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**Alternative test procedure for
measuring accuracy and immunity
of direction finder using a simulator**

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REPORT ITU-R SM.2354-0

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of direction finder using a simulator**

(2015)

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1 Introduction

Recommendations ITU-R SM.2060-0 – Test procedure for measuring direction finder accuracy, and ITU-R SM.2061-0 – Test procedure for measuring direction finder immunity against multi-path propagation, define standardized test procedures for use by direction finder (DF) manufacturers which will allow users to compare the direction finding accuracy of DF systems from different manufacturers.

The simulator described hereunder provides an alternative measurement method where DF accuracy measurement using an anechoic chamber or open air test sites (OATS) is difficult. It is particularly useful for measurement of DF accuracy in areas where it is difficult to secure an OATS with an electromagnetically clean environment and/or where it is difficult to acquire a frequency licence for the measurement on an OATS. And it is also useful when the measurement in an anechoic chamber

has the problem of not being able to secure sufficient distance from the DF system when testing is done in the HF band.

The DF antenna is comprised of multiple antenna elements. The key feature of this simulator is that it simulates the amplitude and phase of the output signals sent from the multiple antenna elements (these signals are collectively called the “array response”), when they receive an input signal from outside. The array response of a DF Antenna can be analyzed at a practicable level of accuracy using the latest electromagnetic field analysis tools available today.¹ Of course, it is also effective to use data measured from the actual array response of the DF antenna.

Annex 1 provides a sample configuration of an arrival angle simulator that can be used with the measurement method as described below. Annex 2 provides some measurement data to show that DF accuracy measurement results obtained using the simulator are comparable to those results obtained by actual measurement.

2 Measurement setup

2.1 Arrival angle simulator

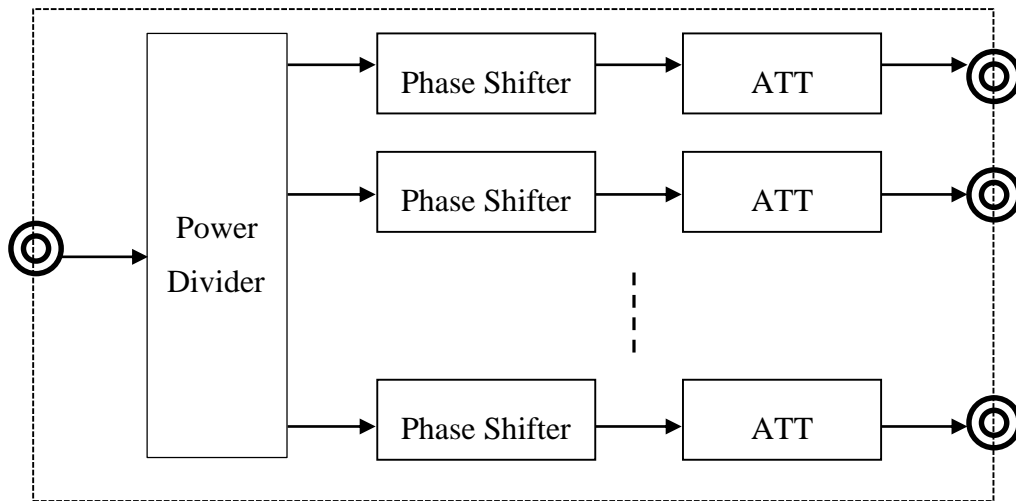
Figure 1 shows the basic circuit of the arrival angle simulator which simulates the array response. This circuit simulates the electric output signals sent from respective antenna elements (i.e. array response) when an input signal arriving from a given azimuth was received by the DF antenna. This arrival angle simulator has much the same functions as the arrival azimuth simulator described in Report ITU-R SM.2125, but it can also take into account the elevation angle.

Both the input and output signals for this arrival angle simulator are RF signals. This simulator reflects various conditions on the output signal. Not only the phase difference caused by the arrangement of antenna elements and the amplitude determined by the directionality of antenna elements, but also the amplitude and phase variation caused by mutual coupling between antenna elements, and even the impact of interference due to the antenna structure (such as interference from the antenna mast, etc.) can be reflected on the output for the tested frequency.

