Unlimited Bandwidth TWT Predistortion Lineariser MMICs for Ku- and Ka-band Operation

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ABSTRACT

Novel types of predistortion MMICs for the linearisation of short and standard length travelling wave tubes were developed. We measured single setting optimum performance over a wider a bandwidth than any previously reported. The two designed chip sets operated correctly at the specified 10.7 to 12.7GHz and 18.5 to 20.2GHz bands, however, there is no limitation to the wider bandwidth operation of the circuits. By utilising a transmission line simulating network of series inductors and shunt Schottky-diodes we designed these MMICs on a commercially available 0.25μm PHEMT process. The chip set includes separate AM/AM and AM/PM circuits for accurate and separate linearisation adjustment of the TWT.

INTRODUCTION

The recently introduced digital services in Ku- and Ka-band satellite and terrestial telecommunications have driven the development of linear high power amplifiers. TWTs are the most efficient high power amplifiers, but typically their linearity is poor. Their distortion specifications limit the useable output power of TWTs to 10dB or more below amplifier saturation. We developed predistortion linearisation MMIC circuits to overcome these limitations. These lineariser circuits were developed as a part of European Space Agency research contract "Microwave Power Modules".

Previous linearisers have been mostly designed as hybrid circuits. Their useable bandwidth has been very limited and their performance has been achieved as a result of a tedious tuning exersice. The main obstacle for broad bandwidth performance has been the use of frequency tuned resonating circuits or accurate summing of signals from a linear and a non-linear channels to achieve the required gain and phase expansion characteristic. We overcame these limitations by introducing a completely new concept in the linearisation of TWTs. A transmission line simulating ladder network of series inductors and shunt Schottky diodes operates as a gain expansion circuit (AM/AM) or a phase expansion circuit (AM/PM) when suitably designed and biased. The high bandwidth of the circuit is caused by the transmission line type of characteristics and only limited by the upper cut-off frequency of the low-pass type network.

DESIGN OF THE MMICS

We designed circuits for the AM/AM linearisation and for the AM/PM linearisation at 10.7GHz to 12.7GHz frequency range and a second set of circuits for linearisation at 18.5GHz to 20.2GHz. The circuits schematic diagram is presented in Figure 1. The junction conductances $G_p(I)$ and capacitances $C_p(V)$ of the Schottky diodes are dependent on the biasing and input power of the circuit.

The circuits were designed to have a characteristic impedance of Z_0=50Ω. Additional design criteria was to have the low-pass cut-off frequency, f_c, of the circuits well above the operating frequency. These properties of the transmission line simulating network are well known from early pulse forming networks for radars [1]. The characteristic impedance and cut-off frequency of an ideal lossless line can be calculated from the following formulas:

$$Z_0 = \sqrt{\frac{L_s}{C_p}} \qquad (1)$$

$$f_c = \frac{1}{\pi\sqrt{L_s C_p}} \qquad (2)$$

The attenuation and phase shift in the line depend mainly on the resistive and reactive elements of the line correspondingly. The real and imaginary parts of the propagation constant γ determine the attenuation constant α and phase constant β.

$$\gamma = \alpha + j\beta = \sqrt{(R_s + j\omega L_s)(G_p + j\omega C_p)} \tag{3}$$

Taking these design criterias into account, the number of sections in the line was chosen to achieve the desired predistortion characteristics when biased through a specific biasing network. We used a standard commercial 0.25μm PHEMT MMIC process for the design of these circuits. The Schottky diode is formed by the gate of the PHEMT. Short 10μm wide stripline inductors connected the diodes. The chips have co-planar transitions for on-wafer measurements.

MEASUREMENT RESULTS

On-wafer measurements of the circuits were performed. The performance of the circuits was uniform over the wafer, with typical results presented in Figures 2, 3, 4 and 5. The gain expansion of the AM/AM circuit is 7dB over typical TWT input compression range and the gain expansion continues even above this range with continuous slope. The phase expansion characteristics of the AM/PM circuit are also very uniform and the phase shift increases as a function of frequency, as required in TWT linearisation. These results were measured without any tuning or bias changes between measurements, so they represent true operational bandwidths of the lineariser MMICs. The circuits can be connected in cascade with an amplifier to linearise a TWT as shown in Figure 6.

