasing battery capacity, using new battery technologies, such as silicon-dominant anodes and solid-state designs, to increase cell-level energy density from 250 Watt-Hours per Kilogram (Wh/kg) to more than 500 Wh/kg within the next 10 years,” says James Hodgson, Principal Analyst at ABI Research.

The expected growth in EVs and the energy density of their batteries represent a considerable challenge to the energy industry, with energy demand for electric passenger vehicles expected to grow from 1,121 Gigawatt Hours (GWh) in 2018 to 19,141 gWH in 10 years. “While this represents a potential of almost US$20 billion in energy sales by 2028, it also places extraordinary demands on national energy grids, with Transmission System Operators (TSOs) struggling to accommodate the onboarding of BEVs due to the limitations in infrastructure at the last mile, particularly with line constraints, transformer limitations, and the syncing of renewable energy supply with usage,” says Hodgson.

These factors have opened a market opportunity for smart energy management companies to support TSOs in the onboarding of EVs, incentivizing consumers via rewards and revenue sharing to encourage charging during off-peak hours. Potential benefits include helping TSOs to strategically improve last-mile infrastructure without impeding EV adoption and helping energy retailers to better predict energy demand to avoid demand charges.

Beyond the core smart charging opportunity, numerous use cases can be exploited via bidirectional energy flow between the EV and the grid, commonly referred to as Vehicle-to-Grid (V2G). As well as receiving energy from the grid, vehicles can act as generators, providing energy back to the grid in order to fulfill several use cases.

—ABI Research
abiresearch.com

Market Reports
Coilcraft 0402DC Series wirewound chip inductors offer the industry’s highest Q factors in an 0402 (1005) size for super low loss in high frequency circuits. And with 112 values from 0.8 to 120 nH, including 0.1 nH increments from 2.8 nH to 10 nH, you’ll have exactly what you need for all your RF and Microwave applications.

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Powering Future Optical Microsystems with Chip-Scale Integrated Photonics

Lasers are essential to many fields – ranging from optical communications and remote sensing, to manufacturing and medicine. While the semiconductor laser was first demonstrated nearly 60 years ago, advances in diode lasers and access to semiconductor fabrication techniques have enabled continued innovation and miniaturization of the technology. Photonic integrated circuits (PICs), which combine many photonic elements onto a single chip, have also transformed the way lasers and other optical systems are engineered, creating improvements in size, weight, and power (SWaP), system performance, and enabling new functionality. Despite these advances, a number of obstacles still hamper the proliferation of optical systems for defense and commercial applications.

Today, PICs take several forms and are defined by the materials used to create the integrated device platform. While the vast silicon electronics manufacturing ecosystem has established silicon photonics as the premier platform for the integration of thousands of high-performance passive components on a single chip, fundamental material constraints preclude efficient generation of light, or optical gain, using on-chip components. Compound semiconductors can efficiently generate light on-chip, but suffer challenges in scaling power or complexity due to high propagation loss – or loss due to light absorption, scattering or other means – and limited manufacturing maturity. An integrated platform with complete photonics functionality on a single chip would improve performance, support design innovation, and reduce development costs, enabling greater deployment and impact across many commercial sectors as well as the Department of Defense (DoD).

“Commercial data center drivers have established integrated photonics platforms that address a specific market segment,” said Dr. Gordon Keeler, program manager in DARPA’s Microsystems Technology Office (MTO). “However, DoD-relevant applications typically require components with higher optical performance, such as lower noise lasers, higher power amplifiers, or operation in different spectral bands. As a result, critical and emerging applications are unable to leverage existing integrated photonics technology effectively. The development of a more capable integrated platform tailored to specialty user needs could have revolutionary impact.”

To address the obstacles impeding the development of optical microsystems, DARPA developed the Lasers for Universal Microscale Optical Systems (LUMOS) program. LUMOS seeks to develop complete and highly capable integrated photonics platforms that enable efficient optical gain, high-speed modulation and detection, and low-loss passive functionality on a single chip. The platforms will integrate various components – lasers, amplifiers, modulators, waveguides, and detectors – onto a single substrate, providing unprecedented functionality for myriad use cases – ranging from digital and analog communications, to navigation and timing, to quantum sensing and computing. To address these requirements, LUMOS seeks to explore new materials and employ recent developments in heterogeneous integration techniques that combine best-in-class materials on a single chip.

