Coverage Flexibility by Means of a Reconformable Subreflector

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Abstract. The generally highly shaped service area for a satellite antenna may change during the planning or manufacturing of the spacecraft as well as during its in-orbit life time. This paper presents results showing the extent to which such changes can be accommodated by modifying the subreflector surface profile in a dual shaped antenna system. If coverage changes are identified before launch it may be possible to exchange the subreflector with a new, fixed one. If the changes occur later, the antenna may be adapted to the new requirements if the subreflector shape can be controlled, for example by using a bendable surface material that can be positioned by motor drives. The study shows that in some cases there is a potential for a significant improvement in the performance by modifying only the subreflector.

1. Introduction. Most communications spacecraft antennas today are designed to produce a highly shaped beam which matches the desired coverage area on the ground. This is achieved by either shaped reflectors or multi-beam antennas with optimized excitation of the individual feed horns. In some cases, for example on INTELSAT spacecraft, antennas of the latter type have been made reconfigurable, such that the same antenna may be put into use at different orbital locations. This is obtained by making the beam forming network switchable between several sets of excitation coefficients. Reconfigurable shaped reflectors have not been implemented in practice, although there have been a number of interesting and promising studies carried out with controllable, shaped reflector surfaces ([1]-[3]).

During the design phase of a spacecraft it is not un-common that the coverage requirements change somewhat. It may be desirable from a business point of view to include a neighbouring country, or it may be required to place the spacecraft at a different orbital position than originally planned. Such change will result in either an increase or decrease of the coverage as viewed from the satellite. If it occurs late in the program it will be expensive, time consuming and, most likely, impossible to modify the main reflector profile in a shaped system in order to meet the new requirements. This is simply due to the fact that the diameter typically is in the order of 1.5-3 meters, making the development and manufacturing effort a schedule driver in the overall spacecraft program. The subreflector, on the other hand, will of course in general be much smaller, and thus there may be a potential for changing this component even late in the program. However, since most of the shaping capability stems from the main reflector, it should first be investigated if acceptable beam shape adjustment can be achieved at all with only the subreflector.

In the remainder of the paper we present results obtained by considering a dual shaped reflector system designed for a hypothetical coverage. The service area is then first enlarged and later made smaller. In each case a new design is created by using the original, shaped main reflector with a new, optimized sub. The performance is compared to what could be achieved if a completely new antenna was employed, and if the original, nominal design was kept for the new coverage.

2. Design procedure. We have considered a Gregorian antenna with a main reflector diameter $D = 50\ \lambda$ and a subreflector diameter $d = 20\ \lambda$, dimensions typical for a C-band or

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Ku-band spacecraft antenna. Both the main and the subreflectors are shaped to cover square and rectangular service areas, with side lengths from 1 to 4 λ/D for the square, and from 2×1 λ/D to 8×4 λ/D for the rectangular shape. This corresponds to subtended angles from 1.1° to 9.2° for the coverage when seen from the spacecraft.

All shaping has been performed by applying physical optics to analyze the radiation from both the main and the subreflector, and changing the profiles until the minimum gain inside the coverage area is maximized. Once an optimized design has been obtained for a particular square or rectangular coverage, one of the sides is reduced or increased by 10%, 20% and 30%. We then evaluate the performance of the original design over the new coverage. If the area has been enlarged there will be a drop in the minimum coverage gain, whereas the gain remains almost unaffected when the coverage size is decreased.

The subreflector shape is now re-optimized whilst the main reflector profile is kept fixed. This will in general result in an increase in the minimum coverage gain compared to the nominal design. Furthermore, a completely new design is made in which both the main and the subreflector are shaped for the new coverage. This will indicate what the maximum achievable gain for the new coverage is, at the expense of building a completely new dual reflector system.

An example of the geometry is shown in Figure 1. This is for the case where the nominal coverage is 9.2° by 4.6° and the long side has been increased by 30% to 11.9°. The subreflector has been re-shaped and the figure shows that the surfaces are well-behaved, there are no big 'bumps' in the profile. An example of the co- and cross polar patterns are presented in Figures 2.(a) and (b).

3. Discussion of results. If we denote the minimum coverage gain obtained by the nominal design on any coverage by G_0 and the gain with a re-shaped subreflector by G_1, we define the performance parameter $P_1 = G_1 - G_0$. Similarly we define the minimum coverage gain achieved with a completely re-designed antenna for G_2 and define $P_2 = G_2 - G_0$. Obviously $P_1 = P_2 = 0$ for the nominal coverage without any enlargement or reduction. Figures 3 and 4 show the performance parameters for two particular coverages, a square of nominally 4.6° by 4.6°, and a rectangle of 9.2° by 4.6°. In all figures the lowest curve shows P_1 and thus indicates the improvement to a design if subreflector re-shaping is employed, whereas the upper curve shows P_2. If P_1 is large, a new subreflector design should seriously be considered, but if at the same time P_2 is much larger than P_1 it may be a question if not a completely new design would be more advantageous.

