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Ultra Low Noise Amplifier

FEATURED ARTICLE »

September 2008

Finally – The Spatial Frontier!

By Scott Behan, Vice President of Marketing, CAP Wireless, Inc.

Spatial combining is a method of increasing microwave and RF power levels by combining the power of many amplifying devices using free space or air as the power dividing/combining medium within a guided wave structure. The spatial combiner, as opposed to traditional circuit-based combiners (**Figure 1**), is formed from an array of amplifying unit cells, with each cell receiving a signal, amplifying it, and then radiating it into free space. The key characteristic is the very low loss with which a large number or elements can be combined. This method offers a unique combination of substantially broader bandwidth and higher power, excellent linearity, and low phase noise, making it suitable for highly specialized applications not possible with legacy circuit combined amplifiers.

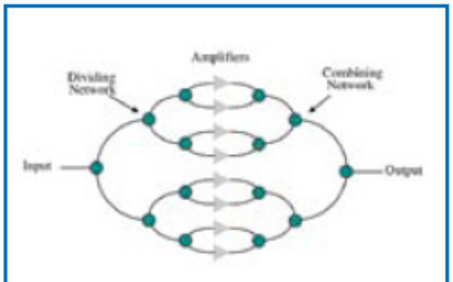


Figure 1: Conventional binary circuit-level combiner [1]

The basic concept of spatial combining was first conceived prior to World War II, along with many other microwave techniques, but only recently have semiconductor device technology, high-frequency three dimensional (3D) electromagnetic (EM) modeling, and mechanical and thermal modeling capabilities matured and converged to enable the development of practical, cost-effective spatially combined platforms. As a result of this recent interest in and demand for spatial combining technologies, solutions incorporating this old/new architecture are beginning to solve problems engineers didn't even know they had.

This article will provide an overview of spatially combined power amplification and explore some of the cutting-edge solutions that are being developed now that this technology is becoming commercially viable.

Background

The earliest known example of spatial power combining actually involved vacuum tubes and was performed pre-World War II by Japanese inventor Shintaro Uda. One of his experiments involved the use of nine vacuum tubes and eight dipole antennas alternately spaced along an open-wire transmission line to form a quasi-optical transmitter amplifier. He noted that power increased rapidly as the number of vacuum tubes and antennas increased. [2]

Substantial development work on spatial combining technology was begun in the mid-1990s at several universities, including the University of Colorado at Boulder, the University of Michigan, North Carolina State University, and the University of California at Santa Barbara. Three basic practical architectures have been developed in the past 20 years: the grid amplifier, developed by David P. Rutledge in 1991; the tray amplifier, and a proprietary coaxial antipodal finline architecture known as Spatium™, the patent for which is held by CAP Wireless, Inc.

