BLOCKAGE EFFECT BETWEEN ADJACENT LUNEBURG LENS ELEMENTS

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The SKA in the large N - small D configuration, will have a large number of adjacent antenna elements within an Array Station. This note describes the blockage effect that is inevitable between adjacent Luneburg lens elements given a sufficiently low elevation observation angle. An estimate is made of the likely losses to be expected by the partial blockage of the signal path. Both the full spherical and hemispherical ('virtual-source') Luneburg lens cases are considered.

Spherical Luneburg lens as the Array Station element

Figure 1 shows the basic operation of an isolated Luneburg lens where the diameter, D, has been normalised to unity. The parameter f is the (normalised) focal length of the lens and is the radius of the focal spherical surface as shown in the figure (by the dashed circle). The particular focal point f_0 on this surface is the focus of an incoming plane wave at an incident elevation angle of θ_0. We note here that operation of the lens is reciprocal, i.e., transmission is the reverse of reception shown in Fig. 1.

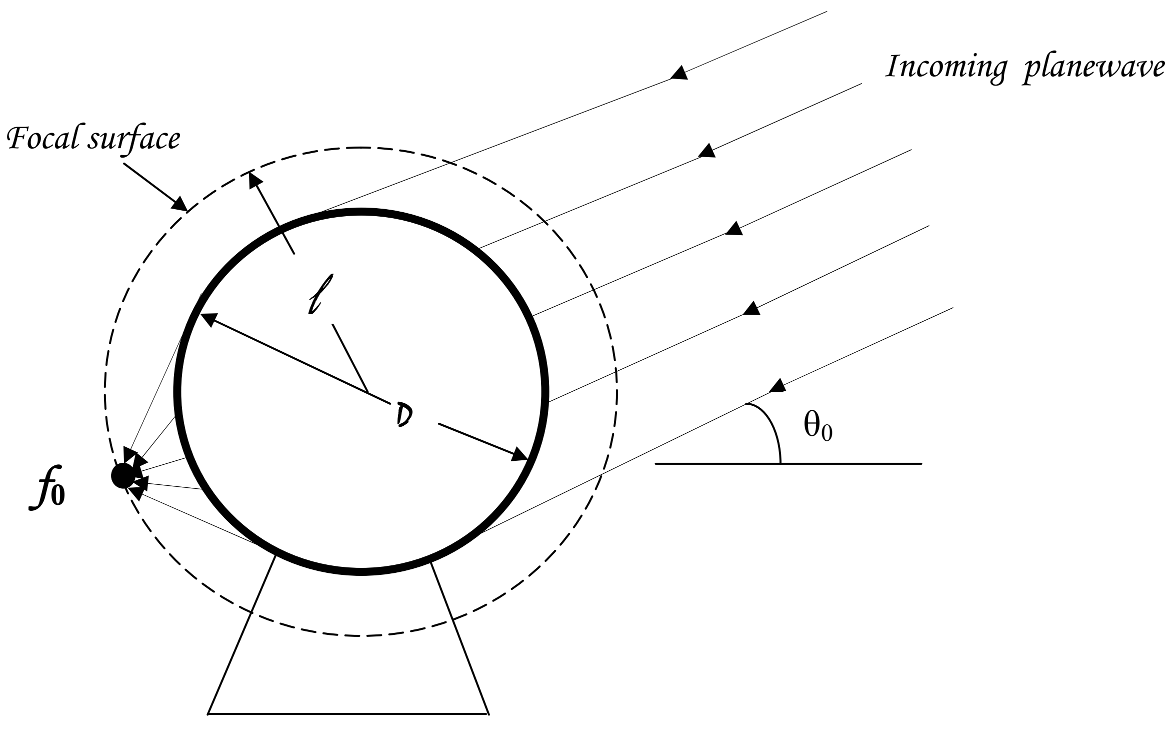

Fig. 1: Luneburg lens focussing an incoming planewave to a point at f_0

Figure 2 shows three adjacent lenses with the same configuration as in Fig. 1. For practical purposes it is assumed that the lens spacing, δ, is a minimum when adjacent focal surfaces just touch each other. Thus we have δ_{min} (where, again, δ is normalised to a lens diameter of unity) given by $2 f/D - 1$ as plotted in Fig. 3. The dashed line at f/D 0f 0.75 is our preferred focal length for the lens as discussed earlier in detail in pp.50-71 of the original White Paper, *Eyes on the Sky: …*, Hall(ed), July 2002.

