Development of 60GHz Millimeter-wave Transmitter using NRD Guide

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ABSTRACT

Allow me to introduce the development of an FM transmitter. The transmitter uses millimeter waves at the frequency of 60 GHz, and it can produce as much as 20 mW power with the band width of 1 GHz. The great feature of the FM transmitter is that it has been created by the special technique of utilizing the NRD (non radiative dielectric) waveguide. The advantage of adopting the NRD waveguide is that it can significantly reduce transmission loss. We can construct a small-size NRD guide transmitter in a simple way that has superb transmission performance.

The NRD guide transmitter is very useful for CATV transmission or transmission over a wide range. In addition, the transmitter has almost the same band width as optical communication, and the data transmission speed of the transmitter is faster than that of optical communication. A transmitter with these merits would be highly appreciated as a way of ultra-highspeed communication network over short distances.

I. Introduction

In the age of multimedia, the content of information delivery has changed from text to text and graphics, and now it is changing to also include moving images. Moreover, the technique of utilizing moving images is now being improved to provide high resolution and delicate color. As a result, computer communication has undertaken the heavy burden of multimedia information delivery, and it looks like this trend will continue. As one way to overcome this problem, computer communication is being upgraded from T1 level to T3 level. However, this upgrade has some shortcomings ; for example, it is a costly mode of communication because, the cost of optical fiber construction is enormous. Furthermore, sometimes the construction itself gets to be difficult in places where a building has already been built. As a result, we are facing the need to improve our technology of radio communication. This field requires urgent growth to keep pace with advancements in mobile communications.

This paper discusses the development of an ultra high-speed radio transmitter that can offer an alternative to fiber optic construction, but also corresponds to the demand for ultra-high speed communication equipment with mobility. In order to increase the capacity of data transmission, we have to raise the carrier frequency. Raising the carrier frequency, however, causes a wavelength to become shorter. One important problem with this is transmission loss. We might think the MMIC method controls more than the microwave frequency band. At the frequency of 60 GHz, however, this method shows the transmission loss of 60 dB per meter[1]. The new method using the NRD waveguide has a considerably lower transmission loss, only 3 dB per meter[2], so it may be much easier to invent a millimeter wave circuit.

II. The NRD Guide

As we know, transmitting millimeter waves

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논문번호 : 99218-0603, 접수일자 : 1999년 6월 3일

through an aluminized micro-stripline brings more than 60 dB of transmission loss per meter[2]. Adopting a dielectric waveguide offers the capability of reducing this loss by a great deal. However, constructing a circuit with a dielectric waveguide could be problematic because, undesirable transmission waves tend to leak out of the dielectric waveguide. In order to solve this problem, Prof. Yoneyama of Tohoku University in Japan invented a new approach called the NRD waveguide technology[2,3]. The NRD waveguide prevents prevent transmission waves from leaking out of the waveguide, even before reaching their destination[4]. This is achieved by inserting the NRD waveguide between two parallel metal plates as in Fig. 1. The two metal plates help prevent waves, which flow through the guide, from leaking. It has been found experimentally that in the case of a curved waveguide, waves cannot escape. When transmission waves flow along the NRD guide, LSM and LSE modes are generated, as in fig. 2, rather than the TE or TM waveguide modes. For the FM transmitter, we use LSM 01 mode which is the lowest of LSM mode.

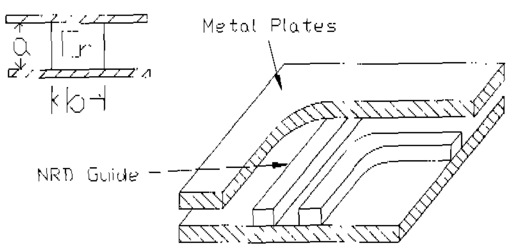

Fig. 1 Structure of the NRD guide

The equations below are needed to fabricate an NRD guide[3].

$$a/\lambda \fallingdotseq 0.45 \qquad \text{Eq. 1}$$

$$\sqrt{\varepsilon_r - 1}\, b/\lambda \fallingdotseq 0.4 \sim 0.6 \qquad \text{Eq. 2}$$

where ε_r is the dielectric constant and λ is the wavelength.

In this case, the waveguide is made of PTFE (Poly Tetra Fluoro Ethlene) which has the dielectric constant of 2.04. Since the frequency of the FM transmitter is 60 GHz, solving for a and b, we have,

$$a = 2.25 \text{ mm}$$
$$b = 2.5 \text{ mm}$$

Consequently, we insert a PTFE block with the thickness of 2.25 x 2.5 mm between metal plates. The PTFE block just serves as a waveguide, and it is also composed of a circuit of oscillation and modulation.

