A SOLID-STATE 2-10 GHz 1 WATT TWT REPLACEMENT AMPLIFIER

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ABSTRACT

The design and performance of a solid-state TWT replacement amplifier for the 2-10 GHz frequency range will be presented with special emphasis on broadband matching and serrodyne techniques. The 55 dB gain GaAs FET amplifier employs resistive equalization, matching networks constructed on high permittivity substrates, and planar SSB mixer technology, in order to achieve its 1 watt power output and serrodyne performance.

INTRODUCTION

As the state-of-the-art in solid-state device technology advances, the familiar TWT amplifier used in many EW systems can be replaced with GaAs FET amplifiers. Although GaAs FET amplifiers have reliability, size and efficiency advantages over conventional microwave tube amplifiers, they are somewhat difficult to design with broadband/flat gain response characteristics. The design is further complicated by the demand for high gain performance which can only be achieved by cascading many FET stages. Some systems also require some form of serrodyne capability.

DESIGN APPROACH

This paper describes the design and performance of a 1 watt broadband power amplifier chain, that consists of small signal feedback amplifiers, serrodyne unit, temperature compensation and balanced power stages (Figure 1). This discussion will be focused on several key components such as the two-stage single-ended feedback amplifier [1], balanced temperature compensation network, single sideband mixer, and balanced medium power amplifiers.

Feedback amplifiers were used throughout the amplifier chain as small signal 15 dB gain blocks, buffer amplifiers for the serrodyne, and a low noise input amplifier. Two balanced programmable RF attenuators were also employed in the amplifier chain so that the TWT gain would

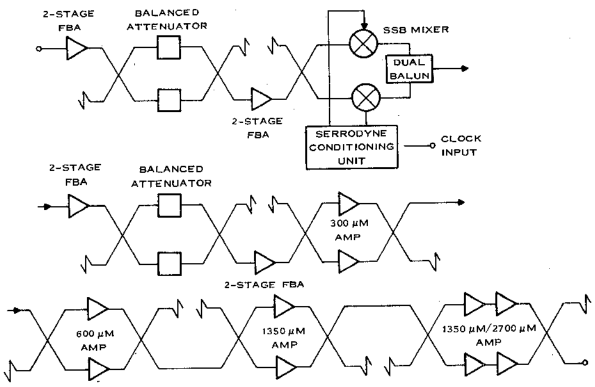

Figure 1. Serrodyne Amplifier Circuit Configuration

remain constant over the temperature range of -55° to +100°C. Several balanced equalized amplifiers were also needed to develop the 0.5 watt drive level required by the output gain block from the available small signal drive level of 0.02 watt. The output gain block consisted of a balanced pair of single-ended, two stage FET amplifiers which exhibited excellent performance throughout the 2 to 10 GHz frequency range (Figure 2).

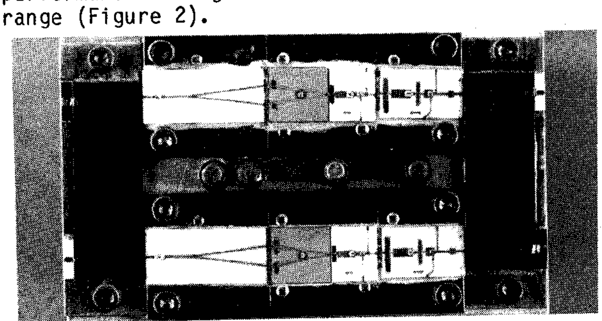

Figure 2. Balanced 1350 μm/2700 μm Cascaded Equalized Gain Block

Three element, resistive equalizers [2] were incorporated into the matching networks for each FET to compensate for the 6 dB/octave gain roll-off. Equalization eliminates the need to employ large amounts of impedance mismatch between power FET's and the amplifier circuit in order to achieve gain flatness over extreme bandwidths; thus, the resulting amplifier is very tolerant of production variances and is unconditionally stable. The resistive shunting effects of these

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networks help confine the load presented to the driver FET. This control of the interstage impedances allows the amplifier to maintain its gain response characteristics into the saturation region.

