PASSIVE FET MMIC LINEARIZERS FOR C, X AND KU- BAND SATILLITE APPLICATIONS

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ABSTRACT

The design and measured performance of GaAs MMIC linearizers for use with space-borne traveling wave tube amplifiers (TWTAs) are presented. New space communications technology requires highly linear amplifiers. Linearizers correct for amplifier distortion to provide the needed linearity. The linearizers described in this paper operate at C, X and Ku-band, and are believed the first to be realized in MMIC form. They are based on a passive FET design similar to that of MMIC switches and attenuators. MESFET varactors and voltage variable resistors are used as control elements. They provide more than 2.5 GHz of bandwidth at Ku-band with an improvement of greater than 10 dB in TWTA carrier-to-intermodulation ratio (C/I), and with a phase change of less than 5 degrees.

INTRODUCTION

New forms of modulations and changes in traffic have created a demand for satellite systems with much greater linearity [1]. In the past, the bulk of satellite transmissions have been single carrier video signals. Digital compression now allows several television signals to be transmitted in the frequency space previously occupied by a single signal. Non-video, multiple signal services such as VSAT (very small satellite terminals) are altering traditional satellite loading. These changes have created a necessity for systems that can carry multi-carrier traffic more efficiently.

Linearization of a satellite's high power amplifiers is one means of satisfying this need without significantly increasing amplifier size, weight and power consumption. The linearizers described in this paper were developed to equalize TWTAs, but can also be applied to compensate solid state amplifiers with little modification.

Most previous linearizer designs have used the non-linear characteristics of amplifiers driven into saturation or diodes in complex bridge circuits to obtain the required non-linear response [2,3,4]. The MMIC linearizers discussed here employ a single GaAs MESFET with zero source-drain bias as the non-linear element [5]. These linearizers provide near ideal equalization over a wide range of amplifier characteristics with a single chip. They also provide this performance over a wider bandwidth than other published designs.

A MMIC linearizer design was chosen to eliminate the need for the expensive and time consuming hybrid assembly of linearizer modules. MMICs also offer wider bandwidth than is achievable using hybrid fabrication, greater reliability, and a savings in size and weight.

LINEARIZER DESIGN

Figure 1 shows a simplified schematic diagram of the basic linearizer. The non-linear element is a MESFET connected in a common gate circuit, and has been patented by GE [6].

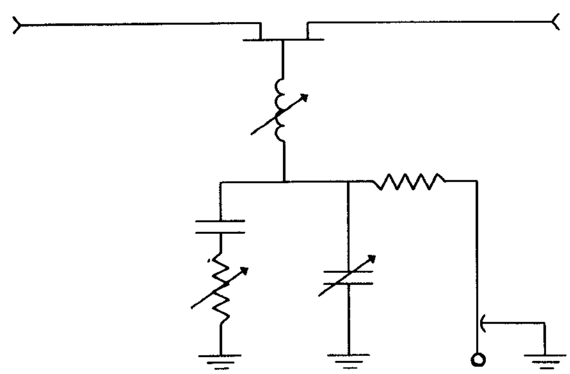

Figure 1. Simplified Schematic Diagram of the Basic Passive MESFET Linearizer.

The transfer characteristics (S21) of the FET are affected by its gate bias potential and the impedance (Zg) at its gate terminal. It is possible to obtain with increasing input power level, an S21 function whose magnitude becomes larger and whose phase angle either increases or decreases. An

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example of typical S21 change with input level for several dc gate bias settings is illustrated in Figure 2. It shows the variation in S21 magnitude and the shift in phase of S21. The on-set of changes in S21 have been observed at input powers as low as -40 dBm. Further, these characteristics can be made relatively constant over frequency.

