PUMPED TUNNEL DIODE FREQUENCY CONVERTERS WITH IDLERS

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This paper is concerned with analytical and experimental results for pumped tunnel diode frequency converters with idlers. The notation used in analyzing pumped varactors is appropriate for this analysis since idling circuits are utilized in conjunction with a pump or local oscillator. Pumped tunnel diode converters with idlers do not perform circuit functions that could not conceivably be performed by pumped varactor circuits with idlers. Tunnel diode converters with idlers are capable of performing similar circuit functions with simpler circuitry (being a pumped conductance device) and with considerable savings in pump power. An experimental tunnel diode converter with idler has been operated in the 2000 Mc region to obtain total power gains greater than 30 db with a pump power requirement of 100 microwatts. Comparable varactor converters would require at least an order of magnitude more pump power.

The theory of a pumped non-linear conductance device can be treated in a form similar to that used in analyzing pumped nonlinear capacitance diodes[1]. For sinusoidal voltage pumping at a frequency ω_p, $g(t)$ can be represented by a Fourier series,

$$g(t) = g_o + \sum_{n=1}^{\infty} 2g_n \cos n\omega_p t \qquad (1)$$

The small signal behavior of these devices are analyzed for frequencies of the form $n\omega_p \pm \omega_s$. A choice is then made for the idler and converted frequencies. With respect to the signal frequency, the terms "up-converter" or "down-converter" apply in describing the converted frequency. In addition, the terms "upper" and "lower" sideband refer to upper and lower sidebands of $n\omega_p$.

[1] P. Penfield and R. P. Rafuse, Varactor Applications, M. I. T. Press, Cambridge, Massachusetts, pp. 79-80, 1962.

Small signal interaction with the pump is represented by the equation

$$I_{ss}(t) = g(t)\, V_{ss}(t)\,. \tag{2}$$

Of particular interest is the frequency spectrum shown in Figure 1(a) for a lower sideband ($2\omega_p$) up-converter with a lower sideband (ω_p) idler. The analytical model for this converter is shown in Figure 1(b) where sidebands not of interest are assumed short circuited for the case of sinusoidal voltage pumping. The equations represented by (2) can be presented in matrix form containing the appropriate pumping coefficients for the model of Figure 1(b). The matrix representation of (2) is given by the matrix equation:

$$\begin{bmatrix} I_i \\ I_s \\ I_{\ell 2} \end{bmatrix} \quad \begin{bmatrix} g_o & g_1 & g_1 \\ g_1 & g_o & g_2 \\ g_1 & g_2 & g_o \end{bmatrix} \quad \begin{bmatrix} V_i \\ V_s \\ V_{\ell 2} \end{bmatrix} \tag{3}$$

In the admittance matrix form, the square matrix elements are specified in advance by the pumping. In scattering matrix form the square matrix elements would also be dependent on the sideband loading. Under conductive sideband loading conditions, expressions can be derived from (3) for the exchangeable[2] signal power gain, exchangeable up-conversion power gain, input conductance at signal frequency, etc.,

$$\text{EXCHANGEABLE SIGNAL POWER GAIN} = \left[\frac{g_s - g_{in_s}}{g_s + g_{in_s}}\right]^2 \tag{4}$$

$$g_{in_s} = \frac{(g_o + g_i)\,(g_2^{\,2} - g_o^{\,2} - g_o\, g_{\ell 2}) - g_1^{\,2}\,(2g_2 - 2g_o - g_{\ell 2})}{g_1^{\,2} - (g_o + g_i)\,(g_{\ell 2} + g_o)} \tag{5}$$

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[2] P. Penfield and R. P. Rafuse, Varactor Applications, pp. 18-19.

$$\text{EXCHANGEABLE UP-CONVERSION POWER GAIN} = \frac{4g\ell_2\, g_s}{(g_{in_s} + g_s)^2} \left[\frac{(g_o + g_i)\, g_2 - g_1^2}{g_1^2 - (g_o + g_i)(g\ell_2 + g_o)} \right]^2 \qquad (6)$$

where g_i = idler conductance, $g\ell_2$ = conductance at lower sideband of $2\omega_p$ and g_s = signal conductance.

The equivalent circuit for an experimental converter in the 2000 Mc region is shown in Figure 2. Here, the simplified tunnel diode equivalent circuit is justified for diodes having resistive cut-off frequencies and self-resonant frequencies above X-band. The pumping parameters needed in evaluating the gain expressions are illustrated in Figure 3 for stable pumping. These parameters were evaluated by an experimental technique similar to that utilized previously[3]. The data in Figure 3 differs from previously published data[3,4]. in the behavior of the g_2 term. Under comparable biasing conditions, the g_2 parameter shown in Figure 3 is negative over the pumping range. This is significant since the gain expressions in (4) and (6) are enhanced by a negative g_2 term. The sign of the g_2 term is related to the I-V characteristic of the tunnel diode used, and this term has been found to be negative over a wide pumping range in low peak current germanium tunnel diodes designed for use at microwave frequencies.

