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TECHNICAL ARTICLE

SWaP: THE RF SOLUTION THAT CAN MEAN THE DIFFERENCE BETWEEN FLYING HIGH AND BEING GROUNDED

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Abstract

Commercial and defense airborne platforms differ in many ways; commercial aircraft place high emphasis on safety and system redundancy, while defense platforms may focus on multifunction systems and power management. One area of common concern for commercial and defense airborne platforms is maximizing payload efficiency. Every ounce of weight, cubic centimeter of space, and milliwatt hour of power is carefully planned. Both are focused on size, weight, and power—SWaP. Advances in RF technology can provided a leap frog advantage for commercial and defense airborne platforms, manned and unmanned. This article will focus on these RF technology advances and give the reader a high altitude view of the problem followed by a detailed look at a few solutions. Some of the systems discussed are multifunction radar, electronic warfare, and wireless sensor technology.

Flying History

The space shuttle was the workhorse of the United States space program and quite frankly the global space exploration and satellite implementation programs. The shuttle or orbital vehicle (OV) was designed starting in 1969 and reached low orbit in 1981. Specifically, the electrical power system (EPS) was given significant consideration. The EPS consisted of power reactant storage and distribution, fuel cell power plants (electrical power generation), and electrical power distribution and control. Much time and effort was given to the EPS for providing the 28 V_{DC} and 115 V_{AC} power rail to the OV. These systems and subsystems were complex, heavy, and very inefficient but the electrical system was a significant part of the overall payload calculation.

Fast forward to 2015, there are several unmanned aerial vehicles (UAV) projects in the development phase that fall into a special category: high altitude long endurance (HALE). One project in particular has set the goal of five years unreplenished flight. The challenges of the environmental, airframe, and power plant system requirements alone are quite daunting and the attention that will need to be given to the electrical power generation, delivery, and recapture will be critical to the success of these programs. The communications systems will also be designed with size, weight, and efficiency at the highest consideration. Thankfully Analog Devices, Inc. (ADI) has been proactive in its effort to provide such components.

A great example of this is ADI's transceiver portfolio; very diverse, full spectrum coverage and highly integrated solutions for low power, small footprint components. Detailed discussions about this and other component solutions are interleaved within this article.

Much of the problems and solutions herein are presented with airborne platform examples; others use shipboard platforms. The reader should be aware that the problem statements and associated solutions for air- and sea-based platforms have close ties and are often variants of the same system.

What Is SWaP?

Size, weight, and power (SWaP) refer to arguably the most important specification in new product, project, or platform definition. Nearly all new developments, whether shipboard, airborne, terrestrial, man carried, or hand carried, share a common requirement: make it smaller, make it use less of the available resources, and make it contribute more to the overall system functionality. In recently speaking to a radar system architect, the discussion was about phased array radar and a active electronically scanning array (AESA), from 50 foot to a 1000 foot view and how the designer had very intelligent ideas to increase system accuracy, range, and data transfer. SWaP challenges killed all of his careful calculations. A lean system is more desirable in the current social, economic, political, and global environments. Lately, and more often, SWaP seems to be the key driving factor, providing difficult trade-offs over system performance enhancements and multifunction architectures.

Culprit Identification

Before we discuss some of the solutions to SWaP problems, let's take a look at a few of the miscreants, scandalous offenders, and substantially burdensome characters.

Cu! Copper is the conductor of choice for electrical power transmission. One thousand feet of AWG 5 gauge copper wire without insulation weighs nearly 100 pounds (50 kg). To add further insult to injury, the inherent resistance of wire causes electrical current to be wasted in the form of dissipated heat. The next perpetrator in the line-up is legacy component size. For example, let's examine the case of the shipboard radar local oscillator (LO). The LO feeds both the transmitter and receiver. The LO must produce a stable frequency with low harmonics and the highest stability requirements must take into account temperature, voltage, and mechanical drift. The oscillator must produce enough output power to effectively drive subsequent stages of circuitry, such as mixers or frequency multipliers. It must have low phase noise where the timing of the signal is critical. Historically the LO was generated and distributed by a separate and specially designed subsystem. The same or similar was true for airborne systems—large size, power hungry, and heavy due the solid-state component content.