Within the program, researchers are tasked with creating platforms optimized across three domains – complexity, power, and spectrum. With a focus on dramatically scaling the complexity and performance of silicon photonics technology, researchers will work to develop a platform that supports the integration of thousands of optical components on a single chip under the first research area. A second research area will focus on the development of high-power, high-speed photonics platforms for defense applications. A third area seeks to develop visible and near-infrared photonics platforms, capable of supporting new classes of applications such as critical sensing, timing, and quantum information applications. Each research area will explore on-chip gain integration strategies and PIC platforms tailored for application-specific needs.

To illustrate the performance gains and SWaP improvements generated by complete component integration, LUMOS will pursue demonstrations on DoD-relevant systems throughout the life of the program.

LUMOS is a part of DARPA’s Electronics Resurgence Initiative (ERI) – a five-year, upwards of $1.5 billion initiative to develop techniques and technologies for advancing microelectronics performance beyond the limits of traditional transistor scaling that has helped realize the projections of Moore’s Law. One aspect of ERI is focused on the creation of unique and differentiated domestic manufacturing capabilities that are accessible to the
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In the News

DoD. In addition to a focus on DoD-relevant applications, LUMOS seeks to develop integrated photonics platforms that can be fabricated in existing foundries, making the technology more accessible for defense users.

—DARPA

Gene Editors Could Find New Use as Rapid Detectors of Pathogenic Threats

In a twist on how gene editing technology might be applied in the future, DARPA’s newest biotechnology funding opportunity aims to incorporate gene editors into detectors for distributed health biosurveillance and rapid, point-of-need diagnostics for endemic, emerging, and engineered pathogenic threats. The “Detect It with Gene Editing Technologies” (DIGET) program could help the Department of Defense maintain force readiness by informing rapid medical response and increasing the standard of care for troops, and preserving geopolitical stability by preventing the spread of infectious disease from becoming a driver of conflict.

The overarching goal of DIGET is to provide comprehensive, specific, and trusted information about health threats to medical decision-makers within minutes, even in far-flung regions of the globe, to prevent the spread of disease, enable timely deployment of countermeasures, and improve the standard of care after diagnosis.

—DARPA

Infinite Electronics CFO Rosner Nominated for CFO of the Year

Infinite Electronics, Inc., announced that CFO Scott Rosner has been nominated for the annual Orange County Business Journal’s CFO of the Year Award.

The CFO of the Year Award program is designed to recognize senior financial professionals for their outstanding performance as corporate stewards. Candidates must be the chief financial officer (or equivalent) of a business headquartered in Orange County, Calif., and are chosen for their positive impact in the Orange County business community, as well as their outstanding leadership and performance for the preceding fiscal year.

Since joining Infinite Electronics almost two years ago, Mr. Rosner has implemented and spearheaded new financial policies and guidelines designed to ensure financial viability, grow revenue, and increase profits. His efforts and financial oversight have helped ensure that Infinite Electronics continues to realize strong revenue and EBITDA growth year over year, greatly increasing shareholder value.

“ Infinite Electronics has experienced a period of rapid expansion, and thus, our needs for financial oversight, governance, and system stability rose to an entirely new level. Scott joined our team and quickly proved himself to be a dependable and effective leader. Being recognized for this award is well deserved. I trust him implicitly as our CFO, and he is a critical member of our team in leading this company to continued success,” explained Penny Cotner, President & CEO of Infinite Electronics.
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Each system is fully customizable and typical features include (but not limited to) an Intel i7 processor, ATX motherboard to your specifications, 32 GB memory, storage options, latest Windows operating system, USB 3.0 ports, a card reader for extra security, fiber port options, DB9/DB37 connectors, and a high-performance power line filter. The system measures: 18.50” high x 6.65” wide x 17.50” deep.

Equipto Electronics
equiptoelec.com

Bandpass Filter
PMI Model No. BPF-5200M-30DB is a 5200 MHz Bandpass Filter and specifications include 3 dB bandwidth of 210 MHz Typ, Rejection -30 dBc min. @<4429 MHz & > 5229 MHz, VSWR Over 90% of the Passband of 2.0:1 Max and 3 dB Passband Insertion Loss of 8 dB Max. Unit is ~1.0” x 0.7” x 0.29” and has SMA female connectors.