The experimental converter gains as a function of pump voltage are shown in Figure 4. Slotted Line techniques were utilized in determining the magnitude of the pump voltage. These voltages were duplicated in making the low frequency measurements of the pumping parameters shown in Figure 3. The measured pumping parameters were utilized in evaluating equations (4) through (6) as a function of pump voltage; and data on these results will be presented. This data fits the experimental behavior rather well and shows the usefulness of the low frequency pumping parameter measurements in evaluating the converter behavior at microwave frequencies.

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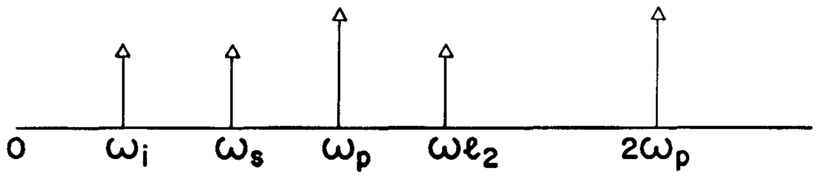
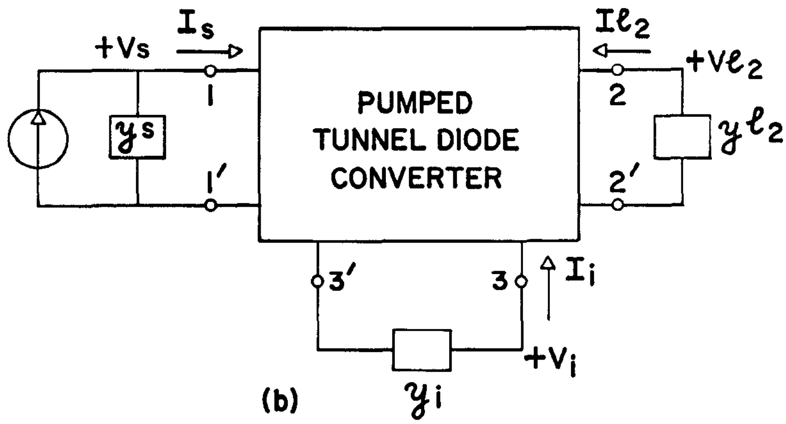
[3] B. Christensen, "Measurement of Tunnel Diode Conductance Parameters," Proc. IRE, Vol. 49, p. 1581, October 1961.

[4] F. Sterzer and A. Presser, "Tunnel Diode Frequency Converters," RCA Review, Vol. XXIII, p. 9, March 1962.



(a)



(b)

FIGURE 1 – (a) FREQUENCY SPECTRUM OF INTEREST FOR PUMPED TUNNEL DIODE CONVERTER WITH IDLER.
– (b) ANALYTICAL MODEL FOR SMALL SIGNAL BEHAVIOR OF PUMPED TUNNEL DIODE CONVERTER.

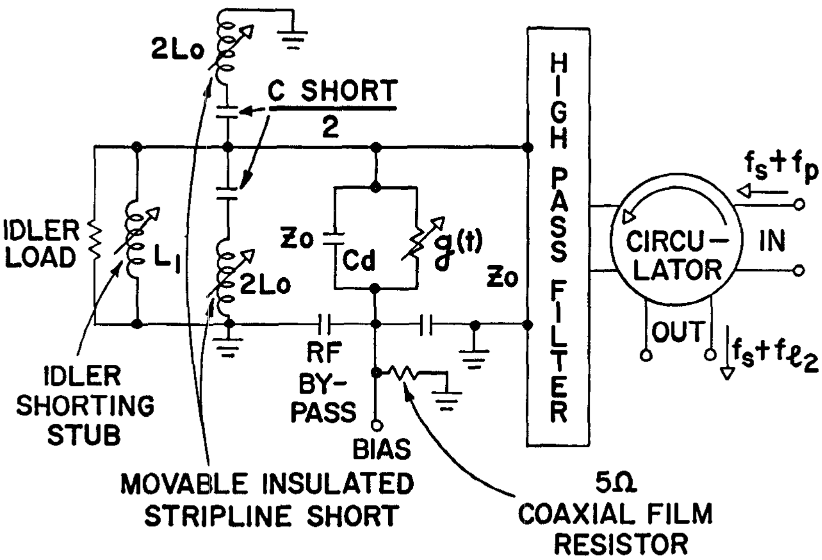


FIGURE 2 - APPROXIMATE EQUIVALENT CIRCUIT FOR EXPERIMENTAL CONVERTER UTILIZING STRIPLINE AND COAXIAL COMPONENTS.

