

## **Interference Limitations and Future Small Earth Stations**

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**Abstract.** Hostile Interference signals are recorded at the top of the Electrical Engineering Department, of King Saud University, using a 3m antenna, which received signal levels from Arabsat. These are good extreme examples of interference associated with the wide spread location sites of future small earth stations. Techniques are discussed to nullify this multiple source interference, for applications of reflectors and phased array antennas. Phased array antennas have more flexibility in this concern, at the expense of lower efficiency and complex design development requirements. Developments of arrangements of active phased arrays are promising for future high quality and mass production.

### **Introduction**

The last few years have been witnessing an extraordinary growth in satellite communication systems. The satellite effective radiated powers (EIRPs) are increasing, which makes it convenient to use small earth stations for receiving broadcast TV, radio, teleconferencing, data, telephony and many other commercial services. Many nations are planning for excessive use of these systems, introducing an unprecedented fast growing market for microwave receiving, transmitting and processing equipments. The eastern nations, in particular, find it a unique opportunity to leapfrog for the necessary fast growth of telecommunications capabilities, which are the essential backbone for the spread of well being. The satellite communications can reach everywhere without the need for expensive connections with wires, microwave links or fibers.

EIRPs reaching more than 60 dBw and advances in digital satellite communications made it very attractive and convenient to develop small earth stations, which even employ small whip or patch antennas [1]. It is now a common practice to use

small earth terminals with 4.5, 3, 2.4, 1.8 and 0.8 meter antennas. The smaller the antenna size the lower the antenna gain [2] and the higher the relative far sidelobe levels. In this concern, it is interesting to note that for a given EIRP level the capability of the antenna to communicate with a satellite is only limited by the noise figure of the receiver, irrespective of the frequency of operation. The frequency dependence of the antenna gain is compensated for by the path loss, leading to the form

$$(C/N) = \text{EIRP} + 20 \log (D/4R) - 10 \log (KTB) + 10 \log (\eta),$$

where  $(C/N)$  is the carrier to noise ratio in decibels,  $D$  is the circular antenna diameter,  $R$  is the distance between the satellite and the earth station,  $K$  is the Boltzman constant,  $T$  is the total system noise temperature, in degree Kelvin,  $B$  is the frequency bandwidth in Hz, and  $\eta$  is the earth station antenna efficiency. (This form is independent of the operating frequency, a point which is not clear to many designers.) It is also clear to see in this form that the  $(C/N)$  is inversely proportional to the system noise temperature  $T$ , which can mainly be limited by the noise figure of the receivers (of modern applications); especially those operating at high SHF frequencies. As a numerical example in this concern, we give the Arabsat numbers for an EIRP level of 34 dBw, using our 3m antenna, a receiver frequency bandwidth of 20 MHz,  $T$  of 200° K, and  $R$  of 4000 Km, yield a  $(C/N)$  ratio of 10 dB, irrespective of the operating frequency, so long as the antenna dimensions, the receiver and the satellite EIRP parameters did not change.

The above insight emphasizes that the modern small earth station problems are mainly due to interference received from the sidlobe structure of the antenna, effectively adding to the thermal noise. In reality as interference arrives from few directions, formed of coherent signals, their cancellation, by elimination of their receiving sidelobes, would sometimes be vital for the receiver operation; especially when their levels are high enough to saturate the ordinary receivers. This paper handles this problem and describes treatment procedures for sidelobe cancellation, of reflector antennas, as well as for the recently developing earth station phased array antennas. The phased arrays are more flexible and more suitable for adaptivity applications, when coping with varying directions of interference.

#### Reflector Sidelobe Levels

The quality of radiation from a reflector antenna is in part dependent on the feed design. The feed design determines the radiation polarization, with its size and configuration yielding a specific edge taper which controls the aperture efficiency, the spill-over efficiency and the sidelobe radiation levels. Another important factor

which controls the sidelobes is the reflector configuration. As an example, feeds, subreflectors and their supports, of on-axis reflectors, cause blockage and increase of the sidelobe levels around the main beam. In order to avoid these sidelobe levels it is necessary to use offset reflectors, either in a Cassegrainian or in a focal point feed forms. Small reflectors, in general, favour the focal point feeds, in order to avoid complications of misalignment, excessive spill-over and scattered radiation of very small subreflectors. These parameters of reflector design arrangements are well known and were subject for many publications, among which are refs [2], [3] and [4]. Generally, it is difficult to comply with the CCIR [8] sidelobe envelope of radiation when small antennas are used; especially if blockage is allowed. The CCIR envelope is an empirical envelope any way, generated during the early days of work with large reflectors, and should not be strictly applied except as a reference comparison level.

