REPORT ITU-R BO.2102

Multiple-feed BSS receiving antennas

(2007)

1 Introduction

This Report addresses technical and performance issues associated with the design of multiple-feed BSS receiving earth station antennas.

The cost of the earth-segment of a BSS system depends on the ability to deploy receiving earth stations with antennas that are relatively small in size and low in cost to the consumer. The benefit of multiple-feed receiving earth stations is that they permit BSS customers to receive services from multiple satellite locations using one antenna, i.e. more programming with a single receiving earth station antenna. From the standpoint of a BSS satellite operator, the multiple-feed antennas allow more efficient use of the spectrum since they avoid the need to transmit the same programming from more than one orbital location. These benefits to both the consumer and the service provider would not be available in the case where only single-feed antennas are deployed.

However, unlike the use of single-feed antennas that typically results in a single beam with an easily predictable symmetrical antenna pattern[1], the use of multiple-feed antennas, involving feeds not at the boresight of the reflector, results in antenna patterns that are broader and highly asymmetrical.

Section 2 of this Report addresses the technical considerations that should be taken into account in the design and deployment of multiple-feed receiving earth station antennas and satellite networks employing such earth station antennas. Section 3 provides descriptions and performance data of typical multiple-feed receiving BSS receiving earth station antennas currently in use.

2 Technical considerations for multiple-feed receiving earth station antennas

In designing multiple-feed antennas for BSS reception it is important to maximize the antenna gain of the individual beams as well as to achieve low side-lobe performance outside these beams. Equally as important for the ubiquitous deployment of BSS receiving earth stations, which are mostly located at individual residences, is to keep the size of the antenna relatively small and the cost down. These two constraints on BSS receiving earth stations make the design of multiple-feed antennas particularly challenging. The following sub-paragraphs describe the main antenna pattern phenomena that occur for offset fed antennas of this type and the inherent mis-pointing effects of such antennas.

2.1 Antenna beam performance

Unlike single-feed antennas that result in one antenna beam pattern, the multiple-feed antenna system will have a different antenna beam pattern for each of the associated feeds. The performance of multiple-feed antennas is generally dictated and limited by the outside feed position(s) and their respective lateral distances from the antenna boresight. The antenna beam pattern for the feed at

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[1] Such antennas have been extensively studied and reported in the ITU-R (e.g. Recommendations ITU-R BO.1213 and ITU-R BO.1443, and Report ITU-R BO.2029).

boresight, or closest to the boresight, will have the best performance in terms of symmetry and side-lobe performance.

The selection of the feed locations on the antenna is dependent on the number of feeds required and the orbital separation between the satellites to be received by the antenna. For example, for the case of a two-feed antenna, the boresight can be centred between the desired positions of the two feeds. This would typically result in equalizing the performance of the two feed positions in terms of gain and side-lobe performance compared with locating one of the feeds at boresight and the other offset from boresight. For cases where three feeds are required, typically one feed is located at boresight and the other two feeds are offset from boresight. This could result in three different antenna-beam patterns (one for each feed) with each having a unique asymmetry and side-lobe performance compared to the other two feeds.

Two significant effects occur with respect to the antenna patterns of feeds that are offset from the antenna boresight (i.e. “defocused” feeds). One is beam width broadening, which impacts the side-lobe performance, and the other is a lower beam-peak antenna gain, which impacts the performance of the system. The beam width broadening effect is due to the fact that the beam is no longer as “perfectly” focused as it would be if the feed was positioned exactly at boresight. This phenomenon can be described as the merging of side-lobe pairs with the main lobe. In other words, where there would normally be nulls in the antenna pattern and exponentially decreasing symmetrical side-lobe pairs, the beam is broadened because of the merging of the main lobe with the first side-lobe pairs. As the defocusing gets worse, more of the side-lobe pairs get merged. The result of this beam broadening is a degradation of the side-lobe performance with respect to isolation of the antenna for a particular feed. It is noted that even a defocused beam from a feed located at boresight could exhibit broadening of the main lobe.

