A LIGHTWEIGHT VARACTOR DIODE LINEARIZER FOR SPACE COMMUNICATION SYSTEMS

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ABSTRACT

It is necessary for space communication systems to achieve both high performance and high efficiency while still retaining light weight and small size. A linearizer can be employed to achieve significant improvements in these areas. This paper presents a new approach to linearizer design that exploits the variable capacitance properties of varactor diodes. The small size and wide availability of varactor diodes makes this approach a cost effective means of simultaneously improving communication system performance and reducing weight and size. An increase in output power of 2.2mW with a 3 degree increase in nonlinear phase deviation was demonstrated.

INTRODUCTION

Space missions require high efficiency, high power and low distortion communication systems to relay information like pictures or atmospheric data from space probes to earth. Linearizers have been successfully employed to increase the output power and efficiency of amplifiers. They work by reducing distortion that occurs when the amplifier is operated in its saturation region. The saturation region occurs when the amplifier is driven by high input powers. It is a desired operating region because a saturated amplifier yields the highest output power and highest efficiency, but it also yields the highest levels of distortion [1]. High distortion limits the amplifiers use in most communication applications. By compensating for the distortion, linearizers have been shown to provide a significant two to three decibel increase in usable power and can double the efficiency of amplifiers [2]. This allows for the improvement of communication systems without the high cost of replacing the amplifier, and it reduces cost because a smaller less powerful amplifier can be used to achieve the same performance of larger non-linearized amplifiers. Furthermore, bandwidth efficiency can be increased because lower distortion levels allow the use of more complex modulation schemes.

A major drawback of conventional linearizers is their high cost, complexity and large size [3]. This research aims to address these issues with a new approach to linearizer design that is based upon a varactor diode. A voltage bias applied to the terminals of the varactor diode controls its capacitance. Changing the capacitance will alter the behavior of a transmitted wave through the varactor. This property can be used to reduce distortion in an amplifier. The small size of the varactor could potentially enable the monolithic integration of the linearizer with the amplifier, offering a compact unit for high efficiency low distortion amplification of microwave signals for space missions.

LINEARIZATION USING A VARACTOR DIODE

Amplifier distortion arises from the nonlinear gain and phase transfer characteristics that start to occur at high input powers. To measure this, a microwave transistor amplifier was built. It's gain and phase curves versus input power were measured with an HP8573B network analyzer, see fig 1. We see that as input power is increased, the gain drops and the phase rises; this is the cause of the distortion. To counteract this, a linearizer is built that has opposite gain and phase behavior. When the linearizer is placed in the signal path before the amplifier, the nonlinearity of the two devices cancel each other out as illustrated in fig 2. As a result, the amplifier can operate at higher power levels with lower distortion levels.

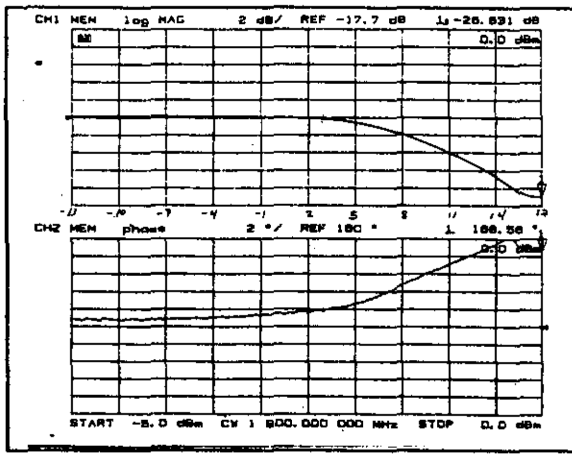

Fig. 1 Measured gain and phase of amplifier vs. input power.

