

REPORT ITU-R SM.2056

**Airborne verification of antenna patterns
of broadcasting stations**

(Question ITU-R 225/1)

(2005)

1 Executive summary

This Report describes the measurement procedures, the equipment required, and the reporting procedures for antenna radiation pattern measurements using an aircraft. This Report is independent of the airborne platform chosen and it can be used regardless of the broadcasting system used. However, additional suggestions are given for specific airborne platforms and specific broadcasting systems, so that it can be tailored to anyone's specific needs.

The Report is divided into three Annexes:

- Annex 1 introduces the different antenna pattern types that can be distinguished, and the measurement procedures to measure those. The equipment needed to perform such measurements is described. This description is sufficiently detailed to assemble one's own system, without limiting the choice of equipment. The post flight analysis, important for evaluating the measurement accuracy, is described, followed by a reporting standard.
- Each broadcasting type and each frequency range requires its own settings and has its own points of attention. Annex 2 is dedicated to these items.
- Annex 3 describes the specific problems encountered when choosing a specific aircraft type, and proposes solutions when possible.

Annex 1**Airborne verification of antenna patterns of broadcasting stations****1 Introduction**

This Annex describes the measurement procedures, the equipment required, and the reporting procedures for antenna radiation pattern measurements using an aircraft. The structure of the Annex is as follows:

Section 2 describes the different antenna pattern types that can be distinguished. Section 3 introduces the measurement method in general. Section 4 defines the different measurement flights types. Section 5 describes the equipment needed to perform these measurements. This description is

sufficiently detailed to enable assembling one's own system, without limiting the choice of equipment. Section 6 describes the measurement procedures involved. Sections 7 through 9 deal with the different aspects of data processing, measurement uncertainty calculation and reporting.

The recommendations in this Annex are independent of the type of aircraft chosen and it can be used regardless of the broadcasting system used. Annexes 2 and 3 will give additional recommendations for specific airborne platforms and specific broadcasting systems.

2 Antenna pattern types

The radiation pattern of any antenna is three-dimensional. Measured antenna patterns are generally two-dimensional cuts of that three-dimensional pattern. Common cuts are the “vertical antenna pattern” and the “horizontal antenna pattern”. The vertical antenna pattern is a vertical cut of the antenna pattern through the antenna and a specific azimuth direction. The horizontal antenna pattern is a horizontal cut of the antenna pattern through the antenna and a specific elevation or down tilt angle. See Figs. 1 and 2. The coordinate systems used are described in Recommendation ITU-R BS.705.

FIGURE 1
Vertical antenna pattern

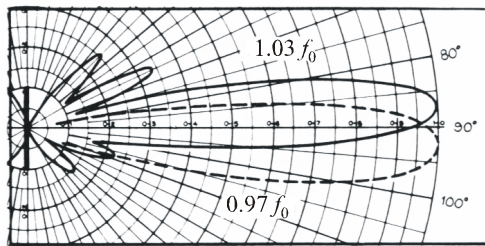
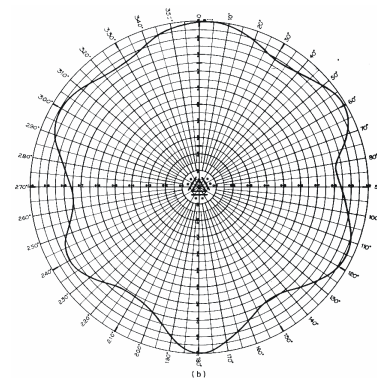