The legacy component that has provided high power RF to a system is the traveling wave tube (TWT). Great, not broken, why fix it? What is a TWT? A TWT is a specialized vacuum tube that is used in electronics to amplify radio frequency (RF) signals in the microwave range. The bandwidth of a broadband TWT can be as high as one octave, although tuned (narrow-band) versions are more common; operating frequencies range from 300 MHz to 50 GHz. These TWT systems are somewhat efficient, but they are a single point of failure. Reliability is a significant concern with TWTs. Microwave tube reliability is strongly dependent on three factors. First, defects introduced during the manufacturing process adversely affect reliability. Production problems, poor workmanship, and lack of process control are major contributors to manufacturing defects. Secondly, tube reliability is heavily dependent upon operating procedures and handling. Finally, adequate design margins must exist between the operating point and the ultimate design capability of the tube in order to have reliable operation. These are just three examples of the many enemies of SWaP.

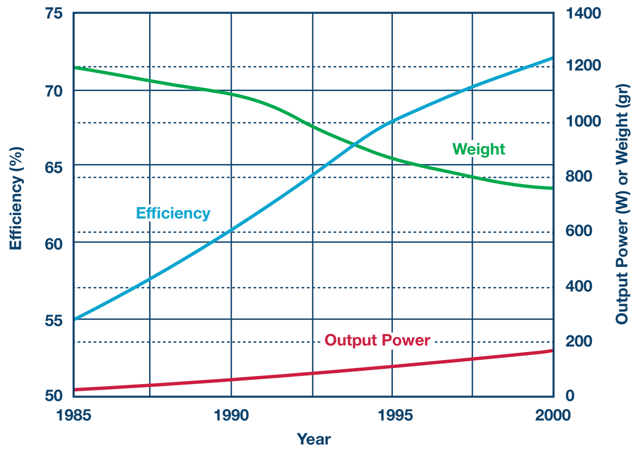

Figure 1. Graph illustrating TWT improvements in efficiency, output power, and weight against time.

The Superheroes of SWaP

Every villain needs an associated superhero. Advances in semiconductor technology and component integration have played a significant role in reducing SWaP. The next section of this article will highlight key achievements that directly affect the SWaP equation and enable technological leap frog advancements starting today and for the foreseeable future. The three technologies that are discussed in this section: solid-state power amplifiers, component integration, and wireless sensor technology.

Solid-state power amplifiers (SSPA) are not a new technology. GaAs (gallium arsenide) and LDMOS (laterally diffused metal oxide semiconductors) have been used for high power amplifiers for many years. Silicon-based LDMOS FETs are widely used in RF power amplifiers for base stations as the requirement is for high output power with a corresponding drain to source breakdown voltage—usually above 60 V. Compared to other devices, such as GaAs FETs, they show a lower maximum power gain frequency. LDMOS FETs operate with the highest efficiencies below 5 GHz. A gallium arsenide field effect transistor (GaAsFET) is a specialized type of FET that is used in solid-state amplifier circuits at microwave radio frequencies. This spans the spectrum from approximately 30 MHz up to the millimeter wave band.

The GaAsFET is known for its sensitivity, and especially for the fact that it generates very little internal noise. The power density is limited by the breakdown voltage. You can get 20 V breakdown on a good day with a GaAs MESFET. Let's review; TWTs have high frequency and high power available, but the reliability, weight, and required supporting subsystems make them undesirable. LDMOS allows for high power, but operates below 5 GHz. GaAs MESFETs operate at very high frequencies, but the low breakdown voltage limit them to the 10 W power range. Is there a hero? Is there SSPA leap frog technology available to save the day? SWaP loves gallium nitride on silicon carbide (GaN on SiC). Both GaN and SiC are wideband gap material, which means the combined breakdown voltages are as high as 150 V. This allows higher power density along with a lower load line for easier impedance matching. GaN on SiC allows power gain at frequencies in the millimeter bands (Ft ~ = 90 GHz, Fmax ~ 200 GHz).