Another issue to consider in the design of multiple-feed antennas is the phasing of the electromagnetic (EM) field at the feeds offset from boresight. When an antenna feed is located at boresight the phasing of the EM field components is “balanced”. Therefore any broadening of the beam because of defocusing results in a beam that is still symmetrical. For the feeds offset from boresight the EM field components are no longer optimally phased. This phase imbalance causes the antenna pattern to be asymmetrical. This phenomenon is known as the “coma lobe” which forms on the side of the offset feeds’ main beam furthest from the boresight focal point. In other words, the beam broadening is more pronounced in the antenna pattern for the side that is furthest from the boresight location. ITU Recommendations dealing with antenna patterns usually assume that the antenna pattern is symmetrical and the feed is at boresight. As this is not the case for multiple-feed antennas, careful consideration of how to define a pattern suitable for such antennas is required.

Another important consideration in the design of multiple-feed antennas is the shape of the antenna reflector (elliptic vs. circular or oval). This is especially important as the lateral spacing of the feeds is increased i.e. the need to receive signals from satellites with wider orbital separations. The reflector shape will not only affect the amount of beam broadening, but also plays a role with respect to the polarization performance. In selecting the shape, it is important to maximize the intersection of the reflector surface areas with each of the feeds in order to improve antenna gain and reduce spillover effects.

2.2 Inherent mis-pointing

Multiple-feed receiving antennas are constructed with fixed (i.e. not adjustable) angular spacing between the axes of the resultant beams. The angular spacing between the beams would ideally correspond exactly to the angular spacing between the satellites that are to be received by the antenna. However, the angular spacing that is seen from the surface of the Earth (i.e. the topocentric angle) is somewhat larger than the geocentric angle between the satellites. Such differences between the geocentric and topocentric angles are not necessarily a problem. Instead, the problem is that the topocentric angle is not constant for a given geocentric separation. It varies based on location of the antenna on the surface of the Earth.

Multiple-feed antennas are typically constructed with beam separation angles corresponding to the average topocentric angles between the satellites. When an antenna is installed any place other than at this "average" location, there is an intrinsic pointing error for one or all of the beams.

At low elevation angles, such as would occur in the extreme North-Eastern or North-Western parts of the Contiguous USA ("CONUS"), the distance to the satellite is slightly larger than average, and so the topocentric angle is smaller. Conversely, in the southern parts of CONUS, and particularly at longitudes close to the satellite longitude, the topocentric angle is larger than average because the distance to the satellite is slightly less.

Consider the example of the triple-feed antenna shown in Fig. 4 that is designed to receive BSS signals from 110° W, 119° W and 129° W. Such an antenna is already in widespread use in the USA. For the two feeds on this antenna whose beams point towards the satellites at 119° W and 129° W, the minimum required angular separation (topocentric angle) occurs in the Northeastern part of CONUS; for example, with a value of 10.56° in Boston. The maximum required angular separation occurs in the South-Western part of CONUS; for example, with value of 11.39° in San Diego. The difference between these two extremes is 0.83°. Therefore the actual fixed angular separation between the corresponding beams of such an antenna would be mid-way between these two, with an angle of 10.97°.

When such an antenna is installed, it must be pointed such that the centre feed (for the 119° W satellite) is pointed as accurately as possible, so as to minimize the simultaneous pointing errors of the 110° W and 129° W feeds. In that case, the feed pointing towards the 129° W satellite would be 10.97° away from the 119° W satellite, which would give a pointing error of 0.41° towards the 129° W satellite when the antenna was installed in Boston (i.e. 10.97-10.56), and a pointing error of 0.42°, in the opposite direction, when the antenna was installed in San Diego (i.e. 10.97-11.39).

These pointing errors due to topocentric angle variation across a geographic area are independent of, and therefore will add to, any random statistical pointing errors resulting from the installation of the multiple-feed antennas. Such random pointing errors result from the practical deployment of large numbers of relatively small and expensive antennas, despite the efforts made to align them correctly during installation. Several recent empirical studies of these random pointing errors in the USA indicate that a large percentage (> 50%) of the total USA 12 GHz BSS installations have pointing errors in excess of 1 degree. These inherent characteristics of multiple-feed antennas and the practical aspects of their installation should be taken into account in deploying such antennas.

The impact of this mis-pointing of multiple-feed antennas must be taken into account especially with respect to the potential increase in interference to these BSS receive antennas from interfering satellite neighbours. This is an important design driver to both the degree of offset desired and the potential interference that a system can withstand from the wider, distorted antenna beam patterns.

