Ground Wave Propagation at 1·8 Mc/s

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THE purpose of this article is to explain some of the features of ground wave propagation and discuss the use of vertical transmitting aerials for fixed station and mobile operation on Top Band. Numerous references [1], [2], [3], [4], [6], [7], to propagation and aerial design have been consulted which, in conjunction with field strength measurements and the use of scale models operating at high frequencies, have provided much useful information on the subject. The co-operation of the operators of several mobile and fixed stations is acknowledged.

As an aid to field strength measurement a pen recorder and a magnetic tape recorder were used to obtain a continuous record of changes in signal level and modulation characteristics over various ground contours and at different ranges. Both recorders were automatically operated from a receiver coupled to an inductively loaded vertical aerial 72 ft. high and tuned to quarter wave resonance in the frequency band 1·8 to 2 Mc/s. The receiver r.f. gain control was calibrated in terms of microvolts at the aerial terminal (70 ohms) without a.v.c.

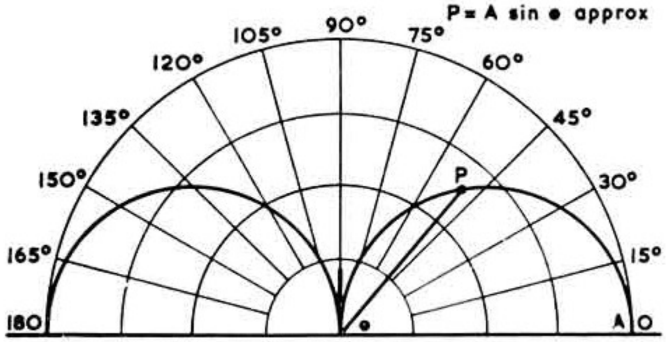

Fig. 1. Vertical radiation pattern for a short aerial.

Propagation from Vertical Aerials

In the frequency band 1·8 to 2 Mc/s a signal at the receiving aerial may originate from: (a) A ground wave; (b) an ionospheric wave (sky wave) reflected from an ionized layer under certain conditions.

When using a vertical aerial, especially for mobile operation, the ground wave is the predominant component and transmitting range is normally set by attenuation or absorption by nearby objects.

Since the radiation of both ground and sky waves are determined by the properties of the transmitting aerial any discussion on propagation must be linked with the characteristics of aerials. Nearly all aerials for mobile operation on 1·8 Mc/s and 3·5 Mc/s for example, consist of vertical rods with inductive and capacitive loading and such aerials produce, as any other vertical aerial, a vertically polarized wave. The field strength depends on the radiation pattern, the power input and the electrical characteristics of the aerial.

Assuming the ground to be flat and perfectly conducting and that the current distribution in the aerial is sinusoidal, the radiated power in the vertical plane of a short aerial, i.e. whose height for example is less than $0{\cdot}12\,5\lambda$ is approximately a semi-circle as shown in Fig. 1. As the aerial height is increased the vertical radiation pattern tends to flatten with an increase in energy along the ground and a reduction of energy skywards.

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Calculation of Field Strength

Prior to 1930 the Austin-Cohen formula had been in general use and although having the advantage of simplicity, was found to be inaccurate for predicting field strength at great distance, especially at the higher frequencies. For lower frequencies, however, and with slight modification, the accuracy is sufficient for calculation of field strength for a few miles. For greater distances the Sommerfeld equation produces results that agree much more closely with actual measurements. This has been used to produce the curves of Figs. 2 and 3 which show the rate of attenuation for *ground wave signals* and are based on the characteristics of actual aerials and their measured (or calculated) field strength at 1 kilometre (0·625 miles). The reference signal level of S9 is taken as 55 microvolts at the receiver terminal assuming reception from an aerial equal to that being used for transmitting.

The field strength due to the ground wave signal at a range (d) assuming the earth to be perfectly conducting is given by Sommerfeld as $\Sigma = \frac{E_1 \cdot A}{d}$ (Fig 4)

where E_1 is the field strength at a horizontal distance (d) of 1 kilometre from the aerial. E_1 is usually designated the unattenuated field strength at 1 kilometre.

