PRACTICAL WIRELESS

pocket guide

* AERIAL DATA

presented with the December 1965 issue

AERIAL DESIGN DATA

Although the treatment of the following data concerns aerials used for transmission (as a matter of convenience), the same principles apply where the aerials are used for reception.

Fundamentals

Resonance occurs when a given frequency r.f. wave travels from one end of an aerial to the other end, and then back again in the time period of one cycle.

The distance such a wave will travel in one cycle is equal to the velocity of light divided by the frequency of the wave in cycles per second, or

$$\lambda = \frac{300{,}000{,}000}{f}$$

Since, however, the r.f. charge travels along the wire twice (from one end to the other, then back again) the length of the aerial wire required to permit a travel of one full wavelength, the shortest resonant wire will be $\lambda/2$—or half-wavelength long.

The formulae expressed more conveniently may read:

$$l = \frac{492}{f}$$

where l = length of half-wavelength in feet.
f = frequency in Mc/s.

Since, however, the resonant length of an aerial depends to some extent on the length/diameter ratio of the conductor this must be taken into account, thus the amended formulae reads:

$$l = \frac{492\,K}{f}$$

where K = Factor derived from l/d ratio.

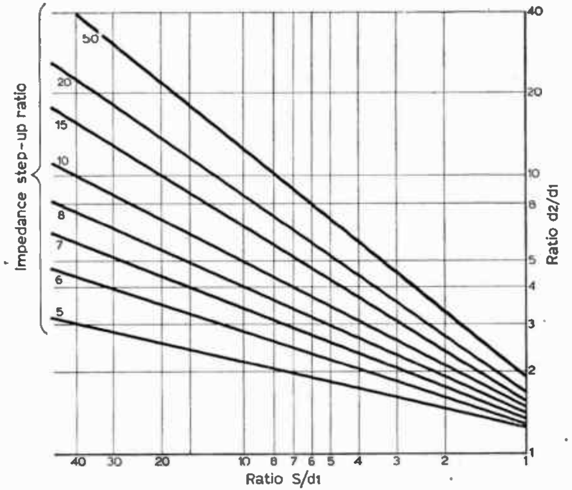


Fig. 11.

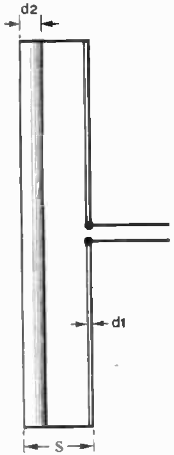


Fig. 12.

For normal aerials used for short wave transmission and reception (with wires of around 12–18 s.w.g.) the l/d ratio is generally between 1,000–10,000. This is fortunate because factor K is relatively flat in this region and thus a generalised factor can be assumed (usually 0·98). More exact multiplying factors can be taken from Fig. 1.

When the aerial is of wire, rather than solid rod or tubing of comparatively large diameter, it will resonate at a lower frequency than required if calculated from the preceding formulae. This is due to the loading effect created by the end-insulators supporting the wire, the small coupling capacitances tending to detune the aerial system. This is called *End Effect* and, although it varies with frequency, sufficient accuracy can be obtained by assuming a general factor up to about 30Mc/s.

Taking all these factors into account, the physical length of a resonant half-wave aerial may be said to be:

$$l = \frac{492 \times 0{\cdot}95}{f} = \frac{468}{f}$$

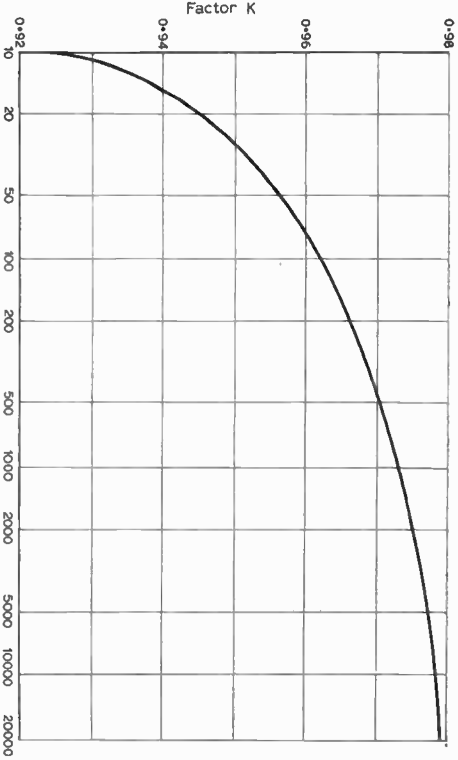
This assumes that the physical length varies by approximately 5% from the electrical length, and is the basis for most half-wave systems.

