The parameter $\beta$ defines the angle of the top corner of the isosceles triangle for the triangular and rhombic loops while $\gamma = W/H$ is used to identify the relative side dimensions of the rectangular loop. The perimeter of each loop is given by $P$; for the rectangular loop, $P = 2(H + W)$. For all configurations, the radius of the wire is $b$.

Included in [32] are the input impedance ($Z = R + jX$) variations, as a function of $P$ (in wavelengths), of the four configurations shown in Figure 5.18. The interval between adjacent points on each curve is $\Delta P/\lambda = 0.2$. Depending on the parameters $\beta$ or $\gamma$, the input resistance of polygonal loops near the resonance frequency changes drastically. The reactance goes to zero when a loop approaches a short-circuited $\lambda/2$ long transmission line. In design, the shape of the loop can be chosen so that the input impedance is equal to the characteristic impedance of the transmission line. Although the curves in [32] are for specific wire radii, the impedance variations of the polygonal antennas as a function of the wire diameter are similar to those of the dipole.

Because the radius of the impedance locus for the $\beta = 60^\circ$ of the top-driven triangular loop [Figure 5.18(a)] is smaller than for the other values of $\beta$, the $\beta = 60^\circ$ has the broadest impedance bandwidth compared with other triangular shapes or with the same shape but different feed points. Similar broadband impedance characteristics are indicated in [32] for a rectangular loop with $\gamma = 0.5$ (the side with the feed point is twice as large as the other).

It can then be concluded that if the proper shape and feed point are chosen, a polygonal loop can have broadband impedance characteristics. The most attractive are the top-driven triangular loop with $\beta = 60^\circ$ and the rectangular loop with $\gamma = 0.5$. A 50–70 ohm coaxial cable can be matched with a triangular loop with $\beta = 40^\circ$. Rectangular loops with greater directivities, but with less ideal impedance characteristics, are those with larger values of $\gamma$.

The frequency characteristics of a polygonal loop can be estimated by inspecting its current distribution. When the current standing wave pattern has, at its antiresonant frequency, a null at a sharp corner of the loop, the loop has a very low current standing wave and, hence, broadband impedance characteristics.

Radiation patterns for the $\beta = 60^\circ$ top- and base-driven triangular loops and the $\gamma = 4$ rectangular loop, for various values of $P$ (in wavelengths), were also computed [32]. It was noted that for low frequencies near the resonance, the patterns of the top- and base-driven triangular loops were not too different. However, for higher frequencies the base-driven triangular loop had a greater gain than its corresponding top-driven configuration. In general, rectangular loops with larger $\gamma$'s have greater gains.

### 5.7 Ferrite Loop

Because the loss resistance is comparable to the radiation resistance, electrically small loops are very poor radiators and are seldom used in the transmitting mode. However, they are often used for receiving signals, such as in radios and pagers, where the signal-to-noise ratio is much more important than the efficiency.

#### 5.7.1 Radiation Resistance

The radiation resistance, and in turn the antenna efficiency, can be raised by increasing the circumference of the loop. Another way to increase the radiation resistance, without increasing the electrical dimensions of the antenna, would be to insert within

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#### 5.7.2 Ferrite Rod

Because of ferrite rod
its circumference a ferrite core that has a tendency to increase the magnetic flux, the magnetic field, the open-circuit voltage, and in turn the radiation resistance of the loop [33], [34]. This is the so-called ferrite loop and the ferrite material can be a rod of very few inches in length. The radiation resistance of the ferrite loop is given by

$$\frac{R_f}{R_r} = \left( \frac{\mu_{ce}}{\mu_0} \right)^2 = \mu_{cer}^2$$  \hspace{1cm} (5-72)

where

- $R_f = \text{radiation resistance of ferrite loop}$
- $R_r = \text{radiation resistance of air core loop}$
- $\mu_{ce} = \text{effective permeability of ferrite core}$
- $\mu_0 = \text{permeability of free-space}$
- $\mu_{cer} = \text{relative effective permeability of ferrite core}$

