COMPUTER-AIDED DESIGN OF SEMICONDUCTOR MOUNTS IN FIN-LINE TECHNOLOGY

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ABSTRACT

Based on both a rigorous eigenmode calculation and a modal analysis of discontinuities, a computer-aided design of some diode mounts in fin-line technology has been performed. Theoretical results on a detector with Schottky-diode, a reflection-type phase modulator with pin-diode, a switch with two pin-diodes, and a Gunn oscillator show good agreement with measurements. Finally, some design rules are outlined for mounting semiconductor devices in a fin-line.

Introduction

Much work has been done on both the realization of fin-line components and the theoretical investigation of eigenmodes. Very little is, however, known about how to design an individual component, like a modulator or an oscillator. We have recently presented an analysis of various discontinuities[1] which are often used for impedance transformation. A detailed description of these calculations has recently been prepared for publication[2]. The present work continues those investigations by using the equivalent circuits of the discontinuities for a computer-aided design of various semiconductor mounts.

The purpose of this paper is (1) to outline some design rules for mounting semiconductor devices, (2) to characterize performance limits (e.g. with respect to bandwidth), and (3) to present and to analyze circuit configurations which are believed to be typical for the device under consideration. The main key to these problems is the availability of a modal analysis program together with an efficient (i.e. time-saving) eigenmode subroutine. Both have been established in [1]. Impedance transformation is performed by the following discontinuities: a step in the slot width, a small strip or notch, a longitudinal stripe (this is the equivalent of a waveguide post), a small slit in the metal fins (for dc-separation), a metallic strip on the back of the substrate which may or may not bridge the slot on the front, and a short- or open-circuited line section. These discontinuities are sketched in Fig. 1. They are used for matching Schottky diodes in detectors and mixers, pin-diodes in switches and digital modulators, varactor diodes and Gunn elements in oscillators.

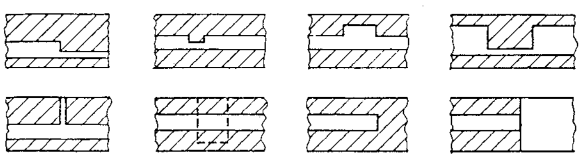

Fig. 1 Slot patterns of some fin-line discontinuities

Schottky Mounts

In a broadband detector or mixer circuit, the diodes are bonded across the fin-line slot. The fin-line is often terminated in a matched load[3]. We have investigated the bandwidth restrictions which would occur due to an "open-circuited" fin-line. In fact, the fin-line ends in an empty waveguide which is below cutoff. Then full-band operation is no longer possible (if bandwidth is defined due to a 1-dB decline in performance), but the bandwidth is still large (> 30 per cent of the waveguide band). In the case of a detector, the minimum detectable power can be decreased by up to 8 dB, if an inductive notch is placed directly in front of the diode. The bandwidth is then, however, limited to < 10 per cent.

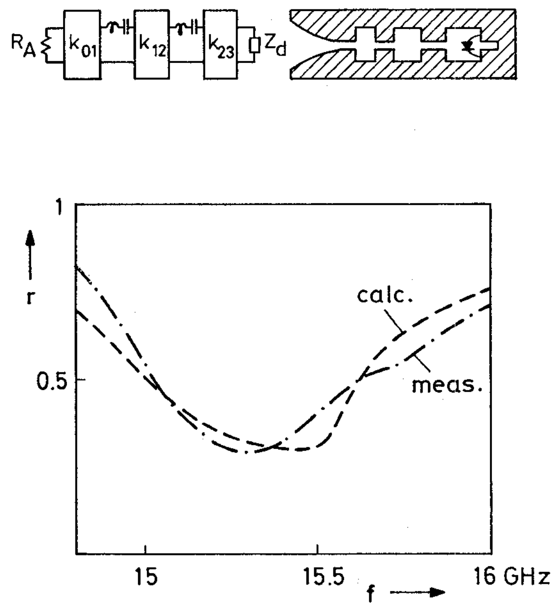

Fig. 2 Slot pattern, equivalent circuit, and input reflection of a detector mount

