MILLIMETER WAVE POWER MODULE FOR WIRELESS APPLICATIONS

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Abstract

The Millimeter Wave Power Module (MMPM) is capable of providing low noise, broadband millimeter wave power at high volume and mass densities and may enable the implementation of the "wish lists" in many engineering notebooks. This article details the development of the MMPM at Litton under the sponsorship of Tri-Service/ARPA Vacuum Electronics Initiatives.

1. Introduction

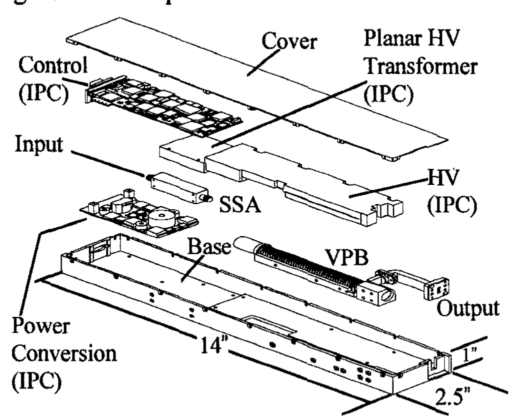
The proliferation of medium and long range wireless applications at millimeter wave (MMW) frequencies is moderated by the lack of reliable, low noise figure ($\leq$10 dB), broadband ($\geq$ 2 GHz), high power ($\geq$ 10 W), efficient ($\geq$ 30%) sources with power densities exceeding 1 W/cu. in. and 10 W/lb. respectively. The high efficiency and power density of the MMPM are appropriate for a variety of applications where size, weight, reliability, efficiency, and upgradability are critical factors.

Under the sponsorship of Tri-Service/ARPA Vacuum Electronics Initiatives, Litton has been developing a compact, efficient, high power, broadband MMW supercomponent coined as the MMPM. [1] This 18 to 40 GHz, 40 Watt MMPM will have far-reaching implications as it integrates and reaps the benefits of leading-edge solid state MMIC, vacuum tube, and power supply technologies in a small package. This paper details the topology, system and component performance goals, system analysis, and current results of the Litton MMPM development program as well as comparisons with other MMW technology. It also covers the potential of MMPM in wireless applications.

2. MMPM Topology, Performance Goals, and System Analysis

A MMPM is a highly modularized and integrated device. In its most basic form, it consists of the three elements as illustrated in Figure 1: Solid State Driver Amplifier (SSA), Vacuum Power Booster (VPB), and Integrated Power Conditioner (IPC). Other elements such as attenuators, equalizers, phase shifters, and tunable filters can be readily added to improve its versatility.

Figure 1. An exploded view of the Litton MMPM.



The major subassemblies and outline dimensions of the 18 to 40 GHz MMPM currently being developed at Litton are shown in Figure 1. Some of the performance goals of the Litton MMPM are given in Table 1.

As a subsystem, technical, cost, and cycle time tradeoffs are required to determine the optimum combination of the SSA, VPB, and IPC. As an example, Figure 2 presents a tradeoff between overall noise figure performance and the

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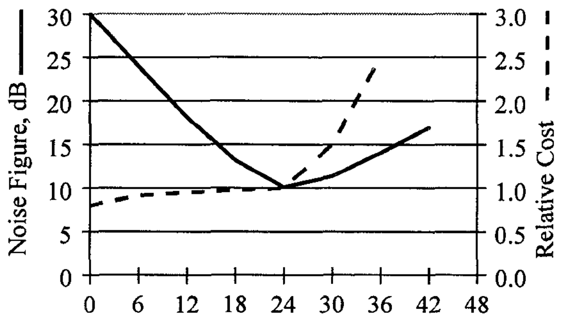
relative cost of the MMPM (for low volume production) as a function of the gain/output power of the SSA. In general, the SSA has lower noise figure and lower cost at lower gain. However, as the gain of the SSA drops, the noise figure of the VPB starts to dominate. At higher gain and output level, the SSA has higher noise figure and higher cost. Beyond a certain gain and output power level, the cost of the SSA goes up rapidly without a corresponding improvement in overall noise figure. The operating point of +24 dBm output for the SSA represents an optimization in overall MMPM noise figure performance and production cost.

Table 1. Performance Goals of the Litton MMPM.

Parameters	SSA	VPB	IPC	MMPM	Unit
Bandwidth, minimum	18- 40	18- 40	-	18-40	GHz
O/P Power , minimum	24	46	-	46	dBm
Efficiency, minimum	8	35	90	30	%
Prime Power	-	-	270	270	Vdc
Small Signal Gain, min.	25	28	-	53	dB
Gain at Rated Power, min.	24	22	-	46	dB
Duty Cycle	0 to 100	0 to 100	0 to 100	0 to 100	%
Noise Figure, max.	8	30	-	10	dB
Size, maximum	0.7	3.3	16	35	cu. in.
Weight, maximum	.15	.75	1.6	3.0	lb.

