ACTIVE INTEGRATED DEVICES ON DIELECTRIC SUBSTRATES FOR MILLIMETER-WAVE APPLICATIONS

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ABSTRACT

Step-by-step evolution of active integrated devices on a dielectric substrate from conventional metal waveguide design is described. Designs of oscillators, mixers and receivers are presented, and their measured performance characteristics are reported.

Introduction

The dielectric waveguide is emerging[1-3] as a promising transmission medium at millimeter wavelengths because of several advantageous features that make it attractive at frequencies above 30 GHz. In designing communication systems (e.g., receivers, using dielectric waveguides) a total integration of the transmission medium with the active and passive components is highly desirable. However, to date, the active devices such as oscillators and mixers have largely been built only with conventional metal cavities. Since this form of design evidently requires several transition sections between the metal and dielectric waveguides, it is obviously desirable to look for alternative approaches that have the potential for total integration using dielectric waveguides and components alone. In this paper, we describe the evolution of such a system from a part-metal part-dielectric system to one which is essentially entirely dielectric. In the following paragraphs, we describe the various states of development of an oscillator, a mixer, and finally, a prototype receiver built by combining the mixer and the oscillator on a single dielectric substrate.

Impatt Oscillator

The designs for the dielectric oscillator presented herein represent a departure from their metal-waveguide counterparts. In the present design we attempt to remove as much of the metal structure from the cavity as possible, and replace it with the dielectric waveguide instead.

The first generation of the oscillator design, shown in Fig. 1, retained only a small metal waveguide section around the Impatt diode. The diode was stud-mounted on a copper ground plane such that only the actual diode protruded over the metal plane. The copper plane served both as a heat sink and a ground for the dc biasing circuit. A planar dielectric waveguide of rectangular cross-section was now placed over the ground plane after drilling a small hole through the dielectric guide. An RF filter section of cylindrical-type design, comprising $\lambda/4$ sections, was connected to the top of the diode through the cylindrical hole in the dielectric guide. A spring-loaded circular hat at the end of the filter section was used to provide a proper electrical contact for the diode. The oscillator was tunable with a movable short placed at one end of the dielectric guide, and the power was extracted from the other end. Control of output power and frequency was achieved by varying the movable short position or the dc bias. The later version of the oscillator in a dielectric guide eliminated the elaborate filter arrangement as well as much of the metal waveguide section near the diode (see Fig. 2). In addition, a very simple and yet effective biasing arrangement was used with only a rectangular metal plate and a cylindrical pin. The plate was attached to the top of the dielectric and was joined to the bias-pin, which in turn pressure-contacted the diode. Once again, a movable short was employed to vary the output power and frequency. The size of the rectangular plate had a direct effect on the frequency of operation of the oscillator.

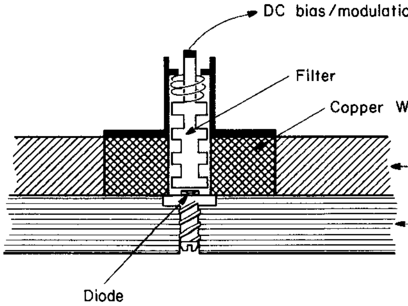

Figure 1: Dielectric waveguide type Impatt oscillator with cylindrical filter.

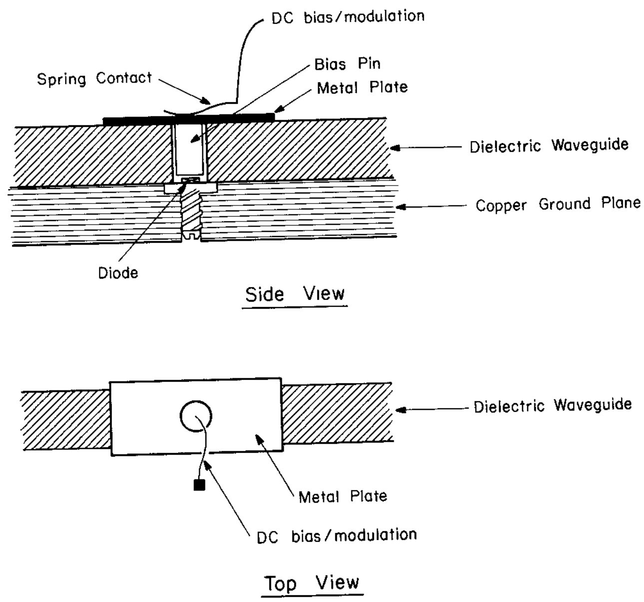

Figure 2 : Fully integrated dielectric waveguide type Impatt oscillator.