As an example, a detector mount has been designed for the Schottky diode 5082-2709 of HP (Fig. 2). Swept frequency measurements have been performed at Ku-band in order to enhance measurement accuracy. The design procedure is as follows: The diode impedance has been measured versus frequency for the diode being directly soldered across a fin-line of slot width 0.25 mm. This width corresponds to the physical size of the diode and leads hence to a minimum bonding wire inductance. The impedance has then been approximated in a ±1 GHz-band by a constant real and a linearly varying imaginary part. The short-circuited stub behind the diode compensates for the latter (Fig. 2), while the former is matched by a three-section transformer whose parameters have been calculated by standard methods[4]. The dimensions of the single sections are taken from numerical results of the modal analysis[1]. Finally, the input reflection coefficient of the detector realized has been measured and compared to theory. The agreement

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is good (Fig. 2).

Pin-Diode Mounts

The most stringent test of the accuracy of our cad-procedure is the design of a digital phase modulator with pin-diode. Therefore it will be described in more detail by regarding a 180 degrees modulator. The diode embedding must transform simultaneously the two impedance states of the pin-diode in such a way that the input reflection coefficients of the modulator show equal magnitude but opposite phase. It has already been shown that this task is fulfilled if a certain weighted average of the two diode impedances (the so-called "hyperbolic middle-point impedance") is matched[5]. We have hence measured the two impedance states versus frequency, calculated the middle-point impedance, linearized its frequency dependence, and designed the matching circuit. A magnitude imbalance of less than 5 per cent and a phase error of less than 5 degrees demand nearly perfect match: the SWR must stay below 1.05, if the quality factor of the diode is about 10 (see Ref. 5!). In the following we will present some examples:

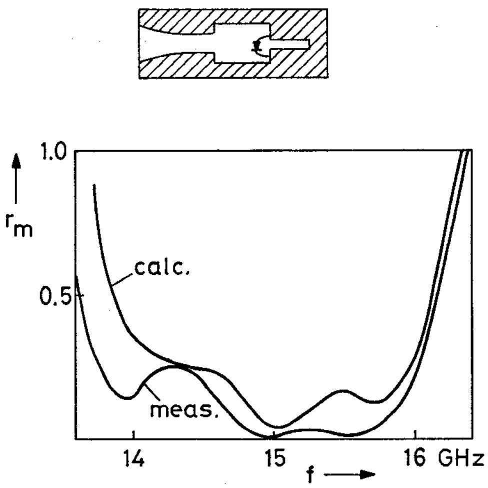

Fig. 3 Slot pattern of a digital 180 degrees modulator and input reflection coefficient of the hyperbolic middle-point impedance

The slot pattern of the matching circuit is shown in Fig. 3. It is a modification of the structure reported in [6]. The short-circuited stub behind the diode compensates for the imaginary part of the hyperbolic middle-point impedance. Its slot width has again been chosen to 0.25 mm for the reasons stated above. The g-parameters of the π-network of the matching section have been calculated with [4]. The series parameter g_2 is directly proportional to the difference between the short- and open-circuit input impedances of the notch section which depends only on the length l of the notch but not on the slot widths if higher-order mode coupling is neglected for the moment. Hence l can be calculated from g_2. After estimating the propagation constant in the notch region, the slot width can be calculated from g_1 by using results from [1]. A corrected value for the propagation constant is then calculated and the whole procedure (including the determination of l) iteratively repeated. (Convergence is most often obtained after the first iteration.) Finally, the slot width at the output is calculated from g_3.

