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LENS TECHNOLOGY ENABLED

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LUNEBURG LENSED ANTENNAS AND THEIR APPLICATIONS IN TELECOMMUNICATIONS

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Explore the design, applications, and advantages of Luneburg lens antennas in telecommunications, including the introduction of a new lightweight material for manufacturing large-size lenses.

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INTRODUCTION

The Luneburg lens is a spherical lens with a gradually varying dielectric permittivity from 2.0 at the core of the lens, to 1.0 on its surface. This design allows the lens to focus incoming plane waves to a point on the surface of the lens directly opposite to the side of incidence. Conversely, a point source (feed) placed on the surface of the lens will be transformed into a plane wave leaving the lens on the directly opposite side to which the point source (feed) is placed (Fig 1).

Therefore, by placing a feed on the focal plane of the lens (any point along the surface of the lens), it is possible to create a high-gain antenna. Since the lens is symmetric, beam scanning can be achieved by moving the feed around the surface of the lens or switching between several feeds placed around the lens. The lens symmetry allows for beams to be scanned (tilted) at any angle with no scanning loss[1] providing useful applications as a high-gain direction finding antenna.

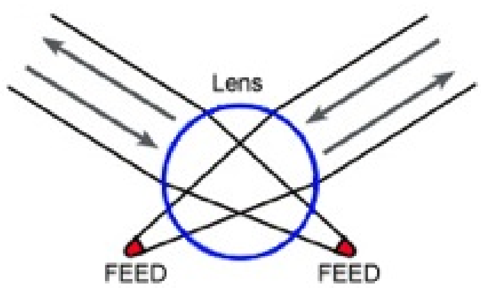


Fig 1. Diagram demonstrating combination of feeds and lens to create high-gain antenna

[1] [1], [2], [3], [4]

An ideal Luneburg lens has a varying permittivity given by $\varepsilon(r) = \sqrt{2 - r^2/R^2}$ where r is the radial distance of any point inside the lens and R is the radius of the lens. To approximate ideal conditions in practice, the lens is manufactured from multiple layers of different permativities. The more layers are used, the greater the efficiency of the lens. Typically, 10 – 15 layers need to be used to construct a 100cm diameter lens (Fig 2). However, the number of layers used also depends on the relationship of wavelength to diameter of lens. Furthermore, since it may not be practical to place feeds directly on the surface of the lens, it is possible to change the focusing distance (focal plane) of the lens by adjusting the permittivity of the layers used. This makes it possible to design a lens with a focal plane away from the surface of the lens."

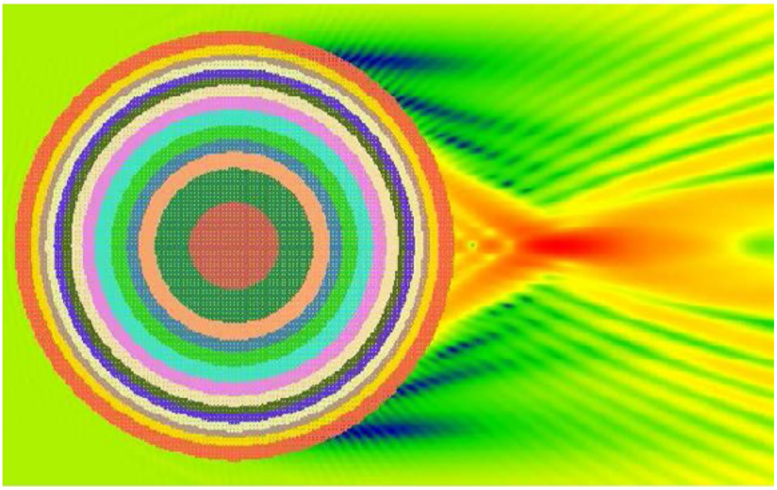


Fig. 2. Simulation of a 10 layer lens focusing an incoming plane wave

Since the lens is symmetric, an incoming plane wave from any direction is focused to the opposite side of incidence, making the lens ideal for multi--beam applications. As each feed in combination with the lens provides an independent beam, when multiple feeds are placed around the focal plane of the lens each beam works independently and with little interaction to other beams. Therefore, by placing several feeds around the lens, a high gain multi--beam antenna with several independent beams is created, with high isolation between beams and individual tilt capabilities for each beam.

Feeds can be placed in any combination depending on the application. In principal, feeds can be placed around the equator of the lens, allowing the lens to cover a complete 360° sector. However, with this type of combination there can be some influence/interference from feeds placed on exactly opposite sides of the lens.

Fig. 3. Feeds placed around a Lens designed with a focal plane several inches away from the surface.

