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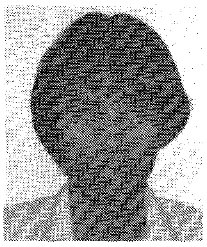

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Integrated Fin-Line Components and Subsystems at 60 and 94 GHZ

WOLFGANG MENZEL AND HEINRICH CALLSEN

Abstract —**This paper describes fin-line receiver components for the frequency ranges around 60 and 94 GHz. In detail, the design and performance of balanced mixers, p-i-n-diode attenuators, and p-i-n-diode double throw switches will be presented. Next, the integration of such components (partly together with fin-line Gunn oscillators) will be demonstrated, showing a number of advantages concerning size, weight, losses, cost, and ruggedness.**

I. Introduction

THE APPLICATION of millimeter-wave frequencies for radar, radiometry, and communication has found an increasing importance during the last years. The demand for reliable low-cost millimeter-wave components and subsystems has led to the development of planar integrated millimeter-wave circuits. One possible choice, the fin-line technique, is employed in the circuits reported in this paper.

Fin-line circuits exhibit a number of advantages such as broad bandwidth, easy implementation of semiconductors, flexible design, simple, reproducible, and cost effective production, and the possibility of integrating several components on the same substrate. On the other hand, higher losses compared with standard metal waveguides restrict the application of fin-line for high-Q filters and for high-power circuits. The latter, however, is presently of minor importance.

A great number of fin-line papers have been published, e.g., [1]–[13], dealing with the calculation of fin-line parameters and discontinuities, fin-line components, and the integration of several components into subsystems. A detailed overview and an extensive reference list concerning fin-line technique is given in [14].

This paper presents design and performance of integrated receiver front-ends at 60 and 94 GHz. In the next two sections, the individual components of these front-ends, such as mixers, p-i-n-diode attenuators, and SPDT switches will be described. Following this, the integration of these components on a single substrate will be shown, yielding a number of advantages over standard waveguide components as well as over discrete-component fin-line circuits.

II. Fin-Line p-i-n-Diode Attenuators and Switches

Fin-line p-i-n-diode devices have been built to provide electronically tunable attenuators, switches, and modulators up to 100 GHz and beyond [7]. Fig. 1 shows the basic

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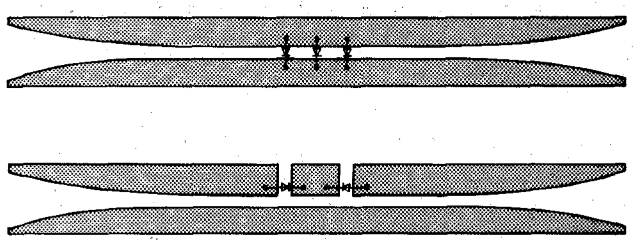

Fig. 1. Basic layout of two types of fin-line p-i-n-diode attenuators.

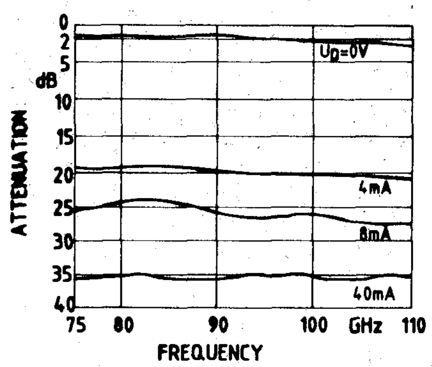

Fig. 2. Attenuation characteristics of a 94-GHz shunt-type p-i-n-diode attenuator.

