A PROJECT REPORT ON

"LOG PERIODIC ANTENNA FOR FREQUENCY INDEPENDENT OPERATION"

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In the partial fulfillment of the requirement for the award of the degree of

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ABSTRACT

IMPORTANCE OF MEASUREMENT IN RADIOASTRONOMY

The exploration of the universe has been going on continuously by investigating the radiations coming from the sky. This radiation covers the entire Electromagnetic spectrum starting from 0.001 micron to 10m. The electromagnetic spectrum can be divided into many bands like X-ray, Ultraviolet, Optical and Radio window. Specialized tool and techniques are required for each of the above bands to collect the energy from the sky. In radio astronomy, the energy collected from the sky lies entirely in the radio window starting from 1cm to 10m. Radio telescopes are used in radio astronomy to receive signals from the sky

A radio telescope consists of three elements:

1. Antenna **2.Receiver** **3.Recorder**

1. An antenna, which selectively collects radiations from a small region of sky.
2. A receiver (radiometer), which measures the total power of the signal received by the antenna and amplifies a restricted frequency band from the output of antenna.
3. A recorder, records the radiometer output, so that data can be analyzed later on.

The radiometer measures the total power content of the band-limited signal received.

The recorder records the measured data for off-line analysis.

Normally a parabolic reflector is used for observing the sky. Even though the parabolic reflector is inherently capable of operating over several decades of frequency, it is limited at low frequencies by its physical size and at high frequencies by the accuracy of the reflecting surface. Hence the frequency band of operation of parabolic reflector is mainly decided by the feed used to illuminate this. It is always highly desirable to have one broadband antenna for

multi wavelength observations of the sky. The greatest advantage that lies in going for broadband antenna is significant reduction in the number of receiver systems required for observing various frequencies.

The antenna used in a parabolic reflector should be frequency independent in its characteristics.

Every celestial body emits radiation at different frequencies and in order to characterize it at all those frequencies, it is very much desirable to have an antenna with a large bandwidth .in order to accomplish this, frequency independent antennas are used most widely.

The trapezoidal structure is one of the wide band antennas, which can be used in a radio telescope. The aim of this project is to build one of that types in the frequency range 0.5GHz to 5GHz.

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Dedicated to our

Beloved Parents.

CHAPTER – 1

CHAPTER- 1

1.0 Antenna

An antenna is a device, which converts the electromagnetic energy to a measurable electrical signal.

1.1 Definitions of Various Electrical and Structural Parameters

Antenna exhibits dual nature, i.e., as a circuit device on one hand and a space device on the other, schematic illustration of this is shown below.

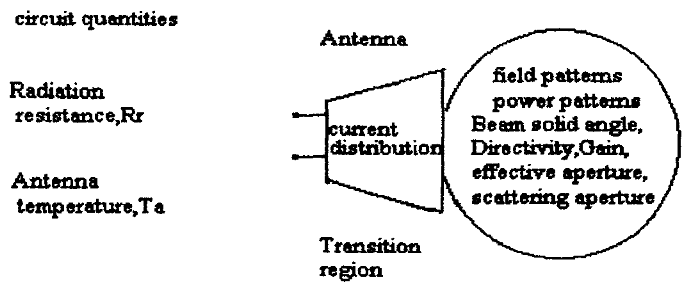


Fig 1.1 Antenna

1.1.1 Radiation Pattern

The radiation pattern of an antenna represents the variation of the voltage gain as a function of angle in two perpendicular variations θ andϕ. A

typical antenna will have one primary lobe and several secondary lobes whose magnitudes are much lower than the primary lobe as shown in the figure. The measure of the radiation pattern is very important to know exactly, the angular region in the sky from where the antenna is receiving the signal.

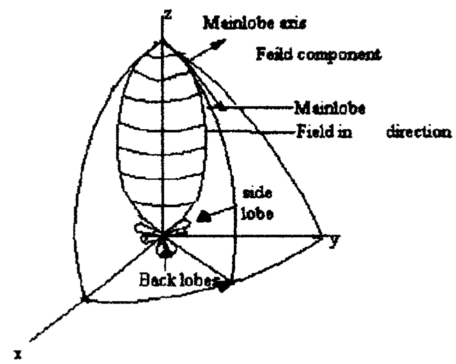


figure:Antenna field pattern with coordinate system

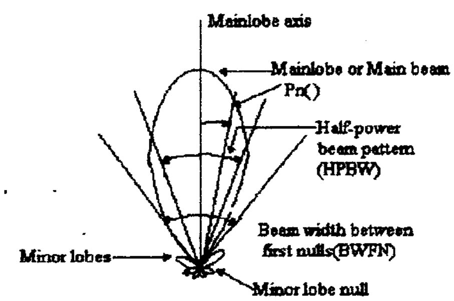


Fig 1.2 Radiation pattern

1.1.2 Beam Solid Angle

It is defined as the solid angle over which the entire power from the antenna gets transmitted with a maximum gain in the primary lobe.

$$\Omega a = \int_{0}^{2\pi} \int_{0}^{\pi} Pn(\theta, \Phi)\, d\Omega$$

Where, Pn (θ, Φ) is the normalized radiation pattern.

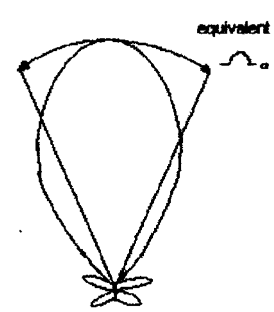


Fig 1.3 Beam solid Angle

1.1.3 Directivity (D)

The directivity of an antenna is given by the ratio of the maximum radiation intensity (power/unit solid angle) to the average radiation intensity Uav(averaged over the entire sphere).

Radiation intensity (U) is the power radiated from an antenna per unit solid angle.

$$D = \frac{U(\theta, \phi)_{max}}{U_{avg}}$$

It is also defined as the ratio of 4π steradian to beam solid angle (Ωa).

1.1.4 Gain (G)

It is defined as the directivity of the antenna including the losses in it. Hence gain is always less than directivity.

$G = kD$

where k = efficiency factor of antenna($0< k< 1$)

1.1.5 Effective aperture (Ae)

It represents the area of the antenna aperture over which the power is extracted from the incident wave and delivered to the load.

If S represents the power in W/m2 of the incident wave and P represents the total power received by the antenna, then the ratio of P to S gives us the effective area of the antenna.

$$Aem = \frac{V^2}{(4 S R_r)} \quad (m^2 \text{ or } \lambda^2)$$

Where, S= Power density of incident wave (W/ m 2)

R_r = Radiation resistance

1.1.6 Scattering aperture

The power in antenna impedance, some of it appears as heat in the antenna and the remainder is reradiated from the antenna. This reradiated or scattered power is analogous to the power that is dissipated in a generator in order that power is delivered to the load. This reradiated power is related to scattering aperture, which is defined as the ratio of the reradiated power to the power density of the incident wave.

1.1.7 Radiation resistance

The antenna appears from the transmission line as a 2- terminal circuit element having an impedance Z with a resistive component called radiation resistance. This resistance is not associated with antenna proper but it is a resistance coupled from the antenna and its environment to the antenna terminals.

1.1.8 Antenna Temperature

For a lossless antenna this temperature is related to the temperature of distant regions of space coupled to the antenna via its radiation resistance.

Antenna temperature is a parameter that depends on the temperature of the regions the antenna is looking at. In this sense, a receiving antenna is regarded as a remote-sensing, Temperature-measuring device.

1.1.9 Front to back ratio

It is defined as a ratio of the power radiated in desired direction to the power radiated in the opposite direction. Front to back ratio changes if frequency of operation of antenna system changes. Its value decreases if spacing between elements of antenna increase.

1.1.10 Half power beam width

The half power beam width is defined as the angle between two directions in which radiation intensity becomes half of maximum in a primary lobe.

1.1.11 Bandwidth

The bandwidth of the antenna is defined as the range of frequencies with which the antenna performs conforming to specified standards.

1.1.12 VSWR

VSWR is a measure of the ratio of the maximum voltages to the minimum voltages set up on the transmission line. It is a measure of impedance mismatch between the transmission line and its load.

1.1.13 Return loss

Return loss is the difference in power (expressed in db) between the incident power and the power reflected back by the load due to a mismatch. It is expressed as

Return loss=10log ($p_{reflected}$/ $p_{incident}$)

1.1.14 Phase center

The phase center is defined as a point inside the antenna from which the spherical waves radiated by the antenna originates.

1.1.15 Balun

It is an impedance matching transition from unbalanced impedance to a balanced two conductor line.

1.2 Types of antennas

1.2.1 Dipole Antenna

Dipole antenna is a system consisting of two straight conductors having a total length l<< λ. A dipole is an extension of transmission line. Any linear antenna consists of a large number of very short conductors connected in series. A short linear conductor is called a short dipole. The dipole may be energized by a balanced transmission line .The conductor with a physical length of approximately λ/2 is known as half wave dipole. It may be defined as "a symmetrical antenna in which the two ends are at equal potential w.r.t the centre point. A dipole is the unit from which many more complex antennas can be constructed.

Advantages: -

1) It is a symmetrical antenna in which the two ends are at equal potential w.r.t the center point.

2) For a given length of the dipole, it can be operated only at a single frequency.

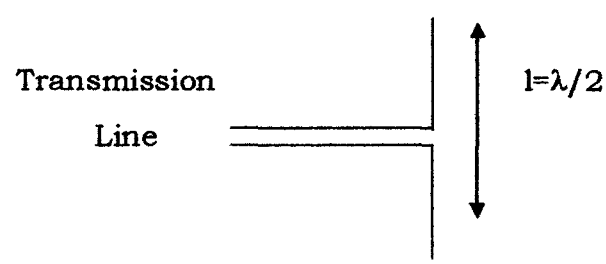


Fig 1.4 Dipole Antenna

1.2.2 Helical antenna

Helical antenna is a basic type of radiator and it is a simplest antenna to provide circularly polarized waves which are used in the extra terrestrial communications in which satellite relays are involved. Helical antenna is broadband VHF and UHF antenna to provide circular polarization characteristics. It consists of a helix of thick copper wire or tubing wound in the shape of a screw thread.

Advantages: -

Single or an array of helical antenna is used to receive or transmit the VHF signals through ionosphere.

It has very high bandwidth.

It is simple in construction.

It has high directivity

The circular polarizations of the helical beam antenna are very useful in radio astronomy.

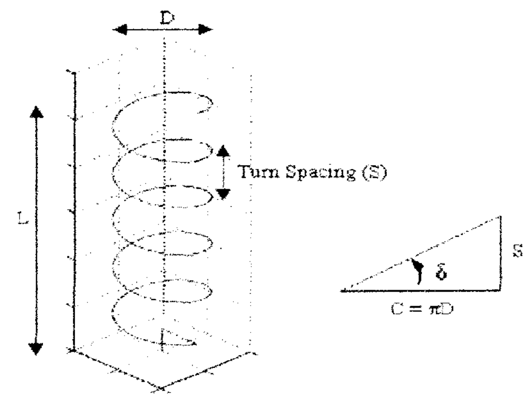


Fig 1.5 Helical antenna

1.2.3 Horn antenna

A horn antenna is a flared out or opened out wave-guide. A wave guide is capable of radiating radiation in to open space provided it is excited at one end and opened at the other end, the radiation is much greater through waveguide than the two wire transmission line. The mouth of the wave-guide is opened out which assume the shape of electromagnetic horn, just like an opened out transmission line resulting in a dipole. There are three four of horn antennas E-plane horn-plane horn, pyramidal horn and conical horn. Horn antennas are used at microwave frequency range.

Advantages: -

1) Horn antennas can be used as source or driven element for parabolic reflectors.

2) Circular horns can be used in radar search antennas.

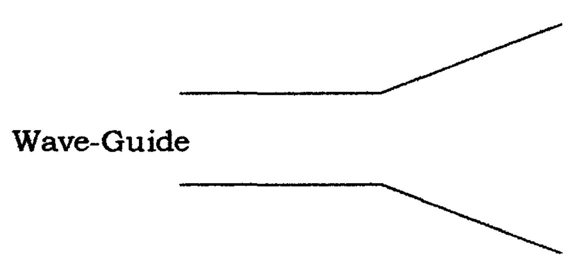


Fig 1.6 Horn Antenna

1.3 Broad Band Antennas

Many antennas are highly resonant operating over bandwidths of only a few percent. Such tuned narrow bandwidth antennas may be entirely satisfactory for a single frequency or narrow-band application. In many situations wider bandwidths are required and these antennas are called broadband antennas. Frequency independent antennas can be used for broadband applications.

1.3.1 Frequency Independent Antennas

Characteristics

Frequency independent antennas are a particular class of wideband antennas, which was first studied by Rumsey. His simple but significant theory has become the foundation for studying many wideband antennas. These are the antennas that have the geometry that are completely specified by angles. These are used for many practical applications such as TV, point-to-point communication, feeds for reflectors and lenses. In antenna scale modeling, characteristics such as impedance, pattern, and polarization are invariant to a change of the physical size if a similar change is made in the operating frequency or wavelength. If the dimensions are reduced by some factor, the performance of the antenna will remain unchanged if the operating frequency is increased by the same factor i.e. the performance is invariant if the electrical

dimensions remain unchanged. Antenna scaling model depends on this principle. The scaling characteristics of the antenna model measurements indicate that if the shape of the antenna were completely specified by angels, its performance would be independent of frequency .To make an infinite structure more practical, the designs usually require that the current on the structure decrease with distance away from the input terminals.

Salient features

Frequency independent antennas exhibit the feature that the impedance of the antenna remains nearly constant over their entire bandwidth of operation. The Radiation pattern also remains independent of frequency. Rumsey proposed that if the shape of a lossless antenna is such that it can be specified entirely by angles, its performance such as pattern and input impedance would remain unchanged with frequency. In other words, the dimensions of this class of antennas, when expressed in terms of wavelength, are the same at every frequency. The implication is that electrical characteristics of the antenna do not change with frequency. This is a very simple and powerful idea for the design of broadband antennas, which are referred to as frequency independent antennas for the ideal case.

CHAPTER – 2

Chapter 2

Frequency Independent Antennas

2.1 Introduction

All astronomers desire to observe over a wide bandwidth to get better sensitivity and frequency coverage required to decipher the source properties. Designing frequency independent antennas which give the required wide frequency coverage has been one of the driving forces in the designing of the modern day radio receivers.

Generally antennas function efficiently over a selected frequency range. For example a conventional half wave dipole is a resonant structure with a moderate bandwidth of around 10%.In general if an antenna designed to operate at a specific frequency is to be made to operate at a slightly different frequency, the structure has to be scaled in a proportion to frequency of operation. If we scale the antenna dimensions and also the operating wavelength the performance of the antenna remains the same. Scaling the structure does not alter the electrical properties of an antenna. Therefore to cover the different frequencies, one has to have more than one antenna to cover the wide bandwidth. Hence these antennas are all wavelength dependent .If a single antenna has to be frequency independent, it has been found out that its structure should be completely specified by angles rather than its linear dimensions.

Frequency independent operation is observed in practice for an antenna only over a limited bandwidth. The low frequency of operation is set by the maximum dimension .The high frequency limit is set by the dimension of the transmission line feeding current to the antenna.

