Multi-Beam Automotive Radar Front End using Non-contact Cylindrical NRD Switch

Toru Tanizaki, Hiroshi Nishida, Taiyo Nishiyama, Hideaki Yamada,
Koichi Sakamoto and Yohei Ishikawa

Murata Manufacturing Co.,Ltd.
26-10, 2-CHOME, TENJIN, NAGAOKAKYO-SHI, KYOTO 617-8555, JAPAN

ABSTRACT

We have developed a multi-beam automotive FM-pulse radar front end for 60GHz band by using the new NRD technologies. The multi-beam antenna consists of a dielectric lens and a non-contact cylindrical NRD switch with four dielectric resonator radiators and a motor. The millimeter-wave circuit consists of our original NRD guide components.

The size of the equipment is W125mm x H80mm x D74mm. This is expected to be applicable for automotive ICC applications.

INTRODUCTION

Recently there has been considerable interest in developing millimeter-wave radar for the intelligent cruise control(ICC). In this system, detecting not only the distance of the target but also the angular position are necessary.

MMIC and MIC technologies are normally used for a millimeter wave module, however the non-radiative dielectric wave-guide (NRD guide)[1] that advantages are low loss and good congeniality to dielectric components is also effective solution.

There are some papers about the fixed beam type radar front end using NRD guide, but the scanning type one has not been reported before. We have developed a multi-beam automotive FM-pulse radar front end for 60GHz band by using the non-contact mechanical NRD switch.

In this paper, we describe the principle of this technology, the construction and the performance of the new radar front end.

PRINCIPLE OF NRD SWITCH AND MULTI-BEAM ANTENNA

The non-contact NRD switch consists of a fixed NRD line and some movable NRD lines on a polyhedral cylinder as shown in Fig.1. When the cylinder is rotated by the motor and the both NRD terminal fit each other at the switching point, electromagnetic distributions existed out of the dielectric strip enables to couple closely and the RF signal can transmit with low loss. Fig.2 shows the cross sectional constructions of the conventional NRD and our original Hyper-NRD[2]. These are designed for 60GHz band using PTFE with a dielectric constant, εr of 2.04 as the dielectric strip. The Normal- SW uses the former and Hyper-SW uses the latter, respectively. Fig.3 shows the experimental results of their transmission characteristics versus rotation angle, ϕ. The both insertion loss of switching point are less than 0.1dB, when ϕ=0. The insertion loss of the Normal-SW is less than that of the Hyper-SW, when ϕ>0. This is because the difference of their electromagnetic distributions. When ϕ is large, both switches are off and high isolations are obtained.

The multi-beam antenna consists of a dielectric lens and this cylindrical NRD switch with dielectric resonator radiators[3]. In order to tilt the beam, the center of the radiator on the each side of the polyhedral cylinder is positioned to the offset point against that of the lens. As its terminal is connected to the TX/RX circuits through the above-mentioned NRD switch, the rotation of the cylinder enables to switch each radiator and tilt the beam. Fig.4 shows this operation. This method doesn't need the electrical switch using millimeter-wave devices and is very practical. This method can also be applied to three dimensional radar system.

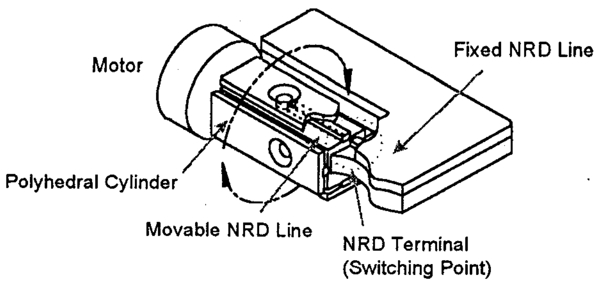

Fig.1 Construction of the NRD switch

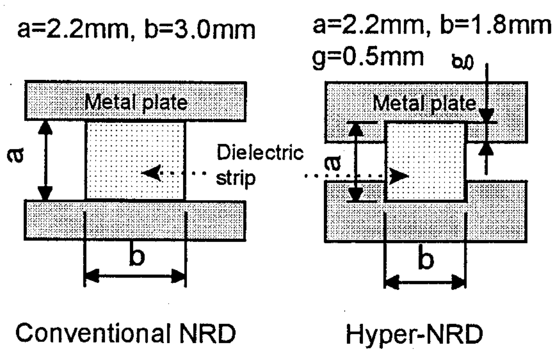

Fig.2 Cross sectional constructions of NRD

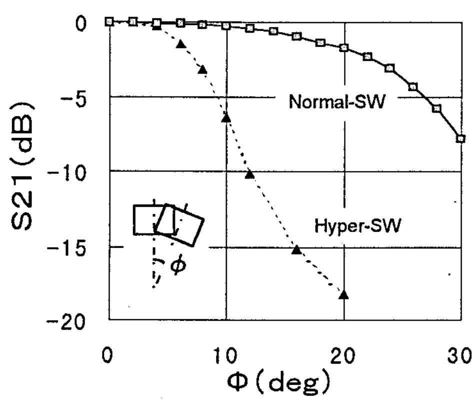

Fig.3 Characteristics of the NRD switch

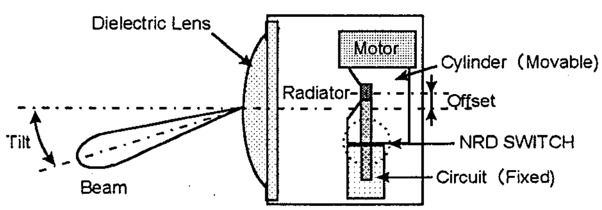

Fig.4 Operation of a multi-beam antenna(top view)

