Optimizing efficiency and gain for horn (Tx) and parabolic dish reflector (Rx) antennas for different frequencies in near field region.

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Abstract : Antennas are basic components of any communication system and are connecting links between the transmitter and free space or free space and the receiver. Thus antennas play very important role in finding the characteristics of the system in which antennas are employed. Antennas are employed in different systems in different forms. in some systems the operational characteristic of the system are designed around the directional properties of the antennas or in some others systems, the antennas are used simply to radiate electromagnetic energy in an omnidirectional or finally in some systems for point-to-point communication purpose in which increased gain and reduced wave interference are required. The gain , directivity and efficiency are the parameters which are mostly dependent on the type of antenna or size and shape of specific antenna as we know the pyramidacal horn has specific directive properties or enhanced directivity as compare to paraboloid antenna and on the other hand efficiency and gain of the parabolic dish reflector are having enormous advantage over the horn antenna therefore the system or setup involving both type antenna give us close determination of parameter's value to enable the lossless communication system as far as satellite communication is concern.

IndexTerms* – *Transmitting, receiving , antenna , Horn , Paraboloid, Efficiency, Gain.

1.INTRODUCTION

To examine and obtain the optimized characteristics parameters we can established the experimental set up and by this experimental setup using Marconi test bench along with horn antenna as a transmitting antenna and parabolic dish reflector as a receiving antenna in the lab we have analyzed and detected efficiency and the most dominant frequency over large group of frequencies used for FSS(Fixed satellite service),BSS(broadcast satellite services) in the range of 8-12(GHz) . the lab results shows by graphical analysis and polar plot synthesis that certain frequencies shows the diversive gain or distributed gain for the different angles but at 9GHz and 10 GHz the maximum gain condition occurred with the set up.

The set up has different devices and components like transmitter which consist Gunn diode Oscillator, Coaxial to wave guide convertor and Horn antenna as a transmitting antenna .on the receiver side we have parabolic dish reflector as a receiving antenna , waveguide to coaxial transformer Frequency meter, Fixed and variable attenuator rectangular waveguide and power meter or sensor to measure the antenna output power and gain. the important thing in this set up is that the Horn antenna (Tx) is having angular or rotary motion for(0°- 180°) span. The observation has been made for different frequencies like (8 GHz.9 GHz.10 GHz,11 GHz,12GHz) for 10° interval separately and polar plot is made for every frequency .the theoretical and practical gain value is calculated and observed systematically with efficiency and the value of different parameter which occurred from the set up have been analysed for result and conclusion.

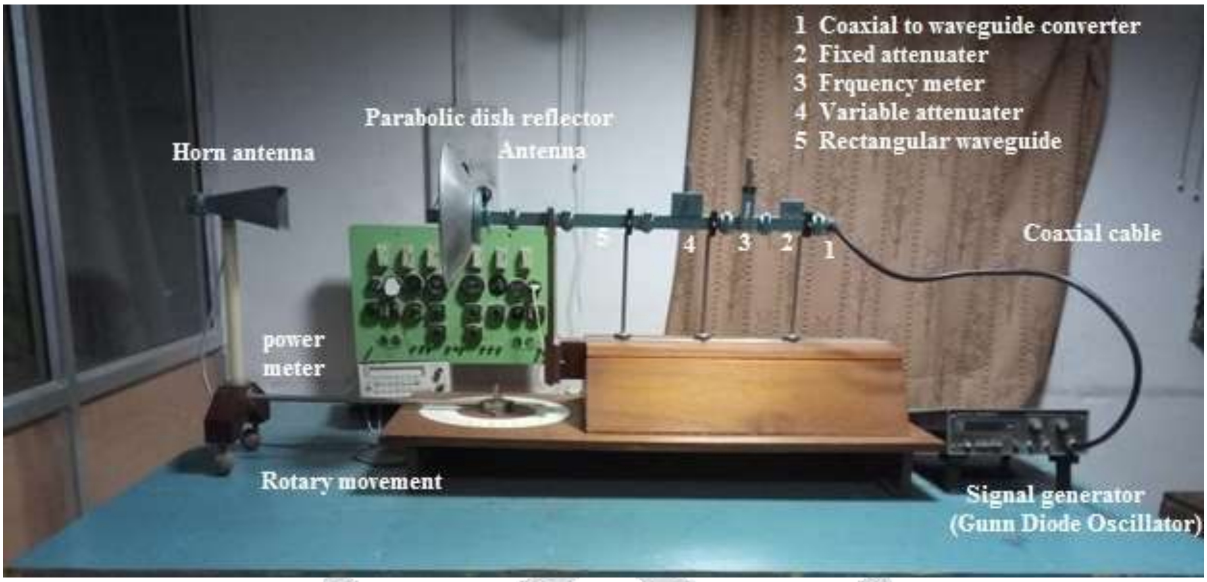

Figure 1 : Actual lab set up of Marconi test bench for measurement of gain and polar plot