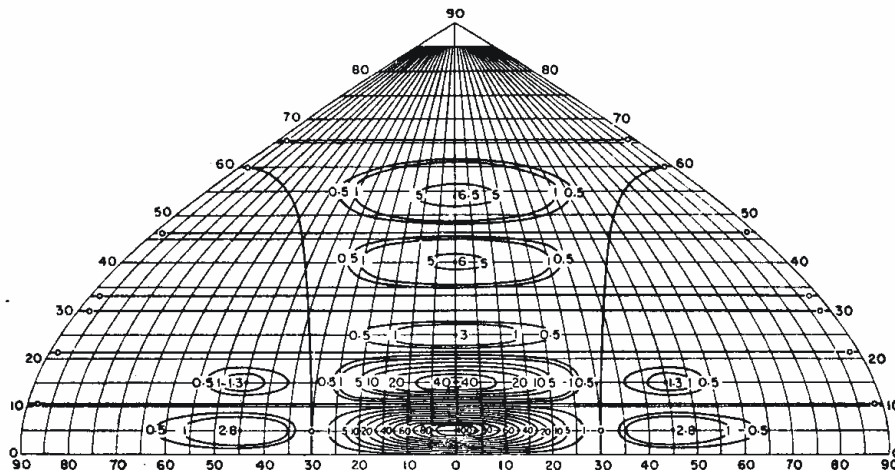
FIGURE 2
Horizontal antenna pattern



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In certain cases a lot of emphasis is put on one specific sector of the antenna. For highly directional HF broadcasting antennas, the exact form and position of the main lobe, as well as the effective radiated power (ERP) in that main lobe determine the footprint on the targeted area, and are therefore very important. A specific antenna pattern measurement could chart that part of the antenna pattern. An example of such an antenna pattern, the Sanson-Flamsteed projection, is given in Fig. 3.

FIGURE 3
Main lobe antenna pattern



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Antenna pattern measurements can be repeated for different azimuths or different elevation angles to obtain more information on the complete three-dimensional antenna pattern. Those azimuths or elevation angles can be strategically chosen based on the geometry of the antenna, simulations and experience from previous measurement campaigns.

Measuring any of these antenna pattern types requires its own set of measurement flights, but the measurement procedure is very similar if not the same.

3 Method of measurement

An antenna pattern measurement is basically a series of field-strength measurements, each taken at an exactly known distance from the antenna to be measured. With these two values the absolute ERP in that point can be calculated. If we measure the ERP at a series of points positioned on a circle around the antenna, the horizontal antenna pattern emerges. Other diagram cuts can be measured at will. The formula for calculating absolute ERP is, in linear form:

$$ERP = \frac{P_{RX} \cdot R^2}{G_{RX}} \cdot \left(\frac{4 \pi f}{c} \right)^2$$

where:

- ERP : power relative to the reference antenna (W)
- P_{RX} : power at the receiver input terminals (W)
- R : distance (m) between the receive and transmit antennas
- G_{RX} : gain (linear value) of the receive antenna relative to the reference antenna
- f : frequency (Hz)
- c : speed of light (m/s).

Care must be taken to measure position and P_{RX} at exactly the same time. If this condition is not met, the resulting ERP-value is not correct. In this formula ERP and G_{RX} are expressed relative to a reference antenna. This reference antenna can be an isotropic radiator, a half wave dipole or a

monopole, depending on the broadcast band used. Additional losses such as cable losses, antenna alignment loss or polarization loss should be included in the value for G_{RX} . Generally, using a logarithmic version of the same formula is more practical:

$$ERP = P_{RX} + 20 \log(R) - G_{RX} + 20 \log(f) + 20 \log(4\pi/c)$$

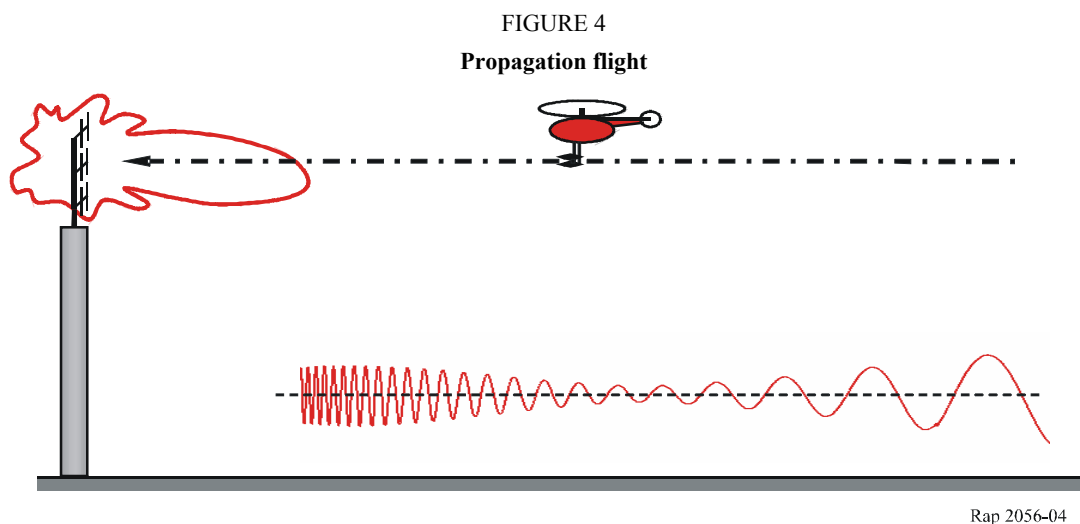
P_{ERP} and P_{RX} are now expressed in dBW, G_{RX} in dBref.