It is possible to simulate the output signal each antenna element sends, by changing the setup of the phase shifter and attenuator (ATT) according to the incidence angle of the input signal.

¹ Examples of electromagnetic field analysis tools include: Non-commercial software: “NEC-4” developed at the U.S. Lawrence Livermore National Laboratory and the University of California; Commercial software: “ANSYS HFSS” licensed by ANSYS, Inc., and “CST STUDIO SUITE” licensed by Computer Simulation Technology AG.

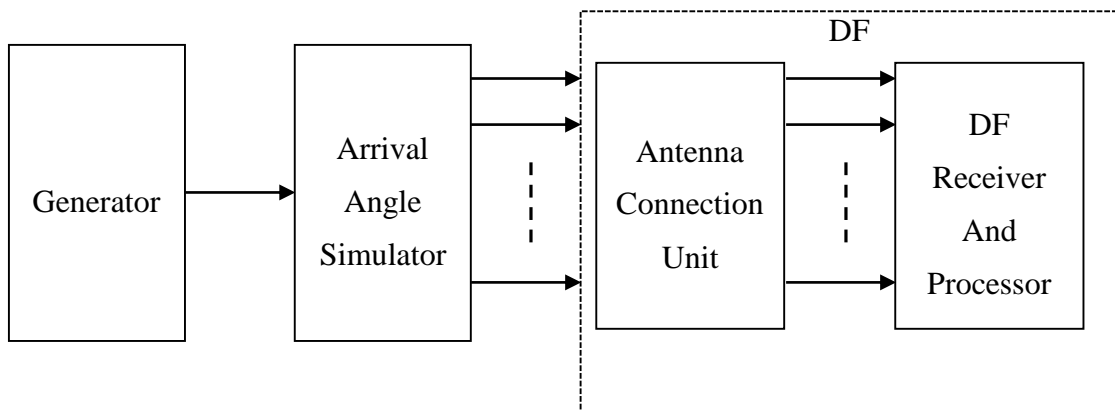
FIGURE 1
Basic circuit of arrival angle simulator



2.2 Simulator for clear environment

The configuration of a simulator for simulating a single input signal is illustrated in Fig. 2. This configuration simulates the test environment shown in Fig. 1 of Recommendation ITU-R SM.2060. A signal is generated using a generator and sent to the arrival angle simulator which simulates the output signal of the DF antenna. Output signal from the arrival angle simulator is connected to the antenna connection unit of the direction finder. Therefore the direction finder is tested for the direction finding system excluding its antenna.

FIGURE 2
Simulator configuration for a single input signal



2.3 Simulator for multipath environment

Figure 3 illustrates the configuration of a simulator for simulating a multipath case in which a signal emitted from a single source arrives along a number of paths. This configuration simulates the test environment shown in Fig. 1 of Recommendation ITU-R SM.2061.