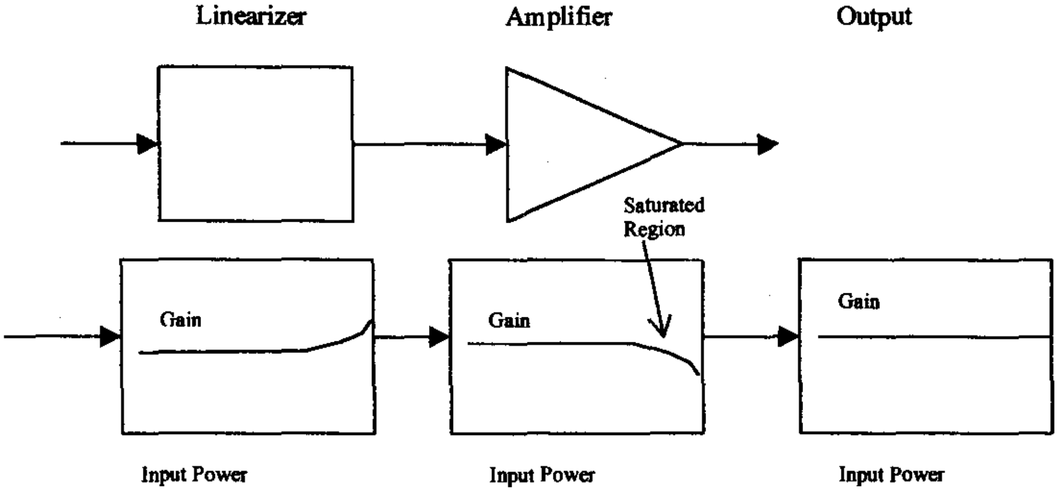

Fig. 2 Block diagram of an amp and linearizer. As the input power is increased, the gain of the linearizer increases while the gain of the amplifier decreases (similarly for the phase).

A schematic of the varactor diode linearizer is shown in fig 3. When a microwave signal is incident upon this circuit, part of the wave is reflected and part of the wave is transmitted. The transmitted wave will have a new gain and phase determined by equation 1 :

$$S21 = (2ZoY)/(1 + 2ZoY) \qquad (1)$$
$$Y = (1/R) + jwC \qquad (2)$$

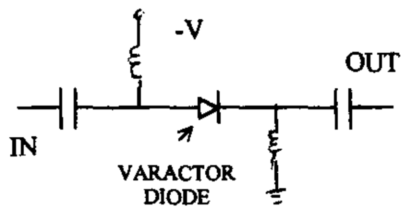

Figure 3 Circuit of varactor diode linearizer.

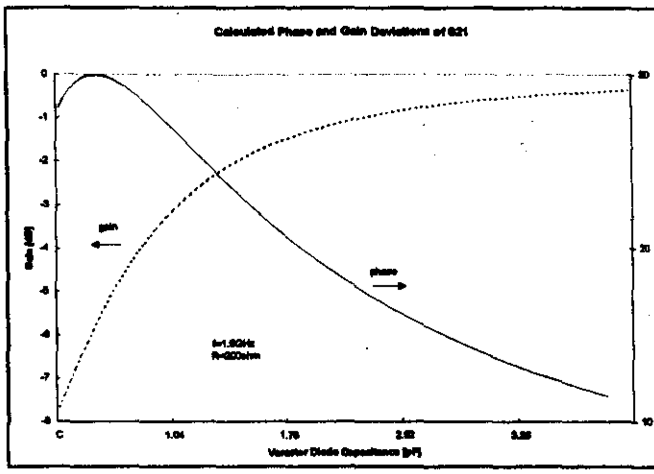

Figure 4 Calculated gain and phase deviation of S21.

, where C is the capacitance and R is the series resistance of the varactor diode. By changing the voltage applied across the varactor diode, its capacitance can be varied. Fig 4 plots equation 1 versus the varactor's capacitance. We see that there is gain expansion and phase compression as the capacitance is changed.

In order for the varactor to be used as a linearizer, the varactor's capacitance must change as a function of input power. This was done with a feedback loop that used a resistor placed in series with the gate of the transistor used in the amplifier. Since gate current in a transistor is a function of input power, the voltage produced by the gate current flowing through the resistor will also be a function of input power. The voltage produced can be amplified and used to control the capacitance of the varactor.