4 Measurement flight types

The type of measurement flights conducted depend fully on the antenna situation and the aircraft used. For example, for the measurement of the diagram of a VHF broadcast antenna with a helicopter, a different approach is needed than for the measurement of a medium-wave array with an aeroplane. The different measurement flight types and their application are described in this Section.

4.1 Propagation flight

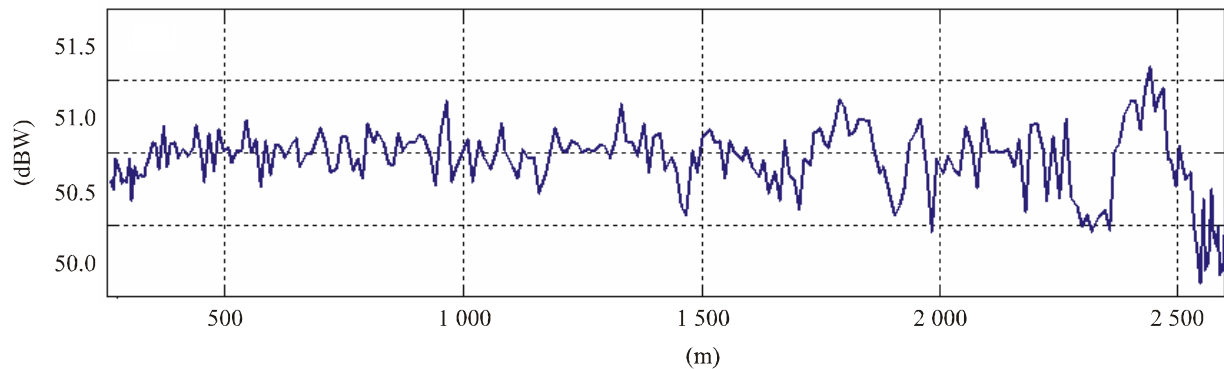
To determine the optimal measurement distance, a propagation flight can be performed. This is a flight in a straight line towards the transmit antenna, at exactly the height of the transmit antenna. That way the angular position of the measurement antenna as seen from the transmit antenna is constant, and therefore the transmitted ERP in that direction is constant. If no reflections are present, the measured ERP during the propagation flight will be constant too. If ground reflections or scattering off buildings is present, their influence will show as deviations from that straight line, as shown in Fig. 4.



The suggested measurement direction for a propagation flight is in the direction of the main lobe in the antenna pattern. Multiple propagation flights are recommended on antennas with multiple radiation directions and in cases where ground conditions and thus ground reflections differ.

In addition to the theoretical graph of Fig. 4, an actual measurement result is given in Fig. 5. This graph is made of a 50 kW VHF FM broadcast transmitter. The transmit antenna consisted of an array of vertically polarized log-periodic dipole antennae mounted on tower approximately 150 m above the ground. The circle indicates the distance that was selected for a subsequent circular flight.

FIGURE 5
Actual propagation flight result



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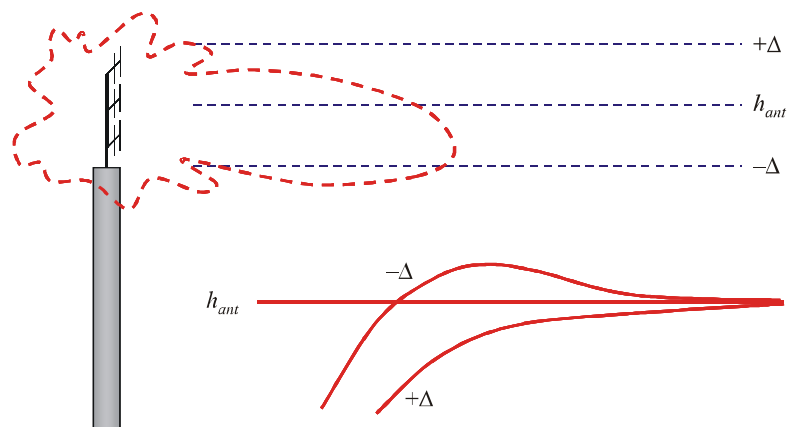
From the result of the propagation flight an optimum distance is selected for subsequent measurements. The optimum distance is the distance where:

- the amplitude of the reflections is least, and
- the minima and maxima are closest together.

