The Linearized Microwave Power Module

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Abstract - **Microwave Power Modules (MPMs) provide the most compact and efficient source of microwave/millimeter wave amplification in the 50 to 150 watt power range. They can also amplify over a multi-octave frequency band. MPMs have been around for almost ten years and applied in military radar and electronic warfare, but have seen little application in communications. This paper shows that by combining an MPM with a linearizer, high power, high efficiency and high linearity can all be achieved. This combination should make linearized MPMs highly attractive for both commercial and military communications applications.**

I. INTRODUCTION

An MPM is microwave power amplifier that integrates a miniature traveling wave tube (TWT), a solid- state driver amplifier and a power supply into a single housing [1]. This combination takes advantage of the small size, low noise and high gain of solid-state devices at low power levels and the high efficiency and small size of TWT technology at higher powers to produce what has been described as a "super component". MPMs can offer a ten-to-one improvement in power density (power per unit weight) and a four-to-one power conversion efficiency advantage over comparable power solid-state power amplifiers (SSPAs) [2]. They can reduce the noise figure of a TWTA by 20 dB. Studies indicate MPMs can provide all these advantages with superior reliability and at a lower cost than comparable power SSPAs [3]. By combining a linearizer with an MPM, it will be shown that they can also provide comparable or superior linearity to an SSPA [6,7].

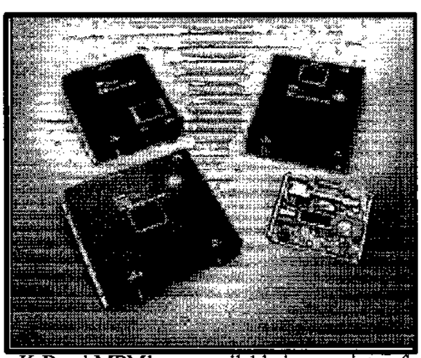

Fig. 1 S to K-Band MPM's are available in a variety of power and form factors. (Courtesy of L-3 Communications)

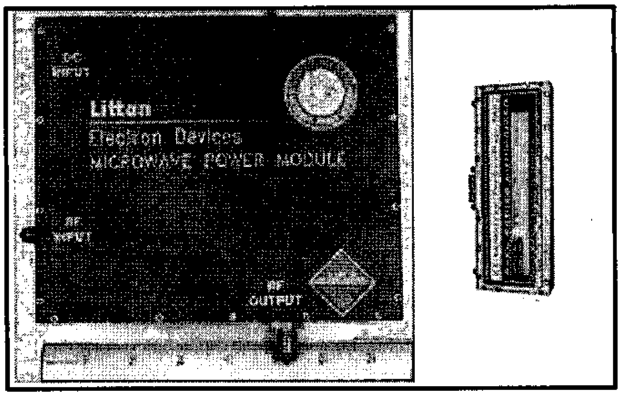

Fig. 2 Test MPM with the external C/ X/ Ku band LTI linearizer.

MPM's have been developed to operate from 2 GHz to over 45 GHz. Standard wideband MPMs operate from 2 to 6 GHz, 6 to 18 GHz, and 18 to 40 GHz with RF output power levels up to 150 watts, noise figures of less than 10 dB, and up to 50% efficiency [1]. MPMs have found use in military applications, including unmanned aerial vehicles (UAVs), decoys, radar and phased array systems [4]. MPMs are designed to be modular and can be reconfigured to a variety of form factors and formats to meet changing systems needs. Figure 1 shows some of the forms in which MPMs can be found. MPMs are manufactured by several TWT producers including CPI, L-3 Communications, NEC, Northrop Grumman and Triton. LTI has tested linearizers with L-3 and Triton MPMs. The test results shown in this paper are for a L-3 (formally Litton Electron Devices) MPM. The OEM linearizer discussed in this paper was mounted external to the MPM, as shown in Figure 2, but could have easily been integrated into the MPM housing. The test MPM was designed for wideband operation over the frequency range from 6 to 18 GHz. It is rated at minimum saturated power of 80 watts, but at some frequencies provided in excess of 100 watts. It was operated from a 270 Volt dc power source, but can be readily modified for a wide range of operating voltages.