DISCUSSION

Problems were encountered with the feedback loop because of the non-linear dependence of the gate current with input power. Only at high levels of saturation, where the amplifier was already experiencing high levels of compression did the gate current start to flow. This eliminated any control voltage for the linearizer at lower levels of saturation. Essentially, the linearizer did not start to work until the amplifier was well into the distorted region. A second significant problem encountered was with mismatch between the amplifier and linearizer. This caused high loss to occur when the linearizer was put in front of the amplifier. For instance, the linearizer by itself had an insertion loss of 5dB, but when it was put in front of the amplifier the loss increased to 10dB. To compensate for the high loss, the voltage swing of the equalizer was reduced from 15volts to 4.1 volts. This improved the insertion loss to 4.7dB with the linearizer in front of the amplifier but reduced the amount of gain expansion attainable with the linearizer. A matching network at the input and output of the linearizer might reduce this problem. Since the bias feedback didn't work, the linearizing potential of the varactor was demonstrated by adjusting the bias manually. Fig 5 shows the measured gain and phase deviation of the varactor as the bias is changed from 15 volts to 0 volts. It is clear that gain expansion and phase compression is achieved. Fig 6 shows the measured gain and phase of the amplifier with the manually adjusted biased linearizer. We see that the

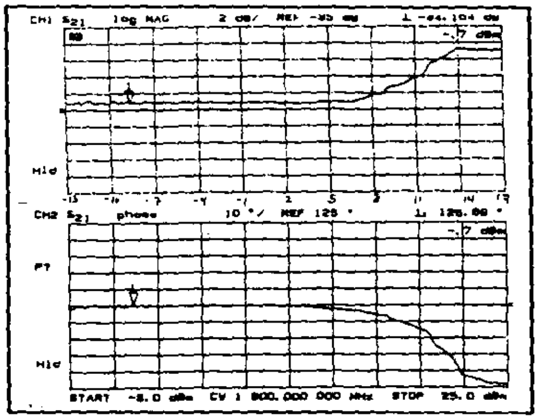

Fig. 5 Measured gain and phase of varactor diode (manually adjusted bias 0 – 15V).

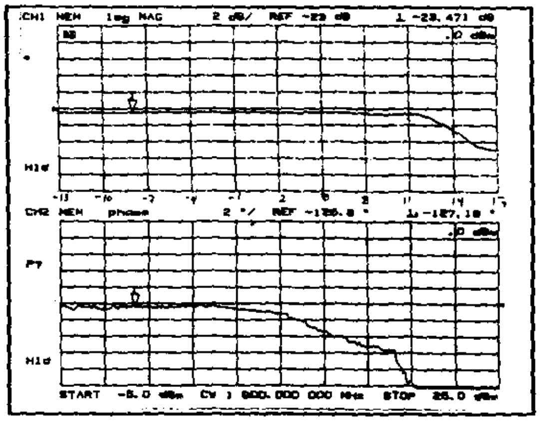

Fig. 6 Measured gain and phase of amplifier with linearizer. (manually adjusted bias 0 – 4.1V)

linearized amp produces a constant gain up to an input power of 11dB which is 8dB higher than the non-linearized amplifier, but the linearizer drastically overcompensates for the amplifier's phase deviation. Table 1 summarizes the efficiency and output power of the linearized and non-linearized amplifier at an operating point where the distortion levels are comparable. The output power of the amplifier was increased by 2.2mW with only a 3 degree increase in non-linear phase deviation, but the high insertion loss of the equalizer reduced the efficiency by a factor of 2. The C/I measurement is the standard measurement used for evaluating distortion of an amplifier. This measurement could not be made however, because a suitable source that could generate enough power to drive the amplifier into saturation was not accessible.

	Amplifier	**Linearized Amplifier**
Gain	6dB	1.3dB
Efficiency	9.4%	4.4%
Input Power	2dBm (1.6mW)	8dBm (6.3mW)
Output Power	8dBm (6.3mW)	9.3dBm (8.5mW)
Gain deviation	0dB	0dB
Phase deviation	1deg	4deg

Table 1. Performance of amplifier with and without linearizer.

CONCLUSION

Linearization of an amplifier using a variable capacitance varactor diode was presented. Problems were encountered with the bias feedback and mismatch between the linearizer and amplifier. Manually adjusting the varactor's bias yielded an improvement in output power of 2.2mW with a 3 degree increase in non-linear phase deviation.

ACKNOWLEDGMENTS

The author extends his thanks to NASA and the Hawai'i Space Grant College for their excellent program and generosity. The author would also like to thank his advisor Dr. Wayne Shiroma for his guidance, encouragement and patience.

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