VII-2 VARACTOR LINEAR MICROWAVE PHASE MODULATOR

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INTRODUCTION

A continuous phase modulator can be made by placing a varactor diode on one terminal of a circulator. Power in the first port of the circulator is reflected by the diode on the second port, and emerges from the third port with a phase and amplitude dictated by the reflection coefficient of the diode. As the reverse bias voltage of the varactor is varied the reflection coefficient magnitude remains high and the phase changes. The modulator requires very little modulation power and responds quickly to changes in modulation voltage. The phase modulator typically has a non-linear voltage-phase relationship, insertion loss that varies with phase, and less than 180° modulation. For most applications the phase should be linear with voltage, the insertion loss should not vary and the modulator should be able to provide 360° modulation.

Kim, et. al. (ref. 1) were able to obtain a linear phase-voltage relationship, but for 300° phase modulation they used two circulators, four diodes, and eight quarter wavelength line sections. They found the phase modulator to be useful at power levels up to 10 mw, however they still had less than 360° modulation and the insertion loss varied with phase.

The new approach taken here solves the linearity problem, the 360° problem, and the variable insertion loss problem with the simple circuit shown in Figure 1.

LINEARITY:

When the varactor diode is mounted with the junction end as input then the cartridge capacitance can be tuned out with a shunt inductor and the equivalent circuit is as shown in Figure 2 (neglecting series resistance for the moment). The capacitance is taken from ref. 2 in which $V = (v - \phi) / (v_B - \phi)$ v = applied voltage, ϕ = contact potential, v_B = breakdown voltage. $\gamma = 1/2$ for abrupt junction varactors and 1/3 for diffused junction varactors. The reactances are shown in Figure 2.

Suppose a movable short circuit is placed on the second port of the circulator, then the phase of the power out port three is changed by twice the change in short position. The reactance of the short circuit terminating a line of length ℓ is represented by $X = Z_o \tan(2\pi\ell/\lambda)$. When the movable short circuit is replaced by an impedance that is a tangent function of applied voltage then the change in phase at the output is linearly related to change in voltage (ref. 1). A simple method of obtaining this linearity is to fit the nonlinearity of the varactor reactance to the tangent curve as indicated in Figure 3 (for $\gamma = 1/2$). This can be done over a range of 90° on Figure 3 (corresponding to 180° phase modulation) to within ± 1.5%. Then an abrupt junction varactor would provide 180° phase modulation within ± 1.5% of linearity when $L = 2.35 Z_o/\omega$ and $C_{min} = 1/(2.78\,\omega Z_o)$.

360° MODULATION:

Two tangent functions can be added as in Figure 4 to provide a tangent of the double angle function. Then two diodes, each providing 180° modulation, can be combined to provide 360° modulation. The spacing and necessary characteristic impedances are shown in Figure 1. The admittances of the diodes were added since they too are tangent functions.

CONSTANT INSERTION LOSS:

The normalized impedance of a diode with parameters selected for linear phase modulation is shown on a Smith Chart in Figure 5 by X data points. Because R_s, the series resistance of the varactor is constant, the points lie on a constant normalized resistance circle (with center at A). As varactor voltage is varied the magnitude of the reflection coefficient, which is the relative distance from the center of the Smith Chart to each data point, varies. This causes the insertion loss of the phase modulator to change with phase. This variation in insertion loss can be reduced by putting a resistance, $R_P \approx Z_o^2/R_s$, in parallel with the diode. The normalized admittance points of the varactor have their center at A' on the Smith Chart. The addition of R_p, here satisfying $Z_o/R_p = 0.2$, moves the data points to the triangle positions with point B as their center and causes the reflection coefficient magnitude (and hence insertion loss) to be constant as varactor voltage is varied.

EXPERIMENTAL RESULTS:

Experimental data to date at 1 GHz is shown in Figure 6. Phase is within $\pm 2\%$ and insertion loss varies by $\pm$ 0.1 db. From a practical point of view L is comprised partly of diode whisker inductance and partly of a short length of transmission line with an rf short circuit terminating it. Since it is difficult to obtain exact diode parameters the Z_o of the $\lambda/4$ section may be adjusted and a quarter wavelength transforming line section may be used between the diode section and circulator.

