A Focusing Metamaterial Based Wollaston Prism

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***Abstract*—By using existing metal mesh technology we propose a new lens design that behaves in a similar way to a Wollaston Prism. That is, a device that separates out the two linear polarised states of the incident field and then focuses them separately on same focal plane. The design is an evolution of an existing GRIN lens based on the same technology. The proposed lens design has a diameter of 75mm while only being 2mm thick. This will focus two beams at a distance of 250mm with a separation of 10mm, over the frequency range of 100-200GHZ. Such a device would be useful where space and weight are an issue and would allow the use of incoherent detectors.**

I. INTRODUCTION

It has been recently shown that metal mesh grids can be used to create a flat lens [1]. This was achieved by combining several grids with a radially varying patch size to create a graded index material, originally designed to mimic the behavior of an existing polyethylene lens that is typically used in THz astronomy. Detailed measurements were performed [2] and it was shown to have good broadband performance. In this abstract we propose a novel lens design, using the same building blocks that can spatially separate the two linear polarisation states on the same focal plane.

The advantages of such a device is that two detectors that are not polarisation sensitive could be placed directly next to each other and resolve the polarisation of the incoming signal. Currently to separate out the polarisation, beam splitters or polarisers must be used, which open additional ports in a system while augmenting the overall volume of the detecting system. This novel device could at the very least allow a more stringent definition of the instrument input while allowing a compact detecting unit.

II. MATERIAL DESING

To build such a device, the polarisation must be independently controlled along each axis, in a similar way to a birefringent crystal. This is achieved by using a rectangular patch element. The unit cell for this is given in figure 1a. This gives four independent variables that can control the transmission properties of the mesh. This structure has a lot of potential due to its broadband transmission. To reduce complexity in the lens design, the outer unit cell size is kept constant and square. This makes placing the elements for the final design simpler. To build an artificial dielectric the same process as first used in Zhang 2011[3] is used. This involves stacking a certain number of grids with a uniform spacing, which can be varied to control the overall effective refractive index. Figure 1b, shows the transmission is different along each axis for a stack of 5 grids, which gives two different effective refractive index. When designing the lens the overall thickness of the structure is constrained, so that the overall number of layers and separation is fixed. This means that the size of patch must be varied to get the required refractive index distribution. We define these varying parameters as the ratios a/g_x and a/g_y .

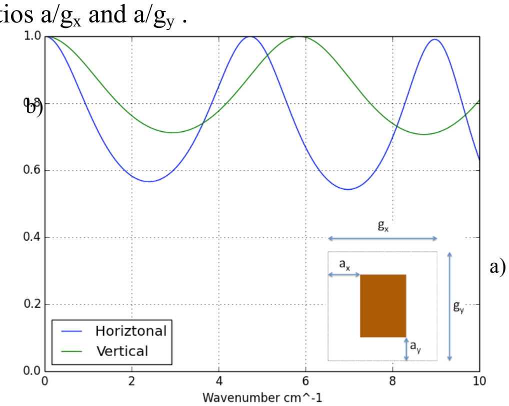

Fig. 1. a) The four parameters that can control the transmission properties. b) Transmission for each axis of the unit cell

To simulate this structure, HFSS is used to model a reduced number of layers, since increasing the amount of layers does not change the effective index. Increasing the number of layers is equivalent to increasing the thickness of a bulk dielectric. This is also complimented with a transmission line model based on an equivalent circuit model by Zarrillo [4]. This was found not to be as accurate as HFSS, but it is able to approximate how the effective index changes with geometry. The effective index is extracted from the Fabry-Perot resonances that occur, by inversion of the first peak. At higher frequencies there is some dispersion, but the effect is minimal[3].

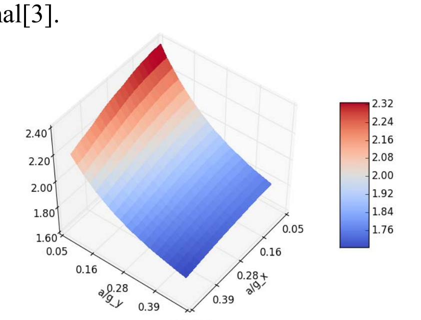

Fig. 2. Refractive index parameter space for a/g_x vs a/g_y as seen by a TE polarised wave.