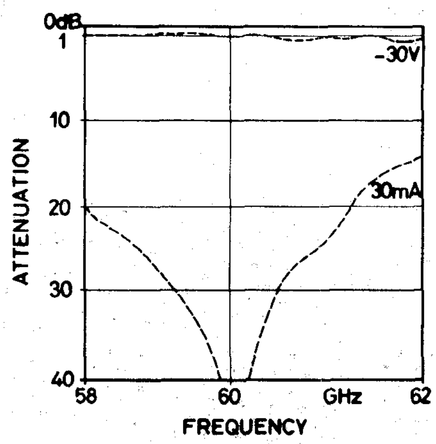

Fig. 3. Attenuation characteristics of a 60-GHz series-type p-i-n-diode attenuator.

layout of two types of p-i-n-diode attenuators. The first type contains one or more p-i-n diodes placed across the fin-line slot. Without bias, or in some cases, with reverse bias, the fin-line is loaded only with the (rather low) capacitance of the p-i-n diode, thus resulting in a very high shunt impedance compared to the characteristic impedance of the line. With forward bias, the low series resistance and the lead inductance of the p-i-n diode nearly short-circuit the fin-line.

In the second case, the p-i-n diodes are placed across series stubs in the fin-line. The series stubs are designed in such a way that, for the case of high attenuation, a parallel resonant circuit is formed by the stub and the diode parasitics. For the case of low attenuation, a rather low impedance results in series with the line. The parallel resonant circuit limits the bandwidth of the attenuator. This disadvantage, however, is compensated for by an increased dynamic range of the attenuation and by an inherent dc isolation from the residual circuit if two diodes are used (see Fig. 1(b)).

Both types of attenuators have been built up to *W*-band (75–110 GHz). Fig. 2 shows a plot of the attenuation of a 94-GHz parallel-type attenuator as a function of frequency for different bias states. As can be seen, the attenuation can be adjusted between 1.5 and 35 dB over a wide frequency range. Nearly 1 dB of the attenuation is due to the loss of the tapers from standard waveguide to fin-line.

As an example for the series-type p-i-n-diode attenuator, the results of a 60-GHz version are plotted in Fig. 3. For narrow-band applications, the attenuation can be adjusted between 1 and more than 30 dB.

Combining two p-i-n-diode attenuators in a series-type Y-junction, a single pole double throw (SPDT) switch is formed, serving as Dicke switch in radiometers or as transmit–receive switch in radar applications [10]. For 94 GHz, such a switch (shunt type) has been built exhibiting nearly the same results as those presented for the attenuator in Fig. 2.

Typical switching times of 20 to 50 ns have been measured with these components.

III. Fin-Line Balanced Mixers

The combination of fin-line and coplanar line, forming a broad-band 180° hybrid, gives the basis for a fin-line balanced mixer, as already described in [15]. In Fig. 4, the basic setup of a fin-line mixer developed at AEG–Telefunken is illustrated. The local oscillator power is fed to the diodes via a transition from an asymmetrical fin-line to a coplanar line, working in a similar way to a "probe-type" transition from standard waveguide to coaxial line. For proper operation, a short is placed a quarter wavelength away from the transition. Additionally, this short allows a final adjustment of the LO-input match. The signal path consists of a symmetrical unilateral fin-line. Schottky-barrier beam lead diodes are placed at the junction between fin-line and coplanar line, as can be seen in the magnified detail of Fig. 4. Reduced dimensions of the waveguide mount cross section in the right part (Fig. 4) of the coplanar line yield a mode filter providing the desired quasi-TEM field configuration for the LO power as well as a reactive termination for the signal path (slot mode) behind the diodes. A microstrip IF low-pass filter is connected to the coplanar line.

As can be seen from the basic layout in Fig. 4, different types of lines such as symmetrical and unsymmetrical fin-line, coplanar line, and microstrip are combined to form the mixer circuit. For the design of this circuit, a computer program based on theoretical calculations [11] is used to calculate the parameters of the different types of lines. Additionally, the characterization of the most important discontinuities, e.g., a step in the fin-line slot width, is under investigation.