2.2 Requirement of Frequency Independent Antennas

Generally frequency independent antenna should satisfy the following two important properties :

i) The electrical properties like radiation pattern, polarization should be invariant to frequency.

ii) The impedance offered by it should remain constant with frequency.

2.3 Conditions to be satisfied by a Frequency Independent Antenna

1) Self scaling:

For a frequency independent antenna the structure should be of self scaling type i.e. the different parts of the antenna should represent the radiating regions for different frequencies.

2) Minimum reflection in the transmission line:

The highest frequency of operation is decided by the minimum reflection in the transmission line feeding the current to the antenna. The reflection co-efficient of the transmission line should be less to reduce the end effect which limits the highest frequency of operation. In order to have minimum reflection the current on the transmission line should reduce to zero near the antenna edge. This is generally known as truncating principle.

2.4 Functional form of the Frequency Independent antenna

Generally the antenna should satisfy the equation given by

$$r=F(\theta,\phi+C)$$

where r represents the distance of the antenna structure from the origin,

θ and ϕ are the angles in elevation and azimuth planes

C represents the angular rotation required for frequency scaling.

The equation implies that given a structure of a frequency independent antenna, different frequencies get radiated at different angular locations of the structure.

The function $F(\theta,\phi)$ should be represented by functions of θ and ϕ independently. The general functional form is given by

$$r = e^{a\phi} f(\theta)$$

where the function $f(\theta)$ is a periodic function whose amplitude is controlled by the function $e^{a\phi}$.

2.5 Classification of Frequency Independent Antennas

The Frequency independent antennas can be classified as

i) Continuosly scaled antenna.
ii) Log-periodically scaled antenna.

2.5.1 Equiangular spiral antennas

The equiangular spiral antennas is an example for a continuously scaled antenna. The geometrical configurations of these antennas are described by angles. It also satisfies the requirements of a frequency independent antenna. Planar and conical spiral are the two types of equiangular antennas. Planar and conical spirals are the antennas belonging to the class of equiangular antennas.

Fig. 2.1 shows the schematic of a Planar spiral antenna. The function defining it is independent of θ. The value of θ is 90 deg. in this antenna. The structure is defined by derivative of $f(\theta)$ as given by

$$\frac{df}{d\theta} = f'(\theta) = A\delta\left(\frac{\pi}{2} - \theta\right)$$

where

A is a constant

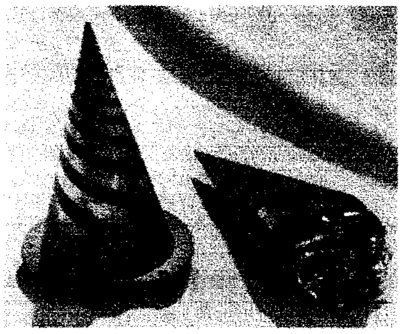


Fig 2.2 Conical spiral

2.5.2 Log-Periodic Antennas

The log periodic antenna is an example for a log-periodically scaled frequency independent antenna.

The log-periodic antennas are classified into

1.Planar and Wire surfaces

2.Dipole Array

3.Loop antenna

4.Non Planar log periodic antenna

1.Planar and Wire Surfaces:

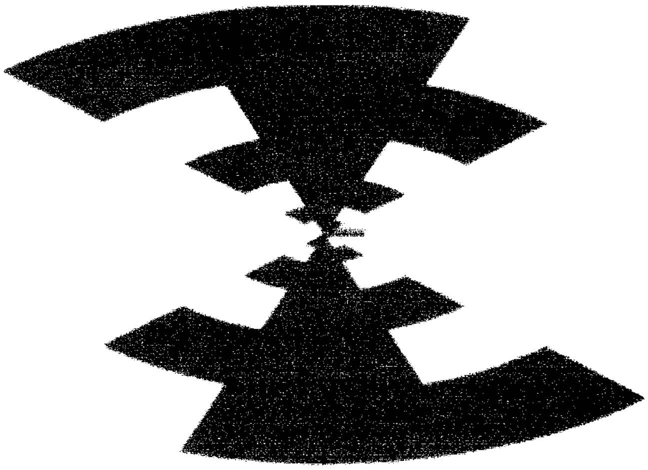


Fig 2.3 Log -periodic toothed planar structure

figure 2.5 (in the form of a V, formed by bending one arm relative to the other are also widely used. If the wires of the plates are linear then the antenna reduces to the trapezoidal tooth antenna or log periodic structure. These simplifications result in more convenient fabrication geometrics with no loss in the operation performance.

The geometric ratio of the log periodic array structure is given by

$$\tau = \frac{Rn}{Rn+1}$$

where R(n+1) represents the axial distance of the last resonating element from the apex of the antenna, and R(n) is the axial distance of the penultimate resonating resonating element.

Width of the antenna is given by

$$X = \frac{r_n}{Rn+1}$$

τ is the geometric ratio representing the periodicity in the structure.

It also indicates the periodicity over which the antenna has periodic behavious. The geometric ratio is also given by

$$\tau = \frac{f_1}{f_2}$$

These are the frequencies one period apart.

2.Dipole Array:

It consists of a sequence of side by side parallel linear dipoles forming a coplanar array. They have similar directivities as the Yagi Uda array. They are achievable and maintained over much wider bandwidths. But they have major differences between them. The dimensions of the yagi Uda array elements do not follow any set pattern where as the lengths (ln's), spacings (Rn's) diameters (dn's),and even gap spacings at the dipole centers (sn's) of the log periodic array increase logarithmically as defined by the inverse of the geometric ratio τ.

$$\tau = \frac{l_2}{l_1} = \frac{Rn}{Rn+1} = \frac{ln}{ln+1} = \frac{Sn}{Sn+1}$$

The straight lines through the dipole ends meet to form an angle α which is a characteristic of the frequency independent structures.

End fire configuration:-The current in the elements has the same phase relationship as the terminal phases. If in the addition the elements are closely spaced, the phase progression of the currents is to the right .This produces an end fire beam in the direction of the longer elements and interference effects to the pattern result.

Crisscrossing the feed:-It was recognized that by mechanically crisscrossing or transposing the feed between adjacent elements the phase of 180 deg. is added at the terminal of each element. Since the phase between the adjacent closely spaced short elements is almost in opposition, very little energy is radiated by them and their interference effects are negligible. The longer and larger spaced elements will radiate at the same time. The mechanical phase reversal between these elements produces a phase progression so that the energy is beamed in the direction of the shorter elements.

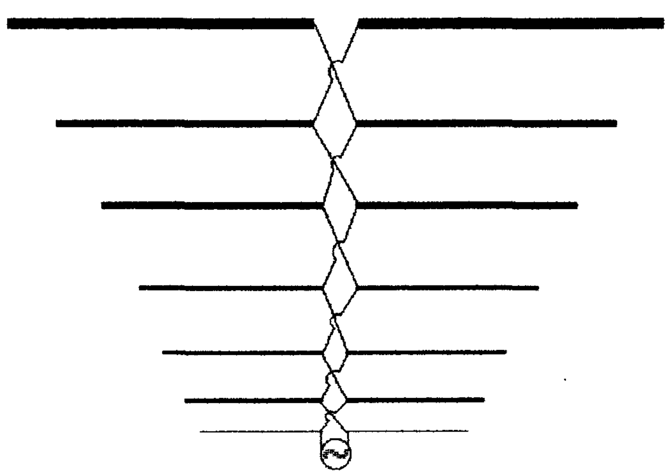


Fig 2.5 A dipole Array with cris cross feed

Limitations of LPDA: - A limitation of the LPDA is that the dipole element for the lowest operation frequency in the HF range may become too long to be conveniently handled in the environment of application. Modifications were made to the structure by replacing the dipoles by monopoles over a ground plane and using log periodic helical antennas.

Active region in a Dipole Array

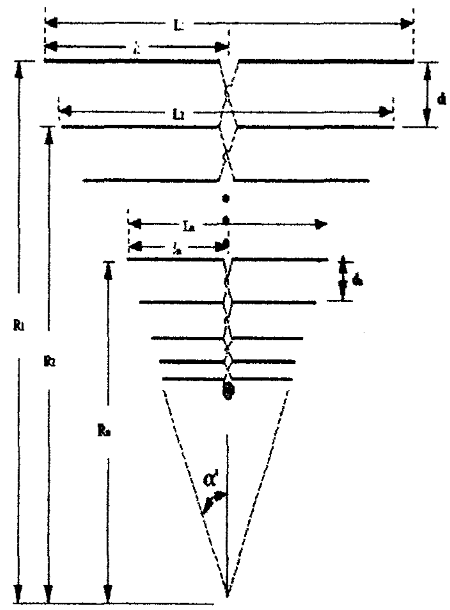


Fig 2.6 Dipole Array

The figure shows that each element is driven with a phase shift of 180 degree by switching or alternating element connections as shown in the figure. The diploes near the input are nearly out of phase and close together nearly cancel each others radiation .As the element spacing expands there comes a point along the array where the phase delay in the transmission line combined with the 180 degree phase gives a total of 360 degree. This puts the radiated fields from the dipoles in phase in a direction toward the apex. This phase relation ship exists in a set of dipoles known as the active region. If we design an antenna for a frequency range, and then the design must include an active region of resonating structures for the highest and lowest design frequency. The active region decides the basic design parameters for the antenna and sets the bandwidth of the structure.

The basic concept is that a gradually expanding periodic structure array radiates most effectively when the array elements (dipoles) are near resonance so that with change in frequency the active (radiating) region moves along the array. This expanding structure array differs from the uniform arrays.

The log-periodic dipole array is a popular design. Referring to Figure, the dipole lengths increase along the antenna so that the included angle α is a constant, and the lengths l and spacing s of adjacent elements are scaled so that where k is a constant. At a wavelength near the middle of the operating range, radiation occurs primarily from the central region of the antenna. The elements in this active region are about $\lambda/2$ long.

$L_{n+1}/l_n=S_{n+1}/S_n=k$

Elements 9, 10, and 11 are in the neighborhood of 1 λ long and carry only small currents (they present a large inductive reactance to the line) the small currents in elements 9, 10 and 11 mean that the antenna is effectively truncated at the right of the active region. Any small fields from elements 9, 10 and 11 also tend to cancel in both forward and backward directions. However, some radiation may occur broadside since the currents are approximately in phase. The elements at the left (1, 2, 3, etc) are less than $\lambda/2$ long and present a large capacitive reactance to the line. Hence, currents in these elements are small and radiation is small.

Thus, at a wavelength λ, radiation occurs from the middle portion where the dipole elements are $\lambda/2$ long. When the wavelength is increased the radiation zone moves to the right and when the wavelength is decreased it moves to the left with maximum radiation toward the apex or feed point of the array.

At any given frequency only a fraction of the antenna is used (where the dipoles are about $\lambda/2$ long).

3. Log periodic Loop Antenna

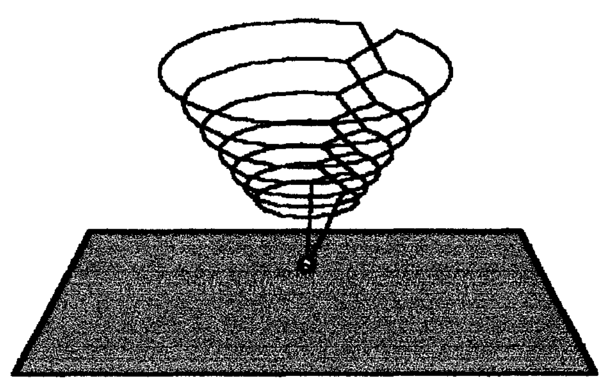


Fig 2.7 Loop Antenna

Using the LPDA concept, in this thesis, a new type of log-periodic antenna, as shown in, is designed, simulated and tested. Since this antenna has a loop as the constituting element and has ground reflector, it is referred to as log-periodic loop antenna with ground reflector (LPLA-GR). Using the circular loop element instead of the dipole agrees with the attempt to reduce the transverse dimension of the LPDA. In addition, the log-periodic loop antennas with ground reflector are expected to have higher gain than LPDAs, because the loop element generally provides a higher gain than the dipole and the ground plane further increases the gain due to the image effect.

4. Evolution of the Non planar Trapezoidal tooth structure

Trapezoidal tooth structure can be thought to have evolved from a simple half wave dipole. This has been shown in the Fig 2.10. In the evolution, a simple **half wave dipole is** a resonant structure with a moderate bandwidth of around 10%. A simple **half wave thick dipole** is also a resonant structure with slightly greater bandwidth than the half wave dipole. But a **Biconical Antenna** consisting of a tapered transmission line has much more broad band. In this antenna, the current does not reduce to zero at the edges. So larger bandwidth may not be obtained from this structure. In the **Trapezoidal Antenna** monopoles are included attached to the tapered transmission line to radiate energy more effectively and letting the current to zero at the edges. Thus the trapezoidal structure possesses a much more broad band performance.

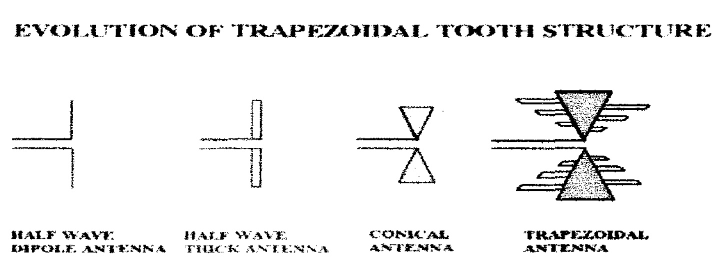
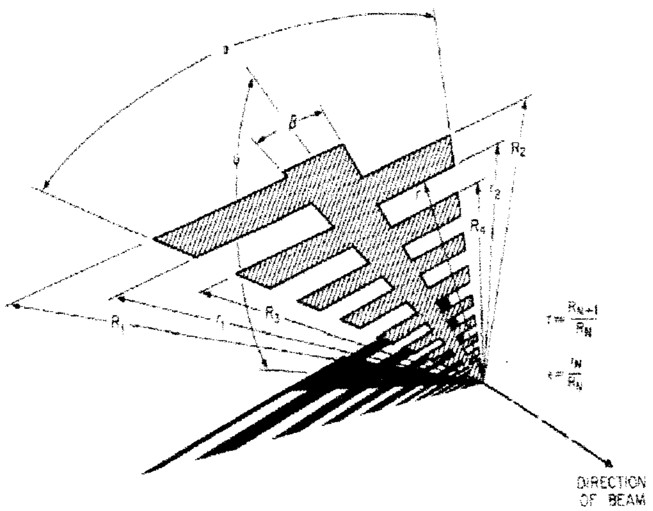


Fig 2.8 Evolution of trapezoidal Tooth structure



Trapezoidal-tooth log-periodic antenna

Fig 2.9 Non-Planar Trapezoidal Tooth structure

2.6 Self complementary Configuration

In addition to the angle dependence, a second principle was used in the early development of frequency independent antennas. This principle states that if an antenna has the same shape as its complement empty part, its impedance is const

ant at all frequencies. Figure 2.8 shows an example of complementary antenna. The relationship between input impedances, Z1 and Z2, for the complementary planar structures is expressed as

Sqrt(Z1 Z2) = z0/2

Where z1 and z2 are the impedances of the metal and its complement structures and z0 is the impedance of the free space.

