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On the Properties of Loop Antennas

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Recent developments have indicated the desirability of setting forth some of the theory of the loop antenna in a non-mathematical and simple way. I am going to attempt to explain the most important properties of these antennas by means of verbal description. The formal development of the basic concepts can be found in undergraduate texts. (Slater and Frank is a good source.) Haven Whiteside presents experimental results in NR 371-016, Cruft Laboratory Technical Report No. 377.

Three laws are implicitly or explicitly employed in the following discussion: Lenz's Law, that the current induced in a circuit by a change in the magnetic field flows in such a sense as to oppose the change; Faraday's Law of induction, which is really a quantitative statement of Lenz's Law; and the boundary condition that the tangential electric field at the surface of a perfect conductor is zero.

As a starting point I choose to consider a loop of perfectly conducting material in space under the influence of a radiation field. Faraday's Law may be stated as follows: The sum of the tangential electric fields around any closed contour is equal to the negative time rate of change of the magnetic flux which is enclosed by that contour. A contour enclosed by a conductor has no tangential electric field so the first half of our equation is zero and we conclude that the flux change inside the loop is also zero. The induced currents exactly cancel any change in the applied field, forming a magnetic dipole with nodes in the direction of the loop axis for a planar loop which is small compared to the wavelength of the incident radiation. By small I mean that the diameter is less than 0.1 wavelength.

The loop also responds to the electric component of the incident field which lies along any diameter. Being a conductor and insisting that no tangential field components exist on its surface, it polarizes itself to cancel those components. The result is an electric dipole whose nodes lie on the diameter of the loop in the plane of the incident electric field, and is therefore perpendicular to the magnetic dipole. By reciprocity, these two dipole patterns are the same for transmission, scattering, or receiving.

In order to use the loop as a probe it is necessary to load it. If a resistor is inserted into a break in a conducting loop we have a region in which tangential electric fields can exist, currents flowing in the loop are limited by the resistor to give the value of voltage drop predicted by Faraday's law, these currents, for practical values of resistance, are small enough that their magnetic field is negligible compared to the incident field, and the end result is that we can use the loaded loop to measure fields quantitatively. The signal voltage is simply equal to the product of the loop area and the time rate of change of the magnetic field, in MKS units, for optimum loop orientation.

So far, so good, but the simple loop suffers from the disadvantage of responding to the electric field also in any orientation in which it has magnetic sensitivity unless it can be balanced to ground with the feed points at the dipole node. This is too drastic a restriction, though it offers a mode of measuring magnetic response in a push-pull circuit and electrical response in push-push. For very small loops the electrical sensitivity can be ignored. The electrical height of a multi-turn loop is not appreciably greater than that of a single turn loop, though its increased capacitance allows it to drive a line more effectively, while its magnetic sensitivity is directly proportional to the number of turns. However, both inductance and capacitance increase with the number of turns so that the resonant frequency goes down and the stored energy goes up. For our purposes we like single turn loops. A 1 m. loop of a single turn of cable may have a resonance at 40 mc, but the stored energy is so low that very little signal is generated by this resonance on a 90 ohm load.

For purposes of determination of pulse shape it is convenient to avoid the necessity of trying to unscramble electric and magnetic signals by the judicious employment of shielded loops. (I guess all I'm really trying to do is to define "judicious".) In the shielded loop the loading is a little more esoteric. It comprises a loop of coaxial cable with a gap, or some gaps, in the outer conductor. Let us confine ourselves to a single gap. Currents induced in the outer surface of the outer conductor transfer to the inner surface at the gap and find themselves traveling down the cable. The load resistance seen by these currents is plainly the characteristic resistance of the cable. It doesn't matter whether the currents are excited by the electric or the magnetic field, but the former can be eliminated by placing the gap at one of the null points of the dipole field of the loop. The loop is thus placed with its load gap on a diameter parallel to the incident electric field and its axis parallel to the magnetic field. Magnetically induced currents go around the loop and don't care where the gap is. Electrical signals travel up and down and have zeros at the poles.

If we place the load gap toward or away from the signal source we maximize electrical sensitivity. In the first case currents due to positive

E and positively increasing B add, in the second they oppose one another. The frequency dependences of the two modes differ, and the result is severe or trivial distortion depending on the relative size of the loop.

I have said nothing about transient effects due to the finite time of transit of signals across the loop and around its circumference. These are of little importance if we confine ourselves to 1 meter loops at frequencies below 50 mc.

Here are Whiteside's measured values of the ratio of electric to magnetic sensitivities of some singly loaded loops, oriented for maximum electrical response. d is, of course, the loop diameter and λ is the wavelength of the signal.

