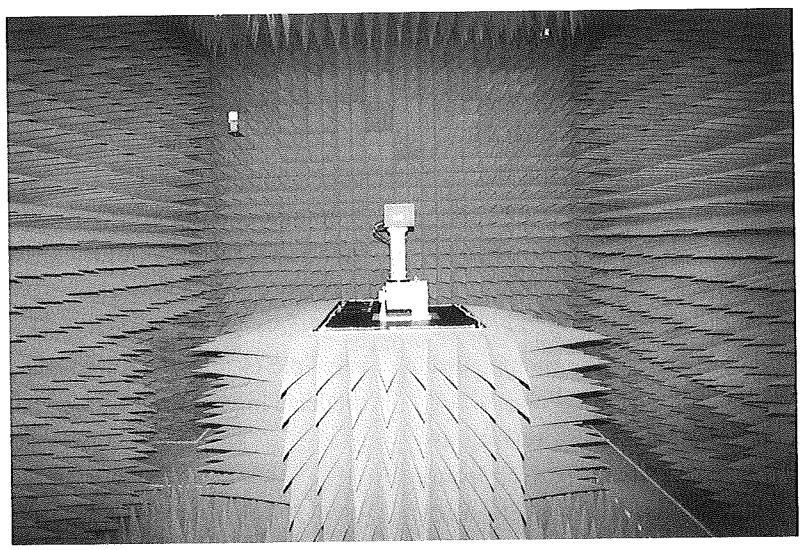
Six-sided Anechoic Chamber and Antenna Evaluation Technology

● Kazushige Ogino ● Keizo Itazu ● Shigeaki Inamura

● Kunitsugu Tanaka



Abstract

The recent introduction of portable satellite telephones brought global communications standards to consumers, demonstrating the way mobile communications markets are expanding beyond the capacity of individual nations to regulate them. In the automobile industry, manufacturers are researching and developing traffic information systems based on the mobile communications technology. Thus, auto makers are also working towards establishing international standards.

One of the essential components of mobile communications equipment is the antenna. Fujitsu Ten is developing next-generation car antennas by maximizing technological expertise accumulated over many years. These advanced R&D activities, in turn, have created a need for a new antenna evaluation technology -- and a cutting-edge facility in which to apply it.

To further our antenna R&D activities, we have constructed an anechoic chamber (six-sided dead room) in the Nakatsugawa Techno Center. This facility is among the largest anechoic chambers of its kind in Japan. It enables the assessment of antenna performance using a broad frequency spectrum, ranging from FM broadcasting frequencies to millimeter waves.

Issues Fujitsu Ten has encountered in the anechoic chamber construction project and the technologies used to deal with them are described in the following synopsis, which also introduces examples of our product evaluations.

1. Introduction

Demand for new car antennas is growing, but the specifications required for them are becoming more and more strict.

Having developed and evaluated car antennas, Fujitsu TEN has constructed a six-sided anechoic chamber to evaluate antennas quantitatively. Fujitsu TEN has constructed this chamber for the purpose of developing new car antennas on a timely basis, to satisfy diversifying customer needs.

This paper explains trends in the car-antenna market that required us to construct the anechoic chamber and the current activities at Fujitsu TEN. Also explained are the conformance to the wideband width and increase in measurement accuracy studied before the construction of the anechoic chamber, quality control in construction processes, and safety equipment for the anechoic chamber.

2. Background of Anechoic Chamber Construction

Car antennas were originally developed for the reception of radio broadcasts. They have been upgraded and have diversified to meet growing needs for applications ranging from TV broadcasts to serving as receptors for car telephones, as cars have evolved from simple forms of transportation to convenient and comfortable mobile spaces.

Lately, car antennas have undergone rapid change to accommodate new communications systems such as navigation systems and VICS based on the developing infrastructure for mobile communications.

Car antenna related needs will likely diversify further, for example, with the use of millimeter-wave radar for collision-prevention systems, as a part of the intelligent transport system (ITS) planned for the future, and the growth of digital broadcasting using terrestrial waves and satellite waves. We have to develop new car antennas quickly to accommodate these increasing needs.