RADAR FRONT END DESIGN

[Radar Circuit]

A multi-beam FM-pulse radar front end consists of a voltage controlled oscillator(VCO), an isolator, a coupler, a circulator, a mixer and a multi-beam antenna as shown in Fig.5. It is single multi-beam antenna system using a circulator. The antenna has four beams by using the above mentioned technology. We realized this radar circuit by using "Multi Block Module (MBM) Method[4]" to improve productivity.

Fig.6 shows the operation of FM-pulse radar[5,6]. The VCO generates FM-pulse waveform by modulation signal. RF(TX) signal is transmitted from antenna to the target. RF(RX) signal from the target has delay time, T. By measuring T in the IF signal from the mixer output port, the distance to the target, R can be obtained as follows.

$$R = C \cdot T/2 \quad (1)$$

C: Velocity of light

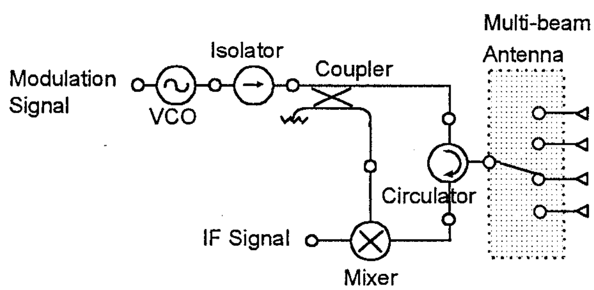

Fig.5 Block diagram of a multi-beam radar front end

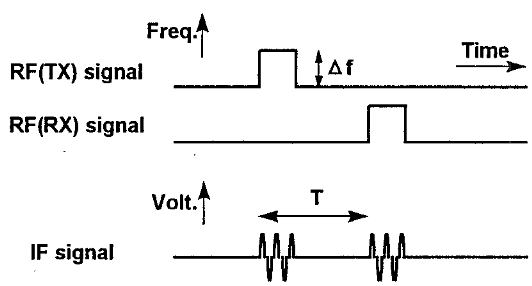

Fig.6 Principle of an FM-pulse radar

[Components]

The components are made by using our original Hyper-NRD guide shown in Fig.2. This realized single mode NRD of LSM mode to improve the size of the circuit and layout design [2]. The VCO consists of GaAs Gunn-diode, dielectric resonator and GaAs beam lead PIN-diode. The mixer is single balanced mixer using GaAs beam lead schottky diode. The radiator of the antenna consists of a dielectric resonator and slots. In order to use the Normal-SW expecting its low insertion loss, we insert transitions between the Hyper-NRD and the conventional NRD. The dielectric lens is made of composite material of high dielectric constant ceramic and engineering plastic material. Its dielectric constant , εr is 4.0. The lens is covered with the quarter wave surface matching plate that is made of the same engineering plastic material (εr = 2.0).

PERFORMANCE

We have trial manufactured a four-beam radar front end for 60GHz band.

Table1 shows the main performance of each components and Table 2 shows that of the radar front end. The RF(TX) output power is 7.7dBm, the antenna gain is 30dBi. The antenna provide an azimuth coverage of 13.8 degrees using four beams, each with an individual beam width of 4.7 degrees. Fig.7 shows the characteristics of the multi-beam antenna.

Fig.8 shows the IF signal versus time T as the results of one evaluation under the conditions that two cars as the target. The pulse width is 40 nsec. IF amplifier (Gain=23dB) are used. The distance of the TARGET1 from the radar front end is 18.6m and that of the TARGET2 is 13.5m. These results show that this front end can detect only one target by one beam and the errors of the measured distance were less than 0.5m. And they show that the noise is appeared at the near distance because of a single antenna system. From the result of another evaluation, the maximum distance to detect is about 70m. The basic performance as the multi-beam radar sensor is obtained.

Table 1 Performance of each NRD components

VCO	Modulation Bandwidth	120 MHz
	Output Power	11.6 dBm
Isolator & Circulator	Insertion Loss	0.4 dB
	Isolation	20 dB
Mixer	Conversion Loss	8.5 dB

Table 2 Performance of the radar front end

Operating Frequency	60-61 GHz
Waveform	FM-pulse
Number of Beams	4
RF(TX) Output Power	7.7 dBm
Antenna Gain	30 dBi
Antenna Beam Width	4.7 degrees
Field of View(Azimuth)	13.8 degrees