2. Horn antenna as transmitter or feeder

The horn antennas consist in a wave-guide enlarging in the shape of a horn that a can be pyramid, sectorial or conical kind. The gain G of the horn antenna depends on the ratio between the surface of the horn opening and the working wave-length, and can be increased by enlarging the same horn. The gain of horn antennas for practical use is however limited generally to a maximum of about 20dB. The horn antennas are used alone, or in combination with parabolic reflector. In this second case, the horn antenna constitutes the so called **feeder** while the parabolic reflector is used to increase the directivity and gain of the set. The radiation diagram of horn antennas depends on the gain and the shape of the same antenna. Figure shows the shape of the main lobes in the planes E and H of a trapezoidal horn antenna and two sectorial horn antennas. Note that in the sartorial antenna the main lobe is narrower in the plane in which the opening is smaller.

Figure 2: Horn Antenna with radiation pattern

The theoretical gain **G** of a horn antenna is provided by the following relation:

$$G = \frac{10A}{\lambda_o^2} \cong \frac{6.4A}{\lambda_o^2} \qquad \text{Eq. 2.1}$$

With: λg = wave-length in guide
λo = wave-length in free space
A = surface (**a, b**) of the horn antenna opening.

Practical gain and beam width calculations by experimental setup through marconi test bench

HPBW = $0.88\ \lambda/_A$ Where a is the dimension of aperture = 3"(inches)
HPBW = $0.88\ \lambda/_B$ Where a is the dimension of aperture = 3"(inches)

Gain and directivity realationship for an antenna

$$G = KD \qquad \text{Eq. 2.2}$$

Where

G = gain of antenna
D = diretivity of an antenna
K = antenna efficiency Factor

Formula for Directivity of an Antenna

$$D = {}^{4\pi}/_{\Omega_A} \qquad \text{Eq.2.3}$$

Ω_A = area of main lobe of antenna
D = diretivity of an antenna

3.Parabolic Dish Reflector

The most well-known reflector antenna is the **parabolic reflector antenna**, commonly known as a **satellite dish antenna**. Examples of this dish antenna are shown in the following Figures .The smaller dish antennas typically operate somewhere between 2 and 28 GHz. The large dishes can operate in the VHF region (30-300 MHz), but typically need to be extremely large at this operating band.

the equation of a parabola with focal length *F* can be written in the (*x*,*z*) plane as:

$$x^2 = 4F(F - z), \quad |x| \le \frac{D}{2} \qquad \text{Eq. 3.1}$$

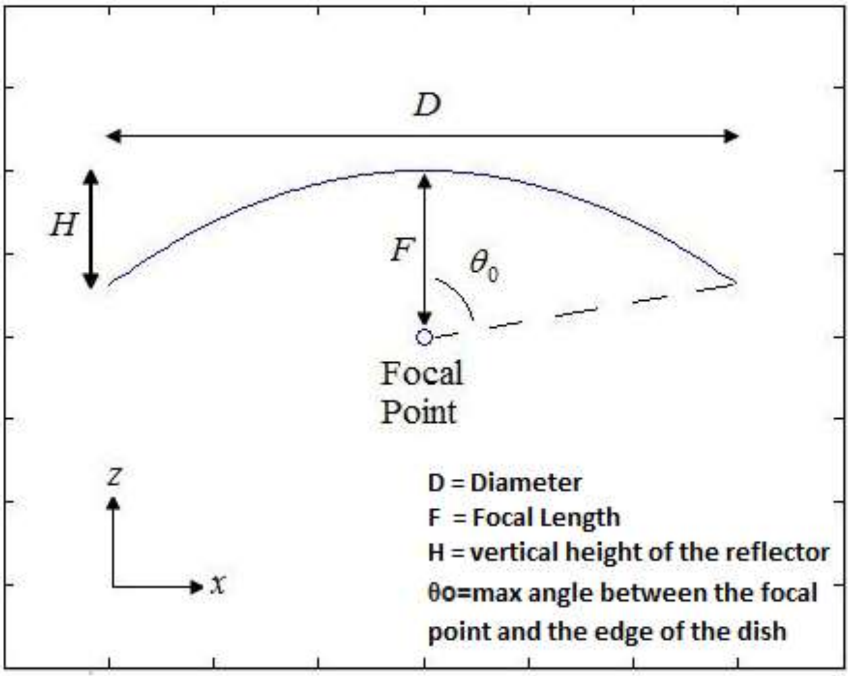

Figure 3 : Parabolic Dosh reflector antenna geometry

These parameters are related to each other by the following equations:

$$\frac{F}{D} = \frac{1}{4\tan(\theta_0 / 2)} \qquad \text{Eq. 3.2}$$

$$F = \frac{D^2}{16H} \qquad \text{Eq. 3.3}$$

To analyze the reflector, we will use approximations from geometric optics. Since the reflector is large relative to a wavelength, this assumption is reasonable though not precisely accurate. We will analyze the structure via straight line rays from the focal point, with each ray acting as a plane wave. Consider two transmitted rays from the focal point, arriving from two distinct angles as shown in Figure . The reflector is assumed to be perfectly conducting, so that the rays are completely reflected.

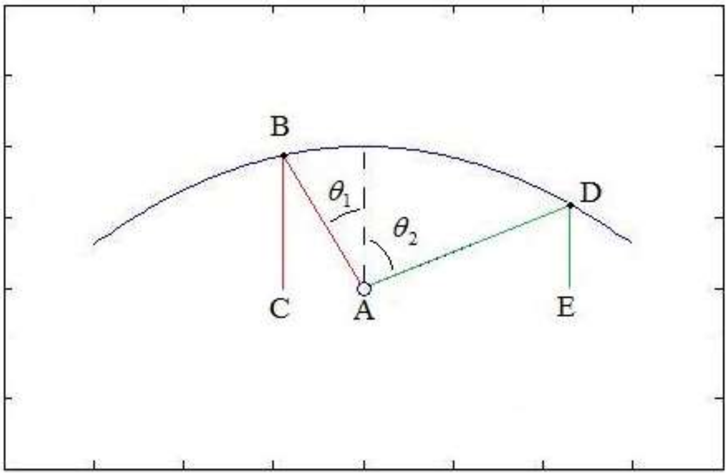

Figure 4 : Two rays leaving the focal point and reflected from the parabolic reflector.

There are two observations that can be made from Figure . The first is that both rays end up travelling in the downward direction (which can be determined because the incident and reflected angles relative to the normal of the surface must be equal).The rays are said to be *collimated*. The second important observation is that the path lengths ADE and ABC are equal. This can be proved with a little bit of geometry, which I won't reproduce here. These facts can be proved for any set of angles chosen. Hence, it follows that:

- All rays emanating from the focal point (the source or feed antenna) will be reflected towards the same direction.
- The distance each ray travels from the focal point to the reflector and then to the focal plane is constant.

As a result of these observations, it follows the distribution of the field on the focal plane will be in phase and travelling in the same direction. This gives rise to the parabolic dish antennas highly directional radiation pattern. This is why the shape of the dish is parabolic. Finally, by revolving the parabola about the z-axis, a paraboloid is obtained, as shown below.

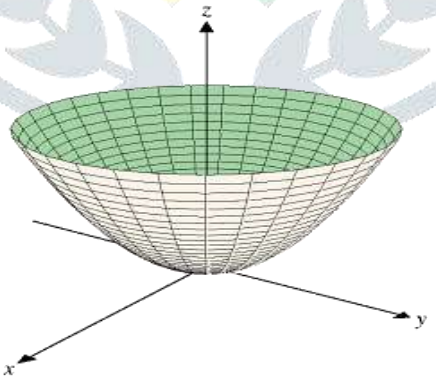

Figure 5 : paraboloid

For design, the value of the diameter *D* should be increased to increase the gain of the antenna. The focal length *F* is then the only free parameter; typical values are commonly given as the ratio *F/D*, which usually range between 0.3 and 1.0. Factors affecting the choice of this ratio will be given in the following sections.