Figure 2. MMPM: Cost and Noise Figure Tradeoff
(with input at 0 dBm and output at 46 dBm)



Varying with the prime power and cooling schemes, existing MMW amplifiers exceeding 10 Watts of output power display power densities in the range of 0.02 to 0.2 W/cu.in. and 1 to 3 W/lb. [2] The Litton MMPM is projected to have a power density of 1.1 W/cu.in. and 16 W/lb., many times higher than existing devices. Due to the high power densities, effective thermal management is critical to assure high reliability. A finite element thermal analysis of the MMPM indicates that hot spots are located at the collector of the VPB, at the junction of the output stage of the MMIC, and at the planar transformer of the IPC. These hot spots are kept to +124 deg. C or less under nominal conditions.

3. The MMPM Development Program

The current MMPM development program is expected to produce ten MMPM prototypes with the performance goals indicated in Table 1 for use in a phased array. These modules may be subsequently repackaged as MMPM transceivers in future programs to include phase-shifters and receivers.

4. Low Noise Broadband SSA MMIC (PHEMT) Driver Amplifier

The driver amplifier consists of a two gain block chipset, fabricated by a proven Litton GaAs foundry process with a proprietary power PHEMT (Psudomorphic High Electron Mobility Transistor) technology. The SSA outline dimensions are given in Figure 3. To achieve broad bandwidth and high gain, each gain block consists of a distributive matched input stage followed by three reactively matched stages. To achieve the required power level, the output stage uses in-phase combining of two 500 μm PHEMT transistors. At the three dB compression point, the amplifier can provide output power level of 25 dBm with 30 dB of gain. The amplifier requires a 4 volt power supply for the drain-source voltage and a negative voltage for the gate-source voltage. It consumes 2.6 Watts and has 10% power added efficiency. The channel temperature of the amplifier is approximately 99° C above ambient. The layout of the SSA is shown in Figure 3.

5. High Efficiency Broadband VPB

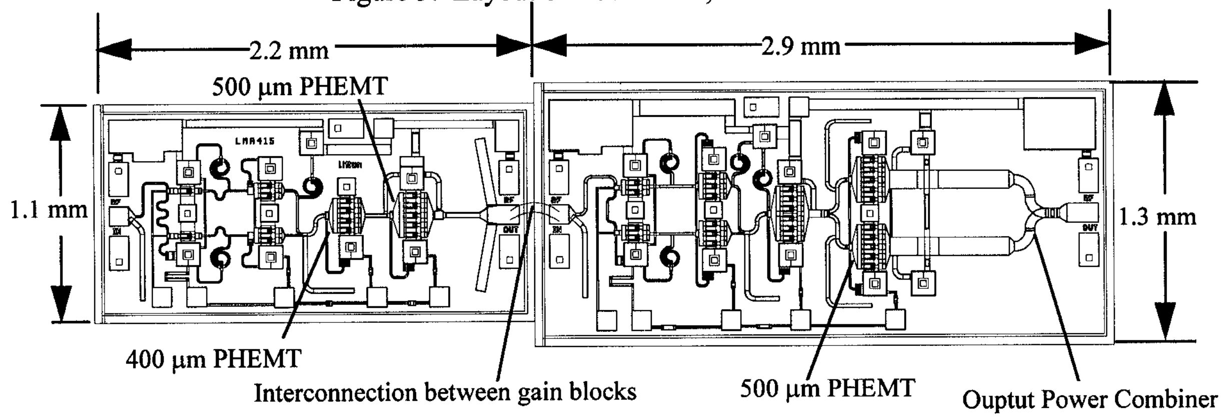
The engineering emphasis of the VPB is size, voltage, efficiency, bandwidth, power handling, and device lifetime. Each of these parameters is affected by the choice of beam voltage and current.

Traditionally, MMW helix tubes in the 25 to 150 Watt power range have been built with helix voltages at or above 12 kV. In building a short, high efficiency tube, it has been necessary to develop a device with as low a helix voltage as practically possible. The Litton VPB has been designed to operate at a helix voltage of 6,950 V and a beam current of ~125 mA. The low cathode voltage and high frequency (up to 40 GHz) constrained the helix diameter to about 0.0255".