Aperture fields, by themselves, yield a reasonable radiation sidelobe envelope, even with high levels of edge illumination. High levels of edge illumination, however, yield high spill-over radiation, contributing to high sidelobes near the penumbra of the reflector. Distinctive regions of radiation from the reflector are illustrated in Fig. 1, and the complete descriptions of these are given in ref. [2]. In region 1, the main beam and its very near sidelobes are controllable by the feed illumination and the reflector surface accuracy. An example of this pattern, without blockage, simulated for an offset reflector, with an edge taper of  $-7$  dB, is shown in Fig. 2. The three meter antenna is simulated by a 1885 element aperture at 4 GHz. As can be seen in this figure the sidelobes decrease monotonically to levels below the isotropic level at  $11^\circ$  off the main beam. Sidelobes below the isotropic level are irregular, and some of them are eliminated. This sidelobe elimination phenomenon is discovered to be due to irregularities at the edge of the sampled aperture, indicating that the sidelobe levels are easy to control, using the extreme edge elements of the radiating device. It is proven in refs. [5,6] that edge elements yield patterns which are almost of the same periodicity as the aperture sidelobes, and hence their excitation can be adjusted to wipe out a few of these sidelobes; especially at low levels, where their amplitudes tend to be steady with their location angles. A demonstration of this is given in Fig. 3, where two edge radiating elements (at the two extreme points of a 3m uniformly illuminated aperture) are adjusted in amplitude and phase conjugation to cancel the sidelobe at  $12^\circ$ . As can be seen in this figure, the cancellation yields low sidelobe levels everywhere in the area around the  $12^\circ$  point.

In the space regions 2 and 3, shown in Fig. 1, the direct radiation of the feed predominates, at levels near to the isotropic level, and falls, in the shadow region 4, to levels far below the isotropic level. (The shadow region levels are dependent on the reflector configuration [2]). An example of a feed pattern of a square horn, 17.5 cm

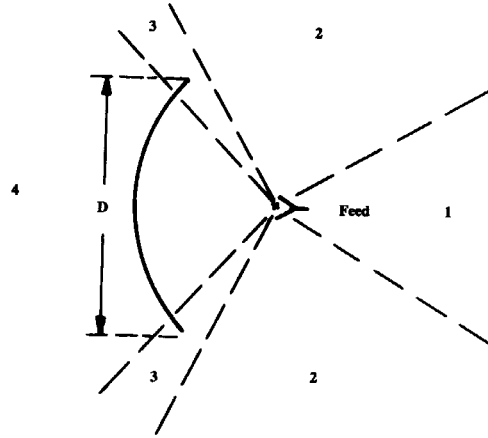
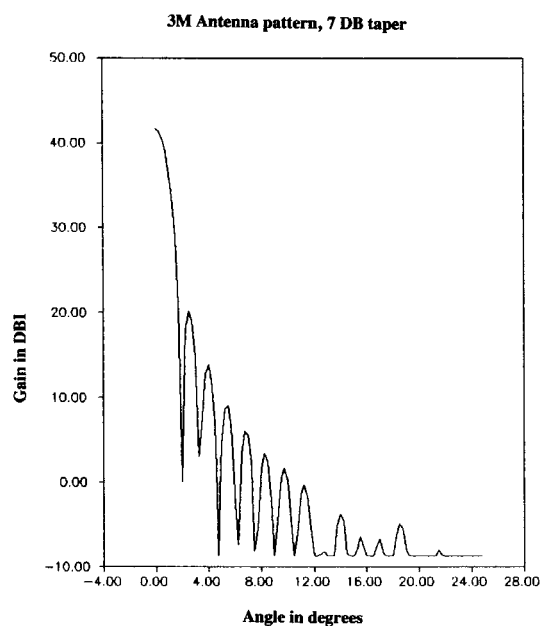