The first criteria is obvious, the second may require explanation. If the minima and maxima caused by ground reflections lie far apart, and the ground is flat and homogenous, e.g. a complete circle flight could be conducted at a distance where the minimum or maximum occurs. This would result in the biggest measurement error achievable, while the problem would show the least as variations in the measurement result. So this situation should be avoided. With the example shown, the optimum measurement distance would lay around 1 300 m. This distance is marked with a circle in Fig. 5.

If the height at which the propagation flight is performed differs from the actual height of the antenna, the graph will drop when the aircraft comes close to the antenna. When flying too low and measuring a transmit antenna with downtilt, the graphs may show a temporary rise before this drop in value occurs. This effect is illustrated in Fig. 6.

FIGURE 6
Effect of incorrect height during the propagation flight

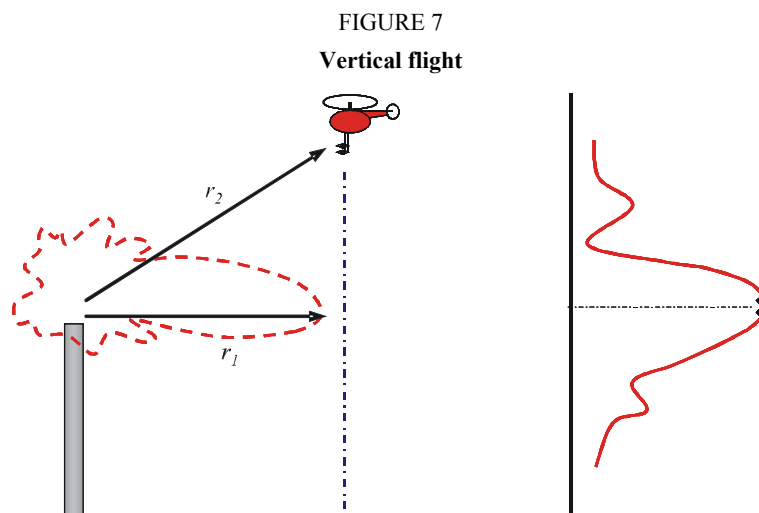


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Prior to the propagation flight, the pilot display assists the pilot by showing the actual position of the aircraft relative to the transmit antenna, as well as the desired start-position of the propagation flight. This position can be described with the desired azimuth angle with respect to the transmit antenna and the desired height. During the propagation flight, the pilot display assists the pilot by showing the offset in metres from the desired flight path. A propagation flight is easier to perform with an aircraft that maintains good control and manoeuvrability at low speed, such as a helicopter. One can fly in a straight line up to 200 m of the tower, then stop and fly away. This is not possible with all other aircrafts. A minimum distance to the transmitting antenna(s) should be kept at all times, to avoid excessive electromagnetic exposure. If the transmit antenna is mounted directly on the ground, as in the case with most long-wave, medium-wave and short-wave antennas, a propagation flight is not possible.

4.2 Vertical flight

To obtain the vertical antenna pattern of a broadcast antenna in a specific azimuth direction, a vertical flight can be performed. Measuring the vertical antenna pattern can be necessary to determine the optimum flying height for measuring the horizontal antenna pattern, as indicated in Fig. 7.



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To perform a vertical flight, the pilot first moves to the desired azimuth direction, then descends to the desired start height. The pilot display assists the pilot by showing the actual position of the aircraft relative to the transmit antenna, as well as the desired start position for the vertical flight. The pilot then starts ascending in a straight vertical line, trying to retain his horizontal position as good as possible. If a helicopter is used, maximum stability is obtained when the flight is performed flying from a low altitude to a higher altitude at full throttle.