New electron gun optics and beam magnetics have been developed for use in this device. A wire-wrapped, BeO-supported, tungsten helix with dispersion loading has been used as the broad-band slow-wave structure. A direct waveguide-to-helix transition based on a 6-step Tchebycheff transformer (low-impedance single ridge to double ridge, wrd-180 waveguide) and a wide-band wrd-180 vacuum window have been used to couple out the MMW. A nominally loaded osmium-sputtered cathode has been used along with a ion trap for greater reliability and life.

New assembly techniques and manufacturing specifications have been employed to maintain tight tolerance control on the completed VPB. These controls have worked so well that the prototype device yielded 99% beam transmission with only a nominal amount of magnetic shimming and without the usual first step of building a beam stick.

Figure 3. Layout of Low Noise, Broadband SSA



6. Compact Integrated Power Conditioner

The IPC accepts prime power and external control signals as input, and provides sequenced internal control signals, low voltage power to the SSA and high voltage power to the VPB.

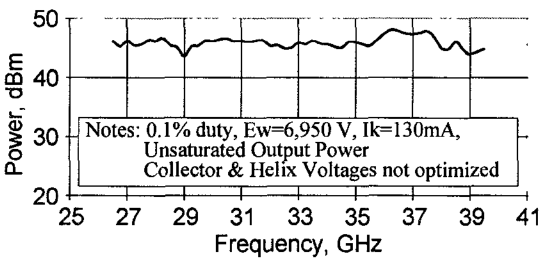
The drastic reduction in size and weight achieved by the MMPM is predominately due to the miniaturization of the IPC. This has been primarily achieved by the use of surface mount technology. Newly developed surface mount high voltage ceramic capacitors and chip diodes are used, which are a fraction of the size of traditional leaded devices. Additionally, a power supply switching frequency of 200 kHz and planar magnetics have allowed the IPC to achieve the low profile form factor required for the MMPM.

The high voltage transformer is constructed with planar magnetics; flexible printed circuit wiring patterns are stacked to form the windings within a low-profile magnetic core. This winding technique has yielded a tenfold reduction in the volume of this component.

7. Current Results

The first prototype MMIC SSA has been fabricated. It provides 24 dBm of drive power to the VPB from 18 to 40 GHz. An experimental VPB has also been built and has demonstrated 44 to 47 dBm of output power from 26 to 40 GHz. (See Figure 4.) The full band VPB prototypes are currently being built. The IPC prototype has been fabricated and is being tested.

Figure 4. MMPM VPB Preliminary Output Power Data



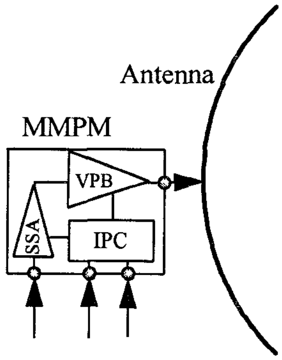
8. Conclusions

The MMPM merges the best of three technologies: solid state devices, vacuum tubes, and power supplies, into a single module. The small size, light weight, and high efficiency of the MMPM make it very versatile. For example, MMPMs can be combined to provide a high power linear output with low intermodulation distortion by operating at less than the rated power. They can also be used to improve reliability and maintainability of existing large size, inefficient, heavy transmitters. A narrow band SSA and VPB can be used to provide better performance in noise power density, efficiency, and output power over a smaller bandwidth. A wide band SSA and VPB can be used to support spread spectrum, frequency hoping, and jamming applications. The small size and light weight allow the MMPM to be bolted directly onto an antenna feed to create a power antenna as illustrated in Figure 5.

Further compaction of the MMPM is possible by: optimizing the fill factor, improving thermal management, increasing the power supply switching frequency, and using hybrids and/or programmable logic devices for the low voltage electronics.

The potential applications of MMPM in the wireless world are extensive. It is capable of supporting links within and between the three domains: space, air, and surface. The immediate ones include: satellite uplinks and line of sight terrestrial links including cellular networks, wireless cable TV , wireless LAN and WAN, and Local Multipoint Distribution Service (LMDS) as well as defense applications in ECM, decoys, seekers, and radars. [1,3,4] The long term applications include satellite downlinks and inter-satellite links. The availability of production MMPMs in the next few years is expected to expand its role in all of the above applications.

Figure 5. A MMPM powered antenna



9. Acknowledgement

We are grateful for the contributions of the following individuals: Dr. R. True, D. Gautreau, R. Rodriguez, B. Pelster, T. Bemis, G. Tucker, and E. Harris. We would like to acknowledge the encouragement of Dr. R. Abrams and Mr. Rick Worley and financial support by Tri-Services/ARPA under contract number F33615-94-C-1581.

10. References

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