rocal theorem. Referring to Fig. 46.1, V_e may be written

$$V_e = h_e \mathcal{H}\mathcal{R}_c \cos\psi = h_e \mathcal{E} \cos\left(\psi + \frac{\pi}{2}\right) \tag{46.2}$$

with

$$h_e \equiv \beta^2 A \cos \bar{\theta}_1 \tag{46.3}$$

where $\mathcal{H} \cos\psi$ is the component of the magnetic field in the plane containing the axis of the loop and a line drawn from the center of the loop to the transmitter (or a line perpendicular to the planes containing the $\mathcal{E}$ and $\mathcal{H}$ vectors), and h_e is the effective length of the loop and has exactly the same form as the effective length of a short straight antenna *insofar as the trigonometric factor is concerned*. If the axis of the loop is in the plane of constant phase for both $\mathcal{E}$ and $\mathcal{H}$, $\theta_1 = 0$, and

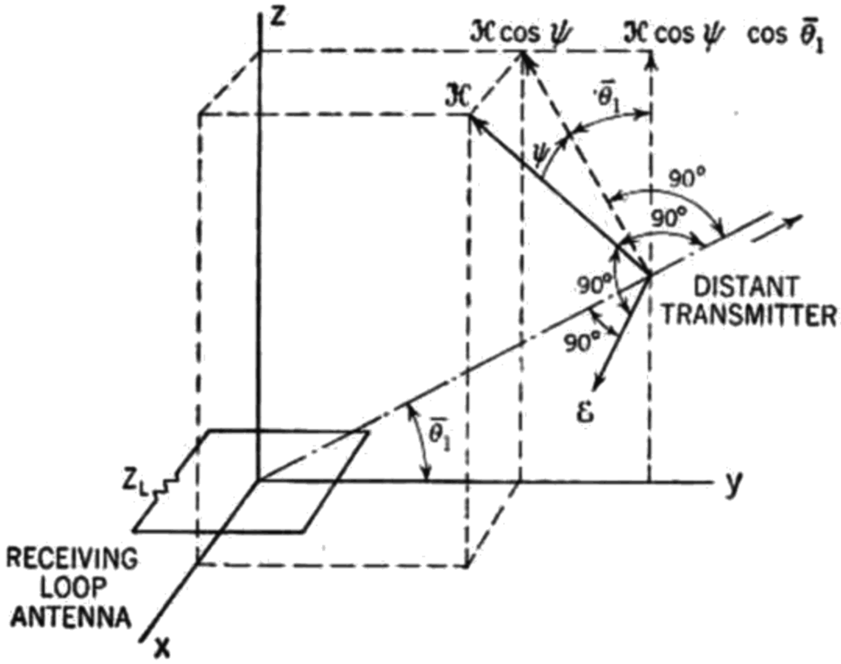


FIG. 46.1.—Horizontal loop antenna in an arbitrarily oriented, linearly polarized magnetic field $\mathcal{H}$.

$$h_e = \beta^2 A \tag{46.4}$$

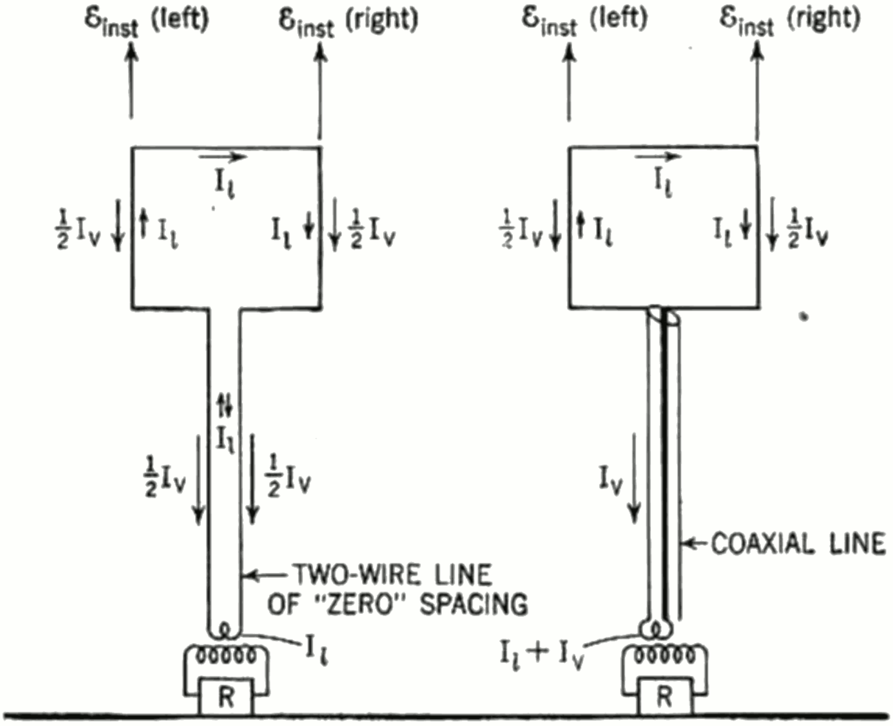
If the loop consists of N turns instead of one turn, Z_0 is changed. In addition, V_e and hence h_e are multiplied by N.