As sea water has the nearest practical approach to perfect conductivity an attenuation factor A must be provided to take into account the effect of the ground. This attenuation varies with frequency and as the ground wave induces a charge into the ground (which travels with the wave), a flow of current is constituted; thus other important constants are

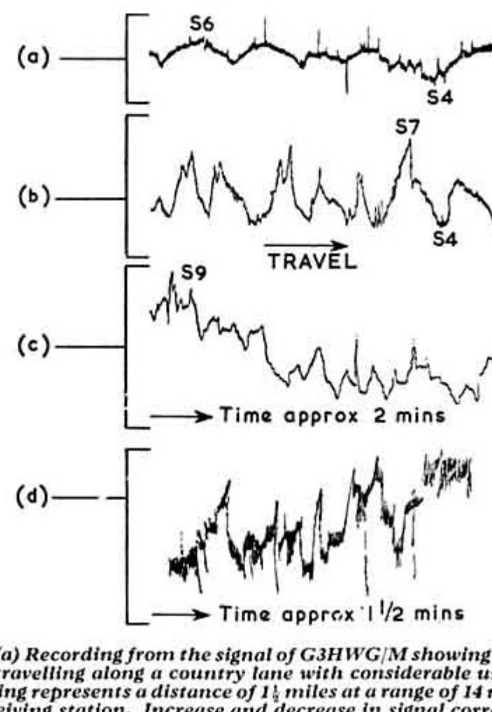

Fig. 2. (a) Recording from the signal of G3HWG/M showing variations whilst travelling along a country lane with considerable undulation. Recording represents a distance of 1½ miles at a range of 14 miles from the receiving station. Increase and decrease in signal corresponds to rise and fall in height of road above sea level. (b) Signals from G3AGP/M travelling under trolley bus wires for a distance of 1½ miles at a range of about 3 miles in a built-up area. (c) Fading on signals from MSF, the frequency standard station at Rugby, over a period of approximate 2 minutes. (d) Noise from rain precipitation during a heavy thunderstorm during a period of 1½ minutes.

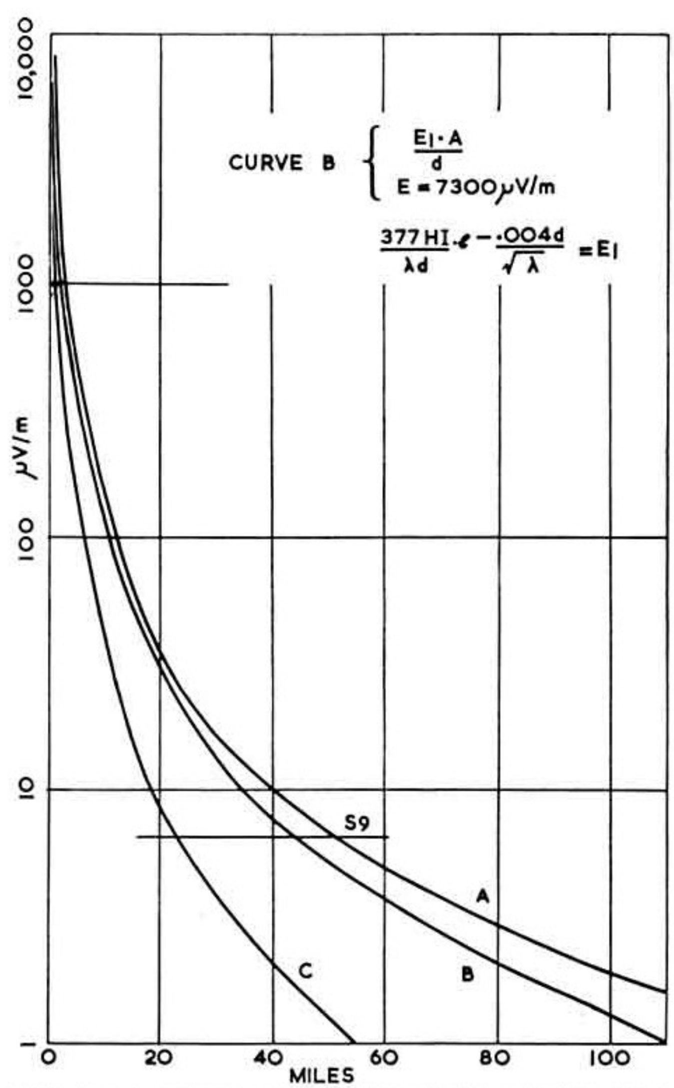

Fig. 3. Sommerfeld curves for (a) a 72 ft. high vertical aerial on 1·8 Mc/s. (b) An average inverted " L " aerial on Top Band. (c) Field to be expected from a poor 132 ft. inverted " L " aerial.