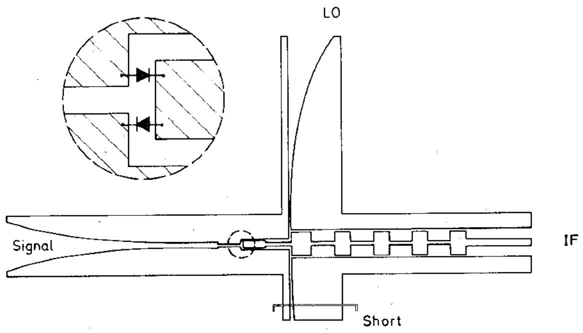

Fig. 4. Basic setup of a balanced fin-line mixer.

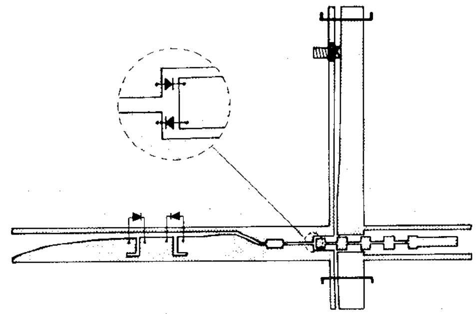

Fig. 7. Principle layout of a 60-GHz receiver front-end.

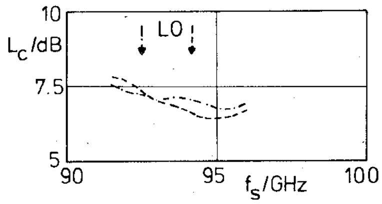

Fig. 5. Conversion loss of a 94-GHz balanced fin-line mixer.

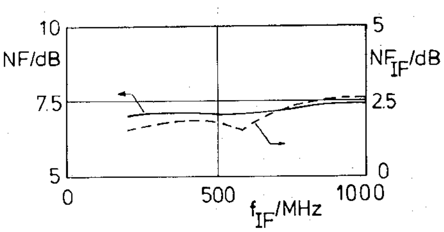

Fig. 6. DSB system noise figure (——) and IF amplifier noise figure (----) for the 94-GHz balanced mixer.

On the other hand, the diode characteristics are of great importance. A large-signal analysis according to [16] and a simplified small-signal analysis give first approximations for the diode impedances. Due to the millimeter-wave frequencies, the diode parasitics can yield a considerable reactive contribution to the impedances and an increase in the required LO power [17].

A number of fin-line balanced mixers of the type described above have been built in the frequency range from 18–100 GHz using commercially available beam-lead diodes. Good results have been obtained for narrow-band as well as for broad-band components covering a whole waveguide band [7]. Fig. 5 gives a plot of the conversion loss of a 94-GHz fin-line mixer with diodes dc 1309 (AEI) for two different LO frequencies. The circuit of this mixer is etched from a 0.5×0.5 in (1.27 cm) gold plated substrate of fused quartz of 0.11-mm thickness [9]. The conversion loss includes the dissipation loss due to the taper of 0.3 to 0.5 dB and the reflection loss of about 0.5 dB. A DSB system noise figure between 7 and 7.5 dB was measured for this mixer at IF frequencies from 200–1000 MHz including an IF amplifier noise figure of 1.6 to 2.6 dB (Fig. 6). An optimal LO power of 10 to 12 dBm was required for self-biased operation. Applying dc bias to the diodes, the mixer operates with an LO power of down to 3 dBm, showing a 1-dB higher conversion loss at this lowest LO level.

IV. Integrated Fin-Line Front-Ends

An important goal of the fin-line technique is the integration of several components on one substrate [4], [5], [8], [10]. The latest results of this work, receiver front-ends at 60 GHz and 94 GHz, will be described here.