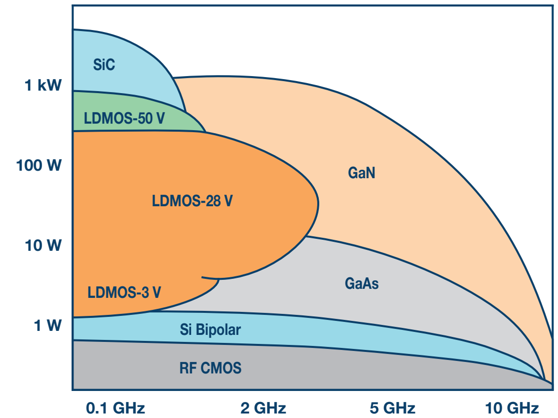

Figure 2. Power vs. frequency per process.

The market acceptance of GaN on SiC LEDs have helped fill the wafer fabs and drive wafer costs down. The device structure of the RF transistors is such that power densities of 5 W/mm can be achieved. The MSL levels for GaN on SiC are near or arrived at industry acceptable ratings. GaN on SiC is widely agreed upon to be interruptive technology and the defense and commercial markets are demanding more of it. The performance of GaN on SiC is limited most by thermal transfer; getting the heat away from the device is the last issue to unravel. Some success has been found with GaN on silicon, but the reduced thermal conductivity limits the output power to near 10 W. The best performance comes from GaN on diamond. Scientific calculation points to power densities at up 10 times higher than GaN on SiC available today.

Figure 3. KHPA-0811 8 kW HPA.

Although the direct growth of GaN on single crystal diamond has been demonstrated, the single crystal diamond substrates currently available have a maximum size that today limits the adoption of the technology. The government and defense contractors are the only early adopters of the GaN on diamond alliance. Similar to GaAs in the 1980s, GaN on diamond will be vetted through these government agencies and the commercial market will follow as the reliability increases and the associated cost decreases. The TWT has an integrated SSPA replacement. ADI offers an up to 8 kW high power amplifier (HPA) that combines many GaN on SiC SSPAs into a single unit. The KHPA-0811 uses a small, dodecahedron package to pack a considerable amount of power in a small footprint and cover a wide bandwidth.

Integration Sinks the Boat Anchor

For clarity, in the U.S. Navy, when large electronic (or other) equipment became obsolete and a burden on the system resources, it was referred to as a "boat anchor." An airborne platform, whether manned or autonomous, will have many forms of communications on board. These comms links vary from voice, navigation, data links, on-board sensor links, radar, munition tracking, and the list gets longer as the skies get more crowded and the warfare theater becomes more complex. In the past, any one of these systems required significant real estate, power resources, and supporting subsystems. The fact that the airborne platforms were actually airborne is amazing. Every ounce was accounted for, every milliwatt was calculated, and the physical system design was considerable to fit into the allotted space. There had to be a better way.

Integrated circuit (IC) design advancements along with system in package (SiP) and system on chip (SoC) advancements have made boat anchors of those bloated systems of yesterday. Let's take a closer look at a great example of system integration. Analog Devices has released an industry-leading transceiver that puts the capabilities of a massive and power hungry comms link into a 10 mm × 10 mm package. The AD9361 is a high performance, highly integrated radio frequency (RF) Agile Transceiver.™ Also from ADI, the AD9671 is designed for low cost, low power, and small size. The original design was intended for 8-channel ultrasound implementation, but many commercial and defense systems designers are looking to use COTS components because of the level of integration, lower cost, and availability. The ADF7242 ultrawideband, low power, low cost transceiver would be another example of an integrated design that is being considered for systems outside of the scope of the original design. Drop the boat anchors, reel in the SiPs and SoCs.