On the other side, the specifications required for the new antennas in demand are becoming more advanced and complex.

Although Fujitsu TEN has carried out antenna evaluation, our conventional evaluation has not been accurate and efficient enough to promote the development of new antennas to the kind of demand expected in the future.

Fujitsu TEN constructed the six-sided anechoic chamber for antenna evaluation at the Nakatsugawa Technical Center, which is a base for the research of radio wave technology. Fujitsu TEN constructed this chamber, aiming to improve antenna evaluations in terms of accuracy and efficiency, and promote the timely development and marketing of new, original antennas.

3. Specifications of Anechoic Chamber and Evaluation Equipment

3.1 Outline of Anechoic Chamber and Evaluation Equipment

An anechoic chamber, also called a "dead room," is a room whose ceiling, floor, and walls are covered with wave absorbers to eliminate the reflection of waves.

The internal space of the anechoic chamber can be equivalent to free space. The outside surfaces of the room are entirely covered with steel plates to form an electromagnetic shield shutting off the room from external waves.

Each wave absorber used in the constructed anechoic chamber is a pyramid-shaped piece of foamed urethane impregnated with carbon. (See Figure 1.)

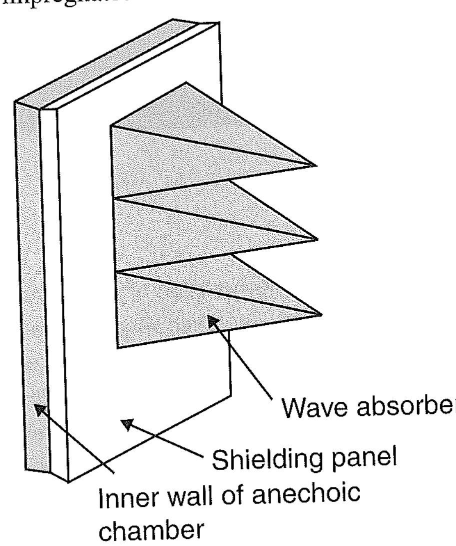


Fig.1 Inner wall structure of anechoic chamber

Inside of the anechoic chamber are a seat for the measurement-wave radiation antenna and a seat for the antenna to be tested, or the measurement reference antenna. Each seat has a positioning unit at its top to mount and turn an antenna. The positioning unit can be turned and positioned in an arbitrary state by the control from an automatic measurement controller installed outside the anechoic chamber. (See Figure 2.)

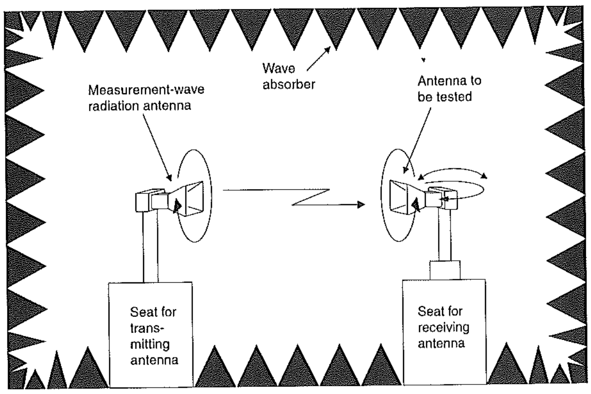


Fig.2 Structure of anechoic chamber

For the evaluation of an antenna, a test wave is radiated from the measurement-wave radiation antenna and received by the antenna to be tested mounted on the other seat. Then, the voltage received by the antenna to be tested is compared with the voltage received by an reference antenna, and the performance of the antenna to be tested is judged. (The voltage received by the reference antenna is measured under the same conditions beforehand.)