Using (5-24), the radiation resistance of (5-72) for a single-turn small ferrite loop can be written as

$$R_f = 20\pi^2 \frac{C^4}{\lambda} \left( \frac{\mu_{ce}}{\mu_0} \right)^2 = 20\pi^2 \left( \frac{C}{\lambda} \right)^4 \mu_{cer}^2$$  \hspace{1cm} (5-73)

and for an $N$-turn loop, using (5-24a), as

$$R_f = 20\pi^2 \left( \frac{C}{\lambda} \right)^4 \left( \frac{\mu_{ce}}{\mu_0} \right)^2 N^2 = 20\pi^2 \left( \frac{C}{\lambda} \right)^4 \mu_{cer}^2 N^2$$  \hspace{1cm} (5-74)

The relative effective permeability of the ferrite core $\mu_{cer}$ is related to the relative intrinsic permeability of the unbounded ferrite material $\mu_{fr}$ ($\mu_{fr} = \mu_f/\mu_0$) by

$$\mu_{cer} = \frac{\mu_{ce}}{\mu_0} = \frac{\mu_{fr}}{1 + D(\mu_{fr} - 1)}$$  \hspace{1cm} (5-75)

where $D$ is the demagnetization factor which has been found experimentally for different core geometries, as shown in Figure 5.19. For most ferrite material, the relative intrinsic permeability $\mu_{fr}$ is very large ($\mu_{fr} \gg 1$) so that the relative effective permeability of the ferrite core $\mu_{cer}$ is approximately inversely proportional to the demagnetization factor, or $\mu_{cer} \sim 1/D = D^{-1}$. In general, the demagnetization factor is a function of the geometry of the ferrite core. For example, the demagnetization factor for a sphere is $D = \frac{1}{3}$ while that for an ellipsoid of length $2l$ and radius $a$, such that $l \gg a$, is

$$D = \left( \frac{a}{l} \right)^2 \left[ \ln \left( \frac{2l}{a} \right) - 1 \right], \quad l \gg a$$  \hspace{1cm} (5-75a)

### 5.7.2 Ferrite-Loaded Receiving Loop

Because of their smallness, ferrite loop antennas of few turns wound around a small ferrite rod are used as antennas especially in pocket transistor radios. The antenna is

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usually connected in parallel with the RF amplifier tuning capacitance and, in addition to acting as an antenna, it furnishes the necessary inductance to form a tuned circuit. Because the inductance is obtained with only few turns, the loss resistance is kept small. Thus the $Q$ is usually very high, and it results in high selectivity and greater induced voltage.

The equivalent circuit for a ferrite-loaded loop antenna is similar to that of Figure 5.4 except that a loss resistance $R_M$, in addition to $R_L$, is needed to account for the power losses in the ferrite core. Expressions for the loss resistance $R_M$ and inductance $L_A$ for the ferrite-loaded loop of $N$ turns can be found in [7] and depend on some empirical factors which are determined from an average of experimental results. The inductance $L$ is the same as that of the unloaded loop.

5.8 MOBILE COMMUNICATION SYSTEMS APPLICATIONS

As was indicated in Section 4.7.4 of Chapter 4, the monopole is one of the most widely used elements for handheld units of mobile communication systems. An alternative to the monopole is the loop, [35]–[40], which has been often used in pagers but has found very few applications in handheld transceivers. This is probably due to loop's high resistance and inductive reactance which are more difficult to match to standard feed lines. The fact that loop antennas are more immune to noise makes them more attractive for mobile communication systems, particularly in urban environments.

Relative to either horizontal or vertical radiation, the radiation pattern for a ferrite-loaded monopole $n$ is similar for $n = 1$, as illustrated in Figure 5.19. Unfortunately, data for $n > 1$ are not available.

The radiation pattern for a ferrite-loaded monopole $n$ is similar for $n = 1$, as illustrated in Figure 5.19. Unfortunately, data for $n > 1$ are not available.

5.9 MULT

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