During the vertical flight, the pilot display assists the pilot by showing the offset in metres from the desired flight path. This could be done representing the aircraft as a dot on a circular display. The centre of the circle represents the desired horizontal position, the circle itself shows the maximum allowed horizontal offset. The pilot should keep the dot within the circle while flying upward. The circular display can be connected to a compass to align its orientation with that of the aircraft. This makes steering easier, as the wind dictates where the nose of the aircraft is pointing.

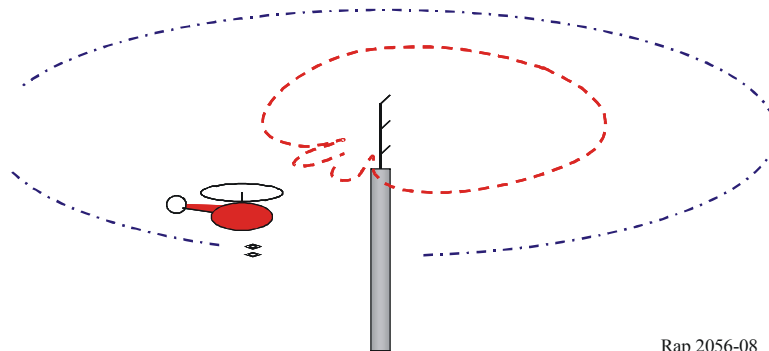
When no aircraft is available for vertical flights, the vertical diagram cannot be obtained this way. It has then to be estimated by interpolating measurement points of subsequent horizontal flights.

During the vertical flight the two correction factors need to be applied. A compensation for the difference in gain in the vertical antenna diagram of the measurement antenna and a compensation for the difference in distance (r_1 and r_2 in Fig. 4).

4.3 Circular flight

To obtain the horizontal antenna pattern of a broadcast antenna, the pilot starts flying a circle around the transmit antenna while correcting his altitude and distance to the transmit antenna until the target values are obtained. The measurement is then started, and the pilot continues flying along a circle around the tower, until the measurements are completed. During this process, the pilot is assisted with information on the pilot display. It shows the actual position of the aircraft relative to the ideal path around the tower in real-time. During the circular flight, the pilot display assists the pilot by showing the offset in metres from the desired flight path (distance and altitude). Generally it is necessary to fly part of a circle to enter the required flight path so the definition of a predetermined start azimuth is not practical. In most cases the pilot likes to see the object he or she is flying around so the layout of the aircrafts cockpit dictates if the circle is flown clockwise or counter clockwise. The software and antenna system should be adapted to this. Best stability is obtained when the aircraft flies with a steady and not too slow speed. As the aircraft flies around the antenna the relative wind direction changes with the azimuth angle, as a result of this the part of the aircraft pointing to the antenna changes during the flight. It is therefore in most cases necessary to steer the antenna during flight.

FIGURE 8
Circular flight



4.4 Other flight types

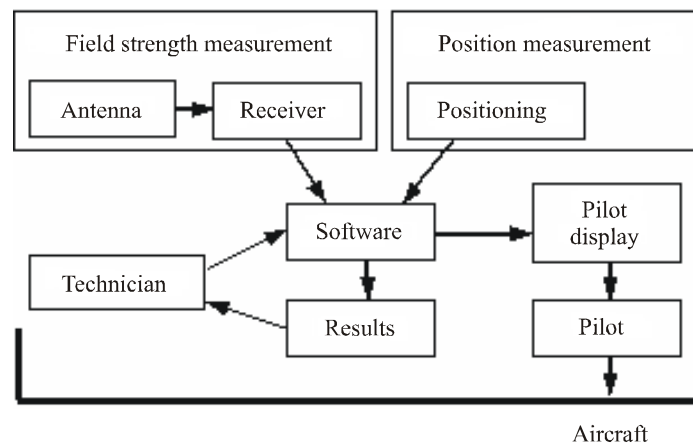
Antenna radiation pattern measurements around ground-based antennas like, e.g. HF curtain arrays and medium-wave towers or arrays require a different approach than tower-based TV or FM broadcasting transmitters. For example: circular flights at other heights than the height of the main lobe can give the measurement points needed to construct a 3-dimensional picture of the radiation pattern, straight flights at low heights in the azimuth of the main lobe can give an impression of the vertical radiation pattern.