(i) Conductivity σ which governs the loss of energy whilst the charge is moving; (ii) Permitivity ϵ which influences the production of the charge.

Conductivity is usually more important as far as propagation is concerned and is expressed in electro-magnetic units (E.M.U.) the values of which vary with frequency and the nature of the ground down to considerable depth.

To use the Sommerfeld equation for calculating field strength the attenuation factor A must first be derived and the field strength found from $\Sigma = \frac{E_1 \cdot A}{d}$ (Fig. 4)

where Σ is the field strength, A the attenuation factor from the Sommerfeld formula and d distance in metres.

The unattenuated field at 1 kilometre must be either measured or can be approximated from

$$\frac{377\,HI}{\lambda\, d} \cdot e^{-\frac{\cdot 004 d}{\sqrt{\lambda}}}$$

where H is the height of the aerial in metres, I the current at the base in amperes, λ the wavelength in metres, d the distance in metres and 377 the impedance of free space (constant).

Field Strength from 1·8 Mc/s Mobile Aerials

The curve A of Fig. 5 shows the field strength to be expected from an average mobile aerial with an approximate height of 14 ft. and is based on a measured E_1 of 110 microvolts at 1 kilometre, and where d = distance in kilometres, σ = average ground conductivity value of 12×10^{-14} E.M.U., c = velocity of propagation of electro-magnetic wave at 3×10^8 metres/second.

Curve B (also based on E_1 as 110 microvolts at 1 kilometre) was produced from the recorded signal of a mobile travelling over ground of average conductivity. The differences in signal level are due to rising ground along the route. The approximate contour of the ground is shown against the curve.

The Pen Recorder

Some details of the pen recording equipment and its operation may be of interest. The instrument is driven from a 24 volt d.c. motor with a speed variation control so that the Teledeltos recording paper will run through at a speed of n feet per second to provide some relationship between the ground covered by a vehicle at an average speed of n miles per hour.

Teledeltos recording paper is marked by applying a voltage which produces an arc between the recording pen point and the metallic undersurface of the paper, thus burning a sharply defined black line as the paper moves along. The pen mechanism has an action similar to that of a moving coil meter with the pen arm traverse at right angles to the direction of the paper. The pen coil operates in a magnetic field of great strength to maintain sensitivity and linearity of the pen movement. With a suitable d.c. amplifier a change in signal level of plus or minus 2 microvolts can be recorded, the amplified signal voltage being rectified and applied directly as a negative voltage to the d.c. amplifier. The sensitivity of the instrument is such that a rapid fadeout due to sudden screening (passing under a bridge, etc.) or a change in signal level of less than 2 microvolts, is faithfully recorded. Some examples of recordings taken from Top Band mobiles in motion and other sources are shown in Fig. 2.

Field Strength from Vertical and Folded Aerials

Probably the most popular aerial used by amateurs for 1·8–2 Mc/s operation is the 132 ft. inverted " L " arrangement which at these frequencies is resonant at quarter wavelength and often used as a harmonic radiator on the higher frequency bands.

In considering an aerial for 1·8 Mc/s operation an average

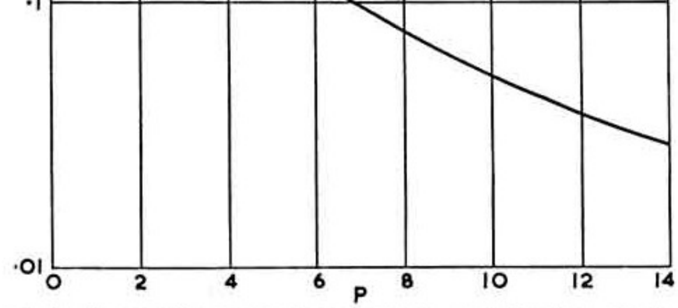

Fig. 4. Sommerfeld attenuation factor A as a function of the numerical distance P for phase constant 0°.