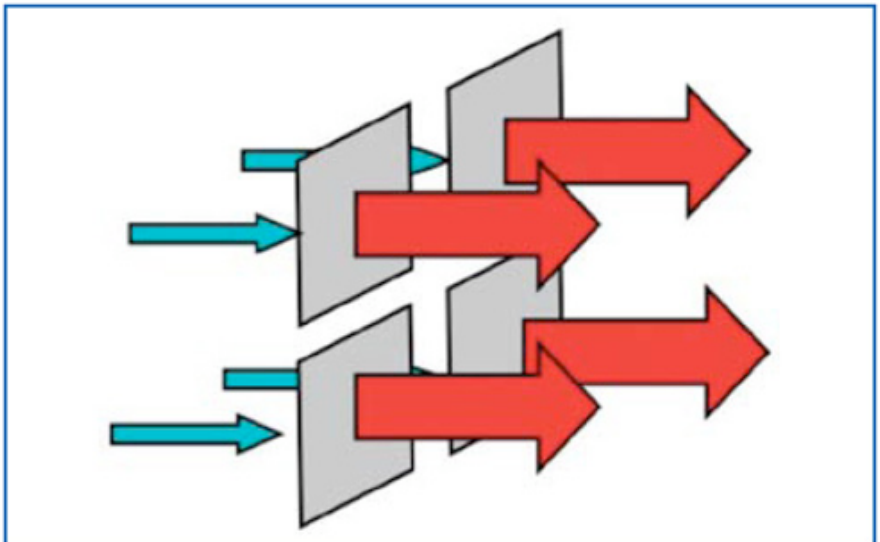


Figure 2: Spatial combining grid architecture

Spatial Combining Architectures
All three architectures lend themselves well to solid state amplifier development, and have proven themselves to be viable replacements for the standard traveling wave tube amplifier (TWTA) for applications that require moderate power, and moving into applications that require higher power and wider bandwidth. These applications include laboratory test equipment, semiconductor test, military, electronic warfare, simulation, and towed decoys. They are also useful for C, X, and Ku and Ka band satellite transmitters, as well as tri-band transmitters and radar simulators.

The grid architecture (**Figure 2**) consists of a number of amplifiers laid out on a grid in array fashion in a rectangular waveguide structure. Each amplifier has its own input and output antennae, the output antennae being orthogonal to the input antennae, which provides isolation through polarization. Grid amplifiers are manufacturable using standard semiconductor technology, making them suitable for high volume applications. They can be used as single-ended (reflection) or two-port (transmission) amplifiers, and are especially good for higher frequencies (millimeter wave and above). A potentially large number (hundreds) of devices can be combined/fabricated from a single monolithic device, providing very high power. However, the inner devices of the array tend to suffer from heat concentration and poor thermal pathways, along with substantial mutual heating, and generally offer narrow bandwidth due to limited bandwidth antennas. They are considered cost-effective primarily for high volume applications, because, although they are expensive to develop and must be customized for each application, they can take advantage of low loss, high volume semiconductor manufacturing techniques.

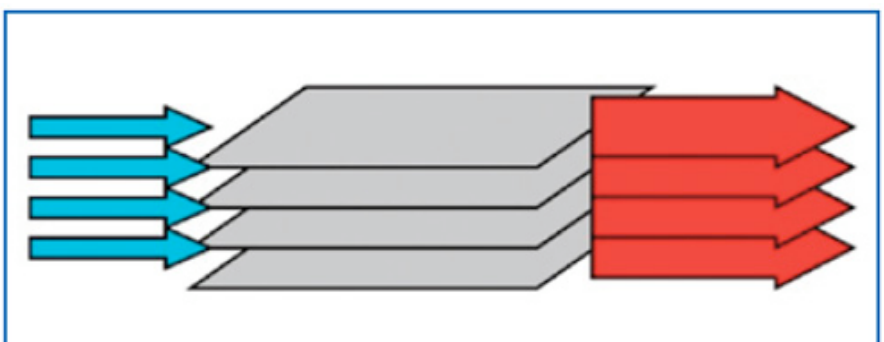
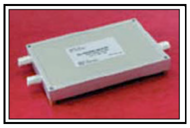


Figure 3: Spatial combining tray architecture

The tray architecture (**Figure 3**) consists of a number of amplifiers situated like cards in a rectangular waveguide. This provides enhanced thermal pathways through individual thermal conduction paths. Tray amplifiers offer an inherent rectangular waveguide interface, are

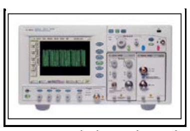

The ultra low noise ZX60-0916LN+ boasts a noise figure of only 0.55 dB, while delivering 18 dB gain and a high output power of up to 16.5 dBm, making it a very desirable amplifier in today's market, as it covers a broad range of applications.

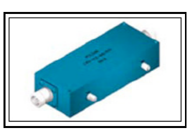

Broadband Switch Matrix
Customized electromechanical switch matrix systems are now available. These bi-directional matrix systems operate from DC to up to 18 GHz and can be configured with up to two inputs and up to 18 outputs. RF performance varies with frequency range.