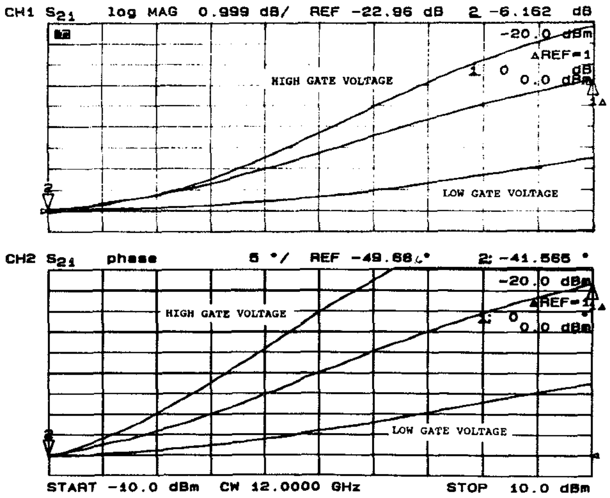

Figure 2. Typical S21 Change of Passive FET Linearizer with Input Level and Dc Gate Bias Settings.

The reactive component of Zg is controlled by a series inductive length of transmission line and the capacitance of a MESFET varactor. The real part of Zg is controlled by a third MESFET operated as a voltage variable resistor. VIA and airbridge techniques were incorporated in the design where feasible to minimize size. The non-linear and control elements were implemented using 0.3 x 300-um MESFETs. The S-parameters of these FETs were measured for a range of voltages. These data were used in CAD simulation to determine element values.

To accommodate a variety of TWTA characteristics and to increase the operational frequency of the MMIC linearizers, the inductive portion (Lg) of Zg was made adjustable. This was accomplished using a unique airbridge-over-metal tuning arrangement which permits the length of Lg to be shortened. Pressure is applied to an oversize air-pad to join the airbridge metal to its underlining metal pad. The MMIC process was adjusted to eliminate the oxide normally formed under the air-pad. During initial tuning, the topology that produces the required response is identified. In subsequent builds the circuit connections are made during assembly. Alternately, a dedicated MMIC chip can be fabricated by altering only two mask layers.

Two MMIC chips were developed. One for C-band and one for X/Ku-band. The airbridge tuning allows the X/Ku-band chip to be optimized for operating frequencies from below 10 GHz to above 15 GHz. Figure 3 shows the MMIC layout of the X/Ku-band linearizer. The C-band version is similar, but with larger reactive components. The non-linear MESFET element is in the center of the chip. The adjustable Lg (ladder structure) connects the FET's gate to the capacitive and resistive control elements in the upper third of the chip.

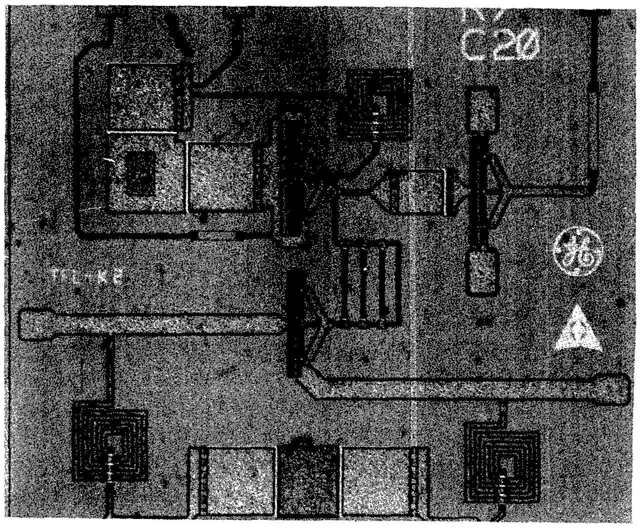

Figure 3. Photograph of MMIC X/Ku-Band Linearizer.

LINEARIZER PERFORMANCE

The MMIC linearizers' performance closely matched their simulated response. The principle goal was to achieve linearizers which provide a decrease in loss on the order of 7 dB, and a positive phase change of about 45 degrees over the frequency range from 11 to 13 GHz by the X/Ku-band chip, and from 3.5 to 4.5 GHz by the C-band chip. Figures 4 and 5 show respectively the measured gain and phase of the Ku and C-band MMICs, at low and high power levels, as a function of frequency. From these graphs it can be seen that the design goal was achieved.