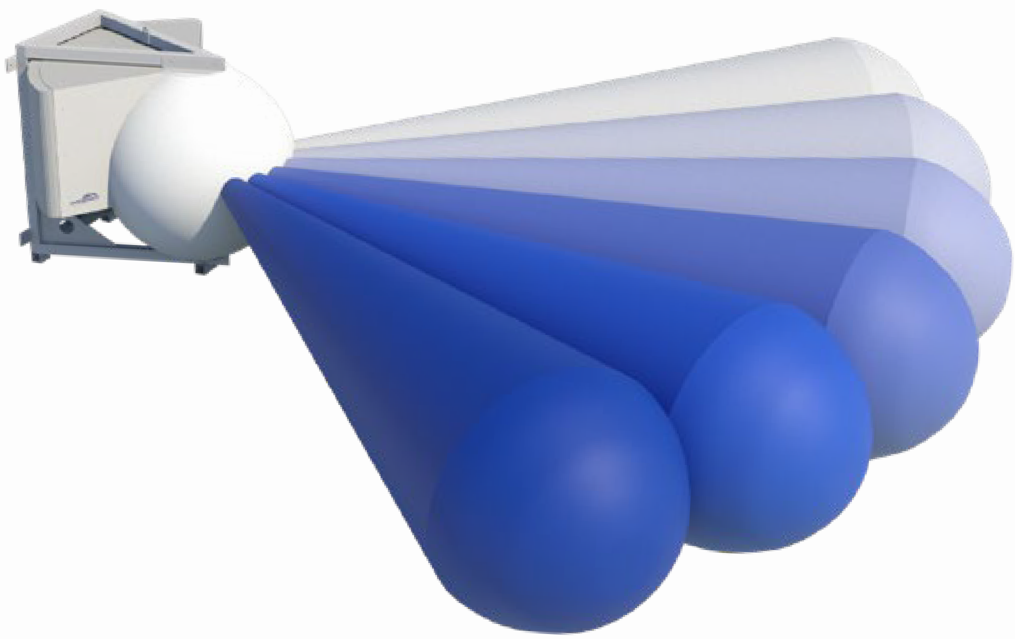
To reduce this interference, the lens typically covers a 120° sector (in both horizontal and vertical plane). Feeds can be placed in any combination (individual feeds/ several rows and/or columns) within this sector depending on the requirements for the total number of beams and beam width per beam. The total number of beams per coverage sector is determined by the beam width which is dependent on the diameter of the lens and wavelength used. An approximation of the different beam widths achievable in relation to diameter of lens is provided in Table 1.

DIAMETER OF SPHERE		BEAM WIDTH (10DB LEVEL)	BEAM WIDTH (10DB LEVEL)
CM	INCH	1.7-2.7GHZ DEGREES (°)	698-960MHZ DEGREES (°)
55	21	30	60
110	43	15	30
165	65	10	20

Table 1.

Therefore, if the lens is used to provide 120° total coverage, for high--frequency application (1.7 - 2.7GHz) the lens will provide; 4 sectors (beams) for a 55cm sphere, 8 sectors for a 110cm sphere, and 12 sectors for a 165 cm sphere.

Or equivalently to provide 120° total coverage, for low--frequency application (698 - 960MHz) the lens will provide 2 sectors (beams) for a 55cm sphere, 4 sectors for a 110cm sphere, and 6 sectors for a 165cm sphere.



CURRENT USES OF LUNEBURG LENSES

Even though Luneburg Lenses have several benefits as compared to traditional (phased array) antenna systems, currently they are mostly used in high-frequency applications (>10GHz) where smaller diameter lenses are required (less then 0.3cm diameter) i.e. F22 Raptor (Fig. 4). Luneburg lenses have found little commercial applications such as telecommunications as lower frequencies (<10GHz) and therefore larger sizes of Luneburg lenses are required. The key difficulty in manufacturing large size Luneburg lenses is in the material.

Fig. 4. Luneburg Lens in use

KEY REASONS WHY LUNEBURG LENSES MADE FROM TRADITIONAL MATERIAL ARE NOT USED

Weight

The density of traditional dielectrics (1000kg/m3) makes large size diameter lenses extremely heavy[2] and therefore not viable for commercial use. A 100cm lens made from traditional material can weigh up to 200kg.

Difficulty of Manufacturing

Furthermore, as the diameter of the lens becomes greater, the process of fabrication becomes even more difficult. The design of the lens makes it necessary to control the dielectric permittivity of the material to a high degree of accuracy and as the diameter of the lens increases so does the number of layers used to construct the lens. Using traditional dielectric material this becomes difficult to do while maintaining acceptable losses. Furthermore, these losses can be increased due to the assembly method of the different layers, as air gaps can arise when using the traditional mold method of construction.

