NEW MILLIMETER-WAVE FIN-LINE ATTENUATORS AND SWITCHES

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ABSTRACT

New diode-controlled mm-wave attenuators and switches using fin-line technique are presented. Design considerations and measurements show, that ultra broadband devices (18-40 GHz; attenuation adjustable from 1.5 to 25 dB) as well as narrow band circuits at higher frequencies (91-93 GHz; attenuations adjustable from 2.9 to 20 dB) can be realized using PIN-diodes. For high speed switching in the subnanosecond range Schottky-Barrier-diodes can be taken (31-33 GHz; attenuation switchable from 2.5 to 25 dB).

Introduction

Two different types of diode controlled mm-wave fin-line attenuators and switches can be distinguished, broadband and narrow-band devices:

The first type, diode shunted fin-lines (fig. 1a), exhibits broadband behaviour, even octave bandwidths are within reach. Well suited for frequencies up to 75 GHz this approach makes use of the ridge-wave-guide performance of fin-line. Typical applications are broadband antenna switches, leveling devices for swept sources and broadband AM-Modulators.

The second type, narrowband devices, incorporates diode switches resonance structures on the backside of the fin-line (fig. 1b) and is used up to 100 GHz. These devices are employed as pulse forming elements for IMPATT radar transmitters, as sensitivity time controll elements for radar receivers or as narrowband modulators.

New examples of both types of devices as well as design considerations are given in this paper.

Fin-line wave impedance and diode parameters

The realisation of fin-line PIN-attenuators needs a good knowledge of the fin-line's wave impedance and the parameters of the employed beamlead diodes. Both can be achieved by measuring the small signal impedance of a single diode, shunted across the fin-line. This approach provides realistic values for the measured wave impedance, because the measurement tool and the later fin-line component are built up similarly. At a certain diode DC level the input reflection coefficient vanishes, if the imaginary part of the diode admittance is brought to zero by terminating the output of the fin-line with a varied backshort. Hence the real part of the diode admittance is equal to the inverse wave impedance Y_L:

$$Y_L = \mathrm{Re}\ (Y) \approx \frac{G}{(1-\omega^2\ LC)^2} \qquad (1)$$

with diode parameters:

- G: small signal conductance (without series resistance) (0.1 ... 200 mS)
- L: series inductance (0.1-0.2 nH)
- C: junction capacitance (10 ... 100 fF)

While the small signal conductance G = G (I) is determined by the DC-characteristic of the diode, the junction capacitance can be measured, using a capacitance bridge. The series inductance of the diode follows from a transmission measurement in the ON-state ($G \rightarrow \infty$), delivering

$$L = Z_L \cdot \frac{|S_{21}|}{2\omega} \qquad (2)$$

(valid for small series resistances)

$|S_{21}|$ is the amount of the transmission factor without line losses.

The described method takes into account the realistic diode environments, i.e., slot-width, influence of dielectric substrat and solder contacts. Inserting equation (2) in equation (1) the wave impedance can be calculated from equation (1) by reducing to Z_L.

As an example, fig. 2 shows measured results of fin-line wave impedance compared to theoretical data, computed exactly by Hofmann /1/. The slotwidth of the fin-line is 180 μm on 0.254 μm 5880 RT-Duroid mounted in Ka-Band (26.5-40 GHz) waveguide. The PIN-diode taken is type MA 47301.

Using this measurement method, the transmission properties at all DC levels can be calculated. Fig. 3a and b show the good agreement of measured and predicted data for one diode attenuators containing a PIN-diode and a Schottky-Barrier-diode respectively.

Broadband applications

The design and performance of PIN attenuators and switches using diode shunted fin-lines has been demonstrated /2, 3/. Full waveguide-band coverage has been achieved for the Ka-Band (26,5-40 GHz) the attenuation being adjustable from 0.6 to about 28 dB. The waveguide bandwidth however is only 50 %. Because of the TE_{20}-mode the upper frequency limit of the fin-line is nearly the same as in the surrounding waveguide itself, while the lower frequency limit is about 0.6 times the waveguide cut-off frequency, derived in /4/. To realize an octave wide PIN-attenuator, from 18-40 GHz for example, the waveguide crossection in the neighbourhood of the diodes must have the broadness of the Ka-Band (26,5-40 GHz) waveguide, while the output should mate K-Band (18-26,5 GHz). That means, in parallel to the fin-line taper, the waveguide broadness must be tapered from K- to Ka-Band dimensions. Fig. 4 gives a graph of the transmission behaviour of a three-diode attenuator, designed in the described way, operating from 18 to 40 GHz. Attenuation can be adjusted between 1.5 and 25 dB with good flatness over frequency. The diode spacing is a quarter wavelength at 35 GHz on the unilateral fin-line and was chosen according to /5/ for maximum attenuation over the entire band.