Fig 2.9 Self Complementary Structure

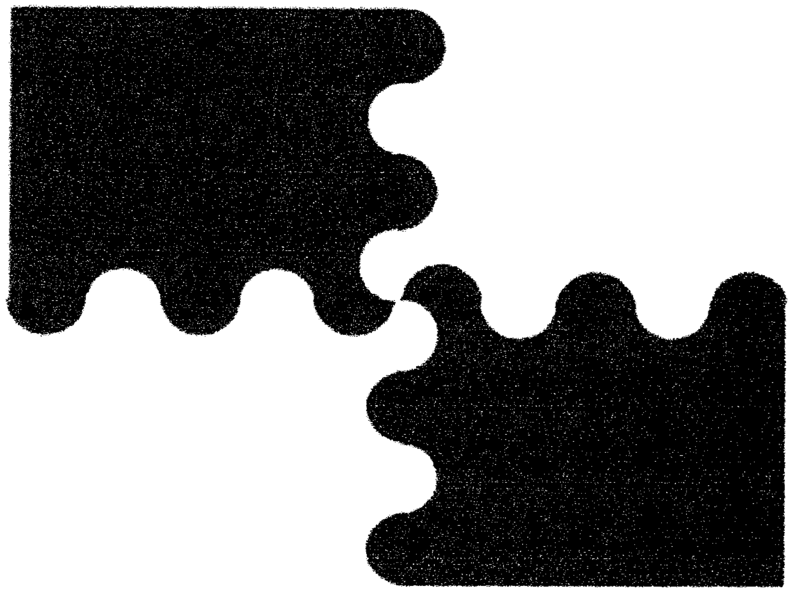


Fig 2.10 Complementary Pair Structure

2.7 Impedance Matching and Tuning.

Impedance Matching Transformer is important for:

1) Maximum power is delivered to the load (Antenna), when it is matched to the line, and the return loss in the feed line is minimized.

2) Impedance Matching reduces the Amplitude and Phase errors and improves the SNR of the system.

3) Impedance Matching reduces the Reflection coefficient at any point on the line.

2.8 Factors Important in selection of Matching Transformer.

Complexity: The simplest design that satisfies the required specifications is generally most preferable.

Bandwidth: Any Matching Network can ideally give a perfect match (zero reflection). But it is desirable to match a load over a band of frequencies.

Implementation: Depending upon the Transmission line being used, one type of Transformer may be preferable compared to another. Ex: - Tuning Stubs are easier to implement in waveguide than in Quarter Wave Transformer.

2.9 Types of Impedance matching Transformers

2.9.1 Quarter wave transformer.

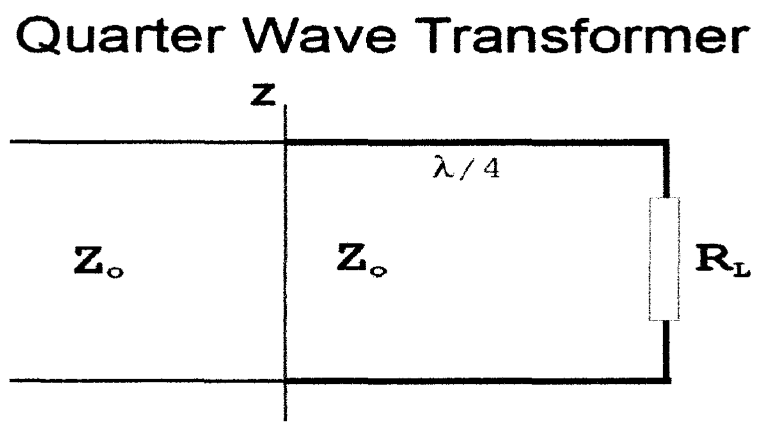
2.9.2 Multisection transformer.

1. **Binomial transformer.**
2. **Chebyshev transformer.**

2.9.3 Transmission line taper.

1. **Triangular taper.**
2. **Exponential taper.**
3. **Klopfenstein taper.**

2.9.1 Quarter wave transformer.



At the input to the $\lambda/4$ transmission line :

$$Z_{in} = Z_o\left[\frac{R_L + jZ_o \tan\beta l}{Z_o + jR_L \tan\beta l}\right] = \frac{Z_o^2}{R_L}$$

Fig 2.12 Quarter Wave transformer

The quarter-wave Transformer is a simple and useful circuit for matching real load impedance to a transmission line. It can be extended to multisection designs in a methodical manner, for broader bandwidth. Multisection quarter-wave transformer designs can be synthesized to yield optimum matching characteristics over a desired frequency band

The single section quarter-wave matching transformer circuit is shown in the figure. The characteristic impedance of the matching section is

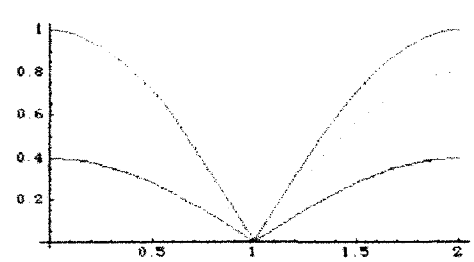
$$Z_0=\sqrt{(Z_{in}.R_L)}$$

At the design frequency the f_0, the electrical length of the matching section is $\lambda_0/4$, but at other frequencies the length is different, so a perfect match is no longer obtained.

Frequency Response

Near the matching frequency, the magnitude of the reflection coefficient can be expressed

$$|\Gamma| \approx \frac{|Z_L - Z_o|}{2\sqrt{Z_L Z_o}} |\cos \beta d|$$



Reflection coefficient vs f/f_c - different colors represent different $Z_L|Z_o$ combinations i.e. bandwidth depends on impedance mismatch. Small mismatch =high bandwidth

Bandwidth:

If we set a maximum value, Γ_m of the reflection coefficient magnitude that can be tolerated, then we can define the bandwidth of the matching transformer as,

$$\frac{\Delta f}{f_0}=2-\frac{4}{\pi}\cos^{-1}\left[\frac{\Gamma_m}{\sqrt{1-\Gamma_m^2}}\frac{2\sqrt{Z_0 Z_L}}{|Z_0-Z_L|}\right]$$

The fractional bandwidth is usually expressed as a percentage. The bandwidth of the transformer increases as Z_L becomes closer to Z_0

2.9.2 Multisection transformer.

1. Binomial transformer.

The pass band response of a binomial matching transformer is optimum in the sense that, for a given number of sections ,the response is as flat as possible near the design frequency (maximally flat) .This type of response is designed for an N-Section transformer ,by setting the first N-1 Derivatives of $\Gamma(\theta)$ to zero, at the centre frequency f_0. Such a response can be obtained if we let

$$\Gamma(\theta) = A\,(1+e^{-2j\theta})^{N}.$$

The expansion of $\Gamma(\theta)$ binomially is given by,

$$\Gamma(\theta)=\Gamma_0+\Gamma_1 e^{-2j\theta}+\Gamma_2 e^{-4j\theta}+\dots\dots\dots\dots+\Gamma_N e^{-2jN\theta}$$

The corresponding coefficients are given by,

$$\Gamma_n=\frac{Z_{n+1}-Z_n}{Z_{n+1}+Z_n}\simeq\frac{1}{2}\ln\frac{Z_{n+1}}{Z_n}$$, and

$$\ln\frac{Z_{n+1}}{Z_n}\simeq 2\Gamma_n\simeq 2^{-N}C_n^{-N}\ln\frac{Z_L}{Z_0},$$

Which can be used to find Z_{N+1}, starting with n=0.

Bandwidth:

The bandwidth of the binomial transformer is given by,

$$\frac{\Delta f}{f_0} = 2 - \frac{4}{\pi}\cos^{-1}\left[\frac{1}{2}\left(\frac{\Gamma_m}{A}\right)^{1/N}\right]$$

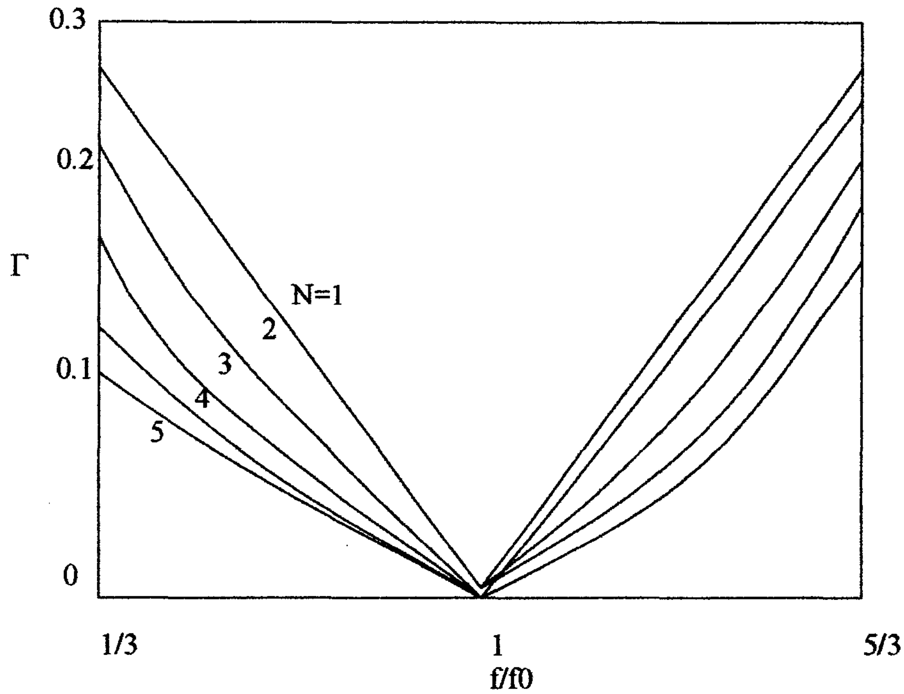


Fig 2.13 The reflection coefficient magnitude versus frequency for the Binomial transformer.

2. Chebyshev transformer.

In contrast with the binomial matching transformer, the Chebyshev transformer optimizes bandwidth at the expense of pass band ripple. If such a passband characteristic can be tolerated, the bandwidth of the Chebyshev Transformer will be substantially better than that of the binomial transformer, for a given number of sections. The Chebyshev transformer is designed by equating Γ(θ) to a chebyshev polynomial, which has the optimum characteristics needed for this type of transformer.

The Chebyshev polynomials are given by,

$$T_n(x) = 2xT_{n-1}(x) - T_{n-2}(x).$$

We can synthesize a Chebyshev equal-ripple pass band by making $\Gamma(\theta)$ proportional to T_N (sec θ_m,cos θ), where N is the number of sections in the transformer. Thus,

$$\Gamma(\theta)=2e^{-jN\theta}\left[\Gamma_0\cos N\theta+\Gamma_1\cos(N-2)\theta+\ldots\ldots\ldots\ldots+\Gamma_N\cos(N-2n)\theta+\ldots\right]$$

Now if the maximum allowable reflection coefficient magnitude in the pass band is Γ_m, then

$$T_N(\sec\theta_m)\simeq\frac{1}{2\Gamma_m}\left|\frac{Z_L}{Z_0}\right|, where$$

$$\sec\theta_m=\cosh\left[\frac{1}{N}\cosh^{-1}\left(\left|\frac{\ln\frac{Z_L}{Z_0}}{2\Gamma_m}\right|\right)\right],$$

Once θ_m is known, the bandwidth can be calculated as,

$$\frac{\Delta f}{f_0}=2-\frac{4\theta_m}{\pi}.$$

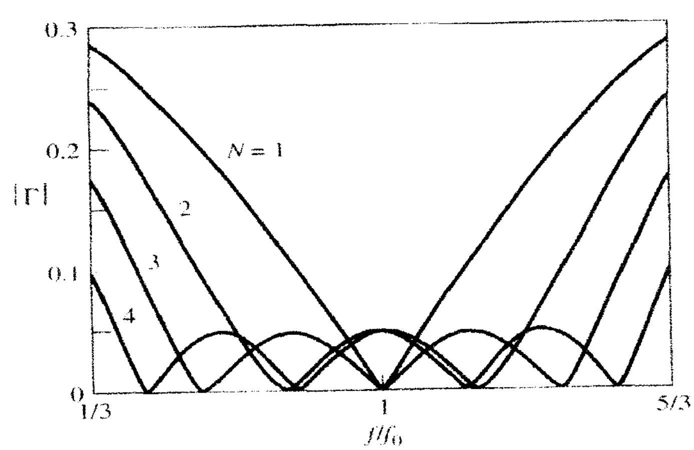


Fig 2.14 The reflection coefficient magnitude versus frequency of the multi section matching transformer.

2.9.3 Transmission line taper.

Tapered lines can be considered limiting cases of multisection matching transformers. As the number, N, of discrete sections increases, the step changes in characteristic impedance between the sections becomes smaller.

In the limit of an infinite number of sections, we approach a continuously tapered line. In practice, of course, a matching transformer must be of finite length. But instead of discrete sections, the line can be continuously tapered, as suggested in the figure. Then by changing the type of taper, we can obtain different pass band characteristics.

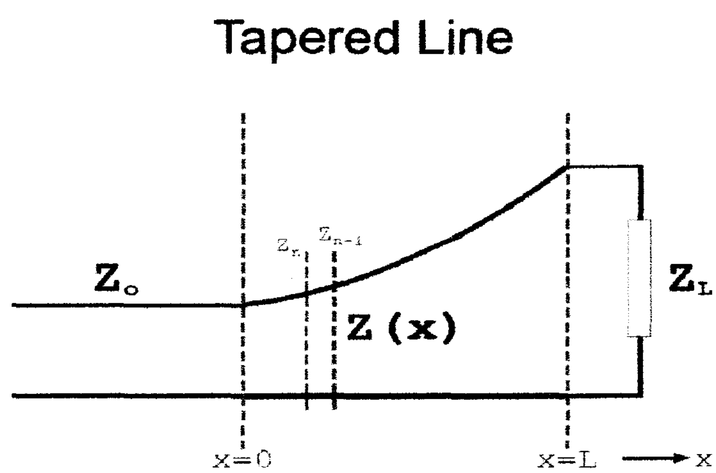


Fig 2.15 Tapered line

A continuously tapered line is made up of a number of incremental sections of length Δz, with an impedance change ΔZ(z) from one section to the next, as shown in the figure.

For an incremental section of line:

$$\Delta\Gamma = \frac{Z_{n+1} - Z_n}{Z_{n+1} + Z_n} = \frac{Z + \Delta Z - Z}{Z + \Delta Z + Z}$$

$$\approx \frac{\Delta Z}{2Z}$$

As the separation approaches zero i.e $\Delta x \to 0$:

$$d\Gamma = \frac{dZ}{2Z} = \frac{1}{2}\left(\frac{d}{dx}\left\{\ln\left[\frac{Z}{Z_o}\right]\right\}\right)dx$$

From which the total reflection coefficient is:

$$\Gamma(\theta) = \frac{1}{2}\int_0^L \exp[-2j\beta x]\frac{d}{dx}\ln\left\{\frac{Z}{Z_o}\right\}dx$$

Where θ=β*l*. So if Z(z) is known, Γ(θ) can be found as a function of frequency. Alternatively if Γ(θ) is specified ,then Z(z) can be found. The value of Z can vary depending upon the type of taper.

