Millimeter-Wave Transmitter and Receiver Using the Nonradiative Dielectric Waveguide

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Abstract

Transmitter and receiver front ends have been fabricated in an integrated manner at 35 GHz based on the nonradiative dielectric waveguide (NRD-guide). Structures and characteristics of various key components are described. Transmission testing over a ten month period using the fabricated front ends has proved that the NRD-guide integrated circuits are reliable in performance, moderate in size and hence promising at millimeter-wavelengths.

I. Introduction

The nonradiative dielectric waveguide (NRD-guide) is a novel type of dielectric waveguide which is built in the below-cutoff parallel plate waveguide to suppress unwanted radiation at curved sections and discontinuities of circuits without spoiling the inherent low loss nature of the dielectric material[1]. Therefore, practical millimeter-wave integrated circuits can be constructed by using the NRD-guide. The NRD-guide integrated circuits are expected to be superior in performance to printed line circuits and more compact in sizes compared with metal waveguide circuits. With such expectations in mind, a transmitter and a receiver have been fabricated at 35 GHz by integrating various NRD-guide circuit components such as a Gunn oscillator, a circulator, a pin diode pulse modulator and a balanced mixer. The transmitter and receiver to be described here are the first practical dielectric waveguide integrated circuits which have ever been constructed.

II. NRD-Guide Circuit Components

A. Transmission Medium

The basic structure of the NRD-guide is shown in Fig. 1. Teflon(ε_r=2.04, tan =1.0x10^{-4}) is the best material for the dielectric strip because of its low loss nature at millimeter-wavelengths and its chemical stability under severe conditions.

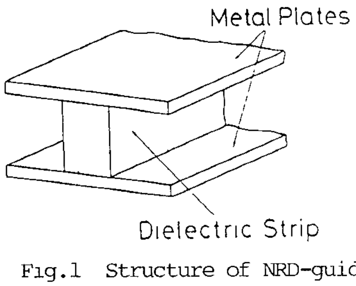

Fig.1 Structure of NRD-guide

Since the center frequency is 35 GHz, a plate separation of 4 mm, less than half a wavelength, is chosen. The dielectric strip is 4 mm in height as well and 3.5 mm in width. The operation bandwidth of this NRD-guide ranges from 32 GHz to 37.5 GHz, and calculated transmission loss is 2.25 dB/m, which includes a conduction loss of 1.55 dB/m and a dielectric loss of 0.70 dB/m[2].

B. Mode Suppressor

The operating mode in the NRD-guide is the so-called LSM_{01} mode, but the LSE_{01} mode is also nonradiative and has a lower cutoff frequency than the operating LSM_{01} mode. Therefore, the LSE_{01} mode is often generated at curved sections and discontinuities of circuits, and the performance of the NRD-guide severely deteriorates once such a mode is generated. In order to eliminate this parasitic mode, a mode suppressor has been devised. The mode suppressor, shown in Fig. 2, is a metal patch etched on a thin teflon substrate and is inserted in the vertical midplane (H-plane) of the NRD-guide. A $\lambda/4$ choke structure is needed to suppress the TEM mode which might be generated otherwise. The mode suppressor is a key component in the NRD-guide integrated circuit. The Gunn oscillator and circulator could never be realized without the mode suppressor.

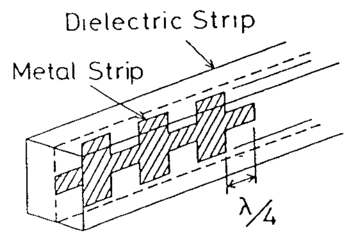

Fig.2 NRD-guide mode suppressor

C. Matched Load

The matched load can be fabricated by inserting a thin NiCr film, 20 mm in length including a

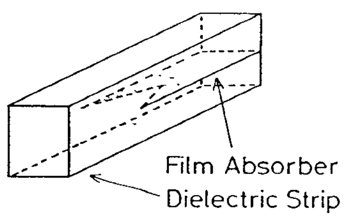

Fig.3 NRD-guide matched load

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taper, in the horizontal midplane (E-plane) of the NRD-guide as shown in Fig. 3. Previously, sheets of NiCr film were attached on the free surfaces of the dielectric strip[3], but in such an arrangement, the sheets often came off and the reliability of the matched load was spoiled. The matched load shown in Fig. 3 is rigid mechanically and excellent in performance. The VSWR is less than 1.1 over the frequency range from 34 GHz to higher than 36 GHz.