Fig. 1. Schematic of a reflector and feed, with identification of regions of radiation

size, fed by a predominant TE<sub>10</sub> mode, is shown in Fig. 4. Note that the E-plane pattern has a narrower beamwidth, and a higher sidelobe level than the H-plane pattern. This horn is used to feed the 3m (of unity focal length to diameter ratio) offset reflector which is used as an earth station antenna, on the top of the Electrical Engineering Department of King Saud University. A picture of this arrangement is shown in Fig. 5. It can be seen in Fig. 4 that the direct feed radiation, off the reflector edge (beyond 30.5°) just falls below the isotropic level, and stays there, till levels slightly below -5 dBi. (Note that the sidelobe radiation from the reflector in these regions is much lower than the isotropic level as can be seen in Fig. 2). Therefore, the feed radiation predominates, and as its periodicity is very slow then if interference occurs from these regions the only way to eliminate it is to use a specific single wide beam radiator oriented to the interference directions.

#### Practical Reflector Arrangements

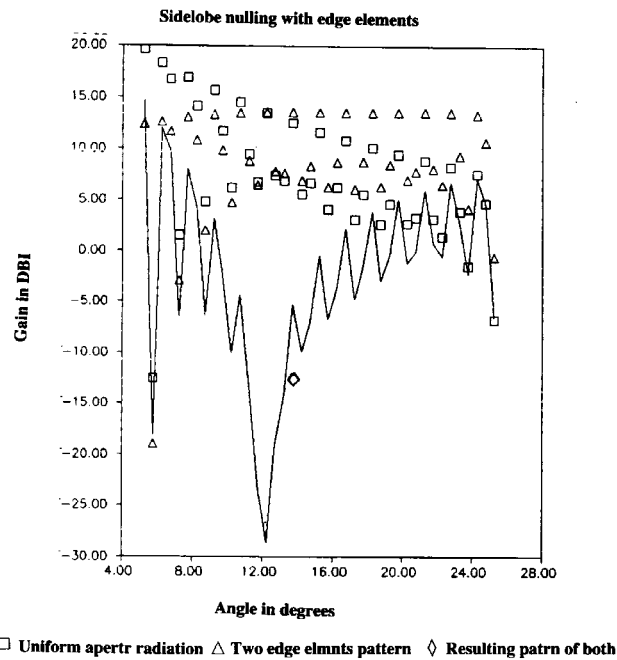
It is easy to see from the above analysis that the antenna feed has an important role to play concerning susceptibility to interference; especially in small earth stations, where the isotropic level is not far below the main beam level. The prescribed levels of side radiation of the square horn are being improved using a circular feed horn. The expected performance of this new feed is described in [10]. The circular horn yields lower side radiation in regions 2 and 3; especially in the E-plane. The antenna gain, using the feed patterns of Fig. 4, is 40 dBi, with aperture efficiency of



**Fig. 2. Simulated radiation of a 3m antenna**

80%, spillover efficiency of 90% and surface roughness degradation of 0.56 dB. The computed gain using the circular feed is approximately 40.5 dBi, an improvement of 0.5 dB, with an improvement for the sidelobe levels in the E-plane (with the circular feed) of about 10 dB. The effect of these improvements on interference is being recognized after recent installation of this circular feed. The present interference levels at the small earth station of King Saud University is approximately 25 dB, in average of different directions, above the Arabsat received signal level, in the 4 GHz band. This level is about 35 dB above the receiver noise level (with a carrier to noise ratio exceeding 10 dB).

The only way to drastically improve the interference levels, as needed for these open reflectors, is to use closed structures (hiding the feed). Well known arrangements of these are the horn reflectors and the parabola-plane reflectors, analyzed in [2]. More advanced models of these are reported later in [11], and shown in Fig. 6. These dual reflectors are easier to build for small earth stations, as they involve two



**Fig. 3. Sidelobe cancellation, around 12° using the edge elements**

reflecting surfaces of comparable sizes, which are harder to build for large earth stations. The main advantage of these structures is wiping out of the sidelobes in their large shadow regions. These shadow regions are formed by both of the reflectors and their binding structures, yielding larger than normal shadow, and reducing sidelobe levels by more than 20 dB, from the levels of the shadow of the regular open reflectors.