Minimizing the linearizer's insertion loss was also a concern. At C-band insertion losses of less than 8 dB, for levels corresponding to TWTA saturation, were achieved. At Ku-band, the corresponding insertion losses were less than 10 dB.

Figure 6 shows the output power, gain and phase as a function of input power for the X/Ku-band MMIC when combined with a TWTA. The transfer responses across a 2.5 GHz frequency band have been overlaid. A peak-to-peak phase deviation of less than 5 degrees, with a separation between the 1 dB compression points and saturation, of less than 2.5 dB in input back-off, was achieved across this entire band.

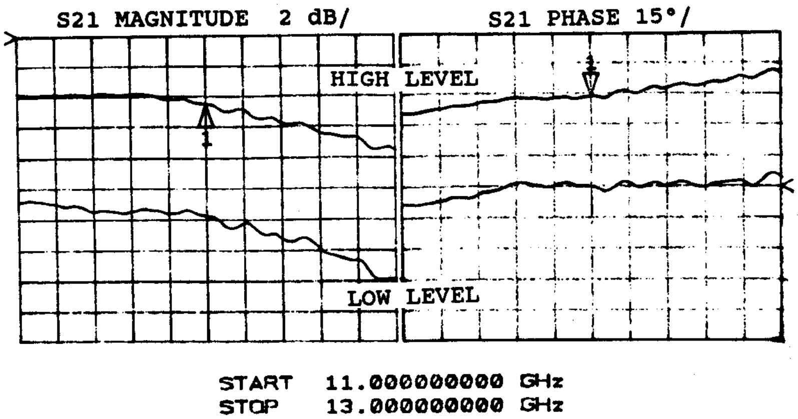

Figure 4. Measured Gain and Phase of Ku-Band MMIC Linearizer at Low and High Power Levels as a Function of Frequency.

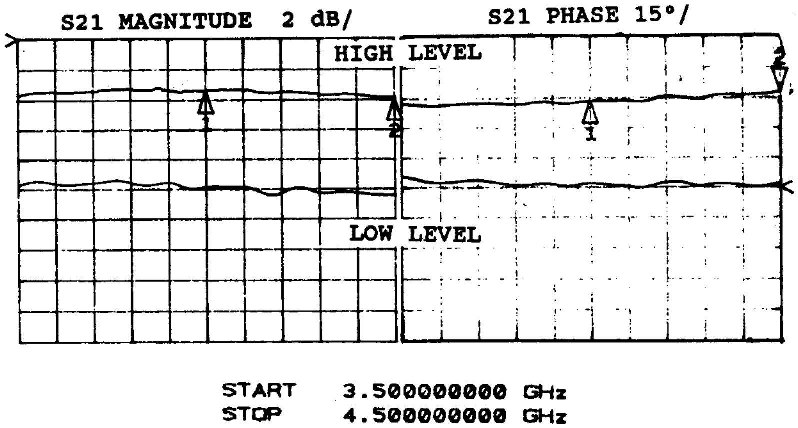

Figure 5. Measured Gain and Phase of C-Band MMIC Linearizer at Low and High Power Levels as a Function of Frequency.

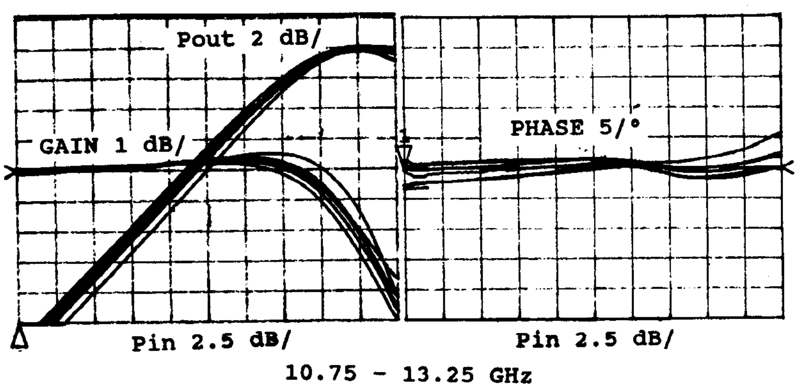

Figure 6. Output Power Sweep, Gain and Phase as A Function of Input Power for Ku-Band MMIC Linearizer Combined with a TWTA Over a 2.5 GHz Frequency Span.

