Compact and High-performance Millimeter-wave Antennas

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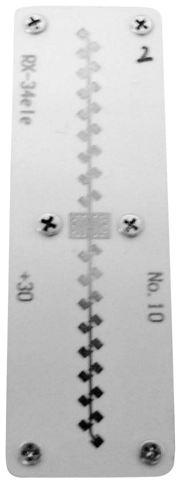


Abstract

Fujitsu Ten has been developing automotive radar using the millimeter-wave (30GHz to 300GHz) since before we were separated from Fujitsu, and we started its mass production in 2003. In this article, we introduce our history of our own radar development for more than 30 years. In addition, we explain a waveguide slot antenna for automotive application and a low-profile triplate antenna whose mass production was started in 2003, focusing on the background of the antenna development.

For further reduction of the cost of the automotive radar, we developed microstrip antennas effective in lowering cost with its extremely simple structure and then reduced the cost by 80%. We also explain our efforts of the design for reduction of transmission loss and the development of printed board materials.

1 Introduction

In the 1980's, Fujitsu Ten made a prototype of V-type radar for evaluation on vehicle installation and secured the prospect of practical application of automotive radar, using the waveguide slot antenna. In the 1990's, we developed the radar with mechanical scan system adopting triplate antenna to improve the installability and detection capability on curves, and then commercialized it in 2003. Now, we promote an establishment of design technology of comb-line microstrip antenna and development of its commercialization for the price reduction of antenna.

In the antenna development, there had been changes in the antenna shape, from solid antenna to planar antenna as well as in the materials, from waveguide using metal to dielectric body. In this article, we introduce the history of our antenna development and our current approach.

2 History of Automotive Radar Development

2.1 Start of Development

In the 1970's, the necessity of the automotive radar began to be recognized as measures to reduce increasing automotive accidents. The frequency allocation policy of 40 GHz or more was decided by Ministry of Posts and Telecommunications at the time and technically 50GHz convenience radio had been put to practical use. In this way, the development environment for the automotive radar began to be improved from standpoints of social needs, government trend toward the radio wave and technical aspects.

In 1974, Fujitsu Limited (hereinafter, referred to as Fujitsu) newly established the Motronics development department to develop the automotive radar. In this department, the possibility of the automotive radar in the millimeter waveband was examined firstly. Giving priority to the detection capability, a prototype model for examination was made, using high-gain and large-size Cassegrain antenna with a diameter of about 30 cm. The evaluation on the detection capability with this prototype model showed that the millimeter waveband was effective as the automotive radar.

In 1979, the development of the automotive radar in Fujitsu was transferred to Fujitsu Ten without any change of the development organization.

In the 1980's, Fujitsu Ten commissioned the development of high-frequency device to Fujitsu. We developed the high-gain and small-size waveguide slot antenna and made a prototype of V-type radar to be installed in the vehicle. With the cooperation of Toyota Motor Corporation, we installed the V-type radar in Toyota's specialty car Soarer and carried out a test run on the open road and a test in cold climates. The fixed beam system was used in this radar, and therefore, we had a problem of deterioration of the detection capability on the curves. However, those tests showed that the V-type radar fulfilled the performance required for the automotive radar, such as detection capability for a leading vehicle and separation from adjacent vehicles.

2.2 Approach to Commercialization

In the 1990's, there had been changes in the vehicle design, from box-shaped design to slant nose design, and thus the automotive manufactures strongly demanded smaller-size and thinner radar. We began to consider the introduction of planar antenna effective in those demands. For its introduction, we had a problem of keeping the same gain as that of the high-efficiency waveguide slot antenna. Therefore, we began to develop the millimeter-wave planar antenna for automotive use with Hitachi Chemical Company, Ltd. (hereinafter, referred to as Hitachi Chemical) that produced the high-efficiency and planar triplate antenna for DBS antenna at the time.

Also in the 1990's, we set up a working group with Ministry of Posts and Telecommunications (name at the time) so that the radar manufacturers and automotive manufacturers achieve the frequency allocation. As a result, in 1997, the frequency of 60 GHz was allocated to the automotive millimeter-wave radar. The frequency allocation removed the significant barrier of laws and regulations for the commercialization and activated the commercialization by each manufacture rapidly.

