MPM TECHNOLOGY DEVELOPMENTS: AN INDUSTRY PERSPECTIVE

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ABSTRACT

The technologies and design approaches being used in the development of the Microwave Power Module are described. The tradeoffs to optimize the overall MPM subsystem performance and the designs and development status of each of the MPM component building blocks are presented. These include the MMIC driver amplifier, the Vacuum Power Booster, and Electronic Power Conditioner. Recent performance results will be available. Future technology enhancements and MPM performance capabilities will be projected.

MPM

The development of the Microwave Power Module (MPM) is a technology breakthrough in broadband microwave power amplifiers. The highly miniaturized MPM subsystem combines the optimum features of a MMIC driver amplifier (low noise, compactness, functionality), a Vacuum Power Booster (high power, wide bandwidth, high efficiency) and an advanced Electronic Power Conditioner (high efficiency, RF modulation, compactness, control and logic functions). The MPM uses a modular architecture to provide the performance, packaging and manufacturing flexibility needed for the broad range of potential system applications in radar, communication and electronic warfare. The MPM is being specifically developed to provide a lower cost, more efficient alternative to solid state MMIC T/R modules for phased arrays. However, the MPM characteristics and features also make it an ideal replacement for Traveling Wave Tube Amplifiers of existing systems in order to upgrade the performance and reliability.

The goals for the MPM program are shown in Table 1, together with a composite of demonstrated performance that has been achieved to date.

TABLE 1
MPM PERFORMANCE CHARACTERISTICS

	Demonstrated (8/92)	Goal (6/94)
Frequency (GHz)	6 to 18	6 to 18
RF Power (W)	30 to 100	50 to 100
Gain (dB)	50	50
Duty	0 to CW	0 to CW
Efficiency	15 to 40% (1 stage)	33% (3 to 5 stages)
Noise Power Density (dBm/MHz)	−45	−45
Volume (Cu in)	7.5 to 40	7.5
Thickness (in)	0.31 to 0.85	0.31

The very small size, both volume and thickness, and high overall efficiency needed for phased array applications of the MPM are major design drivers. Combined with RF output power of 50 to 100 watts and multi-octave bandwidth from 6 to 18 GHz, the MPM package represents a new state of the art in amplifier power density.

A concurrent engineering design approach has been taken in the design of the integrated MPM subsystem. Trade studies were made to tailor each of the components designs in order to optimize the overall MPM characteristics. This process also results in more robust component designs, improved reliability and producibility. For example, the VPB is designed for the lowest possible beam voltage consistent with the achievement of >35% efficiency. This design approach enables a significant reduction in the size of both the VPB and the EPC.

The division of gain between the MMIC driver and the VPB is another key MPM design tradeoff. Higher VPB gain reduces the MMIC output power, but increases overall MPM size and noise. A MMIC design was selected that provides 30 dBm of RF power with 30 dB gain and 10 to 15 dB gain equalization over the frequency band. When combined with the vacuum power booster this produces maximum MPM efficiency and output power, and achieves an overall noise figure of 12 dB. This is more than 20 dB lower than the noise figure of typical TWTAs.

The package and cooling for the MPM is carefully designed to assure performance stability and reliability with the required small size and high power density.

The MPM is designed for either liquid or conduction cooling. High efficiency in the VPB and EPC are key to meeting the overall MPM efficiency goal while maintaining acceptable component operating temperatures. The highest power dissipation occurs in the vacuum power booster which is capable of reliable operation at elevated temperatures. Much lower power dissipation occurs in the MMIC and EPC components which use more temperature sensitive solid state components.

A photograph of the breadboard MPM demonstrator that was developed by the Northrop team is shown in Figure 1. The range of measured RF performance of the initial brassboard MPMs, shown in Figure 2, confirms that the power output, bandwidth and gain objectives can be met.