There are two sets of curves for each coverage. This corresponds to two fundamentally different designs, one we call top-to-top in which the main reflector profile is bent away from a paraboloid in such a way that the rays are diverging, and another called top-to-bottom in which the rays initially converge. Usually the top-to-bottom design will have a more curved main reflector and thus higher cross polarization; it may on the other hand also be less susceptible to blockage problems since the rays are confined to a more narrow region just in front of the aperture. It is not possible in general to state which design is more appropriate since it depends on the particular application. However, it is interesting to see that the top-to-bottom design has significantly more potential for subreflector shaping in the rectangular case. While this seems to be the trend, we have also observed the opposite on other coverages, and we have not yet been able to understand why one solution should be better than the other. Before this is understood, it must be emphasized that there may be significant differences and both designs should always be investigated.

4. Conclusions. The study has shown that there is in some cases a significant advantage to be obtained by re-designing just the subreflector if the coverage is modified. This will typically have much less impact on the overall spacecraft schedule than a complete redesign of the antenna system, and may result in almost the same minimum coverage area gain. However, whether or not the advantage is sufficient to warrant the implementation of a new subreflector must be determined by careful studies in each individual case.

5. References.

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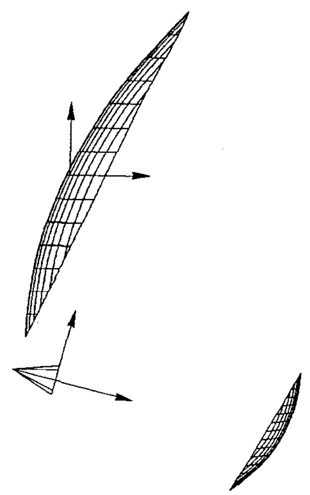

Figure 1. Geometry of shaped dual offset reflector for rectangular coverage. The original system is designed to 9.2° by 4.6°, and the subreflector is re-shaped to an enlarged coverage of 11.9° by 4.6°.

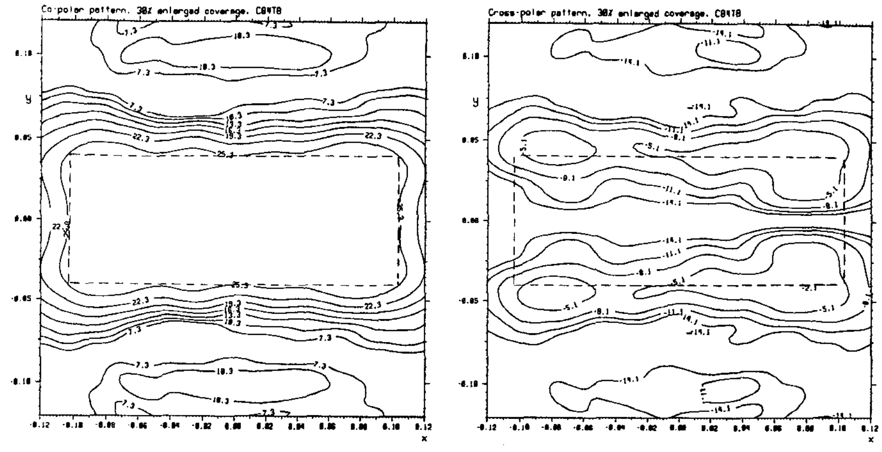

Figure 2. Co- and cross polar radiation pattern for the antenna in Figure 1.

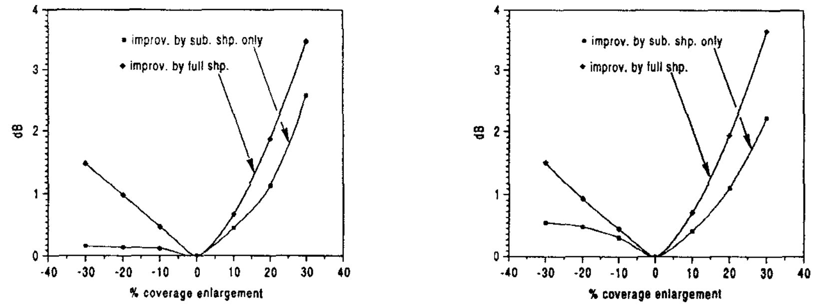

Figure 3. Performance parameter for quadratic coverage with side length 4.6°.Top-to-top at left.

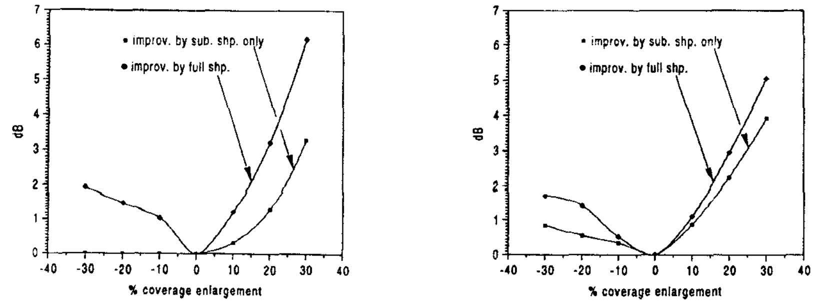

Figure 4. Performance parameter for rectangular coverage of 9.2° by 4.6°. Top-to-top at left.