Mixer

Our objective was to build a mixer on a dielectric substrate which would be compatible with the oscillator from a structural point of view. However, the beam-lead diodes used for the mixer circuit are more suitable for microstrip or stripline-type designs, and posed some mounting problems in the dielectric waveguide environment. After considerable experimentation, a mounting scheme - shown in Fig. 3 - was developed.

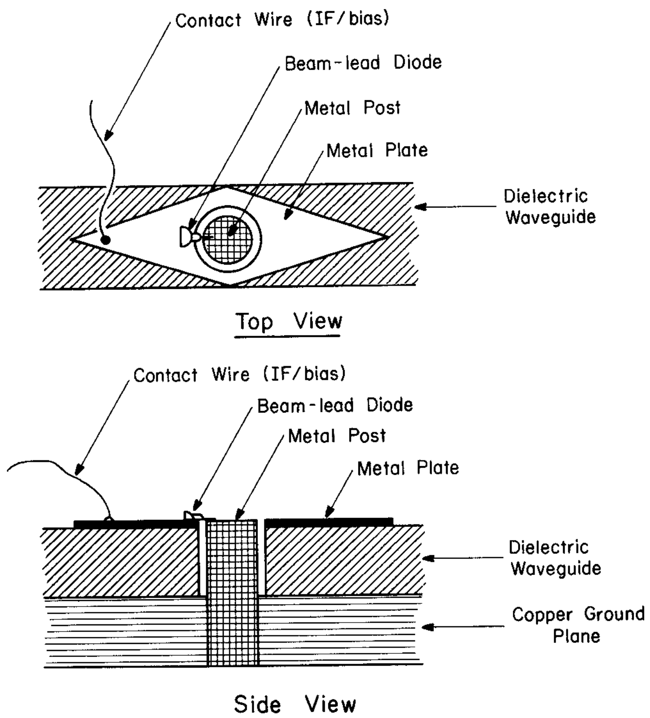

Figure 3: Dielectric waveguide based mixer using beam-lead diode.

A metal post attached to the ground plane passed through a hole drilled in the dielectric waveguide. Next, a diamond-shaped metal plane was deposited around the post on the top surface of the dielectric such that the metal post was electrically isolated from it. A GaAs beam-lead diode was now mounted into the small air gap between the cylindrical post and the metal plate. The metal plate also served as a common terminal for the IF amplifier and the diode bias. Mechanical tuning was provided once again by a movable short at the end of the dielectric guide.

Receiver and Doppler Radar

As a prototype design for a receiver, we have fabricated a local oscillator and a mixer on a common dielectric guide and ground plane (see Fig. 4). A coupler arrangement for the RF signal was incorporated as shown. The tuning of the local oscillator was achieved by varying either the dc bias or the movable short position. The mixer output was fed into an IF amplifier and subsequently into the IF detector or spectrum analyzer. A dielectric Impatt oscillator, which was coupled directly into a dielectric rod antenna, was employed as the transmitter. The Impatt diode was electronically modulated by varying its bias current.

A doppler-shift radar was constructed using the transmitter-receiver design described above. A schematic of this radar is shown in Fig. 5.

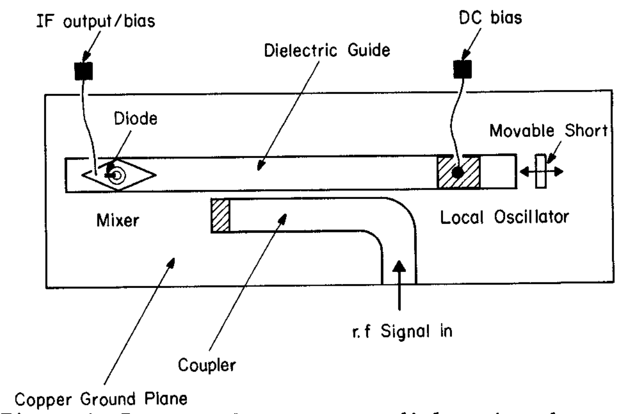

Figure 4: Integrated receiver on dielectric substrate.

