BROADBAND AND BROAD DYNAMIC RANGE GaAs DUAL-GATE MESFET LINEARIZER FOR TWTA AND SSPA USED IN SATELLITE TRANSPONDER

Mahesh Kumar, James C. Whartenby and Herbert J. Wolkstein

RCA Laboratories
Princeton, NJ 08540

ABSTRACT

This paper presents a broadband predistortion technique using dual-gate FETs to linearize the Travelling Wave Tube Amplifiers (TWTA) and Solid State Power Amplifiers (SSPA) used in satellite transponders. The results for a linearized TWTA operating over 11.7-12.2 GHz and a linearized SSPA operating over 3.8-4.2 GHz are presented. The improvement in linearity has been achieved over a broad dynamic range of output power.

INTRODUCTION

Information handling capacity of current communication satellites is limited by nonlinearities in Microwave Power Amplifiers (MPA) used in satellite transponders. These amplifier nonlinearities of the signal being relayed by the satellites lead to such undesirable effects as crosstallk, intermodulation distortions, reduced signal to noise ratio in the presence of multiple signals, etc. In order to reduce the nonlinearities of the signal generated in the MPAs and obtain higher carrier to third-order intermodulation distortion (C/3rd IMD) products ratios, amplifiers are operated well below saturation with consequent loss of efficiency and reduced power output and traffic handling capability.

There are many methods for improving the linearity of the TWTAs/SSPAs, namely, Feedforward [1], Negative Feedback [2], [3], and Predistortion [3]-[7]. Predistortion is one of the best methods among others and has been used to linearize MPAs. Most of the papers reported used diodes or single gate FETs to predistort the input signal of the MPA. Further, the improvement in linearity has been obtained for very narrow dynamic range of output power [4], [7]. In this paper, we present Broadband dual-gate FET predistortion linearizers for a 16-watt TWTA operating over 11.7-12.2 GHz and for a 12-watt SSPA operating over 3.8-4.2 GHz. Both of these linearized amplifiers are intended for use in satellite transponder.

The circuit presented here uses fewer number of components than others presented in the literature and is quite simple. The 10 dB reduction in 3rd order intermodulation distortion (IMD) was obtained for an output power range of 10 dB over 11.7-12.2 GHz for TWTA, and 8 dB reduction in 3rd order IMD was obtained for an output power range of 6 dB over 3.8 to 4.2 GHz for SSPA. The linearizer affects a reduction in 3rd order IMD of 5 dB and 3 dB for TWTA and SSPA at saturation, respectively. The improvement in linearity at saturation can result in the doubling the traffic handling capability of a satellite, employing TWTA in the transponder, for video signal transmission.

PRINCIPLE OF OPERATION

Fig. 1 is a schematic diagram of the linearizer. The input to the linearizer is divided into two equal quadrature components in a 90° hybrid power splitter. Each quadrature component is applied to a dual-gate FET which is biased for non-linear operation. The outputs of each dual-gate FET are then combined in an in-phase power combiner and amplified in a power linear amplifier to compensate for the loss encountered in the linearization process.

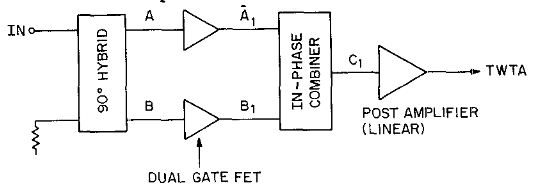

Fig. 1. Schematic of the dual-gate FET linearizer.

The amplitude and phase of the nonlinearity introduced by the two dual-gate FETs can be controlled by adjusting the DC bias on the second gates. Bias points are chosen to provide simultaneously, a decreasing amplitude attenuation and an increasing phase advance with increasing input power level as monitored at the output of the post linear amplifier. This is illustraed by vector diagram representation in Fig. 2 for the circuit shown in Fig. 1. Fig. 2(a) shows the two orthogonal vectors $\vec{A}$ and $\vec{B}$ at inputs of the two dual-gate FETs for a particular input power level. The two signals appearing at the output ports of the two dual-gate FETs are A_1 and B_1 as illustrated in Fig. 2(b). The angle between vectors $\vec{A}_1$ and $\vec{B}_1$ is Θ where $\Theta > 90^\circ$ ($\Theta \approx 160^\circ$). The angle between

