Effective length of ferrite rod aerials

A topic that has received almost no treatment in the literature

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The theory given in this article was recently checked by my colleague M. D. Samain and was at first received with some scepticism because his measurements comparing a frame aerial with ferrite rod aerial were inconsistent. The discrepancy was not explained until he telephoned the BBC and found that the Moorside Edge medium wave transmitter, which had been used as the signal source, has its power boosted as daylight fades and this occurred half way through the exercise. As Sherlock Holmes pointed out, if there is only one possible explanation it must be right, however improbable.

A COMPLETE ANALYSIS of the behaviour of any aerial should be conducted using the concepts of gain, aperture and radiation resistance but this approach gives a tortuous route in answering the following simple question. "If a ferrite rod aerial is located in a radiated field of strength E volts per metre and the p.d. at the coil terminals is V volts, how do we find the effective length L appropriate to the relation $V = LE$?" This is a fair question but, surprisingly, has received almost no treatment in the literature of electromagnetic theory and aerial design. There is a fairly simple approach to a solution which will be presented later in this article, but first examine that simpler structure, the loop or frame aerial.

Suppose a loop, small in size compared with a wavelength and with n turns enclosing an area A square metres, is sitting with its plane in line with the transmitter. Then the transmitted magnetic field will pass normally through A and if no current is taken from the coil the p.d. can be calculated from the flux-changing law. If the magnetic field is $H = H_m \sin 2\pi ft$ the linked flux is $\mu_0 AH$ and the p.d. is

$$V = \frac{d}{dt}(\mu_0 AnH)$$

$$= \mu_0 AnH_m 2\pi f \cos 2\pi ft$$

It is conventional to describe aerial performance in relation to electric field strength E rather than magnetic field strength H. For normal propagation the two are in phase and at right angles to each other, and have the ratio $E/H = 120\pi$ ohms $= R_0$, and called the impedance of free space. We insert this relation and get

$$V = E_m\left(\frac{\mu_0\ Anf}{60}\right)\cos 2\pi ft$$

or $V = LE_m \cos 2\pi ft$

where L can be defined as the effective length of the loop aerial.

The next stage in considering the connection of a loop aerial to a receiver is to draw the equivalent circuit. The real circuit might be as shown in Fig.1(a) and then the equivalent circuit appears as at(b)

In the equivalent circuit L_L and R_L are the inductance and series resistance of the loop. R_{rL} is a component that has been ignored in the discussion so far. It is the radiation resistance of the loop and represents the power lost by radiation when current flows. For loops of size small compared with a wavelength, R_r is found to be so minute compared with R_L that it is of no practical importance. The voltage V_o across the capacitor may be regarded equally legitimately as the output voltage of the aerial circuit and is greater than V in proportion to the Q-factor of the circuit. It would be quite acceptable to define L as V_0/E or to define the L-value for one turn only of the loop, so it appears that the L-value of this kind of aerial is not a unique property but must be related to some particular aspect of the associated circuit.

So much for the loop aerial, which was discussed solely to explain a sequence leading from an easily understood physical process, voltage induction in this instance, via concepts of equivalent circuits to a method of calculating voltage and current signal levels in circuits associated with the aerial. Can we follow the same argument with the ferrite rod aerial?

It is tempting to regard the rod as an extension of the loop, collecting and concentrating the radiated magnetic field and channelling it through a coil wound round the middle of the rod. This approach is strangely unrewarding, though it has provided several theoreticians with a challenging exercise in field theory and mathematics. There is another route to the solution of the problem* more appropriate to circuit designers, and this alternative approach will now be presented.

The argument begins by considering an idealized ferrite structure similar in shape to the ball-ended magnet that was, and perhaps still is, common in school physics laboratories. This structure is called a magnetic dipole and has the property that its magnetic flux enters and leaves the magnetic material only at the ends, which are distance l metres apart. Now suppose the dipole to be wound with n turns of wire and to be aligned with an alternating magnetic field H amps per metre. Flux will oscillate through the winding and voltage will be induced, but we must postpone this concept. Instead we imagine the application of a current generator I to the terminals of the winding as shown in Fig.2. The magnitude and phase of I is adjusted exactly to balance the magneto-motive forces, so that no flux passes through the dipole and no voltage is induced in the winding. In these circumstances the relation between I and H is very simple and is