3.2 Conformance to Broad Band

The lineup of Fujitsu TEN's antennas cover a broad band from AM/FM broadcasting waves to millimeter

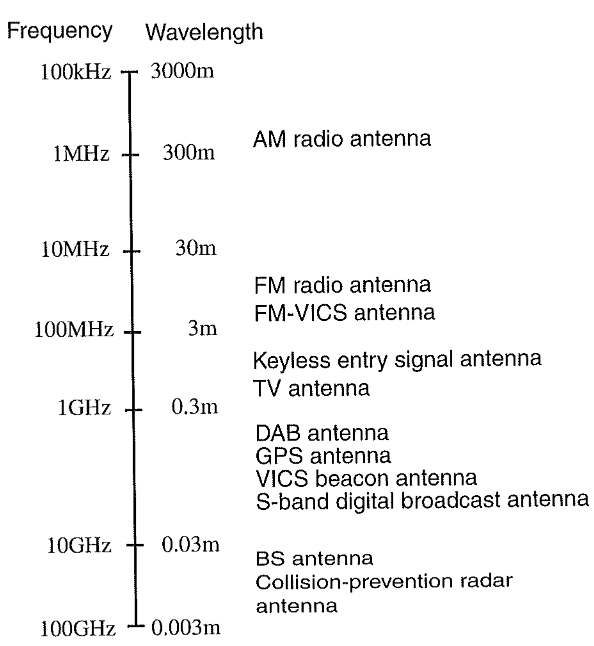


Fig.3 Fujitsu Ten's main antenna line

waves, which are used for collision-prevention systems. (See Figure 3.).

The anechoic chamber was designed to be capable of evaluating all of the above antennas except for AM radio antennas for frequencies with long wavelengths.

1) Distance between antennas
   The distance between the transmitting and receiving antennas must be set so that the following condition is met. Among the electric field components radiated from the transmitting antenna using the minimum usable frequency, the quasi electrostatic field and induction field components must be sufficiently smaller than the radiation field component. (The degrees of quasi electrostatic field and induction field components are in reverse proportion to the square and cube, respectively, of the distance between the transmitting and receiving antennas.) (The degree of the radiation field component is in reverse proportion to the distance between the transmitting and receiving antennas.)
   For the anechoic chamber, we decided the distance between the transmitting and receiving antennas to be 8 meters so that the ratio of each of quasi electrostatic field and induction field components to the radiation field component is -20 dB at the minimum frequency of 76 MHz.
   Before deciding the distance, we examined the factors that affect the gain and directivity of the antenna to be tested in relation to its open area and the wavelength of test wave. These factors included the flatness of the equiphase signal and amplitude of the test wave radiated from the radiation antenna.
2) Size of anechoic chamber
   The size of the anechoic chamber depends on the distance between the transmitting and receiving antennas and the required size of each quiet zone.
   The quiet zone is the space where reflected waves(*1) are minimized and the electric field fluctuates less. Each antenna is installed in the space. (See Figure 4.)
   We decided on a quiet zone of such size that each antenna would be kept within the zone even when the antenna was turned by the positioning unit for directivity measurement. In consideration of the size of the quiet zone and the distance between antennas, we decided that the size of the anechoic chamber should be 13 meters x 7 meters x 7 meters (effective size in the chamber).

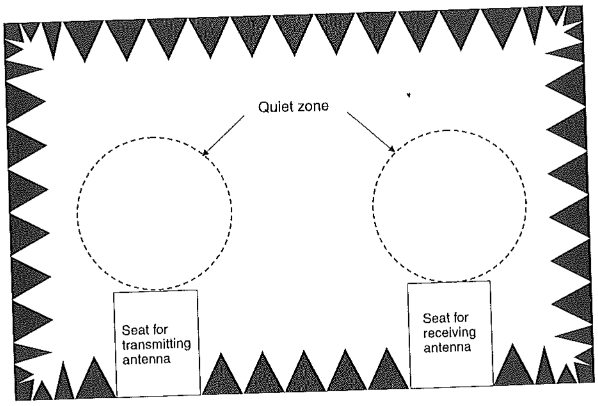


Fig.4 Quiet zone

In view of the measurement system design, the transmission distance as long as 8 meters was expected to cause a large loss in free space in millimeter wave bands. We installed a down converter right below each antenna to minimize the loss and avoid the degrading of the dynamic range. To eliminate reflection, we also covered all of the equipment installed in the anechoic chamber fully with wave absorbers.