Novel FET input networks were synthesized using a high permittivity ceramic substrate material (ε_r=42). This material was chosen because of the low gate impedance of power FETs which usually requires matching network elements with characteristic impedances less than 10 Ω. This technique was especially helpful when multi-cell FETs were employed since the drive power and output power for each cell must be either divided from a common source or combined into a common load. The small signal gain of the output gain block is shown in Figure 3.

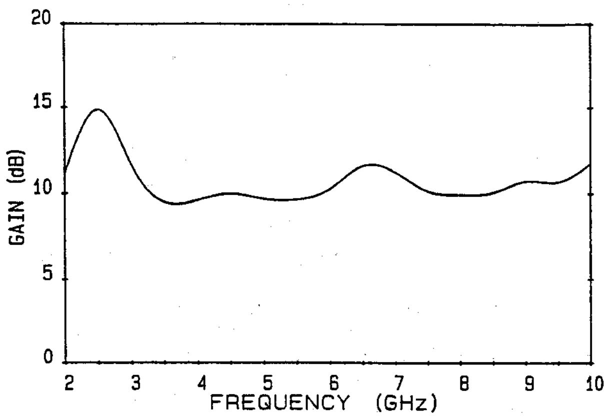

Figure 3. Small Signal Gain of the Balanced Output Gain Block

The broadband serrodyne consisted of two balanced MIC mixers, a 3 dB MIC quadrature coupler, and a digital sawtooth to sine wave serrodyne conditioning unit, which simulates the serrodyne performance of a conventional TWT. Potential sideband suppression can be calculated as a function of the phase and amplitude tracking of the two balanced mixers, and amplitude balance of the hybrid coupler. Excellent amplitude and phase tracking, and hence, good sideband suppression was achieved by virtue of the mixer's common RF balun configuration [3] and velocity compensated three section coupler. The mixers were completely planar and constructed on 0.5 mm thick fused quartz substrates. A common balun functions as the output RF port of two double balanced mixers, thus providing in phase E field excitation tangential to the plane of the substrate. The input RF ports of both mixers, which are combined in quadrature with a three section coupler, are coupled to the diodes through microstrip to balanced line (suspended) tapered transitions. Since the input and output ports exhibit orthogonal field relationships, and monolithic diode pairs were employed, the SSB mixer has inherently good carrier suppression. The planar single sideband mixer and typical serrodyne performance are shown in Figures 4 and 5 respectively.

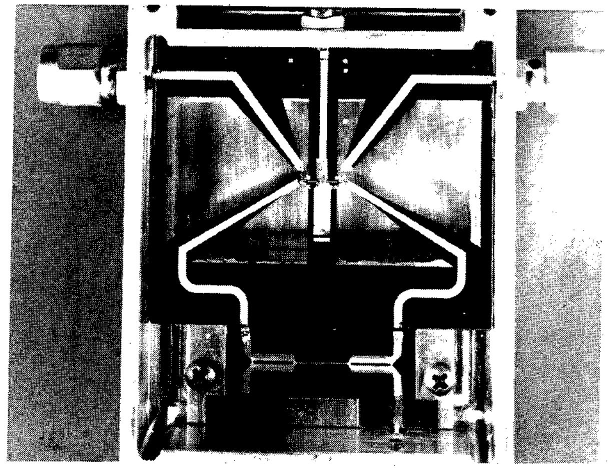

Figure 4. Planar Single Sideband Modulator

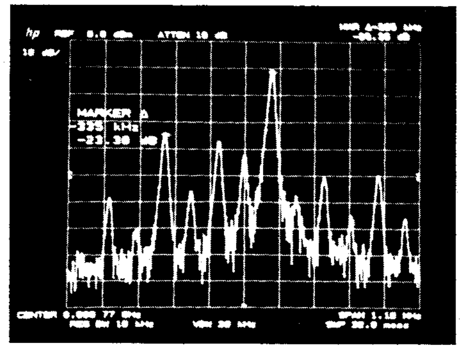

Figure 5. Typical Serrodyne Performance

The sine and cosine waveform modulation method was selected because it provides lower spurious levels than direct sawtooth modulation. A variable frequency sawtooth to sine wave converter was implemented in this serrodyne design so that it may directly replace existing TWT serrodynes without modification to external circuitry. Because of the large frequency variation requirements of the input sawtooth voltage (100 Hz to 50 KHz), a digital generator of SIN/COS waveforms using sampling techniques was implemented.