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**Source Modules and More**

The deployment of Gigabit Wireless is happening today. Backhaul (e.g., E-band 70-80-90 GHz) takes advantage of an atmospheric absorption “valley,” which corresponds to minimum attenuation that is conducive to applications requiring relatively longer transmit/receive paths. Similarly, mobile applications (e.g., WiGig, 802.11ad) occupy the 57-64 GHz band where atmospheric absorption can help mitigate interference in dense signal environments. OML is supplying vital frequency extension technology to characterize these emerging applications.

OML offers source modules, VNA modules and harmonic mixers that are plug-and-play compatible with modern microwave signal generators, vector network analyzers and spectrum analyzers, respectively. These modules enable engineers to easily and affordably expand their measurement capabilities to the mm-wave frontier. Using these tools, engineers can characterize their devices for emerging gigabit applications, including WiGig and E-band backhaul.

**OML omlinc.com**

**Sector Antenna: 65-Degree Azimuth Beamwidth**

KP Performance Antennas launched a new horizontal/vertical polarized, 8-port ProLine sector antenna that is ideal for broad-frequency, point-to-point, point-to-multipoint and backhaul applications.

KP’s new KPP-2HV5HVX8-65 ProLine horizontal/vertical polarized sector antenna operates in the 2.3 GHz to 2.7 GHz and 4.9 GHz to 6.4 GHz frequency ranges. It features a
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65-degree azimuth beamwidth and zero-degree fixed electrical downtilt. It also boasts 8 ports, gain performance of 17 dBi and 16.8 dBi respectively and excellent front-to-back of 31 dB and 34 dB. This antenna is engineered to deliver high, stable gain over wide bandwidths and suppress side-lobes and back-lobes for mitigating inter-sector interference.

KP Performance Antennas
kpperformance.com

Frequency Divider
Fairview Microwave introduced a new line of frequency divider modules that cover broadband frequencies from 0.1 GHz to 20 GHz. A comprehensive offering of 28 different models features fixed divide-ratios from 2 to 40. These compact prescalers are ideal for use in frequency synthesizer and phase locked loop (PLL) circuit designs, as well as test instrumentation systems. These rugged frequency dividers are typically used in applications such as satellite communications, VSAT, aerospace and defense, test and measurement, and point-to-point radio networks.

Fairview Microwave
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Synthesizer: Low Phase Noise
We’re pleased to announce that we’ve increased the offerings for our high-performance, low phase noise benchtop frequency synthesizers. In sync with our evolving catalog of YIG synthesizer components, our custom-tuned benchtop YIG synthesizer line now offers RF and microwave designers working at frequencies up to 20 GHz the chance to upgrade their test benches with the best technology at their specific bands.

Offering up to -125 dBc/Hz @ 10 kHz offset phase noise at a carrier frequency of 10 GHz, these frequency synthesizers set the standard for phase noise performance. They are also capable of tuning speeds up to 50 uS over wide bands, and offer output power levels of +15 dBm, with power leveling in frequency bands up to 10 GHz.

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RF Low Noise Amplifier Technology Landscape Grows More Diverse

By Tim Galla

Abstract
RF low noise amplifiers (LNAs) fabricated with solid state technology have been in use for several decades. The early transition to solid state was pioneered with germanium, has subsequently transitioned to silicon, and has now expanded to include a wide range of compound III-V semiconductors and new carbon-based materials. The rapid adoption and advancement of LNA technologies is largely due to the growth and diversification of RF applications, and the specific requirements for these new and varying use cases. These requirements include the recent focus of greater linearity demands that complex modulation schemes for 5G applications pose on receivers at millimeter-wave frequencies, large-scale deployments of automotive radar, adoption of beam steering/antenna arrays, and advancements in low-probability-of-detection/low-probability-of-intercept (LPD/LPI) and high survivability radars.