Fujitsu Ten introduced the triplate antenna and developed the radar with high-resolution mechanical scan system, without the deterioration of detection capability even on the curves by scanning the antenna mechanically with the advantages of thinness and lightness of the antenna. In 2003, we commercialized the radar, and in 2006, we commercialized backward-looking radar.

2.3 Approach to Price Reduction

There is a problem of the price reduction of radar with the spread of automotive radar. The microstrip antenna using a printed board to be patterned by etching is effective in the price reduction. However, it had not been used because of significant transmission loss in the millimeter-wave band and low efficiency.

Recently, the microstrip antenna with low loss and high efficiency by coupling the radiation element with feed line has been offered [(3) (4)]. Fujitsu Ten applies this technology and develops the materials with Nippon Pillar Packing Co., Ltd. In this way, we have been approaching to the development of practical application of the microstrip antenna.

3 History of Antenna Development

Fig. 1 shows the history of our antenna development. We began with the development of waveguide slot antenna, and then we have been promoting the development from the triplate antenna to the microstrip antenna, aiming for the reduction in size/weight/price.

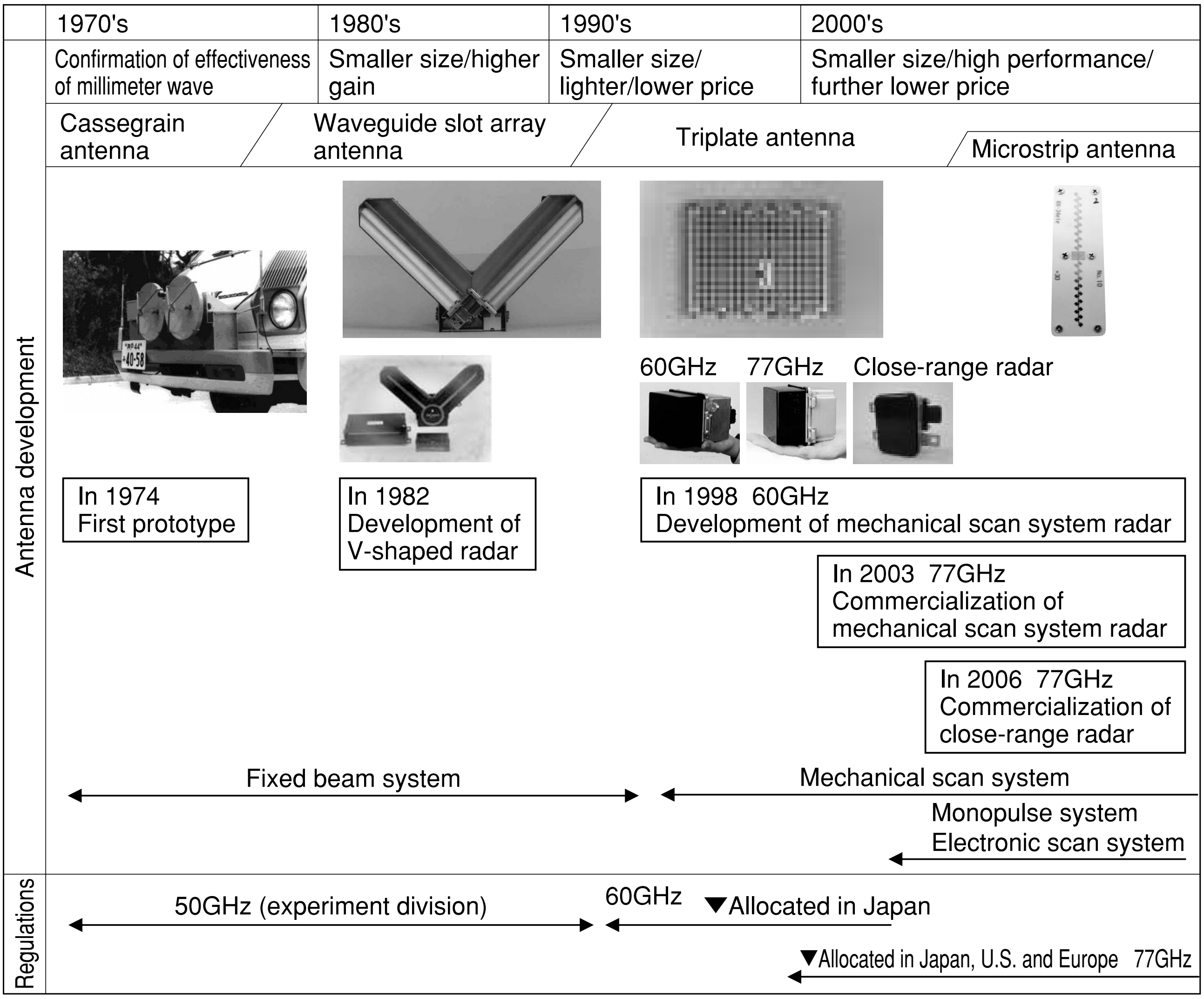


Fig.1 History of Antenna Development

In this chapter, we describe details of structure and characteristic of each antenna that we developed.

3.1 Waveguide Slot Antenna

For the prototype model for the evaluation on vehicle installation, we discussed the optimum beam width taking into consideration the separation from adjacent vehicles and influence of road surface reflection.