II. TEST RESULTS

The performance of the linearized MPM was tested at the up-link satellite bands. Figure 3 shows the C-band transfer response of the linearized MPM and of the MPM by itself for comparison. The 1 dB compression point was moved from about 5 dB from saturation to within 2 dB. The phase change between small signal and saturation was reduced from more than 45 degrees to less than 1 degree.

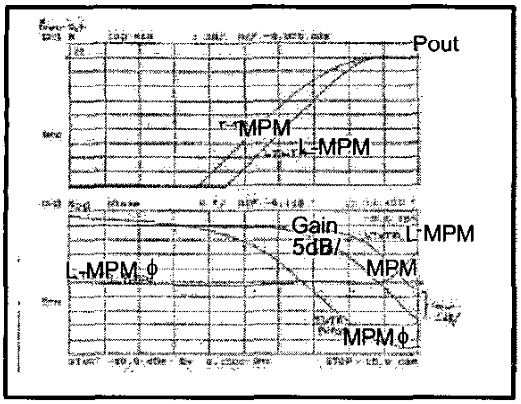

Fig. 3 C-Band transfer response of the MPM with and without a Linearizer.

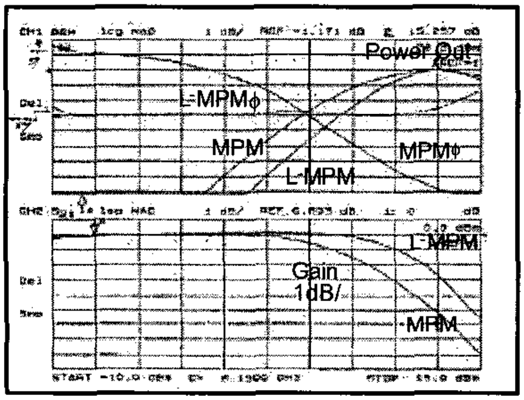

Fig. 4 X-Band transfer response of the MPM with and without a Linearizer.

Figure 4 shows the X-band transfer response. The 1 dB compression point was moved from about 6 dB from saturation to within 2.5 dB. The phase change between small signal and saturation was reduced from more than 45 degrees to less than 2.5 degrees. The Ku-band transfer response was also measured and similar improvements in gain and phase correction. Here the 1 dB compression point was also moved from more than 6 dB from saturation to within 2.5 dB. The phase change between small signal and saturation was reduced from more than 52 degrees to less than 8 degrees. The transfer response of the MPM was also evaluated at the DBS satellite band (18 GHz) and could also have been linearized at this band.

The measured 2-tone carrier-to-intermodulation ratio (C/I) corresponding to these responses are shown respectively in Figure 5. On all bands (C, X and Ku) more

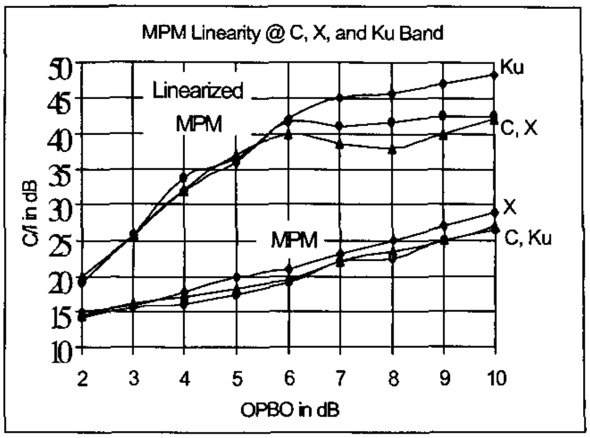

Fig. 5 More than a 15 dB improvement in C/I performance can be obtained by linearizing an MPM

than a 4 dB increase in effective power is provided by the linearizer for the minimum C/I of 26 dB required by most satellite operators, and more than a 6 dB power increase for C/Is > 30 dB. Linearization yields more than a 15 dB increase in C/I for OPBOs > 4 dB.