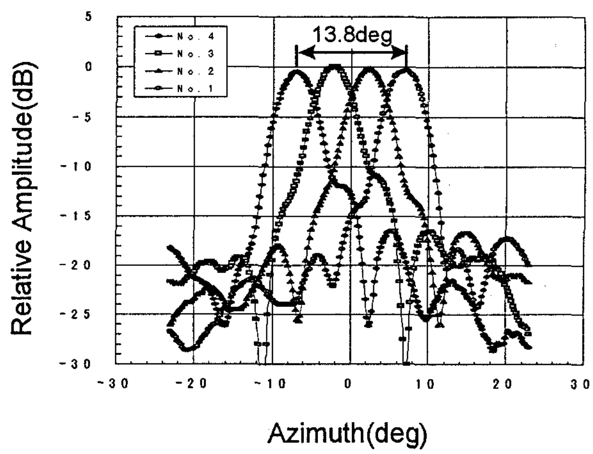

Fig.7 Characteristics of a multi-beam antenna

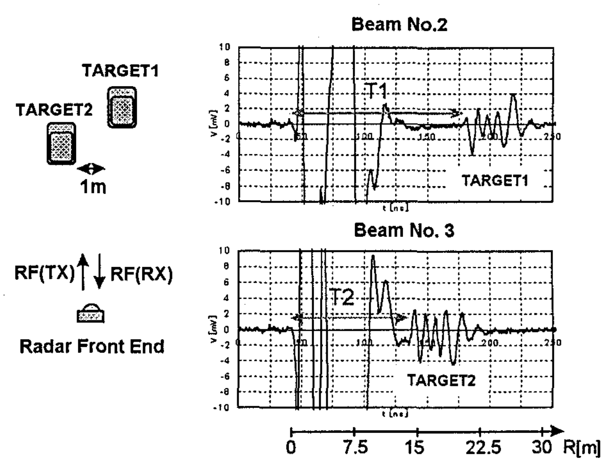

Fig.8 Experimental results of the radar front end

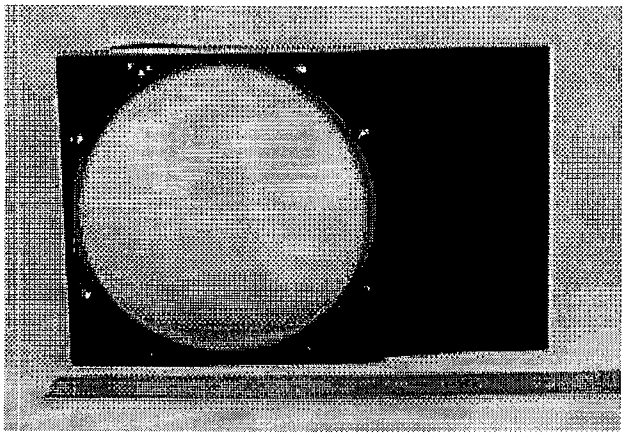

Fig.9 Front view of the radar front end

The front view of the radar front end is shown in Fig.9. The diameter of the dielectric lens is 75mm and the thickness is 23mm. The size of the front end is W125mm x H80mm x D74mm. This is expected to be applicable for automotive ICC applications.

CONCLUSION

The non-contact cylindrical NRD switch with low insertion loss and high isolation was presented. A multi-beam automotive FM-pulse radar front end for 60GHz band by using this mechanical switch was developed. The millimeter-wave circuit is based on our original NRD technologies. The antenna consists of a dielectric lens with εr of 4 and four dielectric resonator radiators. The antenna has four beams with the beam width of 4.7 degrees. The size of the equipment is W125mm x H80mm x D74mm. This is expected to be applicable for automotive ICC applications.

ACKNOWLEDGMENT

The authors are most grateful to Professor T. Yoneyama for his many helpful suggestions.

REFERENCES

[1] T.Yoneyama and S.Nishida, "Nonradiative dielectric waveguide for millimeter-wave integrated circuits," IEEE Trans. Microwave Theory Tech., vol. 29, no. 11, pp. 1188-1192, Nov. 1981.

[2] Y.Ishikawa, T.Tanizaki, H.Nishida and A.Saitoh, "Single Mode NRD Guide Coupled with Planar Circuit," 1996 IEICE General Conf., C-169.

[3] H.Yamada, N.Tanaka, F.Nakamura, Y.Saitoh and Y.Ishikawa, "A high efficient dielectric lens antenna for millimeter-wave band placed above the vertical radiating plane of NRD circuit," 1996 IEICE General Conf., C-172.

[4] Y.Ishikawa, T.Tanizaki, H.Nishida and A.Saitoh, "A Construction of Millimeter Wave Integrated Circuits Using Surface Mount Type NRD guide," 1995 Electronics Society Conf. Of IEICE, C-133.

[5] Y.Ishikawa, T.Tanizaki, H.Nishida and Y.Taguchi, "60GHz Band FM-Pulse Radar Head Using New Type NRD-Guide and Small Size Dielectric Lens Antenna," 1996 Electronics Society Conf. Of IEICE, C-118.

[6] Y.Ishikawa, T.Tanizaki, H.Nishida and Y.Taguchi, "60GHz Band FM-Pulse Automotive Radar Front End using New Type NRD Guide and Dielectric Lens Antenna," TSMMW'97, 7-4, pp. 70-71.