Reflection coefficients:

1. Exponential taper.

$$\Gamma(z) = \frac{1}{2}\int_0^L e^{-2j\beta z}\frac{d}{dz}(\ln e^{az})dz$$

$$= \frac{\ln\frac{Z_L}{Z_0}}{2} e^{-2j\beta z}\frac{\sin\beta L}{\beta L}$$

2. Triangular taper.

$$\Gamma(\theta) = \frac{1}{2}e^{-2j\beta L}\ln\left(\frac{Z_L}{Z_0}\right)\left[\frac{\sin(\beta L/2)}{(\beta L/2)}\right]^2$$

3. Klopfenstein taper.

For a given Taper length, the Klopfenstein impedance taper has been shown to be optimum in the sense that the reflection coefficient is minimum over the pass band. Alternatively, for a maximum reflection coefficient specification in the pass band, the Klopfenstein taper yields the shortest matching section.

The Klopfenstein taper is derived from a stepped Chebyshev transformer as the number of sections increases to infinity

The logarithm of the characteristic impedance variation for the Klopfenstein taper is given by

$$\ln Z(z) = \frac{1}{2}\ln Z_0 Z_l + \frac{\Gamma_0}{\cosh A}A^2\phi(2Z/L-1, A),$$ For 0<=z<=L,

Where $\phi(x,A)$ is the first order Bessel function.

Reflection coefficient:

$$\Gamma(\theta) = \Gamma_0 e^{-j\beta L} \frac{\cos\sqrt{(\beta L)^2 - A^2}}{\cosh A}, \quad \text{For } \beta l > A$$

The pass band is defined as βl>=A, and so the maximum ripple in the pass band is

$$\Gamma_m = \frac{\Gamma_0}{\cosh A}$$

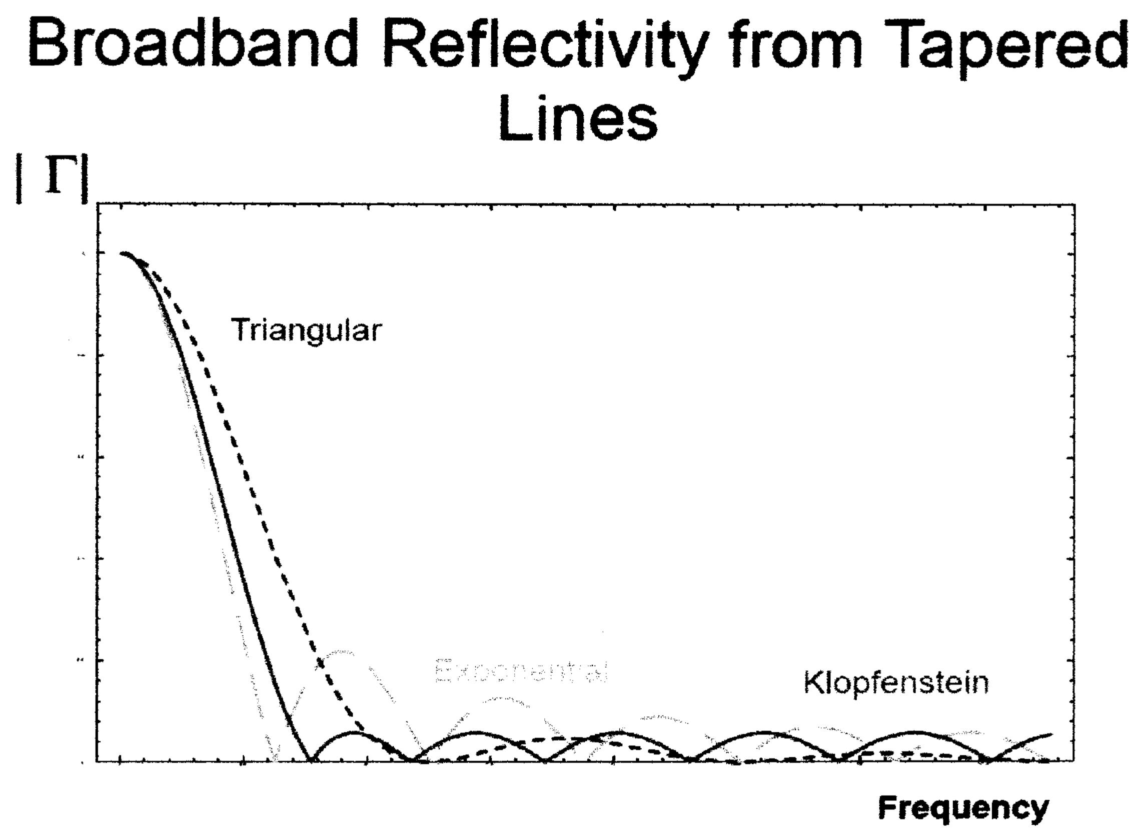


Fig 2.16 The reflection coefficient magnitude versus frequency for the Triangular, Exponential and Klopfenstein tapered lines.

CHAPTER – 3

3. Design of Trapezoidal Structure

3.1 Salient Features

1.Frequency Independent Log periodic antenna

Trapezoidal structure is a non-planar LPA. The logarithmically periodic antennas have pattern and impedance characteristics which are essentially independent of frequency over large bandwidths. The antenna radiates essentially a unidirectional, linearly polarized beam in which the electric field is parallel to the teeth. The geometry of logarithmic periodic antenna structures is so defined that the electrical characteristics repeat periodically with the logarithm of the frequency, one period being defined as the range from τf to f. Since variations within one period are generally small they will similarly be small over small periods, leading to a very wide band antenna. The two halves of the structure are fed against one another by means of a balanced transmission line connected to the apices.

2.Offers very large operating bandwidth

Since variations within one period are generally small they will similarly be small over small periods, leading to a very wide band antenna. The two halves of the structure are fed against one another by means of a balanced transmission line connected to the apices.

3.Possesses constant input impedance over a large frequency range

The Impedance can vary from 170 Ω to 190 Ω depending upon the angle between the two halves, increasing to about 190 Ω when γ becomes 60^0 . This range of variation in the impedance over one period can be expected to be about 1.5:1.At lower frequencies a simple two wire line may be connected to the feed point of the apex .At high frequencies where the coaxial cable desirable, or some kind of wide band balun is needed.

4.Adjustable E-plane and H-plane beamwidths

Since a dipole possess an unequal E and H plane patterns , for an angular separation γ=60° the E and H plane beam widths are each equal to about 100° and such a tooth structure would therefore provide circularly symmetrical illumination for a suitable paraboloid reflector.

A typical structure is shown in the figure 3.1

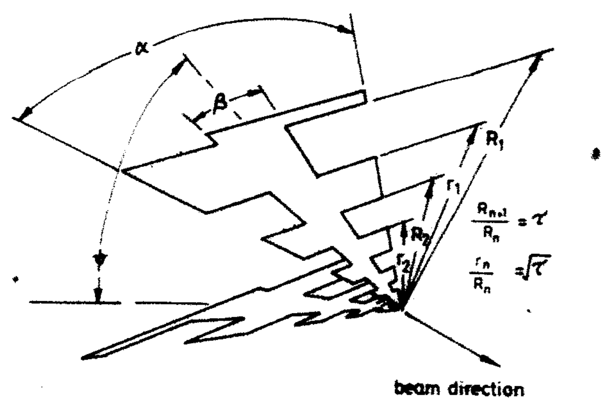


Fig 3.1 A Trapezoidal tooth structure

3.2 Design parameters:

The various antenna parameters to be determined while designing the trapezoidal structure are

1) Lengths of biggest and smallest finger.
2) Angles α , β, γ and τ which are defined in the figure.
3) Dimensions L_f and b

Included angle between the monopoles in each planar structure is α

The properties of a log periodic toothed planar antenna depends upon τ .It has been experimentally found that the half power beam width increases with the increasing value of τ as shown in the figure 3.2

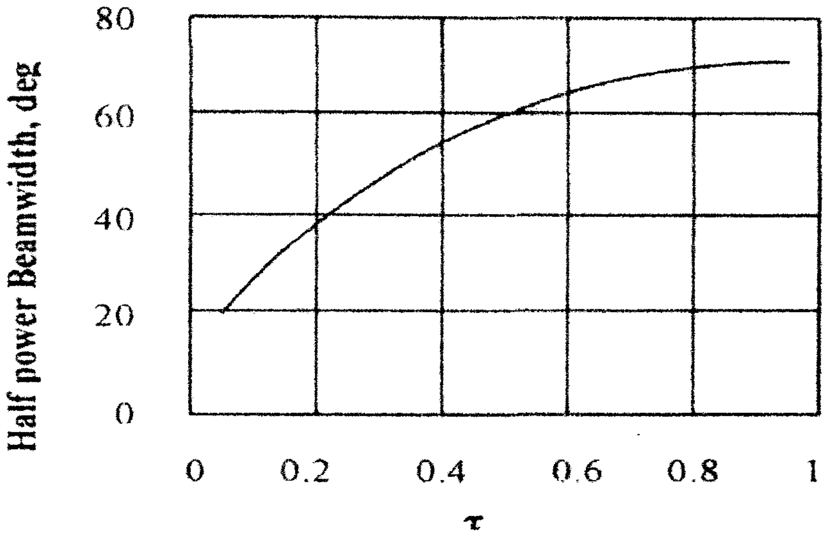


Fig 3.2 Half power beamwidth versus τ

Angle α is the included angle between the monopoles in each planar structure. This angle is set to have an effect on the phase center of the antenna. For the given included angle α of the structure there is a minimum value of the design ratio τ which can be used .for values of τ smaller than this minimum, the pattern breaks up considerably and for larger values the beam width will decrease. The variation of α w.r.t to τ and 3dB beamwidth is given by figure 3.3

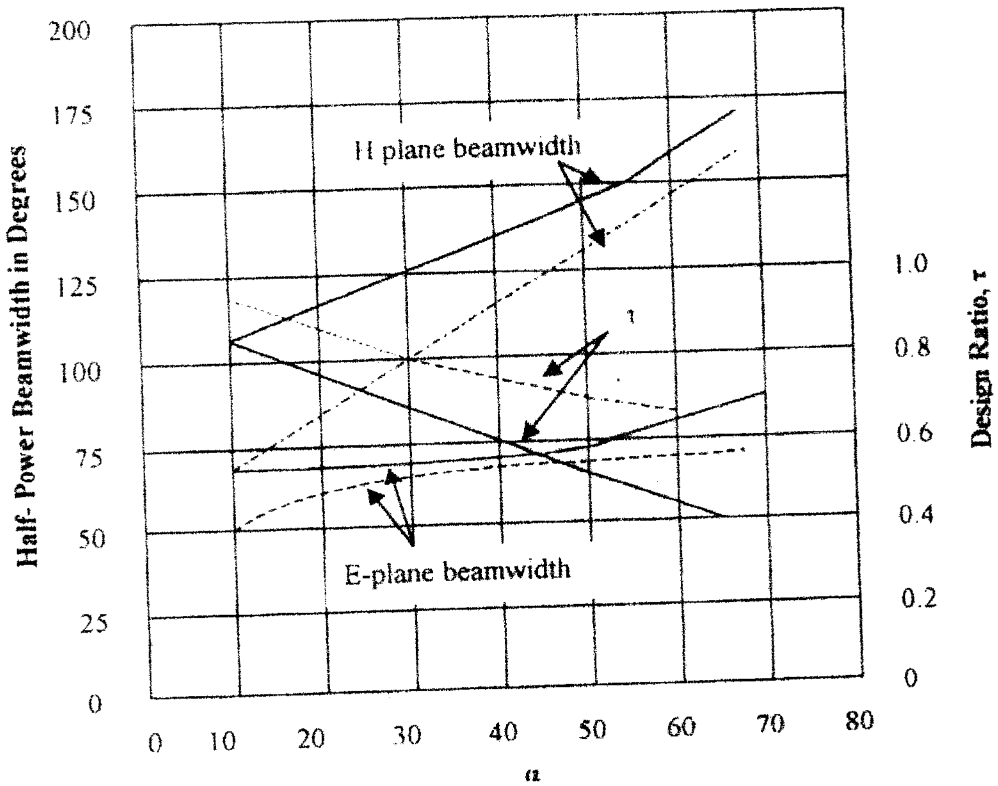


Fig 3.3: Pattern Characteristics of Wire Trapezoidal Element

The phase center of a log periodic structure does not lie at the vertex ;rather it lies some distance d behind a vertex. figure 3.4 shows the distance of the phase center from the vertices as a function of α. for values of α < 60 degree and for values of τ given in the previous figure the position of the phase center is independent of τ

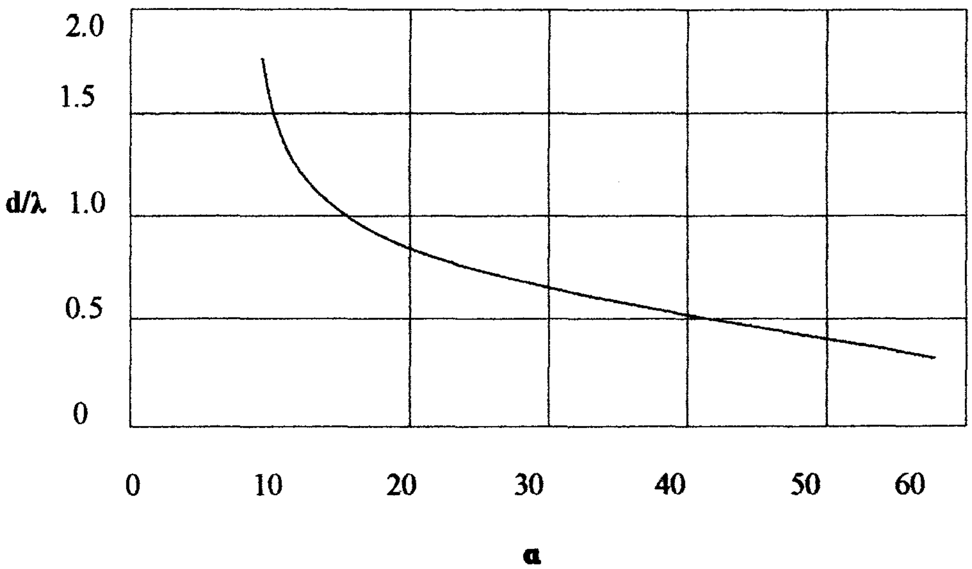


Fig 3.4 Distance from vertex to phase center as a function of α

The angle γ is defined as the angle between the two planes of the antenna . The figure 3.5 gives the variation in 10 dB beamwidth as a function of γ. For value of γ =60° E and H plane beam patterns are identical.