As long as the 3-dimensional position of the measurement point is known exactly, and the ERP is calculated in that measurement point, there are no limits to the actual flight path used, as long as the engineer that interprets the measurement data has a profound knowledge of the matter.

5 Measurement equipment

As shown in § 3, ERP can be measured by exactly measuring position and field strength. Position can be measured using any positioning device that gives fast and accurate 3D position information. Field strength can be measured with a free space calibrated antenna and a calibrated measurement receiver. The position and field-strength values are recorded and processed by a computer. It calculates ERP and the position of the measurement point relative to the antenna under test, and displays the results in an appropriate form to the technician. The technician controls the measurement system and takes decisions based on the results shown on the screen. The software also generates information for the pilot, to assist his navigation around the antenna site. The pilot is responsible for the flight itself and all related security issues. A simplified schematic presentation of a typical measurement set-up is shown in Fig. 9, subsystems of which will be discussed in the following paragraphs.

FIGURE 9
Schematic presentation of an airborne antenna pattern measurement system



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5.1 Positioning equipment

As the distance used in the formulae is 3D distance, the position of the measurement and the position of the transmit antenna have to be known along three axes, e.g. latitude, longitude and height. The difference of the 3D position of the measurement antenna relative to the positioning device should be taken into account.

The positioning system used should in any case meet the criteria for accuracy and update rate. The accuracy depends on the application but is typical ± 1 m in all directions. Requirements for the update rate can be found at the end of this section and in § 5.5 of this Annex. Hybrid positioning systems using reference beacons can be used. Coverage of such beacons may limit the flexibility. The position accuracy determines the accuracy of the calculated distance to the antenna under test. This in turn determines the accuracy of the calculated ERP-value and relative position. Measurements close to the antenna under test require a higher position accuracy than measurements at a larger distance. The optimum measurement distance depends on the wavelength, the dimensions of the antenna under test and environmental conditions that cause reflections. Required position accuracy is in the order of 2 m.

The update rate of the positioning device needs to be sufficient to generate enough measurement points along the curve flown. This is a function of the angular ground speed of the aircraft. Also the update rate of the pilot display should be near real-time. An update rate of 2 Hz is an absolute minimum, 10 Hz or more would be advisable.

5.2 Measurement antenna

5.2.1 Gain

To measure the absolute field strength the antenna has to be free space calibrated. Gain has to be expressed relative to the appropriate reference antenna. The calibration accuracy of the antenna is one of the main factors influencing the total measurement accuracy. A calibration accuracy of 0.5 to 1 dB is achievable and advisable.

The actual value of the antenna gain is not critical as long as it is exactly known. However, an antenna gain lower than -20 dBi will make the unwanted pickup of the antenna cable dominant. And a directivity above about 6 dBi will result in lower accuracy due to alignment errors.

5.2.2 Diagram of the measurement antenna

The measurement antenna only exhibits its calibrated gain figure when aligned bore sight to the antenna under test. Exact alignment of the measurement antenna during the flight is rather difficult, therefore it is preferable to use a measurement antenna which has as little as possible gain variation around the main lobe. That way alignment becomes less critical, improving the measurement accuracy.

When a flight is made on a different height than the antenna under test, e.g. during a vertical flight, the gain of the measurement antenna will vary with the angle of the incoming wave. When the vertical pattern of the measurement antenna is known, one can compensate for this in the measurement software. To be able to do this the measurement antenna should have a smooth antenna pattern.

It is not necessary to design a measurement antenna that has a high front to back ratio. The antenna under test is relatively close to the wanted antenna and other broadcast transmitters on the same frequency are relatively far away. As the signal strength is inversely proportional to the distance, the wanted signal is several magnitudes stronger than the signal of other broadcast transmitters received from other broadcast towers. There is generally no need to suppress them any further using the directivity of the measurement antenna.

5.2.3 Alignment of the measurement antenna

In most cases, the measurement antenna has directivity. So during flight, the measurement antenna has to be kept as close to bore sight to the antenna under test as possible. This can be done using some mechanical or electromechanical rotator controlled by the technician. Some indication of the actual antenna position is necessary in all cases, to roughly aim the antenna at the antenna under test. To adjust the direction more precisely, some aiming device is necessary. A small camera mounted on or near the antenna and looking in the same direction is a good and cost effective solution. Some sunlight filtering is needed to prevent overloading of the camera chip.