Harmonic wires:

As with the half-wave aerial, the physical length of a harmonic wire differs from its electrical length. The actual length is less than an equivalent number of half-wave lengths, and the generally adopted working formula is:

$$l = \frac{492\,(N - 0{\cdot}05)}{f}$$

with l = length in feet,
f = frequency in Mc/s.
N = the number of half-waves on the aerial.



Factor K
0·92
0·94
0·96
0·98
10
20
50
100
200
500
1000
2000
5000
10000
20000

Long single wires:

The formula given for harmonic wires is satisfactory for calculating the length of long single wire systems, but is more conveniently expressed as

$$l = \frac{984\ (N - 0{\cdot}025)}{f}$$ where N = the number of full waves on the aerial.

PRACTICAL AERIAL SYSTEMS

The accompanying diagrams show various half-wave aerial systems. The length l is, in each case, calculated from $l = \frac{468}{f}$, except in the case of the T matched half-wave aerial which is calculated from $l = \frac{475}{f}$.

Folded dipoles

Three examples of equal-çonductor folded dipoles are shown in Fig. 2. They vary only in regard to feed impedance; that is to say the standard two-wire folded dipole has a feed impedance equal to approximately four times that of an ordinary dipole, which provides a good match for 300-ohm feeders. The three-wire systems have an input impedance roughly that of nine times an ordinary dipole and thus a good match may be obtained with 600-ohm open-wire feeder line. The parallel system is favoured as it is easier from the insulation point of view.

It is common practice to construct folded dipoles of 300-ohm ribbon feeder throughout as a matter of convenience. However, under these conditions, a folded dipole cut to standard length does not give correct quarter-wave transmission line sections each side and thus the impedance/frequency characteristic suffers. This can be corrected by loading each end capacitively to change the electrical length as shown in Fig. 2. The value of the capacitance may be calculated from $C=6{\cdot}9\lambda$

where $C=\text{pF}$

$\lambda=$ operating wavelength (metres)

(e.g. for an aerial cut for the 20 metre band $C=6{\cdot}9\times 20=138\text{pF}$).

In practice the nearest standard value mica capacitors may be used.

General: Folded dipoles will not accept power at twice the resonant frequency, or at even harmonics. They may be operated at odd-order harmonics fairly satisfactorily.

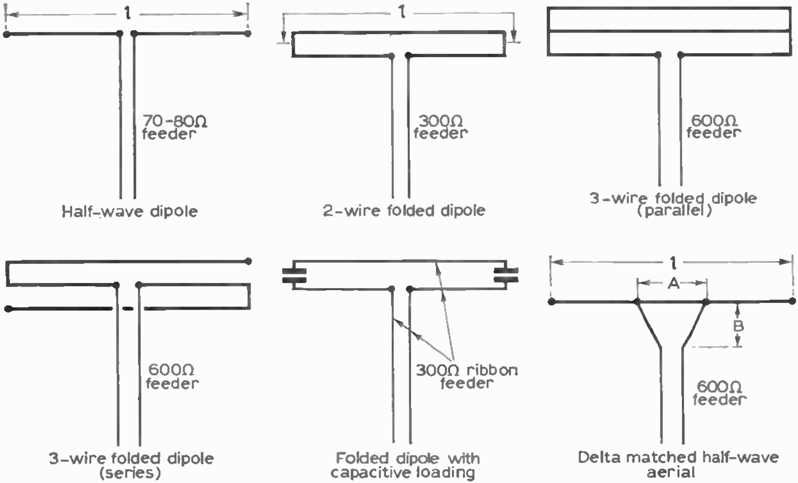
Half wave matched aerials

For the Delta matched aerial, the impedance tapping dimensions A and B should be found by experiment. As a general guide, suggested nominal dimensions may be calculated from:

$$A=\frac{118}{f} \qquad B=\frac{148}{f}$$

A, B in feet
f in Mc/s.