$nI = Hl, \quad I = Hl/n$

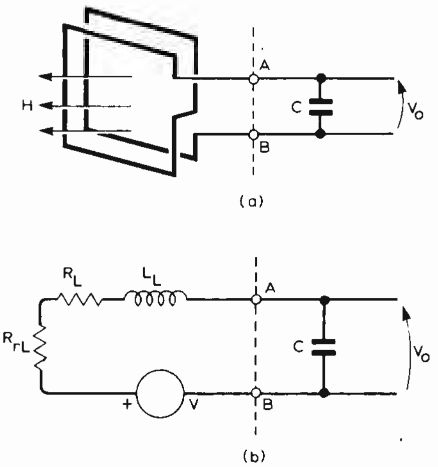

Fig. 1. *Loop aerial (a) and its equivalent circuit (b). V is $LE_m \cos 2\pi ft$, where L is the effective length.*

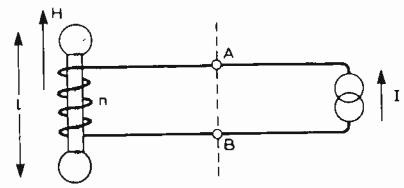

Fig. 2. *Magnetic dipole in H field connected to a current generator. Flux and voltage are zero if $nI = Hl$.*

* Ferrite rod aerials, by H. Sutcliffe. *Int. J. Elect. Enging Educ.* Vol.13 1976, pp. 35-40.

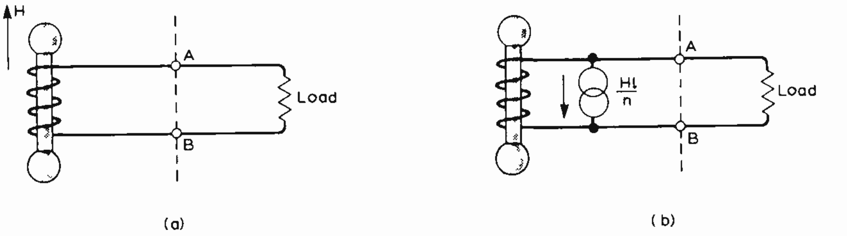

Fig. 3. *Magnetic dipole in H field connected to load (a) and its equivalent circuit (b) in which the dipole is now a passive component.*

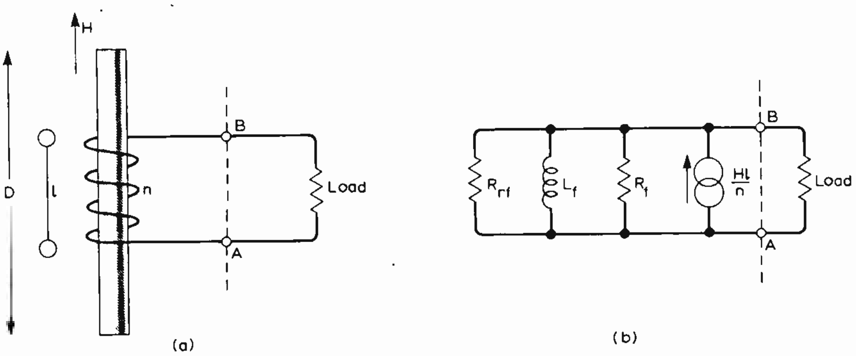

Fig. 4. *In equivalent circuit of ferrite rod aerial, I is calculable, L_f and R_f measurable and R_{rf} negligible. Effective length can be defined as lR_f / nR_0, manufacturers should quote l.*

The next step is to invoke the principle of superposition and add another generator in parallel with the first, identical to it but with opposite polarity. This step will achieve two things. Firstly and obviously it will nullify the effect of the previous external generator, so that any p.d. appearing at terminals AB is now caused by the transmitted field *H*. Secondly, the voltage that now appears is calculable solely from the effect of applying the second generator. The equivalent circuit of the magnetic dipole is therefore related to the real circuit as illustrated in Fig.3.