*1 The reflection by the inner walls of anechoic chamber and reflected waves are usually referred to as "scattering" and "scattered waves" because these waves are not plane waves. However, we used the terms "reflection" and "reflected waves" in this paper for convenience.

3) Wave absorber

A pyramid-shaped wave absorber theoretically provides higher absorbing capacity for higher frequencies. In consideration of the wave absorbing capacity in the minimum frequency band (76 MHz), we chose a large wave absorber (whose height is 1.5 meter) to conform to wideband width.

We used an ether urethane material for the wave absorber because its strength is not easily degraded by hydrolysis.

3.3 Improvement of Measurement Accuracy

Typical measurement errors in antenna evaluation in an anechoic chamber are as follows:

(1) Error due to the reflection from inner walls
(2) Error due to the degree of accuracy of the measurement system
(3) Error due to the quasi electrostatic field and induction field components of radiated wave
(4) Error due to the gain accuracy of the standard antenna used as the reference for gain measurement
(5) Error due to the installed position or movement (*2) of the antenna

*2 Antenna movement includes changes in the antenna position in relation to the radiating antenna for directivity measurement.

All of the above errors must be understood for each antenna gain measurement because every error varies depending on the test frequency, antenna specifications, and other conditions.

The following explains errors (1) and (2) which are important for the construction of an anechoic chamber:

1) Error due to reflected wave

An ideal environment for antenna evaluation is the space in which only the direct test wave consistently radiated from the transmitting antenna arrives at the antenna to be tested.

An anechoic chamber is the space that is designed to be such an ideal environment as closely as possible. However, in an actual anechoic chamber, there also exists a wave that is reflected from the inner walls and that arrives at the antenna to be tested. If the reflected wave is synthesized with the direct wave at the antenna to be tested, the received voltage differs from the one measured with only the direct wave. This difference appears to be a measurement error, adversely affecting the measurement accuracy.

The reflected-wave level refers to the ratio of the reflected wave to the direct wave, and is the most important characteristic for the evaluation of anechoic chamber performance.

For the construction of the anechoic chamber, we included the characteristic of reflected-wave level in the specifications of the anechoic chamber and measured the characteristic in all frequency bands. Table 1 lists the measured reflected-wave levels and the errors due to the reflected wave.

Frequency	Reflected-wave level		Maximum error due to reflected wave
	Target value	Measured value	
76MHz	-20 dB or less	-21dB	0.82dB
200MHz	-20 dB or less	-30dB	0.28dB
500MHz	-20 dB or less	-31dB	0.25dB
1GHz	-30 dB or less	-33dB	0.20dB
3GHz	-35 dB or less	-37dB	0.13dB
10GHz	-40 dB or less	-45dB	0.05dB
30GHz	-40 dB or less	-49dB	0.04dB
100GHz	-40 dB or less	-43dB	0.07dB

Error $=20\times\log(1\pm10^{A/20})$ A : Reflected-wave level

We used a free-space VSWR method for the measurement of the reflected-wave level. We also installed two receiving antennas for highly accurate measurement. The measurement using the free-spce VSWR method is outlined below.

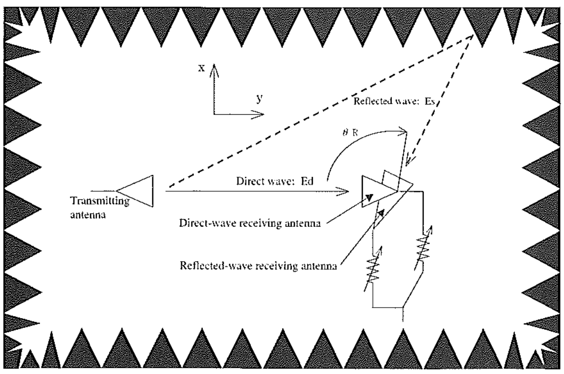


Fig.5 Measurement of reflected wave level with two antennas

Table 1 Reflected-wave levels

The antennas are mounted on the respective positioning units. The angle of the receiving antennas are set off from the direction facing the transmitting antenna. Then, the fluctuation of the reception level is measured while the receiving antennas are moved within the quiet zone. (See

