VERSATILE FET NONLINEAR TRANSFER FUNCTION GENERATOR ELEMENTS

Allen Katz and Shabbir Moochalla

GE Astro Space Division
Princeton, New Jersey

ABSTRACT

A new means of generating nonlinear transfer functions useful in the production of limiters and linearizers has been discovered which offers both simplicity and high performance. This technique employs GaAs MESFETs in a passive configuration similar to that used for MMIC switches and attenuators. The resulting FET Non-linear Generator Elements (NLGEs) are readily adjustable over a wide range of both magnitude and phase transfer characteristics, and have displayed wide bandwidth performance and excellent thermal stability.

FET NLGEs have been applied in both reflective and transmissive networks. A near perfect hard limiter has been produced using a FET NLGE which introduces less than 5 degree change in phase. Linearizers using FET NLGEs have been tested at L, C and Ku-bands and have provided a reduction in total intermodulation distortion products greater than 10 dB at the 2 and 3 dB output power back-off points over a bandwidth of up to 15 percent.

INTRODUCTION

The ability to generate nonlinear (Power-in/Power-out) transfer functions which can be tailored to match specific magnitude and phase characteristics is important in a number of RF/microwave applications. Principal among these applications are 1) linearizers which are used to reduce or eliminate distortion caused by active RF/microwave components - particularly amplifiers, and 2) limiters which are used to limit (or reduce) the maximum signal levels produced by RF/microwave systems and which in some instances are required to provide a shaped response [1]. Nonlinear transfer characteristics are also employed in microwave signal processing applications for the production of logarithmic amplifiers and other similar devices.

Nonlinear transfer functions have been commonly generated by driving amplifiers into their saturation region or by making use of the change in the impedance of diodes with varying power level. Neither of these methods allow the resultant characteristics to be readily modified so as to match a desired transfer response. Diodes, in particular, can also display gross changes in characteristics as frequency is varied. The ability to maintain a specific transfer characteristic over a wide band of frequencies is essential in many nonlinearity generator applications. Nonlinear components have been used in both transmissive and reflective networks, as illustrated in Figures 1a and 1b respectively, for the generation of nonlinear transfer responses. In the simplest transmissive case, the network Transducer gain (loss) (S21) is related to the nonlinear generator element (NLGE) impedance (Zn) by the relation:

$$S21 = 2Zo(Zn+Zo)/(Zn^2+3ZnZo+2Zo^2) \quad (1)$$

If $|Zn| >> Zo$, $|S21|$ becomes inversely related to $|Zn|$.

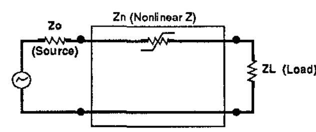

Figure 1a. Transmissive Network

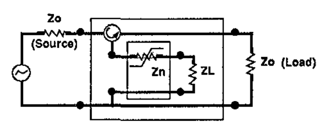

Figure 1b. Reflective Network

For the reflective case shown in Figure 1b, assuming an ideal isolator,

$$S21 = \Gamma n = (Zn + ZL - Zo)/(Zn + ZL + Zo) \quad (2)$$

where Γn is the reflection coefficient of Zn + ZL. Using flow graph theory, S21 can be related to the S-parameters of the Zn network (Sn) and ΓL, the reflection coefficient of ZL

$$S21 = (Sn21\ Sn12\ \Gamma L)/(1 - \Gamma L\ Sn22) + Sn11 \quad (3)$$

When ZL is totally reflective ($|\Gamma L| = 1$) and $|Sn22| << 1$, then

$$S21 = Sn21\ Sn12\ \angle\emptyset + Sn11 \quad (4)$$

Where $\emptyset$ is the angle associated with ΓL. If $|Sn11| << |Sn21|$ and the network is bilateral,

$$S21 = (Sn21)^2 \quad (5)$$

Under these conditions the transmissive characteristics of Zn also establish its reflective characteristics. When $|Sn11|$ is comparable to $|Sn21|$, the angle of ΓL becomes critical; and a variety of reflective transfer characteristics can be established as a result of the addition (or subtraction) of $Sn21^2$ and Sn11.

FET NLGE

It was discovered that a GaAs MESFET, when connected as shown in Figure 2, can display both a significant change in input impedance (S11) and transducer gain (S21) with varying

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power level. This configuration, which will be referred to as an FET Non-linearity Generator Element (NLGE), is similar to that used in Monolithic Microwave Integrated Circuit (MMIC) switches and attenuators. The FET is operated essentially as passive element with the impedance of the the drain-to-source channel controlled by the gate field. Negligible dc power is consumed since there is no drain-source supply.