As an antenna system to realize the optimum beam width, we evaluated the prototype of the antenna using the several types of antennas such as cheese antenna, and compound antenna including the waveguide slot antenna and cylindrical parabola antenna. The antenna system that synthesizes the beam by combining the transmitting antenna and receiving antenna in a V shape made it possible to form the small and sharp beam.

The V-shape radar using this antenna system became the model for evaluation on vehicle installation with excellent detection capability and installability by simplifying and directly connecting between devices at high-frequency area. We had carried out the test run on the open road for about 10 years since 1982, and established the specification as the subsequent radar and the antenna for radar.

3.1.1 Structure of Waveguide Slot Antenna

As shown in **Fig. 2 (a)**, the transmitting antenna or receiving antenna forms 2 degrees beam width with the primary radiator of the waveguide slot antenna and 6 degrees beam width with the cylindrical parabola reflector. As shown in **Fig. 2 (b)**, the transmitting/receiving beam of 2 degrees×6 degrees beam width are combined orthogonally to obtain the transmitting/receiving synthetic beam of 2 degrees×2 degrees.

We ensure 45-degree polarized wave to avoid the radio wave interference of oncoming vehicles. We use the longitudinal shunt slot and edge shunt slot, whose polarizations intersect at a right angle, as the transmitting/receiving antenna, and we keep the polarization in the 45-degree direction by V-shape and orthogonal arrangement of the transmitting/receiving antenna.