3 Antenna beam plots for multiple-feed 12 GHz BSS receiving earth station antennas

This section provides antenna beam plots for three types of 12 GHz BSS multiple-feed earth station antennas widely deployed in the USA. Multiple-feed antennas are widely used in the USA because the orbital locations assigned to the USA in the Region 2 BSS Plan are typically spaced at 9-degree intervals across two broad segments of the orbital arc (e.g. 101° W to 119° W and 148° W to 175° W). Sections 3.1, 3.2 and 3.3 contain the antenna patterns for dual-feed, triple-feed and five-feed receiving BSS antennas respectively. All of these receiving antennas have feeds for reception of circularly polarized BSS signals in the 12.2-12.7 GHz BSS frequency band.

3.1 Dual-feed receiving antenna

The dual-feed BSS receiving antenna shown in Fig. 1 was designed to receive signals from the 110° W and 119° W orbital locations in the RR Appendix 30 Plan for Region 2. Figures. 2 and 3 show the antenna patterns for this dual-feed antenna towards the 110º W and 119º W orbital locations, respectively. As shown, the patterns of the two feeds are very similar. In this case the two feeds are positioned each side of the boresight of the antenna.

FIGURE 1

Dual-feed BSS receiving antenna

Rap 2102-01

FIGURE 2

Dual-feed antenna pattern for 110º W

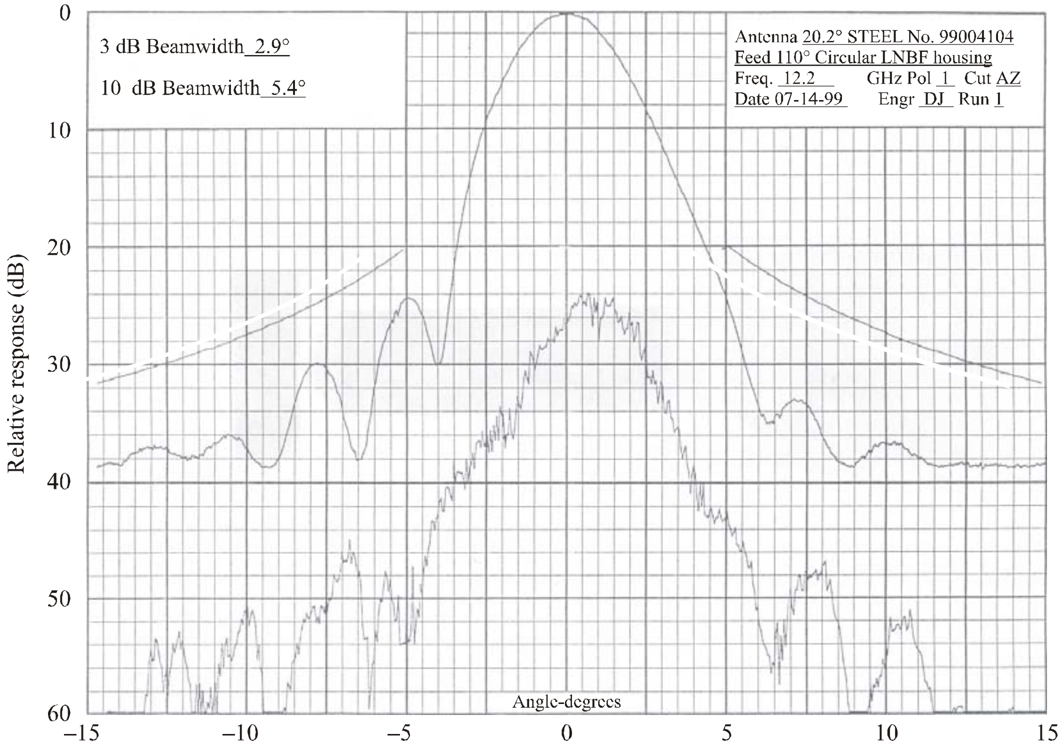

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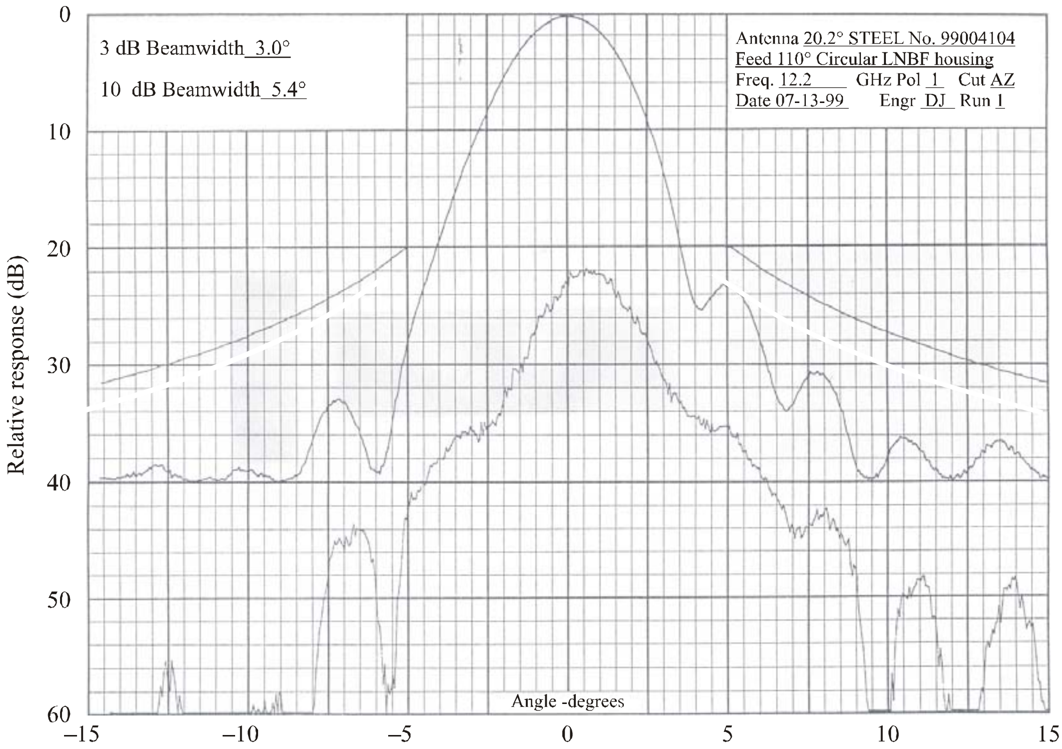
FIGURE 3

Dual-feed antenna pattern for 119º W



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3.2 Triple-feed receiving antenna

The triple-feed BSS receiving antenna shown in Fig. 4 was designed to receive signals from the 129° W, 119° W and 110° W orbital locations. Fig. 5 shows the antenna patterns for this triple-feed antenna.

FIGURE 4

Triple-feed BSS receiving antenna

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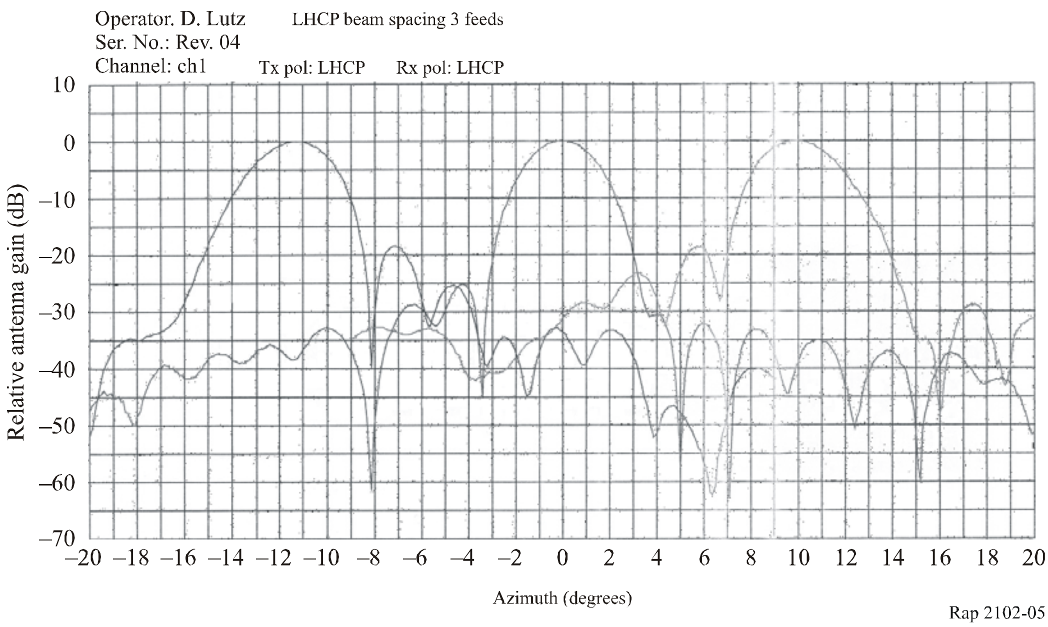
FIGURE 5