Fig. 7 shows the layout of a 60-GHz receiver front-end, consisting of a balanced mixer with IF low-pass filter, a series-type p-i-n-diode attenuator and, optionally, a Gunn-element local oscillator. With this configuration, however, no frequency stabilization is provided for the oscillator. Alternatively, a varactor-tuned fin-line oscillator [18] could provide a frequency control by an additional PLL circuit. Without the integrated local oscillator, this front-end is employed in a 60-GHz pulse radar [19]. As LO, an external, cavity-stabilized Gunn oscillator is used. The p-i-n-diode switch serves as STC and corresponds to that described in Section II (Fig. 3). The balanced mixer was built using diodes ND 5558. (NEC). Due to the relatively high parasitics of these diodes (specified for *X*- and *Ku*-band), a narrow-band impedance match of the mixer results. Fig. 8 is a plot of the conversion loss of the front-end including the loss of the p-i-n-diode switch. A minimum conversion loss of less than 7 dB is obtained at the frequency of operation. This conversion loss doesn't differ markedly from that of a mixer as a single component, thus showing that the loss of the basic p-i-n-diode switch (without tapers) is very low. The DSB system noise figure of the receiver unit lies around 8.3 dB for an IF frequency of 200 MHz, including an IF-amplifier contribution of 1.6 dB. The split-block housing of this front-end (without LO) has outer dimensions of $20 \times 20 \times 35$ mm and a weight of approximately 100 g (brass mount). A photograph of this unit is given in Fig. 9.

For 94 GHz, a radiometer receiver has been built, integrating a fin-line balanced mixer and an SPDT switch on a single substrate (Fig. 10). At this frequency, Gunn oscillators exhibit a harmonic mode of operation [20] and, at the moment, provide severe difficulties integrating them into a planar design. In addition to the radiometer application, this front-end can be used in a radar module with

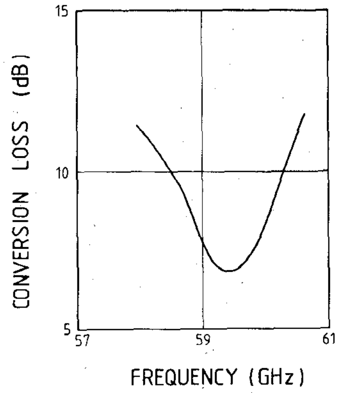

Fig. 8. Conversion loss of the 60-GHz front-end.

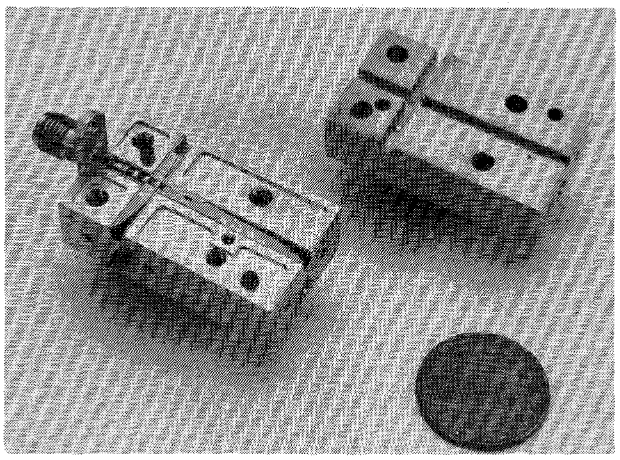

Fig. 9. Photograph of the 60-GHz front-end.

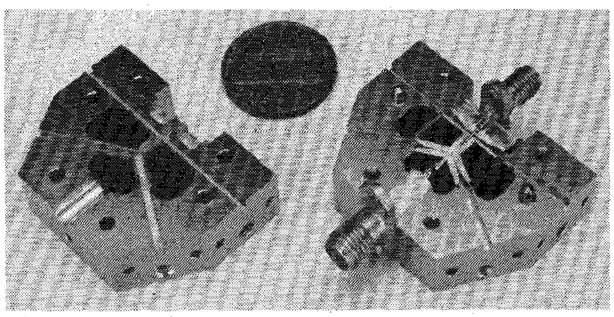

Fig. 10. Photograph of the 94-GHz front-end.

polarization diversity by switching between the two polarization channels.