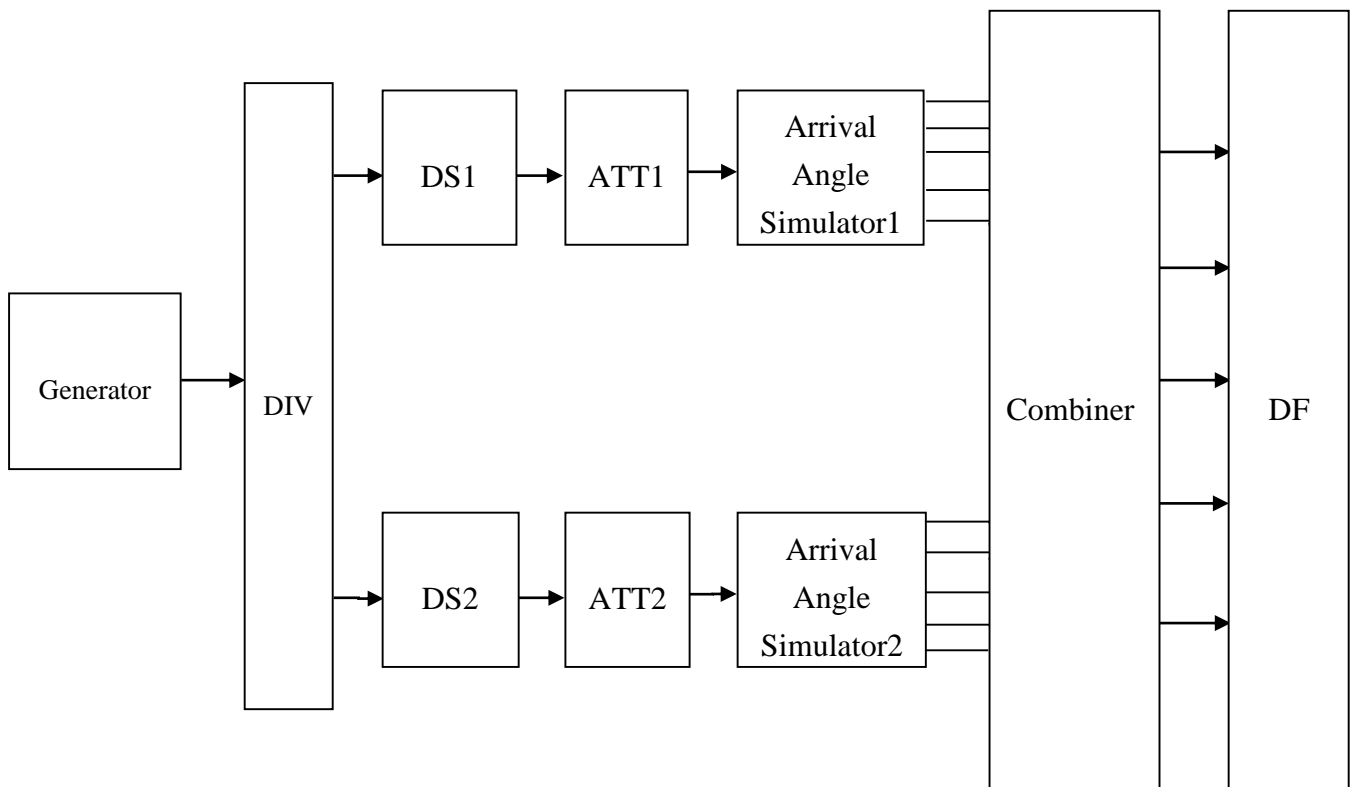
Using a power divider, a single signal generated by the generator is divided into two signals, one of which represents the main signal, while the other represents a reflected signal. The amplitude and phase delay can be controlled for each of the main and reflected signals.

The lines for transmitting the main and reflected signals are respectively connected to arrival angle simulators 1 and 2, which simulate the array response of the DF antenna according to the respective arrival angles of the main and reflected signals.

The output signals of the two arrival angle simulators are combined for each antenna element to reproduce the reception signal sent from each antenna element. This enables simulation of the reception signals of the DF antenna in a multipath propagation environment.

The combined output signal is connected to the antenna connection unit of the direction finder.

FIGURE 3
Simulator configuration for a multipath signal



DS: Delay Shifter

2.4 Calibration of the simulator

The simulator should be calibrated either regularly or each time before using. Accuracy of the simulator can be checked by measuring its output signal using a network analyser generally sold on the market.

To conduct measurement, select two of the multiple output ports of the simulator and connect them to the reference port and measurement port of the network analyser. Set the simulator and network analyser to the frequency you wish to test. Set the phase and amplitude of the two output ports of the simulator and measure the phase and amplitude differences of the two ports using the network analyser. Record the difference between the measured data and the values set on the simulator as the calibration value.

The simulator is set to a certain set of amplitudes and phases representing the array response when conducting simulation. Accurate simulation can be achieved by correcting the amplitude and phase based on the calibration value obtained. Calibration measurement can be made clearer if the simulator has a reference port.

3 Antenna modelling

The array response of the DF antenna can be obtained using either one of the modelling approaches described below.