Introduction
Evolving from the early germanium transistors, modern low noise amplifiers (LNAs) are fabricated using compound semiconductors with heterojunctions and even new carbon materials. The effort and advancement in LNA device technology is driven by a growing need for LNAs with specific performance parameter improvements for the many, and growing, receiver and signal chain applications seen today. Balancing factors of cost, availability, ruggedness, noise

Figure 1 • A comparison of the highest frequency capability of several transistor technologies considered for terahertz applications. (Source [1.3]) https://www.mdpi.com/sensors/sensors-19-02454/article_deploy/html/images/sensors-19-02454-g001-550.jpg
isn't substantially different from that of producing conventional silicon transistors (much of the same infrastructure can be used). SiGe transistors are also used in cryogenic applications, due to their wide operating temperature capability. Commonly, SiGe heterojunction bipolar transistors (HBTs) are the type of transistor used for high frequency and high performance applications. This includes devices that operate to a significant fraction of a terahertz [1.3].
The most common application, historically, for SiGe technology has been in cell phone receivers, as the combination of low noise and wide dynamic range in the cellular spectrum (700 MHz to 3 GHz) compared to conventional silicon made this technology more viable [1.4].

**Advantages of SiGe LNAs over CMOS LNAs [2.1, 2.2]**

- Lower inherent noise
- Better input match for optimized gain
- Improved gain/noise figure trade-off
- Better linearity (higher dynamic range)
- Possibility of die size advantages at innate input match is superior and additional on-chip inductors aren’t needed
- SiGe BiCMOS brings the best of both worlds
- Operation well into millimeter-wave and sub-millimeter wave frequencies

**Silicon Germanium:Carbon (SiGe:C)**

With the addition of carbon to SiGe heterojunction transistors, even more control of a silicon transistor’s band-gap is possible. Moreover, with added carbon, SiGe:C HBTs have demonstrated lower noise figure, higher collector current, higher unity gain frequency, and better linearity than Si BJTs. In essence, SiGe:C provides the advantages of SiGe with even greater maximum frequency and lower noise figure while still maintaining compatibility with mainstream silicon fabrication process. Hence, SiGe:C BiCMOS processes are capable of producing cost effective and still high performance wireless device chips, including complete Systems-on-Chip (SoCs) for applications such as Bluetooth, wireless data links, 3G/4G LTE, 5G low-/mid-/high-band, WiFi, automotive radar, and fiber optic drivers.

**Gallium Arsenide (GaAs) for RF LNAs**

With advances in semiconductor processing technologies that include metal-organic chemical vapor deposition (MOCVD) and molecular beam epitaxy (MBE), compound semiconductors based on III-V materials deposited in this layers became possible. Thus GaAs substrates and AlGaAs/GaAs high electron mobility transistors (HEMT) were born and found use in a wide range of high performance, frequency, and bandwidth applications. One of the
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main advantages of AlGaAs/GaAs HEMTs is an increase in bandgap over GaAs of 1.4 eV to 1.8 eV.

Further advances led to the development of Pseudomorphic HEMTs (pHEMTs), which required the use of InGaAs material to increase the electron mobility in the 2-dimensional region, with the result of yielding higher transconductance.

However, lattice mismatch and the mechanical strain of using Indium sets a limit of roughly 30% Indium concentration, limiting the overall potential performance increase from the pHEMT design. Innovation of an additional InAlGaAs buffer layer and a graded Indium concentration to achieve better lattice constant match with the GaAs substrate and InGaAs channel, led to the development of ever higher frequency and lower noise performing metamorphic HEMT (MHEMT) devices. MHEMTs made with GaAs substrates are generally lower cost, benefit from Gallium’s higher crystal quality, have better mechanical strength, and have a larger 6” wafer size compared to Indium substrates.

In industry, GaAs HEMT, pHEMT, and mHEMT processes are all used to make practical and high performance LNAs. These devices. Generally, for upper micro-wave and millimeter-wave frequencies, pHEMT and mHEMT transistors are used instead of standard HEMTs. Hence, there are ultra-wide bandwidth (UWB) GaAs LNAs that operate to several gigahertz, tens of gigahertz, and to hundreds of gigahertz. There are also many GaAs LNA technologies that have been approved/certified for use in space as well as aerospace vehicles. GaAs LNAs, power amplifiers (PAs), and transmit/receive (TR) modules are commonly used in many aerospace, defense, and security (ADS) applications, as well as automotive, cellular, and is being evaluated for upcoming 5G small cells and handsets [3.1].