The efficiency of the test MPM was not optimum relative to a single band amplifier because of its wideband design.[5] In X-band the overall efficiency (TWT, driver amplifier, power supply) of the MPM was measured as > 35 %, but varied with frequency. Figure 6 shows both high and low efficiency for the MPM. For a 2-tone C/I of 26 dB, linearization provides more than 3 to 1 improvement! It increases the efficiency from less than 9 % to greater than 28 % in the high efficiency case.

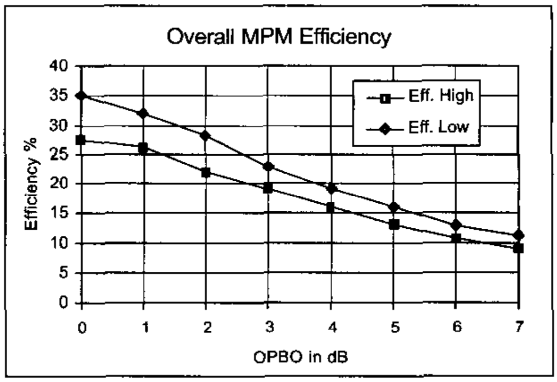

Fig. 6 MPM efficiency varies with OPBO and frequency (upper and lower bounds shown).

III. BANDWIDTH EFFICIENT MODULATION AND MULTI CARRIER EXCITATION

The reduction in spectral regrowth (SR) provided by linearization was next investigated. These SR measurements were made at X-band, but very similar results would be expected at C and Ku as indicated by the C/I measurements. Figures 7, 8 and 9 show the spectral growth (SR) for a single carrier QPSK signal with and without linearization at 0.5, 2, and 3 OPBO respectively. At 0.5 dB OPBO the linearizer provides a SR of better than 26 dB.

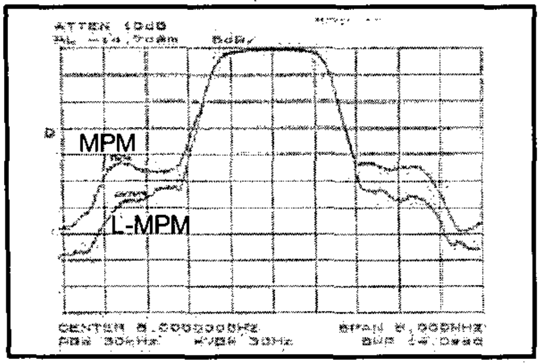

Fig. 7 Spectral Regrowth with and without Linearization at 0.5 dB OPBO.

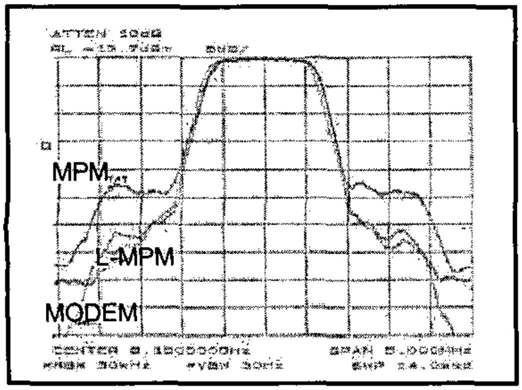

Fig. 8 Spectral Regrowth with and without Linearization at 2 dB OPBO.

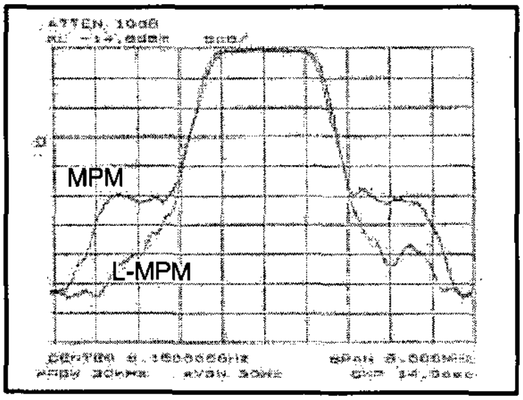

Fig. 9 Spectral Regrowth with and without Linearization at 3 dB OPBO.