3.1 Modelling by electromagnetic field analysis

The DF antenna array response can be obtained using an electromagnetic field analysis tool (software). Set the mechanical shape of the antenna and the impedance at the output point of the antenna elements before conducting the analysis. Analyse the far-field solution (the solution for when the emission source was located at an infinite distance) using the electromagnetic field analysis tool to obtain the output signals that would be sent from each antenna element when the DF antenna receives an input signal at the specified frequency, arriving from the specified angle. The result of this analysis reflects not only the phase difference caused by the spatial arrangement of the antenna elements and the amplitude components determined by the directionality of each of the antenna elements but also mutual coupling between antenna elements and the interference from the antenna mast and other parts of the antenna structure. Convert the output data obtained by the electromagnetic field analysis tool to the phase and amplitude of the received voltage and record them. Repeat the analysis for different arrival angles. The phase and amplitude data corresponding to each antenna element obtained for different azimuths comprise the array response of the DF antenna for the respective arrival azimuths.

Not only the arrival azimuth but the elevation angle can be set when conducting the electromagnetic field analysis.

3.2 Modelling by measurement data

For those frequencies that can be measured in an anechoic chamber or an OATS, conduct actual measurement and record the phase and amplitude of the output signal from each antenna element. This data can be used in the simulation as the array response of the DF antenna. To conduct actual measurement, arrange the measurement setup as shown in Fig. 1 of Recommendation ITU-R SM.2060 – Test procedure for measuring direction finder accuracy, in an anechoic chamber or an OATS. Set up the recording device so as to record the phase and amplitude of the multichannel output signal from the DF antenna.

Use the transmit antennas (Tx) to transmit signals at the tested frequency and receive the signals with the DF antenna (Rx). Control the turn table to rotate the antenna in azimuth steps suitable for the tested DF. Record for each azimuth step the phase and amplitude of the output signal of the receiver system corresponding to each antenna element.

Phase and amplitude data corresponding to each antenna element will be obtained for each azimuth. These data comprise the array response of the DF antenna for the respective arrival azimuths.

4 Measurement procedure

4.1 Clear environment

Conduct measurement using the measurement setup described in Fig. 2 in § 2.2 and the same parameters indicated in Table 1 of Recommendation ITU-R SM.2060. Set the arrival angle simulator to the appropriate phase and amplitude (or attenuation) for the tested frequency and azimuth by referring to the array response data obtained in § 3.1 or 3.2 described above. Here, the phase and amplitude (or attenuation) need to be set separately for each line that correspond to each of the antenna element of the DF antenna.

First, set the generator to generate a signal at Frequency 1. The arrival angle simulator should be set to the phase and amplitude (or attenuation) corresponding to Frequency 1 and the specified azimuth. Record the DF output signal for the azimuth. Repeat the measurement for all the specified azimuths.

Next, set the generator to generate a signal at Frequency 2. Set the arrival angle simulator to the appropriate phase and amplitude (or attenuation) and conduct measurement likewise above. Repeat measurement through Frequency 3 to Frequency 16.

4.2 Multipath environment

Conduct measurement using the measurement setup described in Fig. 3 in § 2.3 and the same parameters indicated in Table 1 of Recommendation ITU-R SM.2061 – Test procedure for measuring DF immunity against multipath propagation. Set Arrival Angle Simulator1 and Arrival Angle Simulator2 to the appropriate phase and amplitude (or attenuation) for the tested frequency and azimuth by referring to the array response data obtained in § 3.1 or 3.2 described above. Here, the phase and amplitude (or attenuation) need to be set separately for each line that correspond to each of the antenna element of the DF antenna.

Set ATT1 and ATT2 to 0 dB and 6 dB, respectively. Set DS1 to 0 degree. These setting values will not be changed throughout the measurement.

First, set the generator to generate a signal at Frequency 1. Arrival Angle Simulator1 should be set to the phase and amplitude (or attenuation) corresponding to Frequency 1 and the specified true azimuth. Arrival Angle Simulator2 should be set to the phase and amplitude (or attenuation) corresponding to Frequency 1 and the specified azimuth with an arrival angle difference of $\Delta\theta$. Set DS2 to the three specified phases of $\Delta\phi$, one at a time. Record the DF output signal for each azimuth.