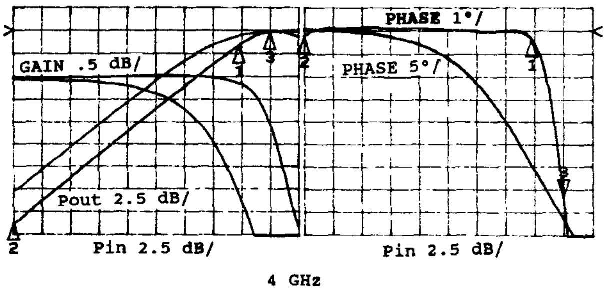

Figure 7. Comparison of Output Power, Gain and Phase as a Function of Input Power of a TWTA to the C-Band MMIC/TWTA Combination.

Figure 7 compares the power sweep response of a TWTA to that of the C-band MMIC/TWTA combination. Note the virtually flat phase. The linearized 1 dB gain compression point has been moved by nearly 7 dB, and is located at TWTA saturation.

Figures 8 and 9 show the 2-tone carrier-to-intermodulation ratio (C/I) achieved when the MMIC linearizers were mated with laboratory TWTAs at Ku and C-band respectively. The output power backoff required for a 25 dB C/I is decreased by 3.5 dB at both Ku and C-bands.

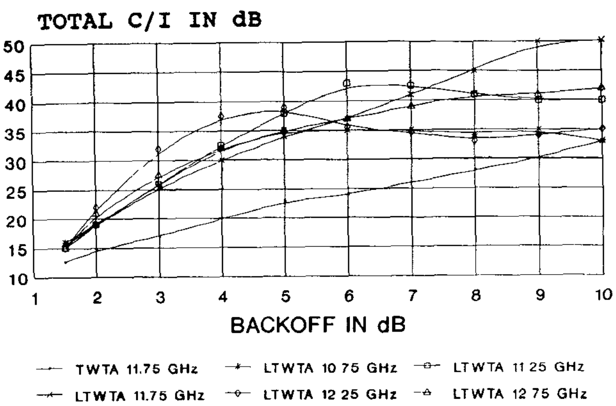

Figure 8. C/I Achieved by MMIC Linearizer with TWTAs at Ku-Band.

CONCLUSION

All MMIC linearizer design goals were achieved at both C and X/Ku-bands. Bandwidths of more than 25 percent were provided with a significant reduction in C/I for output power backoff levels greater than 2 dB. TWTA phase shift as a function of power level was reduced to less than 5 degrees, and effective output power was more than doubled for C/I greater than 25 dB, across the bands of interest. Linearizer insertion loss was reduced to below 8 dB at C-band and 10 dB at Ku-band. The MMICs also verified the soundness of the CAD modeling techniques used to develop the chips, and the value of the unique MMIC air bridge over metal tuning technique incorporated into the designs.

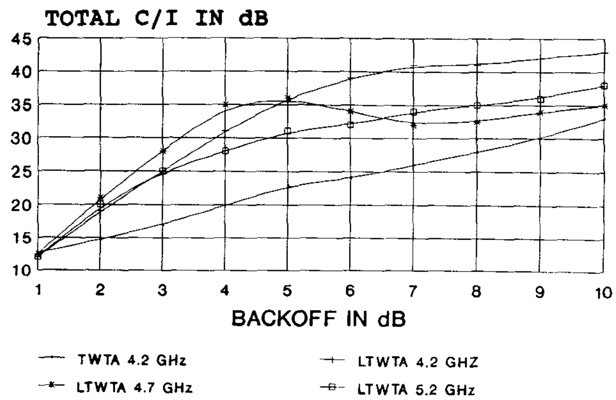

Figure 9. C/I Achieved by MMIC Linearizer with TWTAs at C-Band.

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