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LARGE SIGNAL ANALYSIS OF NONLINEAR MICROWAVE SYSTEMS

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INTRODUCTION

In some applications, microwave systems are subjected to large input signals. For example, with front-end receivers in radar systems, the range of the target determines the size of the input signal. In communications and radar systems, nearby transmitters can result in a large, undesired input signal. The resulting intermodulation products (IP's) can lead to significant degradation of performance. However, with some systems, e.g. mixers, intermodulation is an inherent part of system operation. Detailed numerical analysis of a nonlinear system with large signal excitation, is notoriously difficult and often does not yield the qualitative understanding required for design. In this paper we present a noniterative, algebraic treatment of large signal effects. The method provides valuable insight into the way in which circuit and device parameters affect large signal performance. As an example we investigate the gain compression performance of diode mixers and parametric amplifiers. (These systems were chosen as they both incorporate the nonlinear resistance and reactance of a diode junction. The resistive nonlinearity is dominant with a mixer and the reactive nonlinearity with a parametric amplifier.) However, the approach can be applied to any system and to other types of nonlinear distortion (e.g. cross-modulation, intermodulation and detuning distortion).

BACKGROUND

The spectrum at the diode junction when two signals are present in the input passband of a parametric amplifier (diode mixer), is approximated by the spectrum in figure 1 where f_1 is dc; $f_2(f_4)$ the frequency of the input signal and f_3 the frequency of the pump or local oscillator. In this paper we investigate gain compression--the variation of gain or conversion loss with increasing amplitude of the input signal. The lowest order IP's contributing to conversion are defined by $f_2 = f_3 - f_4$ and $f_4 = f_3 - f_2$. At large signal levels, higher order IP's (e.g. $f_2 = 2f_2 + f_4 - f_3$) become significant.

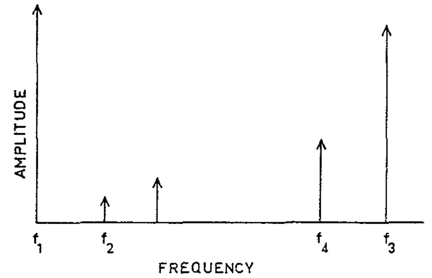

Figure 1. Approximate frequency spectrum across the diode junction when there are two signals in the passband of a parametric amplifier.

ALGEBRAIC TREATMENT OF LARGE SIGNAL EFFECTS

In an earlier paper [1], we developed a nonlinear analysis technique using a generalized power series (a power series having complex coefficients and frequency-dependent time delays) expansion of the input-output characteristics of a nonlinear system. Thus a system not having a conventional power series expansion (with real coefficients and no time delays), may have a generalized power series expansion. The algebraic formula for the phasor Y_ω of a frequency component of the output of the generalized power series having a multifrequency input $x(t)=\Sigma x_k\cos(\omega_k + \phi_k)$ is the summation of IP's. The radian frequency of Y_ω is defined by $\omega = \Sigma n_k\omega_k$. Numerical analysis proceeds using an harmonic balance technique. The main advantage of this analysis method is that it can handle nonlinear systems with large multifrequency input. (The analysis has been verified by comparing numerical and experimental results of large-signal gain compression, intermodulation and detuning distortions of an S band parametric amplifier.)

Each IP is itself the product of an intermodulation term, IT $(=\Pi X_k^{|n_k|})$ and a saturation term, ST (= nonlinear function of all X_k's). When all excitation components are small, the ST is independent of the input. However, for large input components, the ST is affected by the amplitudes of all components. The ST incorporates all parameters (i.e., complex power series coefficients and time delays) describing the system. Unlike the ST term, the IT is only dependent on a few input components for which n_k is non-zero. The IT is independent of the nonlinearity and merely defines the IP being considered.

Expressions for both mixer conversion loss and parametric amplifier gain have been developed showing that the output signal power at significant gain compression is greatest for minimum S where S is a sensitivity function given by

$$S = \frac{1}{IP}\cdot\frac{\partial IP}{\partial V_o} \approx \frac{1}{|V_p|} + \frac{1}{ST}\cdot\frac{\partial ST}{\partial V_p}$$

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and V_o and V_p are components of voltage across the diode junction at the output and pump frequencies respectively. IP and ST are those for the lowest order pump-signal intermodulation.