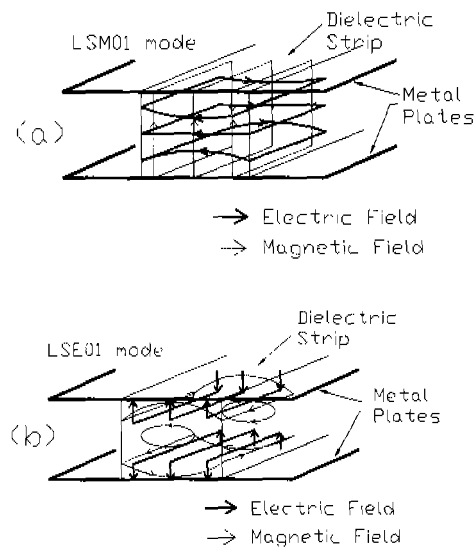

Fig. 2 The Electromagnetic Field on the NRD waveguide

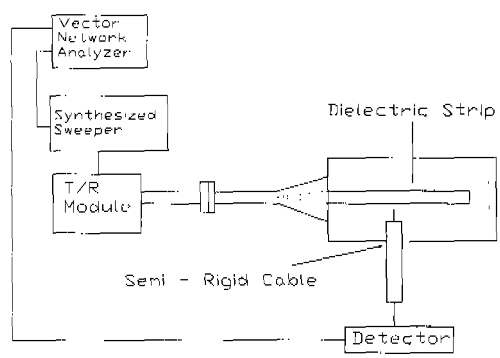

Fig. 3 VSWR Measurement of the NRD waveguide

For an experiment to ensure that waves are not leaking out of the NRD waveguide, we set up some devices as shown in Fig.3. From the resulting graph in Fig. 4, it is clear that transmission waves are hardly lost. As seen in Fig. 3, the network analyzer creates millimeter waves at the 60 GHz frequency, and they travel along the PTFE waveguide to a cutting edge. At the cutting edge, they begin to rebound. We measure the VSWR (Voltage Standing Wave Ratio) to make certain that the waves return with a minimum of loss. The VSWR could be measured as in Fig. 4 with the help of the semi-rigid cable placed next to the PTFE block. In measuring the VSWR, a waveguide probe is used as the signal source so as to prevent transmission loss. From Fig. 4, we learn that all the millimeter waves come back to the signal source and the difference between the maximum and minimum is as much as 40 dB. The values of the maximums in the same direction of travel are almost identical. In conclusion, this transmission circuit produces very little transmission loss.

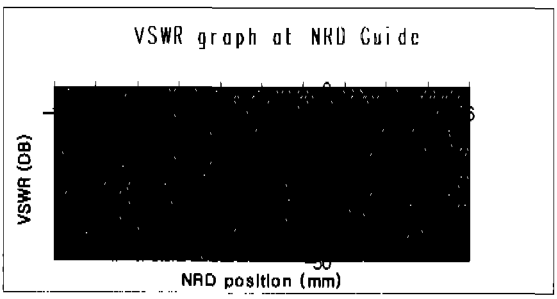

Fig. 4 VSWR Graph of the NRD waveguide at the cutting edge

Ⅲ. 60 GHz Gunn Oscillator

We have frequency fixed at 60 GHz. We also choose a gunn diode as an oscillator because it easily generates millimeter waves and it is also easily obtainable. As in Fig. 5, the gunn diode is fixed on a metal plate, and a bias voltage is applied to it. By doing this, millimeter waves start to oscillate. Then, we fine-tune a resonant frequency with the use of a metal resonator. This operation makes the waves travel along the NRD waveguide. Since the frequency is 60 GHz, the size of the PTFE block becomes 2.5mm x 2.25 mm, and it is used as a transmitter guide. The millimeter waves oscillated at the gunn diode pass through a metal strip resonator, as in Fig. 5, and then flow along the NRD waveguide. Fig. 6 is the spectrum photograph of this oscillation.