D. Coupler

A 3-dB coupler is essential for constructing a balanced mixer. A pair of bends, 30 mm in curvature radius, are put side by side with spacing of 2.6 mm so as to achieve 3-dB coupling at 35 GHz. The coupling characteristics of this coupler can be calculated theoretically[4] and are shown in Fig. 4. The coupling property is by no means satisfactory, especially in the lower half of the frequency range, but this is not a problem if the LO frequency is set around 35 GHz and the RF frequency is chosen to be higher than the LO frequency.

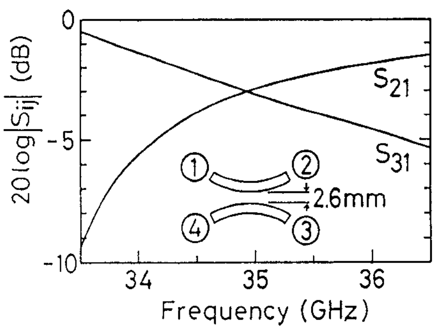

Fig.4 Calculated coupling characteristics of NRD-guide coupler

E. Circulator

The circulator is required to protect the Gunn oscillator from interruption by reflected waves. A pair of ferrite disk resonators are located in contact with the top and bottom metal plates, since the magnetic field in the NRD-guide is maximum there. Such an NRD-guide circulator has already been developed at 50 GHz[5]. Another circulator has been newly designed and fabricated at 35 GHz

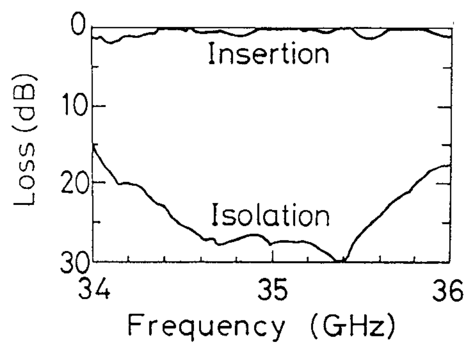

Fig.5 Measured characteristics of NRD-guide circulator

for the present purpose. Measured characteristics of the circulator are shown in Fig. 5. Bandwidth of the 20-dB isolation is about 1.7 GHz and insertion loss over this frequency range is less than 0.5 dB though small ripples appear.

F. Gunn Oscillator

A Gunn diode has to be so installed in the NRD-guide that the electric field of the oscillator output is parallel to the metal plates. The structure of the Gunn oscillator is shown in Fig. 6. The diode is fixed in the metal block on which the microstrip line having a $\lambda/4$ choke circuit is attached to supply the bias voltage to the diode. The output power of the oscillator is led to the NRD-guide through a strip line resonator which is etched on a teflon substrate and attached by adhesive to the truncated end of the dielectric strip. The mode suppressor is also provided at the same end to prevent the generation of the parasitic LSE_{01} mode. The power and frequency of the oscillator depend on the length of the strip resonator as shown in Fig. 7. It should be noted

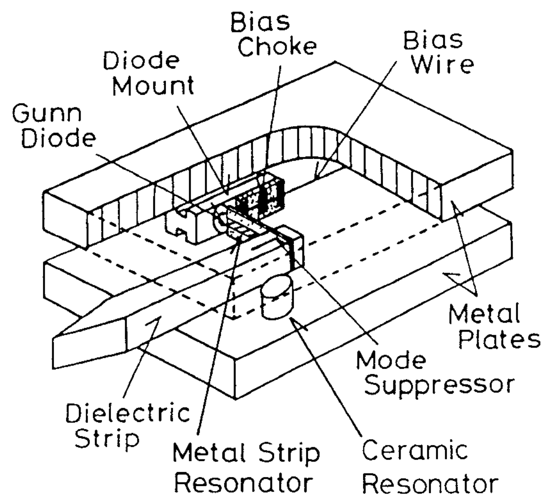

Fig.6 Structure of NRD-guide Gunn oscillator

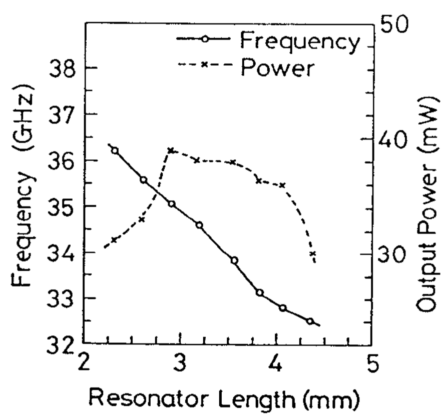

Fig.7 Characteristics of NRD-guide Gunn oscillator as a function of strip resonator length