Triple feed antenna pattern for 110º W, 119º W and 129º W



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The main lobe in the centre is for the 119° W orbital location, the one on the right is for 129° W and the one on the left is for the 110° W. As described in § 2 the antenna pattern for the feed located in the centre (receiving signals from 119° W) is symmetrical around the peak gain. The antenna patterns for the two offset feeds (receiving signals from 110° W and 129° W) are not symmetrical. As Fig. 5 shows there is a bulge effect on the side of the pattern that is furthest from the boresight. Figures 6 and 7 provide the individual antenna patterns for these two offset feeds (receiving signals from 129° W and 110° W).

FIGURE 6

Triple feed antenna pattern for the 129º W orbital location

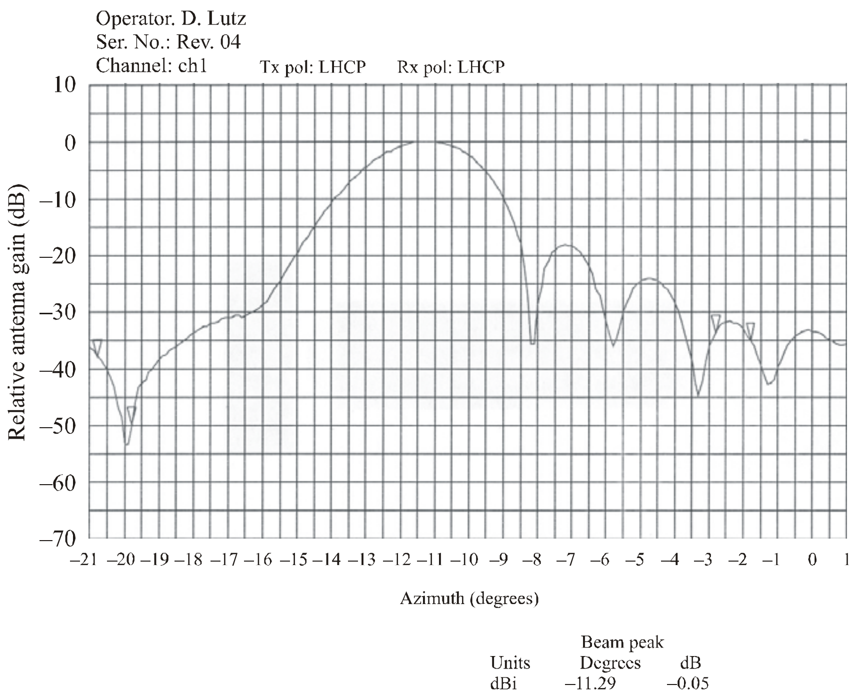

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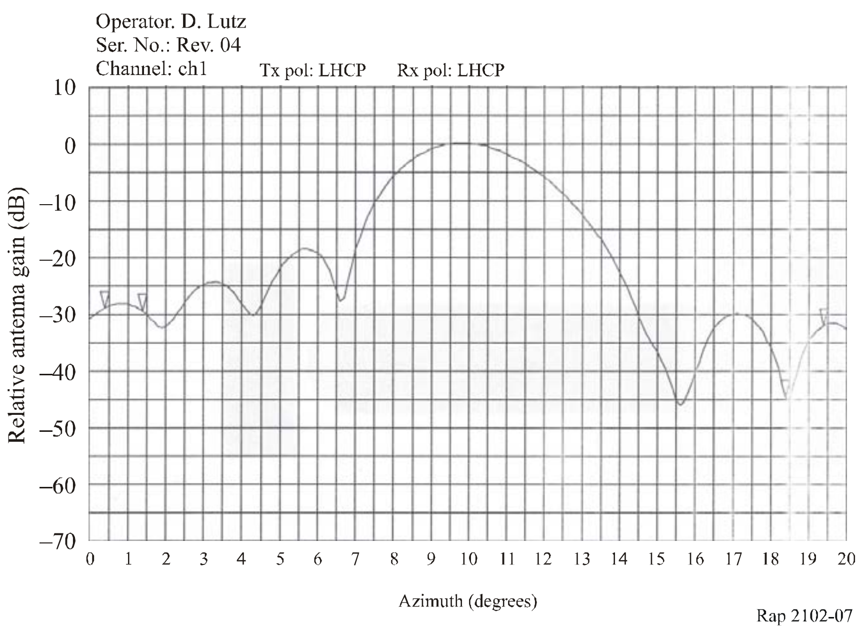
FIGURE 7