GaAs technologies are some of the most widely used for LNA applications due to GaAs good noise figure performance, reasonable gain and power, as well as balance of cost and technological maturity. GaAs LNAs typically have a higher noise figure than InP and tend not to operate to as high frequency (with the exception of some GaAs MHEMTs). Moreover, GaAs LNAs tend to have a lower noise figure than GaN, but have a much lower maximum operating voltage.

**Indium Phosphide (InP) for RF LNAs**

InP LNAs are generally considered some of the lowest noise figure and highest frequency performance LNAs. Much like with GaAs HEMTs, and pHEMTs, layers of InAlAs and InGaAs are placed on an InP substrate to develop high bandwidth and high frequency transistors. Also similar with GaAs LNAs, UWB LNAs are often developed in cascaded or distributed approaches that achieve low noise figure over tens of gigahertz of bandwidth. These types of LNAs are sometimes called low noise distributed amplifiers (LNDAs). InP HEMT transistors are sometimes fabricated on substrates, such as silicon carbide (SiC) for high voltage and high power applications, and SiC exhibits better thermal conductivity performance than InP substrates.

InP HEMT transistors can typically handle higher voltage and power than GaAs transistors, especially at higher frequencies. However, InP technologies are more expensive and are generally less widely used than GaAs HEMTs. InP LNAs are common in test and measurement equipment, radio astronomy, highly sensitive radar, fiber optic receivers, cryogenic sensors and other applications that require the lowest noise figure and highest frequency. These applications include LNAs that operate from several gigahertz and into the terahertz range.

More recent research of InP LNAs involves the development of double HBTs (DHB Ts). DHB T processes exhibit a wider bandgap and higher breakdown voltage compared to HEMT devices, which is desirable for high power and high frequency applications, but also distributed LNAs [4.1].

**Gallium Nitride (GaN) for RF LNAs**

GaN is a widely hyped and emerging transistor technology that is finding use in high power and high frequency applications in virtually all microwave and millimeter-wave applications. GaN devices exhibit a very high breakdown voltage and power density capability that far exceeds GaAs and InP. Hence, GaN devices are most often used in PA applications.

However, there are some cases in which receivers experience high input powers. In these cases, limiters are added to the input of the LNA, which intrinsically reduces both noise and bandwidth performance of the receiver. These applications typically include receivers that experience jamming or high levels of interference (solar storms/cosmic radiation). An alternative is to use GaN-based LNAs with much higher input power capability, while still offering good noise figure features. GaN LNAs have been reported to survive input power levels over 30 dBm continuous wave (CW) and nearly 50 dBm pulsed [5.1]. Moreover, extremely high linearity GaN LNAs have also been demonstrated with third-order output intermodulation points (OIP3s) around 40 dBm [5.1]. Both GaN HEMT LNAs and GaN FET LNAs have been studied for the purpose of developing high-survivability LNA technology.

**Silicon (RF CMOS/SOI/BiCMOS) for RF LNAs**

Stressing cost efficiency and compatibility with existing semiconductor manufacturing and processing infrastructure, there are a wide range of various Si-based transistor technologies that can be used to make RF LNAs. This includes silicon-on-insulator (SoI) technologies, which are now a significant contributor to cellular
user equipment (UE). GaAs and RF SoI are competing technologies for 4G and upcoming 5G technologies, but still lacks GaAs in transmitter and receiver performance [6.1].

However, Si-based LNA technologies do benefit from enhanced integration with other components, devices, and domains, which enables the realization of complete RF front-end modules (FEM) systems-on-chip (SoC). As a consequence of Si-based LNA integration and cost efficiency, there are many CMOS and SoI technologies used commercial products, such as Bluetooth, WiFi, Zigbee, Cellular, and other Internet-of-things (IoT) modules, as well as part of larger SoCs and ICs with integrated wireless modules.

Generally, Si-based LNA applications operate to a maximum of several gigahertz. In some cases, advanced SoI and CMOS technologies are being pioneered for millimeter-wave frequencies in anticipation of upcoming millimeter-wave 5G user equipment, handsets, and base stations in addition to potentially reducing costs of millimeter-wave radar used in automotive driver-assist systems.