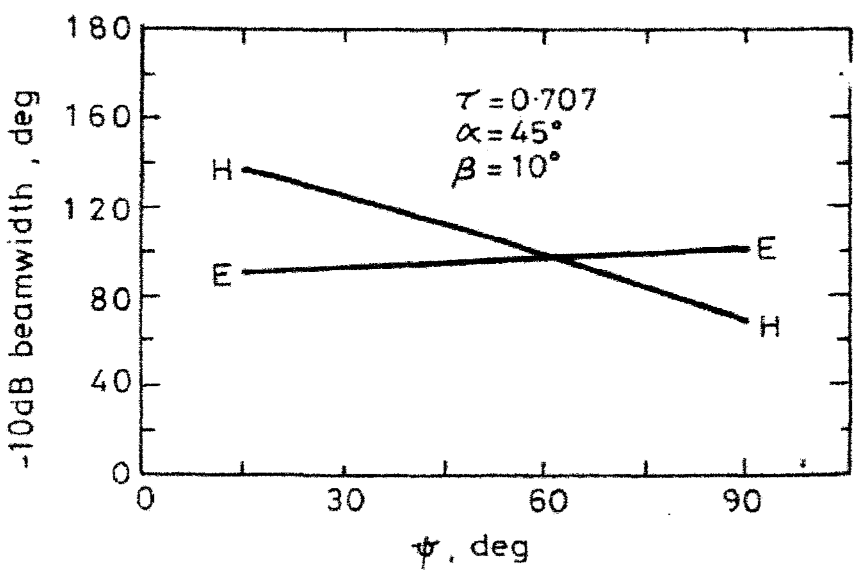


Fig 3.5 Gives the distance in wavelength in both E and H plane phase centers from the apex of the structure.

Figure 3.6 gives the distance in wavelength in both E and H plane phase centers from the apex of the structure. We have designed the trapezoidal structure by assigning the fixed values for α,β, and τ as suggested by the literature and varying only the parameter γ .We have chosen the value of γ for maintaining equal 10 dB beamwidths in the E and H planes.

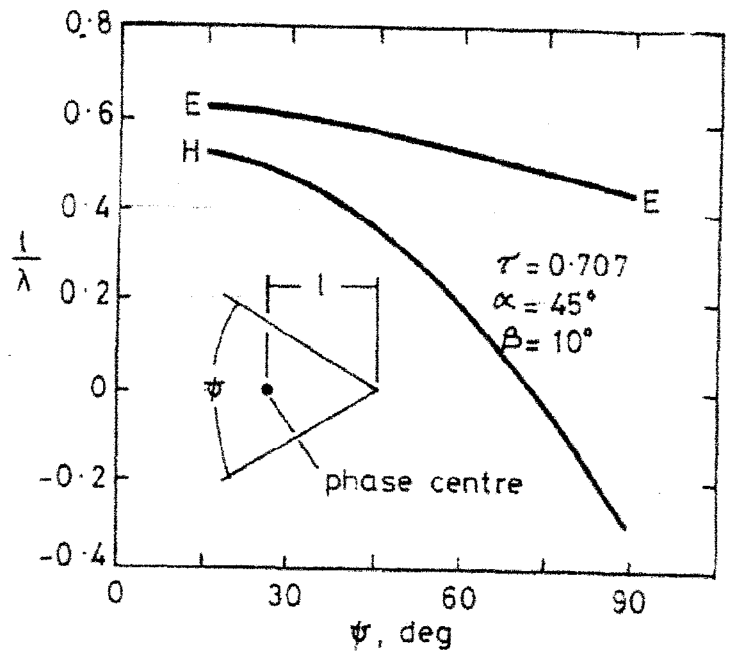


Fig 3.6 Location of phase center vs γ

3.3 Design

The experimentally optimized values for the Trapezoidal structure are given below

Frequencies range 0.5-5GHz.

Included angle between the monopoles in each planar structure is $\alpha = 45^0$

Taper angle of the central transmission line $\beta = 10^0$

Included angle between the two plane structure $\gamma = 60^0$

Geometric ratio τ =0.707

Since the antenna is designed to operate from 500 MHz to 5GHz; the wavelength corresponding to lowest frequency is 60 cm.The lengths lmax is fixed at half the wavelength at the lowest frequency.

$L_{max} = \lambda_{max}/2 = C/(2*f_{min})$

$= 3*10^8/500*10^6$

$= 0.3$ m

$L_{min} = \lambda_{min}/2 = C/(2*f_{max})$

$= 3*10^8/5000*10^6$

$= 0.03$ m

The various dimensions, R_1, R_2..., R_n and r_1, r_2,... r_n are calculated using the relations given in the equation 2 and 3.the values are given in the table.

$R_{n+1}/R_n = \tau = 0.707$----------------------------2

$r_n/R_n = \sqrt{\tau} = \sqrt{0.707} = 0.8408$------------------3

Table 3.1: Trapezoidal tooth structure dimensions

Parameter	Dimension (cm)	Parameter	Dimension (cm)
R_1(=L)	45.6	r_1	38.3
R_2	32.2	r_2	27.04
R_3	22.7	r_3	19.0
R_4	16.1	r_4	13.5
R_5	11.39	r_5	9.56
R_6	8.0	r_6	6.76
R_7	5.7	r_7	4.78
R_8	4.0	r_8	3.38

R_9	2.84	r_9	2.38
R_{10}	2.0	r_{10}	1.7
R_{11}	1.42	r_{11}	1.2
R_{12}	1.0	r_{12}	0.84
R_{13}	0.707	r_{13}	0.6

$Sin^2\ \beta l$ varying curve:

The taper angle of the center transmission line in the antenna structure is a $Sin^2\ \beta l$ varying curve. This curve is expected to improve the performance of the feed and also increases the bandwidth. This is a $\lambda/2$ cycle over the length of the trapezoidal structure at the lowest frequency.

The values for the curve are plotted using MAT lab for various values of $\beta=2\pi l/\lambda$

where the length of the trapezoidal structure is $\lambda/4$.

The width of the transmission line at different distances l is given by the equation $Sin^2\ \beta l$.

Where β=phase constant of the transmission line given by $\beta=2\pi/\lambda$ and l is the length of the antenna which varies from 0 to 45.6

This curve is accommodated in the β=10 degree transmission line of the structure.This is shown in the figure.

LOG-PERIODIC TRAPEZOIDAL TOOTH STRUCTURE

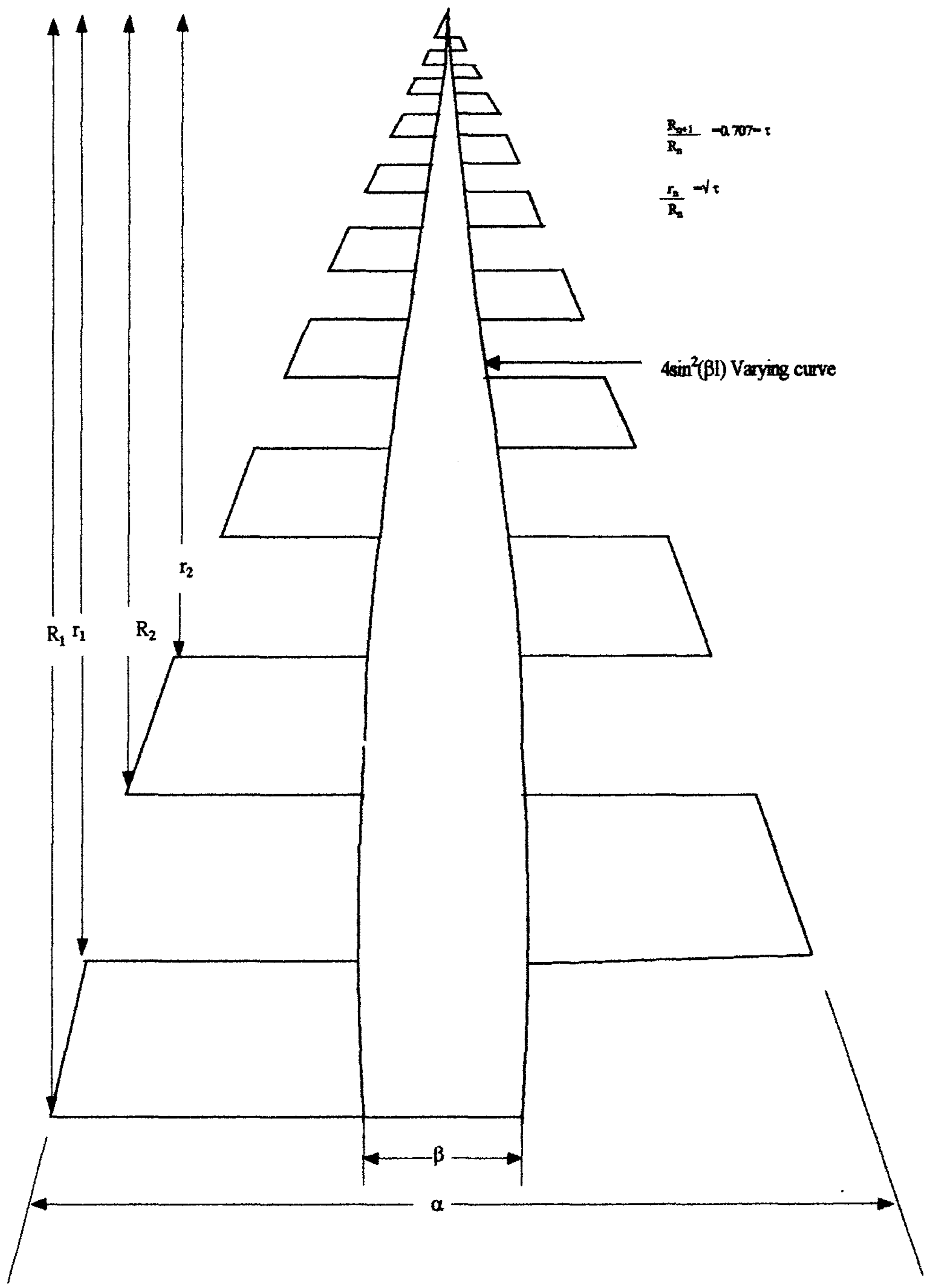


Fig 3.7 Log periodic trapezoidal tooth Structure

3.4 Slotted Coaxial Balun

The Balun is basically an impedance matching transformer from coaxial to a balanced two conductor open line. The transition is accomplished by opening the outer wall of the coax so that the cross section view shows the sector of the outer conductor removed.

It starts with a coax cable of unbalanced impedance at the lower end. The outer conductor is slowly peeled away until it becomes a two wire-transmission line with balanced impedance at the upper end.

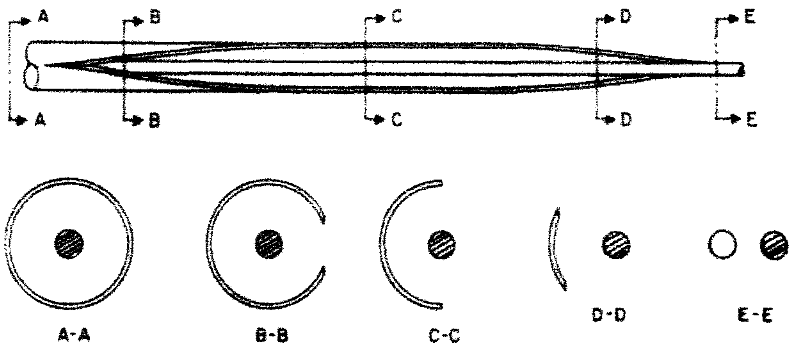


Fig 3.8 Slotted coaxial Balun

A specific balun design was undertaken. A transition from 50-ohm coaxial line to 180-ohm two-conductor line was selected for the balun. The characteristic impedance of the balun transformer is tapered along its length so that the input reflection coefficient follows a Tchebycheff response in the pass band. The maximum allowable reflection coefficient in the pass band was chosen as 0.03. This corresponds to a maximum standing wave ratio of 1.06 to1. It follows that the length of the balun is $l=0.478\lambda$ where λ is the largest operating wavelength. The lowest frequency was selected as 50 MHz which fixed the length l as approximately 29 cms.

The corresponding impedance contour was obtained by the Klopfenstein Taper method. The design equations are given by,

$$\ln(Z0) = 1/2\ln(Z1\,Z2) + \frac{\rho_0}{\cosh(A)}[A^2[\varphi(2x/l,A)+U(x-l/2)+U(x+l/2)]], \text{ for } X<=l/2$$

$$=\ln(Z2), x>l/2$$

$$=\ln(Z1), x<-l/2$$

where $\varphi(z,A) = -\varphi(-z,A) = \int_0^z \frac{I_1 A\sqrt{(1-(y^2)}}{A\sqrt{(1-(y^2)}}dy$ and

$$Z0=\left[\frac{\frac{1}{2\pi}\sqrt{\frac{\mu}{\varepsilon}}\ln(b/a)}{\left[1-\frac{4}{5}\left(\frac{\alpha}{\pi}\right).c1\right]}\right] \text{ ohms}$$

Where $\frac{1}{c1}=\frac{4}{5}\left(\frac{\alpha}{\pi}\right)+\frac{40}{\pi}\ln(b/a)\sum_{n=1}^{\infty}\left[\frac{1+\coth(n\ln(b/a))}{(n\alpha)}.\left[\frac{An.\cos(n\alpha)-Bn.\sin(n\alpha)}{(n\alpha)^4}\right]^2\right]$

Where $An=(n\alpha)^3-6n\alpha$,

$Bn=3(n\alpha)^2-6$.

Where b= i.d of outer conductor

And a= centre conductor diameter.

The corresponding values for the impedance Z_0 and the slot angle(2α) was computed using MATLAB at various lengths along the Balun.

3.4.1 Slotted co-axial line taper from 50 to 180 ohms

As an application of the preceding results, the design of an optimal 50-180 ohm slotted coaxial transmission line taper will be indicated in detail. The taper is to be designed so that the input reflection coefficient magnitude does not exceed about 'three' per cent in the pass band.

The initial value of the reflection coefficient in this case is equal to 0.64. The value of ρo for use in the design of the taper is found to be

$\rho o = 1/2 \ln(Z_2 / Z_1)$

where Z_2=180 ohms,

Z_1=50 ohms.

It will be required that the maximum reflection coefficient magnitude in the pass band shall not exceed one-twentieth of p0(0.03). Thus, from (10)

$$\cosh(A) = 20,$$

so that

A = 3.6887.

The characteristic impedance contour can now be obtained directly from the figure 3.9. The resulting 'Z₀' curve is illustrated in Figure, and the corresponding opening of the slotted coaxial line is shown in figure 3.10. As mentioned previously, the characteristic impedance of the balun transformer is tapered along its length so that the input reflection Characteristic impedance has a discontinuous jump from 50 to 53 ohms at left-hand end and a corresponding jump from 178 to 180 ohms at right-hand end. Characteristic impedance at center of taper is equal to 98 ohms, geometric mean between 50 and 180 ohms is 95 ohms.

Having established the characteristic impedance of the uniform, slotted coaxial line, a specific balun design was undertaken. A transition from 50-ohm coaxial line to 180-ohm two-conductor line coefficient follows a Tchebycheff response in the pass band. The maximum allowable reflection coefficient in the pass band was chosen as 0.03. This corresponds to a maximum standing wave ratio of 1.06 to 1. It follows that the length of the balun is $l = 0.478.\lambda$, where λ is the largest operating wavelength. The lowest frequency was selected as 500mc which fixed the length l as approximately 29 cms.