0149-645X/85/0000-0609 $01.00 © 1985 IEEE 1985 IEEE MTT-S Digest

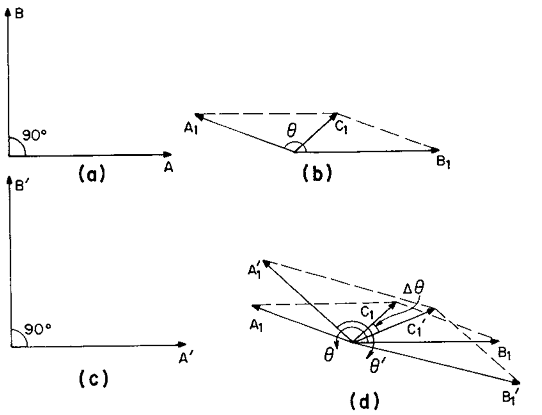

Fig. 2. Linearizer vector diagram.

two vectors increases because of the nonlinearities of the dual-gate FETs. The resultant vector is C_1 at the output of the inphase combiner. When the input power increases to a higher level, the input vectors appearing at the inputs of the dual-gate FETs are $\vec{A}^1$ and $\vec{B}^1$ as shown in Fig. 2(c), where $A^1 > A$, $B^1 > B$ and $A^1/A = B^1/B$. The vectors appearing at the outputs of the dual-gate FETs are $\vec{A}_1^1$ and $\vec{B}_1^1$ are shown in Fig. 2(d). The angle between vectors A_1^1 and B_1^1 is Θ^1 and $A_1^1/A_1 > A^1/A$; $B_1^1/B_1 > B^1/B$. The angle between the two vectors C_1^1 and C_1 is $\Delta\Theta$ such that $\Delta\Theta = \Theta^1 - \Theta$ and $C_1^1/C_1 > 1$.

Thus, gain expansion and phase advance is obtained as the input power to the linearizer is increased. The amount of phase advance and gain expansion can be adjusted by varying the bias voltages of the two gates of the dual-gate FETs. The nonlinearities in amplitude and phase generated by the linearizer are inverse to that generated in the Microwave Power Amplifier.

EXPERIMENTAL RESULTS

Two linearizers were designed and fabricated to linearize a Ku-band 16-Watt TWTA and a C-band 12-Watt SSPA. The results of both TWTA and SSPA with and without linearizers are presented below.

A. TWTA Linearizer

Fig. 3 shows the variation of the output power backoff with input power backoff for a single carrier from saturation for a 16-watt TWTA with and without linearizer. The amplitude transfer characteristics of the TWTA with linearizer have better linearity than that of TWTA alone. The phase transfer characteristics of the TWTA with and without linearizer are presented in Fig. 4. The total phase shift of the TWTA output for a 20 dB dynamic range (0 dB corresponds to saturation) has been reduced from 45^o to less than 14^o over the frequency range of 11.7-12.2 GHz. One measure of improvement

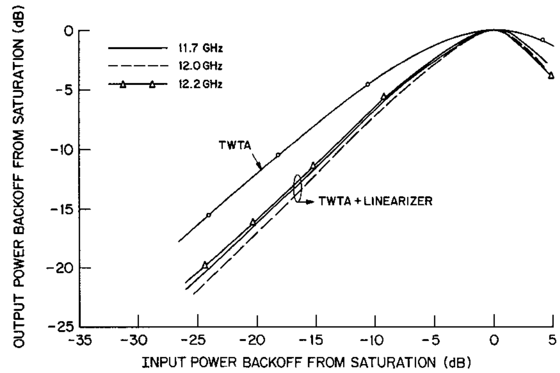

Fig. 3. Output backoff of the TWTA as a function of input power backoff.

