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MULTI-OCTAVE PHASE MODULATORS

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Summary

A new type of reflection circuit for microwave phase modulators is presented. The circuit, which consists of two semiconductor diodes and two stubs, provides extremely broad-band of modulators. A binary circuit with p-i-n diodes exhibits an over octave frequency band with phase shift error less than 5% and 3-octave band with 10% error. For analog modulators the reflection circuit with varactor diodes gives frequency band 0.8-1.2 GHz with the phase shift 90°±5° and nonlinearity of 5.5%. Experimental results for binary reflection circuits and modulators are presented.

Introduction

The semiconductor diode microwave phase modulators are now indispensable components in communication systems, phased array antennas or in some measurement systems. Of the various types of phase modulators described so far a reflection type is commonly used because of easy and chip technology, small size [1]. Constant phase shift between the bias states of the diode in binary modulators, or linear phase dependence on supply voltage in analog modulators, both in broad frequency band, are the most important performance requirements for such circuits. Classical reflection circuits with one diode may reach relative bandwidth of 20-50% [1] , [2]. However commonly used 3 dB directional couplers provide considerable wider frequency band than binary or analog modulators [3]. Therefore the frequency band of modulators is strongly limited by the reflection circuit.

Two-Diode Reflection Circuit for Binary Modulators

A typical reflection binary phase modulator consists of 3 dB, 90° directional coupler and two identical reflection circuits (Fig.1).

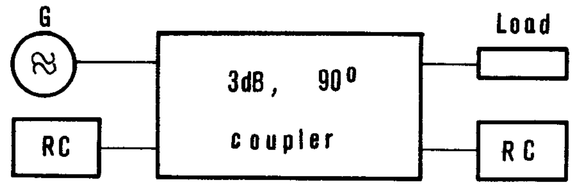

Fig.1 Binary phase modulator.

In order to extend the frequency band we propose a new and simple reflection circuit shown in Fig.2 [4],[5].

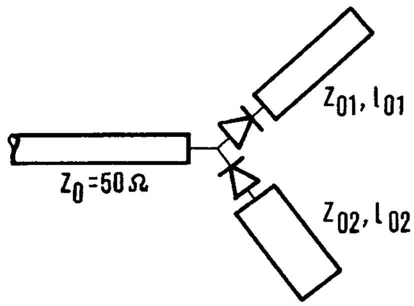

Fig.2 New two-diode reflection circuit for binary phase modulators.

The circuit consists of two oppositely biased switching diodes loaded with two open- or short-circuited stubs.

The process of design of reflection circuit which leads to the phase shift as close to the assumed value as possible, can mathematically be expressed as a minimax problem of the form

$$\underset{x}{\text{minimize}}\ \underset{f}{\max}\ \left| |\varphi_1(x,f) - \varphi_2(x,f)| - \Delta\varphi \right| \quad (1)$$

where: f - frequency, discrete values from the range (f_{max}, f_{min}) $\Delta\varphi$ - assumed phase shift, x - vector of optimized variables impedances and lenghts of stubs , φ_1 , φ_2 - phases of reflection coefficient at the input in two bias states.

The minimax subgradient methods [6] have been involved to solve this problem. Computer programs utilize a variable metrix method with estimation of the second derivatives and a method with space dilation in direction of consecutive subgradients.

A number of the two-diode circuits for different bandwidths were designed by the optimization approach mentioned. Their parameters were then compared with one-diode circuits of similar level of complexity designed for the same bands. The results of comparison for a 90° reflection circuit with HP5082-3077 p-i-n diodes are shown in Fig.3 (for one-diode circuit the best results were chosen).

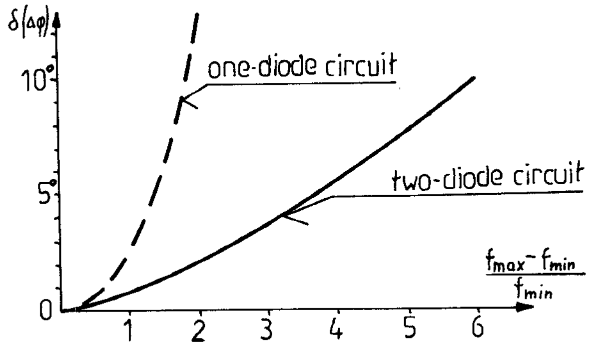

Fig.3 Frequency band of a two-diode circuit compared to the corresponding classical one.