WiMAX Injector-Diplexer
A new low cost WiMAX Injector-Diplexer has been developed to separate or combine the 2500 to 2700 MHz WiMAX band with all the wireless frequencies from 80 to 2170 MHz. Using suspended substrate, wireless frequency loss is minimized to less than 0.3 dB and the loss at WiMAX frequencies is just 0.8 dB.


Cable Connectors
This line of precision coaxial cable connectors for semi-rigid and flexible cable is available in direct solder and/or solder clamp attachment. Interfaces include 1.85, 2.4, 2.92 and 3.5mm, plus N, SMA, SSMA, and TNC.


Flexible Cable Low Pass Filter
Cable Low Pass Filters are now available with hand formable .086 semi rigid cables. Passbands are available up to 26 GHz. Impedance is 50 ohms, power rating is 2W (average), and connector type is SMA Male. Minimum bend radius is 0.23.

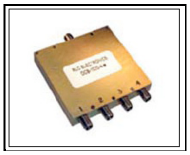

DCA-J Firmware Update
A firmware update for the 86100C DCA-J allows R&D engineers to run MATLAB® scripts and directly calculate Transmitter Waveform Dispersion Penalty and other performance parameters without external processing. This direct link saves timeby displaying live numerical results.


Coupler
Model C40-112-481/5N covers the frequency range of 0.1 to 500 MHz with a power rating of 200W, 40 +/-1 dB coupling, 0.5 dB insertion loss and 20 dB directivity. Coupling flatness is +/-0.5 dB and VSWR is 1.2:1. Outline dimensions are 5.0 x 2.0 x 1.2".

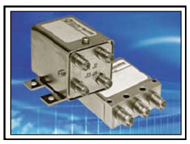
Voltage Controlled Oscillator
The CVCO55CC-2425-2440 VCO operates from 2425 to 2440 MHz with a control voltage range of 0.3 ~ 4.7V. It features a typical phase noise of -113 dBc/Hz @ 10 KHz offset and has excellent linearity. It comes in the industry standard 0.5 x 0.5" SMD package.

Conformance Testing

Support
The company's 6401 AIME A-GPS is the only test platform available that supports the industry-standard TTCN A-GPS protocol test cases as well as the Minimum Performance tests and the OMA (Open Mobile Alliance) SUPL V1.0 (Secure User Plane Location) conformance tests, as mandated by the Global Certification Forum (GCF) and PTCRB handset certification bodies.



DC Block Power Dividers/Combiners
Series DCB-1020 is an in phase power divider/combiner with high isolation, small size and superior performance in a single package. These units utilize microstrip construction with blocking capacitors on all ports except those that are intended to pass DC.



Five Million Cycle Switches
Part of the 5 Million Cycle Switches line, the SPDT (401-U series) and the transfer (411CU-series) switches offer high reliability with five times the life. Applications include commercial, wireless and satellite communications, as well as many others.

mechanically simple because of the multiple, stacked machined or cast units, and can use standard or custom integrated circuits (ICs) or devices for amplification. They are effective as feedmount amplifiers because the transmitter can be mounted at the antenna, minimizing feed losses. Some of the disadvantages, however, are that their center elements have increased thermal load and they are limited to the waveguide bandwidth. In addition, the rectangular waveguide has varying field distribution across waveguide, resulting in inefficient use of amplifiers at the waveguide boundary or requiring complex scaling of devices for efficient power amplification or implementation of complicated H-plane boundaries to improve the E-field uniformity.