When used for frequencies at and above 30Mc/s read $A=\dfrac{113}{f}$



l
70-80Ω
feeder
Half-wave dipole
l
300Ω
feeder
2-wire folded dipole
600Ω
feeder
3-wire folded dipole
(parallel)
600Ω
feeder
3-wire folded dipole
(series)
300Ω ribbon
feeder
Folded dipole with
capacitive loading
l
A
B
600Ω
feeder
Delta matched half-wave
aerial

Fig. 2.

Multiband aerials

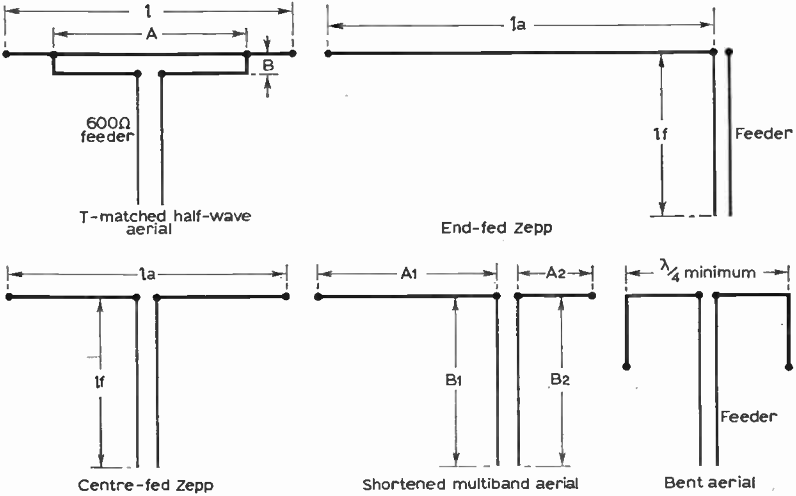
Most popular of the multi-band aerials is the Zepp (Zeppelin). With the end-fed version, the feeder may be any convenient length although it is advisable to avoid it being to multiples of quarter-wavelengths. The line is generally tuned. (See Fig. 3.)

The centre-fed Zepp, although structurally sometimes inconvenient, is to be preferred inasmuch as the feedline currents will be balanced at all frequencies. In either case, the length of the top should be cut for half-wave resonance at the lowest frequency band required. Thus, a Zepp cut for 3·5Mc/s will operate satisfactorily at 3·5, 7, 14Mc/s, etc. A good match may be obtained by using a 300-ohm feedline.

For restricted spaces, shortened multiband aerials can be quite effective. Here, the length A1+B1+A2+B2 should be a half-wavelength for the lowest frequency band (usually 3·5 or 1·7Mc/s). The feeders should be tuned. Advantage may also be taken of the fact that the high-current portion of a half-wave aerial (the central portion) provides the main radiation. Thus, a normal half-wave aerial may have the ends bent down, if space is restricted, without undue loss in efficiency. The horizontal portion of the wire should be not less than a quarter-wave in length.

Vertical aerials

Vertical aerials can be made to perform satisfactorily on one band but are generally unsuitable for multi-band operation owing to the increase in high angle radiation at the higher frequencies. There is also the possibility of more TVI/BCI trouble. However, for mobile and portable work vertical quarter-wave aerials are frequently used.



l
A
B
600Ω feeder
T-matched half-wave aerial
la
lf
Feeder
End-fed Zepp
la
lf
Centre-fed Zepp
A1
A2
B1
B2
Shortened multiband aerial
λ/4 minimum
Feeder
Bent aerial

Fig. 3.

Fig. 4 shows two versions. Note that such aerials must be earthed at one end and that the radiating portion is cut to the *electrical* and not the physical quarter-wave length, i.e. $l = \frac{296}{f}$.