The loop antenna has the same directional characteristics for receiving as for transmitting. They bear the same space relations to the *magnetic* component as those of a short straight antenna do to the *electric* component of a plane-polarized electromagnetic field.

47. Unbalanced Loop Antenna—Shielding.—In describing the properties of the loop or frame antenna for both transmission and reception, all consideration of the construction and the location of the generator or load as well as of the transmission line that may lead to one or the other was omitted in order to simplify the discussion. Accordingly, the transmitting and receiving properties of the frame antenna as described are correct only if the presence of the generator or load or of the connecting transmission line does not produce a condition of unbalance in the loop. This presupposes that the loop itself as well as an attached transmission line and the load or generator *are symmetrical* with respect to a plane perpendicular to the plane of the loop and passing midway between its symmetrically located terminals. Furthermore, if the transmitting or receiving loop is near a conducting surface such as the earth, this surface must be perpendicular to the plane of symmetry across the loop. When all these requirements are fulfilled, the forces acting on the charges in the loop are distributed symmetrically with respect to the input or load terminals, and the ideal conditions and characteristics described in the preceding sections obtain. Symmetrical systems of this type are not always easy to design, because all unbalanced elements such as coaxial lines, and loads or generators not symmetrical with respect to a center tap (which may be grounded) must not be used. If a system is unsymmetrical, the same difficulties arise that are encountered in an unbalanced transmission line. For example, in a driven loop with horizontal axis, supported at some distance above the earth and using a connecting coaxial transmission line, the entire outer surface of the system may be excited as a single vertical antenna with the loop serving as a top load. The resulting field pattern is a superposition of that of a loop and that of a vertical antenna. Obviously the sharp nulls in the distant field of the loop will not be observed.

If a receiving loop is placed well above the surface of the earth (with its axis horizontal), and a two-wire line runs vertically down from it to a receiver, Fig. 47.1, an electromagnetic field with horizontal magnetic and vertical electric component induces currents in the loop and in the line that can be resolved into two parts. There is a circulating current around the loop as a consequence of the small *difference*, $\mathcal{E}_{\text{inst}}$ (right) $-$ $\mathcal{E}_{\text{inst}}$ (left), in the values of the electric field along the two vertical sides of the loop due to the phase difference resulting from their separation in space. Half of this difference in field is considered conveniently to be acting downward on the left and half upward on the right. The remaining components of the electric field on the two sides are both equal to

$\frac{1}{2}[\mathcal{E}_{\text{inst}}\ (\text{right}) + \mathcal{E}_{\text{inst}}\ (\text{left})]$ and are directed upward. They induce equal and codirectional up-and-down currents in *both* sides of the loop. If the spacing of the transmission line is assumed to be practically zero, the same field $\frac{1}{2}[\mathcal{E}_{\text{inst}}\ (\text{right}) + \mathcal{E}_{\text{inst}}\ (\text{left})]$ acts on both conductors simultaneously and induces equal and codirectional currents in the two wires, *i.e.*, the line acts as a single conductor with the loop as a top load. If the spacing of the wires is not so small compared with the wavelength that it may be taken to be zero, the line acts as an extension of the loop.



(*a*) (*b*)

FIG. 47.1.—(*a*) Symmetrical loop receiver. The vertical-antenna current I_v maintains no potential difference across the receiver R. (*b*) Unsymmetrical loop receiver. The vertical-antenna currents I_v maintain a potential difference across the receiver R because a part of I_v continues through the coupling coil. (The dimensions of the loop are assumed to be small compared with the wavelength.)

The circulating current around the loop is the desired one. It produces a true transmission-line current in the connecting line, and this maintains the required potential difference across the load. The codirectional currents, on the other hand, contribute nothing useful but cannot be avoided entirely. If, however, as considered here, they are *equal* currents in the *same direction* in the two sides of a symmetrical loop and line, they can alternately charge and discharge the ends of the line, but they cannot maintain a potential difference across the load, *provided that this is symmetrical* with respect to its terminals. If the load or the line or the loop is unsymmetrical, or if the line is attached to the side of the loop instead of at the bottom, currents of this second type in general can maintain a very significant potential difference across the load. If this is true, the sharp nulls of current in the loop when turned parallel to the magnetic field are obscured by a uniform signal that does not depend upon the purely circulating currents in the loop. Consequently, unless a loop or frame antenna with all its accessory circuits is symmetrical with respect to a plane perpendicular to the loop passing midway between its terminals, the characteristics obtained are a combination of the characteristics of a loop and a vertical antenna.

