MPM APPLICATIONS: A FORECAST OF NEAR- AND LONG-TERM APPLICATIONS

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Abstract

Applications for a family of microwave power modules (MPMs) in both military and civil systems have been surveyed and analyzed. Important applications in military radar, electronic warfare, missiles, communications, and space systems will generate demand for quantities in excess of 10^6 units over the next 15 years, while civilian demands will be an order of magnitude higher for data services and "smart highway" applications.

Achieving commonality across these applications will provide an economy of scale that can drive MPM unit costs to perceived cost levels that have met success in related military and consumer product applications.

Introduction

This paper has been prepared for the purpose of providing planning information to guide the development of the evolving microwave power module (MPM), a super-component consisting of a wide-dynamic-range hybrid solid-state/vacuum-electronics microwave amplifier with an integral power conditioner. Such a device could be used in military applications, such as radar, electronic warfare (EW), guided missiles, communications, and space system applications, as well as for an evolving, and possibly, extensive set of commercial uses in surveillance, navigation, traffic control and routing, and weather and earth resources monitoring, surveying, and prediction. Significantly expanded markets are projected for consumer-oriented data services and transportation segments of the infrastructure modernization being highlighted as part of the Administration's current effort to stimulate the economy.

To meet the most demanding needs, yet preserve the broadest commonality among the applications, it is necessary to understand the technical, cost, and logistic support requirements imposed by this diverse application set. Meeting this goal would provide central focus to the continued Exploratory Development program, ultimately providing for the necessary concentration of Advanced Development funding, the economics of high rates of production, and a basis for fair competition in the marketplace. All of these goals are in the best interests of the development and user communities in Government and industry. The results reported here are based on a survey of identified user communities undertaken in support of the Microwave Power Module Program. [1]

The MPM Program evolved from an Advisory Group on Electronic Devices (AGED) Panel convened to help define the needs and feasibility of a wide-dynamic-range microwave power amplifier module. (See Paper D-1.) The Panel considered options to extend and enhance the performance achieved with the DoD-developed solid-state-based MIMIC Transmit/Receive (T/R) module developed for both radar and EW applications, the most demanding applications being represented by phased-array and EW expendable applications.

The goal of the MPM program is to extend the performance of these MIMIC modules, especially with regard to power output, from a few watts to a few hundred watts. Advancing the power output by two orders of magnitude would expand the applicability of the modules to larger higher-ERP arrays and more capable EW expendables, especially for the large inventory of conventional aircraft where the MIMIC modules lack adequate power output or where the aggregated cost of large arrays based on MIMIC modules is prohibitive.

It is clear that a by-product of this effort could be an effective insertion of the MPM into the commercial sector. If successful, this insertion will provide an overwhelming driving force, affecting not only performance, but also cost resulting from economies of scale. Most consumer applications would provide a demand for quantities an order of magnitude larger than most military applications, extending to quantities of the order of 10^5 to 10^6 per annum or larger for consumer-oriented products; the better-defined individual military application areas would demand quantities in the 10^4 to 10^5 per annum range, aggregating to only 10^6 - 10^7 over near term and mid-range 5-year intervals.

The survey indicated a probability that high commonality of function, if not form, can be achieved at major MPM sub-systems levels; i.e., at the driver amplifier, output amplifier, and the power conditioner levels. A family of these sub-systems can be envisioned, that with different combinations, would satisfy, most requirements. Applications that differ in externals, i.e., for array elements, expendables, or missiles, could be met best by commonality at the sub-system level, maximizing the through-put of the common elements, with different final assembly of the various MPMs. This approach to commonality has been successfully applied to other multi-product lines, e.g., the automobile industry, where several models with different options are all built on the same production line with common modules assembled into different products on a "custom" basis for individual customers.

Military Applications

The use of higher-power-output wide-dynamic-range array modules would permit obtaining higher ERP active arrays with a smaller number of elements, for both large and small arrays. This use would enable radar detection of very small cross-section targets (e.g., tactical antiballistic missiles) or for higher-power jamming from arrays where moderate beam-width is defined by a limited direction finding accuracy, and, therefore, a maximum number of elements.