The fields across the aperture of the parabolic reflector is responsible for this antenna's radiation. The maximum possible antenna gain can be expressed in terms of the physical area of the aperture:

$$G_{\max} = \frac{4\pi}{\lambda^2} A = \frac{(\pi D)^2}{\lambda^2} \qquad \text{Eq. 3.4}$$

The actual gain is in terms of the effective aperture, which is related to the physical area by the efficiency term (ε). This efficiency term will often be on the order of 0.6-0.7 for a well designed dish antenna:

$$G = \varepsilon \frac{4\pi}{\lambda^2} A = \varepsilon \frac{(\pi D)^2}{\lambda^2} \qquad \text{Eq. 3.5}$$

4. Radiation Efficiency

Understanding this efficiency will also aid in understanding the trade-offs involved in the design of a parabolic reflector. The antenna efficiency can be written as the product of a series of terms:

$$\varepsilon = \varepsilon_r \varepsilon_{AT} \varepsilon_S \varepsilon_O \qquad \text{Eq. 4.1}$$

The radiation efficiency ε_r is the usual efficiency that deals with ohmic losses, as discussed with the efficiency . Since horn antennas are often used as feeds, and these have very little loss, and because the parabolic reflector is typically metallic with a very high conductivity, this efficiency is typically close to 1 and can be neglected.

4.1 Aperture Taper Efficiency

The aperture radiation efficiency ε_{AT} is a measure of how uniform the E-field is across the antenna's aperture. In general, an antenna will have the maximum gain if the E-field is uniform in amplitude and phase across the aperture (the far-field is roughly the Fourier Transform of the aperture fields). However, the aperture fields will tend to diminish away from the main axis of the reflector, which leads to lower gain, and this loss is captured within this parameter.

This efficiency can be improved by increasing the *F/D* ratio, which also lowers the cross-polarization of the radiated fields. However, as with all things in engineering, there is a tradeoff: increasing the *F/D* ratio reduces the spillover efficiency.

4.2 Spillover Efficiency

The spillover efficiency ε_S is simple to understand. This measures the amount of radiation from the feed antenna that is reflected by the reflector. Due to the finite size of the reflector, some of the radiation from the feed antenna will travel away from the main axis at an angle greater than θ_0 , thus not being reflected. This efficiency can be improved by moving the feed closer to the reflector, or by increasing the size of the reflector.

4.3 Other Efficiencies

There are many other efficiencies that I've lumped into the parameter ε_O. This is a major of all other "real-world effects" that degrades the antenna's gain and consists of effects such as:

Surface Error - small deviations in the shape of the reflector degrades performance, especially for high frequencies that have a small wavelength and become scattered by small surface anomalies
Cross Polarization - The loss of gain due to cross-polarized (non-desirable) radiation
Aperture Blockage - The feed antenna (and the physical structure that holds it up) blocks some of the radiation that would be transmitted by the reflector.
Non-Ideal Feed Phase Center - The parabolic dish has desirable properties relative to a single focal point. Since the feed antenna will not be a point source, there will be some loss due to a non-perfect phase center for a horn antenna.

Calculating Efficiency

The efficiency is a function of where the feed antenna is placed (in terms of *F* and *D*) and the feed antenna's radiation pattern. Instead of introducing complex formulas for some of these terms, we'll make use of some results by S. Silver back in 1949. He calculated the aperture efficiency for a class of radiation patterns given as:

$$R(\theta) = \begin{cases} \cos^n \theta, & 0 \le \theta \le 90^\circ \\ 0, & 90^\circ \le \theta \le 180^\circ \end{cases} \qquad \text{Eq. 4.2}$$

Typically, the feed antenna (horn) will not have a pattern exactly like the above, but can be approximated well using the function above for some value of *n*. Using the above pattern, the aperture efficiency of a parabolic reflector can be calculated. This is displayed in Figure 1 for varying values of and the *F/D* ratio.