The lineariser consept was verified with 3rd order intermodulation, Noise Power Ratio and AM to PM transfer (K_t) measurements at TTEG facilities in Ulm, Germany. The results of the intermodulation measurements of Ku-band linearisers together with a Ku-band TWT are shown in Figure 7. The lineariser was tuned to eliminate the TWT AM/AM and AM/PM distortion at 11.7GHz. With this single setting the intermodulation was measured over the whole 2GHz bandwidth. The optimum performance improvement could be maintained over the operating bandwidth of the TWT. At 12.75GHz the TWT input power level had to be increased significantly and thus a misalignment in the linearisation was caused. The NPR and K_t were also measured for the Ku-band unit.

Figure 8 shows the results of NPR measurements of the Ka-band lineariser. The approach to TWT lineaser tuning was the same as for the Ku-band unit. The lineariser AM/AM and AM/PM characteristics were tuned to eliminate the TWT AM/AM and AM/PM distortion at 19.5GHz and then these settings were maintained during the measurements. The operate the TWT with 20dB NPR, 4dB back-off from the TWT nominal output power is required over the whole bandwidth. This demonstrates how the lineariser can be used to obtain high output power from the TWT without sacrificing the linearity.

CONCLUSION

The presented MMICs for predistortion linearisation achieved the widest possible operating bandwidth due to the transmission line type characteristics of the circuit topology. These MMICs are the optimum solution for the linearisation of normal or short TWTs and well suited for connection with other solid state components, such as amplifier MMICs. This patent pending lineariser design enables simple tuning and easy mass production of linearisers for various TWT linearisation needs.

ACKNOWLEDGEMENT

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REFERENCES

[1] White, H.J., Gillette, P.R. and Lebacqz, V.J. "The Pulse-Forming Network" in Pulse Generators, MIT Radiation Laboratory Series, McGraw-Hill, New York, 1948, pp. 175-225.

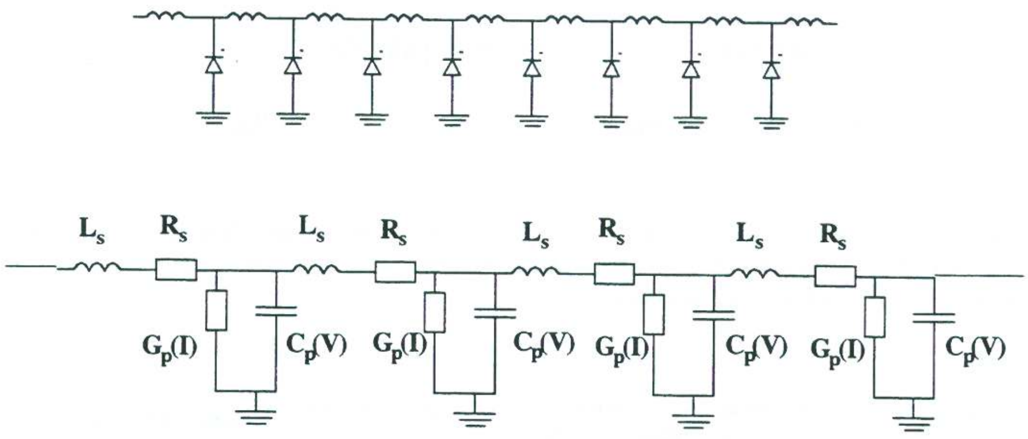

Figure 1. Schematic diagram of the AM/AM and AM/PM linearisation circuits and the electrical equivalent circuit including Schottky junction nonlinearities.