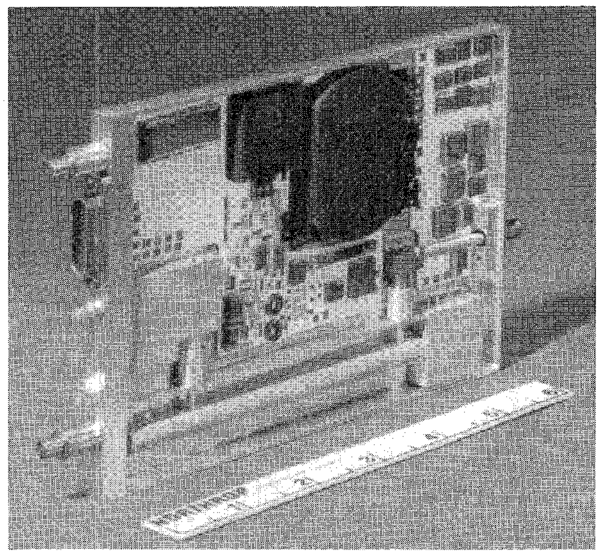

Figure 1 Microwave power module.

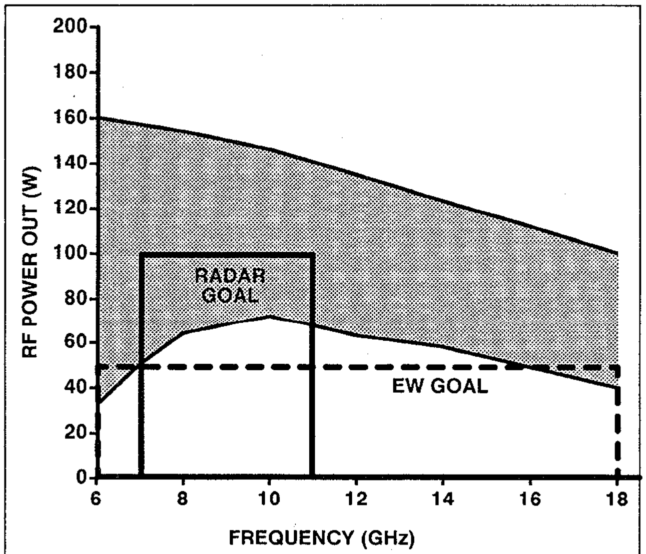

Figure 2 MPM demonstrator RF performance.

MMIC Driver Module

Teledyne Monolithic Microwave has developed a low cost solid state driver amplifier module that uses MMIC power amplifier technology and new metal matrix package material. The initial prototype module, shown in Figure 3, is approximately 2" x 0.35" x 0.35" and provides 30 dBm power, 30 dB gain and 10 dB noise figure over 6 to 18 GHz with a -54 to +85°C baseplate temperature. The small cross-section is achieved by extensive MMIC integration and is ultimately limited by RF connector and control line requirements. Additional features that are incorporated into the module include TWT gain equalization, phase adjustments for unit-to-unit tracking and temperature compensation. Several of the functions can be integrated directly into the MMIC circuitry.

Future challenges for the driver module are in technology advances to permit high temperature baseplate operation up to +125°C. Other enhancements such as linearization and