Therefore, Luneburg lenses have found little commercial application because traditional materials are simply too heavy and controlling the dielectric permittivity of each layer becomes increasingly difficult. Even though the difficulties of the manufacturing process can be overcome, the high weight of large size lenses has kept them from being a viable option for commercial applications.

[2] [5], [6]

NEW MATERIAL

To overcome some of these obstacles and allow for the construction of large size, light weight Luneburg lenses for commercial applications, Matsing Pte Ltd has developed a new, patented meta-material. The dielectric permittivity of the meta-material can be controlled with a high degree of accuracy, making it possible to construct large-size multi-layer Luneburg lenses.

The meta-material has very low loss which is a key requirement in the construction of large size Luneburg lenses. The imaginary part of the permittivity is less than 0.001 allowing for large-size Luneburg lenses to have low-losses and high gain.

The meta-material is broad-band with isotropic properties, allowing for the lenses to operate on a broad frequency range.

The meta-material has low density (40kg/m3), making it lightweight and allowing for the construction of large size Luneburg lenses. Due to the low-density of the meta-material as compared to traditionally used dielectrics, the weight of the Luneburg lens can be decreased by 8-10 times, making a 100cm diameter lens weigh only 20kg as compared to the traditional 200kg.

Therefore, using this newly developed meta-material, the difficulty of manufacturing and high weight of large size Luneburg lenses can be overcome.

The meta-materials have also been tested for environmental and mechanical test requirements such as;

• Thermal Test: Cold Exposure (as per IEC 60068-2-1), Heat Exposure (IEC 60068- 2-2),
• Temperature Cycling (as per IEC 600068-2-14).
• Humidity Tests: Humidity Exposure (as per IEC 60068-2-56), Humidity Cycling
(as per IEC 68-2-30).
• Random Vibration Test: Vibration and Settling Test (as per IEC 60068-2-64)
• Salt Fog Corrosion Test (as per IEC 60068-2-11 test Ka ASTM B117).

APPLICATION IN MULTI-BEAM TELECOMMUNICATION ANTENNA

KEY BEAM PARAMETERS:

When applied as a multi-beam telecommunication antenna, the Luneburg lens has the following key beam parameters;

- Since the lens is spherical, the resultant beam from each feed is conical (cone shaped both in the Horizontal and Vertical plane)
- The HBW of a beam can be estimated by the following equation;

$$HBW = \frac{60\lambda}{D}$$

Where λ is the wavelength used, and D is the diameter of the lens.

- The gain per beam can be estimated by the gain achievable using a traditional dish antenna with similar diameter as the lens.
- The max gain per beam is given by the following equation;

$$Max\ Gain\ per\ Beam = \frac{4\pi(\pi r^2)}{\lambda^2}$$

KEY ADVANTAGES FOR TELECOMMUNICATION APPLICATIONS:

- The number of beams and their layout (number of rows, columns) can easily be adjusted with feed placement.
- Each beam acts independently and can be independently tilted and adjusted. The tilt of the beam can be adjusted Vertically and Horizontally if required by simply adjusting the position of the feed on the lens.
- Beams can be tilted to greater angles since tilt is achieved by moving feed location on lens; when a beam is tilted there is no degradation of the beam pattern (unlike antenna systems based on phased array Butler matrix).
- Since each beam works independently with the lens, there is very high isolation between beams (> 30 dB)
- The lens is broadband and can cover all frequency bands simultaneously
- Meta-material used for the lens has extremely low losses, allowing for the lens to have high efficiency and handle high power
- Since meta-materials used have extremely low losses, the losses of the antenna for receiving signals are very low
- Unlike phased array antennas, the lens antenna does not require multiple elements and supporting hardware to form a beam (such as phase shifters, dividers etc) thus eliminating performance degradation associated with multiple elements i.e. lower efficiency due to higher losses in matching network and pattern distortion off axis
- Due to the low density of the meta-materials used, the lens is light-weight (see Table 2).
- The Lens can easily be customized (in terms of number of beams etc)
- Luneburg Lens allows for dual-band application with similar clusters by grouping 2 hi-band beams with 1 low-band beam for common tilt adjustment.
- Luneburg Lens based multi-beam antenna platform supports infinite combinations of frequency bands and number of beams thus empowering network operators to match a solution to their particular situation.

LENS DIAMETER		APPROXIMATE WEIGHT	
CM	INCH	KILOGRAMS	POUNDS
55	21	5	11
110	43	35	78
165	65	117	260

Table 2.

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