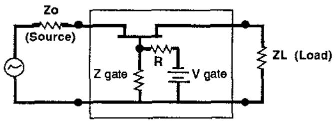

Figure 2. Basic Nonlinear FET Generator Element (NLGE)

In the case of passive MMIC switches/attenuators, a change of input impedance or insertion loss with power level is undesirable. Where such changes have been observed, it has been reported as occurring at higher power levels (Pin > 20 dBm) and attention has focused on how to minimize this effect [2]. With standard MESFETs, the on-set of changes in impedance/loss have been observed at input powers as low as -25 dBm. Further, it was found that the loss and impedance characteristics displayed can be relatively insensitive to frequency change. A comparison of the wide-band frequency characteristics of a FET NLGE and that of a pair of Schottky diodes, connected back-to-back, is shown in Figure 3.

FET NLGE

DIODE PAIR

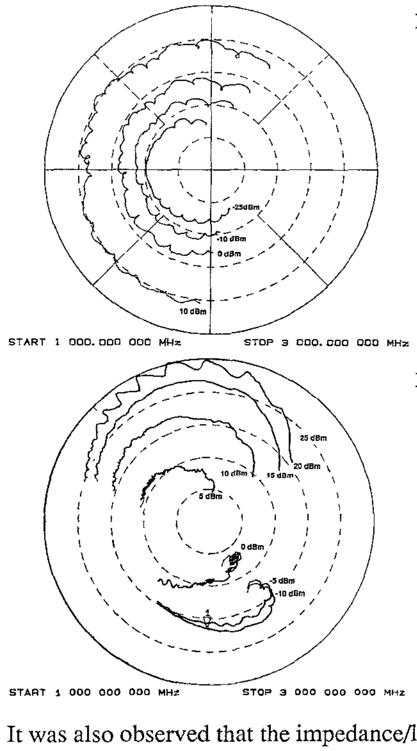

Figure 3. Comparison of the Wide-band Frequency Characteristics of a Schottky Diode Pair and a FET NLGE

It was also observed that the impedance/loss transfer characteristics of a basic FET NLGE are easily altered to cover a wide range of values by varying the gate parameters. Most important of these gate controls are the dc bias voltage and the RF impedance between the gate and ground. Depending on parameter values, it is possible to obtain with increasing power levels, an S21 function whose magnitude becomes either larger or smaller and whose phase angle either increases or decreases.

Examples of S21 change with dc gate bias and gate reactance are shown in Figures 4 and 5 respectively. (Transfer functions which display expansion or compression or a combination thereof can be obtained with either positive or negative gate bias.) Examples of S11 shift with dc gate bias and gate reactance are shown in Figures 6 and 7 respectively. In general S11 is less sensitive to power level than S21; however, by appropriate choice of ΓL, as predicted by equation (4), a great variety of input reflection coefficient responses are available. Near identical characteristics of S21 and S11 are obtained with the NLGE connected in either a source-to-drain or a drain-to-source configurations, i.e., NLGEs act as approximately symmetrical devices.

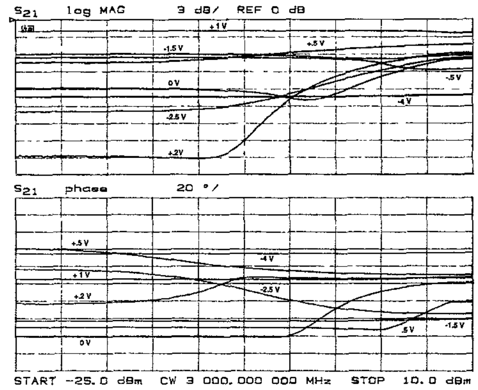

Figure 4. Example of change in S21 as a Function of Power Level with Gate Bias Voltage as a Parameter. (Zg = j30)

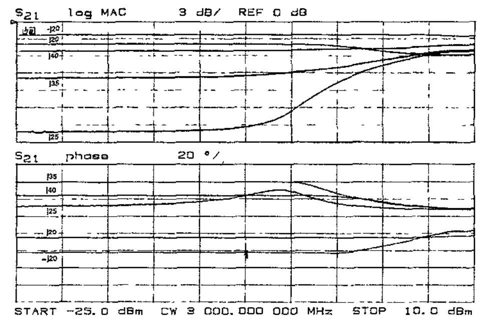

Figure 5. Example of change in S 21 as a Function of Power Level with Gate Impedance as a Parameter. (Vg = 0Volts)