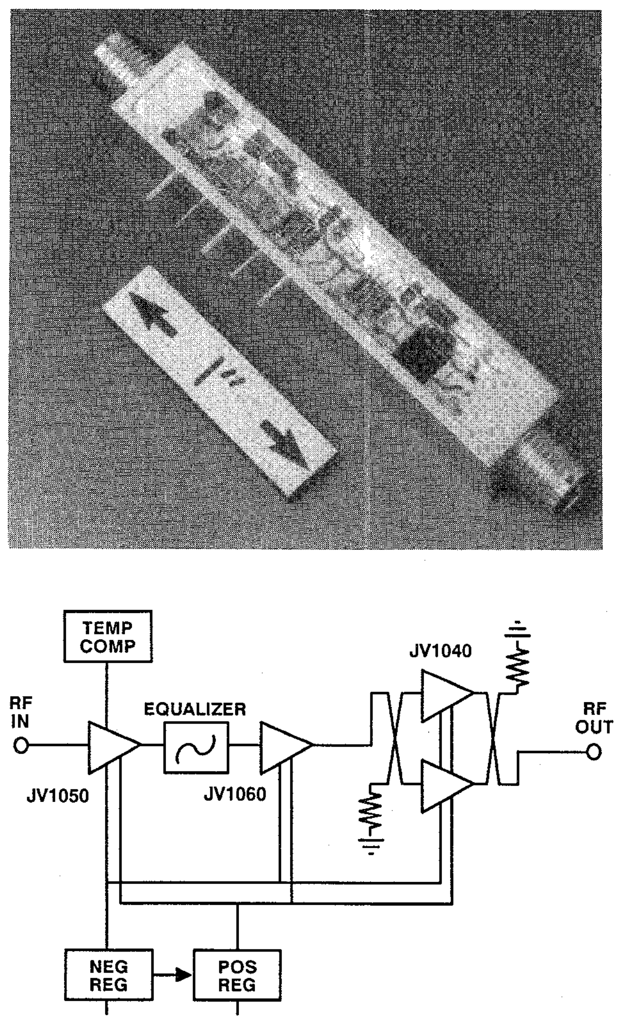

Figure 3 Micro-TWT driver module.

harmonic injection to improve overall MPM performance can also be included using advanced MMIC design techniques.

Vacuum Power Booster

The Vacuum Power Booster (VPB) is the final power amplifier in the MPM, producing 50 to 100 watts of RF power over the entire 6 to 18 GHz frequency band with 20 to 30 dB gain. The efficiency goal of the VPB is 35 to 40 percent.

The VPB uses traveling wave tube concepts and state of the art design and materials technologies to met the required performance characteristics in a package as small as 0.30 inches in thickness and 6 in. long (a volume of only 1.2 cubic inches). The small size is achieved by designing for the lowest possible beam voltage, minimizing the gain and using a very small multistage depressed collector to enhance the VPB efficiency. High efficiency greatly reduces power dissipation which also contributes to a reduced size. A typical vacuum power booster cross section, showing the key design elements is shown in Figure 4.

The RF circuit is a broadband helix supported by dielectric rods. The helix pitch is modified near the output to increase the RF to beam interaction for increased output power. Distributed loss or a two section circuit (sever) is used to provide stability and reduce the effects of external mismatches.

A convergent electron gun, equipped with a long life dispenser cathode is used to generate the electron beam. The small electron gun size (typically 0.3 to 0.5 inches diameter) which is made possible by the low beam voltage, permits close tolerance, self-aligning assembly techniques. For pulsed operation, beam modulation capability is provided by either a grid, or focus electrode.

Beam focusing is accomplished using small rare earth periodic permanent magnets and accurately aligned soft iron pole pieces. Beam transmission of greater than 98% has been demonstrated.

A Multi-stage Depressed Collector (MDC) is used to increase the Vacuum Power Booster efficiency from approximately 10 percent (undepressed) to 40 percent (depressed). The MDC incorporates from 2 to 5 electrodes, each at a successively lower voltage with respect to the cathode. Spent beam electrons, after interacting with the RF wave during the amplification process are decelerated and collected at their lowest possible energy. More than 80 percent of the spent beam energy can be recovered with a concurrent reduction in heat dissipation.

The achievement of 40 percent efficiency with a low voltage, high perveance beam, using a collector diameter of less than 0.3 to 0.5 inches is a significant design challenge requiring the use of state of the art computer design codes. Graphite electrodes are used in some of the VPB designs to reduce the secondary electrons which degrade the collector efficiency. Performance data on VPBs with multi stage depressed collectors will be presented.

Electronic Power Conditioner

The Electronic Power Conditioner (EPC) for the MPM provides all of the specialized electrical power inputs needed for operation of the MMIC driver amplifier and the Vacuum Power Booster. It delivers up to 325 watts with an efficiency of greater than 90 percent from a standard 270 V DC input line. The most challenging EPC requirement for the MPM program is the very small size. The goal for the EPC volume is only 6 cubic inches with a maximum thickness of 0.3 inches.

The electrical outputs generated by the EPC include the regulated cathode high voltage, up to five depressed collector voltages, the cathode heater voltage, EMI filtering, regulated MMIC power inputs, protection and control logic functions. The EPC also incorporates a modulator which provides pulsed MPM operation at up to 100 kHz PRF at duty cycles from 0 to CW.