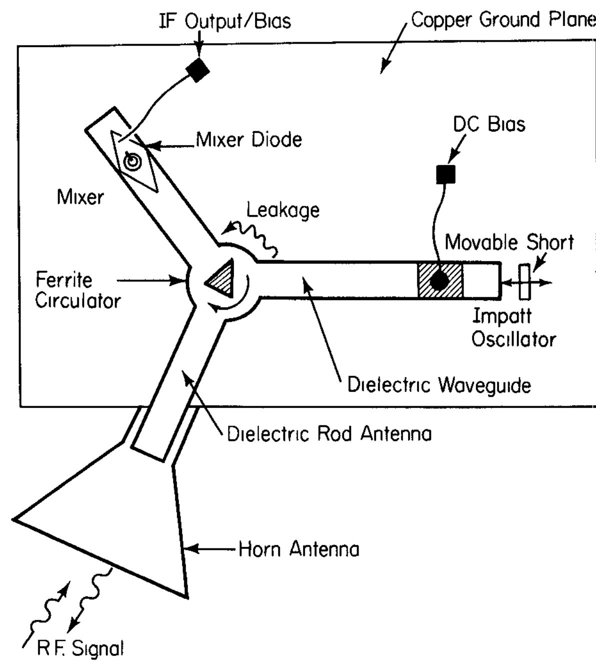

Figure 5: Homodyne dielectric integrated Doppler Radar.

Performance Characteristics

These devices have been experimentally tested and found to exhibit satisfactory performance. In particular, the receiver module has been successfully tested for a transmitter frequency of 29.6 GHz and a tuning range of 10 to 500 MHz. Similar systems have also been constructed at the frequencies of 59 GHz and 80 GHz. The following performance characteristics of the above devices have been measured: (i) output power; (ii) frequency of operation; and (iii) tunability.

References

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2. M.M. Chrepta and H. Jacobs, "Millimeter-Wave Integrated Circuits," Microwave J., vol. 17, Nov. 1974.
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AN 88-100 GHz RECEIVER FRONT-END

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ABSTRACT

A millimeter wave receiver front-end is described which downconverts frequencies from 88-100 GHz. The downconverter used a wideband MIC balanced mixer and a three diode sequentially switch local oscillator to provide a 4-8 GHz IF.

Introduction

A compact millimeter wave downconverter covering 88-100 GHz has been built which occupies a volume less than 1.5 cubic inches. The front-end sequentially downconverts three 4 GHz bands between 88 and 100 GHz to a 4-8 GHz IF.

The downconverter consists of two basic elements; a wide band MIC balanced mixer and a three diode local oscillator. A block diagram of the front-end is shown in figure 1. The local oscillator frequency is selected by applying DC bias to one of the three Gunn diodes. A photograph of the complete front-end is shown in figure 2.

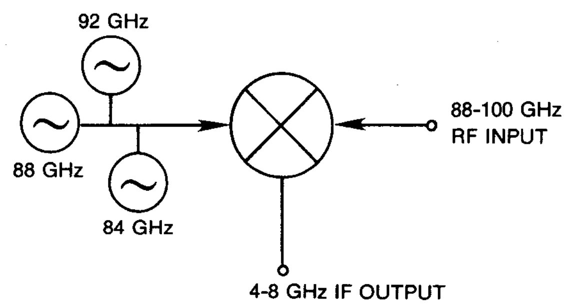

Figure 1. Downconverter block diagram.