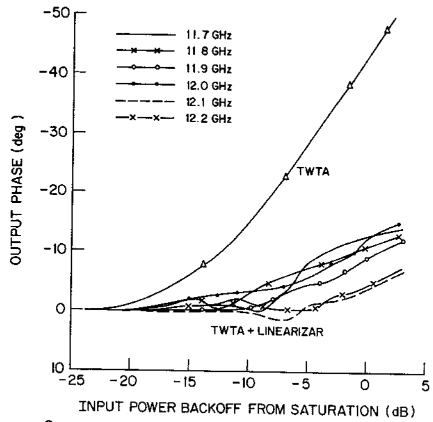

Fig. 4. Output phase of the TWTA as a function of input power backoff.

in the linearity is the third-order intermodulation distortions generated in the TWTA for a two carrier input signal. Fig. 5 shows the comparison of the performance obtained for a standard TWTA and one that has been linearized using the dual-gate FET predistorting method. In Fig. 5 C/3rd IMD ratio is plotted as a function of output power backoff from single carrier saturation at 25^oC for a TWTA at center frequency and for TWTA with linearizer at frequencies 11.7 to 12.2 GHz. These results are obtained for two input carriers separated by 5 MHz. Improvements in C/3rd IMD of 4 to 5 dB at saturation, 7 to 12 dB at 4 dB output power backoff have been obtained over 500 MHz band of 11.7-12.2 GHz. An improvement in C/3rd IMD of more than 7 dB has been obtained over a output power dynamic range of 10 dB. Fig. 6 shows the spectrum analyzer display of the output of the TWTA for two input carriers separated by 5 MHz with and without linearizer, at 3 dB output power backoff.

If two video signals are transmitted through one transponder (channel) the undesired chroma and luma cross-talks are high due to the nonlinearities at saturation. Fig. 7(a) shows the variation of chroma cross-talk as a function of separation of the carrier from the center of the band at saturated output power levels for both with and without

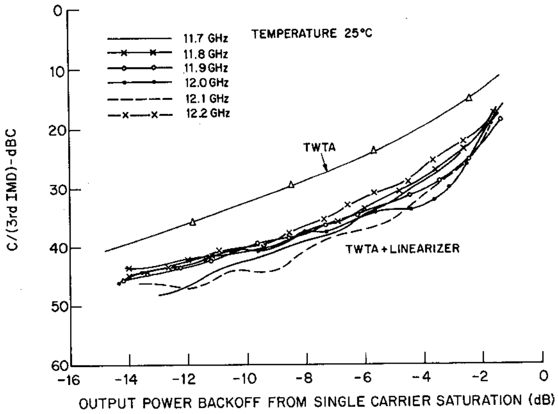

Fig. 5. C/3rd IMD ratio of the TWTA as a function of output power backoff.

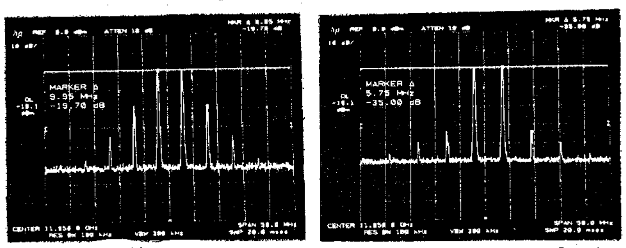

Fig. 6. Two tone frequency spectrum of the outpot of the TWTA at 3 dB back off/without and with linearizer.

linearizer for a 16-watt TWTA at 12 GHz. With linearizer the chroma cross-talk has been reduced to less than 1.5% which is within acceptable limit. Fig. 7(b) shows the variation of luma cross-talk as a function of input power back-off from saturation with and without linearizer. The luma cross-talk is about 4.5% at saturation and reduces as the input power is reduced. The luma cross-talk, has been reduced to less than 1% for all power levels including saturated power. Thus, by using linearizer with TWTA, two video signals can be transmitted through one transponder at saturated power levels. Thus, performance improvement can virtually double the traffic handling capability of the satellite.