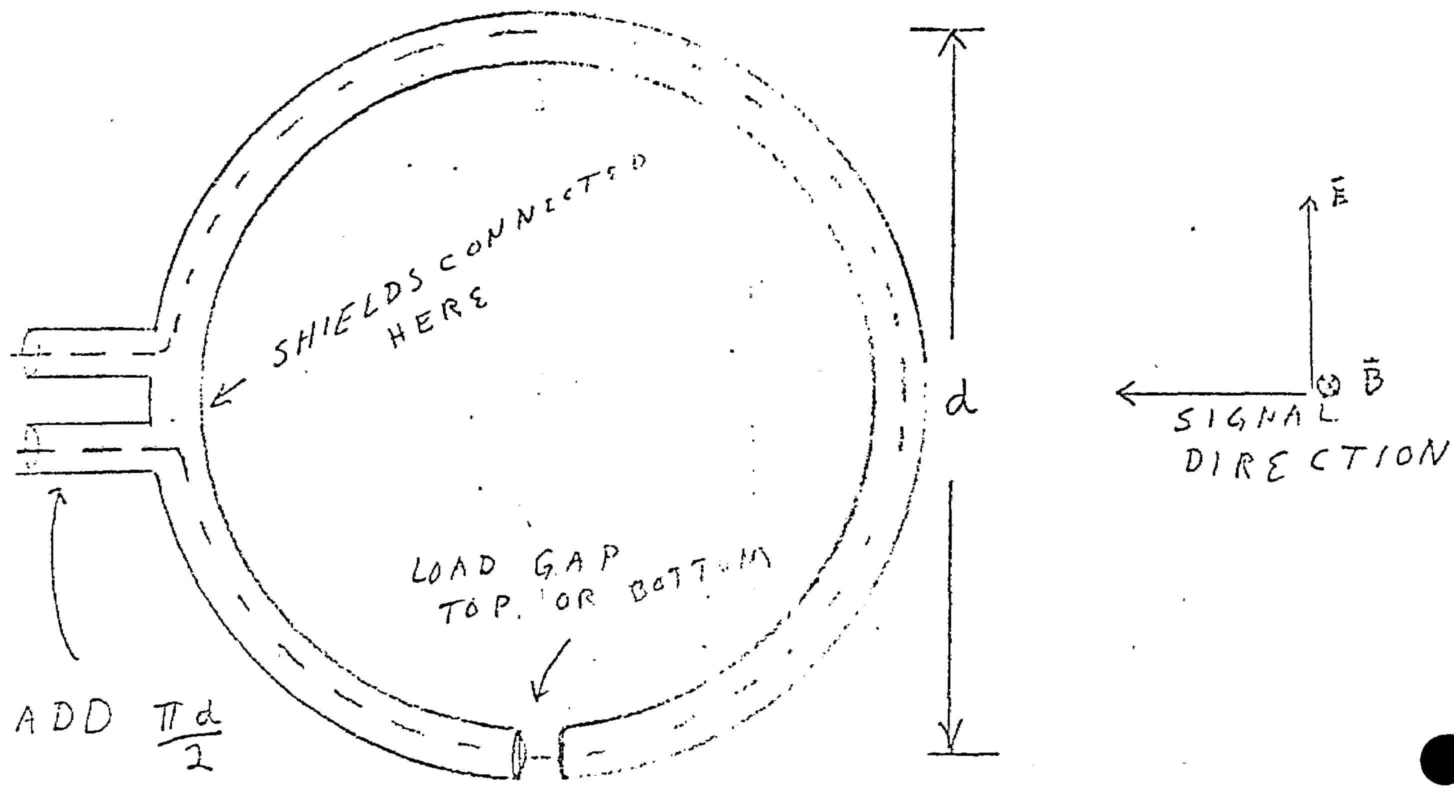
d/λ	S_E/S_B
0.1	-2 db
0.05	-9.5
0.025	-15
0.013	-20

For a 1 meter loop, d/λ amounts to 0.1 at 30 mc, and the electrical signal is 80% of the magnetic signal. The resulting distortion is non-trivial.

Any area enclosed by the cables of the system between the gap and the tie point between the two outer conductors is part of the loop. For clear-cut knowledge of the effective area of the loop it is best to place that tie point as shown in Fig. 1, which shows the manner in which a loop might be installed in an airplane wing or other unlikely location.

In Fig. 1, I illustrate a case in which it is not feasible to bring the signal leads out either opposite or adjacent to the load gap. The resultant loss of symmetry is only a minor nuisance because it is restored by adding a little delay to the short leg of the loop. From this figure one can readily see how the loop can act as a magnetic dipole, a folded electric dipole, or both. The signal shown on the drawing produces maximum B and null E effects. If the loop is rotated 90° around its axis, both magnetic and electric sensitivities are maximum. The loop has no magnetic sensitivity to a signal traveling normal to the plane of the paper, but has maximum electric sensitivity to that signal when the electric vector is in the left-right direction.

This discussion has been conducted on a very inelegant and primitive basis, not in an attempt to insult anybody's intelligence, but in the hope of not missing any significant factor.



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