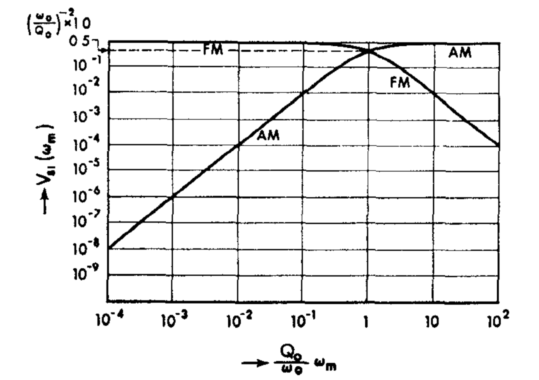

Fig. 2. Ideal case frequency dependence of $V_{si}(\omega_m)$ normalized to $m_s(\omega_m)$ and $\Delta\Omega_s(\omega_m)$ for AM and FM, respectively.

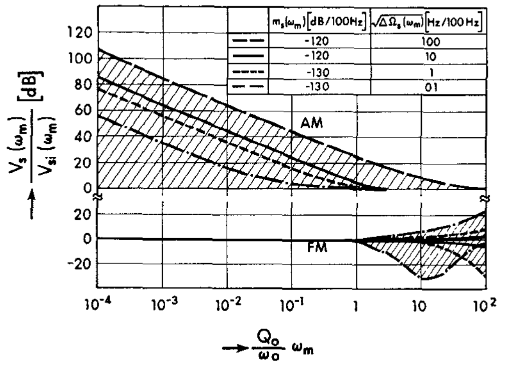

Fig. 3. Nonideal case frequency dependence of $V_s(\omega_m)$, normalized with respect to that of the ideal case, $V_{si}(\omega_m)$, with the system parameters varying as follows: $A = 0.0$ to 0.01, $\gamma = 0°$ to $2°$, $\Delta = 0.0$ to 0.01, $\Gamma(\omega_c) = -\infty$ to -50 dB, $\Delta\psi = 0°$ to $5°$, $L = 0.316$ (-10 dB).

in the range $-\infty$ to approximately -50 dB, and the relative detuning of the cavity, $\Delta = Q_0(\omega_c/\omega_0 - 1)$, may vary in the range from zero to 0.01 if extreme care is taken and frequent corrections are made when tracking the measured oscillator. The error in the adjustment of ψ (maximum of "video" output for small sinusoidal deviations of the test signal is an indication) can be about $\pm 5°$.

For various combinations of the above measurement conditions $V_s(\omega_m)$ has been calculated and compared with the ideal curves. The overall range of inaccuracy is plotted in Fig. 3, assuming conditions vary in the ranges indicated. The computations were carried out for four representative pairs of $m_s(\omega_m)$ and $\Delta\Omega_s(\omega_m)$, as indicated in Fig. 3. The value of L was chosen 0.316 (-10 dB), a typically used coupling. Generally, the inaccuracy increases with decreasing L. However, for FM measurements this effect is small in the range $L = 0.0$–0.1 (0 to -20 dB), and the overall range of inaccuracy of AM measurements is such that the effect of L is insignificant.

For the case of FM measurements, only the inaccuracy of ψ and the fact that $\gamma \neq 0$ affect to some extent the measurement accuracy at relatively high modulation frequencies. According to Fig. 3, the FM measurements can be made within a given accuracy up to a certain modulation frequency which decreases as the FM noise decreases and AM noise increases. For most oscillators to be measured, the relative modulation frequency $Q_0 \cdot f_m/f_0 = 1$ (cavity bandwidth) will be a safe limit. For a typical 6-GHz cavity with $Q_0 = 20\,000$, this corresponds to $f_m = 300$ kHz.

As can be seen from (9), even for the ideal case the AM measurement at frequencies within the cavity 3-dB points is impractical due to the large suppression introduced by the term $\omega_m Q_0/\omega_0$. A slight deviation of one of the circuit parameters from ideal conditions has a profound effect on the AM measurement accuracy, especially at modulation frequencies within the cavity 3-dB points. According to Fig. 3, the AM measurement can be made accurately from a certain modulation frequency which increases as the AM noise measured decreases and the FM noise increases. This lower limit may be as high as $Q_0 f_m/f_0 = 10^2$. Hence it is concluded that the "double-channel" mode is unsuitable for near-carrier AM noise measurements.