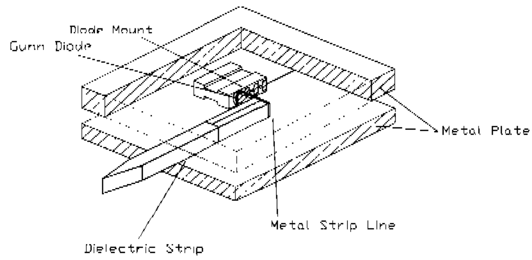

Fig. 5 Structure of the gunn oscillator

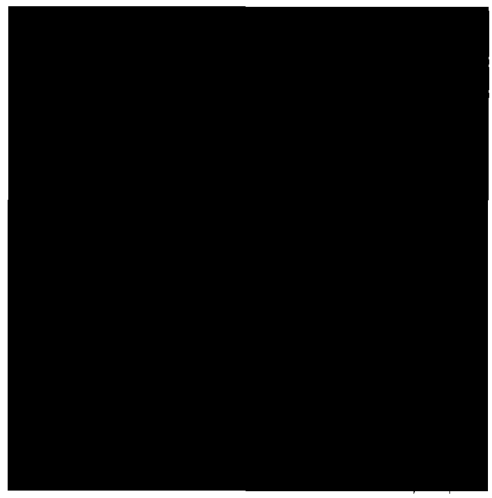

Fig. 6 Spectrum photography of gunn oscillation

Fig. 7 Photograph of the gunn diode circuit

The voltage of 4 V is applied to the gunn diode in order to generate a 60GHz frequency. Fine-tuning is done by the metal strip resonator attached between the gunn diode and NRD waveguide. When the waves from the gunn diode run-free, the power output is from 70 mW to 100 mW, which changes to 20mW after modulation. Fig. 6 shows the spectrum of oscillated frequencies. Then, in Fig. 7, we can see the photograph of the gunn diode circuit.

Ⅳ. 60 GHz Frequency Modulator

Fig. 8 illustrates the block diagram of a frequency modulator. To perform frequency modulation, first we oscillate millimeter waves of 60 GHz with the use of the gunn diode. Then, we let them pass through the frequency modulator. The frequency modulator consists of a varactor diode which acts as a capacitor and PTFE blocks that act as an inductance. According to a signal from an external circuit, we apply a reverse bias to the varactor diode. Then the varactor diode acts to alter capacitance. The change of the capacitance causes frequency modulation. By following the above steps, the carrier signals oscillated from the gunn diode are modulated in frequency. As Fig. 9 shows, the circuit with the varactor diode consists of a 60 GHz millimeter filter and a terminal that provides a reverse bias. From Fig. 10, we see that the PCB containing the varactor diode is set with the L component facing the cutting edge of the NRD waveguide, which in turn is connected to the gunn diode. The reverse bias, that is, a signal from an external circuit, becomes the applied voltage that acts on the varactor diode. The reverse bias goes through an IF signal input terminal. If the reverse bias appears weak, then it could be reinforced by adding some more reverse bias to it. As in Fig. 10, the millimeter waves oscillated from the gunn diode turn into their suitable frequencies by passing through the strip resonator. Then they move to the PTFE guide. At this moment, there is a turning point in the varactor diode. The turning point is made by both the varactor diode and the L component of the PTFE guide. In this case, since the size of the PTFE block is fixed, the variable condenser acts to vary resonant frequencies. This process finally brings frequency modulation. When the frequency modulation is conducted, it is expected that there may be change in oscillation power. This is because, according to the frequency modulation, its related parameters can be influenced. However, this change can soon be eliminated by rearranging the turning point at which the oscillation power stabilizes. Fig. 11 represents the variation of power as a function of the frequency modulation. As it tells us, we can hardly find any change in oscillation power.