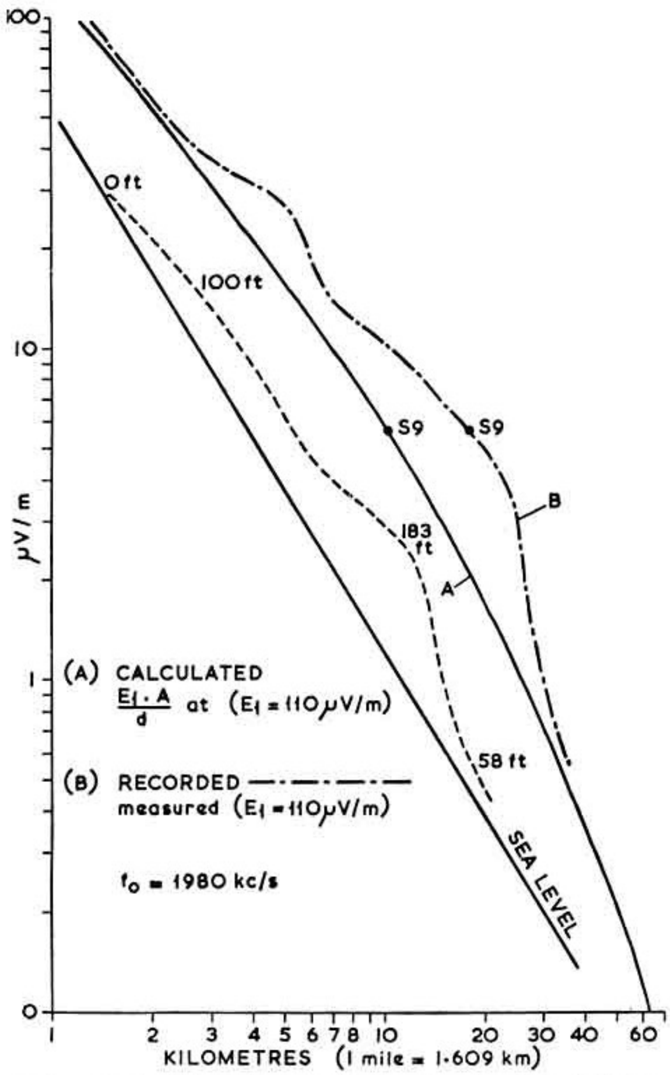

Fig. 5. Sommerfeld curve for a mobile aerial 13·5 ft. high. (a) Calculated. (b) Measured.

physical height of 30–35 ft. will be assumed, leaving 90–100 ft. for the horizontal portion. The effective height will be:

$$\frac{2H}{\pi} \cdot Aff$$

$$(\textit{where } H \textit{ in metres} = \frac{Hft.}{3} \times 0{\cdot}9114)$$

The aerial form factor (*Aff*) is derived from the ratio of *L*, the length of the horizontal portion, and *l* the height of the aerial. For an average height and length the form factor is about 0·98 so the effective height will be of the order of 10m. For a fully vertical radiator the effective height is simply $\frac{2\,H.}{\pi}$

The Sommerfeld curve of Fig. 3(b) is based on the calculated average field of three 132 ft. inverted aerials each with slightly different values of height and length and with slightly different power inputs. The curve of Fig. 3(a) shows the field from a fully vertical aerial (72 ft. high tuned quarter wave) [8]. Again it must be emphasized that the curves show the rate of attenuation for *ground wave signals only*.

The Efficiency of Vertical and Inverted " L " Aerials

Aerial efficiency can be derived from

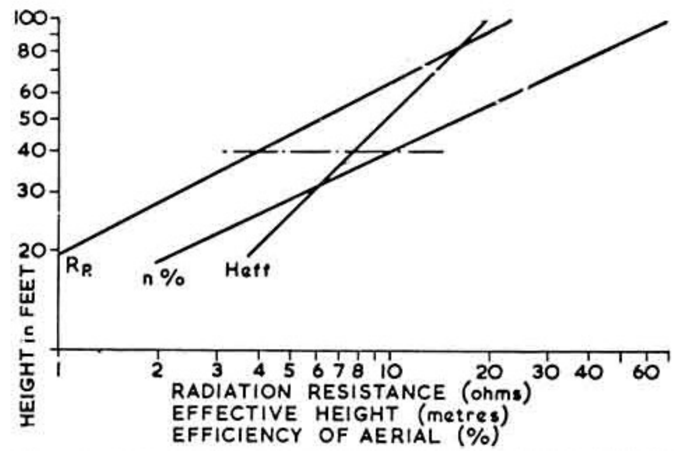

Fig. 6. Radiation resistance v. effective height of vertical aerials from 20 to 100 ft.