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A Note on Designing Digital Diode-Loaded-Line Phase Shifters

T. YAHARA

***Abstract*—A note is described to design digital diode-loaded-line phase shifters. A 75° separation between the loading susceptances has been shown to give the same or better performance in VSWR, loss, and phase-shift setting than a 90° separation.**

The theory of operation of the diode-loaded-line phase shifter has been widely studied in the past [1]. It is well known that the ideal lossless diode-loaded-line phase-shift section and its electrical equivalent can be shown as in Fig. 1.

In Fig. 1, Opp *et al.* [2] pointed out that a $\theta = 75°$ separation between the loading susceptances B rather than a 90° separation would yield the better performance in VSWR, loss, and phase-shift setting. Garver [3], however, reported that the widest bandwidth occurs around the 90° separation. If the 75° separation gives the same or better performance than the 90° one, the 75° separation has a great advantage in minimizing physical size and loss.

This short paper describes the performance of a 45° bit phase shifter comparing the two cases of the 75° and 90° separation theoretically and experimentally in the frequency range from 8.0 to 11.0 GHz. Numerical calculation was made based upon measured impedance data on leadless-inverted-device (LID) ceramic-encapsulated p-i-n diodes in the same frequency range. Experimental phase-shift networks were fabricated by thin-film techniques incorporating the same type of diodes used in the calculation.

The loading susceptances in Fig. 1 were controlled using the p-i-n diode to electrically shorten or lengthen the transmission line. The general expression for the electrical length θ' and the characteristic admittance Y_0' are given in (1) and (2), assuming lossless elements. Using these equations, the desired performance is therefore set by specifying B, Y_0, and θ:

$$\theta' = \cos^{-1}\left[\cos\theta - (B/Y_0)\sin\theta\right] \tag{1}$$

$$Y_0' = Y_0[1 - (B/Y_0)^2 + 2(B/Y_0)\cot\theta]^{1/2}. \tag{2}$$

The loading susceptance B as shown in Fig. 1(b) is given in (3):

$$jB = (Z_B + jZ_D \tan\theta_B)/Z_B(Z_D + jZ_B \tan\theta_B) \tag{3}$$

where θ_B is the electrical length of the stub of characteristic impedance Z_B, and Z_D is the diode impedance.

In computing the frequency dependence of the performance of the phase-shift section, electrical lengths θ and θ_B are easily calculated as a function of frequency. However, it is usually very difficult to calculate the loading susceptance B in agreement with the experimental values without using the measured diode impedance Z_D in the frequency range of interest. The impedance Z_D was therefore mea-

Manuscript received February 10, 1972; revised April 17, 1972.
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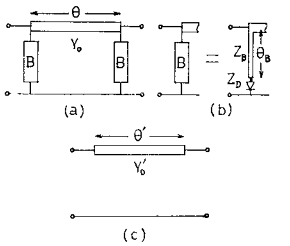

Fig. 1. (a) Typical loaded-line section. (b) Loading susceptance. (c) Electrical equivalent.

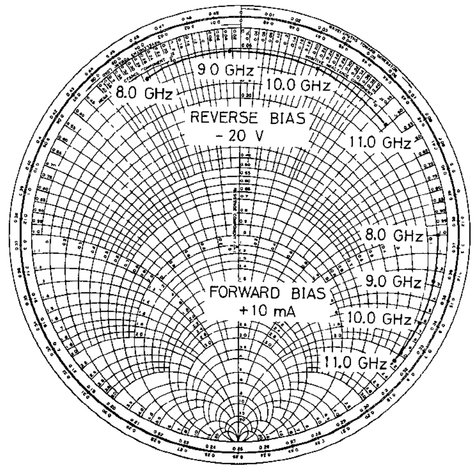

Fig. 2. Typical measured impedance plot for a LID-encapsulated p-i-n diode having capacitance of 0.30 ± 0.05 pF at reverse bias of -20 V (normalized to 50 Ω).

