Bachelor Thesis

Thema: Numerical Simulation and Optimisation of Spherical Lens Antennas for Use in Diagram Synthesis with Arrays of Waveguide Fed Horn Antennas

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Studiengang: Elektrotechnik und Informationstechnik

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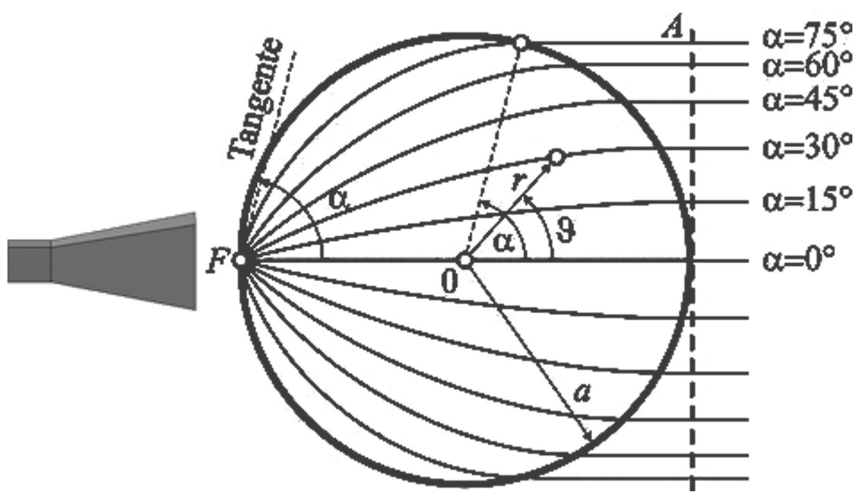
Objective

The main purpose of this thesis was to model and optimize a spherical Luneburg lens which is fed by a rectangular waveguide pyramidal horn antenna and display the results in numerical and graphical way using CST Microwave Studio software tool.

Luneburg lens

It is a spherical symmetrical refracting lens of radius *R* consisting of an inhomogeneous dielectric ε_r. The value of ε_r varies along the sphere radius *R* in a radial direction *r*. As it falls from 2 at the center to 1 on the outer surface of the sphere (which matches with air ε_r = 1).



The radiation path of the luneburg lens with excitation at the feeding point *F[Kark393].*

$$n(r) = \sqrt{\varepsilon_r} = \sqrt{2 - \left(\frac{r}{R}\right)^2}\ , \qquad 0 \le r \le R \qquad (1)$$

The Luneburg lens has a uniquely designed focusing/defocusing characteristics according to the gradient distribution of the refractive index $n(r)$ along the radius *R*. As a result, every point on the surface of an ideal Luneburg lens where *(r = R)* is a focal point *F* for a parallel radiation incident on the opposite side of the spherical lens. By placing the feeding antenna device (antenna phase center) at the focal point *F*, the radiated waves are refracted with a specific angle α inside the sphere and then will travel as parallel rays (plane wave) into the free space.

Luneburg lens is constructed by adding different number of discrete concentric shells to each other. Whereas the approximation of the continuous gradient *n(r)* gets better by increasing the number of the shells (minimum 10 layers).

The symmetric characteristic of the Luneburg lens makes it flexible to move and change the position of the feeding device along the sphere's surface [Kark 393].

Simulation

Two different types of Luneburg lens (equidistant and non-equidistant) were created for use in this project. Solving the refractive index equation *(1)* and rearranging it mathematically gave us the formulas for the two types of the lens (next view).

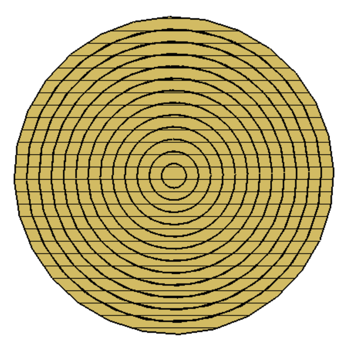
These two formulas were processed and programmed using VBA macros which is built into CST Microwave Studio program, resulting in the two forms of the sought Luneburg lens. To feed the lens with energy, a pyramidal horn antenna is used. The horn has a rectangular waveguide type of R_{100} and H_{10} mode. Alternatively, a conical horn was used as a feeding device.