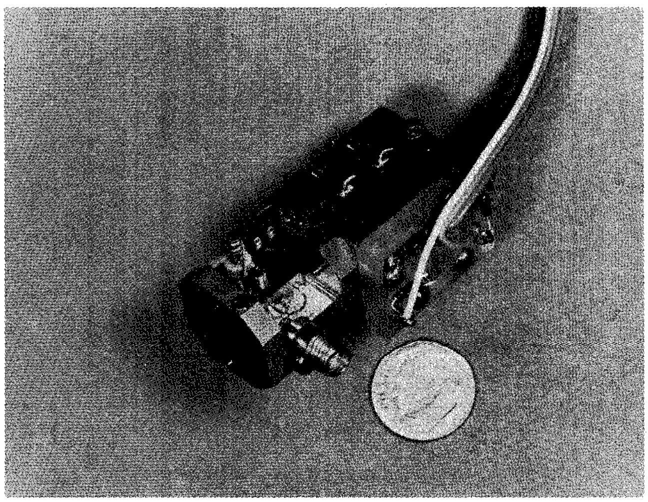

Figure 2. Photograph of complete front-end assembly.

Mixer Circuit

The wideband balanced mixer uses a microstrip rat-race hybrid on a .005 inch thick Duroid substrate. Circuit layout is shown in figure 3. The rat-race hybrid is probe coupled to the RF and LO waveguide ports, and is modified by the addition of a fifth port to extract the IF signal. A single section parallel coupled filter on the LO line eliminates the reactance of this line at the IF frequency.

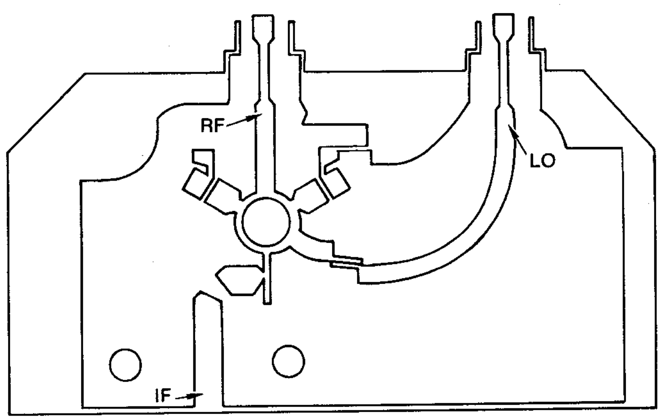

Figure 3. Microstrip mixer substrate layout.

The mixer uses Alpha Industries DMK 6606 Gallium Arsenide beam lead diodes which are biased for minimum conversion loss (approximately 1.8 mA). The diodes are bonded to the substrate with conductive epoxy. Quarter wavelength open stubs provide an RF ground for each of the diodes, and two chip capacitors provide IF grounds.

The IF signals from the two diodes are summed by the hybrid ring and extracted through a symmetrically placed fifth port on the ring. An open stub RF filter on the IF line minimizes the effect of the IF line on the mixer at the RF and LO frequencies. Return loss of the mixer RF port is 7 db minimum, and averages 10 db from 80-100 GHz. IF port VSWR is less than 2.5 from 4 to 8 GHz.

The mixer conversion loss is approximately 12-14 db from 88-100 GHz, as shown in figure 4.

Hewlett Packard 5082-2264 silicon diodes were also used on the same substrate with conversion loss results 1 to 2 db higher.

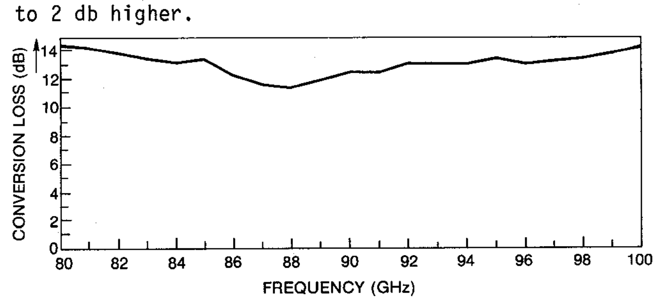

Figure 4. Mixer Conversion loss.