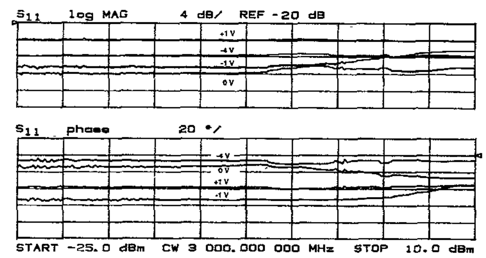

Figure 6. Example of change in S11 as a Fuction of Power Level with Gate Bias Voltage as a Parameter. (Zg = j30)

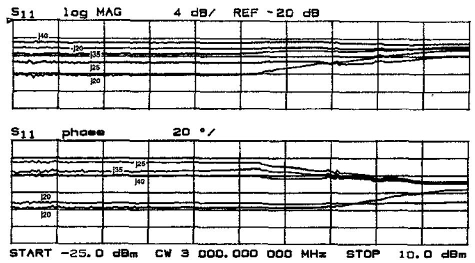

Figure 7. Example of change in S11 as a Function of Power Level with Gate Impedance as a Parameter. (Vg = 0 Volts)

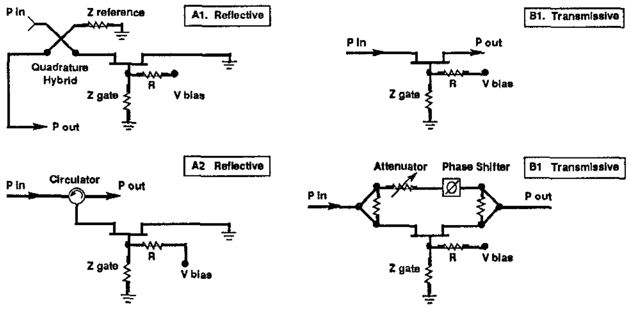

Figure 8. Possible FET NLGE Networks

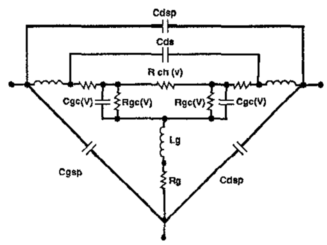

Figure 9. Cold FET Equivalent Circuit used to model NLGE

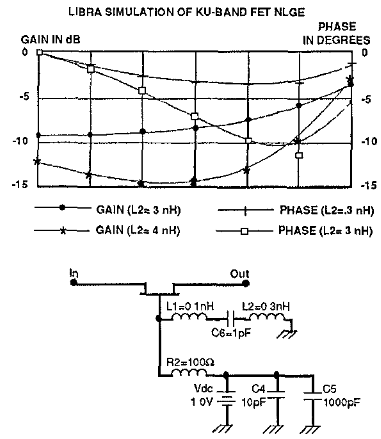

Figure 10. Response of Libra Simulation of Transmissive FET NLGE

The FET NLGE has been applied effectively in both transmission and reflective circuitry. Figure 8 shows examples of some networks in which the FET NLGE can be used to produce a nonlinear transfer function. The networks shown include reflective configurations employing a circulator and a quadrature hybrid, and transmissive configurations using single (basic) and 2-path connections. In practice a FET NLGE may require input/output matching networks, as well as adjustable gate bias circuitry and gate impedance tuning, to help tailor the device's characteristics to that required by a particular application. Several FET NLGEs, when adjusted for different bias/ match conditions, can be combined in parallel and/or cascade to obtain an even greater variety of transfer responses. In this manner, by properly adjusting the FET NLGE's parameters, virtually any transfer characteristic can be achieved.

MODELING

To help in the the design of FET NLGEs several models of the MESFETs under zero drain-to-source bias conditions have been investigated. Most useful of these was a modified version of the cold FET Model proposed by Chen and Kumar shown in Figure 9 [3]. Element values can be extracted from the variation in S-parameters as a function of available source power and gate bias. Success was also achieved using EESOF's LIBRA nonlinear analysis program to predict the transfer response of FET NLGEs. Figure 10 shows a typical response obtained from LIBRA. Although the bias value and external reactance required to obtain the desired response with LIBRA does not exactly match that measured in the laboratory, values are of the same order of magnitude. Efforts are presently under way to utilize a model similar to that of Figure 9 with LIBRA to reduce this difference.