The phase modulator is intended for single sideband modulation in the 1-5 GHz frequency range by the application of a sawtooth wave to the varactors. Amplitude modulation of ± 0.1 db provides about 45 db of carrier suppression.

REFERENCES:

1. C.S. Kim, C.W. Lee, and J.R. Borer, "Varactor S-Band Direct Phase Modulator," IEEE Journal of Solid-State Circuits, Vol. SC-1, September 1966, pp. 45-51.
2. P. Penfield, Jr. and R.P. Rafuse, Varactor Applications. Cambridge, Mass.: The M.I.T. Press, 1962.

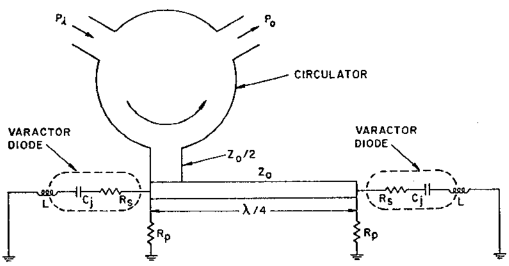

FIG. 1 - Circuit for 360° Diode phase Modulator

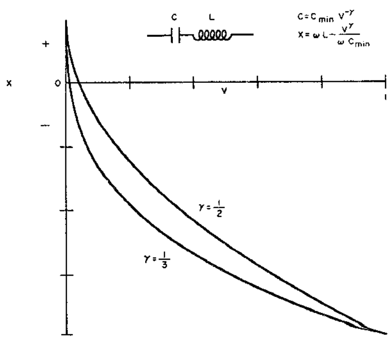

FIG. 2 - Reactance non-linearity of Varactors

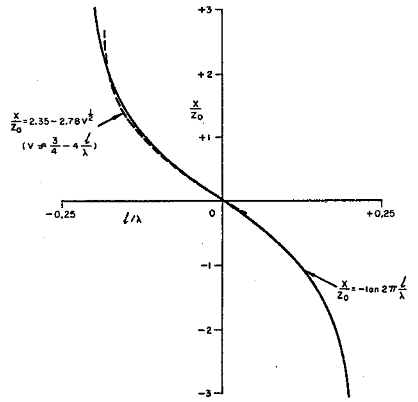

FIG. 3 - Matching the non-linearity of varactor reactance to the non-linearity of a tangent curve

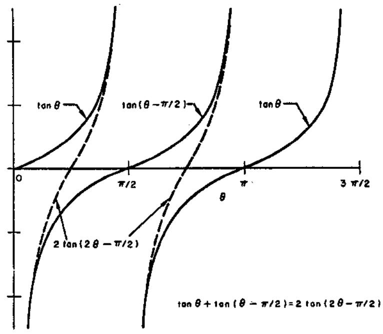

FIG. 4 - The addition of two tangent Θ curves to produce a tangent 2Θ curve

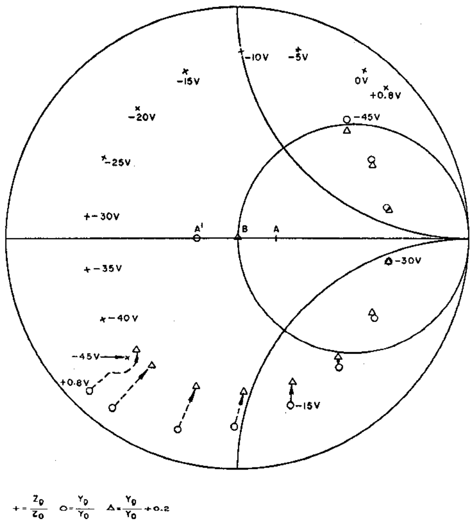

FIG. 5 - Making the magnitude of the reflection coefficient constant by the addition of a parallel resistance.

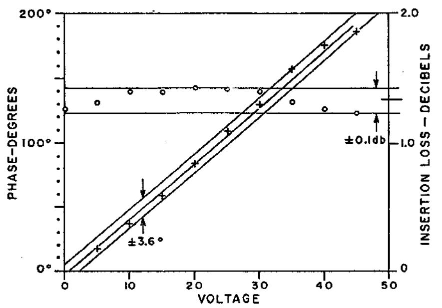

FIG. 6 - Phase modulation characteristics of a MA4325C1 varactor as deduced from VSWR measurements at 1 GHz.