Narrow band applications

Calculations on the basis of the derived model show, that the same approach is not valid for 90 GHz applications. At present the parasitics of commercially available PIN diodes, junction capacitance, lead inductance and series resistance, prohibit high frequency operation. The insertion loss of a one diode PIN-attenuator at 90 GHz has been computed to about 7 dB. To overcome this problem of high insertion loss in the OFF-state of the switch, the PIN-diode can be placed onto a microstrip-resonator, as explained above. This design gives the opportunity to decouple the diode from the transmission line, because the microstrip-resonator/PIN-diode circuit (half wave resonator in the ON-state) has a resonance frequency above the operating range in the OFF-state. Forward biasing of the PIN-diode results in an adjustable attenuation. Fig. 5 gives a graph of the transmission behaviour of a three-diode attenuator. The operating range spans from 91 to 93 GHz; attenuation can be adjusted from 2.9 to more than 20 dB.

This described resonance technique cannot only be used for high frequency PIN-diode applications, but also for the design of high speed switches with Schottky-Barrier-diodes in the Ka-Band (26,5-40 GHz) region for example. Employing three Schottky-Barrier-diodes the following performance has been achieved (fig. 6). The attenuation can be switched from 2.5 to 25 dB, the operating range is 31 to 33 GHz. First results, achieved with a non optimized switch driver, show rise and fall times in the subnanosecond range.

Acknowledgement

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References

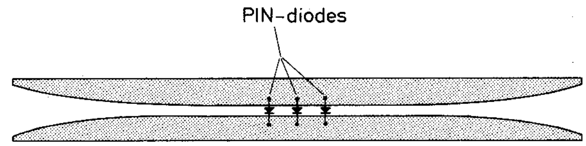
/1/ H. Hofmann: Calculation of quasi-planar lines for mm-wave applications. IEEE Symp. Digest MTT-S, 1977, San Diego, pp. 381-384.

/2/ H. Hofmann, H. Meinel and B. Adelseck: New integrated mm-wave components using fin-lines. IEEE Symp. Digest MTT-S, 1978, Ottawa, pp. 21-23.

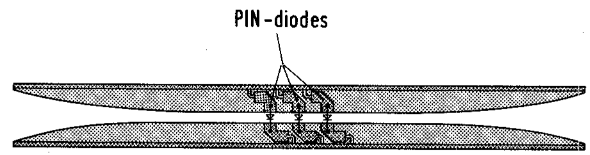
/3/ P.J. Meier: New developments with integrated fin-line and related printed millimeter circuits. IEEE Symp. Digest MTT-S, 1975, pp. 143-145.

/4/ A.M.K. Saad and K. Schünemann: Field description for multi-slot fin-line structures. 8th EuMC, 1978, Paris, Proc. pp. 101-105.

/5/ T. Glynn and L. Duter: Voltage variable attenuators: getting smaller and better. MSN June/July 1976, pp. 48F-49.



a: Diode shunted fin-line type



b: Diode switched resonance type

Fig. 1
Typical configurations of fin-line PIN-attenuators

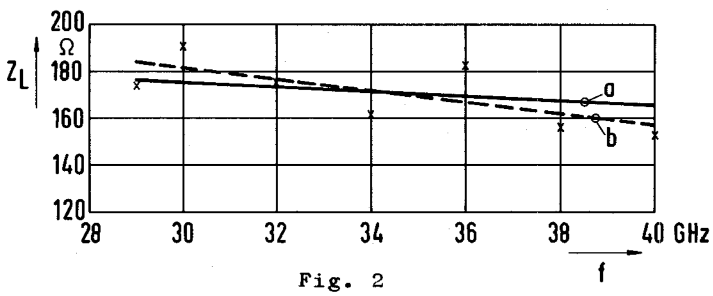
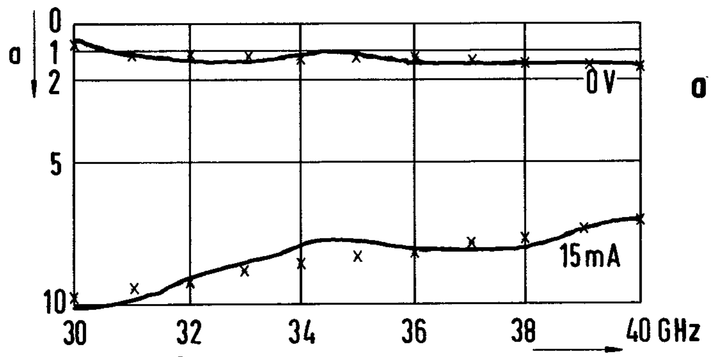


Fig. 2
Fin-line wave impedance

a: Computed by Hofmann /1/
b: Measured data (average)