$$\frac{\textit{Power Radiated}}{\textit{Power Supplied}} = \frac{R_R}{R_L + R_R}.$$

where R_L denotes loss resistance due to ground and other components and R_R is the radiation resistance. A fully vertical (quarter wave) radiator whose radiation resistance

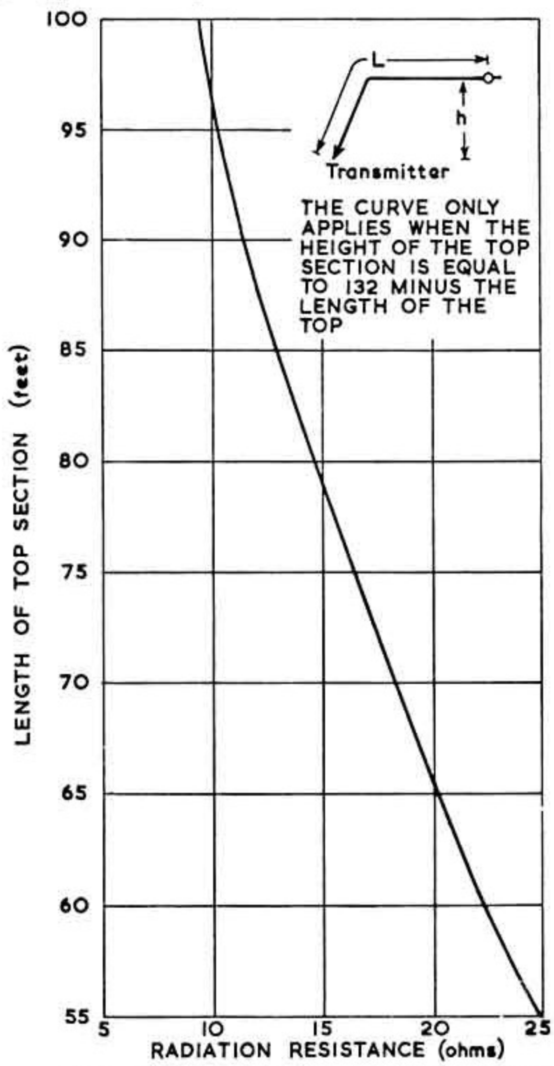

Fig. 7. Radiation resistance of inverted " L " aerials with a total length of 132 ft. (L).

is approximately equal to its base impedance (36–40 ohms) will radiate all the power supplied to it, assuming no other losses, and may be regarded as 100 per cent efficient. By comparison (but including ground loss) an average mobile loaded whip aerial will have an efficiency of around 4 per cent.

The effective total resistance of an aerial is therefore made up of two parts—*radiation resistance* and *loss resistance*, the former useful and the latter wasteful. Loss resistance is due to a number of causes and it is clearly desirable that this "resistance" should be small and the radiation resistance large.

Most of the loss resistance is due to the ground, eddy-currents in nearby conductors, poor insulation and dielectric losses due to nearby trees and buildings, etc. The radiation resistance R_R is proportional to the effective height which, in the case of an all vertical aerial, is considerably less than the physical height. Taking for example, a 30 ft. high radiator, the effective height, when operated on 1·8 Mc/s, will be

$$\frac{2H}{\pi} = 5{\cdot}8 \text{ metres}$$

where H is in metres

$$\left(\frac{Hft}{3} \times {\cdot}9114\right)$$

The radiation resistance R_R is derived from

$$\frac{160\pi^2\ Heff^2}{\lambda^2} = 2{\cdot}05 \text{ ohms.}$$

The power actually radiated will be due to I^2R_R.

The curves in Fig. 6 show the effective height, radiation resistance and efficiency of verticals up to 132 ft. high. The curve of Fig. 7 is for inverted "L" aerials of 132 ft. total length and shows the radiation resistance for various ratios of height (l) to length of top section (L).