that the maximum output power of the NRD-guide oscillator is 38 mW at 35 GHz and this value is not much different from the catalogue datum (Alpha), 46 mW, measured in the metal waveguide. In order to stabilize the performance, a ceramic resonator having a very small temperature coefficient is located in the proximity of the dielectric strip as shown in Fig. 6. Though the output power is reduced to 10 mW owing to the locking, a remarkable frequency stability can be achieved.

G. Mixer and Pulse Modulator

Beam lead diodes are suitable for use in the NRD-guide integrated circuits. As shown in Fig. 8, a patch antenna having a $\lambda/4$ choke circuit to suppress RF leakage is etched on a thin teflon substrate and a beam lead diode is bonded across the gap in the antenna. Then, the antenna is attached to the transverse plane of the dielectric strip. Though simple in structure, this method of fixing a beam lead diode is quite practical since the mount is compact in size and mechanically rigid. In order to achieve a good matching between the NRD-guide and the diode, a high ε_r sheet is inserted in front of the diode, and an air gap, if necessary, is provided at a suitable position on the dielectric strip. A pair of Si mixer diodes are set in the 3-dB coupler to create a balanced mixer. The measured conversion loss of this mixer is 6.8 dB in average over the IF bandwidth of 1 GHz as presented in Fig. 9. If GaAs beam lead diodes are employed, the conversion loss will be further improved.

A pin diode pulse modulator can also be fabricated by using the same technique. Transmission characteristics of the modulator are shown in Fig. 10. An ON/OFF ratio higher than 20 dB can be obtained, but the insertion loss at the ON state should be further reduced.

III. Transmitter and Receiver

Transmitter and receiver front ends have been constructed by integrating the NRD-guide circuit components described above. The transmitter consists of a stabilized Gunn oscillator with an output power of 10 mW, a circulator with one port terminated, a pulse modulator and a rod antenna. On the other hand, the receiver front end consists of a stabilized Gunn oscillator with an output power of 10 mW, a circulator with one port terminated, a 3-dB coupler, a balanced mixer and a rod antenna. Since frequencies of the transmitter and receiver are set at 35.145 GHz and 34.980 GHz, respectively, the IF frequency is 165 MHz. Frequency variations of the transmitter and receiver due to a temperature rise from 30°C to 60°C are 3.0 MHz and 3.2 MHz, respectively, while frequency variations of the Gunn oscillators themselves are around 1.9 MHz for the same temperature rise. Dimensions of the transmitter are 68 mm x 66 mm, while those of the receiver are 85 mm x 75 mm. Photographs of the transmitter and receiver with their top plates removed are shown in Fig. 11(a) and (b).

In order to check performances of these front ends, transmission testing has been carried out by using audio signals in the PCM scheme. Though the received pulse wave form shown in Fig. 11(c) was taken over a limited distance of 30 m, a similar clear wave form could be observed over a much longer distance of propagation. The test has already been continued for over 10 months, and no serious trouble has occurred. This confirms that the fabricated NRD-guide front ends are quite

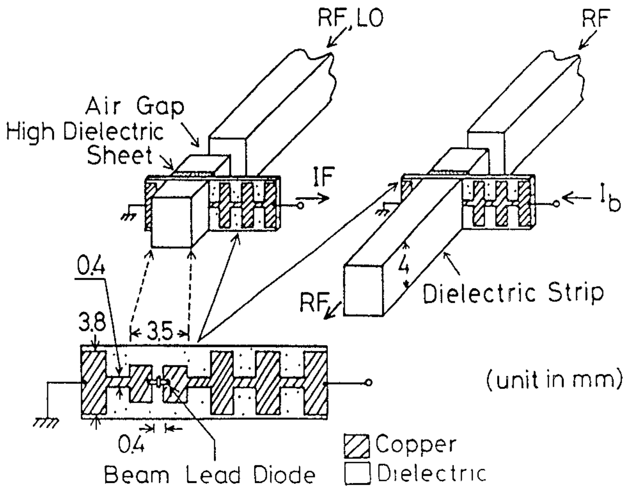

Fig.8 Structures of NRD-guide mixer (left) and NRD-guide pin modulator (right)

