A QUADRIPHASE MODULATOR IN FIN-LINE TECHNIQUE

Elias Kpodzo, Klaus Schuenemann, Hadia El-Hennawy
Institut für Hochfrequenztechnik der Technischen Universität
Postfach 3329
D-3300 Braunschweig
West Germany

Abstract

A hybrid-coupled, quadriphase modulator is described, which has been realized in fin-line technique. It operates over an 8 per cent frequency band around 15 GHz with an insertion loss of 1.7 dB.

Introduction

Digital phase modulators with pin-diodes are normally realized in rectangular waveguide techniques[1], in order to keep the insertion loss low and the modulator bandwidth wide. (The latter is defined here with respect to deviations in the desired phase shift of less than 4 degrees and to an amplitude imbalance of less than 5 per cent.) Insertion losses of 2 dB and a bandwidth of 1 per cent of the quadriphase modulator have been achieved at millimeter wavelengths[1]. More recently, a microstrip realization has been reported[2], which shows higher losses (3 dB at Ku-band frequencies) but the same bandwidth. In fin-line technique, the advantages of rectangular waveguides (low loss) and of microstrip lines (low-cost production) can be combined[3]. It should hence be possible to realize a phase modulator, whose performance is similar to that of a rectangular waveguide structure. This paper presents a solution to this problem.

3 dB-Hybrid

Our aim is to develop a quadriphase modulator by cascading a 180 degrees modulator with a 90 degrees modulator. In order to avoid nonreciprocal devices, the input and output waves of each modulator are separated in a 3 dB-hybrid, as has e. g. been shown in [2]. Either modulator then consists of a 3 dB-hybrid and of two identical reflection-type phase modulators with pin-diode, which terminate two ports of the hybrid.

A simple configuration for a 3 dB-hybrid in fin-line technique has not been reported until now. The directional coupler of [4] or the magic-T circuit of [5] could indeed be utilized to implement a hybrid-coupled phase modulator, they do not, however, lead to a simple construction of the integrated device. A practical solution of the problem is the fourport, whose slot pattern on the dielectric substrate is sketched in fig. 1. (It has first been proposed in [6].). The

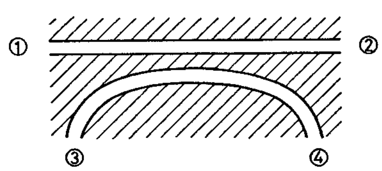

Fig. 1 Slot pattern of the 3 dB-hybrid

slot width has been chosen to 0.2 mm, in order to realize a low wave impedance of 100 Ω. The coupling between the two fin-lines can be adjusted by varying both the distance between the two slots and the length of the coupling section. The directivity is greatly influenced by tapering the coupling strength versus the waveguide axis. This, on the other hand, influences the effective coupling length and thus the coupling too[7]. It has been found experimentally, that a broadband performance of the 3 dB-hybrid can already be achieved with a coupling section, which is 2 to 3 wavelengths long. Then the narrowest distance between the slots is 2 mm, in order to obtain equal power splitting between ports 2 and 4 at Ku-band.

The performance of the 3 dB-hybrid is shown in fig. 2. Both the forward coupling and the directivity are flat over a frequency band from 13 to 17 GHz, the insertion

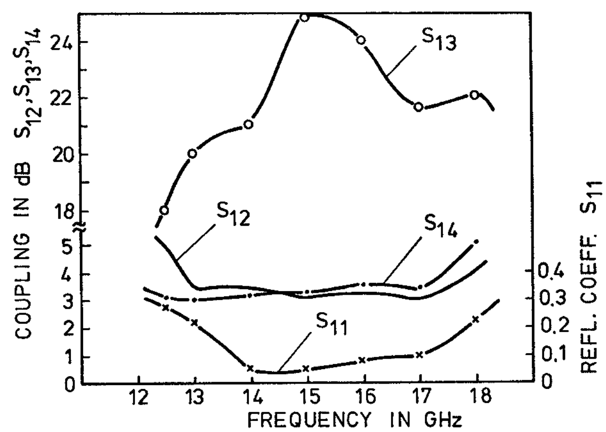

Fig. 2 Performance of the 3 dB-hybrid

loss amounts to 0.5 dB. The directivity is better than 20 dB. It can be increased to more than 30 dB in a fractional bandwidth of about 20 per cent.