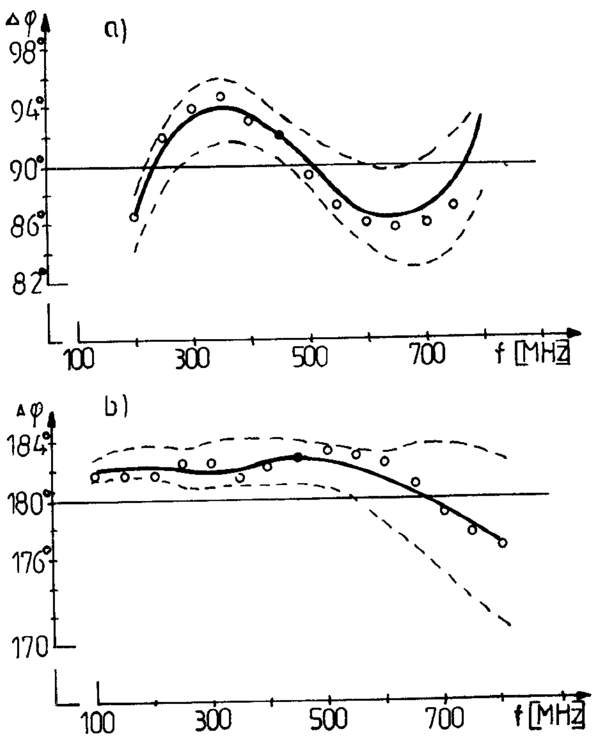

Fig.4 Phase shift characteristics of binary reflection circuits:
a) $\Delta\varphi = 90°$, b) $\Delta\varphi = 180°$.
—— calculated
ooo measured
--- tolerance zone for 2% variation of parameters values.

The numerical analysis proved that losses and parasitic amplitude modulation for both circuits are almost the same [4]. Typical characteristics obtained both theoretical and measured are shown in Fig.4a ($\Delta\varphi = 90°$) and in Fig.4b ($\Delta\varphi = 180°$).

Theoretical analysis of complete modulator leads to the conclusion that the main influence produced by directional coupler on phase shift error is due to isolation i and return loss s [4]

$$\delta(\Delta\varphi) \leqslant 2 \sin\frac{\Delta\varphi}{2}(|s| + |i|) \qquad (2)$$

In our experimental work the following directional couplers were used to build broad-band binary modulators:

A - 3 dB shorted ring type coupler, band 350-700 MHz, $|i| > 30$ dB, $|s| > 20$ dB,
B - 3 dB Lange-type coupler, band 200-600 MHz, $|i| > 28$ dB, $|s| > 35$ dB,
C - 3 dB multi-section Lange-type coupler, band 100-800 MHz, $|i| > 24$ dB, $|s| > 16$ dB.

The relative phase shift error measured in phase modulators with directional coupler A in the octave frequency band is less than 5%, for $\Delta\varphi = 45°, 90°, 180°$. Wider frequency band with similar phase shift error is obtained when employing directional coupler B. The measured characteristics are shown in Fig.5a ($\Delta\varphi = 90°$) and in Fig.5b ($\Delta\varphi = 180°$).

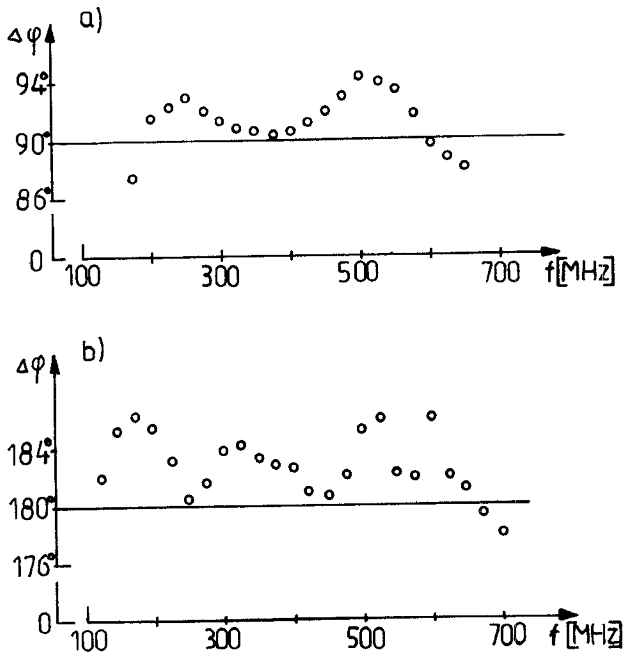

Fig.5 Phase shift characteristics of modulators: a) $\Delta\varphi = 90°$, b) $\Delta\varphi = 180°$.