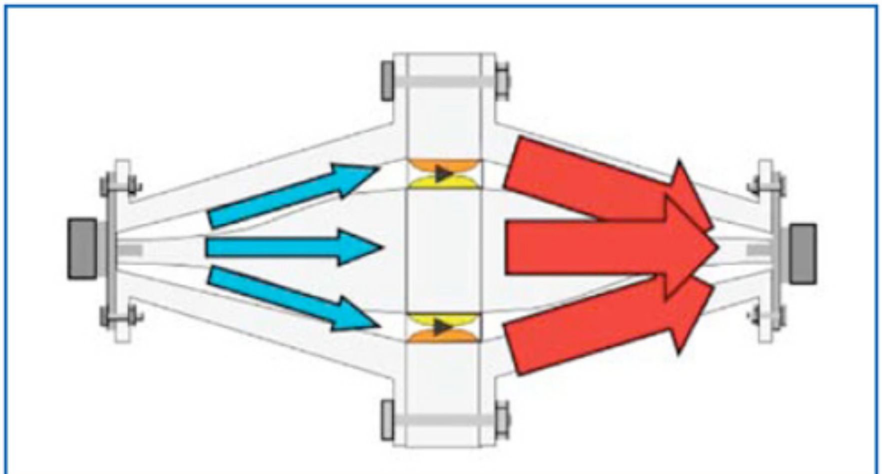


Figure 4: Spatial combining coaxial architecture as implemented in Spatium power amplifiers

The coaxial arrangement, as implemented in the Spatium technology (**Figure 4**), can be visualized as an oversized coaxial guided wave structure. A tapered center conductor transitions from the coax connector interface to a larger center conductor. Once the enlarged radius coaxial line is reached, multiple antipodal finline antenna elements arranged radially around the center gather all the microwave energy across a wide frequency spectrum, and transition the gathered signals to several microstrip transmission lines. Each microstrip line feeds a monolithic microwave IC (MMIC) power amplifier housed in a 20 GHz resonance-free ceramic package, where the signals are simultaneously amplified by equal amounts. The amplified signals out of the MMICs are launched back onto microstrip lines, which then couple to output antipodal finlines back into a coaxial waveguide, where the fields coherently combine. The output signal transitions through a tapered coaxial line back to an output coaxial connector, providing the high output power levels.

Coaxial amplifiers combine large numbers of amplifiers in an inherently low loss structure, providing a unique combination of broad bandwidth and high power. They are efficient and linear, and operate in a transverse electromagnetic (TEM) mode that means all amplification elements operate on the same amplitude signal. They can use standard or custom MMICs, and the uniformity of the MMICs and the intrinsic structure enables the maintenance of nearly identical phase and amplitude variation through all amplification channels, resulting in high power combining efficiencies. The radial structure of the elements enables three-dimensional heat dissipation. Coaxial amplifiers are mechanically complex and have multiple non-orthogonal surfaces.

Renaissance of Development in the 1990s

The explosion of the wireless revolution in the 1990s has influenced and affected virtually everything about the way the world operates. From key enabling wireless technologies have sprung many other technologies, not the least of which is spatial power combining. The development of high power semiconductors using wide band gap technologies, combined with more sophisticated and accurate 3D EM modeling techniques and mechanical and thermal modeling capabilities, has spurred renewed interest in the 1990s in the development of practical, cost-effective spatially combined platforms. 100-150 watt X-band power amplifiers as well as multiwatt Ka band amplifiers have been demonstrated. The spatial combining structure has been implemented with gallium arsenide (GaAs) MMICs and gallium nitride (GaN) semiconductor technology.

As the wireless revolution moves into the 2000s, universities continue their research and several private organizations are developing and deploying practical architectures which, in turn, are spurring the development of sophisticated applications never before possible with older, less powerful, less reliable, and more costly power amplifier technologies.