Mobile Aerials

The curve of Fig. 8 shows the effective height *v.* radiation resistance for aerials up to 20 ft. high. Increasing the height by $\sqrt{2}$ will double the radiation resistance and therefore the radiated power. With the mobile type of loaded aerial the position of the loading coil has some effect on the radiated power but because of the complex nature of these aerials it is not easy to allow for the exact impedance at the base. For an average short length resonant aerial the impedance lies between 10 and 15 ohms, so that careful design of the transmitter output circuit is essential if all the power is to be transferred to the aerial.

A centre loaded aerial will generally radiate more effectively than one with base loading and a theory which may or may not be accepted is that more radiation occurs from the length of aerial under the coil by virtue of the amplitude ($I = Imax \sin \theta$) of the current flowing in that portion, if the current distribution is as shown in Fig. 9. On the other hand,

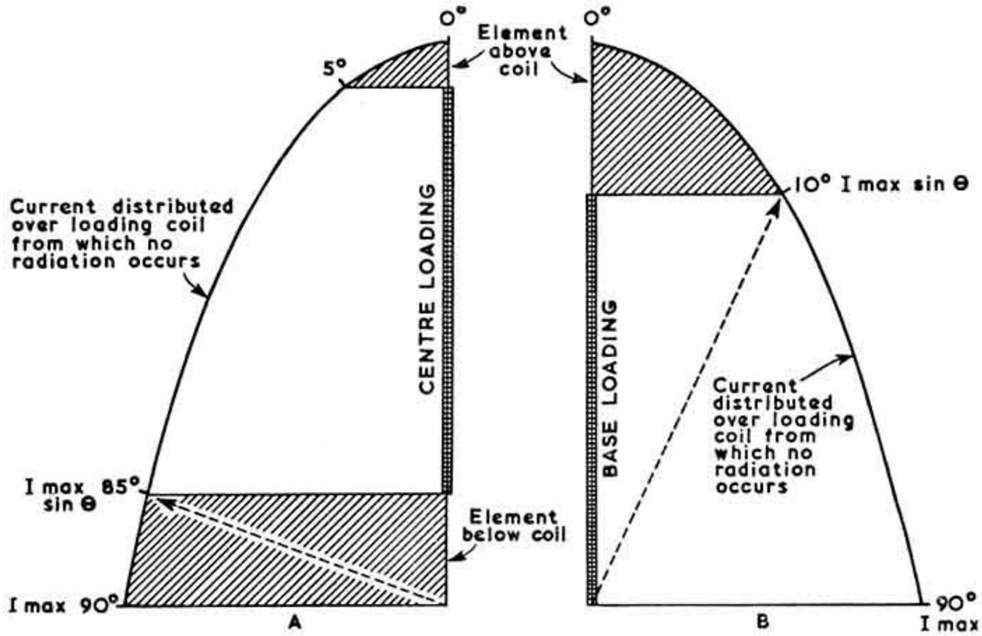

Fig. 9. Current distribution in (a) a centre loaded aerial; (b) a base loaded aerial.

as the current distribution over the actual radiating element is linear, there would be no gain in radiated power providing the radiation resistance and base impedance of a centre loaded aerial remained the same as for a base loaded version. The loading coil contributes very little to the *radiated* power.

Owing to the small height, the efficiency of a mobile aerial is extremely low. An example of this, based on a 13·5 ft. high aerial driven by a transmitter with a 10 watt input, is as follows:

Effective height—2·61m.
Radiation resistance—0·42 ohm.
Power to aerial—6 watts.
Power dissipated in losses—5·68 watts.
Ground and coil resistance loss—10·24 ohm.
Power radiated—235 milli-watts.
Efficiency of aerial—approximately 3·9 per cent.