Resistive Mixer Gain Compression Performance

Using the sensitivity function, the effects of diode parameters on large-signal performance can be investigated. Here we consider the effects of C_{jo} (zero bias capacitance), γ (capacitance index of nonlinearity), ϕ (contact potential), V_d (dc bias), I_s (reverse saturation content), η (ideality factor) and V_p (pump level). S is plotted in figure 2 as a function of C_{jo}/I_s and V_p for $\gamma = 0.5$, $(\phi - V_d) = 1$ V, $\eta = 1$, and an IF of 1 GHz. For $C_{jo}/I_s = 0$, mixer action is due solely to the nonlinear resistance of the junction. As C_{jo}/I_s increases, the nonlinear reactance of the diode becomes significant and the large signal performance of the mixer improves. Thus gain compression performance can be improved by the presence of the nonlinear junction capacitance. As well, there is an optimum pump level for best gain compression performance.

Parametric Amplifier Gain Compression Performance

S is plotted as a function of γ and pumping level in figure 3 together with loci (curves a-c) for various pump power levels. (The qualitative gain compression behavior is in complete agreement with the response obtained with a full numerical analysis.) At larger pumping levels, S reduces and so the large signal performance of the junction improves. Generally, for fixed V_p, γ has little effect on large signal behavior.

CONCLUSION

The major contribution of this study was the development of a noniterative algebraic treatment of distortion in nonlinear devices. Graphical presentation yields valuable design information for minimizing distortion effects.

ACKNOWLEDGEMENT

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REFERENCES

(1) M. Steer and P. Khan, "An algebraic formula for the complex output of a system with multi-frequency excitation," Proc. IEEE, Jan. 1983, pp. 177-179.

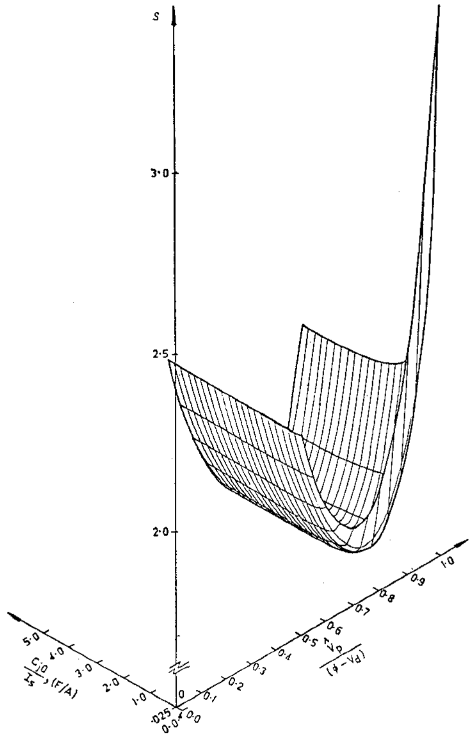

Figure 2. S as a function of $V_p/(\phi-V_d)$ and C_{jo}/I_s.

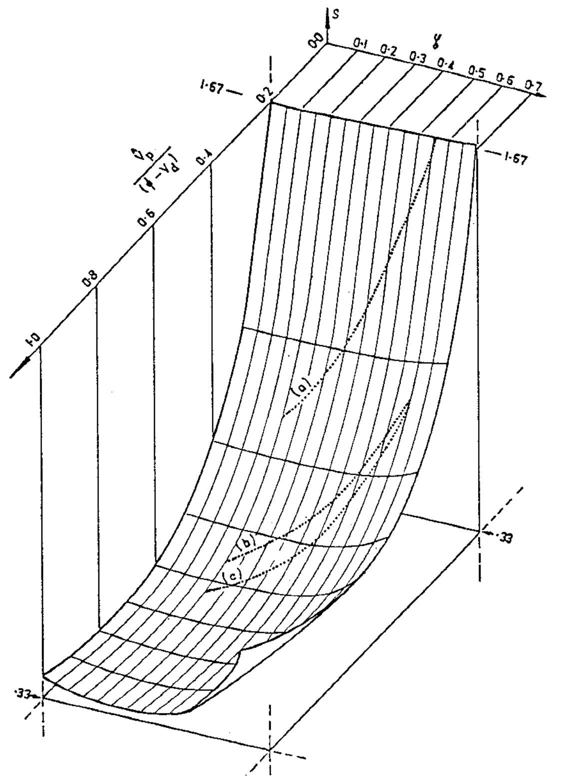

Figure 3. S as a function of γ and $V_p/(\phi-V_d)$ for negligible I_s. (a) P_a = 0 dBm, R_s = 2Ω; (b) P_a = 0 dBm, R_s = 0.38Ω; (c) P_a = 10 dBm, R_s = 2Ω.