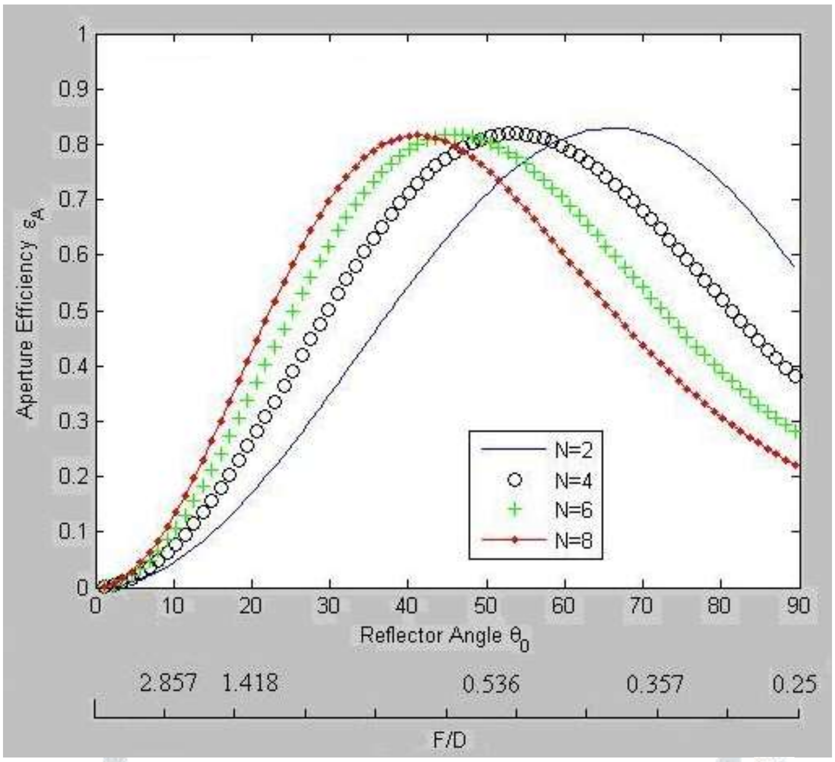

Figure 6 : Aperture Efficiency of a Parabolic Reflector as a function of *F/D* or the angle θ_0 , for varying feed antenna radiation patterns.

Figure gives a good idea on design of optimal parabolic reflectors. First, *D* is made as large as possible so that the physical aperture is maximized. Then the *F/D* ratio that maximizes the aperture efficiency can be found from the above graph. Note that the equation that relates the ratio of *F/D* to the angle θo can be found in plot

Calculating gain and plotting the graph

As we have rotary movement of transmitting antenna which provide different angular displace motion upto 180^0 and we have group of frequencies on which we have taken reading from power sensor or HP make power meter . EM signal or waveform is generated by this generator feed to transmitting antenna and received by parabolic dish reflector antenna which is already connected to power meter which provides gain and output power w.r.t. angular motion of antenna as shown below.

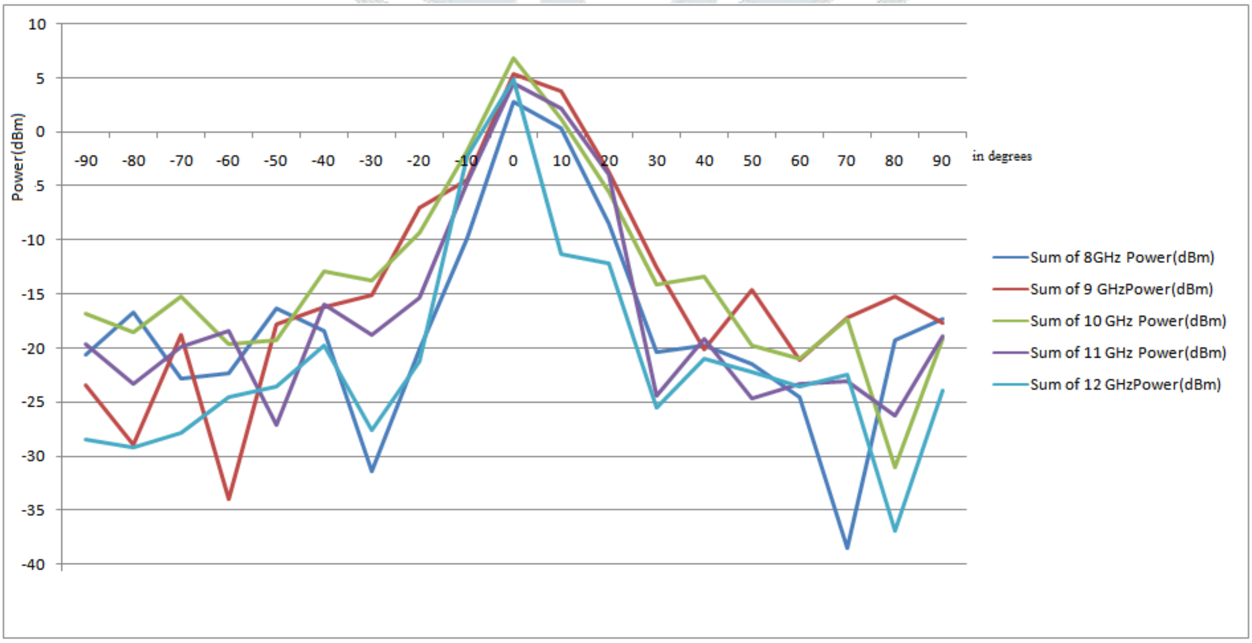

Figure 7 : Relationship between power in dBm verses angular movement in degrees for different frequencies.