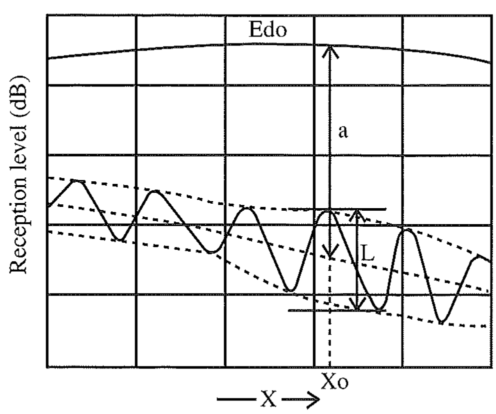


Fig.6 Example of reflected wave level measurement

Figure 5.)

If there is a wave reflected from a wall, a standing wave exists in the space and the reception level fluctuates repeatedly between the maximal and minimal levels as the antennas are moved. The reflected-wave level can be calculated as described below from the difference (L) between the envelopes of maximal and minimal values. (See Figure 6.)

$$Es/Ed[dB]=20\cdot Log((10^{L/20}-1)/(10^{L/20}+1))-a\ [dB]$$

Es/Ed : Reflected-wave level

a: Off-peak value (difference between direct-wave level received at receiving antenna facing directly toward transmitting antenna and the average of maximal and minimal values)

Item	Specification	
Format	Dead room with shielding panels	
Application	Antenna evaluatio	
Dimen-sions	Inside dimensions	16m(L)×10m(W)×10m(H)
	Effective dimensions	13m(L)×7m(W)× 7m(H)
Electrical character-istics	• Reflected-wave levels (in quiet zone): 76 MHz to 1 GHz: 20 dB or less 1 GHz to 10 GHz: 30 dB or less 10 GHz to 100 GHz: 40 dB or less	
	• Field amplitude fluctuation level (in quiet zone) 76 MHz to 1 GHz: 0.75 dB or less 1 GHz to 10 GHz: 0.25 dB or less 1 0 GHz to 100 GHz: 0.10 dB or less	
Measurement system	HP8530A microwave receiver system	
Auxiliary equipment	• Transmitting-antenna seat with single-axis positioning unit (Polarization)	
	• Transmitting-antenna seat with double-axis + single-axis positioning unit (Azimuth/elevation + polarization)	
Evaluation item	• Antenna absolute gain • Antenna directivity (Azimuth/elevation) • Cross-polarization discrimination	
Others	• Monitoring camera • LAN line	

Through the above evaluation, we were able to construct an anechoic chamber that has superior

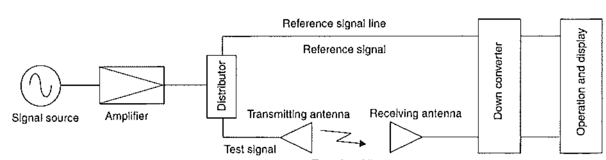


Fig.7 Antenna performance measurement with vector network analyzer

characteristics in a wideband width ranging from FM broadcasting frequencies to millimeter waves. Table 2 lists the specifications of the anechoic chamber.

Table 2 Facility specifications of anechoic chamber

2) Error due to measurement system

We used a vector network analyzer as the measurement system for the anechoic chamber.

The test wave generated from the signal source for the transmitting antenna is input, via an amplifier, to the distributor mounted right under the antenna. There, the test wave is distributed as the test signal to the transmitting antenna and as the reference signal to the vector network analyzer. The vector analyzer compares the voltage of the test signal transferred via the antennas with the voltage of the reference signal, and cancels the fluctuation in test wave output and other factors of measurement error. Thus, the accuracy of measurement is increased. (See Figure 7.)

If especially high accuracy is required for a measurement or the antenna to be tested inevitably requires temporary installation of a jig that will reflect waves, the time domain gate function of the vector network analyzer can be used. This function executes the operation to cancel reflected waves, for higher accuracy.

3.4 Increase in Evaluation Efficiency

For the anechoic chamber, we also improved the efficiency of the evaluation to attain high measurement accuracy.