Next, set Arrival Angle Simulator2 to the second specified value of $\Delta\theta$ and record the DF output signal for each azimuth by switching among the three phases of $\Delta\phi$, one at a time. Repeat the measurement for the third value of $\Delta\theta$.

The above steps will complete measurement for Frequency 1. Move on to Frequency 2 and on and repeat the measurement by setting the generator to Frequency 2 to Frequency M, until measurement of all specified frequencies are finished.

5 Additional consideration for HF DF measurements

It is also possible to measure DF accuracy for input signals with an elevation angle. It has already been noted above that measurement of HF DF accuracy in an anechoic chamber or OATS environment involves some degree of difficulty, but it is even more difficult to measure input signals with an elevation angle because it requires not only a planar expanse but also space in the vertical direction.

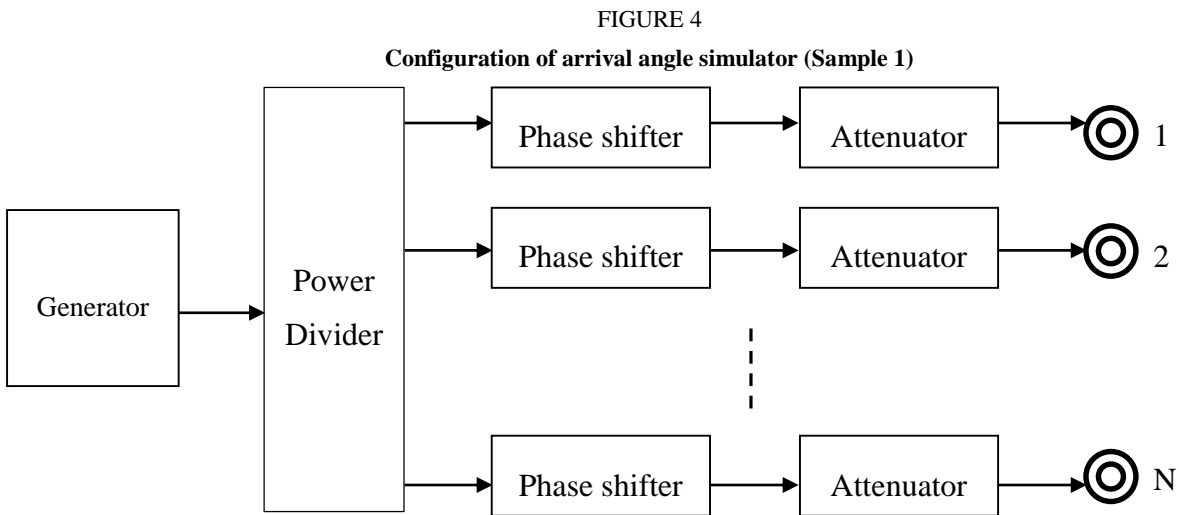
Using electromagnetic field analysis described in § 3.1, however, it is possible to obtain the phase and amplitude of output signal produced by each antenna element when the DF antenna receives an input signals with an elevation angle. The accuracy of HF DF when it receives an input signal with a given frequency, azimuth, and elevation angle can be measured using data obtained from the electromagnetic field analysis for the setting of the simulator.

Annex 1

Sample configuration of arrival angle simulator

The following are some examples of simulator configuration.