This result is somewhat surprising, for we expect from the physical behaviour of the dipole as a receiver that the generator will appear as a voltage generator in series with the coil. Instead we find that in the equivalent circuit the most natural and basic form of the generator is a current generator in parallel with the coil. Before proceeding further with a discussion of circuit topics though, we must examine the situation where the coil is wound not on an ideal dipole but in the usual form of a concentrated coil at the centre of a cylindrical ferrite rod. If we are to use the expression for the size of the current generator ($I = Hl/n$) for a ferrite rod we need to know the length *l* of the equivalent ideal dipole. The argument becomes less precise at this point but still yields useful results.

An illuminating experiment is to excite a rod by a coil at its centre and measure the voltage induced in a coil which can slide along the rod. This provides a measure of the magnetic flux in the rod at various distances from the centre. It is found that the flux is a maximum at the centre and negligible at the ends, and the distribution follows approximately a raised cosine pattern. This experiment has been performed with rods of various lengths, diameters and permeabilities, and for the types common in receivers there is very little difference in the general pattern of behaviour. Further experiments based on the equivalent circuit of Fig.3, in which the *H* field was generated by a local air-cored coil, confirmed the conclusion that for common ferrite rod aerials the equivalent dipole length *l* is approximately 1/3 of the rod length. The ratio rises to 1/2 for thick rods of high permeability and falls to 1/4 for thin rods and low permeability ($\mu_r \approx 200$). It can be concluded therefore that the equivalent circuit of a ferrite rod aerial can be described conveniently by reference to Fig.4.

In Fig.4(b) the value of *I* is readily calculable with no requirement to know the diameter or permeability of the rod, though there is some lack of precision because the effective dipole length *l* is only approximately given by 1/3 of the rod length.

The inductance L_f and parallel loss resistance R_f of the coil are easily measured. Both are approximately proportional to n^2. The resistance R_{rf} is the radiation resistance in its parallel form and is so large in practice compared with R_f that its effect is negligible.

It would be quite proper to halt at this stage in the discussion, for the circuit of Fig.4(b) provides everything a circuit designer needs to know, but since the whole exercise was generated by a question about equivalent length, in formulae of the type $V = LE$, it may be appropriate to continue with a little more analysis.

Suppose the load in Fig.4(b) is a capacitor and the aerial voltage is specified as the p.d. V_0 across the resulting parallel LC circuit at resonance. Then

$$V_0 = IR_f = HlR_f/n,$$

and since $E/H = R_0$,

$$V_0 = \frac{lR_f}{nR_0}E = LE, \text{ where } L = \frac{lR_f}{nR_0}.$$

A typical situation is l 0.05m, R_f 80 kilohms, n 50 turns, and R_0 377 ohms, for which $L \approx 0.21$ metres, or volts per (volt/metre).

This definition of *L* is arbitrary as a definition of aerial performance but it does at least have the merit of being easy to remember. Also it gives a correct answer subject to a lack of precision about the value of *l*, the effective dipole length. This normally lies between 1/4 and 1/2 of the rod length, but it would be advantageous if manufacturers of ferrite rods were to quote this most useful parameter when specifying their products.

UK firms' microelectronics "incompetence"

ACCORDING to union leader Ken Gill, the recent ACARD report on the utilization of microelectronic devices in British industry is "a damning indictment of employers' incompetence". Gill, who is general secretary of TASS (the technical, administrative and supervisory section of the Amalgamated Union of Engineering Workers), was speaking at an AUEW officials' conference at Eastbourne in September. He quoted the ACARD report as saying that we have been overtaken by competitors in fields such as cash registers, food processing equipment, process instruments, machine tools, telephone switching systems, printing machinery and even in ship chronometers. In many of these fields we had previously had a dominant position. "Moreover, we failed to recognise new opportunities until others produced the products" (said the report). "Examples are calculators, electronic watches and clocks, word processing and television games .... On production methods the picture is just as gloomy. Industrial firms are only slowly incorporating new technology such as numerically controlled machine tools into their manufacturing and into production planning control". The main conclusion in the report, said Gill, is that every department and agency of the Government including nationalised industries must accept the importance of the new semiconductor technology.

"Technology must be our slave and not our master," he went on. "Our members must be alerted to negotiate on every aspect of the new technology and warn them of those areas of importance of which they may not be immediately aware. The multi-national corporations see this technology as a means for greater profits, and greater controls over their employees and the consumer. The union movement see it as more employment and more purchasing power and more leisure for the workers. The massive increase in productivity derived from these developments must go to the benefit of all and not to the few."