At 2 dB OPBO the linearizer can provide a SR of 30 dB. Figure 8 shows not only the SR of the MPM and linearized MPM, but also the spectral response of the modem/upconverter. This figure shows that at some frequency points the linearizer actually improves upon the input signal spectrum. Figure 10 shows a plot of SR versus OPBO with and without the linearizer. The observed improvement in SR was very close to results obtained with conventional TWTA's. Similar results would be expected for OQPSK. BPSK would be expected to provide about one dB poorer performance and 8-PSK about one dB better performance [8].

The performance of the linearized MPM with many carriers and with wideband code division multiple access (WCDMA) signals was also measured. The performance of HPA's with many carriers (>10) is normally tested using a noise power ratio (NPR) measurement. In this test white noise is used to simulate the presence of many carriers of random amplitude and phase. The white noise is passed through a bandpass filter (BPF) to produce an

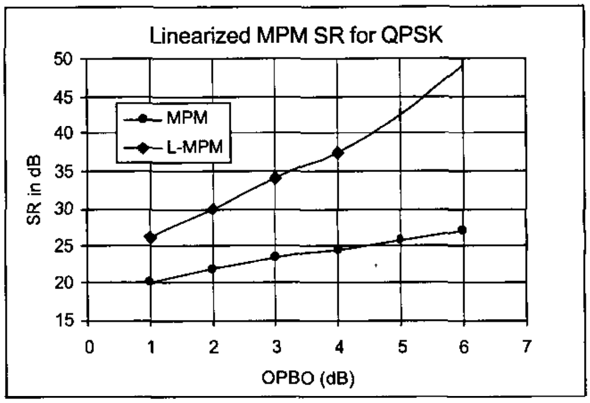

Fig. 10 Spectral regrowth is reduced by >20dB at 6 dB OPBO.

approximately square spectral pedestal of noise about the same bandwidth as the signals of interest. This signal is then passed through a narrow band-reject filter to produce a deep notch at the center of the noise pedestal. The depth of the notch at the output of the test HPA is the measure of the NPR. NPR can be considered a measure of multi-carrier intermodulation ratio (C/I). To evaluate the multi carrier performance of the MPM a 40 MHz X-band noise pedestal was employed. This bandwidth is typical of most satellite transponders. The result of this measurement is shown in Figures 11 and 12. For an NPR of 20 dB, the linearizer achieves a 4.75 dB increase in effective output power.

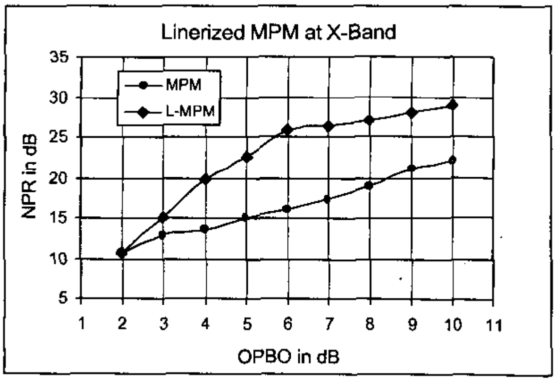

Fig. 11 Almost a 3 dB increase in power is provided for a 16 dB NPR.