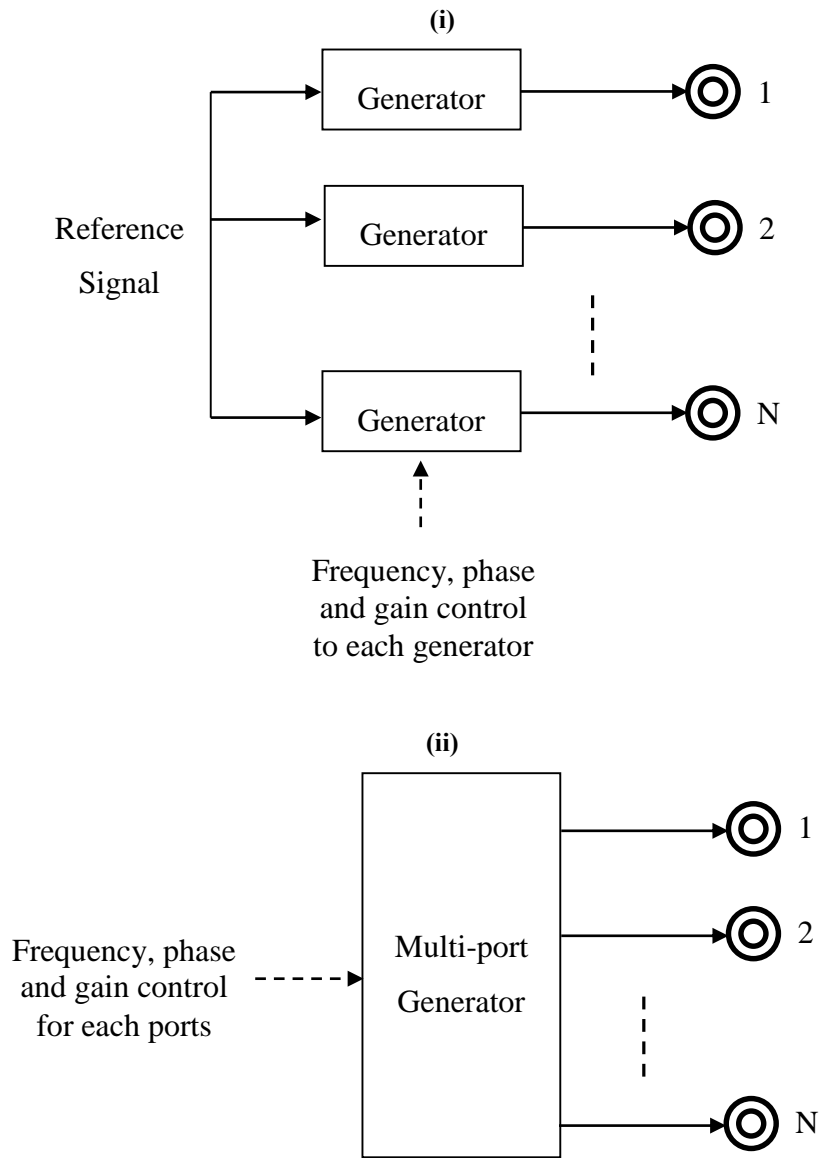
- a) The power divider, phase shifters and attenuators of the analogue circuit module are connected in a configuration shown below (Fig. 4) to simulate the output signals of a DF antenna made up of N antenna elements.



- b) The configuration shown in Fig. 5 requires the use of commercially available phase-controllable signal generators that allows for synchronous operation of multiple units. Provide the same number of units as the number of antenna elements comprising the DF antenna and generate CW signals. In the method shown as Fig. 5 (i), set a specific frequency, phase and gain (amplitude) for each of the signal generators to simulate the array response. However, some of the latest signal generators are equipped with multiple output ports. If using such multi-port generators, the configuration will become much simpler as shown in Fig. 5 (ii).

FIGURE 5

Configuration of arrival angle simulator (Sample 2)