TABLE I

Final Computed Design Values of θ, Z_B, Y_0, and θ_B (Normalized to 50 Ω)

Bit size (DEG)	θ = 75°			θ = 90°		
	Z_B	Y_0	θ_B (DEG)	Z_B	Y_0	θ_B (DEG)
45	1.153	1.046	77.137	1.092	1.084	61.592

sured as shown in Fig. 2 in the frequency range from 8.0 to 11.0 GHz under application of forward bias of +10 mA and reverse bias of −20 V. The reverse bias capacitance of a LID-encapsulated p-i-n diode was 0.30 ± 0.05 pF, and the typical package parasitic capacitance was 0.03 pF.

Initial computed results made using the measured diode impedance at 9.5-GHz center frequency were usually not satisfactory, especially in the case of 75° separation. The final design values as shown in Table I were determined making iterative computer calculations until the desired performance was achieved for both the 75° and the 90° separation.

These computed results are shown in Fig. 3 for the case of a 45° phase-shift section. Fig. 3 indicates that no outstanding difference was observed in performance between the 75° and the 90° separation.

Phase-shift sections have been designed in the same frequency range in accordance with the calculated results. Here thin-film techniques were used to construct the experimental 45° bit phase-shift section; i.e., the circuit pattern was adequately delineated on substrate using photolithographic techniques. The thickness and purity of the substrate were 640 μ and above 99.5 percent, respectively. The effective dielectric constant was 6.80 on 50-Ω microstrip line at about 9.0 GHz. The p-i-n diodes used in the experiment had the same impedance characteristics as used in numerical calculations. The experimental results are shown in Fig. 4. These results indicate that

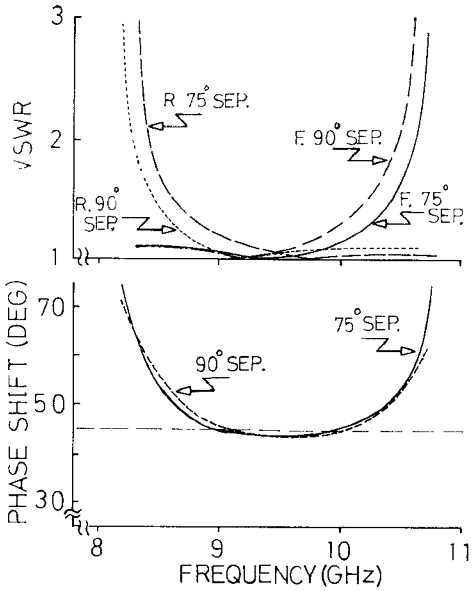

Fig. 3. Computed performance of 45° bit phase-shift section in both cases of a 75° separation and a 90° separation.

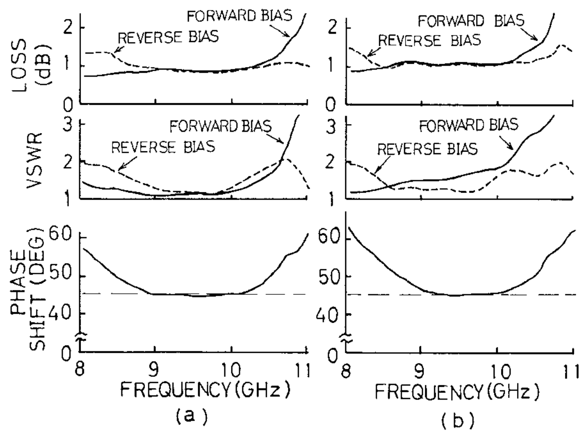

Fig. 4. (a) Experimental results of a 75° separation. (b) A 90° separation.

the 75° separation gives a better performance in bandwidth, loss, and VSWR than the 90° separation.

In this short paper, only the 45° bit phase-shift section was described, but similar results were obtained in a 22.5° bit phase-shift section using the same diodes as in the 45° bit phase-shift section. An 11.25° bit phase-shift section also yielded similar results with diodes having reverse bias capacitance of 0.60 ± 0.05 pF, but otherwise similar to those previously described.

The experimental results agreed closely with the numerical calculations. It can be concluded that the 75° separation between the loading susceptances gives the same or better performance in bandwidth, loss, VSWR, and phase-shift setting than the 90° separation.

Acknowledgment

The author wishes to thank H. Hoshika and A. Kondo for their contributions in the manufacturing of p-i-n diodes suitable for phase-shift sections.

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