WCDMA, a modulation scheme used in some cellular telephones, is starting to be used for satellite and other communications applications. SR is a major concern in these applications. The SR produced by an LMPM in response to a 3G WCDMA signal was thus investigated. The resulting SR produced by the MPM and LMPM at 2.5 and 5 MHz offsets are shown in Figure 13. This figure

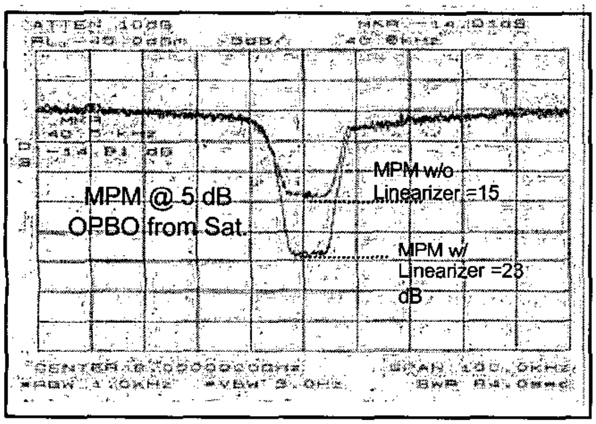

Fig. 12 NPR improvement with linearization at 5 dB OPBO.

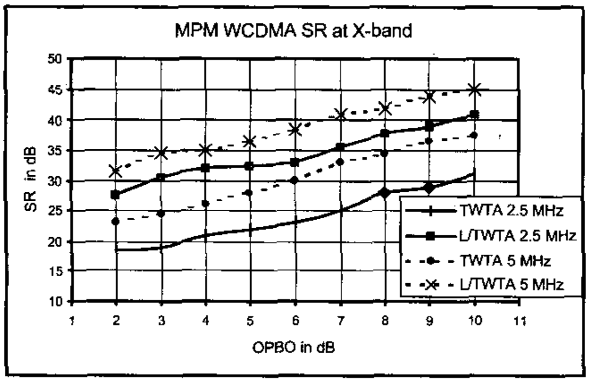

Fig. 13 At 2.5 MHz more than 6 dB of additional power is provided.

shows that as in the case of NPR, linearization provides a huge power advantage. At 2.5 MHz and an SR of 30 dB more than 6 dB of additional power is provided.

IV. SUMMARY

The results in this paper clearly illustrate value of combining an MPM with a linearizer. This combination makes linearized MPMs highly attractive for commercial and military communications applications. The linearized MPM provides high power, high efficiency and high linearity. The linearizer allows an MPM to provide 4 times the output power for C/Is > 30 dB, and more than a 10 dB improvement in C/I over much of its power range. It also allows QPSK operation with an MPM at 0.5 dB OPBO for an SR of 26 dB and at 2 dB OPBO with an SR of 30 dB. Similar advantages are shown for WCDMA.

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REFERENCES

[1] M.A. Basten and et al, "Design and Development of a 2-18 GHz MPM TWT, IEEE International Conference on Plasma Science, 1999, pp137

[2] J.A. Christensen and et al, "MPM Technology Developments: an Industry Perspective," IEEE, MTT-S Digest CH3277, pp 115-118, Jan. 1993

[3] Matthew C. Smith and et al, "Comparison of Solid State, MPM, and TWT Based Transmitters for Spaceborne Applications," Southeastcon '98. Proceedings. IEEE , 24-26 Apr 1998

[4] Richard H. Abrams, "The Microwave Power Module: A Supercomponet for Radar Transmitters," Radar Conference, 1994., Record of the 1994 IEEE National , 29-31 Mar 1994, Page(s): 1 -6

[5] Armstrong, C.M., "60% efficient C-band TWT for the Microwave Power Module," Plasma Science, 1997. IEEE Conference Record - Abstracts., 1997 IEEE International Conference, 19-22 May 1997

[6] A. Katz, "TWTA Linearization," Microwave Journal, Vol. 39, No4, April 1996

[7] A. Katz, "Linearization: Reducing Distortion in Power Amplifiers," IEEE Microwave Magazine, Dec. 2001

[8] A. Katz, "Multi-Carrier 16QAM Over a Linearized TWTA," MTT-S International Microwave Symposium Digest, May, 2001.