4. Broadband Antennas

4.1 Introduction

The advent of broadband system in wireless communication area has demanded the design of antennas that must operate effectively over a wide range of frequencies. An antenna with wide bandwidth is referred to as a \textit{broadband antenna}. But the question is, wide bandwidth mean how much bandwidth? The term "broadband" is a relative measure of bandwidth and varies with the circumstances.

Bandwidth is computed in two ways:

\begin{equation}
B = \frac{f_u - f_l}{f_c} \times 100\% \quad (4.1)
\end{equation}

where $f_u$ and $f_l$ are the upper and lower frequencies of operation for which satisfactory performance is obtained.

$f_c$ is the center frequency.

\begin{equation}
B = \frac{f_u}{f_l} \quad (4.2)
\end{equation}

Note:

- The bandwidth of narrow band antenna is usually expressed as a percentage using equation (4.1), whereas wideband antenna are quoted as a ratio using equation (4.2).
- $f_u$ and $f_l$ are determined by the VSWR = 2 points.

The definition of a broadband antenna is somewhat arbitrary and depends on the particular antenna. "If the impedance and pattern of an antenna do not change significantly over about an octave ($f_u/f_l = 2$) or more, it will classified as a broadband antenna". Broadband antennas usually require structures that do not change abruptly in its physical dimensions, but instead utilize materials with smooth boundaries. Smooth physical structures tend to produce patterns and input impedance that also change smoothly with frequency. This simple concept is very important in broadband antennas.

Various categories of antennas come under the preview of broadband antenna viz., travelling wave antenna, helical antennas, biconical antenna, frequency-independent antenna,
log-periodic antennas etc. In this chapter, we will focus on two major varieties of antennas, such as, (i) frequency-independent antennas and (ii) log-periodic antennas with a minimum of analytical formulations.

4.2 Frequency-Independent Antennas

An antenna with a bandwidth of about 10:1 or more is referred to a frequency-independent antenna. The purest form of a frequency independent antenna has constant pattern, impedance, polarization, and phase center with frequency.

A distinguishing feature of frequency-independent antennas is their self-scaling behavior. Most radiation takes place from that portion of the frequency-independent antenna where its width is a half-wavelength or the circumference is one wavelength. This region is called as the active region. Radiation is maximum perpendicular to the plane of the structure. As frequency decreases, the active region moves to a larger portion of the antenna, where the width is a half-wavelength.

Scaling characteristics of antenna [V.H. Rumsey, 1957] model measurements indicate that if the shape of the antenna were completely specified by angles, its performance would have to be independent of frequency.

It was showed by Rumsey that this requirement would be fulfilled by antenna whose equation in spherical co-ordinates is of the form:

$$ r = e^{a(\phi+\phi_0)} f(\theta) $$  \hspace{1cm} (4.3)

This equation of an equiangular or logarithmic spiral where \(a\): rate of expansion and \(\phi_0\): orientation.

(a) Co-ordinate system for antenna based on equiangular spiral.
(b) Two symmetrical arms of flat spiral antenna.
(c) Two asymmetrical arms with $a \to \infty$. A biconical antenna is obtained if rotated about the common axis.

Fig. 4.1: Equiangular spiral antenna

Frequency-independent antennas can be divided into two types: spiral antennas and log-periodic antennas.

4.2.1. Analysis of frequency-independent antennas:

Let the surface of an edge on its surface is described by a curve:

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

$r$: distance along the surface or edge

[Assume that the antenna has both terminals close to the origin and each is symmetrically disposed along the $\theta = 0$, $\pi$-axis]

If the antenna is to be scaled to a frequency that is $K$ times lower than the original frequency, the antenna's physical surface must be made $K$ times greater to maintain the same electrical dimensions.

The new surface is described by:

$$ r' = KF(\theta, \phi) $$

The new and old surface is identical; that is, not only are they similar but they are also congruent (if both surfaces are infinite).

Congruence can be established only by rotation in $\phi$.

For the second structure to achieve congruence with the first, it must be rotated by angle $C$, so that

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

**Note:** $C$ depends on $K$ but neither depends on $\theta$ or $\phi$.

Physical congruence (coinciding exactly when superimposed) implies that the origin antenna electrically would behave the same at both frequencies.
Note: However the radiation pattern will be rotated azimuthally an angle C.

To obtain the functional representation of $F(\theta, \phi)$

\[
\frac{d}{dC}[KF(\theta, \phi)] = \frac{dK}{dC}F(\theta, \phi) = \frac{\partial}{\partial C}[F(\theta, \phi + C)]
\]

\[
= \frac{\partial}{\partial(\phi + C)}[F(\theta, \phi + C)]
\]

\[
\frac{d}{d\phi}[KF(\theta, \phi)] = K \frac{\partial F(\theta, \phi)}{\partial \phi} = \frac{\partial}{\partial \phi}[F(\theta, \phi + C)]
\]

\[
= \frac{\partial}{\partial(\phi + C)}[F(\theta, \phi + C)]
\]

Equating (4.4) and (4.5)

\[
\frac{dK}{dC}F(\theta, \phi) = K \frac{\partial F(\theta, \phi)}{\partial \phi}
\]

or

\[
\frac{1}{K} \frac{dK}{dC} = \frac{1}{r} \frac{\partial r}{\partial \phi} \quad \text{[using } r = F(\theta, \phi) \text{]}
\]

(4.7)

Since the left side equation (4.7) is independent of $\theta$ and $\phi$, a general solution for the surface $r = F(\theta, \phi)$ of the antenna is

\[
r = F(\theta, \phi) = e^{a\phi} f(\theta)
\]

where

\[
a = \frac{1}{K} \frac{dK}{dC}
\]

$f(\theta)$: arbitrary function.

Thus for any antenna to have frequency independent characteristics, its surface must be described by the above equation. For this specification of $f(\theta)$, derivative of $f(\theta)$ is required.