A critical feature of the MPM for several of these critical applications is a small module cross-sectional area so that it can be inserted in arrays with fractional wavelength separation of elements. This requirement also implies unique cooling arrangements that would permit heat extraction longitudinally rather than transversely as has been the case for earlier-generation devices such as mini-TWTs or MIMIC-based modules that convey heat losses to a heat sink, via a structure whose cost would be prohibitive for the MPM.

These characteristics tend to raise the priority for achieving high efficiency for the MPM design, which is intended to operate at intrinsic RF power levels two orders of magnitude higher than its MIMIC counterpart.

The use of MPM in EW expendables or guided missile seekers also implies that module costs be held to an absolute minimum to meet the goals of affordability for expendable systems used in large numbers. The unit cost of the MPM, used as a transmitter/power conditioner, represents approximately 50 percent of the cost of an EW expendable, and somewhat less for that of an active missile seeker. For this reason, emphasis on all possible means of cost reduction is of the highest priority in the program. Factors such as sub-system commonality and manufacturing technology, including automation and robotics, will be important contributors to program success.

But the issues of reliability and long shelf life may be equally important because of perceptions of poor reliability that persist for vacuum-tube-based components in the defense electronics sector, a reputation that can be overcome by the approaches imbedded in the MPM program. It has been shown quite confidently, that the problem is not intrinsic to the technology, but rather stems from marginal designs, poor control of manufacturing processes, improper design of interfaces between the vacuum tube and its power conditioner, and inadequate environmental controls in applications, especially for aircraft.

Military applications for data transmission and communications require high fidelity (linearity) and high reliability at an affordable life-cycle cost. These requirements exist for both terrestrial and space segments of such systems, and for a growing set of tactical line-of-sight data links using microwave and millimeter-wave frequency regions. Traveling-wave tubes have long been the device of choice, providing the large dynamic range, efficiency, and bandwidth especially pertinent for space applications. They have also demonstrated the high reliability demanded for space hardware; with operating life-cycles measured in years. The introduction of the MPM to this environment has been received enthusiastically, with promise of further improvements in all significant areas -- size, cost, reliability, and performance.

Commercial Applications

The primary application area for the MPM in the near-term lies in communications and data relay services with insertion in both ground- and space-segments. Although this does not presently represent a high-volume application, the MPM development goals of wide-bandwidth, wide dynamic range, and high operating efficiency in a compact package, and high overall reliability, are targetted directly to these needs

In the longer term, consumer-oriented data services and transportation routing and monitoring using compact two-way links will increase the demand for MPM devices. For application to "smart highways" where vehicle control, monitoring, and collision avoidance will require "intelligent highways" with continuous coverage for detection, data reporting, and remote control, the requirements projections will be significant. One can easily project MPM requirements that exceed those for data services, possibly by an order-of-magnitude.

Commercial sector applications of the MPM will depend, to a large extent, not only on the technical requirements, but also on economic issues and competing technologies, especially the abilities of MIMIC to meet operation frequency, power, and efficiency. Although monolithic semi-conductor process and controls promise high confidence in attaining low cost and high reliability for competing devices, operating power outputs, efficiency, and operating temperature environments will probably be lower as compared to the MPM, where the advantages of both MIMIC and vacuum-electronics technologies are combined synergistically.

Application Area Commonality

Various potential applications of the MPM were grouped according to their basic requirements, specific design goals, and issues identified. Although each potential application area requires specific essential characteristics, it might not preclude the simultaneous achievement of specific, but different, characteristics demanded by a different application area. An example here might be the need to obtain low phase noise, moderate bandwidth, and efficiency for a radar application. A similar device for EW might not be so concerned with phase noise as with extended RF bandwidth or modulation capabilities. However, achievement of low phase noise, high efficiency, and extended RF bandwidth simultaneously would satisfy both application areas and provide for extended commonality of the MPM. An alternative approach would be to provide for commonality of MPM components, with variations of some key component to meet specific requirements that a "common MPM" might not best accommodate.