Unlike the conventional evaluation by an external organization, the evaluation in the company enables us to manage evaluation data in an integrated manner. Accordingly, we can increase the efficiency of evaluation.

The measurement system has the following features:

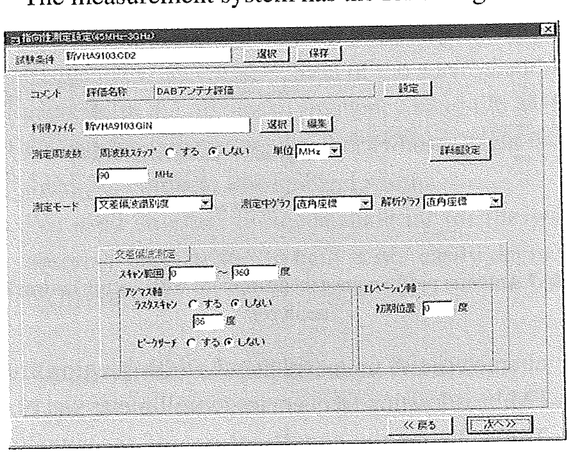


Fig.8 Automatic measurement setting screen

(1) A personal computer can be used to control all those operations of the measurement system which account for most of the measurement operations.

(2) The personal computer can operate with our original evaluation software to evaluate the performance of antennas accurately and efficiently.

(3) The evaluation software allows us to perform measurement settings in an interactive mode. This gives us voice guidance for every important setting operation. (See Figure 8.)

(4) The positioning unit rotation speed can be varied, and detailed test data can be obtained as required.

(5) The measurement system is connected to a LAN line, and measurement results can be transferred to the Kobe office on a real-time basis for the sharing of measurement data. An optical fiber cable is used for the LAN line to add to the shielding characteristics of the anechoic chamber.

3.5 Quality Control during Anechoic Chamber Construction

The performance of the anechoic chamber ultimately depends on the quality control applied at each stage of its construction.

We applied the quality control procedure that we used for the construction of our 10-meter anechoic chamber to the construction of the six-sided anechoic chamber. We did not leave quality control entirely to the anechoic chamber maker. As instructed in this procedure, we passed the instructions defining the flow of quality control to the maker before the construction of the chamber, and agreed to carry out an inspection at the end of each construction process specified in the instructions. The maker was able to proceed to the next process only when the completed process met the specifications.

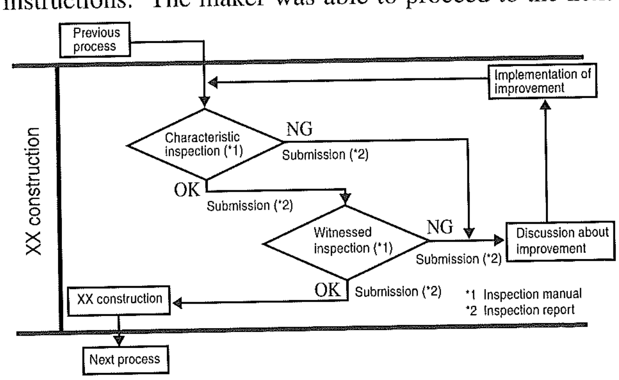


Fig.9 Quality control follow-up using anechoic chamber

We attended and witnessed inspections, especially in cases involving processes related to important characteristics, such as shielding and reflected-wave level characteristics.

We also provided a copy of the inspection results report for each process to the maker, to retain quality records. (See Figure 9.)

3.6 Safety Facilities

When using the anechoic chamber, workers usually access the walkway, antenna seats, and stairways. These structures are as high as about 1 to 3.8 meters from the floor. We installed tie-down chains on these structures for the workers' safety.

There was the possibility that the safety facilities, including the tie-down chains and their supports, installed inside the anechoic chamber could reflect waves and lower measurement accuracy. To avoid this, we installed them in such a way that we would be able to cover them with wave absorbers and store them in positions where they would not reflect waves. Thus, we were able to maintain both worker safety and measurement accuracy. (See Figure 10.)