Triple feed antenna pattern for the 110º W orbital location



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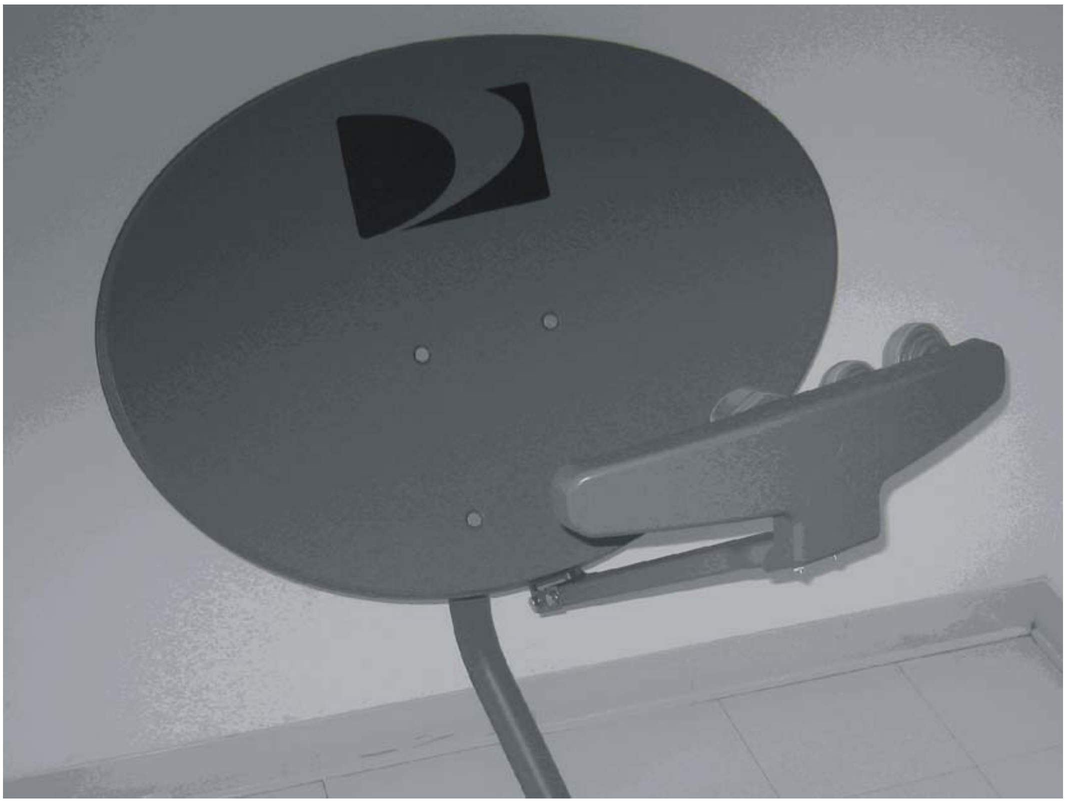
3.3 Five-feed receiving antenna

The five-feed antenna shown in Fig. 8 has three feeds for reception of 12 GHz BSS signals from the 101° W, 110° W and 119° W orbital locations, and two feeds for "direct-to-home" reception of circularly-polarized signals from satellites using the 18.3-18.8 GHz and 19.7-20.2 GHz FSS (space-to-Earth) allocations at the 99° W and 103° W orbital locations.

The antenna patterns presented in this sub-section are for the 12 GHz BSS band and in particular those for the 110° W and 119° W feeds that are not located at the antenna boresight and which therefore show the characteristics typical of multiple-feed antennas. The dimensions of the reflector of this antenna are approximately 84 cm wide by 57 cm high. In Fig. 8 the three feeds for 12 GHz BSS reception can be seen, but the two feeds for the FSS bands are smaller and are not visible behind the feed support structure.