What is desired is to achieve the highest commonality basis that has the lowest acquisition and life-cycle costs to the user in terms of initial cost or logistics support costs. It is often difficult to establish early in a program just what the life-cycle costs will be; the focus is often on least acquisition cost which can be defined more readily. During this survey, the approach was to identify a "baseline" MPM and to identify specific deviations required to meet user requirements after exploration of various means of meeting the requirement through use of the baseline performance. The result defines total MPM commonality, commonality at the component level, (MIMIC driver, vacuum power booster, or power conditioner levels) or long-range development objectives where technology gaps exist.

It is expected that the economies of scale will define "commonality" at the MIMIC driver, the vacuum envelope, and power conditioner sub-system levels, with a "mix-and-match" assembly procedure for the MPM required for each specific application area. This will permit maximum "through-put" in each of the basic component areas, automated assembly and testing of multi-product groupings for final assembly, test, and delivery of the family of MPM devices optimized for specific applications.

Costs

The use of electron devices in military systems can have a large impact on acquisition or life-cycle costs, depending on the percent of content that they represent or their failure rate. In retrofit, success in transition hinges on some combinations of improvement sought in terms of life-cycle cost reduction or performance improvements. Commonality arguments can be brought to bear if it represents a significant logistics support cost reduction.

In new system applications or where a competitive selection of device type is appropriate, the functional cost to achieve comparable functions is a good measure. For direct replacement or interchangability, the relative device costs are easily established, but where architectural changes are necessary for achieving comparison, a modeling or simulation effort is required. Examples of this analytical approach demonstrate favorable military insertions, especially where improved reliability can be assured, for MPM unit costs in the $4K range. Commercial applications demand significantly lower unit costs, especially for consumer products, and the unit price must be driven down by another order of magnitude, a goal that can only be achieved by economy of scale that is driven by a large market expectation.

Applications Summary

The analysis of the survey data led to groupings according to the specific focus of the application performance requirements. Although a high level of commonality exists across the total set, there is a higher level of commonality within the sets for various potential insertions. If we limit the MPM requirements to the basics, i.e., a compact, highly efficient, high power wide-bandwidth amplifier operating in the 6- to 18-GHz band, (the MPM baseline definition), then commonality exists across a rather large basis as shown in Table 1, when the applications are aggregated over 15 years in 5-year intervals.

The total requirements for MPMs over this period is projected to be in the range of 10^7 to 10^8 MPMs. The largest potential military application lies in active arrays of advanced design (higher ERP) for radars, jammers, and expendables. Larger volumes are projected for commercial applications in consumer-oriented data services and for transportation infrastructure modernization involving monitoring, data transfer, and remote control of highway vehicles for improved traffic control and safety of operations.

Conclusions

The primary finding of the survey is that there a large-volume potential exists for MPMs in military and commercial systems that have a high degree of commonality. Successful transition depends highly on programmatics of the various systems, as well as on successful prosecution of the MPM program, including both development and production mechanization. The mutual dependence of these aspects of the programs constitutes a significant management challenge where segmentation of the problem exists among the development and procurement phases in

