A NOVEL UNIPLANAR BI-PHASE(0°-180°) MODULATOR/MIXER

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Abstract:

The overall goal of this paper is to design a new modulator/mixer at 38 GHz in uniplanar technology. The primary objective is to developing a theoretical and an experimental study of each elementary block in the millimeter frequency range allows us directly to design the device at 38 GHz. As part of this study, a uniplanar modulator/mixer was built in X band in order to aid in the verification of the design concept.

Introduction:

Radio communication in millimeter waves are highly attractive for space and terrestrial applications, in both civil and military areas. Indeed, a high antenna gain, combined with compact and wide bandwidth circuits, makes these frequency bands very advantageous for intersatellite communications, local area communication networks and so on [1][2].

For such applications, a phase modulator/mixer device, which combines several functions, may be of great interest due to the simplification of the Rx and Tx channels. In addition, in these frequency ranges, the uniplanar technology appears to be well-suited today for high performance, compact and low-cost components; for few years, the development of this alternative technology offers a lot of new possibilities for MIC or MMIC circuit designers: it allows an easy mounting of active and passive devices, both in shunt and series connections, and a reduction of the discontinuities effects, which can be very limitative in high frequencies.

Recently, some work has been published on either balanced modulator structures or balanced uniplanar mixers [3]-[5], showing the uniplanar technology possibilities for integration of this kind of function. In this paper, we will demonstrate that this uniplanar approach allows the design and the integration of more complex functions, such as a bi-phase modulator/mixer. We will successively detail the different steps for the circuit design, in the millimeter frequency range, and present the simulated and experimental results obtained at each step.

The objective to design modulator/mixer in millimeter frequency range using uniplanar technology requires three steps:

1/ To validate the design concept. As we have shown, in low frequencies, it was possible to use very simple models to design uniplanar subsystems [6], so we have decided to make such a validation for the mixer/modulator in the X band.

2/ To characterize theoretically and experimentally the effects due to the main discontinuities in the millimeter frequency range.

3/ To divide the device into elementary blocks which are separately designed and experimentally tested. for each elementary block, S-parameters block is defined and introduced in commercial C.A.D Software. At this step, we can perform a simulation of the whole circuit. We must remark that such an approach can be efficient only if the simplest topologies are chosen for each block.

I. Validation of the design concept:

The configuration of the uniplanar bi-phase modulator/mixer is shown in fig.1.

I.1. Bi-phase (0°-180°) modulator principle:

The modulating signal alternately forward-biases one of the two diodes and reverse-biases the other, giving respectively, for each diode, a conducting and a non conducting state (short-circuit/open-circuit). The microwave signal from the input port (1) is guided in the branch of the T junction in which the non conducting diode is located. The principle of circuit operation is presented in fig.2.

The arrows indicate the electric field in the slot. Depending on the chosen path, the electric field in the output plan of the ring represents two possible phase states 0° (fig.2a) or 180° (fig.2b). Theoretically, the phase shift is independent of the frequency; however, in the real case, the phase shifting is slightly affected by the diode parasitics. In the modulation case, the equivalent circuit of the device is presented in fig.3.

I.2. Balanced mixer:

This circuit can also be used as a single balanced mixer, using a uniplanar magic tee composed of a series T junction and a parallel T junction [6]. This magic tee has two fundamental functions: first, it distributes the RF and LO signals with appropriate phases on the two non-linear devices; secondly, it assures a high isolation between the RF and LO input. In order to optimize mixer performance, it is important to isolate the different ports at each frequency by filter structures as shown in fig.1.