Let the total length l of the balun be defined from $z=-l/2$ to $z=l/2$. Figure shows the impedance contour required for Tchebycheff response under the prescribed design criteria . The angle 2α which yields the proper impedance at each position along the balun may be extracted from the figure. The outer conductor of the co-axial line had an inside diameter of 6cm. The balun was fabricated by milling through the coax outer conductor to the depth which yielded the angle 2α.The milling cut was performed in discrete increments along the balun until the outer conductor was reduced to a thin concave strip having a width equal to the centre conductor diameter. This occurred at the position z/l=0.373 where 2α=340° and Z_o=169 ohms. The strip outer conductor was transformed to a circular cylinder identical to the centre conductor over a 4cm length from z/l=0.373 to z/l=0.426. The spacing between cylindrical conductors at z/l=0.426 was such that the impedance was the required ohms as shown in the figure. From z/l=0.426 to z/l=0.5 the spacing of the cylindrical conductors was gradually increased so that the impedance followed the contour of figure.

3.4.2 Design

Length of the balun $l = 0.478.\lambda$

$\lambda = C/f_{min}$

f_{min} is the lowest operating frequency= 500MHz.

l=29 cm

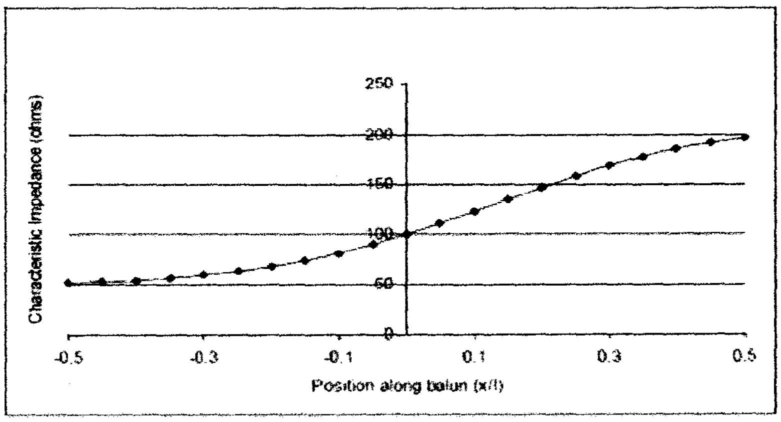


Fig 3.9 characteristic impedance along klopfenstein taper.

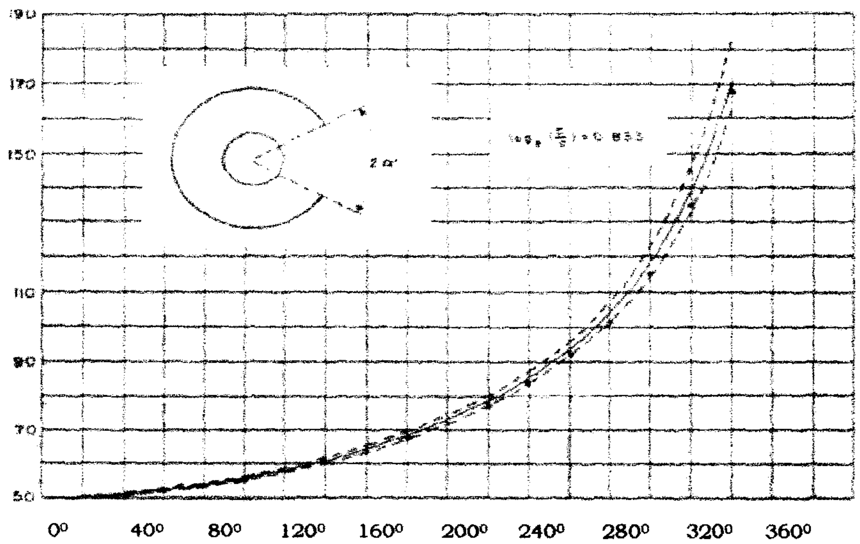


Fig 3.10 Slot angle(2α) versus impedance Z_0(ohms).

Table 3.2 Balun design for 50-180 ohms

Length along Balun(cm)	Impedance Z_0(OHMS)	Slot opening angle α(degrees)
-14.5	53.7	0
-13.8	54.4	19
-13.0	55.2	30
-12.3	56.1	37
-11.6	57.1	43
-10.9	58.3	48
-10.2	59.7	54
-9.4	61.2	59
-8.7	62.8	66
-8.0	64.7	72
-7.3	66.7	79
-6.5	68.9	86
-5.8	71.4	91
-5.1	74	97
-4.3	76.8	102
-3.6	79.9	108
-2.9	83.2	114

-2.2	86.7	119
-1.4	90.4	124
-0.7	94.3	129
0.0	98.3	133
0.7	102.6	137
1.4	107	140
2.2	111.6	144
2.9	116.3	148
3.6	121.1	150
4.3	125.9	153
5.1	130.7	156
5.8	135.5	158
6.5	140.3	161
7.3	145	163
8.0	149.6	165
8.7	153.9	166
9.4	158.1	168
10.2	162.1	168
10.9	165.8	169
11.6	169.3	170
12.3	172.4	171
13.0	175.2	172
13.8	177.8	172
14.5	180	173

CHAPTER – 4

CHAPTER 4

Measurements and Results:

4.1 Measurement of Return loss

When the load impedance is not matched, not all power delivered to the load from the generator will be radiated. So there will be loss of power due to reflections. This loss is called "Return Loss"; it is defined in terms of dB as follows.

RL=20 log (1/|Γ|) dB.

Where Γ=Vr/Vi=Reflection Coefficient.

Where Vr is the reflected voltage

Vi is the incident voltage

The value of Γ lies in then range of $0 \leq \Gamma \leq 1$.

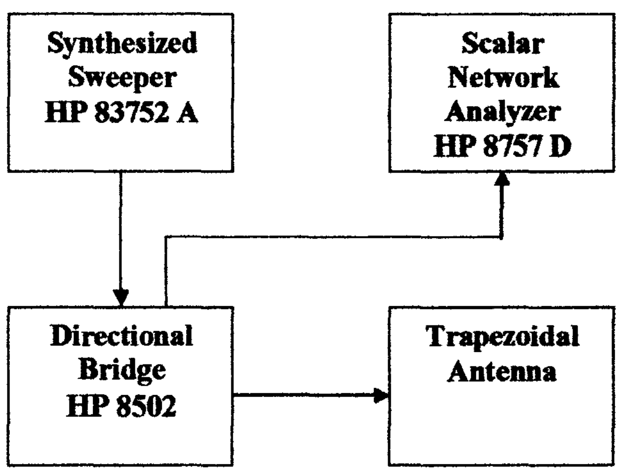


Fig 4.1 Experimental setup for measuring return loss

Figure shows the experimental setup to measure the Return loss of the Trapezoidal structure. It consists of a scalar network analyzer, frequency synthesizer and directional bridge. The frequency range is set between 500MHz to 5GHz. Its power level is set at 0dBm. The system is calibrated only for the return loss using the standard loads like open, short,

Average. Then the antenna is connected to measure its Return-loss characteristics.

Table 4.1 Return loss of trapezoidal Structure at various frequencies

Frequency in MHz	Return loss in dB
500	-16.0
600	-8.25
700	-11.25
800	-10.24
900	-14.3
1000	-5.73
1100	-6.23
1200	-10.5
1300	-5.7
1400	-14.46
1500	-4.85
1600	-3.12
2000	-9.1
2500	-10.0
2700	-10.11
3000	-8.7
3200	-14

The return-loss response obtained is shown in the figure.

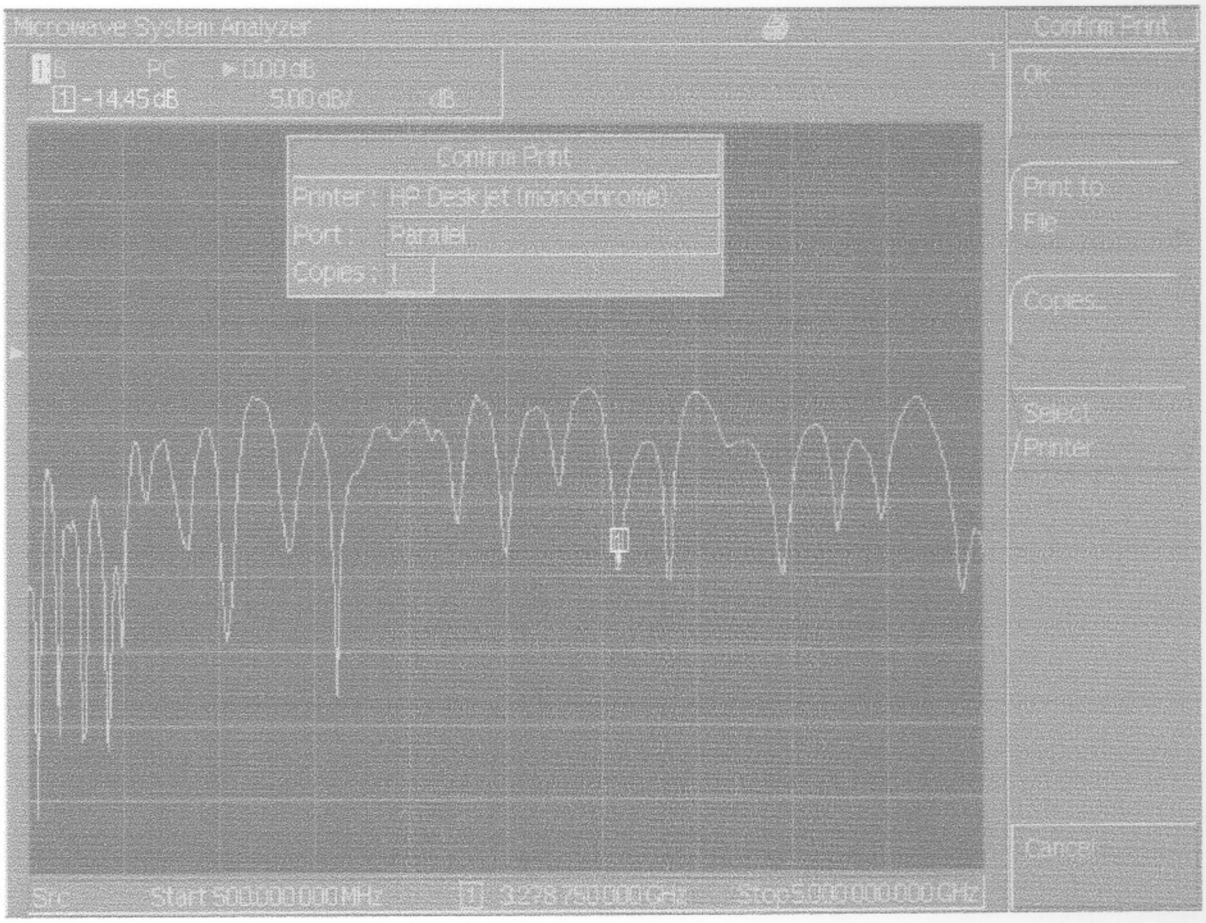


Fig 4.2 Return loss characteristics of the Antenna.

4.2 Radiation pattern measurements.

Generally the performance of an antenna is evaluated in the far field region, since the pattern is independent of the distance. In a typical far field setup the transmitting antenna and the receiving antenna are separated by a certain distance. The three main important parameters considered in the measurement of outdoor test ranges are

1. Range length.
2. Receiver tower height.
3. Transmitter tower height.

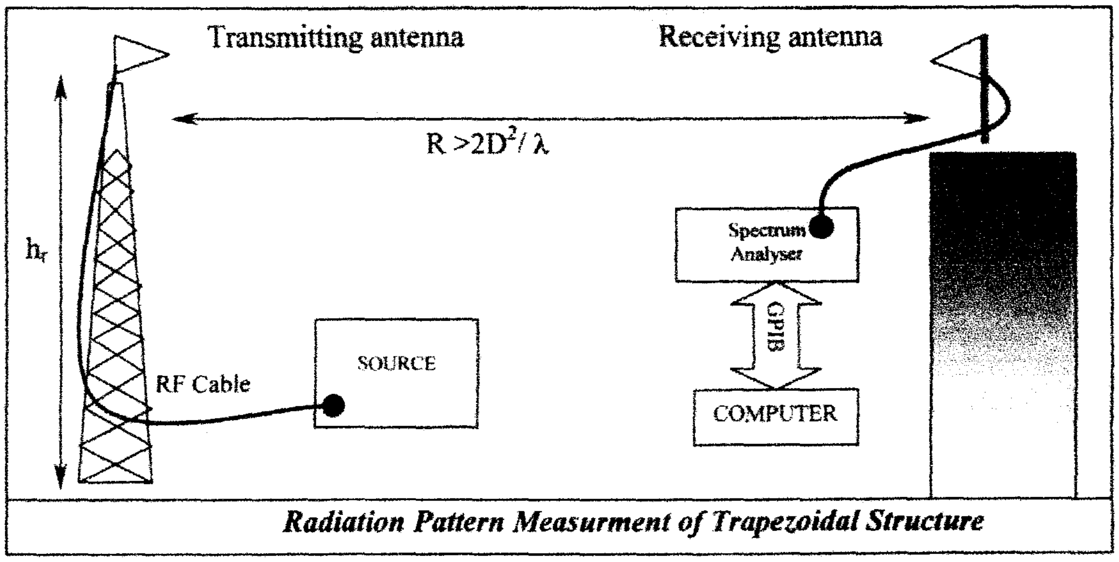


Fig 4.3 Radiation pattern measurement Experimental setup

1. Range Length.

The range length is the distance between transmit and receiving antenna. It is normally greater than the far field distance of the transmit antenna, if D is the maximum dimension of the transmitter, the range R can be given by,

$$R \geq 2D^2/\lambda$$

2. Receiver tower height.

The height of the test antenna and hence that of the receive tower, is the second parameter which should be determined. The distance of the source and the receiver above the ground 'h' is normally kept at 4 times the diameter (D) of the antenna to be tested. This will ensure the uniform illumination of the source on the test antenna.

$h \geq 4D$

3. Transmitter tower height.

The height of the transmitting antenna is placed at the same height as that of the test antenna.

4.3 The Test System.

The test system is as shown in the figure 4.3. The signal to be transmitted is generated by a frequency synthesizer connected to the transmitting antenna. The transmitting antenna is connected to the signal generator through a coaxial cable. The antenna used is a scaled model of the Trapezoidal structure

The log-periodic trapezoidal antenna is placed at the far field distance of the transmitter and connected to the spectrum analyzer. The spectrum analyzer is connected to the GPIB (General Purpose Interface Bus) .The computer generates the square pulses required for the translator to run. These pulses are fed into the translator through the relay devices connected to it. The translator in turn rotates the Antenna.