In earthed quarter-wave aerials, the current loop impedance (at which position it is fed) is approximately 35 ohms. In practice 50 ohm feeder can be used quite satisfactorily.

The tuned aerial shown has the advantage that the feeder may be of any convenient impedance. The tuned circuit L/C should resonate at the operating frequency.

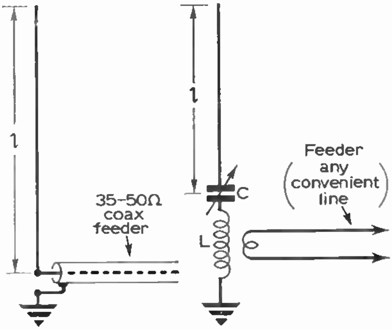


Fig. 4. Earthed $\frac{\lambda}{4}$ verticals.

Long Wire Aerials

End-fed long wire aerials are very popular, particularly with short wave listening enthusiasts. For all-round s.w. listening, the random-length long wire is very effective, while for transmitting the end-fed aerial, if cut to resonance, has interesting directional properties.

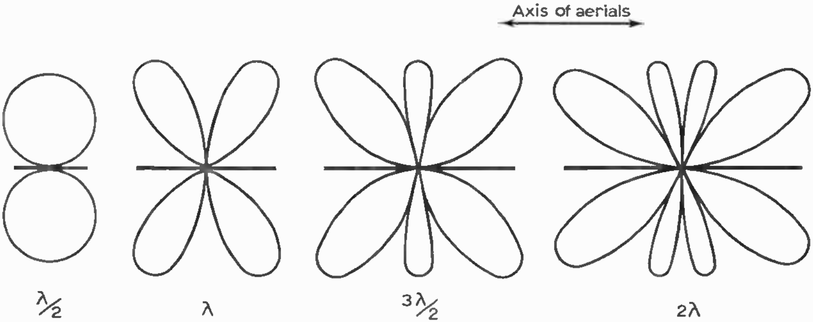


Fig. 5.

Polar diagrams for long wire aerials are shown in Fig. 5 and it will be seen that as the number of resonant wavelengths increases so does the all-round coverage. One difficulty, however, is the rather long (and often impractical) wire lengths on the lower frequency bands. Note, however, that in estimating the length of a long wire aerial that this includes not only the "top" (horizontal) section but also the down lead up to the connection to the receiver or transmitter.

For instance, a full-wave long wire for 7Mc/s would be approx. 126ft long; this would give 2λ at 14Mc/s, 3λ at 21Mc/s and 4λ at 28Mc/s. A full-wave long wire for Top Band (1·8Mc/s) would need to be more than 500ft long!

Listeners interested in general short wave coverage, rather than peak performance on the amateur bands, will find that best all round results will be obtained by using a wire as long and as high as can reasonably be erected. Matters can be improved by coupling the aerial to the receiver by means of an aerial tuning unit.

Multi-element aerials

The element dimensions for a three-element parasitic array may be obtained from:

Driven element (Dipole): $l = \frac{475}{f}$

Director: $l = \frac{455}{f}$

Reflector: $l = \frac{500}{f}$

Element spacing may be between 0·1 and 0·25 wavelengths and the length/diameter ratio should be between 250–450.

The polar diagram of a simple vertical half-wave dipole is shown in Fig. 6 and it will be seen that the system is omni-directional, being equally sensitive in all directions about the plane of the conductor rod. If a second element, a reflector, is placed behind the dipole, the currents induced due to the signal are 90° out of phase and the reflector re-radiates this signal in phase with the dipole. The result is an increase in gain.

A further element, a director, may be placed in front of the dipole element to further increase the gain and reducing the beam width of the system. Neither reflector nor director is connected electrically to the dipole itself.

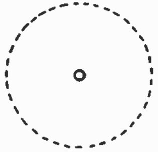


Fig. 6.

Such an aerial, consisting of a dipole, reflector and one or more directors is known as a Yagi array.