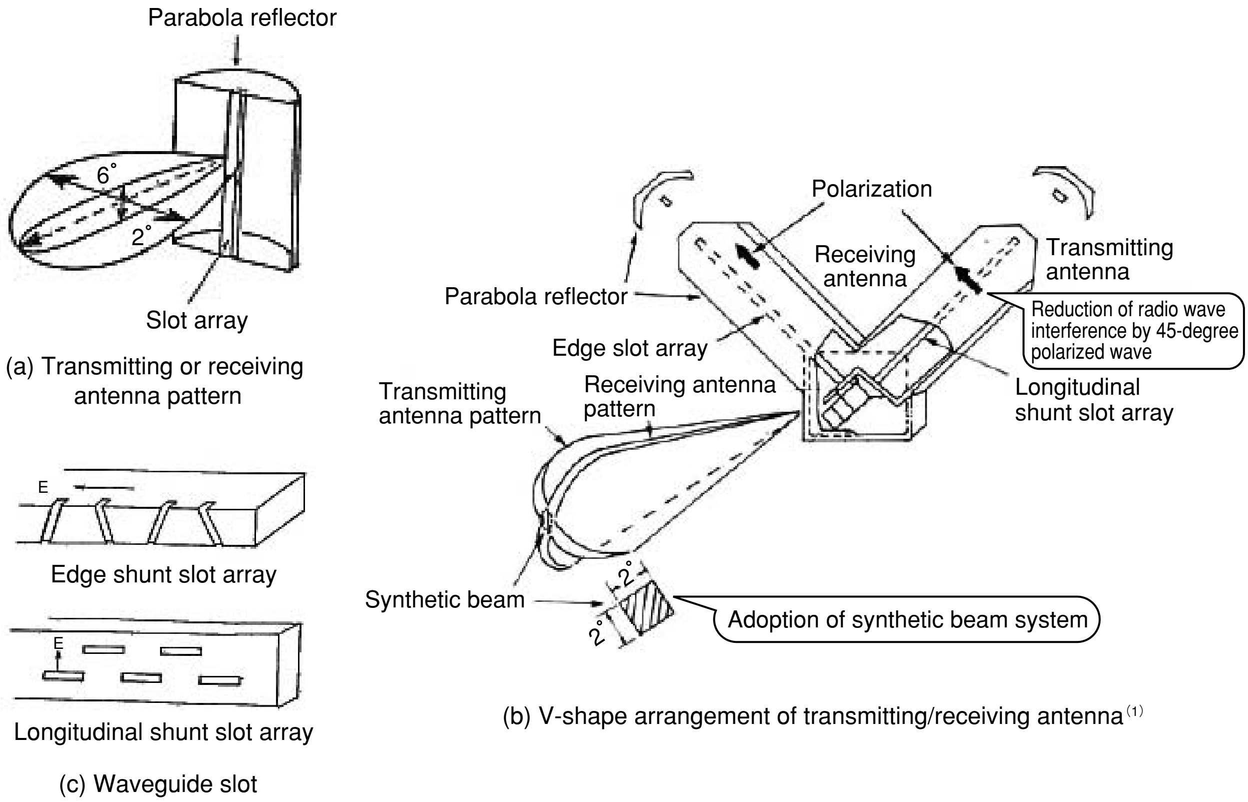


Fig.2 Structure of Waveguide Slot Antenna (1)

3.2 Triplate Antenna

For commercialization of high-efficient millimeter-wave planar antenna, Fujitsu Ten and Hitachi Chemical implemented joint development. The examination of specification as the automotive radar antenna and its evaluation were implemented by Fujitsu Ten, and the design/prototype of antenna were implemented by Hitachi Chemical.

3.2.1 Structure of Triplate Antenna

As shown in **Fig. 3 (a)**, the triplate antenna is composed of copper foil pattern (feed line and patch) formed by etching process on the extremely thin film substrate, parallel plate (slot plate and ground plane) placed at the top and the bottom of the structure, and foam material holding the film substrate. The transmission line from the feed line to patch is composed of the triplate transmission line held between the parallel plates shown in **Fig. 3 (b)**.

The triplate transmission line has low dielectric loss depending on the material and no radiation loss into the space due to the interruption of signal by the parallel plates because the dielectric material such as resin substrate is not used in the space between slot plate and ground plane, comprising the feed line. Therefore, there is only conductor loss by the current in the parallel plates, and if the triplate transmission line is used in the feed line of antenna, the planar antenna with high radiation efficiency is realized.

4 Development of Low-cost Antenna

To ensure the installability and scanning function at the same time, the planar antenna is essential. Also, the demand for the low cost has been increased with the expansion of usage of automotive radar and its spread. Among the planar antennas, the microstrip antenna having simple structure is effective in the price reduction. However, there is a problem of high transmission loss and decrease in efficiency because the resin substrate is used for the microstrip antenna.

As a solution for this problem, there is technique to directly connect the radiation element and feed line (3). This technique reduces the transmission line loss to each radiation element, and therefore, the microstrip antenna with high efficiency is realized. With the cooperation of Toyota Central R&D Labs., INC., we worked on the commercialization development including the optimum design of this type of antenna.