The radiation pattern of an antenna shows the gain variation of the antenna as a function of angle on either sides if the antenna axis. Normally two radiation patterns are measured. They are

1 E plane pattern.
2 H plane pattern.

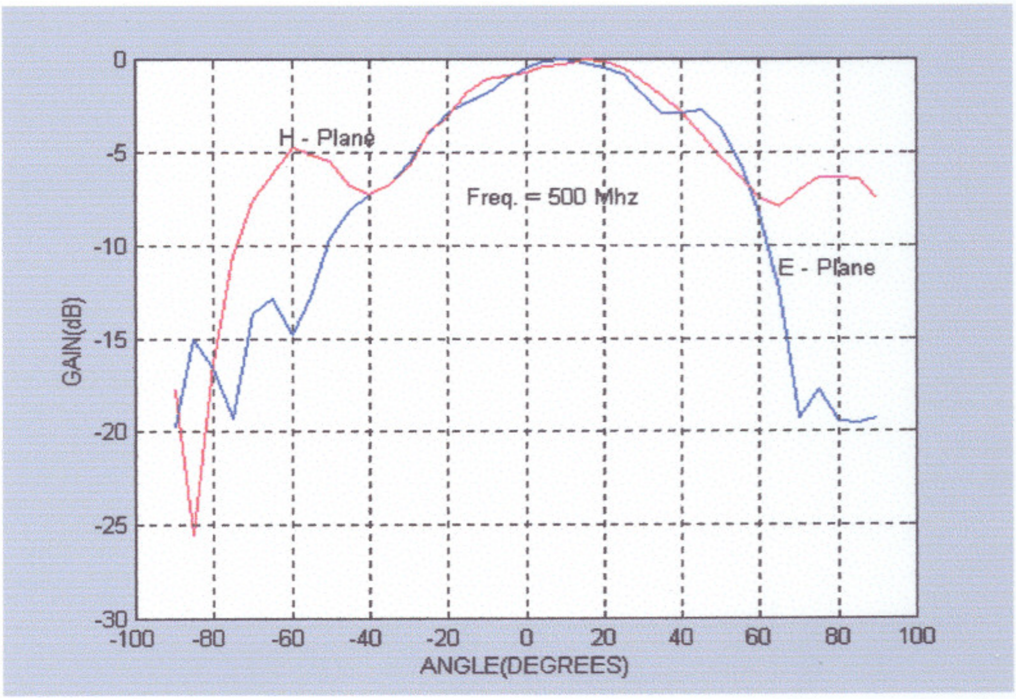
E plane pattern gives the variation of the antenna in the direction of electric field in the aperture. On the other hand, the H plane pattern gives the gain variation of the antenna gives the gain variation of the antenna in a direction perpendicular to the electric field.

The Spectrum Analyzer .

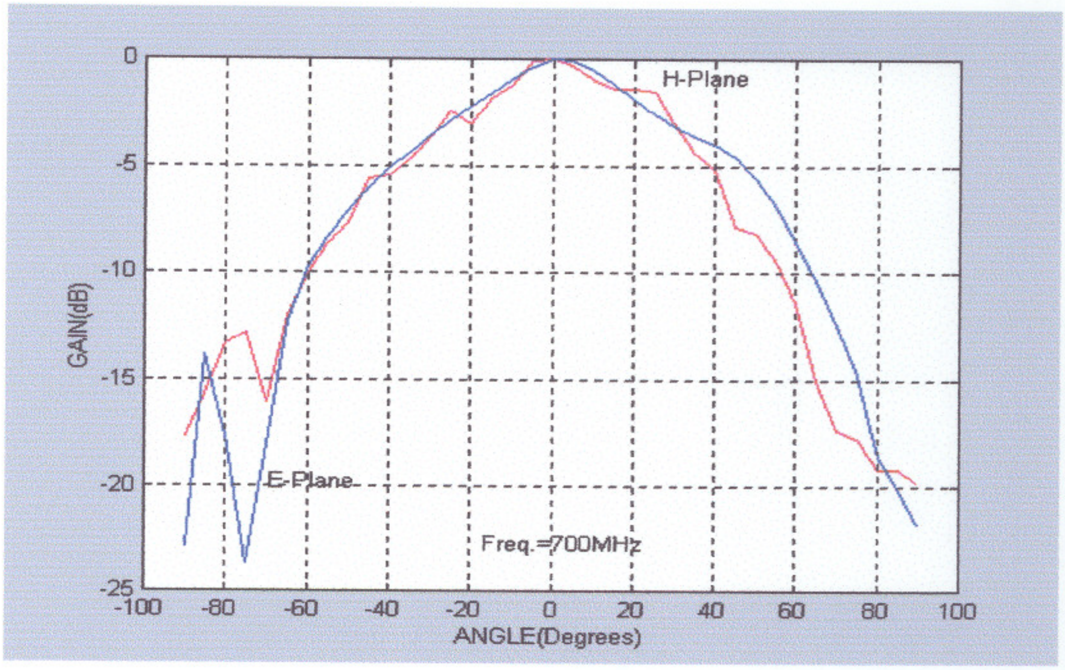
The spectrum analyzer is an instrument, which displays the frequency spectrum and characteristics of an input signal. It can be used to view signals across a wide range of frequencies

A continuous wave source was connected to the transmitting antenna and the output of the antenna under test was connected to the spectrum analyzer. Both transmitting and receiving antennas were positioned such that there polarizations were identical. After setting the frequency of the source, the test antenna which is mounted on a rotating platform was rotated at various angles from -90^0 to $+90^0$. At each location the spectral output was read into the computer and stored. The above procedure was repeated for various frequencies and polarization. The stored data in the computer was plotted against the Azimuth angle to get the beam pattern of the antenna.

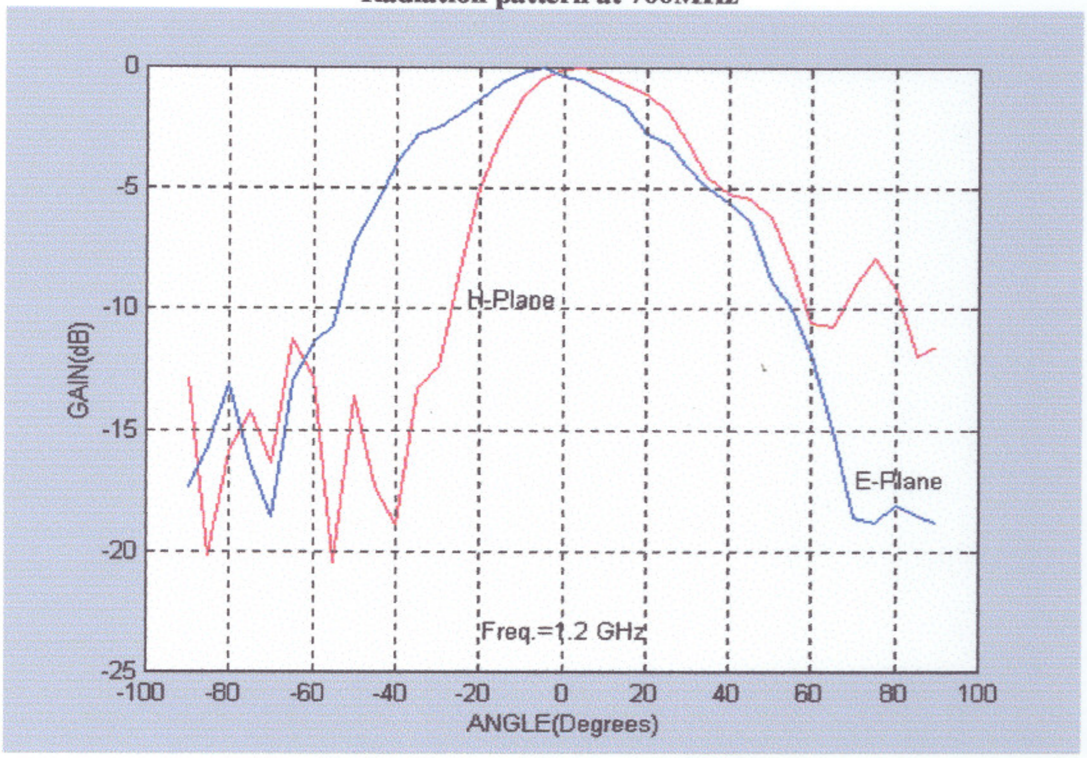
Fig 4.4 Radiation patterns at various frequencies are as shown in the figure.