In such arrays (i.e., those which have elements not directly connected to the feed line) the dipole element is cut for resonance using the formula previously given, the factor being the frequency required and the wavelength/diameter ratio. The reflector is spaced between $\lambda/4$ to $\lambda/8$ behind the dipole, the spacing having little effect on the gain achieved, but having some effect on the feed impedance of the system. There is very little to be gained by adding more reflectors and only one is generally used.

As directors are added in front of the dipole the gain increases and the beam width narrows. The addition of directors, however, has the effect of reducing the bandwidth of the system, although this can be offset to some extent by making them progressively shorter in length.

Polarisation

One important factor which must be taken into account when designing aerials is the polarisation of the waves from the transmitter. This governs whether the receiving aerial needs to be placed with the plane of the elements vertical or horizontal.

Aerials are often said to be "directional". This means that, when mounted, they have to be moved or rotated until the signal received is as strong as possible. Generally, they are then pointing towards the station but, sometimes, a signal is reflected from an obstacle and this reflected signal is stronger than the direct signal and then the aerial is pointed to receive the reflected signal. It should be noted that a simple, vertical dipole is not directional and receives signals equally well from any direction. However, a horizontal dipole is directional and must be arranged for best reception, generally broadside on to the direction of the station. It must be stressed that arrays do not necessarily have to be pointed direct at the station; much depends on local conditions and the only method is to move the aerial to point in different directions until best results are obtained.

Illustrated opposite are various television aerials with their dimensions indicated by letters. Table I gives the dimensions required for reception of the various BBC and ITV stations. It will be noted that no details are given of BBC aerials with more elements than three, as such aerials would be very large and impossible to mount or accommodate.

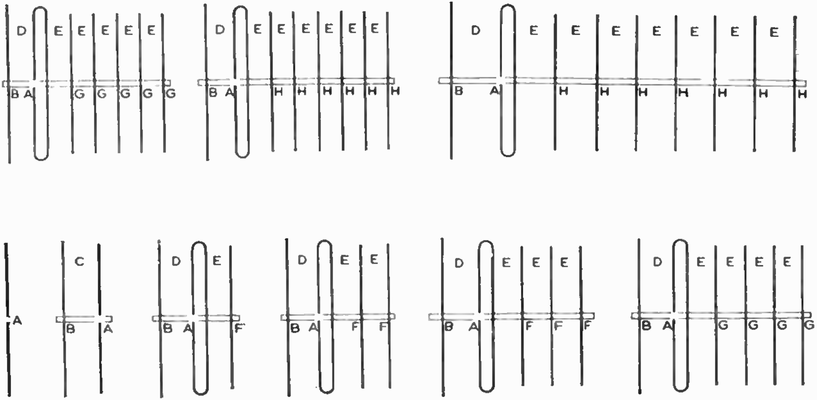

D E E E E E
B A G G G G G
D E E E E E E
B A H H H H H H
D E E E E E E E
B A H H H H H H H
A
C
B A
D E
B A F
D E E
B A F F
D E E E
B A F F F
D E E E E
B A G G G G

Fig. 7.

TABLE I—DIMENSIONS FOR AERIALS SHOWN IN FIG. 7

Channel	A		B		C		D		E		F		G		H	
	ft	in.	ft	in.	ft	in.	ft	in.	ft	in.	ft	in.	ft	in.	ft	in.
1	10	7	10	11	5	7	2	9½	2	3	9	9	*		*	
2	9	2	9	8	4	10	2	5	2	0	8	5	*		*	
3	8	4	8	9	4	5	2	2½	1	10	7	8	*		*	
4	7	8	8	1	4	0	2	0	1	8	7	1	*		*	
5	7	1	7	5	3	9½	1	10½	1	6	6	6	*		*	
8	2	5½	2	7	1	3½	0	7¾	1	1	2	3½	2	3	2	2
9	2	5	2	6½	1	3	0	7½	1	0½	2	2½	2	2	2	1½
10	2	4	2	5½	1	3	0	7½	0	11½	2	2	2	1½	2	1
11	2	3½	2	5	1	2½	0	7¼	0	11	2	1	2	0½	2	0
12	2	3	2	4½	1	2	0	7¼	0	11	2	0½	2	0	1	11½
13	2	2½	2	4	1	1½	0	7	0	10½	2	0	1	11½	1	11
33	0	9⅞	0	10⅜	0	5¼	0	2⅝	0	3⅜	0	9⅛	0	9⅛	0	9⅛

