Microwave Power Modules (MPMs)
Miniature Microwave Amplifiers for Radars

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Abstract

A recent and dramatic shift with military aircraft has been the widespread use of UAVs (unmanned aerial vehicles). Most previous-generation UAVs do not carry radar and, therefore, do not have all-weather visibility. But now, nearly all large UAVs have radars as standard equipment.

UAVs require miniature and lightweight radars with low power consumption. Previously, there was little demand for such radars and industry had few product offerings. However, several manufacturers are now developing new miniature airborne radar systems. This creates a need for miniature radar transmitters. Microwave Power Modules (MPMs), a new class of microwave amplifiers, is the enabling technology for these transmitters.

MPMs are hybrids of solid state and vacuum tube technology. Within the MPM is a solid state driver amplifier, a TWT output amplifier, and an integral power supply. MPMs provide approximately 100 watts in narrow and wide band versions within the 2 to 18 GHz frequency range.

To date, the primary use of MPMs has been in satellite uplink systems. But now, MPMs are being increasingly used in new miniature transmitters for radars. The requirements for radars are more stringent than for communication applications, particularly the phase noise and pulse characteristics. This paper describes MPMs and their performance characteristics for miniature radar transmitters.

Keywords: Microwave Power Module, MPM, miniature radar, transmitter, SSPA, TWTA

Introduction

After decades of development, Unmanned Aerial Vehicles (UAVs) are now being used with great success in a variety of applications. UAVs perform tasks that would put lives at risk or would be more difficult and/or expensive if performed by piloted aircraft. In addition to their usefulness, UAVs are relatively affordable compared to similar piloted aircraft. As a result, the UAV market is growing at an accelerated rate.

There are a wide variety of UAVs under development, from small hand-launched devices to full-sized aircraft. The larger of these, typically medium and high altitude long endurance aircraft, have over 100 kg available for sensors. Electro-optical and infrared systems have been standard equipment on these aircraft, but these technologies have limited visibility through poor weather and smoke. The solution to this problem has been the incorporation of radars, since they have the ability to see through these conditions.

In order for radars to be useful for UAVs, they must be extremely small, lightweight, and efficient, consuming a limited portion of the overall space, weight, and prime power available for sensors. However, they must also be powerful enough to be effective from 5,000 to 15,000 meters in altitude. Several years ago, the best radars available for UAVs were those used on helicopters and maritime patrol aircraft, as these were the smallest of the high-resolution airborne radars. However, even these radars were too heavy and consumed too much power to be practical for most UAVs.

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As a result, there is now a significant and growing market for miniature, low power, high-resolution radars for UAVs. In response, several companies are developing synthetic aperture radar (SAR) systems specifically designed for UAVs at a fraction of the size and weight of their standard airborne radars. General Atomics in the U.S. and Sandia National Laboratories collaborated on a 52 kg. Lynx radar that has a range of 35 km[1]. Sandia recently demonstrated an 11 kg. miniSAR radar with a 6 km. range[2]. In Europe, EADS has a 5 kg. radar called MiSAR with a range of 5-10 km[3] and Thales has the I-Master radar at 30 kg. with a range of 20 km[4].

A key determinant in the size, weight, power consumption, heat dissipation, range, and cost of a radar system is the output transmitter. Since these parameters are extremely important to UAVs, the transmitter takes on even greater importance for these applications. Transmitters include a high power microwave amplifier, a regulated power source for the amplifier including the control electronics, and the associated cooling.

Thus, the new miniature radar market has created the need for miniature transmitters, much smaller, lighter, and more efficient than previous airborne transmitters. Enabling the development of these transmitters are Microwave Power Modules (MPMs). MPMs are a relatively new class of microwave amplifiers, with tremendous advantages over other technologies for UAV applications. This paper describes the performance achievements of standard MPMs and a new product – a pulsed MPM designed for miniature radar systems.

Microwave Amplifiers for UAV Radars

There is a tradeoff between the output power of the amplifier and the size of the antenna. For a given effective radiated power (ERP), an increase in the amplifier output power will result in a smaller and lower gain antenna.

For UAVs, it is desirable to have a very small and lightweight microwave amplifier with relatively high output power. It is also important for the amplifier to have high efficiency in order to keep the UAV prime power source and the transmitter cooling as small and light as possible.