Combining the designed Luneburg lens with the feeding antenna required a specific optimisation to reach the desired results of the device (Horn + Lens). These settings were; <u>Size of the lens,</u> <u>Number of the shells in the sphere</u> and <u>The distance between lens and the horn aperture.</u> These settings were based on the measurements of the main radiation characteristics parameters (*The Realized Gain, S_{11} Parameters and The Side Lobe Suppression*).

The final sweep results led to a Luneburg lens of 13 internal shells, with a Diameter of $\approx$ 96 mm (2 times the aperture size). and about (0-2) mm distance between the horn aperture and the lens surface.

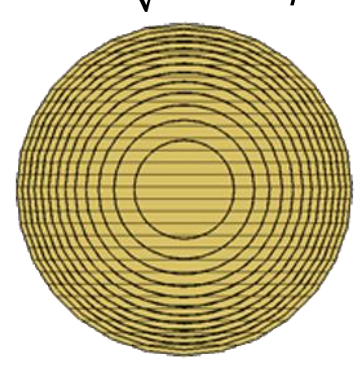
The graphs are displayed around the center frequency (10.35 GHz) and the lens has losses of ($\tan\delta = 10^{-3}$).

$$\varepsilon_r = 2 - \left(\frac{r}{R}\right)^2$$

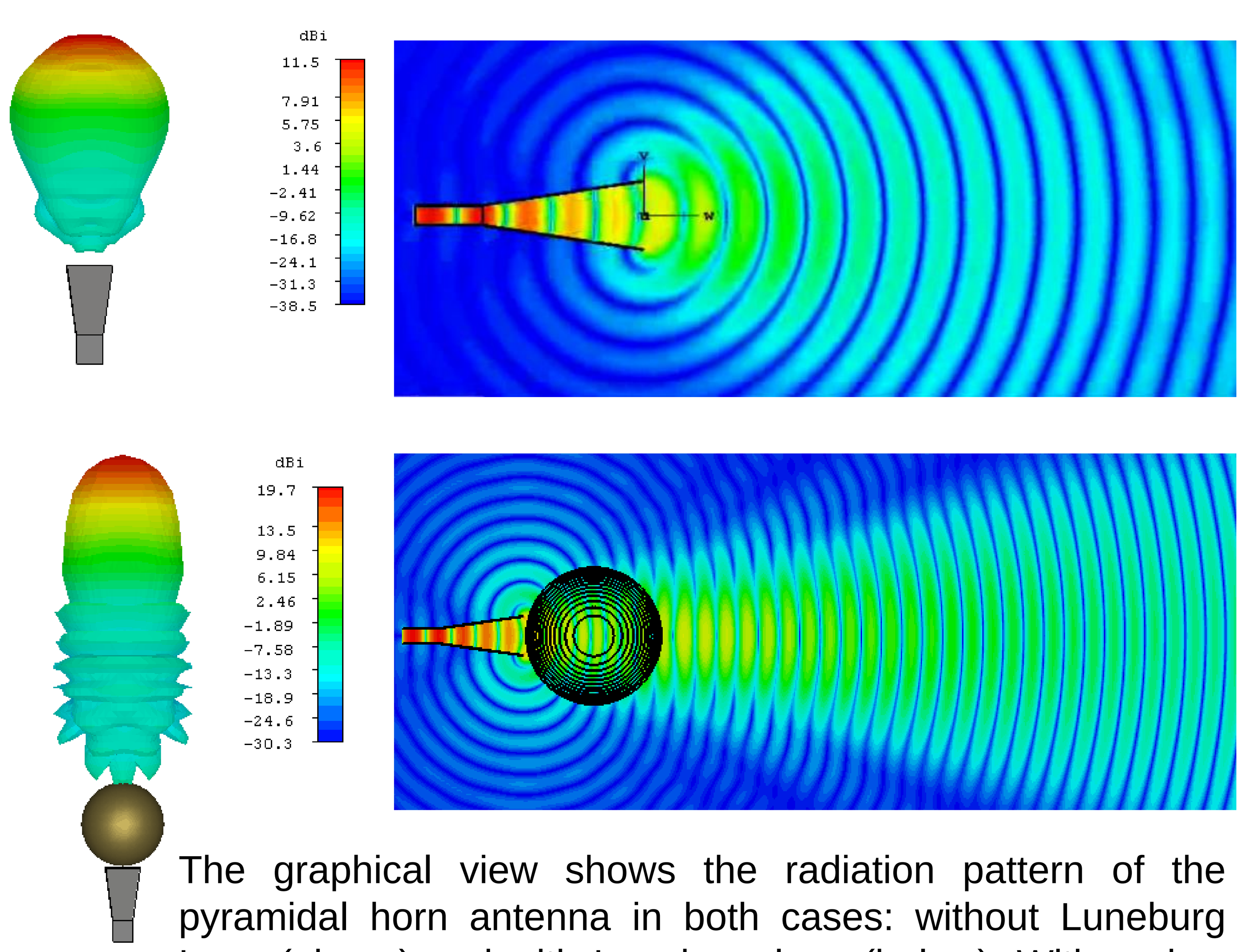


Equidistant (2).
Fixed Δr

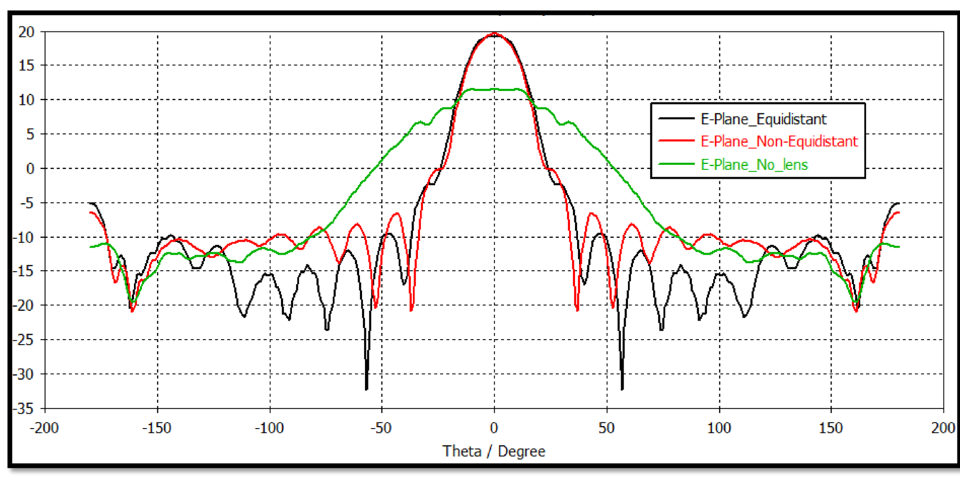
$$r = \sqrt{2 - \varepsilon_r}\ .\ R$$



Non-equidistant (2).
Fixed $\Delta\varepsilon_r$

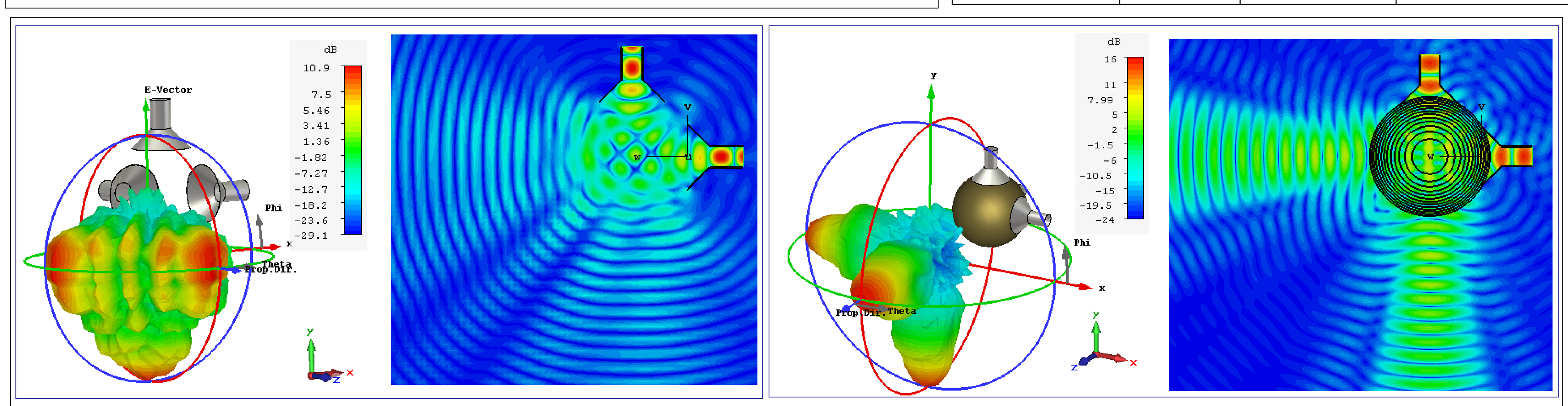


The graphical view shows the radiation pattern of the pyramidal horn antenna in both cases: without Luneburg Lens (above) and with Luneburg lens (below). With a view of the farfied of both cases (left).