TABLE II

DIMENSIONS OF YAGI ARRAYS FOR THE V.H.F. AMATEUR BANDS

Elements	Length (ins.) 70·3	145	435Mc/s
Reflector	83½	40	13½
Dipole	79½	38½	12⅞
Director (1st)	74	36	12
Director (2nd)	73¼	35½	11⅞
Director (3rd)	72½	35	11¾
Director (4th)	71¾	34½	11½
	Spacing (ins.)		
Reflector/dipole	21	10¼	3⅜
Dipole/1st director	21	10¼	3⅜
1st director/2nd director	42	20½	6¾
2nd director/3rd director	42	20½	6¾
3rd director/4th director	42	20½	6¾
Element diameter	½–¾	¼–⅜	⅛–3/16

Insulation

The various elements do not need to be insulated from the supporting cross bar, provided they are mounted or bolted at their mid-points.

From the information given, it should be possible to construct an aerial suitable for most locations and the procedure is to choose the design from Fig. 7 and then to determine the dimensions from Table I. The dimensions have been calculated to give good results; it is very unlikely that they will be the same as those employed by commercial aerial manufacturers or those mentioned in other publications. This fact should be borne in mind if any comparisons of element lengths and spacings are made.

Table II, on page 17, gives dimensions of Yagi arrays for the 70, 144 and 420Mc/s amateur bands.

Attenuators

Any attenuator placed between aerial and input must introduce the minimum amount of mis-match. The most usual feeder is the coaxial, of 80Ω nominal impedance, and this is an "unbalanced" structure. The choice is between "T" type and "π" type attenuators, as shown in Figs. 8a and 8b.

Tables III and IV give design data for values from 1dB to 10dB of voltage attenuation, but these are for 80Ω nominal impedance only. For other values of feeder characteristic impedance, Zc, the resistor values must be multiplied by Zc/80.

It is unwise to attempt to obtain more than about 10dB attenuation in one attenuator. Instead, where attenuation in excess of 10dB is required, several sections can be cascaded.

In constructing an attenuator, the output should be separated as far as possible from the input and if the attenuator is to be a permanent fixture it is also best to avoid the use of coaxial sockets and plugs.

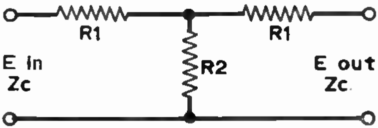


Fig. 8a. T-section attenuator.

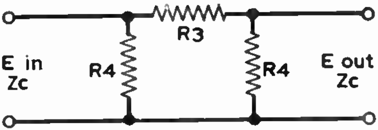


Fig. 8b. π-section attenuator.

TABLE III—T-SECTION
(Resistors as in Fig. 8 (a).)
Decibels Attenuation

	1	2	3	4	5	6	7	8	9	10
R1(Ω)	4·6	9·2	13·7	18	22·4	26·6	30·5	34·5	38	41·5
R2(Ω)	690	345	226	168	131	107	90	75	65	56·2

TABLE IV—π-SECTION
(Resistors as in Fig. 8 (b).)
Decibels Attenuation

	1	2	3	4	5	6	7	8	9	10
R3(Ω)	9·3	18·5	28·2	38	48·7	60	71·5	85	98·5	114
R4(Ω)	1390	700	467	365	285	242	210	185	169	154

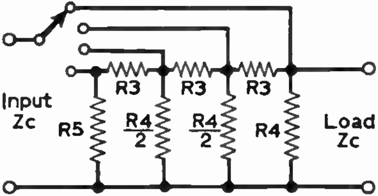


Fig. 9a. π-section ladder attenuator.

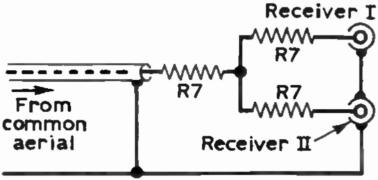


Fig. 9b. Aerial splitter for two receivers.