Reflection Phase Modulator

The reflection phase modulator consists of a fin-line network, which must transform the two steady-state impedances of a pin-diode in such a way, that the phase between the two input reflection coefficients has a prescribed value. The magnitudes of the reflection coefficients must be equal. It has been shown in [8], that a 180 degrees phase modulator is obtained, if a weighted average of the diode impedances, the so-called "hyperbolic middle-point impedance", is matched. This result can be generalized: In order to obtain a 90 degrees phase modulator, the hyperbolic middle-point impedance must be transformed to a well-defined mismatch impedance.

The linear circuitry of a phase modulator (the imbedding of the pin-diode) is hence an impedance transforming network with bandpass character. The fin-line realization is shown in fig. 3. The pin-diode has directly been soldered across the fin-line slot. The matching network consists of a short-circuited transmission line section behind and of an inductance in front of the diode. The inductance has been realized by a short section of a fin-line with a large wave impedance.

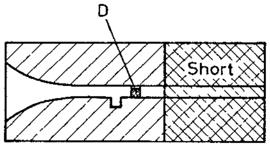

Fig. 3 Slot pattern of a reflection phase modulator with pin-diode D

The input impedance locus curves of a 180 degrees phase modulator are shown on a Smith chart in fig. 4. The

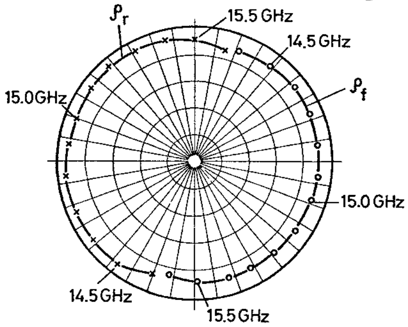

Fig. 4 Input impedances of a 180 degrees phase modulator

modulator bandwidth can be seen to exceed 8 per cent, the losses are less than 0.5 dB. The bandwidth is appreciably larger than has yet been reported. Similar results have been obtained for a 90 degrees phase modulator, as can be seen from the impedance locus curves of fig. 5.

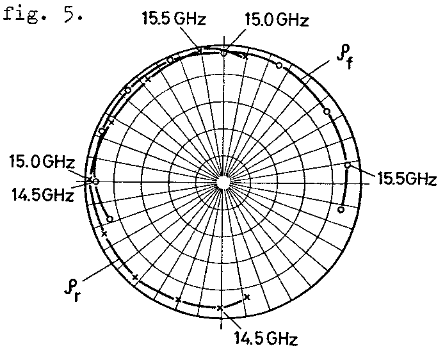

Fig. 5 Input impedances of a 90 degrees phase modulator

Hybrid-Coupled Quadriphase Modulator

The complete quadriphase modulator consists of two hybrids whose ports 2 and 4 are both terminated either in 180 degrees reflection phase modulators or in 90 degrees devices. The hybrids are then cascaded to form a quadriphase modulator. The compound circuit is sketched in fig. 6.

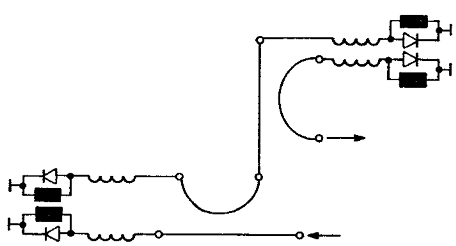

Fig. 6 Equivalent circuit of the quadriphase modulator

The 3 dB-hybrid and the reflection phase modulators can individually be matched and then be coupled together due to the high directivity of the hybrid. The tuning elements of the modulator have only slightly to be changed afterwards. Any corrections turned even out to be unnecessary, when the 180 degrees phase shifter and the 90 degrees phase shifter are cascaded. The input VSWR of the compound modulator is less than 1.3, so that a Gunn oscillator on a fin-line could directly be coupled to the modulator input. The bandwidth of the quadriphase modulator is 8 per cent, its overall insertion loss 1.7 dB at an operating frequency of 15 GHz. (Nearly the same performance could be achieved at 30 GHz except for the insertion loss which degraded to 2.2 dB.) Furthermore, the switching times exclusively depend on the pin-diode, because the response time of the imbedding has been measured to be less than 0.5 ns. Switching times of 1 ns have been obtained.