Cut the Copper Umbilical Cord

Commercial and defense aircraft, manned and unmanned, have hundreds if not thousands of sensors and many have redundancy and backup support systems. These sensors range from flap and aileron position sensors, navigation and positioning sensors, engine vibration, brake temperature; the list is long and growing. Each of these sensors along with their associated redundancies, are connected to a central processor via large heavy cables comprised of copper wiring and stainless or aluminium connectors. The point is, significant platform resources are consumed to support these cables and interconnects. RF technological advancements will once again save SWaP by reducing the dependency on these cables. Many major airframe manufacturers are working together to qualify commercial off-the-shelf (COTS) technology for a low cost, reliable replacement for copper interconnectivity.

For example, take an inertial measurement unit (IMU) sensor with output data bandwidth requirements less than tens of kHz, combined with a precision analog microcontroller ARM® Cortex®-M3 with RF transceiver from Analog Devices. The ADuCRF101 is a fully integrated, data acquisition solution that is designed for low power, wireless applications. It is designed with emphasis on flexibility, robustness, ease of use, and low current consumption. This marriage is purely hypothetical, but would be one example of avionics sensor technology pairing with COTS RF components. Standby for this type of RF implementation to save SWaP in the very near future.

Conclusion

The social, political, and economic environments of today require airborne platform designers to put increased focus on saving size, weight, and power. The reduced loading on system resources allows for longer flight times, reduced fuel requirements, and more efficient payload allowances. The most significant and most interesting advancements to save SWaP come directly from the technological advancements made in the RF community. The most advantageous progress revolves around size reduction from TWTs to SSPAs, component integration, and reduced dependency on copper cable interconnects. RF technology will keep the aeronautical industry flying high for many years to come. The solution that provides reduced SWaP is spelled RF.

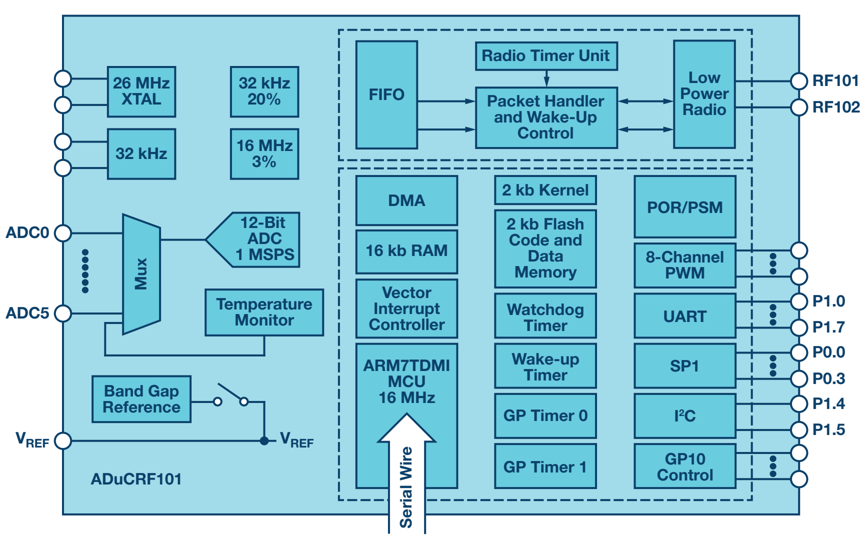

Figure 4. ADuCRF101.

About the Author

Jarrett Liner is an RF systems applications engineer with Analog Devices in the Aerospace and Defense Group, Greensboro, NC. He has significant experience in the area of RF system and component design. Formerly, Jarrett was an applications engineer for GaN on SiC amplifiers for the military and aerospace sector. His prior experience also includes design and test of RF IC WLAN power amplifier and front-end modules for 13 years. He served six years in the United States Navy as an electronics technician. Jarrett received his B.S.E.E. from North Carolina Agricultural and Technical State University located in Greensboro, NC, in 2004. When Jarrett isn't simulating circuit solutions or taking data in the lab he might be found mountain biking, teaching cycle class at the gym, running, or chasing his four kids around the yard. He can be reached at *jarrett.liner@analog.com*.

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