Omission of any means to direct the measurement antenna towards the antenna under test will result in incorrect results. Stabilizing the aircraft at a fixed angle towards the antenna under test is generally not possible, the wind direction will induce a pitch on the flight path. Alignment in the vertical plane is generally not feasible.

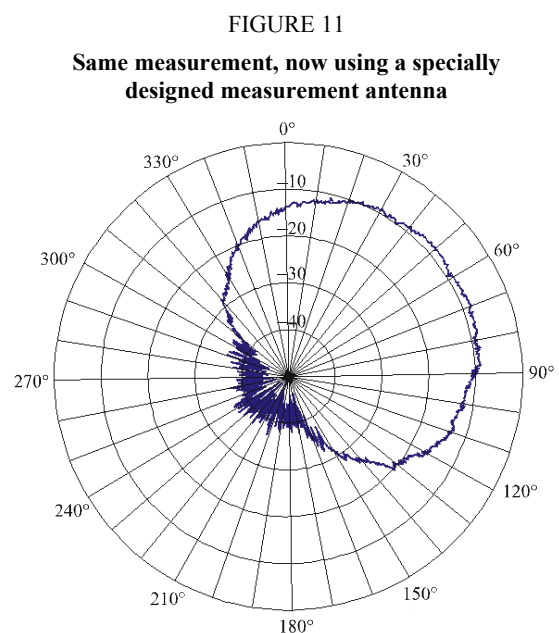
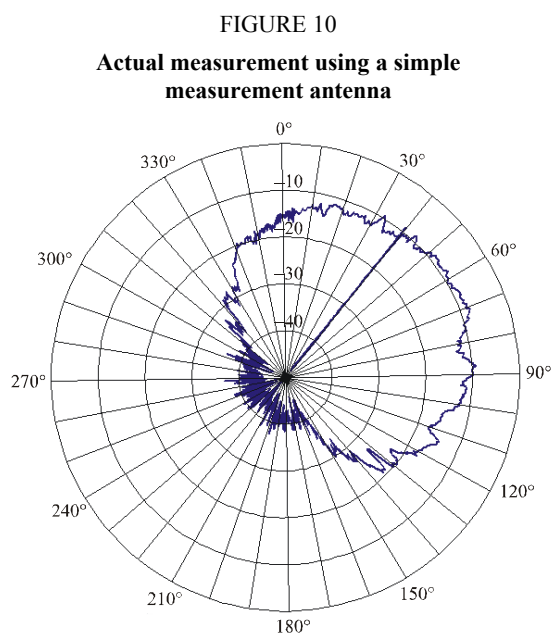
Misalignment and the resulting measurement error should be accounted for in the uncertainty analysis of the measurement.

5.2.4 Suppression of ground reflections

To get an accurate representation of the antenna pattern, only the direct waves from the transmit antenna to the measurement antenna should be measured. However, any object within sight of both antennas may cause transmitted waves to reflect. One should be aware that if no measures are taken, both direct and reflected waves are measured, generating some sort of unwanted “modulation” on the antenna diagram measured and presented.

This problem is very much dependant on the vertical directivity of the transmit antenna and of the receive antenna, and of the height of the transmit antenna versus the measurement distance. For example, low gain VHF FM antennas on low sites offer a much higher challenge in this respect than high UHF TV sites with high gain antennas. Also reflection of the received signal against parts of the aircraft must be considered. As ground reflections are amongst the major contributors to the total measurement uncertainty, this item is worth paying extra attention to.

Proper design of the measurement antenna can make the measurement system less vulnerable to disturbance by ground reflections. This can be done by designing an antenna that suppresses directions from which reflections are expected and favours the direct wave. This is illustrated with a practical example in Figs. 10 and 11:



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In this example, a VHF FM broadcasting antenna was measured twice, once with a simple measurement antenna, and again with an antenna specially designed for airborne antenna pattern measurements. The reflections are shown as “modulations” in the first measurement. The advantage of the second specially designed measurement antenna is obvious.

Another way of attenuating reflections could be the deployment of multiple measurement antennas followed by multiple receivers and using DSP software. This software can use an algorithm for example MUSIC to extract only the direct signal from the sum of the reflected and direct signal. Whatever method is used to eliminate reflections, care must be taken to assure that the reproduced signal level is still an accurate representation of the signal level of the direct wave.