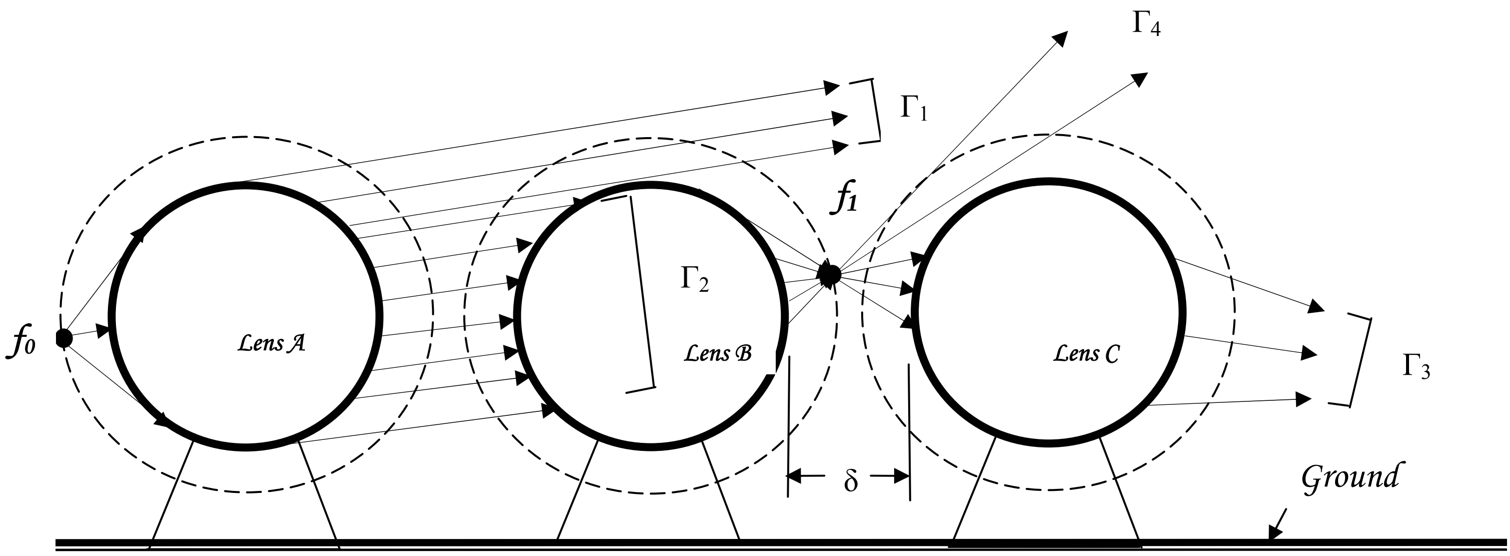

Fig. 2: The effect of shadowing by closely-packed lenses

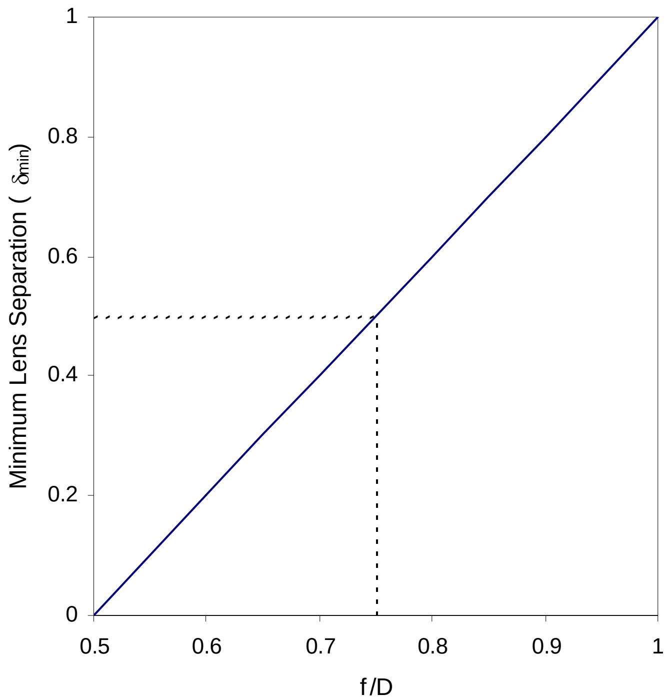

Fig. 3: Minimum lens separation as a function of f/D

For closely packed lenses and low elevation angles blockage between adjacent elements will occur. This is illustrated in Fig. 2 for the 'worst case' where the three lenses are in-line to the signal path. To give a basic description of the physics it is more convenient to consider transmission rather than reception. Assume, therefore, a transmitting source at f_0. The energy transmitted towards and through lens *A* will exit the opposite side of the lens as a collimated beam. Part of this beam, Γ_1, will radiated to free space (skywards) while the remainder, Γ_2, will be incident as a plane wave on lens *B* to be focussed eventually to a point f_1 on the focal surface of lens *B*. This energy will continue to propagate; a portion, Γ_4, will scatter towards the sky as if from a point source at f_1 while the remainder will propagate through lens *C* to emerge on the opposite side as a partially collimated beam shown as Γ_3 in the Figure. This beam is only partially collimated since the effective source at the focal point f_1, will not in general lie on the focal surface of lens *C* and hence a certain amount of defocusing will take place. If additional lenses are in-line, then this process will repeat itself until the energy is eventually dissipated within the lenses and by diffuse scattering into the surrounding environment.