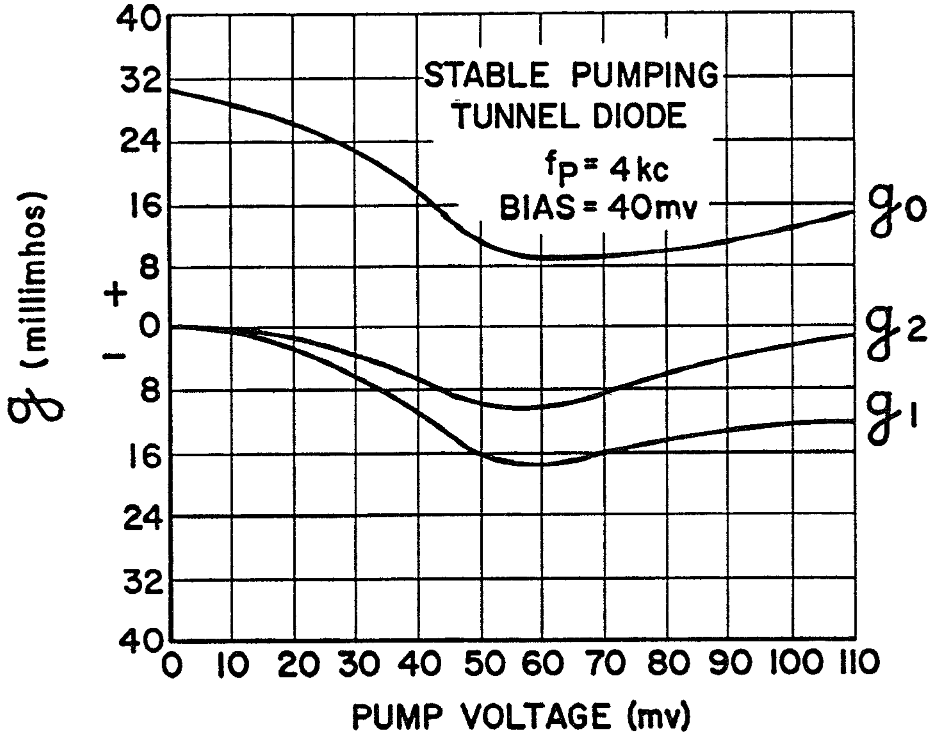


FIGURE 3 – VARIATION OF PUMPING PARAMETERS WITH PUMP VOLTAGE FOR A MICROWAVE TUNNEL DIODE.

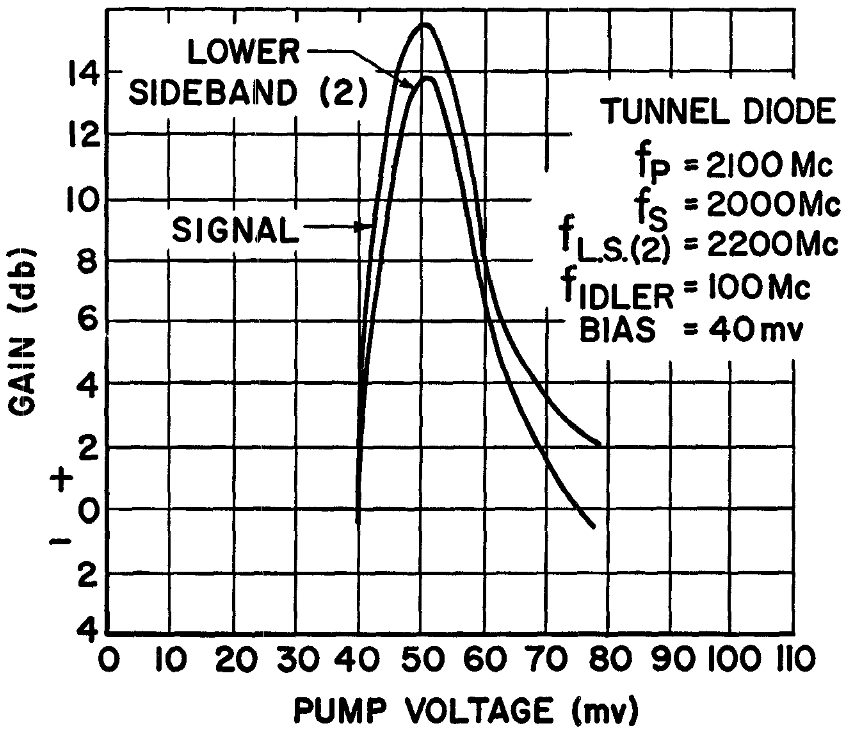


FIGURE 4 - EXPERIMENTAL SIGNAL AND LOWER SIDEBAND (2) GAIN VARIATION WITH PUMP VOLTAGE.

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