FIGURE 8

Five-feed BSS/FSS receiving antenna



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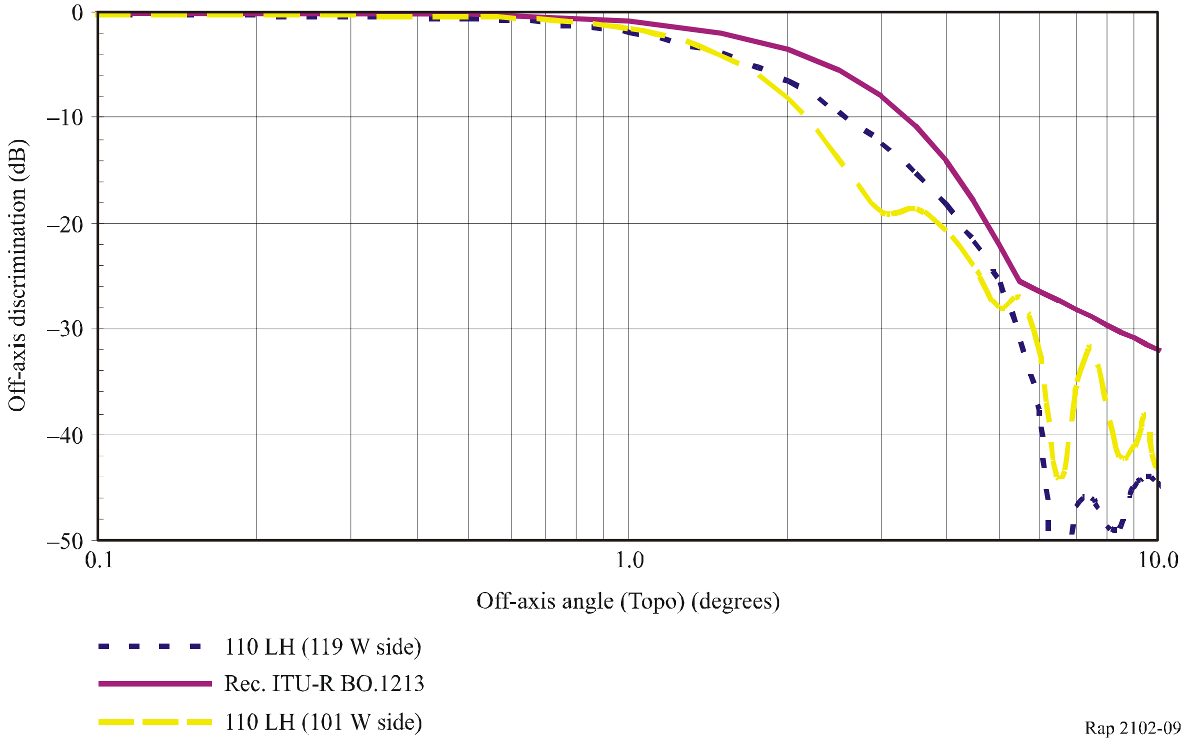
Figures 9 and 10 provide the antenna beam patterns of this antenna for the 110° W and 119° W feeds, respectively. These figures also include the Recommendation ITU-R BO.1213-1 antenna pattern for a 45 cm receive antenna for comparison purposes. As expected, and described in § 2, the figures further illustrate that use of multiple-feed antennas, involving feeds not at the boresight of the reflector, results in antenna patterns that are asymmetrical, with the amount of asymmetry varying with the feed position relative to the physical boresight of the reflector.

FIGURE 9

Antenna patterns for the 110° W feed of the five-feed BSS/FSS receiving antenna



As shown in Fig. 9, the antenna performance for the side of the beam closer to boresight, i.e. 101° W (dashed yellow line), is better in terms of isolation, than the side that is further from boresight, i.e. 119° W (dotted blue line). For this feed, both sides are within the Recommendation ITU-R BO.1213-1 antenna pattern mask for a 45 cm antenna.