This dissipation of the blocked energy should present few operation difficulties and is similar to the situation where closely spaced reflector antenna elements block each other as shown in Fig. 4. While the diffusion mechanism differs, the overall blockage effect is similar.

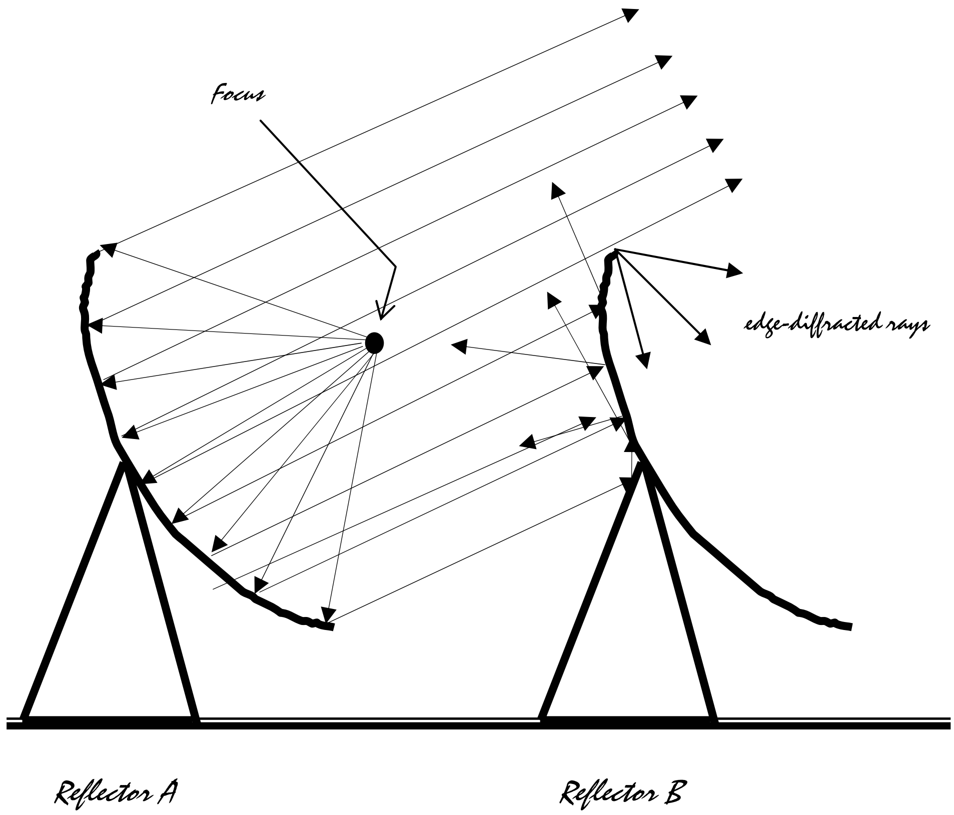

Fig. 4: The effect of shadowing by closely-packed reflectors

It is of interest to note, however, two important distinctions between lenses and reflectors. Firstly, in the case of the Luneburg lens, any substantial ground-directed energy (based on our ray optic model) will occur only after the third or fourth refraction (through lens $\mathcal{C}$ or the next closely-spaced lens, lens $\mathcal{D}$, - not shown - refracting the ray bundle Γ_3). Thus after three of four refractions, the energy directed towards the ground would be minimal. While in the absence of more qualitative data we would hesitate to claim that arrays of closely-spaced Luneburg lenses would have a lower overall noise temperature at low elevation angles than the equivalent reflector antenna array, we should not be surprised if this proved to be the case. In practice, we need to also consider the back radiation of the feed elements and a rudimentary low-cost ground screen may be desirable to direct the ground reflected energy skyward in order to minimise the overall system noise temperature.