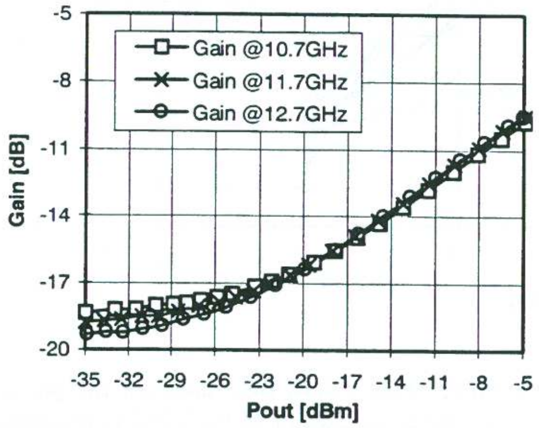

Figure 2. Gain expansion of Ku-band AM/AM circuit using single bias setting.

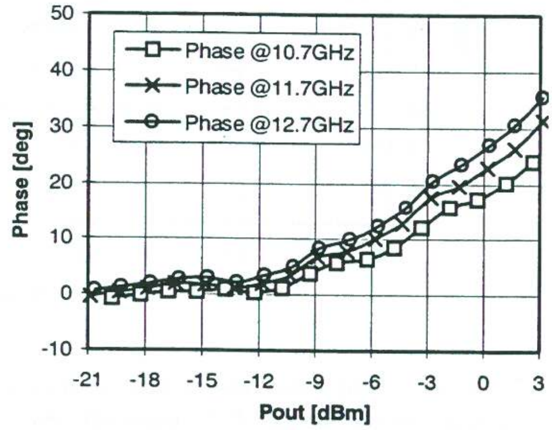

Figure 3. Phase expansion of Ku-band AM/PM circuit using single bias setting.

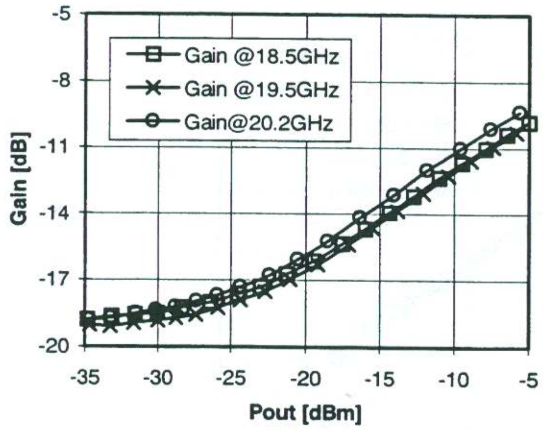

Figure 4. Gain expansion of Ka-band AM/AM circuit using single bias setting.

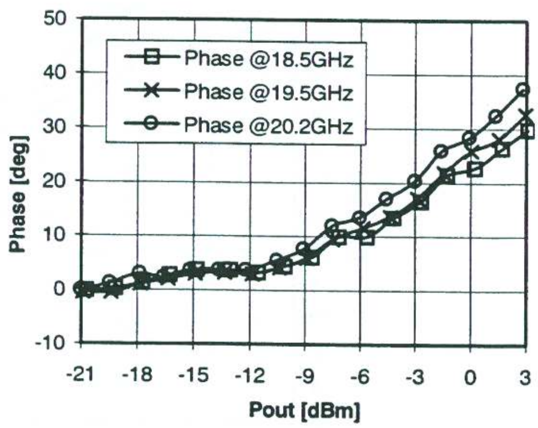

Figure 5. Phase expansion of Ka-band AM/PM circuit using single bias setting.

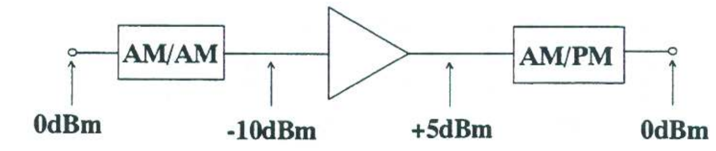

Figure 6. The block diagram of the TWT predistotion lineariser. The AM/AM and AM/PM are separate MMICs, which can be independently tuned with bias voltages to match the TWT characteristics. The power levels shown refer to power levels at TWT saturation.