For radars, the microwave amplifier must also have special performance characteristics. It must have excellent pulse characteristics and extremely low phase noise. The primary requirements for power microwave amplifiers used for UAV radars are summarized below:

- Low phase noise
- Small size and lightweight
- High power
- High efficiency

There are three basic types of amplifier technologies suitable for modern airborne radars:

- Semiconductor technology
  (solid state power amplifiers, or SSPAs)
- Vacuum Electronics technology
  (traveling wave tube amplifiers, or TWTAs)
- Hybrid of semiconductor and vacuum electronics technology (MPM amplifiers)

Each technology has advantages and disadvantages, with the primary discriminators being efficiency, weight, cost, risk, and performance.[5] Figure 1 below shows where each technology excels.

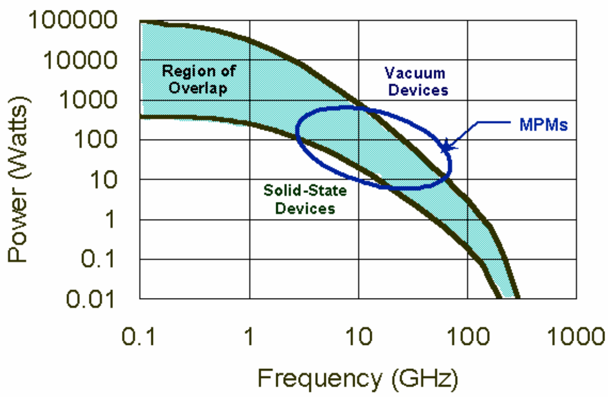

Figure 1 - Amplifier Output Power vs. Frequency

For UAV radars, the primary frequency bands of interest are X, Ku, and to a lesser extent, Ka, and the desired output power is in the range of 25 to 100 watts average and up to 1,000 watts peak. Comparing these numbers with the graph in Figure 1, MPMs are indicated to be the optimum technology for UAV radars.

This is proving true in practice. System developers are turning to the MPM for reduced system size, weight, and cost for new SAR/MTI systems and for upgrades to existing systems.

MPM Description

MPMs are hybrids of solid state and vacuum electronics technology that offer significant advantages over traditional high power amplifiers: a super component that takes advantage of the best features of both solid state and vacuum tube technology.[6,7]

A MPM includes a solid state driver amplifier (SSA), a traveling wave tube (TWT) output amplifier, and an integral high-density power supply as shown in Figure 2.

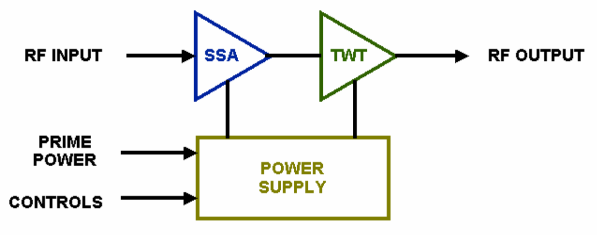

Figure 2 – MPM Block Diagram

The MPM concept surfaced at a US DOD Special Technology Review in 1988.[8] The performance goals developed in 1989.[9,10,11] are listed below in Table 1.

Parameter	Goal
Frequency (GHz)	6 to 18
RF Output Power (Watts)	50 to 100
Gain (dB)	50
Duty Cycle	0% to CW
Efficiency	33%
Noise Power Density (dBm/MHz)	-45
Noise Figure (dB)	10
Volume (cubic in / cc)	7.5 / 123
Thickness (in / cm)	0.31 / 0.79

Table 1

Most of the goals were subsequently achieved in the early 1990s as part of development programs, and now a variety of MPMs are available. An example is L-3 Communications Electron Devices Division's M1220 MPM, with the power versus frequency depicted in Figure 3 below.[12]

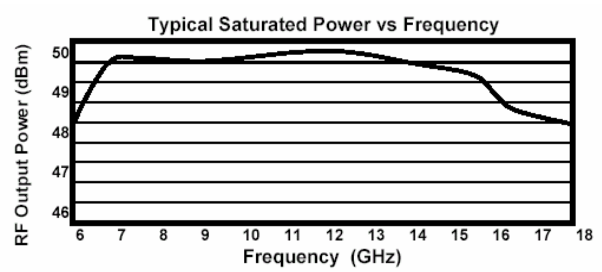

Figure 3 - L-3's M1220 MPM Power Output versus Frequency

The MPM components (SSA, TWT, power supply) are specifically designed for operation within a MPM. The TWT provides the high power RF output. The gain is split equally between the TWT and SSA, which together form a low noise, high gain, high power, and high efficiency microwave chain. The power supply accepts the input prime power voltage, generates the required voltages to the SSA and TWT, and performs timing, control, and protection functions. Figure 4 is a photograph of the internal view of a typical MPM. Each of the three subcomponents is described in greater detail below.