Table 1. MPM Insertion Opportunities

APPLICATION	BASELINE (1993-1998) (6 - 18 GHz)	MID-RANGE (1998-2003) (6 - 18 GHz)	LONG RANGE (2003-2008) (2 - 18 GHz)
Airborne Intercept Radar (100 -- 1000 A/C)	Modular Part. Dist. Array - (~ 10W/el) (Development) >1000 Elements Total: 1 -- 1K MPMs	Modular Part. Dist. Array (Procurement) Total: 10K -- 100K MPMs	Advanced Shared Aperture (~ 20W/el) Total: 120K -- 200K
Ground Based Radar (GBR) (10 -- 100 Systems)	Part. Dist. Array - (~ 20W/el) (Development) >4000 Elements Total: 1 -- 1K MPMs	Dual/Band/Pol Div/Multi-Mode Aperture (~ 20W/el) .>4000 Elements Total: 8K -- 80K MPMs	Production Total: 8K -- 80K MPMs
Missile Seeker (1K -- 10K Inventory) 10%/Yr Consumption	Passive Array -- 100 el (~ 2W/el) (Development) 2 MPMs/Array Total: 2 - 200 MPMs	Passive Array >100 el, 2 - 10 MPMs/Array Total: 1K -- 55K MPMs	Production Total: 1K -- 55K MPMs
Expendable Jammer/Decoys (5K -- 20K Inventory) 10%/Yr Consumption	Active Decoy -- 1 MPM/Decoy Total: 5.55K -- 22K MPMs	Responsive Ex-Jam - 1-2 MPMs/Jam (Block UpDate) Total: 5.5K -- 44K MPMs	Improved Decoy/Jammer 4/Jammer Total: 22K -- 88K MPMs
On-Board DECM/JAM (~ 800 A/C [ALQ-184] ~ 2000 A/C [other] ~ 500 F-22s [INEWS])	ALQ-135 -- 1 to 2 MPM/AC (Retrofit) ALQ-184 -- 2 to 8 el Arrays Single Pol (Retrofit) Total: 18K -- 20K MPMs	INEWS/F-22 - 3-4-5 el Arrays Dual Pol Total: 15K -- 20K MPMs	Advanced DECM Dist. Arch. Avionics Total: >25K MPMs
Airborne Support Jammer (> 125 A/C) 2 Jammers/A/C	ALQ-99 Upgrade - ~ 50 el 2-Line Array Total: >12.5 MPMs	ALQ-99 Redesign - 168 el - 12x14 Array (Development) Total: <1K MPMs	ALQ-99 Redesign Procurement Total: >21K MPMs
Airborne Stand-Off Jammer (HPCM/HPSOJ) (~ 30 A/C) 2 Arrays/A/C		~ 500 el/Array Dual Pol (Prototyping/T&E) Total: 500 -- 1K MPMs	Procurement Total: 60K MPMs
Shipborne Jammers (100 Ships) 4 Arrays/Ship	SLW-32 Retrofit -- 4 -- 40 el Array/Ship (Demo) Total: 160 -- 320 MPMs	SLQ-32 - 4 -- 40 el Arrays/Ship Dual Pol (Development) Total: 16K -- 32K MPMs	SLQ-54/Shared Aperture 6.4K/yr SLQ-32 Update 1.6K/yr Total: 8K -- 32K MPMs
Communications	Feasibility/Prototyping Total: ~ 1K MPMs	Production & Product Improvement Total: ~ 12K MPMs	Production Total: ~ 12K MPMs
Space Systems	Total: ~ 50 -- 100 MPMs	Total: ~ 50 -- 100 MPMs	Total: ~ 50 -- 100 MPMs
Data Services	Feasibility/Prototyping Total 100K MPMs	100K -- 1000K MPMs	1M -- 10M MPMs
Infrastructure Modernization	Concept Development/Initial Development 1 -- 10K MPMs	10K -- 100K MPMs	100K -- 1000K MPMs

Government and industry, and where long-term commitments and continuity cannot be assured.

The technological advantages of the MPM concept are compelling; the inherent advantages of both solid-state and vacuum-electronics technologies are integrated in a device where the separate advantages of the two technologies are combined in a truly synergistic manner. The focus on an integrated product, including the power conditioner will resolve persistent interface problems that exist in programs where these three aspects of the problem are addressed separately, often non-uniformly, and certainly in a process where the necessary trade-offs are difficult to make equitably.

Significant progress has already occurred and the forecast for MPM acceptance in the industry, particularly in the user community, is good. The survey process served to collect information that is useful in guiding the program development, and has also provided criticism in an effective manner; the positive comments, suggestions for improving performance, and exchanging of views on program priorities has occurred in a timely fashion. It is not too late at this juncture to re-vector the program to better fulfill user expectations. Continued interaction through user community dialogue is recommended during follow-on efforts.

<u>References</u>

[1] "Microwave Power Module (MPM) Requirements and Applications," Final Report, September 1992, System Planning Corporation, Contract No. N00173-92-M-6793