Local Oscillator Circuit

The local oscillator circuit consists of three Gunn diode oscillators shunt mounted along a waveguide manifold. The individual oscillator circuits are radial resonators as described by Ruttan[1] and Groves[2]. Each radial resonator consists of a post and disk structure in a full height waveguide. The disk is part of the bias post structure and rests directly on the diode. Frequency of oscillation is determined by the diameter of the disk. Fine tuning of frequency is accomplished by placing small bits of mylar tape on the diode side of the disk. In circuits where space allows, adjustable tuning can be achieved by placing a moveable dielectric rod near the edge of the disk. A waveguide short circuit is fixed in place about one half guide wavelength behind the diode plane. The position of the waveguide short has little effect on frequency, and is adjusted for maximum power output. Drawings of the resonant structure and multiple oscillator layout are shown in figures 5 and 6 respectively. The size of the complete LO assembly is 1 X 1 X .75 inches.

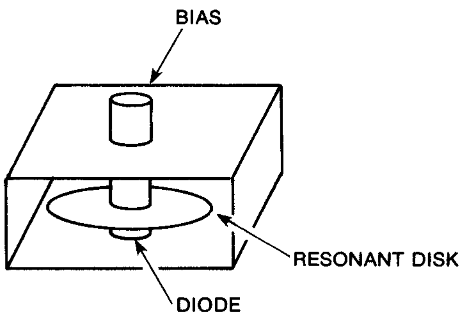

Figure 5. Oscillator resonant structure.

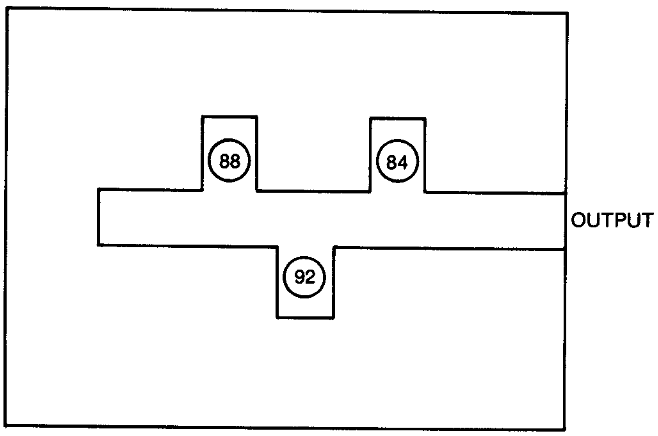

Figure 6. Multiple oscillator layout.

Gunn diodes from several manufactures were used, and were specified for operation at frequencies from 44 to 60 GHz. Useable power was obtained in the 80-100 GHz region for almost all of the diodes tried, indicating that diode selection is not critical. In most cases the bias voltage required for operation was much higher than that required for operation at the lower design frequency of the diodes.

No attempt was made to temperature compensate the frequency of the oscillator. When first turned on, the frequency of oscillation decreases about 15 MHz in the first 500 milliseconds.

With no DC power applied, each oscillator appears almost as a short circuit in the diode plane. The diodes are placed three quarters of a wavelength from the waveguide manifold, and appear as shunt open circuits at the waveguide junction. Each shunt oscillator is placed an odd number of quarter wavelengths from the shorted end of the waveguide manifold. Since the diodes are not perfect short circuits there is some loss associated with each shunt mounted oscillator along the waveguide manifold, thus limiting the total number of oscillators which can be connected in this manner. The power output of the 84 GHz oscillator dropped from +10 dbm to +8.3 dbm when the 88 and 92 GHz oscillators were added to the mount. Power output of the triple oscillator at 84, 88 and 92 GHz was +8.3 dbm, +6.7 dbm and +6.1 dbm respectively. It is believed that as many as five or more oscillators could be connected to one mixer using this technique.

Performance

Noise figure measurements of the front-end were made using a 5 db NF 4-8 GHz IF amplifier. 19.4 db SSB noise figure was measured using the Y factor method. This result is consistant with the conversion loss measurements and the amplifier noise figure.

Conclusion

An extremely compact wide band receiver front-end has been demonstrated which downconverts signals between 88 and 100 GHz. With the addition of two more oscillators, this technique would allow receiver coverage from 80 to 100 GHz with only a small increase in size. The switched local oscillator approach provides a wide band channelized downconverter without the losses usually incurred through the use of input multiplexers or power splitters.

References

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