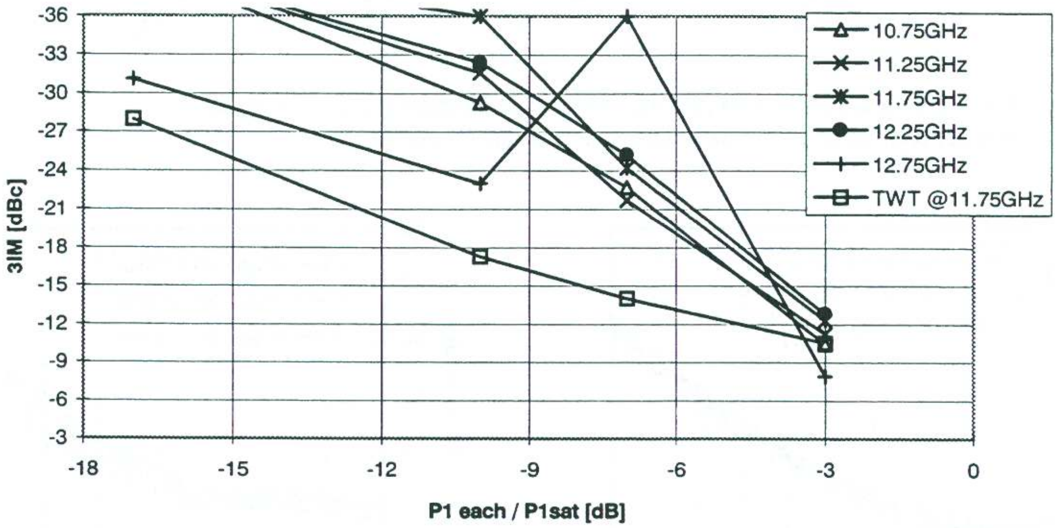

Figure 7. Results of 3rd order intermodulation measurements at Ku-band. These results were obtained without any changes in the tuning of the lineariser. With single setting the 2GHz bandwidth of the TWT is linearised. The input power is single carrier power as compared to single carrier input saturation power of the TWT. Thus the -3dB point corresponds to TWT input saturation. The result of the measurement @11.75GHz for TWT alone is also shown.

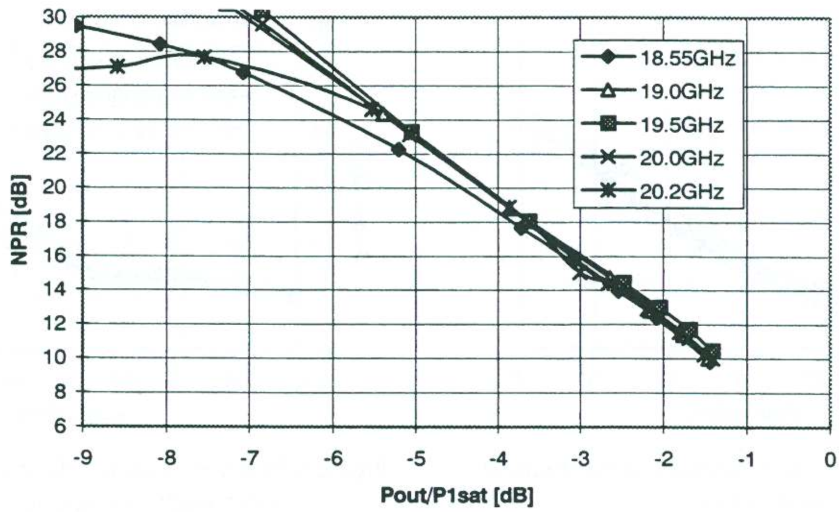

Figure 8. Results of NPR measurements at Ka-band. As in Figure 7, the single setting of lineariser is maintained in all measurements. This figure shows the intermodulation characteristic of the linearised TWT as a function of the TWT output power back-off from single carrier saturation.