In conventional open reflector antennas, the sidelobe level reductions necessitate having a network composed of few antenna elements, scattered around the periphery of the reflector, and interconnected with cables, variable phase shifters and variable attenuators, which need to be electronically controlled and adjusted to eliminate signal levels reaching the receiver from the directions of interference. Such an arrangement has many practical difficulties. It needs knowledge about the sources of interference and its relation to the sidelobe structure of the antenna; especially

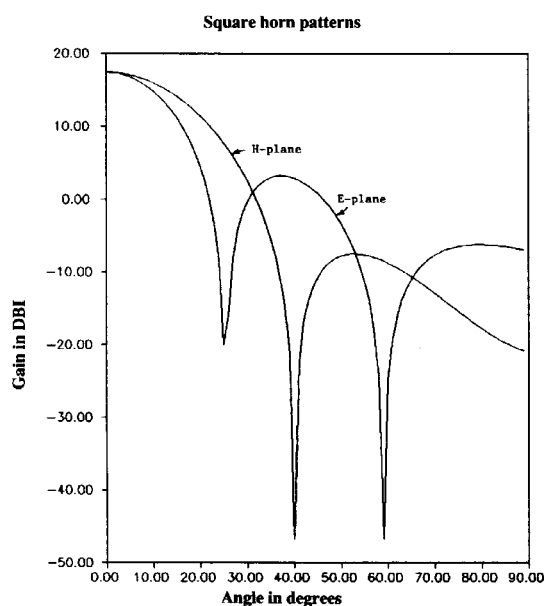


Fig. 4. The E- and H-plane patterns of a square horn feed

when the antenna changes its direction and looks to the interferences with different sidelobe structures. Predominant direct feed radiation interference is the easiest to cancel, even with multiplicity of interfering directions, using one single element canceller. If, however, the interference arrives through the reflector edge diffracted lobes, or scattered radiation due to blockage effects of center fed structures, or due to the sidelobe pattern around the main beam, then a matching cancelling sidelobe pattern is needed, which is difficult to generate. In general, it is a lengthy and tedious design procedure to determine the proper arrangement, at a specific location, which cancels a particular pattern of interference, and which can be made electronically adaptive to specific requirements. Therefore, the previously described closed antenna structures could save many of these headaches, using straight forward design procedures. An exception to this would be the requirement to cancel an interference directed to sidelobes near the main beam.

#### Phased Array Antenna Arrangements

Reflector antennas are well fitted for satellite applications, mainly because of the one point feed at the focal area, saving hardware complexity and connectivity



Fig. 5. Offset reflector and feed, small earth station at King Saud University, Electrical Engineering Department .

losses of multifeed points of antenna arrays. Also the multibeam operation can be performed using a multiplicity of feeds, in the focal area, each feeding a separate communication link [9], with preamplifiers directly connected to the feed ports. Phased arrays on the other hand, are formed of many radiating elements, interconnected with a hardware beam forming network, yielding high noise figures and reducing the gain, which is not desirable for earth station applications. The advantages of using phased arrays are mainly the flexibility to electronically steer the radiation beam and control its sidelobe structure, with the capability to steer nulls in the sidelobe structure to the directions of the interfering sources, without the need for mechanically directing any parts of the antenna. This electronic flexibility is a major advantage for speeding its operating functions; especially in warfare applications.

Sidelobe cancellation of phased arrays proved feasible by using only the array peripheral elements [5,6], which is an efficient simplification and control speed gain advantage. The number of controlling edge elements is approximately equal to the number of nulls needed to be produced in the sidelobe pattern. It is also found that

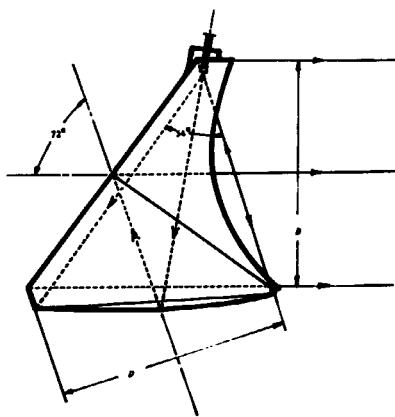


Fig. 6. The high quality parabola-plane reflector antenna

many other nulls are producible in other locations which might not have been specified. This is due to the near matched periodicity between the antenna sidelobe structure and the pattern periodicity of the edge elements, as demonstrated for radiating apertures in Fig. 3. In the following section the feasibility of application of phased arrays to earth stations is discussed, with analysis of its technical limitations and development needs.