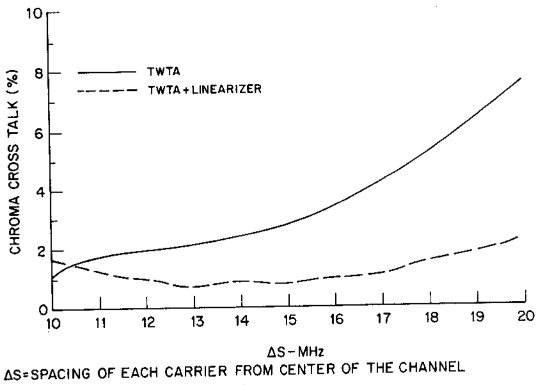

Fig. 7(a). Chroma crosstalk as a function of spacing of the two carriers from the center of the channel at 12 GHz.

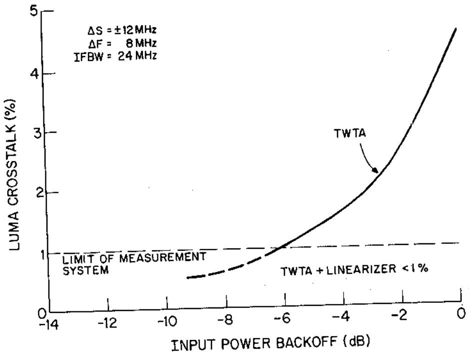

Fig. 7(b). Luma crosstalk as a function of input power backoff at 12 GHz.

B. SSPA LINEARIZER

A linearizer was also designed and fabricated for linearizing a 12-watt Solid State Power Amplifier operating over 3.7 to 4.2 GHz. Fig. 8 shows the variation of the output power backoff with input power backoff for a single carrier from saturation (operating point) for a 12-watt SSPA. The phase transfer characteristics (AM-to-PM) of the SSPA with

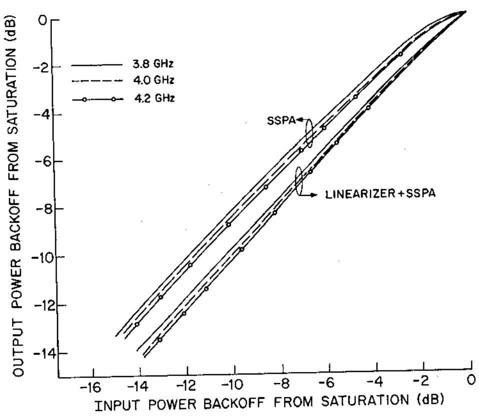

Fig. 8. Output power backoff of the SSPA as a function of input power backoff.

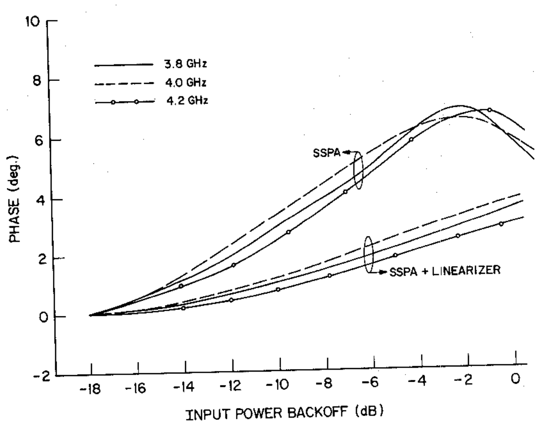

Fig. 9. Output phase of the SSPA as a function of input power backoff.

and without linearizer are presented in Fig. 9. The total phase shift of the SSPA for a 20 dB dynamic range of input power has been reduced from 8^o to 4^o over 3.8-4.2 GHz. Thus, there is a considerable improvement in the amplitude linearity (AM-to-PM) and phase linearity (AM-to-PM) of the SSPA by predistorting the input signal to the SSPA. In Fig. 10, C/3rd IMD ratio is plotted as a function of output power backoff from single carrier saturation for SSPA with and without linearizer for frequency range 3.8 to 4.2 GHz. These results are obtained for two input carriers separated by 5 MHz. Improvements in C/3rd IMD of 2 dB at saturation, 10 dB at 5 dB output power backoff have been obtained over 400 MHz band of 3.8-4.2 GHz.