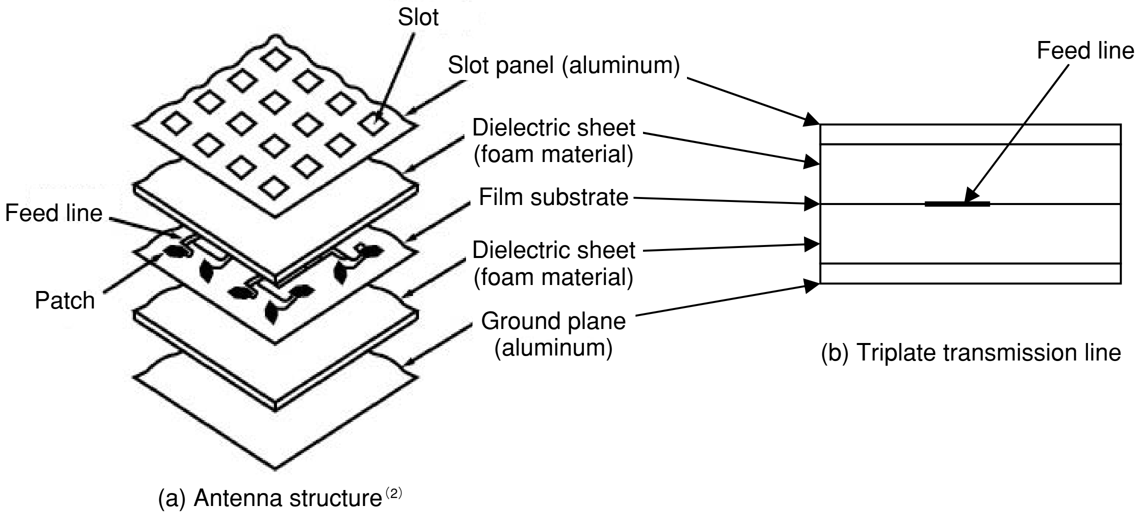


Fig.3 Structure of Triplate Antenna

4.1 Structure of Microstrip Antenna

Fig. 4 (a) shows the structure of the feed line and radiation element in the microstrip antenna, and **Fig. 4 (b)** shows the structure of the microstrip substrate.

As mentioned above, the central transmission line feeding the signal to each radiation element is directly connected with the radiation element. Furthermore, 45-degree polarized wave is also realized at the same time by tilting the radiation element at a 45-degree angle.

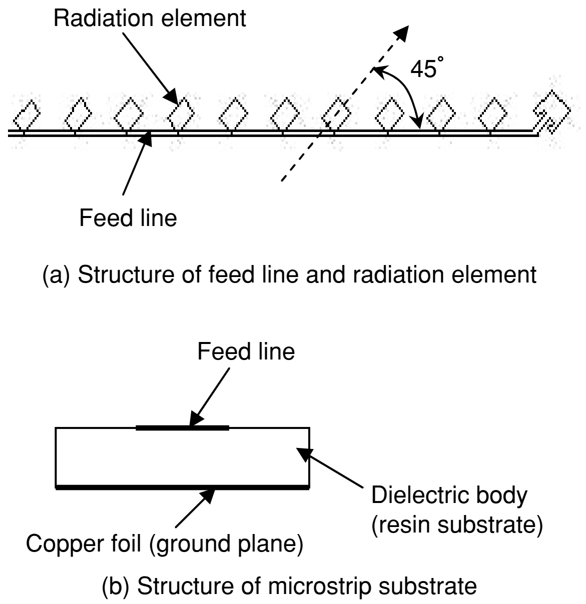


Fig.4 45-degree Polarized Comb-line Microstrip Antenna

4.2 Approach to Commercialization

Our main approaches to the commercialization of the microstrip antenna are as follows:

①**Selection of substrate material**
②**Improvement design of antenna pattern characteristics**
③**Robust design**

Among the above-mentioned approaches, we describe the examinations of ① selection of substrate material and ② improvement design of antenna pattern characteristics.

4.2.1 Selection of Substrate Material

As for the substrate material, we examined every characteristic such as electric property, mechanical strength, environment resistance and others. Especially, the electric property is a key issue because of the usage of substrate in the millimeter waveband.

The electric property of substrate mainly has dielectric constant and dielectric loss. The higher dielectric constant, the narrower frequency width. Therefore, three or less of dielectric constant is suitable for antenna material. We focused on LCP (liquid crystal polymer) substrate and PTFE (poly-tetra-fluoro-ethylene) substrate among the substrates with three or less of dielectric constant, and evaluated them.

The dielectric loss affects the loss in the feed line, and if the loss becomes high, the radiation efficiency is declined. Therefore, the dielectric loss is a critical indicator.

As for the loss of the feed line, the prototype of evaluation sample for only the feed line was made and the loss between both ends of line was measured. As a result, the LCP has a high feed line loss and inferior antenna efficiency than triplate antennal.

On the other hand, PTFE has low loss and high possibility to realize the high-efficiency antenna if the PTFE is used as the substrate material of the microstrip antenna.