FIGURE 10

Antenna patterns for the 119° W feed of the five-feed BSS/FSS receiving antenna

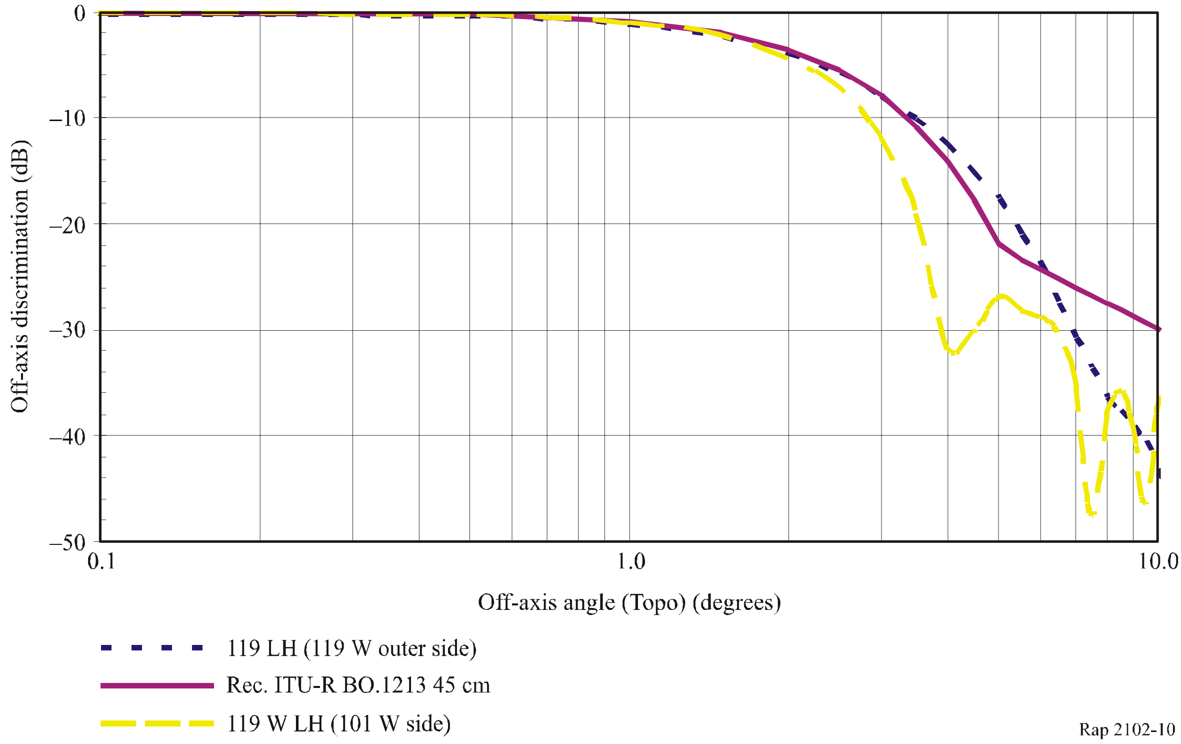


Figure 10 shows the same phenomenon as in Fig. 9 with regard to the asymmetry of the patterns, and the fact that the side-lobe performance is better for the side that is closer to boresight (dashed yellow line). However, in this case, the sidelobe performance for the side that is furthest from the boresight (dotted blue line) is not within the Recommendation ITU-R BO.1213-1 antenna pattern. This is not surprising since the Recommendation ITU-R BO.1213-1 pattern assumes a feed located at the physical boresight of the reflector. In comparing the Recommendation ITU-R BO.1213-1 pattern and the pattern for the side of the feed furthest from boresight (dotted blue line), it can be seen that it exceeds the Recommendation ITU-R BO.1213-1 pattern between approximately 3.5 and 6 degrees off-axis. This deviation from the Recommendation ITU-R BO.1213-1 reference pattern could lead to isolation differences of over 4 dB at certain off-axis angles. These differences should be taken into account in the deployment of multiple-feed antennas.

4 Conclusions

This Report provides a description of the technical aspects that should be taken into account when designing and deploying multiple-feed receiving antennas as well as performance data on existing widely deployed antennas of this type.

The benefit of multiple-feed receiving earth stations is that they permit BSS customers to receive services from multiple satellite locations and/or multiple frequency bands using one antenna, i.e. more programming with a single receiving earth station antenna. For the BSS satellite operator, the multiple-feed antennas allow more efficient use of the spectrum since they avoid the need to transmit the same programming from more than one orbital location. These benefits to both the consumer and the service provider would not be available in the case where only single-feed antennas are deployed.

The key parameters that need to be carefully considered with regard to the performance of multiple-feed antennas include, but are not limited to, frequency, reflector shape and size, number of feeds, and the desired offset feed spacing. The antenna beam performance, as well as the inherent pointing error that results from the use of the multiple-feed antennas, needs to be considered when determining interference from neighbouring satellites.

Further consideration will be required concerning the possible development of asymmetric reference antenna gain masks for such multiple-feed receiving antennas, bearing in mind that their design and performance is very dependent on the particular requirement for simultaneous reception from certain satellite orbital locations. If such a gain mask was to be developed it would likely include the maximum separation between the simultaneously received satellites as an input parameter.

It would also be useful to have additional data on the measured gain patterns of other planned or deployed multiple-feed BSS antennas to include in revisions of this Report in the future.