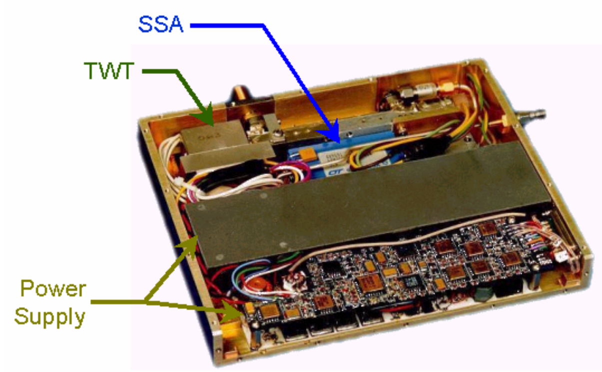

Figure 4 – MPM Internal View

SSA Description

The SSA receives the RF input and amplifies it to provide sufficient RF drive to saturate the TWT. It is typically a PHEMPT GaAs device. Temperature compensation can be added to maintain constant MPM gain over temperature.

Power Supply Description

A block diagram of a typical power supply is shown in Figure 5. The prime power input is shown on the left, as are the control and monitor signals. The outputs for the SSA and the TWT are shown on the right. The Logic/Power Conditioner section is a low voltage subassembly; the High Voltage/Modulator is a high voltage subassembly.

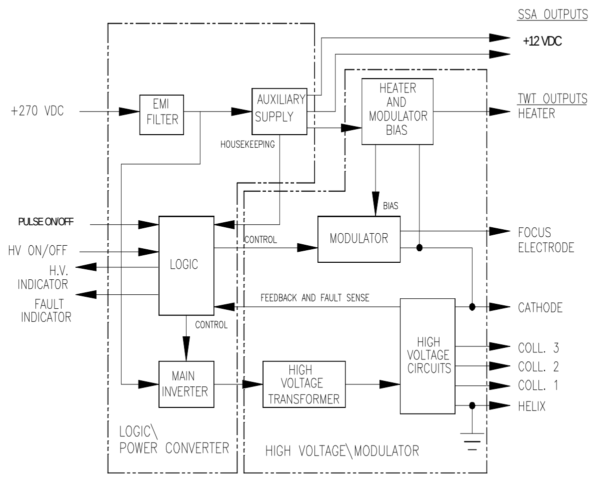

Figure 5 – Power Supply Block Diagram

There are various prime power options for MPM power supplies, including 270 VDC, 28 VDC, or 3-phase, 115 VAC. Extensive use of surface-mount power electronic components, novel planar transformers, high frequency switching, and innovative circuit and packaging techniques have resulted in MPM power supplies that are approximately one-tenth the size and weight of previous generation power supplies.

TWT Description

TWTs are vacuum electronic devices that transfer kinetic energy from an electron beam to a RF signal, thereby providing amplification.[13] TWTs provide microwave power at levels unattainable with solid state technology. TWTs, such as a helix TWT as shown in Figure 6, contain an electron gun, RF circuit slow-wave structure, and a collector.

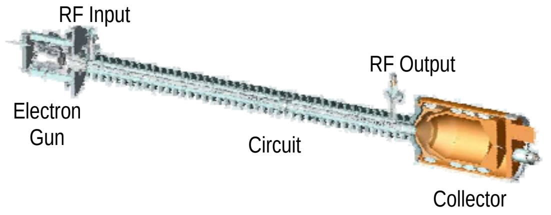

Figure 6 – Cross-Section View of a Helix TWT

The electron gun consists of a cathode, a heater, a focus electrode, and an anode. The heater warms the cathode to a temperature sufficient to release electrons. The anode, at positive potential with respect to the cathode, attracts electrons from the cathode and they gain kinetic energy as they travel towards the anode. The focus electrode compresses the beam so it can pass into the circuit.

Magnets about the circuit keep the electron beam focused as it travels from the electron gun to the collector. The input RF signal is introduced into the circuit at the RF input port. Interaction between the electron beam and the RF signal spiraling about it results in kinetic energy being transferred from the beam to the RF signal. This power is extracted from the circuit at the RF output port.

After RF power is extracted from the electron beam, a large fraction of the remaining beam energy is recovered in a multi-stage depressed collector.

MPMs for UAVs

There are several advantages of MPMs compared to traditional amplifiers employing only solid state or vacuum electronics. The primary advantages for UAV applications are size, weight, and efficiency. These advantages are not incremental in comparison to traditional amplifiers; they are revolutionary. In addition to the size, weight, and efficiency advantages, the MPM also has low noise and is typically lower in cost than traditional amplifiers. These advantages are summarized in Table 2.