Carbon Nanotubes (CNTs) for RF LNAs

For several years there has been the hope of developing carbon-based transistors that can compete with semiconductors that are more expensive or are limited resources. Recently, there has been innovation in the use of carbon-nanotube (CNT) transistors that can operate to millimeter-wave frequencies [7.1,7.2]. In one example, CNT FETs were developed that demonstrate high inherent linearity and may potentially be used to realize future high frequency and wide bandwidth LNAs [7.1].

Conclusion

LNAs are key devices in virtually all RF systems. Depending on the needs of a technology there are now a wide-range of semiconductors and device technologies to choose from. The end-performance of these LNAs depends largely on the inherent properties of the semiconductor, as well as the device type and design of the LNA circuit. This article provided a brief overview of modern LNA technologies, as well as mentioned potential upcoming carbon-nanotube technologies with high inherent linearity that may be used to build future LNAs with extreme linearity.

About the Author

Tim Galla serves as Product Manager at Pasternack.

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5. Gallium Nitride RF Low Noise Amplifiers

6. Silicon RF CMOS RF Low Noise Amplifiers

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Resistive Power Divider with N Female Connectors

BroadWave Technologies unveiled a new resistive power divider featuring an operating frequency range of DC to 6 GHz. Model 152-215-002 is a 50-Ohm, 2 way power divider. This unit has an average power rating of 2 Watts with 1.50:1 maximum VSWR. The insertion loss is 6 dB +/- 1.5 dB nominal, the operating temperature range is 0°C to +70°C and RF connectors are N female.

BroadWave Technologies manufactures a wide variety of resistive power dividers in 2, 3, 4, 5, 6 and 8 way configurations. Available connector types are BNC, N, SMA and TNC or mixed connector types for unique applications. Average power is up to 10 Watts for standard units. Many models are in stock.

BroadWave Technologies
broadwavetechnologies.com
Ducommun offers Switch Matrix Solutions!

For additional information contact our sales team at: 310-513-7233 or rfsales@ducommun.com

Get info at www.HFeLink.com
VNA: 100 kHz to 40 GHz

The R&S ZNBT40 from Rohde & Schwarz is the first vector network analyzer (VNA) with a broad frequency range from 100 kHz to 40 GHz and up to 24 integrated test ports. Developers can use it for applications such as measurements on 5G antenna arrays. The multiport architecture is not only advantageous for tests on multiport components, but also for simultaneous testing of multiple DUTs in production to boost throughput. Rohde & Schwarz ensures specified performance on up to 24 test ports with the R&S ZNBT40. Also new is the R&S ZNBT26 for measurements up to 26.5 GHz.

Rohde & Schwarz
rohde-schwarz.com

Attenuator

PMI Model DTA-2G18G-60-CD-2-OPT-1G18G is a non-reflective, 10 BIT, programmable 60 dB, pin diode attenuator with step resolution as low as 0.06 dB over the frequency range of 1.0 to 18.0 GHz. Specifications include insertion loss of 4.5 dB; VSWR 2.0:1 maximum; attenuation accuracy of ±1.0 dB @ 0 to 20 dB, ±1.5 dB @ 20 to 40 dB and ±2.0 dB @ 40 to 60 dB; typical attenuation flatness of ±1.0 dB @ 20 dB, ±1.25 dB @ 40 dB and ±3.0 dB @ 60 dB; switching speed 1.0 µs and This model is offered in a slim line housing measuring 2.0” x 1.8” x 0.5” with SMA female connectors and a 15 PIN Micro-D-Female control connector. Mating Micro-D Male connector supplied.

Planar Monolithics Industries
pmi-rf.com
FILTERS

Eliminate Stopband Reflections

DC to 40 GHz

- Patented internal load eliminates out of band signals
- Ideal for non-linear circuits
- Now available surface mount and tubular SMA case styles
MMIC Power Splitter/Combiner Channels DC to 18 GHz
Mini-Circuits’ model EP4KA+ is a four-way 0-deg. power splitter/combiner with wide frequency range of 10.7 to 31.0 GHz. Insertion loss above the 6-dB four-way power split is minimal, typically 0.4 dB from 10.7 to 13.0 GHz, 0.6 dB from 13 to 22 GHz, and 1.1 dB from 22 to 31 GHz. Typical isolation between ports is 13.1 dB from 10.7 to 13.0 GHz, 19.3 dB from 13 to 22 GHz, and 21.5 dB from 22 to 31 GHz. The resistive/reactive design is fabricated with GaAs MMIC technology and supplied in a surface-mount QFN package measuring just $5 \times 5 \times 1$ mm. It can handle as much as 0.6 W input power as a divider and as much as 0.6 W per port as a combiner. The 50-Ω RoHS-compliant power splitter/combiner exhibits low 1.40:1 VSWR at all ports with excellent amplitude and phase unbalance. It has an operating temperature range of -55 to +105°C and is a good match for broadband communications and test applications.