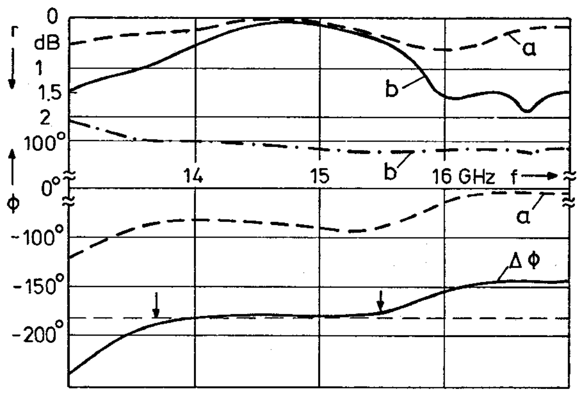

Fig. 4 Magnitude r and phase ϕ of the input reflection coefficients and phase shift $\Delta\phi$ of an 180 degrees modulator (a, b diode states) (The arrows indicate a phase error of 5^0.)

Performance data of a 180 degrees modulator are presented in Fig. 4 for the pin-diode DSG 6470 C of Alpha Industries. A comparison between calculated and measured results (drawn in Fig. 3) shows again good agreement. Similar results were obtained for a 90 degrees modulator at Ka-band. The task of the passive circuitry is again matching a certain weighted average of the two impedance states of the pin-diode[6]. This has again been accomplished with an unsymmetrically designed notch. Results are presented in Fig. 5 for the same pin-diode as above.

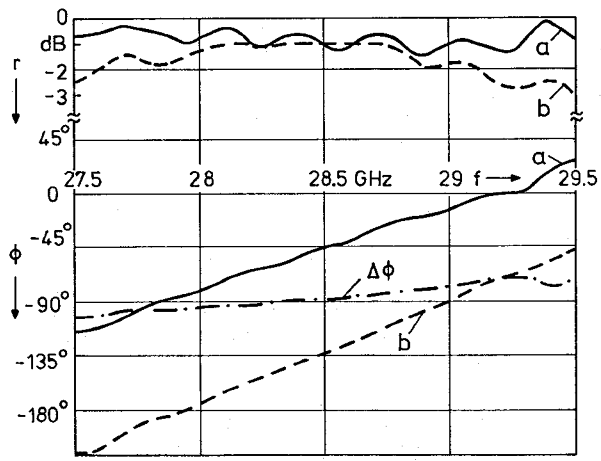

Fig. 5 Performance of a 90 degrees modulator

These investigations yielded the following design rules: The imaginary part of the middle-point impedance should be tuned out by a short-circuited line of width which corresponds to the physical size of the diode. Usable ranges can be given for the notch dimensions, so that the notch mainly acts on the real part of this impedance. The lines on either side of the notch should have unequal impedances in order to enhance the bandwidth.

Further pin-diode mounts have been applied to the design of switches. Two configurations have been investigated, one with the pin-diodes shunting the finline and another one with series-mounted diodes[3]. The latter mount will be treated here in more detail because it is different from the mounts regarded above. The slot pattern of a switch with two diodes and its equivalent circuit are shown in Fig. 6. The pin-diodes are directly soldered across the short notch section

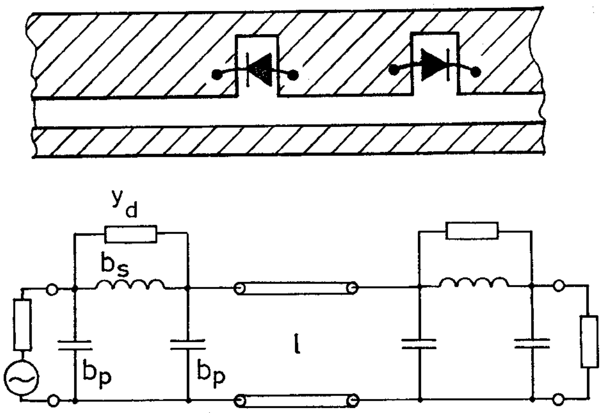

Fig. 6 Slot pattern and equivalent circuit of a switch

of length 0.25 mm, which corresponds again to their physical size. The diode admittance y_d must be measured in a fin-line of equal slot width. The notch can be characterized by a π-network with purely inductive series and capacitive shunt elements. The dimensions of the notches and their distance l are calculated for a given y_d in the following way: The slot width of the main fin-line should be as small as possible so that y_d in the forward-bias state is much larger than the wave admittance. This yields minimum insertion loss for the switch closed. According to the design procedure given in [7], y_d in the reversed-bias state should be tuned out by b_s. This determines the slot width in the short notch section (i.e. the "stub length" in the terminology of [3]). Associated with b_s are certain values for the shunt elements b_p. The two b_p which are adjacent to the line between the notches must be incorporated into the line, so that the effective electrical length of this section equals a quarter wavelength.