Annex 2

Comparison of simulation measurement results and actual measurement results

1 Electromagnetic field simulation of the antenna

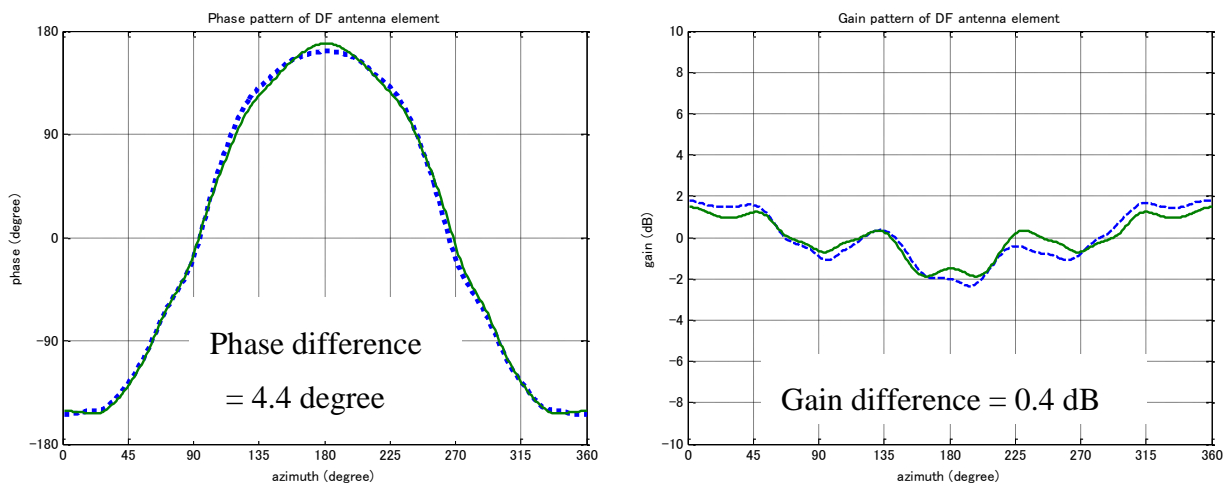
The array response of a DF antenna can be obtained through simulation using a calculator.

Techniques such as Method of Moments (MoM) and Finite-Difference Time-Domain method (FDTD) are used for electromagnetic field analysis. Various types of electromagnetic field analysis software are being provided including NEC-4 developed by the U.S. Lawrence Livermore National Laboratory and the University of California and many other commercially available software. Array response data just as accurate as actual measurement results can be obtained through calculation by using software based on the latest method for electromagnetic field analysis.

Figure 6 shows examples of analysis results and actual measurement results of the phase and gain of a given antenna element of a five-element array antenna. The solid and dotted lines respectively represent the calculation results and the actual measurement results. The test frequency was 402 MHz. The difference between the analysis results and actual measurement results was approximately 4.4 degrees for phase and 0.4 dB for amplitude.

FIGURE 6

Comparison between electromagnetic field analysis results (solid) and actual measurement results (dotted)



2 Comparison between OATS test results and simulator-based test results

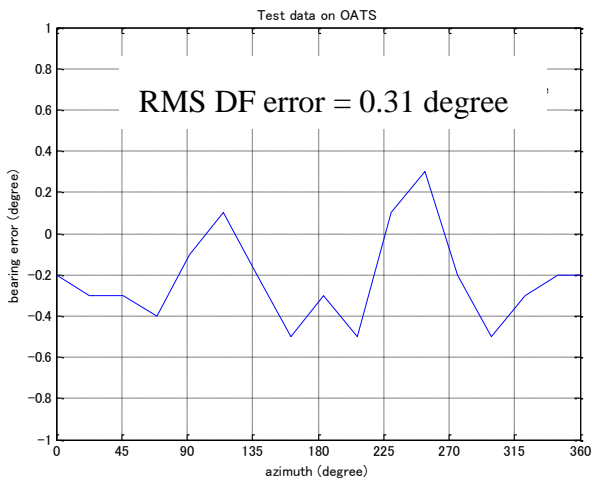
Figure 7 shows the test results of a DF with a five-element array antenna. The test frequency was 402 MHz. The test environment used for the OATS test was equivalent to that described in Fig. 1 of Recommendation ITU-R SM.2060.

The DF accuracy measured in the OATS test environment was 0.31 degree root mean square (RMS), whereas the DF accuracy obtained by means of array response analysis using a simulator was 0.11 degree RMS. The actual measurement results include azimuth errors attributable to the test site conditions, how the DF antenna was installed and the motion of the turn table, other than the measurement errors of the direction finder itself. While the test result obtained by using the simulator indicate less azimuth measurement error than the OATS test result, it can be concluded that this method offers sufficient accuracy for evaluating DF accuracy.

FIGURE 7

Comparison between DF accuracies obtained by actual measurement and simulation

(i) Actual measurement



(ii) Simulation