Figure 5: Physical implementation of spatial combining coaxial architecture in Spatium amplifier

Characteristics Superior to Circuit Combined Amplifiers

Spatial power combining amplifiers augment traditional power amplifier architectures and expand the market space of solid state power amplifiers (SSPAs) into the domain traditionally dominated by vacuum electron devices (VEDs) such as traveling wave tube amplifiers (TWTAs). They provide the stability and reliability associated with solid state amplifiers as well as exceptionally broad bandwidth and high power. Their manufacturability, scalability, linearity, efficiency, and thermal packaging are generally superior to circuit combined amplifiers. Characteristics of spatially combined amplifiers include excellent linearity relative to VEDs, graceful degradation on failure, low voltage operation, solid state reliability, low intermodulation and harmonic distortion, flat gain without equalization, and good phase noise characteristics. They are fault tolerant, so that the loss or failure of one or even multiple elements does not result in total system failure, and they do not have the warm-up, drift, or aging issues associated with TWTAs. Because the combining losses are low and power is not wasted in the combining scheme, the operational efficiencies are maximized, resulting in lower heat dissipation and less prime power for a given power level. Also, because of the high number of combined elements, the root mean square (RMS) phase noise of the amplifier is less than that of a single comparable device and significantly lower than what might be expected from a TWTA.

Spatial combining technology is able to take advantage of commercially available devices and technologies, and it is a simple process to change the design for different applications without having to change the entire structure, eliminating traditional time-consuming redesigns for variations and enabling significant time-to-manufacture cost-savings for customers. Additionally, as semiconductor technology and capability improves, spatially combined amplifiers can rapidly implement the nascent technology.

Current Applications

Test Equipment

The replacement of TWTAs with spatially combined amplifiers in the test equipment market has significantly impacted electromagnetic interference (EMI), safety, and measurement accuracy. Tubes characteristically have high noise floor and poor intermodulation and harmonic signatures. Since they typically take time to warm up and stabilize, tubes are often left on, making them a potential safety issue, as well as a potential cause of EMI. Spatially combined amplifiers require no warm-up, so they can be turned on and off as needed, eliminating concerns about significant short and long term stability, safety, and EMI issues.

Satellite Block Up-converters (BUCs) and Satellite Uplink PAs

Some manufacturers have reported producing moderate (15 watt) hubmount fanless block up-converters for satellite communications applications using spatially combined amplifiers. The outstanding combining efficiency produces a higher overall amplifier efficiency than would be achievable with a conventional architecture SSPA, resulting in less dissipated heat, eliminating the requirement for forced air convection (fans), improving overall reliability, and reducing size. Ka band grid-style amplifiers are also being deployed for the new Ka band satellite communication bands, offering power levels that have previously only been available from VED amplifiers.

TWT Replacement

Because of the similarity in form factor and bandwidth capability, coaxial spatially combined amplifiers are being considered for numerous TWT replacements in everything from unmanned aerial vehicles (UAVs) to ground- and shipboard-based equipment. These implementations bring the promise of increased reliability, robustness and graceful performance degradation.

Summary
The need continues to grow for components that can be implemented in various highly specialized applications with more bandwidth and efficiency, higher power, better noise figure or pulse response, lower spurious, and more compact size. These include wide band applications such as electronic counter measures (ECM), laboratory instrumentation, towed decoys, multi-band communications and EMC/EMI test, and narrower band applications such as ground penetrating radar, microwave imaging, and tri-band satellite communications. Research and development efforts in recent years have been made possible by advances in semiconductor device technology and modeling capabilities and have been spurred by customer demand for an amplifier architecture that could provide, in a compact package, the reliability and ruggedness associated with SSPAs and the signature low thermal-noise characteristic of solid-state performance — all at a competitive price.

The novel spatial power combining structure shows great promise for revolutionizing the microwave power amplifier industry. Applications traditionally dominated by TWT or VED solutions, such as test and measurement, electronic warfare, electronic counter measures, and simulators, can now take advantage of all the associated preferable performance attributes of solid-state implementation, including: higher reliability, low-voltage operation for safety and reliability, longer life, low thermal noise characteristics for improved signal-to-noise ratios, and improved linearity.

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1. Sean C. Ortiz, "High Power Spatial Combiners: Tile and Tray Approaches," P.hD. Dissertation, North Carolina State University, 2001 [http://www.lib.ncsu.edu/theses/available/etd-20011119-214207/unrestricted/etd.pdf] p. 3.
2. Ibid,

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