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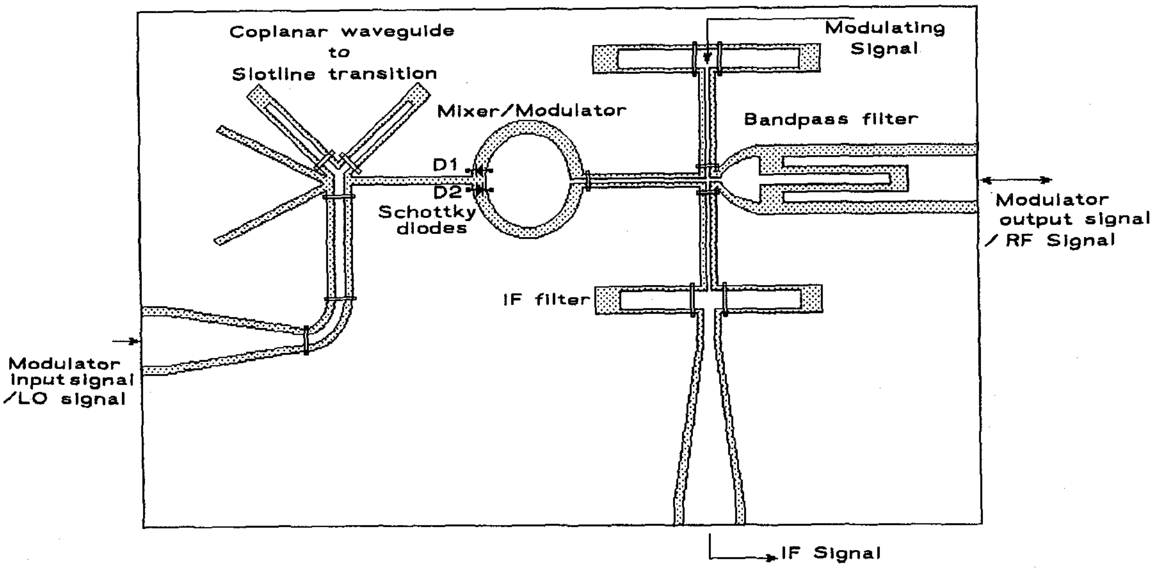


Fig.1 The Uniplanar Bi-phase (0°-180°) Modulator/Mixer Configuration

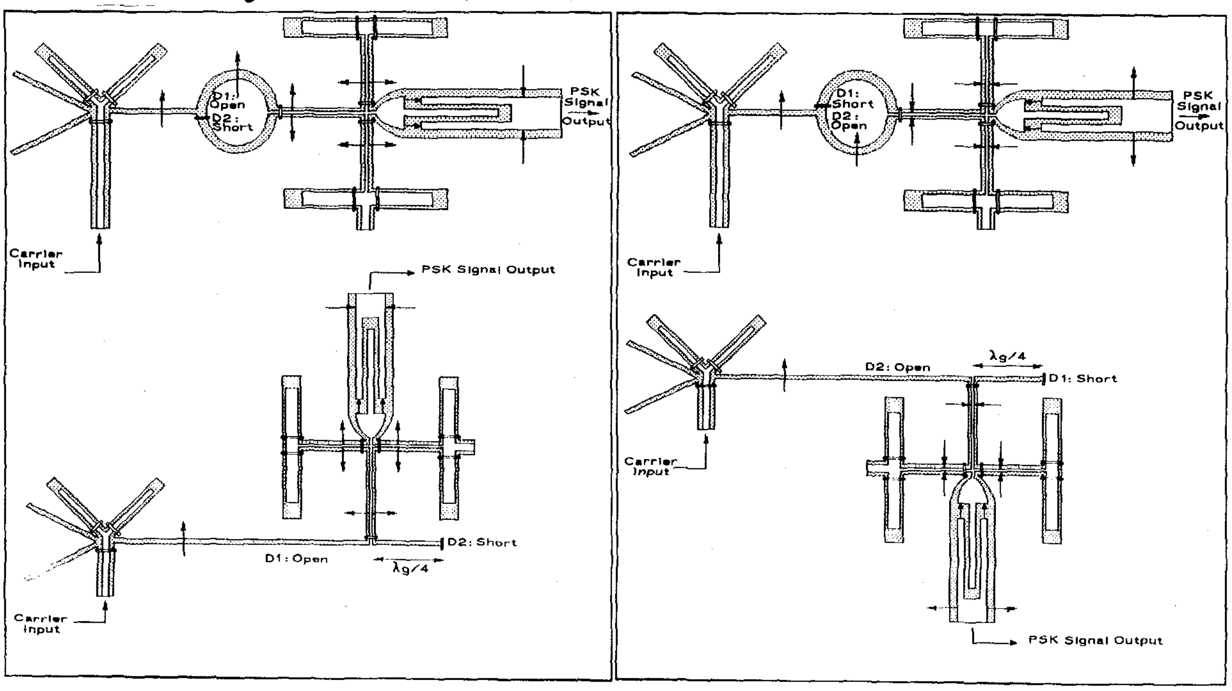


Fig.2 Fundamental operation of the Bi-phase Modulator

The RF signal is applied to mixer diodes from the parallel T junction . The LO is injected via a CPW/slotline transition, whose configuration provides low insertion losses on a large frequency bandwidth, and the IF output is recovered via a lowpass filter. To achieve good RF to IF isolation, a bandpass filter is incorporated into the design. Like for the modulation mode, a simple equivalent circuit can be defined for the mixer simulation.