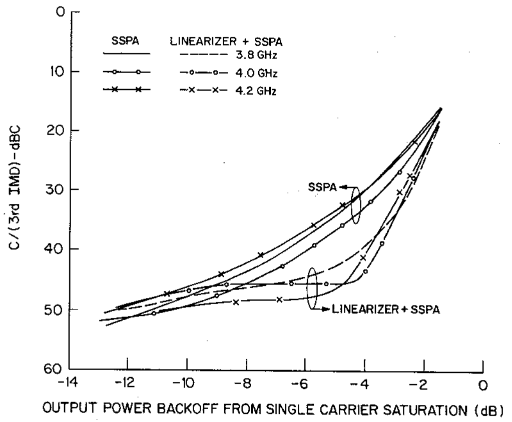

Fig. 10. C/3rd IMD ratio of the SSPA as a function of output power backoff.

Fig. 11 shows the spectrum analyzer display of the output of the SSPA for two input carriers separated by 5 MHz, with the without linearizer at 4 dB output power backoff from single carrier saturation.

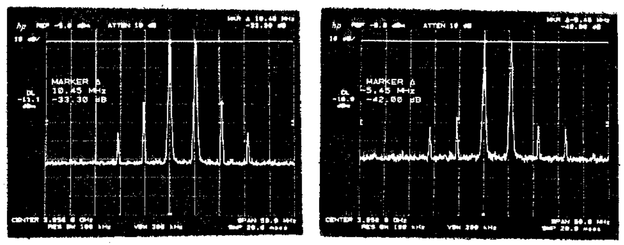

Fig. 11. Two tone spectrum of the output of the SSPA at 4 dB backoff/without and with linearizer

CONCLUSIONS

A new predistortion technique is presented for linearizing microwave power amplifiers such as Traveling Wave Tube and Solid State Power Amplifiers used in Satellite transponders. In this technique, dual-gate FETs are used as nonlinear devices to generate the inverse amplitude and phase nonlinearities to that of the MPA. The results for a linearized 16-watt TWTA for 11.7-12.2 GHz, and a linearized 12-watt SSPA for 3.8-4.2 GHz are presented. In both cases, very good improvements have been obtained in the C/3rd IMD ratios and the AM-to-AM and AM-to-PM distortions are reduced. The improvements obtained in the chroma and luma crosstalks obtained with linearized TWTA at 12 GHz allows the TWTA to be operated at saturation and double the traffic handling capability of the satellite. The circuit for the linearizer is quite simple and is adoptable to different types of TWTAs or SSPAs by changing of the bias voltages of the dual-gate FETs.

ACKNOWLEDGEMENTS

Authors wish to thank Drs. S. Y. Narayan and F. Sterzer for motivating technical discussions, support and encouragement. Thanks are also due to Drs. K. Jonnalagadda and A. Guida for computer simulation studies, and R. J. Klensch and K. Kelly for cross-talk measurements.

REFERENCES

1. M. Sidel, "A Microwave Feed-forward Experiment," Bell System Technical Journal, Vol. 50, September 1971, pp. 2879-2961.
2. P. Lubell et al, "Linearizing Amplifiers for Multisignal Use," Microwaves, pp. 46-50, April 1974.
3. C. C. Hsieh and E. Strid, "A S-Band High Power Feedback Amplifier," 1977 IEEE MTT-S International Microwave Symposium, pp. 182-184, San Diego, CA, June 21-23, 1977.
4. J. Czech, "A linearized 4 GHz wideband FET power amplifier for communications satellite," AIAA communication satellite conference pp. 511-520, Orlando, FL, March 19-22, 1984.
5. P. H. Charas and J. D. Rogers, "Improvements in ON-Board TWTA performance using amplitude and phase predistortion," International Conf. on Communication, Systems Technology, April 7-10, 1975, Savoy Place, London.
6. D. Cahana, "Practical Aspects of Predistortion Diode linearizers for Satellite Transponders," 14th European Microwave Conference, Sept. 10-13, 1984, Belgium, Session A1.
7. S. Lenz, "Design and performance of microwave predistortion networks using MIC-technique," 13th European Microwave Conference, 1983, pp. 687-692.