MPMs are available from manufacturers in Europe, the USA, and Japan, with products providing approximately 100 watts in narrow and wide band versions within the 2 to 18 GHz frequency range, and some lower power versions in Ka band and higher.

Typical MPM Advantages compared to Traditional TWTAs and SSPAs (100 watt Ku band example)

	MPMs vs. TWTAs	MPMs vs. SSPAs
Size*	5:1 reduction	8:1 reduction
Weight*	5:1 reduction	8:1 reduction
Noise	100:1 reduction	~2 dB degradation
Efficiency	50% improvement	3:1 improvement

*Includes Power Supply and Cooling

Table 2

MPMs are presently being used in UAVs with great success. To date, the primary use of MPMs for UAVs has been in satellite uplink systems. Both the Predator and Global Hawk UAVs contain satellite communication links employing MPMs. Their use minimizes the size of the system and the prime power consumption.

The TESAR radar on the Predator uses MPMs[14], and MPMs are being designed into other miniature transmitters for radar applications. The technical requirements for radars are different and more stringent than for communication applications. In particular, since modern SAR (synthetic aperture radar) systems rely on accurate phase information for image processing and since the transmitter is a major component of the overall system phase noise, the MPM phase noise is critical for radar applications. Also very important for radar applications are the MPM pulse characteristics.

100 Watt MPM

Standard MPMs typically provide approximately 100 watts of output power in X and Ku frequency bands. These MPMs are less than 770 cc in volume and 1.75 kg in mass, and require less than 150 watts of prime power when operated at a 25% duty cycle. Such MPMs provide sufficient output power for small SAR/MTI systems for a wide range of UAVs.

However, these standard MPMs are primarily used for communications applications and are typically operated in the CW mode. While they can generally be pulsed, they are not designed for radar applications. For good pulse characteristics, it is essential that the voltages from the power supply to the TWT have minimal deviation (e.g. <0.1% on the cathode) throughout the pulse. Standard MPMs power supplies do not achieve this level of voltage stability and, therefore, standard MPMs are not satisfactory for SAR/MTI systems. But with the addition of one or more of a few key circuits to the power supply, the MPM can attain reasonable pulse characteristics.

One such power supply circuit is a feed-forward circuit that reacts to the digital pulse command and feeds this information to the power supply voltage regulator to allow for improved voltage regulation.

Another power supply circuit for low noise is a linear post regulator for the critical TWT voltages. A linear regulator is inherently much faster than a switching regulator, and allows the voltage regulator to react quickly to minimize pulse droop.

A third power supply circuit for low phase noise is a synchronization circuit, which allows the switching power supply to be synchronized to a multiple of the pulse frequency. This results in consistent voltage ripple on each pulse, thereby minimizing interpulse noise.

Shown in Figure 7 is the phase noise for a 100 watt MPM, with a linear post regulator, operating in Ku band with a pulse width of 150 μsec and a pulse frequency of 1,600 Hz. This graph shows the phase noise level to be -60 to -70 dBc/Hz. Figure 8 shows the phase deviation versus time for the same MPM. After the initial excursion, the phase deviation remains within a five degree window. This performance is generally acceptable for most radar systems. However, ultra-high performance modern radars demand even lower phase noise from high power amplifiers.