#### Phased Array Limitations and Development Needs

Phased arrays are formed of antenna elements distributed on a specific surface which fits a given application. For high gain requirements, such as the situation with space applications, a planar array is desirable. The illustration on Fig. 7 demonstrates this situation, with the X-Y plane as the plane of the array elements, where each element has a location vector  $\bar{r}_{mn}$ . In this situation the space location vector  $\bar{R}$  is given by:

$$E_p = f(\theta, \varphi) \frac{e^{-j\beta R}}{R} \sum_{n=1}^N \sum_{m=1}^M A_{mn} e^{j\beta \sin \theta (x_m \cos \varphi + y_n \sin \varphi)},$$

where  $f(\theta, \varphi)$  describes the identical individual elements radiation patterns,  $R$  is the distance to the far point  $p$ ,  $\hat{a}_R$  (of Fig. 7) is a unit vector in that direction,  $\beta$  is the wave number ( $2\pi/\lambda$ ),  $\lambda$  is the wave length,  $A_{mn}$  is the excitation distribution among the array elements (controlled in amplitude and phase by the beam forming network,

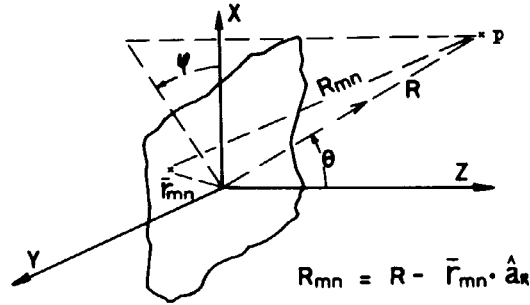


Fig. 7. The phased array antenna configuration

BFN),  $x_m$ ,  $y_n$  are the x- and y- components of the location vector  $\bar{r}_{mn}$  and  $\theta$  &  $\varphi$  specify the direction to the point p.

A uniform phased array, with continuous field distribution between its small elements, yield a satisfactory pattern which is very similar to that shown in Fig. 2, at the expense of the very high loss of the BFN. As the pattern of Fig. 2 is simulated by 1885 elements, an array of such a size necessitates using a BFN of 11 layers and employing a binary tree determined from the equation

$$MN = 2^L,$$

where MN are the total number of elements of the array, and L is the number of layers of the binary BFN, with total number of power dividers (PD) given by

$$PD = MN - 1$$

In this situation the BFN losses are much more than 11 times the losses of a single focal point fed reflector, which besides the complexity it is not tolerable for such an application. Note that the losses of each layer are formed of the connecting hardware losses, added to the extra BFN power divider losses. In order to reduce the number of layers of the BFN a smaller number of elements is needed. Also, these elements need to have radiating complementary field levels among them, as later explained, otherwise:

- 1) The nonuniform distributed field levels in between the array elements cause gaps in the field across the aperture of the array, forming serious grating lobes. An example of such a situation is the use of rectangular horn

radiators as array elements, carrying the predominant  $TE_{10}$  mode, having a cosine form of field distribution in its H-plane, forming periodic nonuniformities of different amplitudes, and giving rise to grating lobes in the H-plane. Such a grating lobe effect is demonstrated in Fig. 8. The pattern shown in this figure is formed by  $11 \times 11 = 121$  element array of radiators, filling a  $3 \times 3$  aperture. the excitation taper across this aperture is  $-7$ dB at the four edge center elements, and zero at the corners (indicating that the excited elements are only 117). The taper across the aperture is cosinusoidal and has circular axial symmetry. The large first H-plane grating lobe of Fig. 7 (which is only 10 dB below the main beam) is similar in shape to the main beam. It extracts large percentage of sidelobe radiation power, and its location (away from the main beam) is inversely proportional to the size of the array elements, *i.e.* it gets farther and its level gets lower as the size of the elements is reduced and their number increased, so that the array size is kept the same. More discussions about this is given in [5]. This grating lobe is very difficult to get rid of and its existence is intolerable for space applications. A three dimensional presentation of this grating lobe is shown in Fig. 9, using smaller number of elements.