The graph above displays the farfield curves of the E-Plane for the three cases; Non-equidistant lens (red), Equidistant lens(black) and the pyramidal horn antenna in single mode(green).
The table below shows the numeric values of the graph

	Pyramidal Horn Antenna without lens	Equidistant Luneburg lens	Non-Equidistant Luneburg lens
Frequency (GHz)	10.35	10.35	10.35
Angular Width at 3dB (deg)	48.7	21.4	20.3
Side Lobe level (dB)	-22.9	-21.5	-19.78
Maximum Gain in dBi	11.51	19.27	19.68



A graphical view indicates the propagation pattern of Luneburg lens when it's fed by multi-feeding conical horn antennas (right) in comparison to the case without the lens (left). With a view of the farfield in both cases.

Results and conclusion

To accomplish the thesis task, two different types of the lens (equidistant and non-equidistant) were created and used in different combinations with the horn antennas. The pyramidal horn antenna is the main device for radiation but the conical horn was used as well and it showed good radiation characteristics when combined with the spherical lens. A single horn antenna as well as multiple horn antennas were used during this project to examine the capabilities of the lens for working under different multi beams modes.

The numerical and the graphical results of more than six simulated models indicated a remarkable change on the electromagnetic radiation as a direct result of applying the Luneburg lens with the feeding antennas. The non-equidistant design of the lens showed better radiation characteristics than the equidistant model. The antenna gain and directivity were increased and the S_{11} parameters were reduced by the lens, it was always located in the acceptable reflection range (10% of the radiated energy) with a relative high side lobe suppression.

Finally, the main aim of this thesis has been achieved by designing the sought Luneburg lens with specific settings (size, shells and dielectric) and using it in combination with a microwave feeding antenna (pyramidal/conical). The results of the simulated designs were displayed in both cases; graphically and numerically as shown.

For future work, we can simulate different geometric constructions of the lens (e.g., hemispherical) with different frequency ranges as well as various feeding methods.

[Kark393] Kark, K.W.: Antennen und Strahlungsfelder, 5. Auflage, Springer Vieweg, Wiesbaden, Apr. 2014.