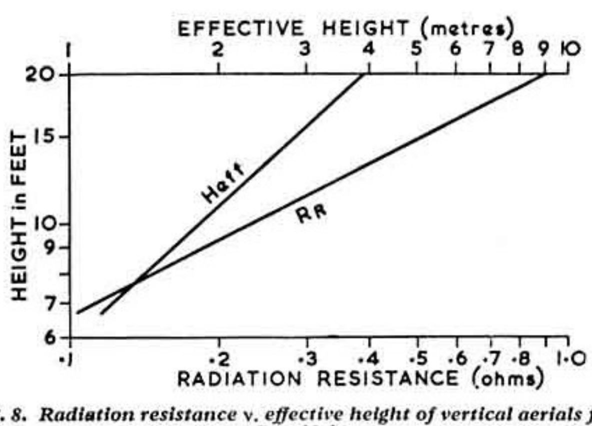

Fig. 8. Radiation resistance v. effective height of vertical aerials from 7 to 20 ft.

Practical use of Loaded Vertical Aerials

Flat dwellers in particular are often limited to an aerial draped around the walls or coiled up in a loft; such aerials are generally rather inefficient. Quite a number of operators in this predicament are resorting to the use of short vertical aerials of the loaded resonant type from which greatly increased efficiency may be gained by simply increasing the length of the aerial and modifying the value of loading inductance to bring the system to resonance. Attenuation due to surrounding buildings can be reduced by increasing the height of the whole aerial system above ground. It is possible then to think in terms of an aerial, say 25 ft. high, mounted on a roof where insulated guy wires may be used for support, or a height of 30 ft. or more where a very short garden may be the only available space. In considering such an aerial the curves of Fig. 6 are useful as they show the effective height, radiation resistance and percentage of efficiency for physical heights up to 132 ft.