I.3. Experimental and simulated results:

A uniplanar modulator/mixer was developed on an Epsilam substrate ($\varepsilon r = 10.2$, $h = 0.635$ mm), with a central frequency of 10 Ghz. In order to validate the design of the modulator function, we tested the device before connecting the diodes. In this case, each diode is alternately replaced by an air bridge simulating the equivalent short circuit. In figure 4a, we can observe a good agreement between theoretical and experimental results. The amplitude imbalance is less than 0.2 dB over a 7 Ghz frequency band (6.5 - 13.5 GHz) (fig.4b). The modulator has less than 3dB transmission loss over this bandwidth and the input return loss S11 is lower than -10dB (fig.4a). The phase error remains lower than 7° (fig.4c).

When we connect the diode (Beam-lead Schottky APX 377), we observe some degradations due to the characteristics

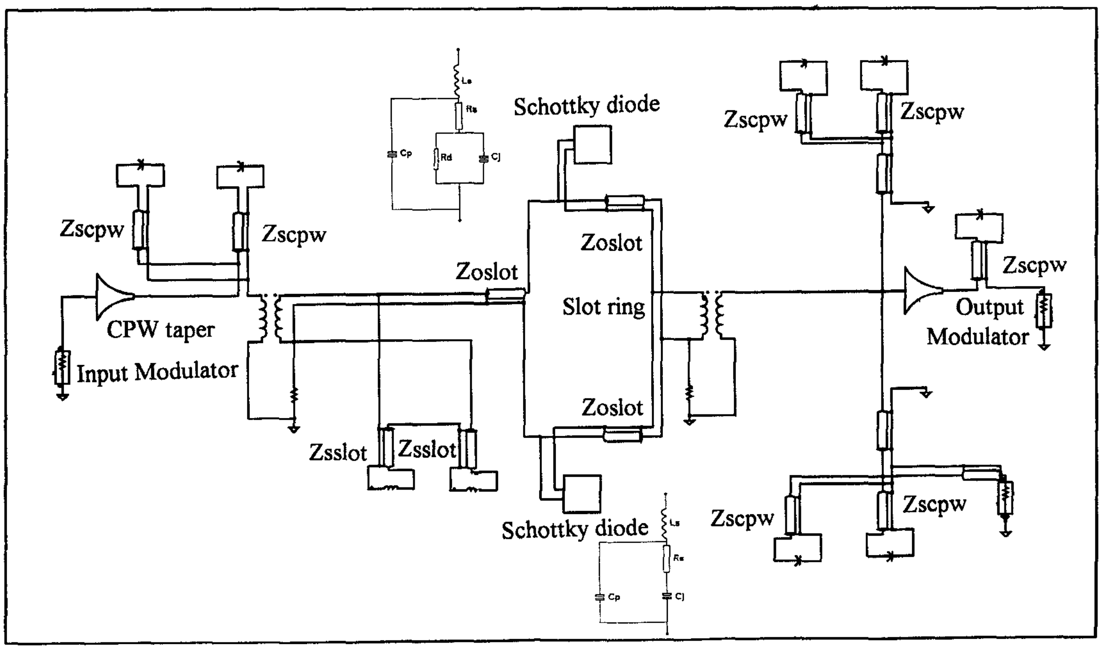
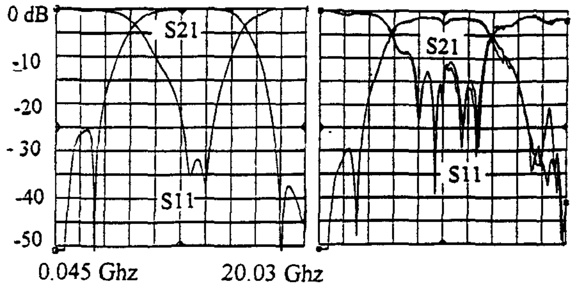


Fig.3 An equivalent circuit of the Bi-phase modulator.