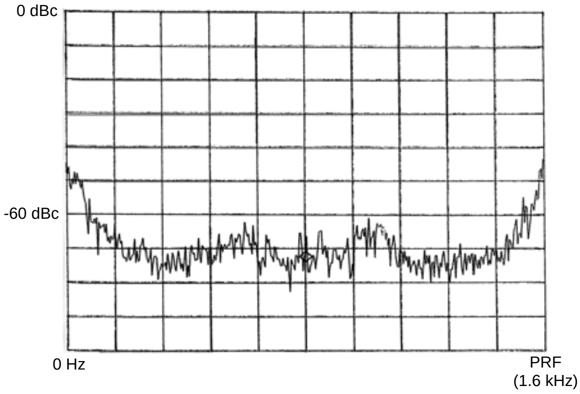

Figure 7 – 100 watt MPM phase noise in dBc/Hz

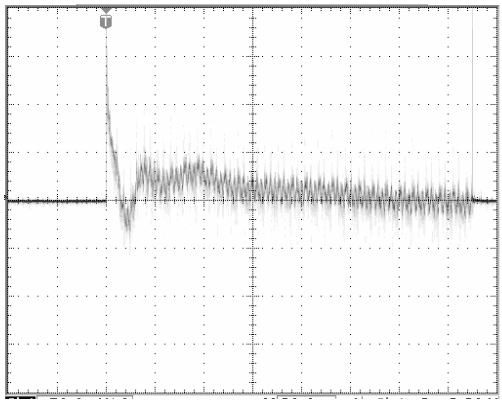

Figure 8 – 100 watt MPM phase vs. time, 5°/division, 20 μsec/division

1,000 Watt MPM

For longer range UAV radars, amplifiers with greater than 100 watts are required. In response to this need, a high peak power MPM has been developed. This MPM provides about the same average power as the 100 watt MPM, but provides 1,000 watts of peak power, a tenfold increase over standard MPMs. This new MPM includes a linear post regulator and can be synchronized. A photo of this MPM is shown in Figure 9.

Figure 9 – 1,000 watt MPM

The TWT within this MPM was specifically designed for this application, and owes more of its lineage to a pulsed helix TWT than a mini-tube such as in traditional MPMs. The peak power output from this TWT is shown in the plot of the MPM output power in Figure 10.

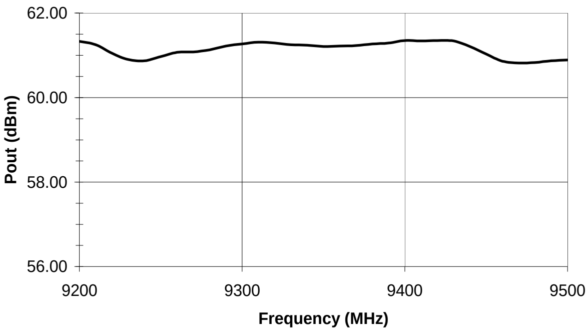

Figure 10 – 1,000 watt MPM power output

The power supply within the MPM was also specifically designed for this application, and in addition to the post regulator and synchronization, it contains increased high voltage capacitance for voltage stability during the pulse. As a result, it allows the pulse MPM to reach performance levels previously unattainable with MPM technology: -110 dBc/Hz (when corrected for a 1 Hz bandwidth) as shown in Figure 11. This figure is a graph of phase noise while operating in X band with a pulse width of 80 μsec and a pulse frequency of 1,600 Hz. Figure 12 shows the phase deviation over the pulse width, demonstrating less than four degrees of pulse droop.

Summary

The success of UAVs has resulted in the demand for a new class of radar – a radar that is extremely small, lightweight, and efficient. Manufacturers are developing new radar systems in response to this need, and require power amplifiers that are also extremely small, lightweight, and efficient.

The MPM, a unique component that combines the advantages of solid state and vacuum electronics, provides an amplifier solution for radar manufacturers. MPMs are being designed into many of the new radar systems being developed for UAVs, and the new pulse MPM represents the enabling technology that will allow modern high-performance radars to achieve long range resolution in a very compact, lightweight, and efficient system.

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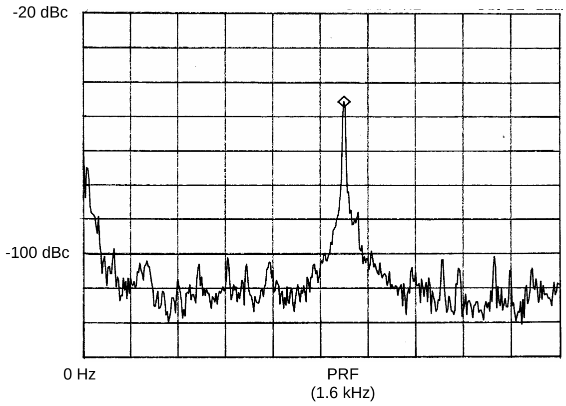

Figure 11 – 1,000 watt MPM phase noise in dBc/10 Hz

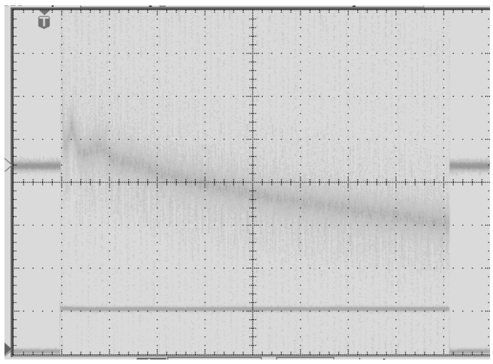

Figure 12 – 100 watt MPM phase vs. time, 2°/division, 10 μsec/division

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