The second distinction relates to the feed-to-feed interaction between adjacent antenna elements. In the case of the reflector, this interaction takes place as soon as blockage occurs by means of the edge-diffracted rays generated at the top edge of reflector $\mathcal{B}$ as shown in Fig. 4. Given the intensity of the collimated beam from reflector $\mathcal{A}$ these diffracted rays will be strongly excited and likely to produce troublesome feed-to-feed coupling. The situation with the lens is quite different. The highly collimated beam from lens $\mathcal{A}$ (in Fig. 2) will not interact significantly with the feed of lens $\mathcal{B}$ until Γ_2 approaches the value of Γ_1 by which time the blockage loss is beginning to be excessive (see below). Thus in operation, lenses are likely to give significantly less feed-to-feed interaction than is the case with reflectors.

The minimum elevation angle before blockage occurs is plotted in Fig. 5 as a function of (normalised) lens separation, δ. This curve must be read in conjunction with that plotted in Fig. 3 for the minimum value of δ for a given f/D. For our preferred f/D of 0.75, the normalised minimum lens separation is 0.5 yielding a minimum elevation angle of 42° (33% sky coverage). Note that for low unblocked elevation angles the necessary lens separation becomes excessively large and some compromise with blockage loss will be inevitable at low elevation angles in any practical design.

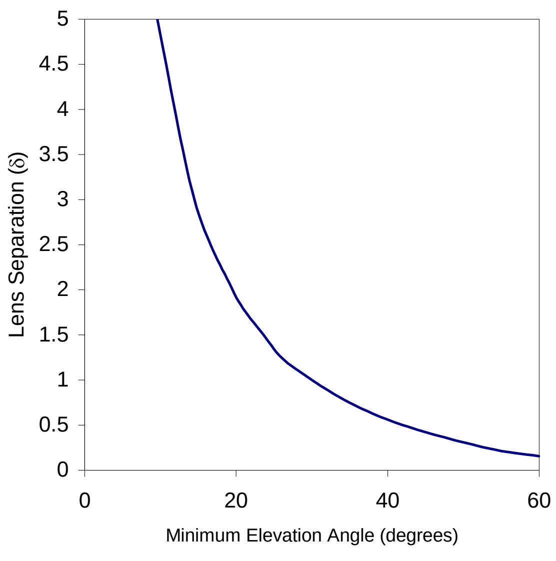

Fig. 5: Required lens separation for unblocked minimum elevation angle

In an attempt to put some quantitative data on the effects of element-to-element blockage, we have plotted in Fig. 6 an estimate (based on the aperture area shadowed) of the loss incurred as a function of $\Gamma_1/(\Gamma_1+\Gamma_2)$. The loss incurred for moderate values of blocking is not particularly severe.

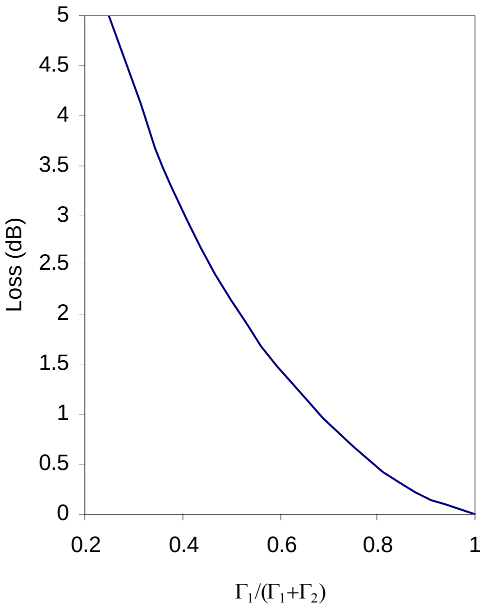

Fig. 6: Loss incurred by partial blockage of the signal path

A more useful and interesting graph for the purposes here is given in Fig. 7 where loss is plotted against elevation angles for a range of lens separation values. The bold curve where $\delta = 0.75$, is the suggested practical lens separation for our Luneburg lens design where $\ell/D = 0.75$. At this separation value, there is enough room for the feeds on adjacent lenses to move about freely while providing an unblocked elevation angle of 35º. At the 30º (the commonly stated low elevation angle required as a minimum for the SKA) the blockage loss is a relatively modest 0.25 dB. This increases rapidly, however, for lower elevation angles being 1.5 dB at 20º and 4.7 dB at 10º. Nevertheless, unlike the case with reflectors as elements, use of lenses of our preferred design should provide both acceptable loss and minimal feed-to-feed interaction down to an elevation angle of about 20º (66% sky coverage). However, at lower elevation angles not only the loss becomes significant but, as indicated in the Figure and discussed above, the feed-to-feed coupling is also likely to be a problem.