PERFORMANCE

The overall design philosophy for the composite amplifier was to operate the low power, intermediate, and driver stages in their linear regions while saturating the final stage for maximum gain and power output. Typically, the serrodyne amplifier demonstrated a small signal gain of 55 dB and a saturated minimum output power of one watt over a bandwidth of 2-9.75 GHz at 25°C. The average power output within the same bandwidth at 100°C was also greater than +30 dBm. To achieve this output level, the output stage employed a balanced two stage amplifier as shown in Figure 2. Each two stage amplifier was comprised of a single FET driving a pair of FET's in a two way Wilkinson-like power combiner scheme using broadband reactive and resistive matching. The 300 μm and 600 μm FET predrivers and 1350 μm FET driver amplifiers were of similar design except no reactive combining techniques were employed. The solid-state TWT replacement and typical gain and power output characteristics are shown in Figures 6 and 7 respectively. Other key performance parameters of the serrodyne amplifier were a noise figure of 6-7 dB, < 2 nsec group delay, input/output VSWR of 2.0:1, and a 15 dB overdrive capability. With the balanced mixer approach, the serrodyne performance was excellent with a minimum of 23 dB carrier suppression and 14 dB sideband suppression. The serrodyne operation was completely controlled by the sawtooth serrodyne input voltage.

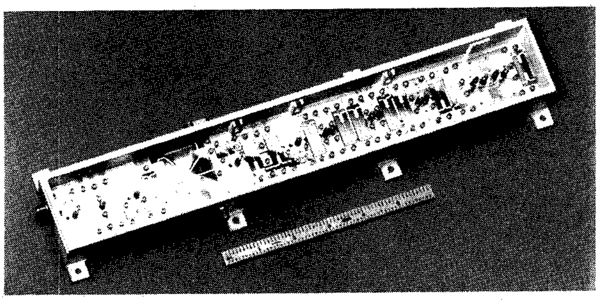

Figure 6. Serrodyne Amplifier Module

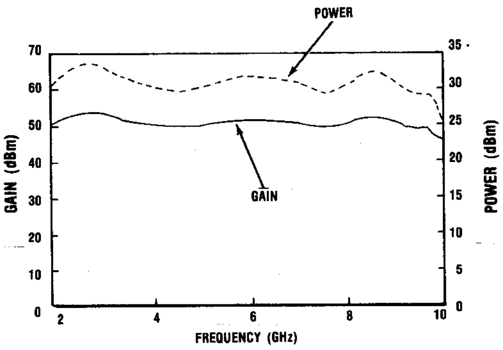

Figure 7. Serrodyne Amplifier Gain and Power Performance

CONCLUSION

The above design approach can be extended to small and large signal amplifiers at any frequency where ultra flat gain response, serrodyne capability, and minimum size are required. It also allows the design engineer to synthesize stable, cascadable amplifiers with excellent power and bandwidth performance.

ACKNOWLEDGEMENT

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REFERENCES

1. A.M. Pavio, "A Network Modeling and Design Method for a 2- to 18-GHz Feedback Amplifier," IEEE Trans. Microwave Theory & Techniques, Vol. MTT-30 (December 1982).

2. Douglas J. Mellor, "On the Design of Matched Equalizers of Prescribed Gain Versus Frequency Profile," IEEE MTT, International Microwave Symposium, San Diego, CA (June 1977) pp. 308.

3. Roy B. Culbertson and A.M. Pavio, "An Analytic Design Approach for 2-18 GHz Planar Mixer Circuits," IEEE Trans. Microwave Theory & Techniques, Vol. MTT-30 (December 1982).