The 3-octave directional coupler C gives worse results because of poor parameters s and i. For the whole modulator we have obtained:

- $\Delta\varphi = 45° \pm 6°$ in band 165-825 MHz,
- $\Delta\varphi = 90° \pm 10°$ in band 140-810 MHz,
- $\Delta\varphi = 180° \pm 15°$ in band 100-850 MHz,

Reflection circuits and modulators were also designed for the band f > 1 GHz, giving an octave bandwidth 1.3-2.6 GHz with phase shift $\Delta\varphi = 90° \pm 6°$.

Taking wide frequency band into consideration it is always possible to find sub-bands with almost constant phase shift. Employing a method of "practical centering" extremely small phase shift errors were obtained, e.g. for modulator with directional coupler B in sub-bands:

- 210-420 MHz, $\Delta\varphi = 90° \pm 1°$
- 240-330 MHz, $\Delta\varphi = 90° \pm 0.2°$.

In each case the parasitic amplitude modulation coefficient was less than 4%.

The presented two-diode phase modulators exhibit also a very good temperature behaviour. Phase shift drift less then 0.5° was observed in the temperature range from 15°C to 80°C.

Reflection Circuit for Analog Phase Modulator

Requirements imposed on reflection circuit for analog modulators are much stronger than for binary ones. Besides constant phase shift linearity of the phase characteristics phase versus bias voltage U is necessary. Such demands may be fulfiled by some complication of the circuit (Fig.6).

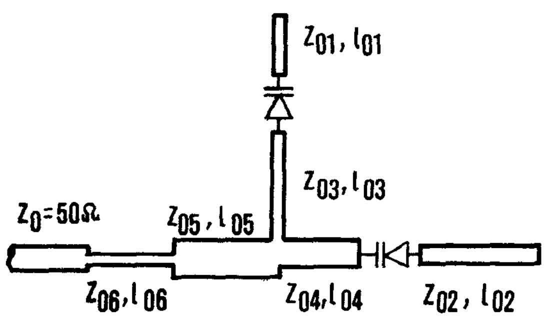

Fig.6 Reflection circuit for analog phase modulators.

In the circuit of Fig.6 two varactor diodes are reversaly biased, one of them with voltage of V + U and the other one with V - U (U < V). Stub 1 is short-circuited and stub 2 open-circuited.

The problem of optimization of analog reflection circuit can be expressed in the form

$$\underset{x}{\text{minimize}} \ \max_{f,U_1,U_2} \left| \left|\varphi(U_1,f,x)-\varphi(U_2,f,x)\right| - \Delta\varphi(U_1-U_2) / (U_{max}-U_{min}) \right|$$

where: U_1, U_2 - discretized values of voltage supply from range (U_{min}, U_{max}), φ-phase of reflection coefficient. So defined error function is equal to either phase range error or nonlinearity coefficient, which-ever is greater. Similarly, CAD methods are involved. Computer simulation of 90° circuit in the band of 0.8-1.2 GHz shows a phase range error of 5° and nonlinearity of 5.5%.

Conclusions

The results of this work prove that phase modulators with extremely broad frequency bands can be obtained by employing the two diode reflection circuit proposed. For analog modulators the ratio f_{max}/f_{min} can reach 1.5 with phase shift $90° \pm 5°$ and nonlinearity 5.5%. However, for binary modulators the ratio may be as high as 8 with relative phase shift error of 10% or "only" 2- for small error modulators $90° \pm 1°$.

The latest research work proved that further modification of two diode binary reflection circuit leads to a decade frequency band with phase shift $\Delta\varphi = 90° \pm 1.5°$.

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