For low loss at low angles the antenna element separation must be increased substantially (whether lenses or reflectors are used). Even in the case of the planar array, where the elements can in principle be packed closely together for low loss at low elevation angles, the situation is no better, and in fact could be significantly worse, given that planar arrays suffer from foreshortening and do not scan well beyond about ± 45º, so that by 30º the performance is likely to be considerable inferior to that from arrays of lenses or reflectors.

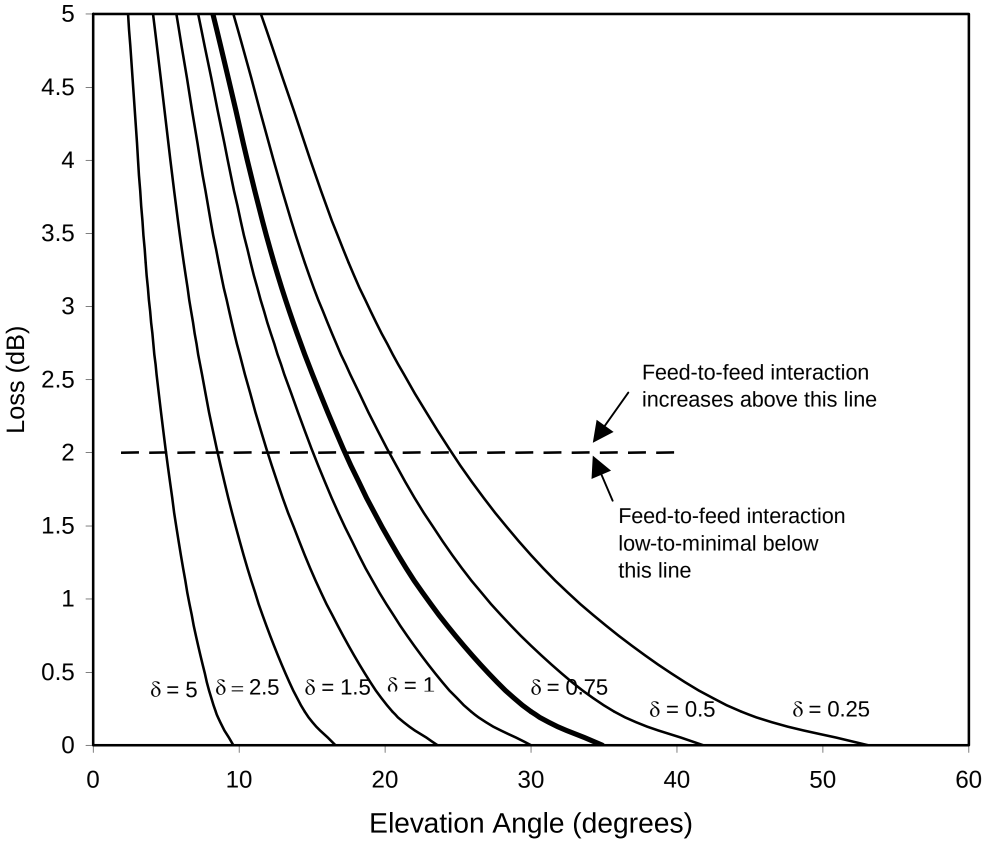

Fig. 7: Blockage loss as a function of elevation for various lens separation values

Virtual-source (hemispherical) Luneburg Lens

Much of the above results apply directly to the 'virtual-source' or hemispherical Luneburg lens. The original concept of this lens is illustrated in Fig. 8. A plane metal plate divides a spherical lens in two where, initially, this plate extends as far as the focal surface only; the radius $\mathcal{R}_e$ as shown in the Figure.

As for lens $\mathcal{A}$ in Fig. 2, consider a source at the focal point f_0. The presence of the metal plate will reflect the refracted field through the lens so that the emerging plane wave front from the lens will tend to be in the upper half space. If the metal plate were infinite in extent then all the energy would remain in the upper half space. However, for a finite-sized plate, at a sufficiently low value of θ_0 (i.e., as the position of f_0 moves towards plate) the beam will split into Γ_1' and Γ_2' as shown in the Figure where Γ_2' is that portion of the energy not reflected by the plate. If we were to extend the plate from $\mathcal{R}_e$ out to $\mathcal{R}_e'$ (shown by the dashed line in Fig. 8) then all the energy for the angle of θ_0 shown would be reflected into the upper half space leaving, again, a single beam only.