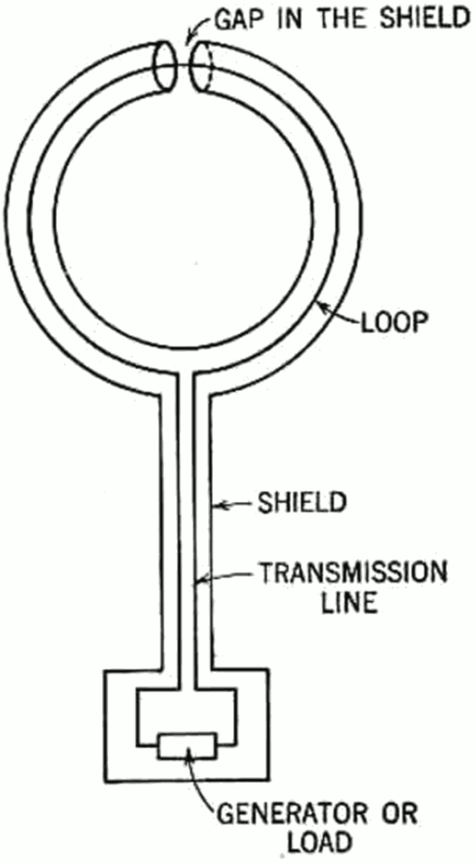


Fig. 47.2.—Shielded-loop antenna.

It is possible to achieve complete structural symmetry for a transmitting or receiving system using a loop by enclosing it entirely in a metal shield that has a gap at the top, Fig. 47.2, (or in some instances at the bottom). In the transmitting loop, essentially only currents that are on the outside of the metal shield are effective in setting up a significant distant field. But this outside surface is excited uniquely by the field maintained in the immediate vicinity of the gap by a potential difference established across it by a large current on the inner surface of the shield. Consequently, complete driving symmetry obtains, and only a circulating current around the outer surface of the circular shield can be excited; there is no codirectional up-and-down current, and a true loop field is set up. Beginning with the generator end, the transmission system consists of a length of shielded pair which connects to two coaxial lines. The load, consisting of the radiating loop, is connected in series with the two coaxial lines. It is interesting to note that the current on the shield is in effect a current on the outside surface of a coaxial line, a current that is most undesirable in coaxial feeders for linear radiators because it makes the line a part of the radiating system, but is precisely the desired current in the shielded loop. In the one case, the coaxial line must not radiate; in the present case, it must be the entire radiator.

In a receiving antenna, a load is connected to the feeder line, Fig. 47.2. A potential difference is maintained across the gap, almost wholly as a result of currents around the outside of the shield. In general, codirectional up-and-down currents also are excited, but they contribute nothing to the potential difference across the gap because they charge the edges equally with charges of the *same sign*. Under these conditions, currents on the inside of the coaxial line, excited by the electric field across the gap, are due only to true circulating currents on the outside of the shield. Therefore, the voltage maintained across the load is due only to these currents, and the ideal loop characteristics obtain.[1]

48. Radiation from Transmission Lines.—In discussing electric currents and the electromagnetic field in Sec. 1 transmission lines were used to illustrate how equal and opposite currents that are parallel and very close together (in comparison with the wavelength) set up electromagnetic fields in the far zone that practically cancel. Actually, complete cancellation is achieved for lines with equal and opposite currents only when the conductors are virtually coincident, or for a coaxial line when both ends are completely closed by metal disks.[2] When this is not the case, the field at distant points does not vanish. In the open-wire line, the field is only partly canceled because the equal and opposite currents in the wires are never infinitely close together, and because there are no equal and opposite currents to cancel the fields due to the often widely separated currents in the load and generator.

The small nonvanishing field when the ends of a coaxial line, are not closed by metal disks is due primarily to the absence of the radial currents in these disks. With the disks removed and the line left open or connected to a short straight wire, the currents along the interior of the line readjust themselves in magnitude and phase so that the field due to them again vanishes in the metal of the conducting walls. This distribution involves a slight unbalance which is compensated by a small but significant current on the *outside surface* of the outer conductor. The line currents inside but near the open or bridged end together with the currents on the

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[1] The operation of the shielded loop is explained popularly by first stating that the desired loop current is due to the magnetic field, the undesired up-and-down current to the electric field, and then maintaining that the metal shield cannot be penetrated by the electric field but can be penetrated by the magnetic field. All these statements are incorrect in the light of fundamental electromagnetic principles.

[2] Strictly, all conductors would have to be perfect.