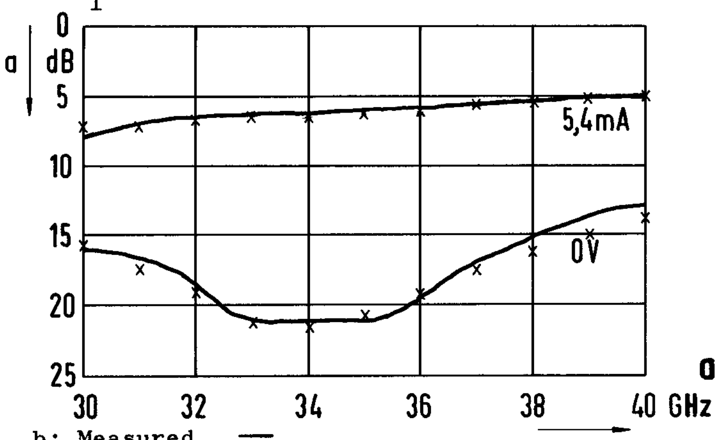
a: Measured —

PIN-diode Thomson-CSF. EH 403 01

calculated x

C_j = 17 fF

L_1 = .18 nH



b: Measured —

Schottky-Barrier-diode NEC ND 5558

calculated x

C_j = 85 fF

L_1 = .26 nH

Fig. 3

Attenuation of one-diode devices

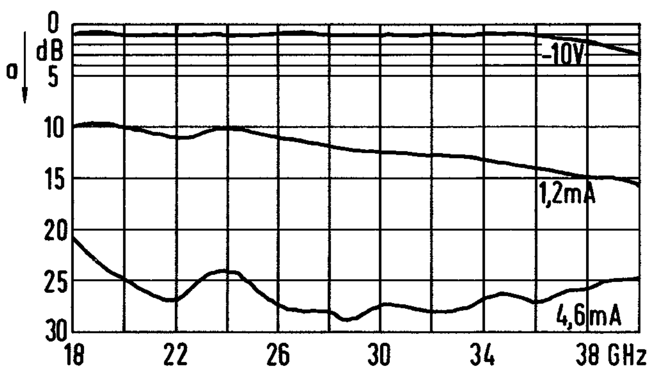


Fig. 4

Attenuation of a three-diode PIN-attenuator for octave band wide utilization

PIN-diodes: ai 6-6474-30

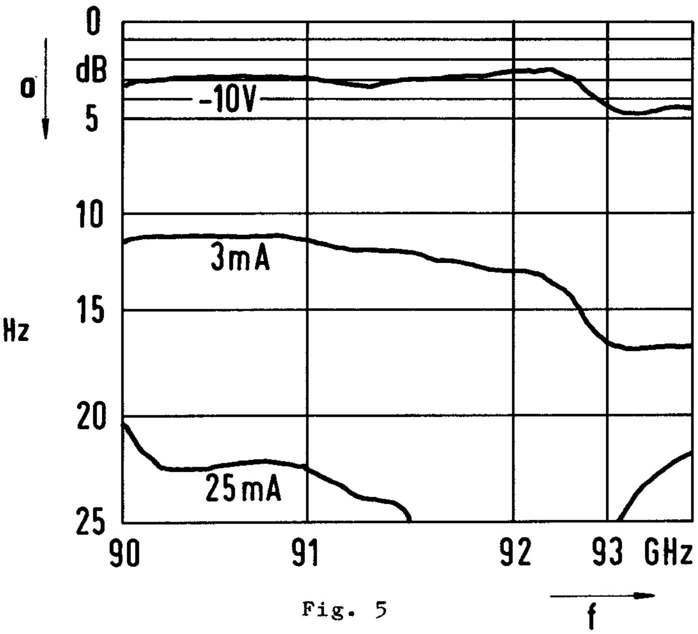


Fig. 5

Attenuation of a three-diode PIN-attenuator for narrowband utilization

PIN-diodes: MA 47 301 sp.

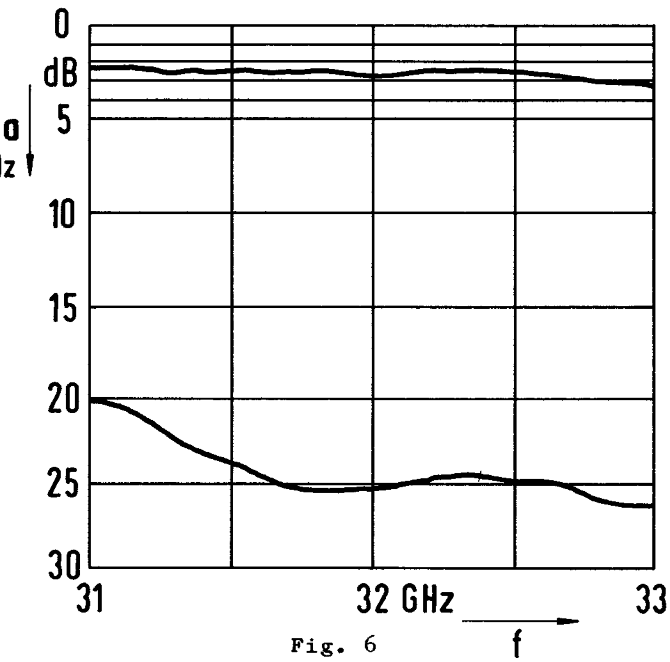


Fig. 6

Attenuation of a three-diode Schottky-Barrier-switch for high speed switching

Schottky-Barrier-diodes: NEC ND 5558