In Fig. 10, the two signal ports and two further waveguide connections, one for the LO, the other one will be terminated with a short circuit (see Fig. 4), can be clearly recognized. The mixer circuit is identical to that described previously. The SPDT switch contains two shunt-mounted p-i-n diodes in each of the input arms. An extremely short connection between SPDT switch and mixer reduces the line loss. Fig. 11 displays the conversion loss of the complete receiver front-end. Compared to the results of the mixer of Fig. 5, the loss has only increased by 0.8 dB, while

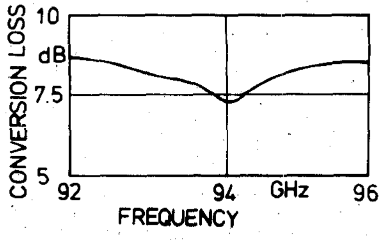

Fig. 11. Conversion loss of the 94-GHz radiometer front-end (including p-i-n-diode switch).

the p-i-n switch as a single component exhibits a loss of at least 1.5 dB. This difference is a consequence of the integration, for taper loss and line loss can be reduced significantly.

V. Conclusion

Design and performance of single fin-line components as well as integrated fin-line circuits have been presented. The achieved results prove the feasibility of this technique up to 100 GHz; it is believed, however, that the operation frequency can be shifted at least up to 140 GHz.

In addition to the previously discussed advantages of fin-line, a few remarks should be made concerning the integration. The integration of several components on one substrate leads to very compact circuits. Their weight can be reduced further by taking away excess metal parts of the waveguide mount or using aluminum or metallized plastic mounts. Losses are reduced by a close assembly of the circuit elements; tapers from metal waveguide to fin-line are no longer necessary except those to external waveguide ports. Costs can be reduced as the complete circuit requires only one substrate, and assembling of single components is no longer necessary. Finally, the compact setup leads to very rugged units. For example, a fin-line balanced mixer on a quartz substrate has withstood an acceleration test of 30000 g for 2 ms without performance degradation.

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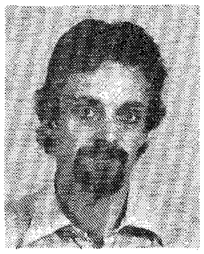

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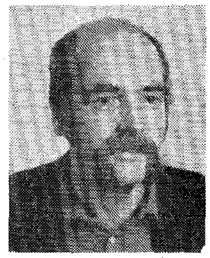

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V-Band Low-Noise Integrated Circuit Receiver

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***Abstract* —A compact low-noise *V*-band integrated circuit receiver has been developed for space communication systems. The receiver accepts an RF input of 60–63 GHz and generates an IF output of 3–6 GHz. A Gunn oscillator at 57 GHz is phaselocked to a low-frequency reference source to achieve high stability and low FM noise. The receiver has an overall single sideband noise figure of less than 10.5 dB and an RF to IF gain of 40 dB over a 3-GHz RF bandwidth. All RF circuits are fabricated in integrated circuits on a Duroid substrate.**

I. Introduction

THE RAPID ACCELERATION of millimeter-wave activities has led to a strong demand for low-noise integrated circuit receivers for both civil and military applications. These include communications, instrumentation, radiometry, radars, missile seekers, and electronic warfare. Conventional millimeter-wave receiver technology is well established based on waveguide components. Integrated circuit technology, on the other hand, has been trailing waveguide technology because of the absence of good beam-lead diodes, the difficulty in achieving low-loss and wide bandwidth, and the radiation loss involved in mounting active devices in integrated circuit media. Resolving these problems is important because integrated circuit receivers provide significant advantages.

a) Beam-lead mixer diodes eliminate the need for mechanical contacts; they are mechanically rugged and able to withstand high vibration and shock.

b) Planar circuits can be precisely controlled through high resolution processing techniques to achieve a high degree of reproducibility.

c) When a design is established, the complicated circuit can be fabricated at low cost through the use of photolithographic methods.

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