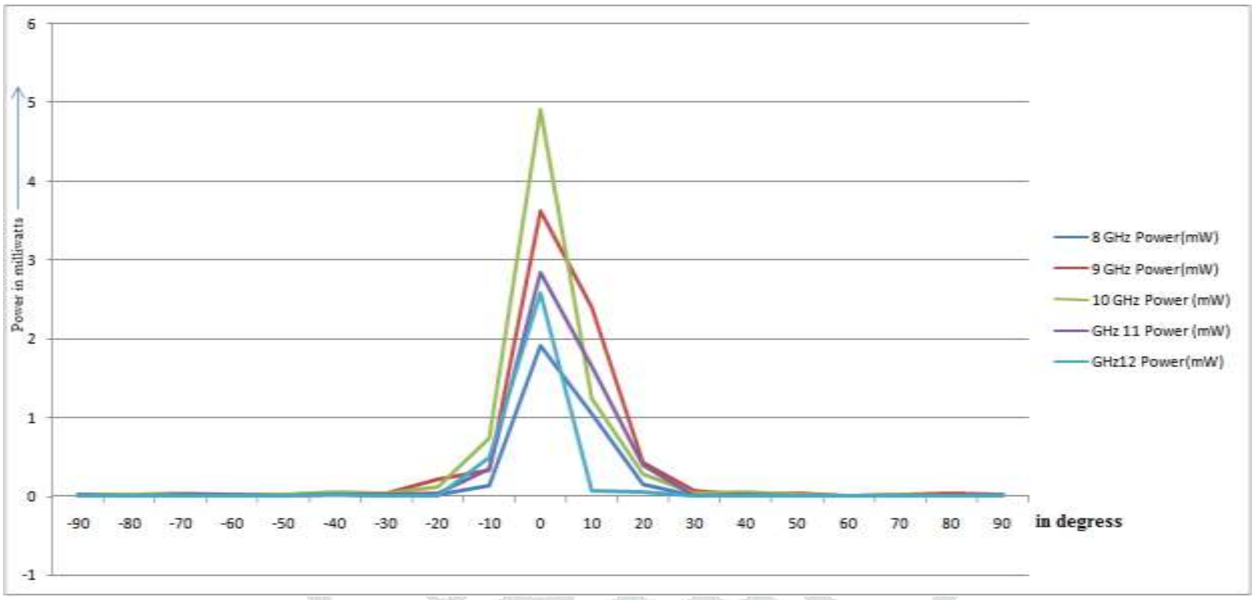

Figure 8 : Relationship between power in mw verses angular movement in degrees for different frequencies.

5. Result and Conclusion

The 2D radiation patterns or polar plot are presented to give an idea of what they look like. This example will be for a parabolic dish reflector with the diameter of the dish *D* equal to wavelengths. The *F/D* ratio will be 0.5. A pyramidacal horn antenna will be used as the feed.

The maximum antenna gain from the physical aperture is $(11\pi)^2 = 1194 = 30.7\text{dB}$; the theoritical gain is 29.3 dB = 851, the actual gain is less than one so we can conclude that the overall efficiency is 77%. which is not fully match with the practical lab readings as far as near field shown but lies in range of approximately 10 % The 2D patterns are shown in the figures (graphs).

8GHz, 9GHz, 10GHz, 11GHz, 12GHz are the dishtinguished frequncies which are basically used to measure and satisfy the maximem gain conditions or in other words we have tried to find out the maximmem gain or lossless output by receiving parabolic dish reflector antenna. the particular frequency or frequencies on which maximem gain can be occured in normal lab condition on Marconi Test Bench are find to be as 9GHz and 10GHz frequncies in fresnel region so the polar plot or graphs which have been plotted for the above said frequencies (8GHz, 9GHz, 10GHz, 11GHz, 12GHz) shows that minimem lossless propagation can be found on 9GHz and 10GHz frequencies.Therefore by the setup we can assure the suitability or selection of frequencies can be made for different antenna so that they can provide the sustained link between Tx and Rx antennas.

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