Tolerance Analysis

It has been demonstrated that the electrical performance of an integrated quadriphase modulator can compete to that of a waveguide realization even in the millimeter-wave region. In the following we will like to stress, that the fin-line technique is even an alternative to microstrip at centimeter wavelengths. As it is obvious that the electrical performance of fin-line circuits can be better than that of microstrip circuits, one has still to consider the economic point of view. A fin-line housing can be produced with low cost provided that there are no severe tolerance limits for the dimensions of the waveguide cross section.

To ask this question, a theoretical analysis has been set up. Based on the closed form solutions for the eigenvalues and the wave impedances for fin-line in [9], we have investigated how sensitive these quantities are with respect to variations in the dimensions of the waveguide cross section (width, height, and distance between substrate and side wall). Analytical expressions can be derived for the centric bilateral fin-line, whose cross section is shown in fig. 7, and for the unilateral fin-line. The variation of the cutoff wave number of the

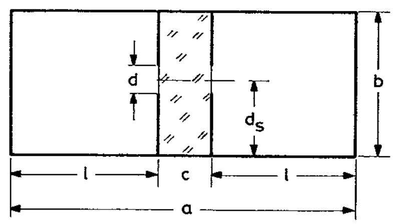

Fig. 7 Cross section of bilateral fin-line

air-filled fin-line k_{cair} with the waveguide width a is

$$\frac{\partial k^2_{cair}(fin)}{\partial a} \approx \frac{H(1 + H)}{2} \frac{\partial k^2_c(w.g.)}{\partial a} \quad (1)$$

(the symbol w.g. means the rectangular waveguide) with

$$H = k_{cair}(fin)/k_c(w.g.). \quad (2)$$

The sensitivity against variations in b is

$$\frac{\partial k^2_{cair}(fin)}{\partial b} \approx \left(\frac{a}{b}\frac{H(1 - H)}{2} - \frac{c\pi^2 H^2}{8d}\right)\frac{\partial kc^2(w.g.)}{\partial a} \quad . \quad (3)$$

The effective dielectric constant k_e of the fin-line changes with a according to

$$\frac{\partial k_e}{\partial a} = H \frac{1 - k_e}{a} \qquad (4)$$

and with b according to

$$\frac{\partial k_e}{\partial b} \approx \frac{H}{b} \left[k_e - 1 + \frac{\pi^2}{8} \frac{c/a}{d/b} \left(1 - \frac{\varepsilon_r}{k_e} \right) \right] . \qquad (5)$$

The slope of k_{cair} and of k_e versus d_s is proportional to $\cos(\pi d_s/b)$ and hence zero for a symmetric fin-line ($d_s = b$). The expressions for the slopes of k_{cair} and of k_e versus l as well as for the slopes of the wave impedance versus a, b, d_s, and l are lengthy and will not be given here. Instead we will summarize the results of these analyses: The sensitivity of the electrical parameters of a fin-line with respect to variations in the dimensions of the waveguide housing is much less than for a rectangular waveguide provided that the impedance of the fin-line is not larger than 100 Ω. It is typically reduced to about 20 per cent due to the tight coupling of the wave to the slot between the fins. It is hence not necessary that the fin-line housing is carefully machined. This shows that the fin-line might be preferable to the microstrip even at say X-band frequencies, if integrated circuits with filter networks must be realized.

The validity of these theoretical results can be demonstrated with our modulator. Its performance does not deteriorate, if the dimensions of the housing are changed by 4 per cent (without any further tuning).

Conclusions

A quadriphase modulator has been realized by cascading two hybrid-coupled modulators with a phase shift of 180 degrees and 90 degrees, respectively, in an integrated fin-line circuit. The overall insertion loss is 1.7 dB at 15 GHz, which is comparable to what has been obtained in waveguide technique, while the bandwidth is an order of magnitude larger (it amounts to 8 per cent). The modulator has likewise been realized at 30 GHz. The bandwidth stayed constant while the insertion loss slightly degraded to 2.2 dB. The switching times exclusively depend on the pin-diodes: the response time of the imbedding network has been measured to be less than 0.5 ns. Switching times of 1 ns could be obtained.

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