Theoretical data Experimental data

Fig.4a Insertion loss and return loss

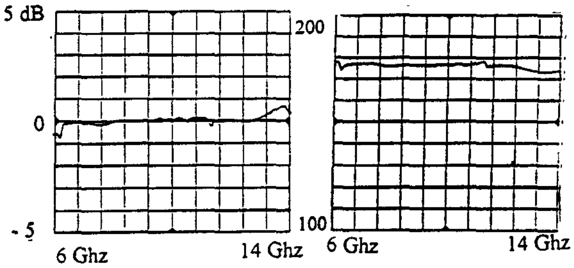


Fig 4b Amplitude imbalance Fig.4c Output signal phase difference

(In this case, each diode is alternately replaced by an air bridge)

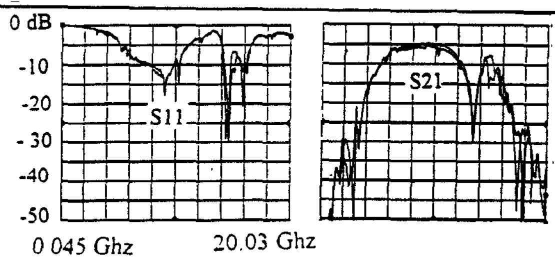


Fig 5a Insertion loss and return loss

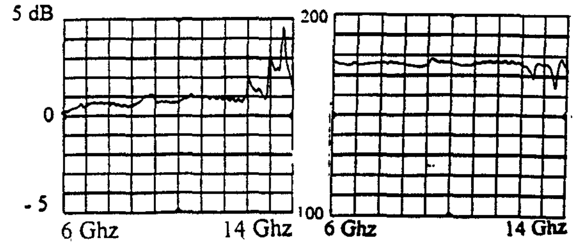


Fig.5b Amplitude imbalance Fig.4c Output signal phase difference

of the Schottky diode, especially the parasitic elements (Rs, Lp and Cp). The insertion loss increases with an increase of the resistance and the capacity of the diode. Moreover, we can observe a resonance peak which can be due to the mounting of the diodes over the slotline. In conclusion, to improve the performance of the modulation mode, high Q factor diodes have to be chosen. For the mixer mode, a minimum conversion loss of 5.4 dB has been obtained for a RF signal of 10.06 Ghz and a LO at 10 Ghz, with a pump power of 15 dBm. This relativily high value of the LO power is due to the high barrier diodes used at this time. The mixer presents good port-to-port isolations, with 22dB RF/IF isolation and 43dB LO/IF isolation in relation to the minimum conversion loss operation. Fig 6 shows the dependance of the conversion loss versus the beating frequency (IF). It varies from 5.4 to 12 dB for a IF

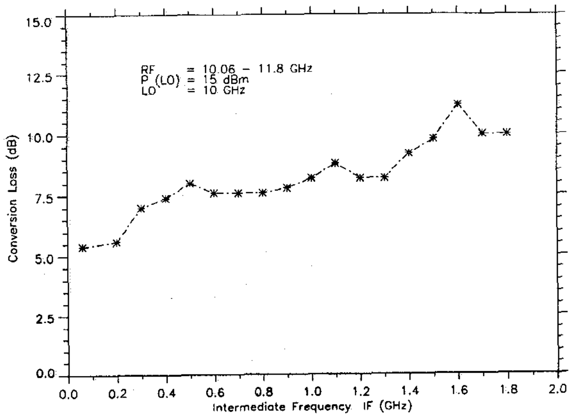


Fig.6 Mixer performance

tuning from 0.06 to 1.8 Ghz. It should be noted that this conversion loss is achieved at a pump power of 15 dBm for a fixed LO frequency of 10 Ghz.

II. The study in the millimeter frequency range:

To analyse the elementary blocks of the uniplanar modulator/mixer topology, an specific program has been developed . It is based upon an integral equation technique [7]. This program allows the prediction of the electrical performance of the different structures; to validate this approach, some experimental results from 1 to 40 GHz are given in fig.7. As we can see, the agreement between simulated and measured results is excellent. This circuits were realized on Alumina substrate ($\varepsilon r = 9.9$, $h = 0.635$ mm) and tested using a microwave coplanar probe station and a HP8510B vectoriel network analyser. Considering the validation of the basic elements of the modulator/mixer in the millimetric frequency range, we are now working on the third step of the study : the design of the whole circuit at 38 GHz.