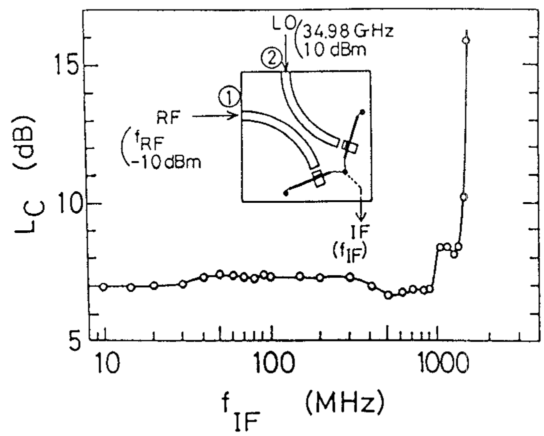

Fig.9 Conversion loss of NRD-guide balanced mixer

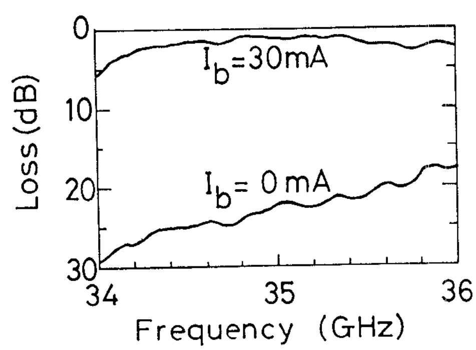

Fig.10 ON/OFF characteristics of NRD-guide pin modulator

reliable and practical at this stage of development.

IV. Conclusions

By using the NRD-guide which possesses the ability to suppress parasitic radiation, transmitter and receiver front ends have been constructed in an integrated manner at 35 GHz. Transmission testing has been carried out successfully and the performance has been proved to be quite practical. The NRD-guide technique can also be applied to other millimeter-wave systems such as radars and radio meters.

Acknowledgment

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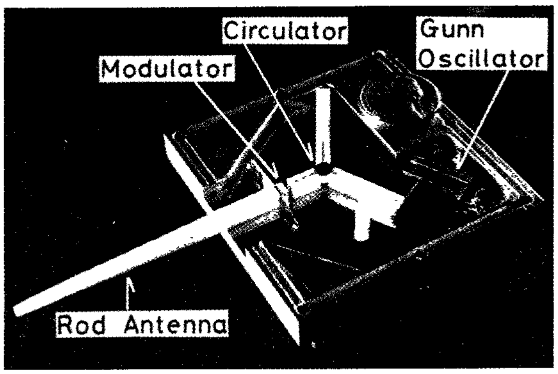

Fig.11(a) Millimeter-wave NRD-guide transmitter front end

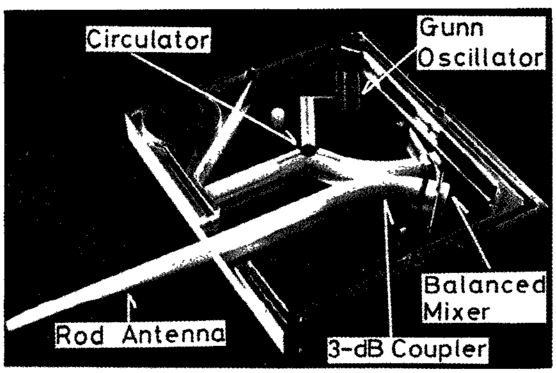

Fig.11(b) Millimeter-wave NRD-guide receiver front end

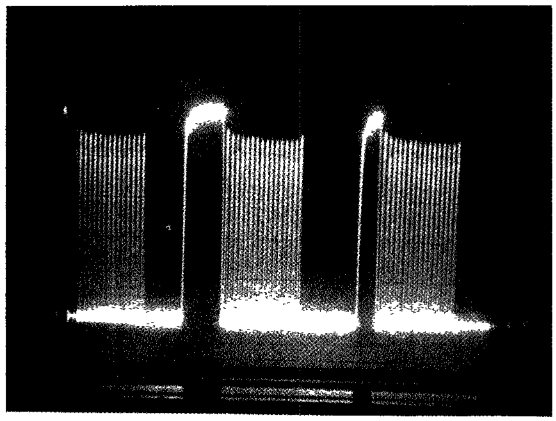

Fig.11(c) Received PCM waveform