Using these models, a parameter space containing all possible simultaneous dual values of effective refractive index can be created which is shown in figure 2. This is based on a separation of 100um and $g_x = g_y = 200$um. This surface shows the values of n_y that can be achieved for a given a/g_x and a/g_y. The corresponding plot for n_x is the same but with the axis swapped. This means that there are different combinations of parameters that produce the same index.

III. IDEAL DESIGN

The lens design is based on the same Woods lens formula, which relates the diameter and thickness of the lens to the focal length through a radially distributed graded index. The idea for the lens is to take two identical lenses and superimpose them with a given separation, which corresponds to a separation on the focal plane. To design this, a common reference frame is used, in which each point has a corresponding n_{te} and n_{tm}. As shown in Figure 3, there are lines of constant index that are formed around the center point of the lens. When they are overlapped the situation occurs that one polarisation must see a constant index while the other must be able to vary. The amount it must vary depends on the separation of the two lenses.

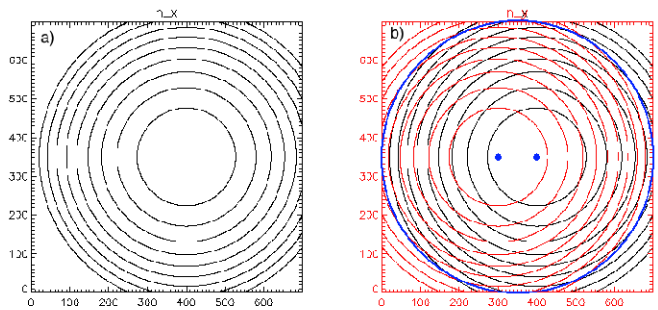

Fig. 3. a) Radial distribution of index for one lens. b) Combined index distribution for both lenses.

IV. PROPOSED DESIGN

Once an ideal lens design has been decided, the corresponding material parameters must be selected. This is achieved by searching the parameter space. The result of this comparison is shown in figure 4. This is for a lens separation of 10mm between focal points. This shows the corresponding values of a/g that produce the required refractive index.

This comparison shows that it is possible to produce this lens. However, there is a limitation in this design. The separation of the two lenses is set by the maximum delta n that can be achieved between the two effective indexes any patch can have. It is not possible to have an index of 1 for one polarisation and a value for the other. This means that only the portion of the lenses that overlap can be physically realised.

Any area where the effective index of one GrIn lens falls below that of the substrate (effectively mimicking the flat ring- like slab surrounding a classical convex or planar-convex lens) will not allow for any GrIn behavior of the other lens, thus breaking the overall cylindrical symmetry of the device. Future studies will investigate potential aberrations, if any that are induced.

This design will then be fabricated using the same method previously[1]. Only a single mask is required due tot he fact that all the mesh layers are identical. The layers are then hot pressed together using polypropylene spacers.

Like the previous design, the lens has not been impedance matched to free space, meaning that there will be reflection losses. This could be addressed by using an ARC on the surface of the lens. However, since the purpose of this prototype is to test the basic principles, the ARC will only add unnecessary complexity to the design.

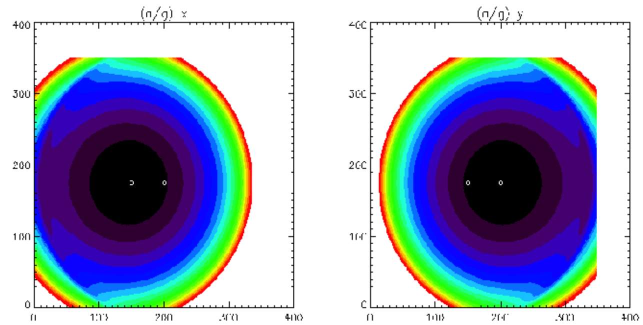

Fig. 4.Contour plots showing the spatial variation in a/g for each axis.

V. CONCLUSION

We have shown it is technically possible to produce a GRIN lens that is capable of separating the two linear polarisation components on the focal plane. With the parameter space now found, the lens can now be fabricated. Further analysis will be done to evaluate the performance of this device, the nature of the aberrations caused by the loss of symmetry and any potential chromatic effect caused by the capacitive nature of the GrIn grids.

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