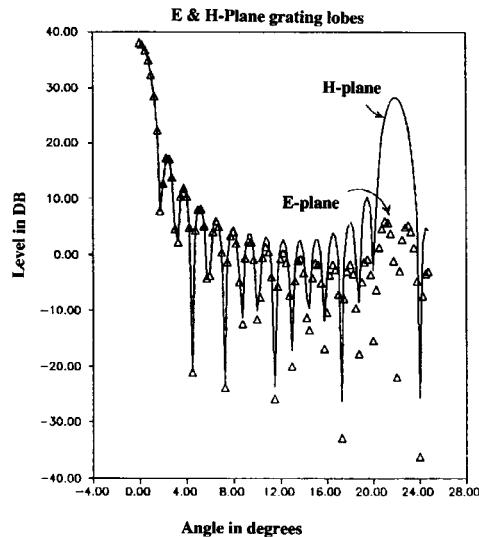


Fig. 8. The  $11 \times 11$  element array pattern, with E- and H-plane grating lobes

- 2) The taper of illumination across the aperture is needed to reduce the sidelobe levels. Such a taper implies compulsory stepping of the apertures excitation at the edge-to-edge points of the elements of the array, due to the discreteness of their locations. A good presentation of this situation is the E-plane of the previously described horn array. This E-plane pattern is also shown in Fig. 8 (with triangular marks). The nature of the grating lobes in this situation is different. Their relative location to the main beam is exactly the same as the location of the H-plane lobe. It is split, however, into two lobes, and its level is approximately 20 dB lower.

In order to avoid these grating lobes it is essential either to increase the number of the array elements, at the expense of feed losses, or to treat the stepping in excitations of the adjacent elements, as well as the discontinuity of fields, using passive local fit feed designs. These passive designs can have the form of distributed branching elements, in patch and printed circuit designs, and partitioning in horn feed designs. These passive designs can have the form of distributed branching elements, in patch and printed circuit designs, and partitioning in horn feed designs. Successful

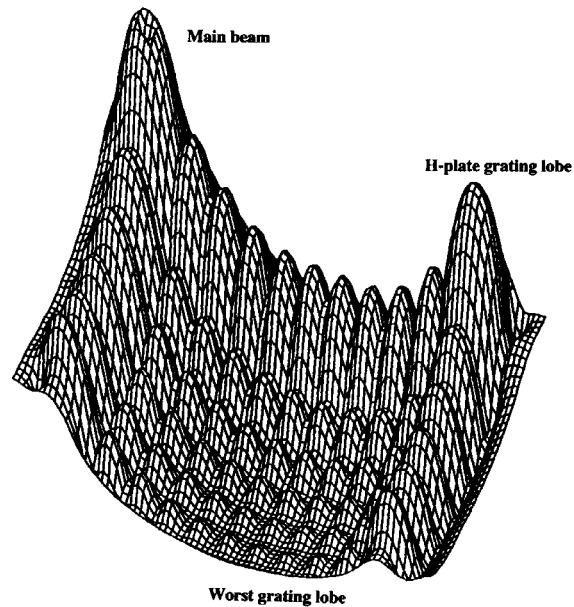


Fig. 9. Three dimensional presentation of the H-plane grating lobe

application of these techniques can reduce the number of elements of the array and hence reduce the feed losses. The controllable elements of the array, which can be used to eliminate specific interference sidelobes, are only at the periphery of the aperture (which are  $4 \times 9 = 36$  elements, disregarding the corner elements of the array). The rest of the elements can be hard-wired in order to reduce the RF losses.

#### **Practicality of Phased Arrays As Earth Terminal Antennas**

It is essential to reduce the number of array elements in order to reduce the losses. Hence, large radiator elements are needed. These, as previously explained, has the disadvantage of creating large grating lobes, which reduce the efficiency of radiation and increase the susceptibility to interference. Therefore, it is essential to use special designs of these elements which realize complementation of field distributions, at their edge-to-edge points. The practical handling of this requirement necessitates using horn partitioning techniques and extended branching patch designs. Both of these techniques are subjects of practical applicability to earth station designs.