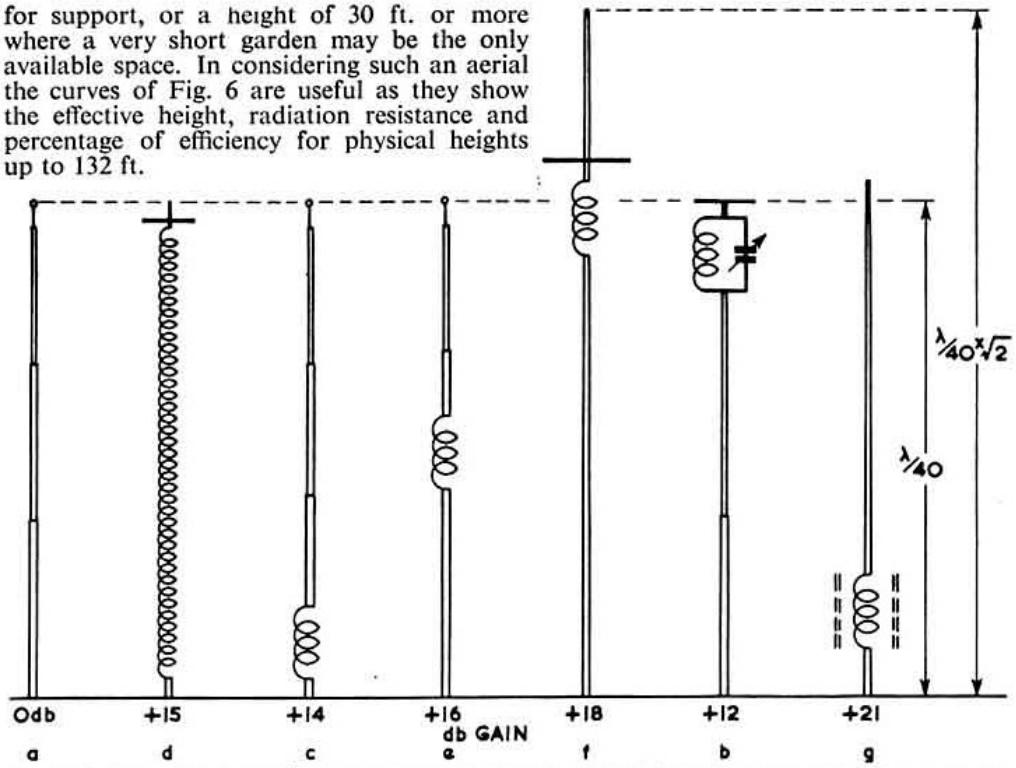

Fig. 10 (a). Unloaded vertical λ/40 (approximately 13 ft. for 1·8 Mc/s). Used as the 0 db reference. (b) Top loaded with a height of λ/40. Small inductance tuned with shunt capacitor and capacity hat (gain 12 db). (c) Base loaded aerial, same height as (b), using high Q coil at base (gain 14 db). (d) Height λ/40. Uses no open elements as the loading inductance is distributed over the length of the aerial. This type of whip is used by some mobile operators and constructed from fibreglass rods with the coil wound the whole length of the rod. A small variable capacity hat could be placed at the top to facilitate tuning (gain 15 db). (e) Centre loaded aerial (λ/40) with high Q coil (gain 16 db). (f) Aerial with height λ/40 increased by √2 and having the loading coil placed at approximately one third of the length from the top. Use of capacity hat reduces coil inductance (gain 18 db). (g) Height λ/40. Using a very high Q coil with a laminated core of special high grade ferrite. Capable of handling up to 400 watts without overloading the ferrite (gain 21 db).

The approximate capacity of the section of aerial above a loading coil can be obtained from

$$Ca = \frac{17L}{\left[\left(Log_{\epsilon}\frac{24L}{D}\right)-1\right]\left[1-\left(\frac{FL}{246}\right)^2\right]}$$

where Ca is the capacity in pF, F the frequency in Mc/s, L length of aerial in feet, D the diameter of the radiator in inches.

$$Log_{\epsilon}\frac{24L}{D} = 2{\cdot}3 \times Log_{10}\frac{24L}{D}$$

Tapping points should be provided every four or five turns at the lower end of the loading coil as other conductors and nearby walls are likely to effect calculated values. Placing the inductance high up the aerial and the use of a capacity hat above the coil will increase the efficiency. The use of combination loading coils for multi-band operation is possible and some details of this application may be found in the reference [5].

The inverted " L " aerial with an average height of 30 ft. has some advantage in sky-wave propagation since radiation from the horizontal portion will be at a high angle to the ground. The ground wave signal, however, will be less than that from a vertical of twice the height.

The following results of tests with six different types of aerials will be of particular interest to mobile operators. All show that radiation is maximum at an angle of about 10 deg. to the ground and probably due to a theory which proves that there is a certain critical angle of incidence for vertically polarized waves after which a change of phase of 180 deg. occurs in the reflected wave. This critical angle, sometimes known as " Brewster's Angle," varies with frequency and earth constants generally becoming greater as the frequency increases and as the conductivity of the earth decreases.

Other tests with respect to radiated power were made using full size aerials of approximately λ/40 at 1·9 Mc/s and scale models of λ/40 at 21 Mc/s. Fig. 10 shows the type of aerials tested where the gain of each aerial is compared with a non-resonant vertical of the same height.

References

[1] *Radio Engineering*, Terman, McGraw-Hill.

[2] *Long and Medium Wave Propagation*, H. E. Farrow, Iliffe & Sons.

[3] " Sommerfeld Formula," W. A. Fitch, *Electronics*, September, 1936.

[4] *The Admiralty Handbook of Wireless Telegraphy*, Section R.

[5] *A.R.R.L. Antenna Handbook*.

[6] *Electric Oscillations & Electric Waves*, G. Pierce, McGraw-Hill.

[7] *Reference Data for Radio Engineers*, S. T. and C.

[8] " Vertical Transmitting Aerials," F. C. Judd, *Short Wave Magazine*, June 1958.

GB2RS SCHEDULE

R.S.G.B. News Bulletins are transmitted on Sundays in accordance with the following schedule:

Frequency	Time	Location of Station
3600 kc/s	9.30 a.m.	South East England
	10 a.m.	Severn Area
	10.30 a.m.	North Midlands
	11 a.m.	North East England
	11.30 a.m.	South West Scotland
	12.00	North East Scotland
145·55 Mc/s	11.15 a.m.	Beaming south-east from Leeds
	11.30 a.m.	Beaming south-west from Leeds
	11.45 a.m.	Beaming north from Leeds
145·3—145·4 Mc/s	12 noon	Beaming north from South East England
	12.15 p.m.	Beaming west from South East England

News items for inclusion in the bulletins should reach Headquarters not later than first post on the Thursday preceding transmission. Reports from Affiliated Societies and from non-affiliated societies in process of formation will be welcome.

Quote of the Month

ON the air checks prove that double sideband with injected carrier is still the most popular mode of transmission.—*Amateur Radio.*