NASA TECH BRIEF

Goddard Space Flight Center

Microwave Diode Amplifiers With Low Intermodulation Distortion

The problem:

Microwave tube-type amplifiers with low-to-intermediate powers in high microwave bands may soon be replaced by solid-state diode devices. For example, in the band above 5 GHz, Gunn diodes may be used if low noise is of prime importance, and IMPATT (impact-avalanche-and-transit-time) diodes or Read diodes may be used if power output and efficiency are more important. The difficulty, however, with these nonlinear elements is that with improved efficiency there is also an increased intermodulation distortion.

The solution:

Recent analysis indicates that intermodulation distortion can be greatly reduced, at least in narrow-band applications, using the second harmonic.

How it's done:

A simplified diode amplifier model is used. The assumption is that the ac behavior of the diode is like that of a tunnel diode: i.e., it has a negative resistance depending on the slope of an equivalent I-V curve. The diode current I can be expressed as

$$I_{diode} = \Sigma \, a_i V^i_{diode} \qquad (1)$$

where a_i is an admittance coefficient having dimensions of admittance/volts^{i-1}.

To obtain expressions for the third-order and fifth-order intermodulation (IM) products, it is assumed that the two input signals have the form $V_1 \sin \omega_1 t + V_2 \sin \omega_2 t$ where $\omega_1 \approx \omega_2$. Based on this, the right side of equation (1) can be expanded to
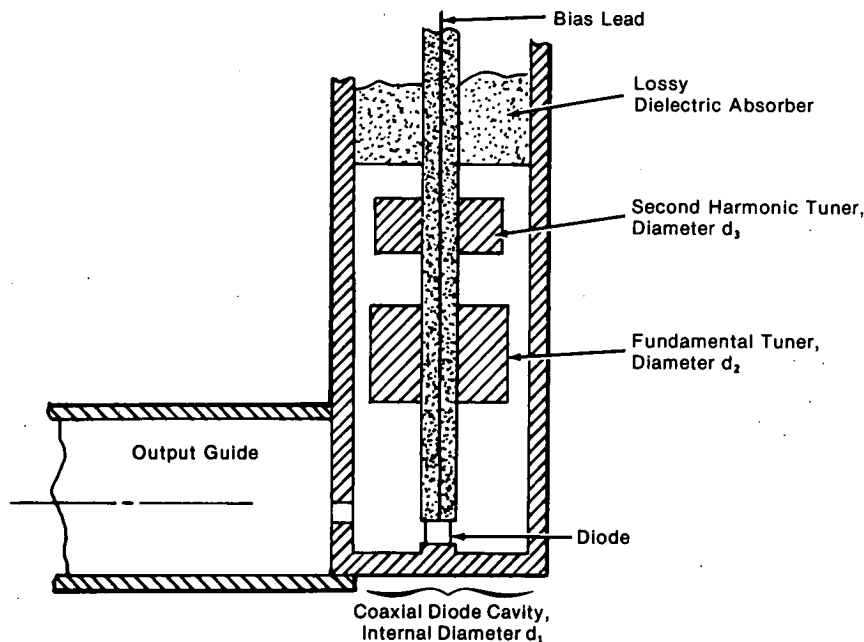
Coaxial Diode Cavity Amplifier

obtain expressions for the third-order IM products (i.e., frequencies of the form $2\omega_2 - \omega_1$ and $2\omega_1 - \omega_2$, etc.):

$$[3/4(a_3V_1{}^2V_2) + a_5[15/8(V_1{}^2V_2{}^3) + 5/4(V_1{}^4V_2)]]\cos(2\omega_1 \pm \omega_2)t$$

and a similar term for $\cos(2\omega_2 \pm \omega_1)t$.

From the V_2 terms, it is obvious that the second harmonic signals play an important role in the formation of the third-order IM products. The third harmonic power is usually very far down from the fundamental, assuming one operates a decibel or so below saturation. This is a useful assumption for avalanche diode amplifiers, as their maximum efficiency occurs for input powers below the saturation input power. The objective then is to reduce or cancel out the second harmonic while not appreciably reducing the fundamental at high input drive, which should reduce the third-order IM products.

The approach is modeled by using as input voltages the two fundamental inputs as before but, in addition, their respective second harmonics, including for each of their amplitudes V_3 and V_4 and their phases Φ_1 and Φ_2 as independent variables:

$$V_1 \cos \omega_1 t + V_2 \cos \omega_2 t + V_3 \cos(2\omega_1 t + \Phi_1) + V_4 \cos(2\omega_2 t + \Phi_2)$$

This is done using the diode power series truncated to three terms ($a_i = 0$, $i > 3$), with the following result for the IM products:

$$3/4(a_3V_2V_1{}^2)\cos(\omega_2 - 2\omega_1)t + a_2(V_2V_3)\cos[(\omega_2 - 2\omega_1)t - \Phi_1] \quad (2)$$

and a similar expression for $\omega_1 - 2\omega_2$. At the same time, the fundamental term comes out to be

$$[a_1V_1 + 3/4(a_3V_1{}^3)]\cos \omega_1 t + a_2V_1V_3 \cos(\omega_1 t + \Phi_1) \quad (3)$$

and a similar expression for the ω_2 term.

The first terms of these expressions (2) and (3) are those obtained with no harmonic injection. If it is assumed further that the two fundamental signals are of equal magnitude ($V_1 = V_2$), then the second terms of expression (2) can be recognized as the cubic term correction for the fundamental term for one input, which should be of the same order as the first term of expression (2). Thus, if we set $\Phi = \pi$, then expression (2) can be made very small, while (3) will not change

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appreciably because $a_2V_1V_3$ is much smaller than the fundamental form a_1V_1. In the ideal case in which expression (2) becomes zero, expression (3) with $\Phi = \pi$ becomes $a_1V_1 \cos \omega_1 t$; the two correction terms just cancel. Thus, it appears that if a π phase shift can be provided for the second harmonic signal generated by the diode, the third-order IM products can be greatly reduced without appreciably affecting the fundamental.

The proposed coaxial cavity is shown in the illustration with the diode at one end where the impedance is low. Toward the other end of the cavity, two tuning cylinders are used; their diameters determine the amount of reflection of the fundamental and second harmonic signals. The axial lengths of the cylinders determine the fundamental and second harmonic frequencies, and their positions affect the phase of the reflections.

The length of the fundamental tuner is one-fourth the wavelength of the fundamental frequency and one-half the wavelength of the second harmonic frequency. Thus as the second harmonic is transmitted from the diode, it passes the fundamental tuner and is reflected off the second harmonic tuner (which has a length of one-fourth the wavelength of the second harmonic). The fundamental frequency reflects off the fundamental tuner, thus defining the phase of the fundamental frequency. The phase of the second harmonic, generated by the square (a_2) term of the diode, is determined by the harmonic tuner. Its magnitude is, again, determined by the diameter d_3 and the internal diameter of the coaxial diode cavity d_1. The result is that the fundamental and the second harmonic are tuned independently of each other.

Note:
No further documentation is available. Specific questions, however, may be directed to:
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Patent status:
NASA has decided not to apply for a patent.