The analyses in this paper are restricted to  $3m$   $11 \times 11$  and  $15 \times 15$  element arrays, applicable to small earth stations. The  $11 \times 11$  square array pattern is shown in Fig. 8, and the  $15 \times 15$  array pattern is shown in Fig. 10, with the same edge taper of  $-7$  dB. Application of compensating powers of 16 edge elements, at the periphery of the array (using half the original amplitudes of excitation) demonstrates the case of cancellation of the first grating lobe (as shown in the same figure with full lines), all the way around the axis of the main beam.

Another possibility exists for the reduction of the BFN loss effects by use of preamplifiers, with low noise figures, at each of the array elements, feeding the BFN with high level signals. This situation is known as active antenna arrays. The analysis of these, along with the applicability to practical installations is subject of another publication.

#### **Conclusion**

Different interference limitations to small earth stations are discussed, along with performance analysis of practical systems. In order to compensate for interference effects three distinct options are given. First, to apply sidelobe cancellation techniques to widely used small reflectors, using discrete radiating elements around the reflector edge or at its feed. Secondly, to use high quality folded multi-reflectors. These yield sidelobe reductions, in wide space angles, by more than 20 dB. The third option proposes specially designed phased arrays, with controllable edge elements,

in order to have electronic adaptivity for changing sidelobe cancellation requirements. The special designs deal with proposed developments to reduce discreteness of the array excitation, which cause large grating lobes, and with application of active concepts.

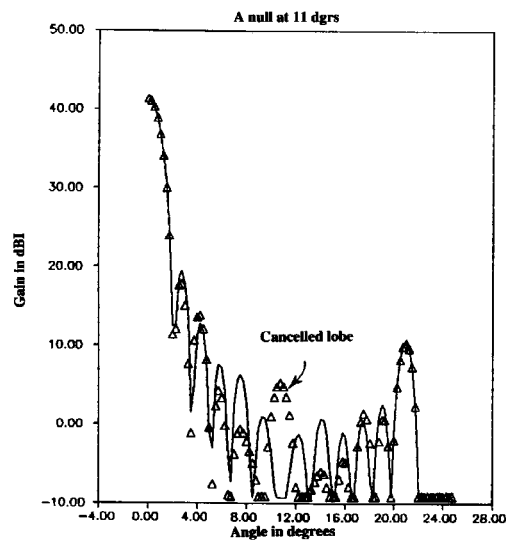


Fig. 10. 3m aperture with 161 circular array elements (original  $15 \times 15$  square array), noting the first grating lobe cancellation.

**Acknowledgement.** The authors acknowledge the support, with equipments and manpower, of the research council at the College of Engineering of King Saud University. Also, the support of the workshops, at the College of Engineering, with building of the offset reflector antenna and its feeds is most appreciated.

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## تأثير التداخل على المحطات الأرضية المستقبلية الصغيرة

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ملخص البحث. سجلت المحطة الأرضية الصغيرة ذات الهوائي العاكس الذي يبلغ قطره ثلاثة أمتار الموجودة في أعلى قسم الهندسة الكهربائية لجامعة الملك سعود تداخلا شديدا عند استقبالها لموجات القمر الصناعي العربي. وتكون هذه الظاهرة مثلا حيا لذروة التداخل على المحطات الصغيرة المتوقع انتشارها العريض في المستقبل القريب. ويناقش هذا البحث التقنيات المختلفة للهوائيات العاكسة والمصفوفات الهوائية التي يمكن استخدامها مستقبليا للتخلص من هذا التداخل. وتتميز المصفوفات الهوائية بزيادة مرونة تصميماتها للتخلص من التداخل على حساب قلة الكفاءة الإشعاعية والاحتياج لتطويرات تصميمية أساسية حتى تتواءم مع تطبيقات معالجة التداخل المطلوب. ويتوقع نجاح تطبيقات هذه التصميمات الجديدة خاصة فيما يتعلق منها بالمصفوفات ذات التكبير الذاتي والتي تنبئ بحسن الأداء وسر الإنتاج الصناعي الجماعي للمحطات الأرضية الصغيرة.