Antennas for Wireless Systems

Frequency independent antennas

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Antenna Theory: Analysis and Design, Wiley
Broadband antennas (1)

Arrival of broadband systems in wireless communication area ⇒ design of antenna that must operate effectively over a wide range of frequencies

**Broadband antenna** = antenna with a wide bandwidth

- Arbitrary definition
- It depends on the type of the antenna

The impedance and pattern of an antenna do not change significantly over an octave (one octave corresponds to a doubling of frequency, \( f_{up}/f_{low} = 2 \)) ⇒ the antenna is classified as broadband

Broadband antennas are generally made of structures that do not change abruptly in their physical dimensions ⇒ they use material with smooth boundaries

**Smooth physical geometry** ⇒ antenna pattern and input impedance change smoothly with frequency ⇒ very important for a broadband antenna operation
Broadband antennas (2)

Typical broadband antennas are

- log-periodic antennas
- traveling-wave antennas
- helical antennas
- biconical antenna
- **frequency independent antennas**

1950s: breakthrough in antenna evolution ⇒ **frequency independent antennas** introduced, which extended the bandwidth to as great as 40:1 or more

These antennas are primarily used in the **10 MHz – 10 GHz region** in a variety of practical applications such as **TV, point-to-point communication, feeds** for reflectors and lenses, and so forth

Frequency independent antennas (1)

All the dimensions of a lossless antenna are increased by a factor $K \Rightarrow$ the pattern and impedance remain fixed if the operating wavelength is also increased by the factor $K$

The performance of a lossless antenna is independent of frequency if its dimensions measured in wavelengths are held constant

$\Rightarrow$ If the shape of the antenna were such that it could be specified entirely by angles, its performance would be independent of frequency

Example: infinite biconical antenna
It is specified by the angles of the two cones and the angle between their axes
There is an infinite variety of shapes which are completely specified by angles $\Rightarrow$ starting point for the design of frequency independent antennas
Frequency independent antennas (2)

Frequency independent antennas must all extend to infinity (if they did not, they would have at least one characteristic length) ⇒ they do not immediately lead to practical designs.

Key problem: to determine how rapidly, if at all, the performance of the finite structure converges to that of the infinite one.

To make infinite structures more practical, the designs usually require that the current on the structure decreases with distance away from the input terminals.

After a certain point the current is negligible, and the structure beyond that point to infinity can be truncated and removed ⇒ the truncated antenna has a lower cutoff frequency above which its radiation characteristics are the same as those of the infinite structure.

Example: the current on the biconical antenna structure does not diminish with distance away from the input terminals ⇒ the biconical structure cannot be truncated to form a frequency independent antenna.

Frequency independent antennas (3)

In practice, however, antenna shapes exist which satisfy the *general shape equation* proposed by V. H. Rumsey, to have frequency independent characteristics in pattern, impedance, polarization, and so forth, and with current distribution which diminishes rapidly.

Classical shapes of such antennas include:

- the *logarithmically periodic structures*
- the *equiangular geometries* of planar and conical spiral structures
Log-periodic antennas

A type of antenna configuration which closely parallels the frequency independent concept is the **log-periodic**

Because its entire shape cannot be solely specified by angles, it is not truly frequency independent.

Planar log-periodic antenna

Wire log-periodic antenna

Planar log-periodic antenna

Wire log-periodic antenna
Dipole array

To the layman, the most recognized log-periodic antenna structure is the configuration which consists of a sequence of side-by-side parallel linear dipoles forming a **coplanar array**

Although this antenna has slightly smaller directivity values than the Yagi–Uda array, they are achievable and maintained over much wider bandwidths.
Equiangular spiral antennas (1)

Equiangular spiral = geometrical configuration which can be described by angles ⇒ it fulfills all the requirements for shapes that can be used to design frequency independent antennas

Since a curve along its surface extends to infinity, it is necessary to designate the length of the arm to specify a finite size antenna

The lowest frequency of operation occurs when the total arm length is comparable to the wavelength

For all frequencies above this, the pattern and impedance characteristics are frequency independent
Equiangular spiral antennas (2)

Spiral plate antenna: it consists of two metallic arms suspended in free-space

Spiral slot antenna: it consists of spiraling slot on a large conducting plane
Equiangular spiral antennas (3)

Spiral slot antennas have a variety of applications (for example, wireless communication, sensing, positioning, tracking) for different microwave frequency bands, due to their inherent versatility and wideband frequency response.

In addition, the design of spiral slot antennas allows them to be conformally mounted on a variety of objects ⇒ useful in the defense industry (for example, spiral slot antennas can be mounted on military automobiles and aircraft, and used for communication and surveillance purposes).

Another version of the spiral is the Archimedean spiral.

Although the Archimedean spiral antenna is not described only by angles, it gives excellent performance and is widely used.
Radiation properties of spiral antennas (1)

Spiral antennas operate through an “active region” from which the radiation takes place.

At the highest frequency: the active region is contiguous with the feed.

As the frequency decreases: the active region moves out to the edge.

Active-region movement ⇒ rotation of the pattern.
Radiation properties of spiral antennas (2)

The pattern is circularly polarized corresponding to the direction of the spiral arms, it exhibits a peak on the axis and, typically, it is broad.

The gain is slightly more than that of a dipole.
Radiation properties of spiral antennas (3)

Archimedean spiral pattern on a single-sided metal substrate

Bidirectional far-field radiation pattern

- symmetric
- direction of maximum radiation along the z-axis
- similar shape for different frequencies

3 GHz

Applications of spiral antennas (1)

Software-defined radio (SDR)-based radar finds many applications in modern electronic systems such as

- air traffic radar controls
- real-time processing FMCW (= Frequency-Modulated Continuous Wave) radar for target detection
- space communications

SDR has many advantages such as

- a multipurpose system with the ability to reuse the hardware and signal processing algorithms
- low cost
- faster development

In this system, a wideband antenna is applied to scan over all the frequencies ⇒ spiral antenna

Figure: broadband two-arm logarithmic spiral antenna designed for 3-6 GHz frequency band
Applications of spiral antennas (2)

Spiral antennas are **compact** antennas because of their windings. A **bandwidth** of 5:1 or 10:1 can be obtained, and a **stable input impedance** is achieved through a self-complementary geometry (self-complementary planar structure = planar structure the shape of which is identical to the complementary one).

The wideband characteristic of the spiral antenna makes it an attractive choice for **GNSS** (Global Navigation Satellite System) where a single antenna is required to transmit and receive over multiple channels.
Applications of spiral antennas (3)

The spectra of GPS, GLONASS, Beidou and Galileo spread densely across 1.15-1.62 GHz, covering a frequency bandwidth of 446 MHz.

For performance and redundancy, it is highly desirable for a GNSS receiver to cover more than one of these GNSSs.

Figure: two-arm Archimedean spiral antenna used for broadband GPS, covering multiple bands.

The spiral is cavity-backed and the conductive cavity changes the antenna pattern to a unidirectional pattern.

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