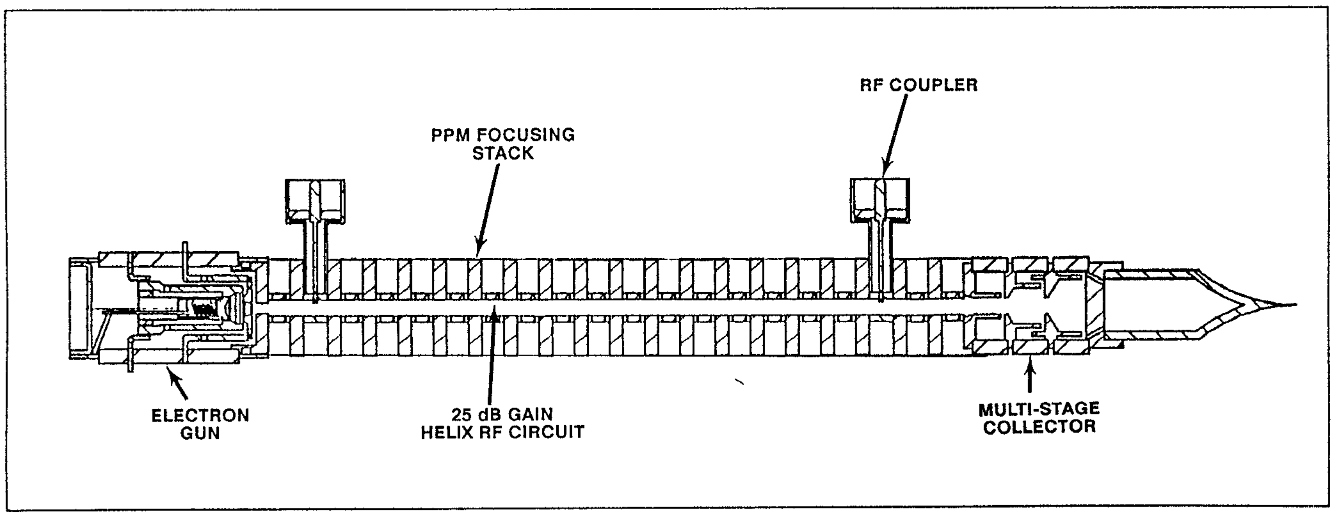

Figure 4 Vacuum power booster cross section.

The development of the miniaturized EPC to meet the combined requirements of high efficiency and very small size is a major goal of the MPM program. This represents an increase in efficiency of 5 to 10 percentage points and a reduction in volume of 10 to 20 times compared to supplies currently available at this power level. The EPC designs also address a requirement for low manufacturing cost in high volume production.

Significant progress has been demonstrated by the MPM development teams using a number of different design approaches. These early successes indicate that the ultimate EPC performance and size objectives can be met.

A typical example of an MPM EPC can be seen in Figure 1. Major EPC characteristics that have been demonstrated on early brassboards developed by Varian-Westinghouse and Northrop are summarized in Table 2. These impressive results were achieved through the use of state of the art circuit designs, low-loss high frequency switching inverters, miniature high voltage transformers and some circuit hybrids. The low beam voltage design of the vacuum power booster is a key factor in both reducing the EPC size and maintaining high reliability.

Future challenges in the development of the EPCs for the MPM program include additional size reduction, addition of a modulator and multi-stage depressed collector capability. Further reductions in the EPC size will involve development of low profile planar high voltage transformers, and use of additional circuit hybrids and ASICs. Future advances in high speed switching diodes and transistors will enable higher frequency EPC designs with even smaller size and increased efficiency.

TABLE 2
ELECTRONIC POWER CONDITIONER CHARACTERISTICS

	Varian-Westinghouse	Northrop	MPM Goal
Beam Voltage (kV)	4.1	3.9	–
Output Power (W)	320	300	300
Inverter Frequency (KHz)	150	300	–
Efficiency (%)	91	90	90
Duty Cycle	0 to CW	1%	0 to CW
Volume (Cu in)	14	6	6
Cooling	Cond.	Liquid	Cond/ Liquid