4.2.2 Improvement Design of Antenna Pattern Characteristics

If the radiation element is arrayed linearly (**Fig. 4 (a)**), the temperature characteristic of dielectric constant affects the antenna pattern characteristic. If the dielectric constant is varied by the temperature, the wavelength inside of dielectric body is varied and the signal phase radiated from each radiator is varied. If the signal phase radiated from each radiation element is in phase, each signal phase becomes equal at the antenna front side (in a vertical direction of antenna surface) and the main lobe peak becomes the antenna front side. If each signal phase is varied, the main lobe peak position of antenna is varied (the beam tilts). Hence, as measures against the influence exerted by the temperature characteristic of dielectric constant, on the antenna pattern characteristic, we adopted a center-fed system to be described in (a) below, and approached to the development for mass production with improvement design of antenna pattern characteristic. This system had a new problem of deterioration of side lobe ratio because the feeding part was placed in the center of antenna. However, this problem was solved by the measures described in (b) below.

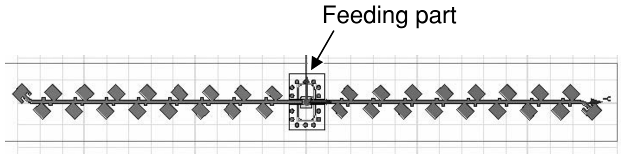
(a) Adoption of center-feeding system

In the center-fed system, the phase variation symbol of radiation element, divided into a right and a left half with reference to the feeding part, is reversed as shown in **Fig. 5 (a)**, and therefore, the phase variation is negated at the antenna front side and the peak position is not varied. However, by the presence of feeding part in the center of the antenna, the radiation from around center part is prevented and side lobe ratio of antenna pattern characteristic is deteriorated.

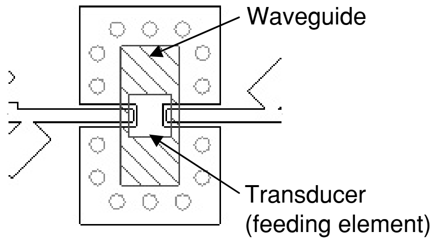
The most significant task in adoption of center-fed system is to reduce the deterioration of the side lobe ratio. Our approaches to this reduction are shown below.

(b) Reduction of side lobe ratio deterioration

As shown in **Fig. 5 (b)**, the feeding part is comprised of the waveguide part and transducer part. The transducer has function to reduce the reflection and loss in the case of signal transmission between the waveguide for connecting with RF part and feed line of antenna (microstrip line). For the center-fed system, the signal to be input to the feeding part is needed to be divided into two and fed into the right-and-left radiation elements. We achieved the same size of feeding part as that of the conventional one by adding the two-distribution function to this transducer. Therefore, we were able to minimize the area where the radiation cannot be given, and reduce the side lobe ratio deterioration. **Fig. 6** shows the evaluation result of antenna pattern. We obtained the gain, the side lobe ratio, for the automotive radar antenna.



(a) Antenna structure



(b) Structure of feeding part

Fig.5 Structure of Center-fed Microstrip Antenna and its Feeding Point

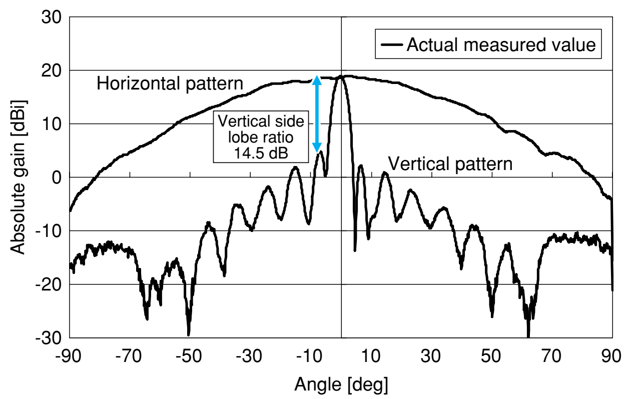


Fig.6 Evaluation Result of Antenna Pattern

5 Conclusion

With the evolution of our millimeter-wave radar, we have advanced the development of antenna from the waveguide slot antenna to the triplate antenna and microstrip antenna. With the transition of antenna to be developed, the materials and structures also had been altered significantly, and we had faced the task of efficiency, temperature characteristic, environment resistance and others in the new structure. However, we had modified and improved in each case and found out the possibility of commercialization. We will establish the mass production design technology for millimeter-wave microstrip antenna aimed at smaller size/lower price antenna by introducing the robust design against machining errors.

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