APPLICATIONS/TEST RESULTS

Several linearizers utilizing FET NLGEs have been fabricated and evaluated with TWTAs and SSPAs at L, C and Ku-band. Both transmissive and reflective networks were investigated. The typical performance of a reflective FET NLGE linearizer with a TWTA is shown in Figure 11 and that of a transmissive linearizer is shown in Figure 12. The near constant temperature performance displayed by a Ku-band transmissive linearizer is illustrated in Figure 13. The same linearizer was operated at 100 degrees C. for 72 hours with no discernible change in performance. Similar results were obtained on all bands investigated. All data shown is in terms of 2-tone carrier-to-total intermodulation power ratio (C/It) and output power backoff referenced to the single carrier saturation level [4].

FET NLGE limiters were also investigated. Both hard and soft limiter characteristics are easily produced. Figure 14 shows output power and phase as a function of input power for a C-band reflective limiter which provided a near perfect hard limiter response while introducing less than a 5 degree change in phase.

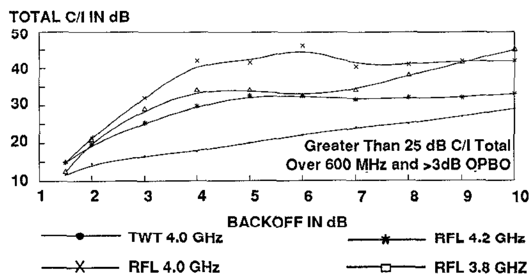

Figure 11. FET NLGE Reflective Linearizer Performance

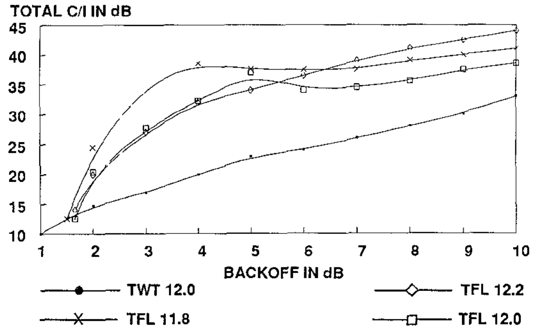

Figure 12. Tramsmissive Linearizer Performance

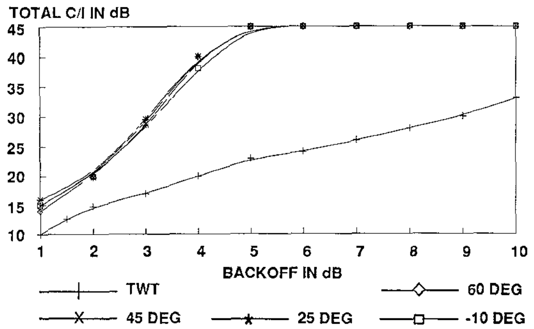

Figure 13. FET Transmissive NLGE Linearizer Temperature Performance

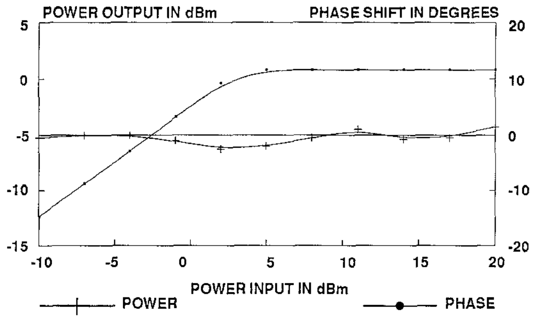

Figure 14. C-band Limiter Response of Reflective FET NLGE

CONCLUSIONS

FET NLGEs offer significant advantages in terms of circuit simplicity, performance, bandwidth, temperature stability and control of transfer characteristics over other nonlinearity generators. Because of their passive nature, they require negligible dc power and offer the potential of high reliability. FET NLGE performance can be predicted from S-parameter measurements, FET models based on zero drain voltage, and nonlinear analysis techniques as those provided by EESOF's LIBRA program. The value of FET NLGEs has been demonstrated in a variety of linearizer and limiter applications. These devices can be fabricated with minimum size and weight while providing features as remote commandability, wide bandwidth and outstanding performance.

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