Conclusion

In this paper we have proposed a method to design high performance modulator/mixer for millimeter communications systems. The general concept has been verified in low frequency the characterization of all the elementary blocks has been done in millimetric frequency range.

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References

[1] H. Callsen, H.Meinel and W.Hoefer "Pin diode control devices in E-plane technology"
IEEE Trans on MTT vol 37, pp. 1568-1573, Sept 1989
[2]H.Ogawa, M.Aikawa and M.Akaike "Integrated balanced BPSK and QPSK modulators for the Ka-band"
IEEE Trans on MTT vol 30, pp. 227-234, Mar 1982
[3]S.Maas and K.W.Chang "A broadband, planar, doubly balanced monolithic Ka-band diode mixer"
IEEE Trans on MTT vol 41, pp. 2330-2335, Dec 1993
[4]Y.Tarusawa, H.Ogawa and T.Hirota "A new constant-resistance ASK modulator using double-sided MIC"
IEEE Trans on MTT vol 35, pp. 819-822, Sept 1987
[5]J.Eisenberg, J.Paelli and W.Ou "A new planar double-double balanced MMIC mixer structure"
IEEE MTT-S Int.Microwave Symp., 1991, pp.81-84
[6]K.Hettak, J.Ph.Coupez, A.Sheta, T.Le Gouguec and S.Toutain "Practical design of uniplanar broadband subsystems application to a wideband hybrid magic tee"
IEEE MTT-S Int.Microwave Symp., 1994, pp.915-918
[7] N.Dib, L.P.Katehi, G.E.Ponchak and R.N.Simons "Theoretical and experimental characterization of coplanar waveguide discontinuities for filter applications "
IEEE Trans on MTT vol 39, pp. 873-882, May 1991

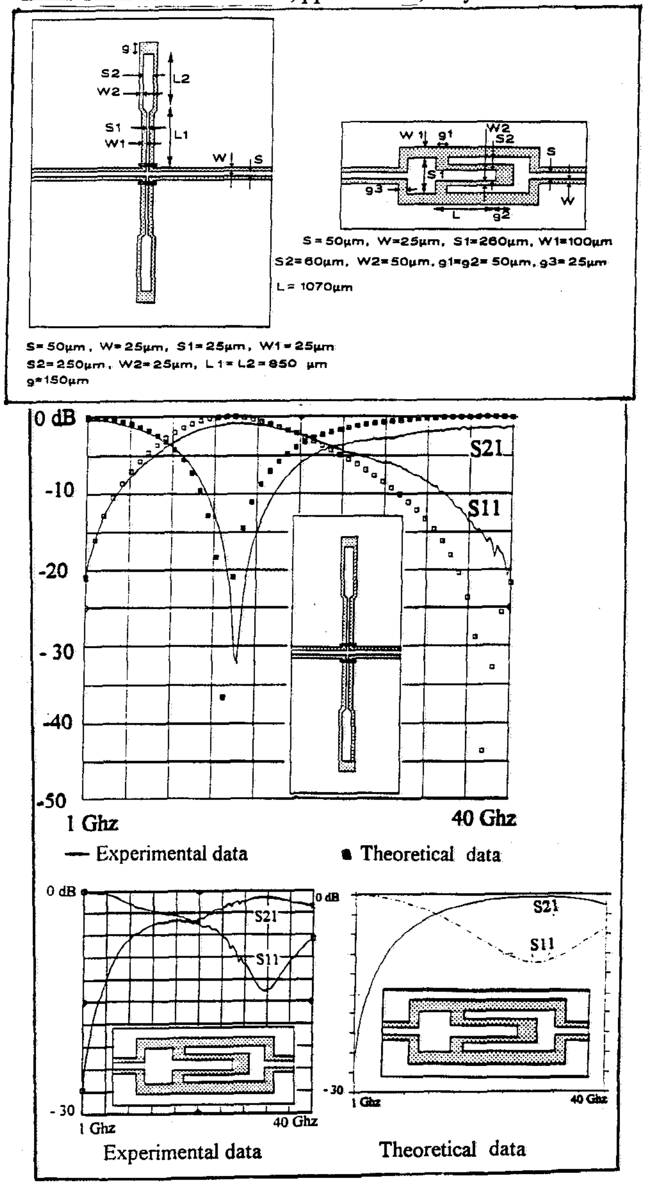

Fig.7 Measured and Simulated S-parameters for two elementary blocks of the uniplanar Modulator/Mixer topology.