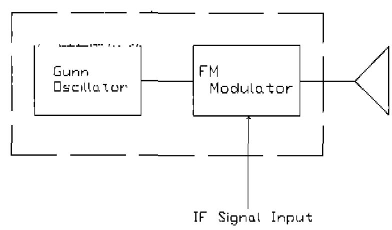

Fig. 8 Block diagram of frequency modulation

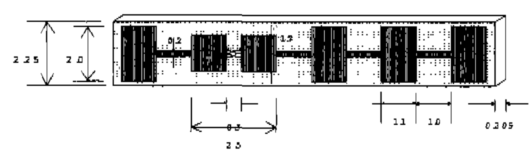

Fig. 9 Varactor diode circuits

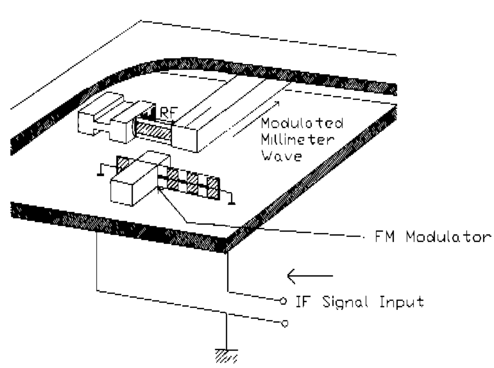

Fig. 10 Structure of frequency modulation circuit

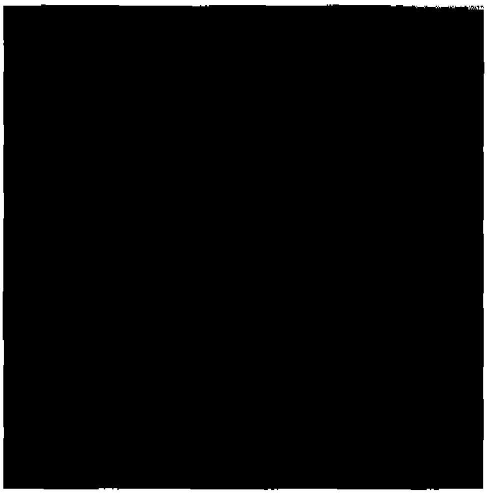

Fig. 11 Response at frequency modulation due to variation of capacitor of varactor diode

Fig. 12 Photograph of frequency modulation circuit

In the circuit of oscillation and modulation, the applied voltage of the varactor diode is manipulated from the range of 0 V to 10 V. By doing this, the characteristic frequency modulation band achieves a width of as much as 1.2 GHz. For the reason, to maintain the linearity of modulation, we choose an area of frequency modulation that appears to be flat and in which the variation of oscillation power is as little as possible. Therefore, we succeed in completing the modulation circuit, whose properties are described in Fig. 13. The modulation frequency determines the band width of a transmitter. The greater the band width is, the wider its range gets. Finally, an FM transmitter has been completed that has the frequency of 60 GHz, the maximum transmission band width of 1 GHz, and the power of 20 mW after FM modulation.

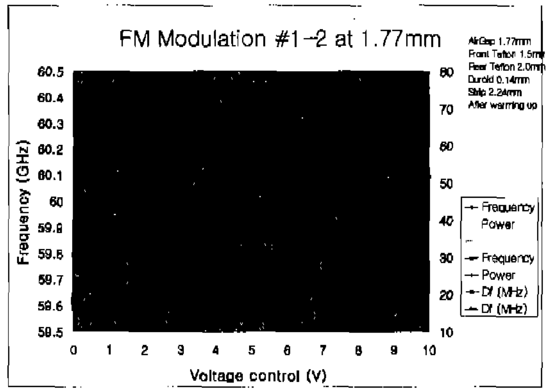

Fig. 13 Graph for FM modulation property

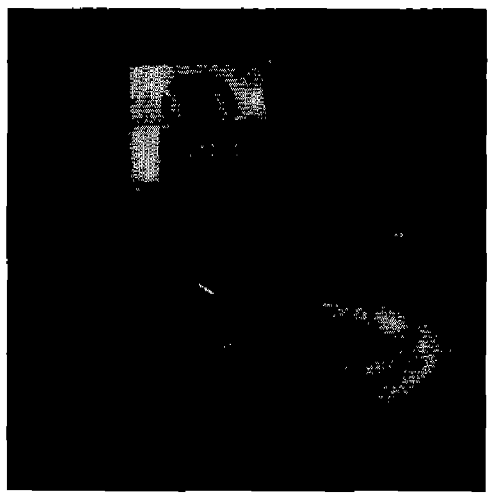

Fig. 14 Photography of developed 60GHz FM transmitter

V. Conclusion

Our study has finally created an FM transmitter which sends out millimeter waves of the frequency of 60 GHz. It can produce as much as 20 mW after FM modulation, and its maximum band width is 1 GHz. These features are possible because it employs an NRD waveguide. The NRD waveguide makes transmission loss as little as possible, so the transmitter can be invented in a convenient way. Another advantage of the waveguide is that the transmitter may be constructed in a small size, providing excellent transmission.

The NRD waveguide transmitter has some applications. It is used when we transmit CATV or when we transmit over a wide range. It offers some advantages; one advantage is that the transmitter has almost the same band width as optical communication, and another advantage is that its data transmission speed is faster than that of the optical communication. We expect the FM transmitter to be soon recognized as a great tool of ultra-highspeed communication networks over short distances. The FM transmitter is superior enough to replace optical communication, which demands high construction expenses or sometimes whose coupling may be problematic.

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