MMIC Power Splitter/Combiner Channels DC to 18 GHz
Mini-Circuits model EP4RKU+ is a four-way 0-deg. power splitter/combiner with broadband frequency range of DC to 18 GHz. Insertion loss above the 6-dB four-way power split is extremely low, typically 4.2 dB from DC to 4 GHz and only 3.4 dB from 4 to 18 GHz. The tiny splitter/combiner handles maximum full-band power of 0.6 W as a divider and as much as 0.6 W per port as a combiner. The 50-Ω RoHS-compliant component is fabricated with GaAs MMIC technology; the resistive/reactive design extends the EP power splitter/combiner series to DC. The splitter/combiner is supplied in a surface-mount QFN package measuring just $5 \times 5 \times 1$ mm. Despite the small size, the typical isolation between ports is 20 dB at 9 GHz. With outstanding amplitude and phase unbalance, the power splitter/combiner is a good fit for a wide range of wireless communications and test-and-measurement applications. It is designed for operating temperatures of -55 to +105°C.

MMIC Amplifier Maintains Flat Gain from 50 MHz to 8 GHz
Mini-Circuits’ model PHA-83W+ is a high-dynamic-range MMIC amplifier with broad frequency range of 50 MHz to 8 GHz. It runs on 5 or 9 V dc supply voltage, with typical gain of 10 dB or better and gain flatness of ±2.8 dB across the full frequency range with a 5-V dc supply and typical gain of 14.2 dB and gain flatness of ±1.4 dB across the full frequency range with a 9-V dc supply. The noise figure is typically 3.1 dB or less from 50 to 4000 MHz and typically 4.7 dB or less across the full frequency range. The miniature 50-Ω amplifier delivers typically +15.9 dBm or more output power at 1-dB compression from 50 to 4000 MHz, and typically +13.2 dBm or more across the full frequency range. The RoHS-compliant GaAs pHEMT amplifier is supplied in a thermally efficient SOT-89 package and has an operating temperature range of -40 to +85°C.

SP6T Switch Matrix Commands DC to 40 GHz
Mini-Circuits’ model RC-1SP6T-40 is a PC-controlled electromechanical single-pole, six-throw (SP6T) switch matrix for applications from DC to 40 GHz. The rugged unit can handle as much as 5 W signal power during cold switching and is rated for at least 2 million switch cycles with cold switching. The SP6T switch matrix can be controlled with a PC running Windows 98 or later operating system (OS); graphical-user-interface (GUI) and other support software is available for free download from the Mini-Circuits site. The switch matrix is equipped with 2.92-mm female coaxial connectors on all RF ports and USB and Ethernet ports for control connections. It features typical insertion loss of 0.2 dB from DC to 12 GHz, 0.4 dB from 12 to 26 GHz, and 0.7 dB from 26 to 40 GHz. Typical isolation is 90 dB from DC to 12 GHz, 80 dB from 12 to 26 GHz, and 70 dB from 26 to 40 GHz. The 50-Ω switch matrix is designed to run on +24 V dc and at operating temperatures of 0 to +40°C. It has typical switching speed of 25 ms and worst-case VSWR of 2.20:1 across the full frequency range. It is supplied in a rugged metal case measuring $5.5 \times 6.0 \times 2.75$ in. (139.70 × 152.40 × 69.85 mm).
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High Frequency Electronics (USPS 024-316) is published monthly by Summit Technical Media, LLC, 3 Hawk Dr., Bedford, NH 03110. Vol. 18 No. 12 December 2019. Periodicals Postage Paid at Manchester, NH and at additional mailing offices.

POSTMASTER: Send address corrections to High Frequency Electronics, PO Box 10621, Bedford, NH 03110-0621.

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