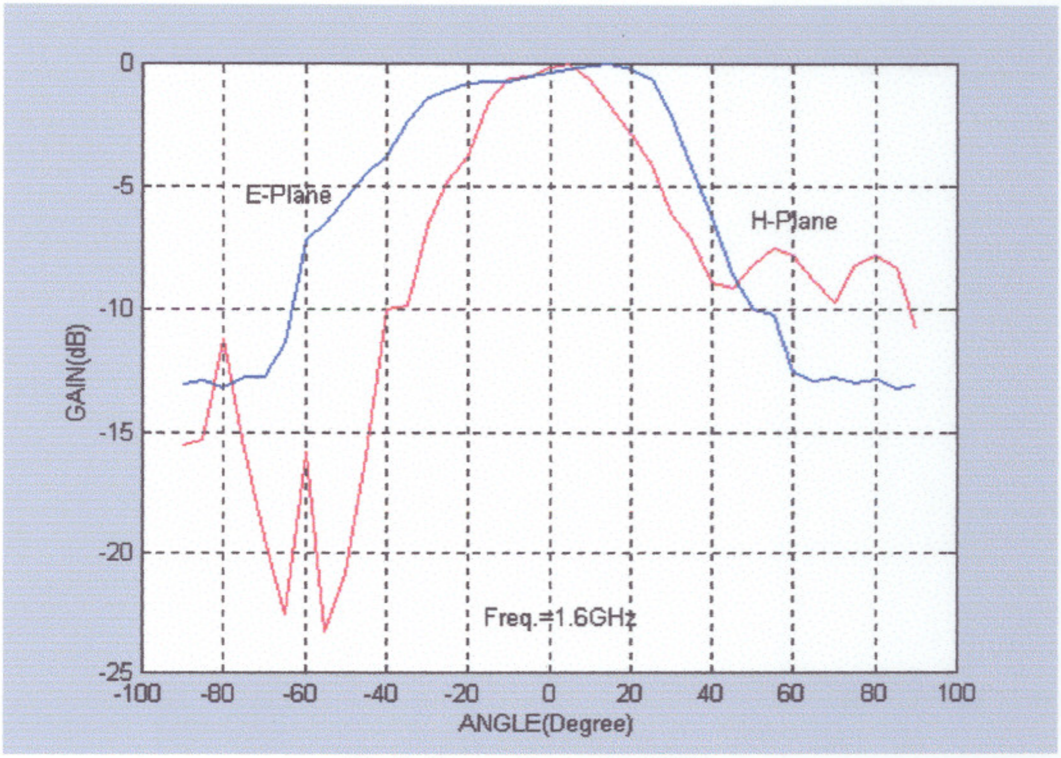
Radiation pattern at 500MHz



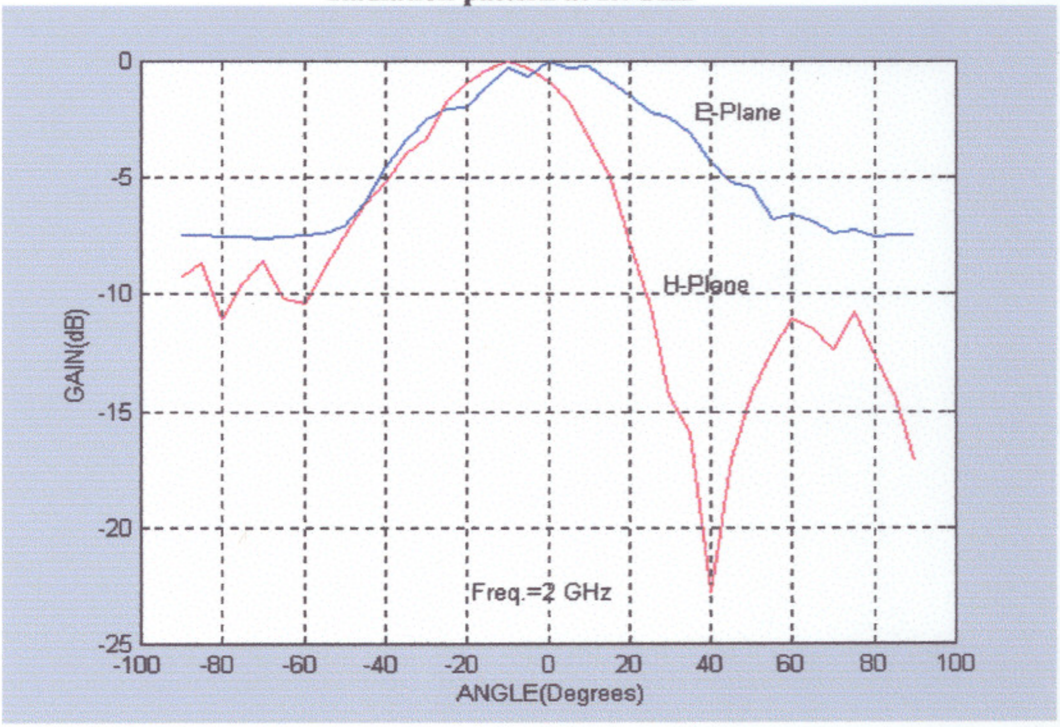
Radiation pattern at 700MHz



Radiation pattern at 1.2GHz

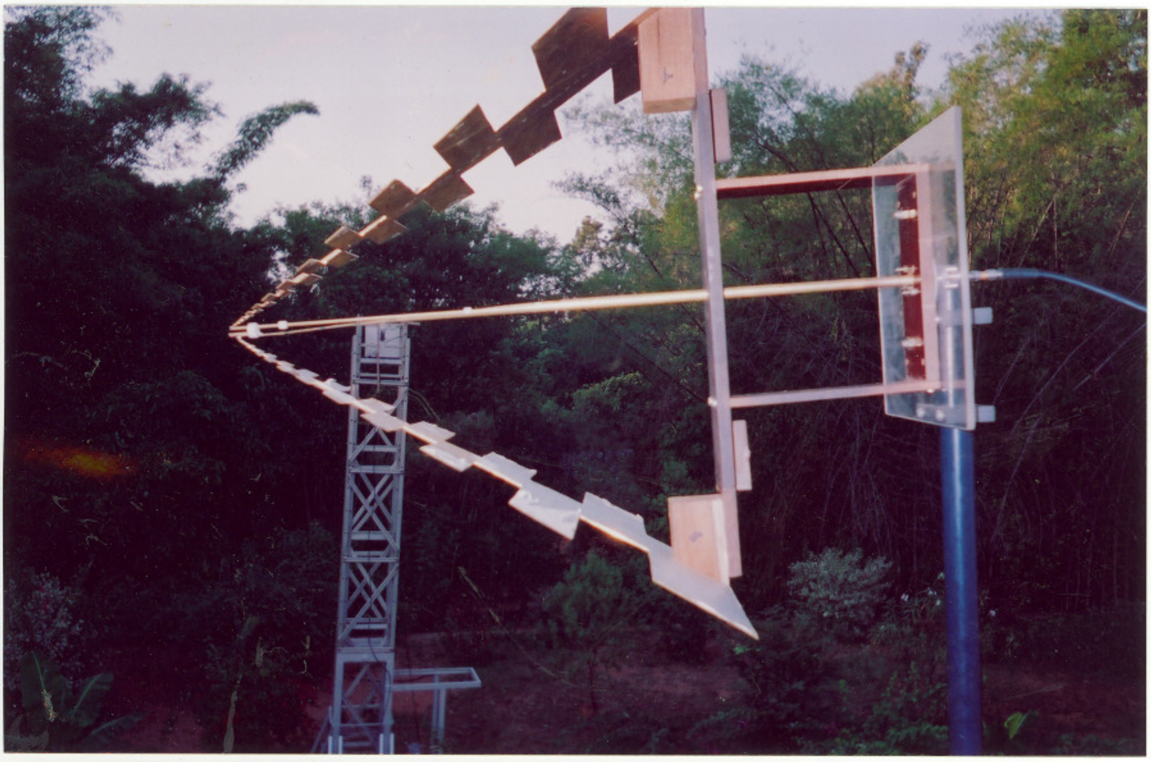


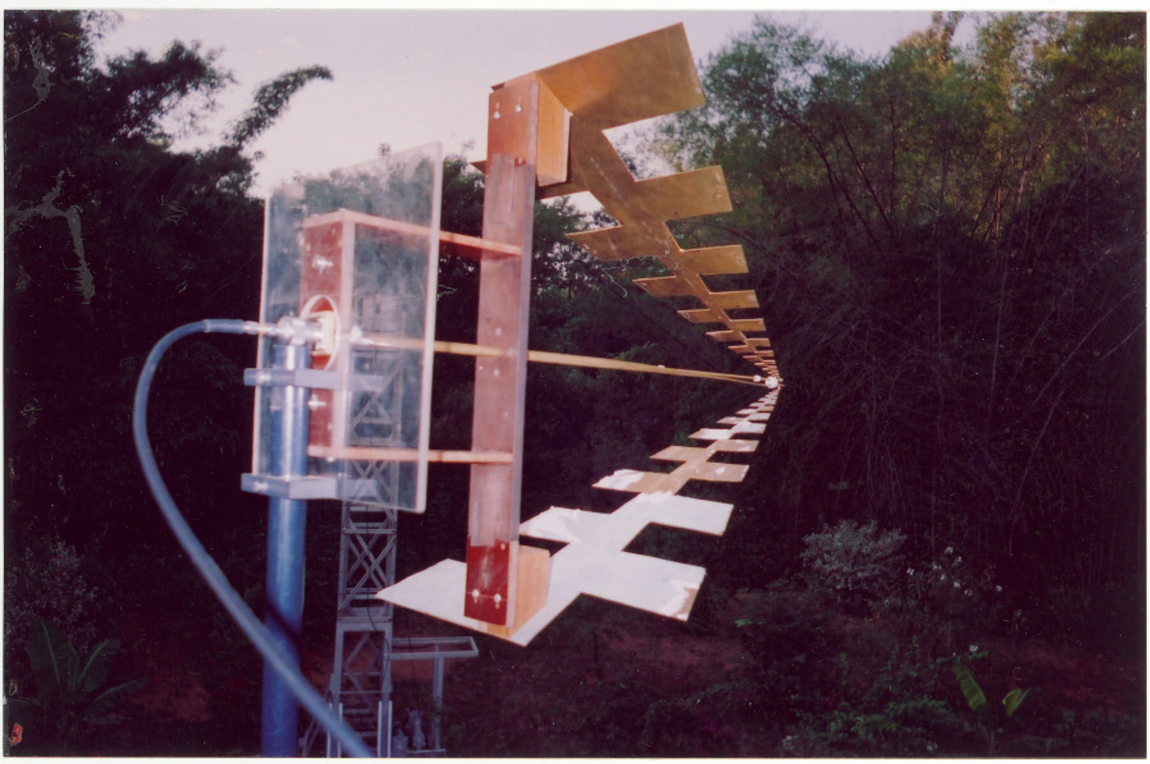
Radiation pattern at 1.6GHz



Radiation pattern at 2GHz

4.3 Photograph of the Trapezoidal Tooth Antenna





Conclusion

Conclusion

We have successfully designed and implemented a trapezoidal tooth log-periodic antenna for frequency independent operation. Our characterization was restricted to the frequency range of 0.5GHz to 2GHz, because of the non-availability of the signal generator at high frequency at the time of our experimentation. An average of -5dBm of return loss is obtained over the entire bandwidth. Our results indicate that the trapezoidal structure can be used as a multi-octave primary focus feed, if proper care is taken while fabricating the mechanical structure of the antenna and the balun is tuned for optimum performance.

Scope for further Development

1. There is a large scope for improving the performance of the antenna over the range as high as 0.5GHz to 5GHz.
2. The antenna has to be tuned in order to improve the performance.

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Appendix A
Mat lab program for Characteristic Impedance versus length of the Balun.

```
Z1=50;
Z2=180;
r0=.5*log(z2/z1);
k=r0/17.78;
a=3.57;
phi1=[-1.3164 -1.2894 -1.2581 -1.2226 -1.1825 -1.1378 -1.0885 -1.0346 -
0.976 -0.913 -0.8456 -0.7741 -0.6988 -0.6198 -0.5376 -0.4526 -0.3651 -
0.2756 -0.1846 -0.0925  0  0.0925  0.1846 0.2756 0.3651 0.4526 0.5376
0.6198 0.6988 0.7741 0.8456 0.913 0.976 1.0346 1.0885 1.1378 1.1825
1.2226 1.2581 1.2894 1.3164 ];
phi=reshape(phi1,41,1);
for i=1:41
  lnz0(i,1)=0.5*log(z1*z2)+(k*(a^2*phi(i,1)+1));
end;
z0=exp(lnz0);
x=0:0.725:29;
grid;
xlabel(' Length(cm)  ');
ylabel(' zo(ohms)    ');
plot(x,z0);
```

Mat lab program for Characteristic Impedance versus Slot Angle of the Balun.

```
x=0.01 ;
for i=1:314;
 data(i,1)=x^3-6*x;
 data(i,2)=3*x^2-6;
 data(i,3)=8*x^3-12*x;
 data(i,4)=12*x^2-6;
 data(i,5)=27*x^3-18*x;
 data(i,6)=27*x^2-6;
 data(i,7)=64*x^3-24*x;
 data(i,8)=48*x^2-6;
 data(i,9)=((data(i,1)*cos(x)-data(i,2)*sin(x))/x^4).^2;
 data(i,10)=((data(i,3)*cos(2*x)-data(i,4)*sin(2*x))/(16*x^4)).^2;
 data(i,11)=((data(i,5)*cos(3*x)-data(i,6)*sin(3*x))/(81*x^4)).^2;
 data(i,12)=((data(i,7)*cos(4*x)-data(i,8)*sin(4*x))/(256*x^4)).^2;

data(i,13)=(0.255*x)+(12.73*.875*((2.42*data(i,9)/x)+(1.03*data(i,10)/x)+(0.6
7*data(i,11)/x)+(0.5*data(i,12)/x)));
 data(i,14)=52.5/(1-(0.255*x/data(i,13)));
 x=x+0.01;
end ;
x=0.01:0.02:6.28;
plot(x,data(:,14));
xlabel('2alpha(radians)');
ylabel('  Z0(ohms)  ');
grid;
```

A Transmission Line Taper of Improved Design*

R. W. KLOPFENSTEIN†

Summary—The theory of the design of optimal cascaded transformer arrangements can be extended to the design of continuous transmission-line tapers. Convenient relationships have been obtained from which the characteristic impedance contour for an optimal transmission-line taper can be found.

The performance of the Dolph-Tchebycheff transmission-line taper treated here is optimum in the sense that it has minimum reflection coefficient magnitude in the pass band for a specified length of taper, and, likewise, for a specified maximum magnitude reflection coefficient in the pass band, the Dolph-Tchebycheff taper has minimum length.

A sample design has been carried out for the purposes of illustration, and its performance has been compared with that of other tapers. In addition, a table of values of a transcendental function used in the design of these tapers is given.

Introduction

THE ANALYSIS of nonuniform transmission lines has been a subject of interest for a considerable period of time. One of the uses for such nonuniform lines is in the matching of unequal resistances over a broadband of frequencies. It has recently been shown that the theory of Fourier transforms is applicable to the design of transmission-line tapers.[1] It is the purpose of this paper to present a transmission-line taper design of improved characteristics. The performance of this taper is optimum in the sense that for a given taper length the input reflection coefficient has minimum magnitude throughout the pass band, and for a specified tolerance of the reflection coefficient magnitude the taper has minimum length.

For any transmission line system the applicable equations are

$$\frac{dV}{dx} = -ZI$$

$$\frac{dI}{dx} = -YV, \qquad (1)$$

where

V = the voltage across the transmission line,
I = the current in the transmission line,
Z = the series impedance per unit length of line,
and
Y = the shunt admittance per unit length of line.

Fig. 1 illustrates the configuration to which the above equations are to be applied.

For nonuniform lines, the quantities Z and Y are known nonconstant functions of position along the line, and the properties of the system are determined through a solution of (1) along with the pertinent boundary conditions. Through use of the waveguide formalism[2] (1) is applicable to uniconductor waveguide as well as to transmission line. Strictly speaking, of course, (1) is not precisely applicable to any system since it accounts for the propagation of a single mode only. It furnishes an excellent description, however, as long as all modes but dominant mode are well below cutoff.

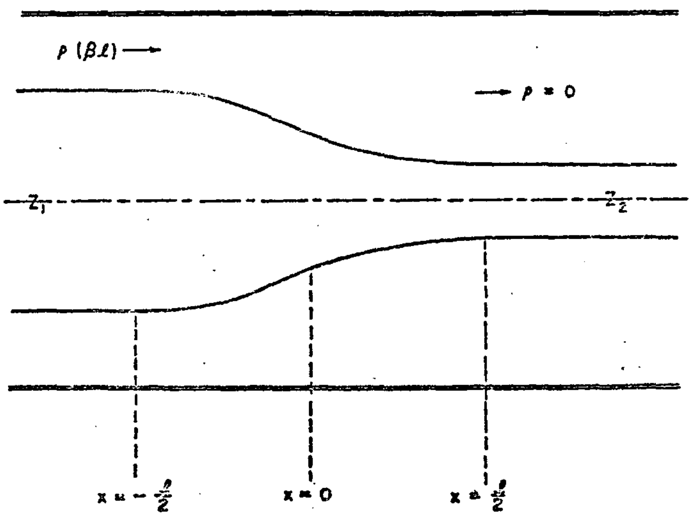

Fig. 1—Tapered transmission-line matching section.

Eq. (1) can be recast in a more directly useful form through the introduction of the quantities

$\gamma = \sqrt{ZY}$ = the propagation constant of the line,

$Z_0 = \sqrt{Z/Y}$ = the characteristic impedance of the line,

and

$$\rho = \frac{V/I - Z_0}{V/I + Z_0} = \text{the reflection coefficient at any point along the line.} \qquad (2)$$

These lead to first order nonlinear differential equation[3]

$$\frac{d\rho}{dx} - 2\gamma\rho + \frac{1}{2}(1-\rho^2)\frac{d(\ln Z_0)}{dx} = 0. \qquad (3)$$

This equation has the advantage that it is in terms of the quantity of direct interest in impedance matching problems. Likewise, a very natural approximation for impedance matching purposes can be made directly in this equation. If it is assumed that $\rho^2 \ll 1$, (3) becomes

$$\frac{d\rho}{dx} - 2\gamma\rho + F(x) = 0,$$

* Original manuscript received by the IRE, June 9, 1955.
† RCA Labs., Princeton, N. J.
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100:1 Bandwidth Balun Transformer*

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Summary—The theory and design of a Tchebycheff tapered balun transformer which will function over frequency bandwidths as great as 100:1 is presented. The balun is an impedance matching transition from coaxial line to a balanced, two-conductor line. The transition is accomplished by cutting open the outer wall of the coax so that a cross-sectional view shows a sector of the outer conductor removed. As one progresses along the balun from the coaxial end, the open sector varies from zero to almost 2π, yielding the transition to a two-conductor line.

The balun impedance is tapered so that the input reflection coefficient follows a Tchebycheff response in the pass band. To synthesize the impedance taper, the impedance of a slotted coaxial line was obtained by means of a variational solution which yielded upper and lower bounds to the exact impedance. Slotted line impedance was determined experimentally by painting the line cross section on resistance card using silver paint and measuring the dc resistance of the section.

The measured VSWR of a test balun did not exceed 1.25:1 over a 50:1 bandwidth. Dissipative loss was less than 0.1 db over most of the range. Measurements show that the unbalanced current at the output terminals is negligible.

INTRODUCTION

IN utilizing some of the recently developed broad-band antennas such as the logarithmically periodic antenna, it is sometimes advantageous to excite the antenna from balanced, two-conductor terminals.[1] In order to match the balanced antenna impedance to the unbalanced impedance of a coaxial line, a balun transformer is required. Moreover, the balun transformer must be capable of operating over a very large frequency range if it is to be compatible with the antenna performance. This paper presents the theory and design of a Tchebycheff tapered balun transformer which will function over bandwidths as great as 100:1.

The balun transformer is illustrated in Fig. 1. The balun is an impedance matching transition from coaxial line to a balanced two-conductor open line. The transition is accomplished by cutting open the outer wall of the coax so that a cross-section view shows a sector of the outer conductor removed. The angle subtended by the open sector is denoted by 2α. As one progresses along the balun from the coaxial end, the angle 2α varies from zero to almost 2π, yielding the transition from coax to an open two-conductor line. The cross section of the conductors is then varied as required. One is not limited to conductors having a circular cross section; a transition from coaxial cable to a balanced strip line is one of the possible configurations.

The broad-band impedance matching properties of

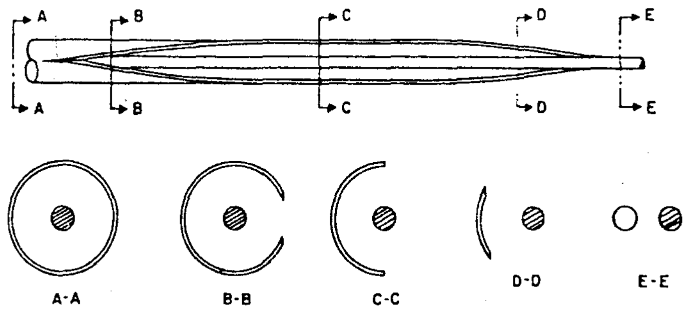

Fig. 1—Tapered balun transformer.

the balun are obtained by utilizing a continuous transmission line taper described by Klopfenstein.[2] The characteristic impedance of the balun transformer is tapered along its length so that the input reflection coefficient follows a Tchebycheff response in the pass band. The length of the balun is determined by the lowest operating frequency and the maximum reflection coefficient which is to occur in the pass band. The balun has no upper frequency limit other than the frequency where higher order coaxial modes are supported or where radiation from the open wire line becomes appreciable.

Before discussing the "balun" property of the device, a brief review of balance conditions on an open transmission line is in order. A balanced two-conductor transmission line has equal currents of opposite phase in the line conductors at any cross section. System unbalance is evidenced by the addition of codirectional currents of arbitrary phase to the balanced transmission line currents. The order of unbalance is measured by the ratio of the codirectional current to the balanced current. Now in a coaxial line, the total current on the inside surface of the outer conductor is equal and opposite to the total current on the center conductor. The ideal balun functions by isolating the outside surface of the coax from the transmission line junction so that *all* of the current on the inside surface of the coax outer conductor is delivered in the proper phase to one of the two balanced conductors. Unbalance of the transmission line currents results if current returns to the generator on the outside surface of the coaxial line.

Consider the Tchebycheff tapered balun transformer which is formed by increasing the slot aperture in the outer wall of the coax until an open two-conductor line is obtained. Over the length of the transition the electromagnetic field changes from a totally confined field in the coax to the "open" field of a two-wire transmission line. It is evident that the total current on the out-

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