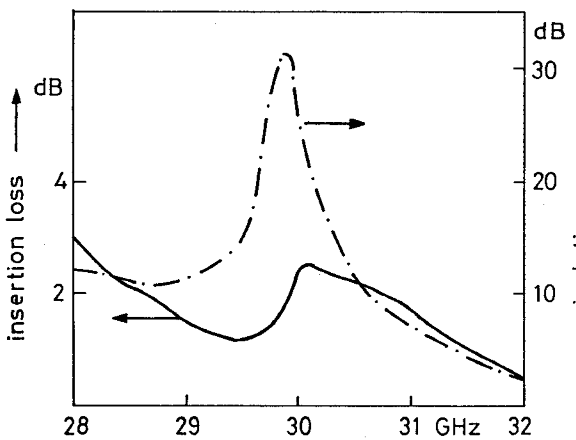

Fig. 7 Performance of a switch with two series-mounted pin-diodes MA 47301

Performance curves for a ka-band switch are given in Fig. 7. The switch has been designed for a single frequency, namely for 30 GHz. Theoretical values are 0.5 dB for the insertion loss and 26 dB for the isolation. One recognizes that these design goals are nearly met at a frequency which is 150 MHz lower than the desired 30 GHz. This slight shift can be attributed to the influence of the slit in the waveguide housing which has not been taken into account in the eigenmode analysis. The larger insertion loss is due to errors in the measurement of y_d.

Gunn Mounts

We have completed the investigations of various Gunn mounts presented in [8] by a theoretical analysis. According to the experimental results, the configuration of Fig. 8 shows the best performance, namely high circuit efficiency together with high loaded Q-factor. The planar slot pattern resembles the post-coupling structure familiar from conventional rectangular waveguide technique. The performance of the fin-line oscillator circuit is hence similar to that of a waveguide circuit.

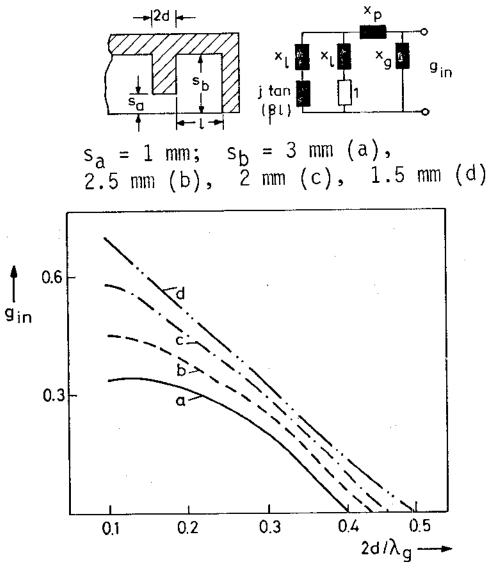

Fig. 8 Slot pattern, equivalent circuit, and driving point conductance of a Gunn oscillator at 30GHz

A Gunn oscillator at 30 GHz has been designed as example. The diode is mounted in the gap of a longitudinal stripe[8]. The slot width s_a corresponds to the height of the package, because calculations showed that a high enough driving point conductance can thus be attained. Slot pattern and equivalent circuit are shown in Fig. 8. The gap reactance x_g is capacitive, the stripe (or "post") reactance x_p inductive. The reactances x_l are inductive for the stripe length 2d being less than a wavelength. The modal analysis of [1] yields only the total shunt reactance (x_g+x_p). x_p is, however, known from [9] for the case of a short-circuited gap (s_a=0), so that x_g can be determined approximately. The reactances are tuned out with l, while the diode is matched with d (Fig. 8).

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