For an array of hemispherical Luneburg lenses over a ground plane, while the mechanism differs in detail, quantities Γ_1 and Γ_2 will apply as before, and setting $\delta = (\ 2\mathcal{R}_e' - 1)$, all the results of Figs 5-7 can be used here.

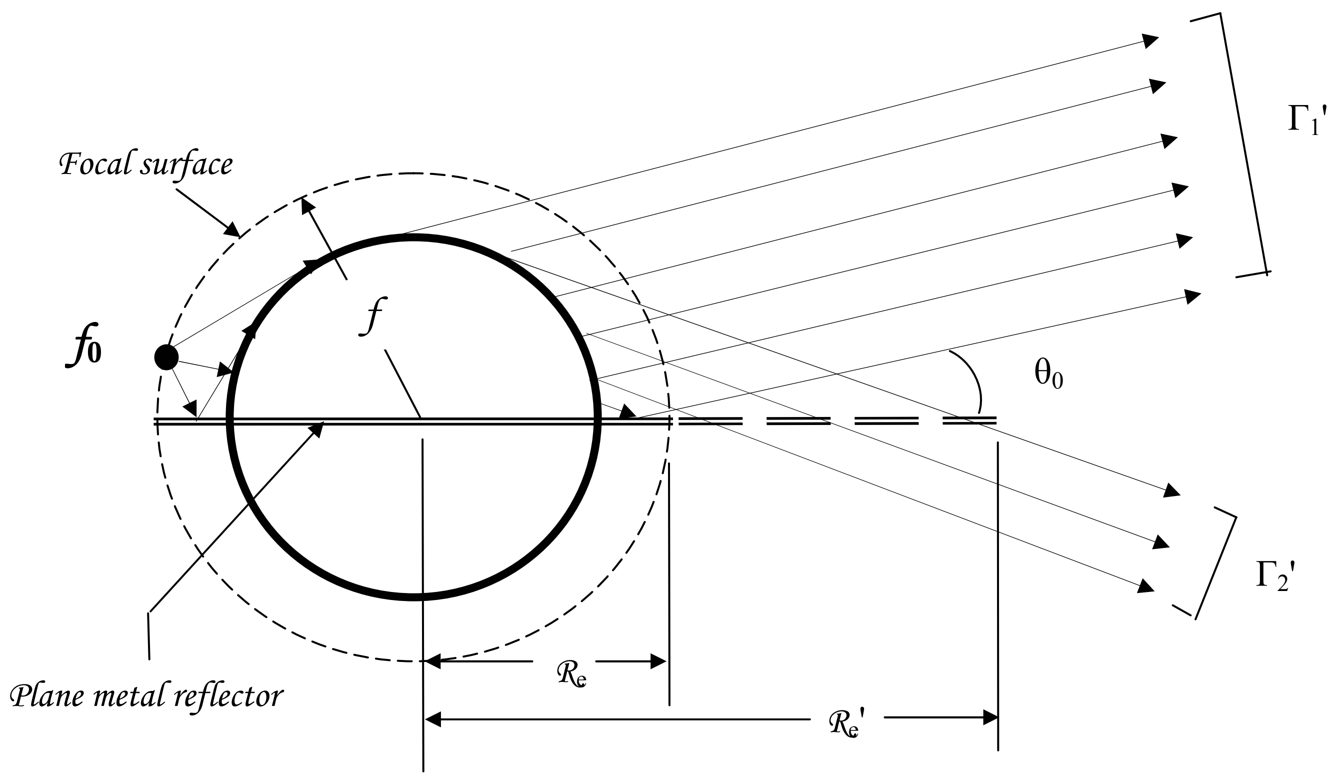

Fig. 8: Virtual-source Luneburg lens

Conclusion

In this brief report we have considered the blockage effect between adjacent Luneburg lenses in an SKA array. By comparison with reflectors as array elements, use of lenses appear to offer two unexpected advantages when blockage is considered; lower system noise temperature and, in particular, lower feed-to-feed interaction between adjacent elements.

In an accompanying file note (GLJ SKA File Note 2-04) we shall discuss further the relative merits between a spherical and hemispherical Luneburg lens as the element in an SKA array.