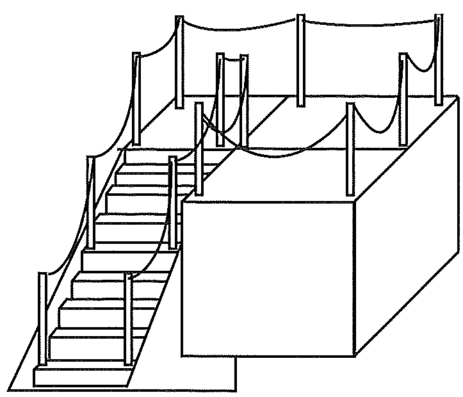


Fig.10 Tie-down chain

We also designed the anechoic chamber to allow workers to use a hoist when installing a heavy antenna. We defined a set of rules on how to handle the safety facilities for their operations without incurring risk.

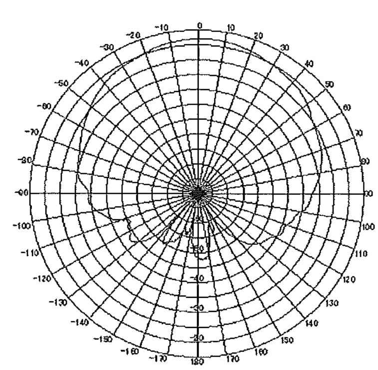


Fig.11 Example of measurement of 2-GHz band patch antenna directivity

4. Example of Antenna Evaluation

Figure 11 shows the results of the measurement of the directivity of a 2 GHz band patch antenna evaluated using the anechoic chamber. The measured directivity matched the requirement for the antenna. (See Figure 11.)

Conventionally, it took about five days to obtain the same evaluation , when the measurement was consigned to an external organization. Using the anechoic chamber, we were able to complete the same evaluation in one day and a half. Accordingly, use of the anechoic chamber substantially shortened the evaluation period.

5. Conclusion

This is the first six-sided anechoic chamber constructed at Fujitsu TEN. We had many problems to be solved in the course of building it.

We had already constructed an EMC anechoic chamber so, in a sense, one might say that this was the second anechoic chamber we constructed. However, because of the difference between antenna evaluation and EMC evaluation, we were unable to incorporate all of the things we learned during the construction of the EMC anechoic chamber, into the construction of the 10-meter anechoic chamber. We solved the problems in cooperation with an anechoic chamber maker, and decided on an optimum construction method after studying the nature of antenna evaluation.

As a result, we were able to construct an anechoic chamber that could meet initially required specifications and be one of the largest six-sided anechoic chambers in Japan. This was the product of a fusing of the anechoic chamber's technologies and Fujitsu TEN's antenna evaluation technologies.

We intend to make full use of the six-sided anechoic chamber to improve our antenna evaluation technologies and support Fujitsu TEN in the further development of our car antenna business in the coming century.

References

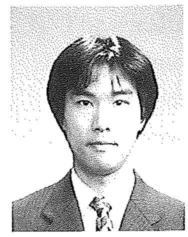
Togawa et al: Evaluation of Scattered Waves in Anechoic Chamber (EMCJ90-44, PP.9-14)

Electronic Information Communications Society: Antenna Engineering Handbook

Authors

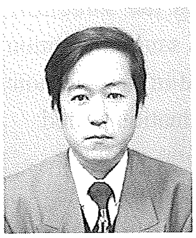
Kazushige Ogino

Employed by Fujitsu TEN since 1989. Engaged in developing antennas and related equipment. Currently in the Audio Visual R&D Department, A.V.C. Division.



Keizo Itazu

Employed by Fujitsu TEN since 1992. Engaged in designing car audio circuits and supporting the sales of line-genuine audio products. Currently in the Nakatsugawa Technical Center.



Shigeaki Inamura

Employed by Fujitsu TEN since 1982. Engaged in developing antennas and related equipment. Currently in the Quality Control department, A.V.C. Division.

Kunitsugu Tanaka

Employed by Fujitsu TEN since 1963. Engaged in developing broadcast relay and mobile radio equipment and preparing for the foundation of the Nakatsugawa Technical Center from June, 1996. Currently in the Assistant Department General Manager of the Nakatsugawa Technical Center.