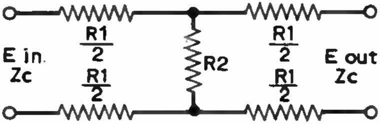


Fig. 10a. T-section attenuator for balanced feeders.

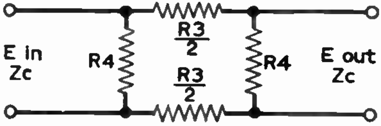


Fig. 10b. π-section attenuator for balanced feeders.

Multiple Section Attenuators

Sometimes it is desired to arrange a variable attenuator, operated by a switch. The "ladder" attenuator results from cascading a number of T or π sections, as shown in Fig. 9a.

The resistance values correspond to those in Table IV, R5 being given by $\frac{R4 \, . \, Zc}{R4+Zc}$

An Attenuator for two or more Receivers

Another use of a resistor network exists where several receivers have to be connected to the same aerial (Fig. 9b). If two receiver inputs are paralleled, the impedance presented to the feeder cable is half that of either. If three receivers, the effective load on a feeder of characteristic impedance Zc is Zc/3. The calculation of R7 is as follows. Assuming all characteristics and input impedances are Zc, the impedance at either receiver input, with the aerial feeder disconnected is R7+R7+Zc.

The aerial feeder will see an impedance, for "n" receivers, of R7+(R7+Zc)/n and for correct matching this is equal to Zc.

$$\text{Thus } n.R7+R7+Zc=n.Zc \therefore R7=\frac{Zc\ (n-1)}{n+1}$$

Thus, for two receivers with Zc equal to 80Ω the resistors R7 must be 27Ω.

TRANSMISSION LINE DATA

Standing Wave Ratio

(Measure of mismatch)

$$SWR=\frac{Zr}{Zo} \text{ or } \frac{Zo}{Zr}$$

where Zr = Load impedance (pure resistance)
Zo = Line impedance.

Example: A feeder line of 80 ohms is terminated in a resistive load of 20 ohms.

$$\text{The SWR}=\frac{80}{20}=4:1$$

Characteristic Impedance

Parallel conductor line with air dielectric:

$$Z_o = 276 \log \frac{b}{a} \qquad C = \frac{3{\cdot}679}{\log \frac{b}{a}} \qquad L = 0{\cdot}281 \log \frac{b}{a}$$

Where:

Zo = Characteristic impedance,
C = Capacitance of feeder (in pF per foot)
L = Inductance of feeder (in mH per foot)
b = centre-to-centre spacing of conductors
a = radius of conductor

Coaxial cable with air dielectric:
(Concentric line)

$$Z_o = 138 \log \frac{b}{a}$$

Coaxial cable with solid dielectric:

$$Z_o = 138 \log \frac{b}{a}\left(\frac{1}{\sqrt{K}}\right)$$

where K = dielectric constant of insulating material
a = outside diameter of inner conductor
b = inside diameter of outer conductor.

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$$\lambda=\frac{300{,}000{,}000}{f}$$

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The formulae expressed more conveniently may read:

$$l=\frac{492}{f}$$

where l=length of half-wavelength in feet.
f=frequency in Mc/s.

Since, however, the resonant length of an aerial depends to some extent on the length/diameter ratio of the conductor this must be taken into account, thus the amended formulae reads:

$$l=\frac{492\,K}{f}$$

where K=Factor derived from l/d ratio.

Matching

Impedance transformation:

$$Zs=\frac{Zo^2}{Zr} \qquad Zo=\sqrt{Zs\ Zr}$$

Where: Zs = Impedance looking into feeder line,
Zr = Load impedance,
Zo = Characteristic impedance of line.

Quarter-wave transformer:

A quarter-wave section may be used as an impedance transformer and may be calculated from:

$$Zm=\sqrt{Za\ Zo}$$

where Zm = Impedance of matching section,
Za = Aerial impedance,
Zo = Impedance of line to which the aerial is to be matched.

Folded dipole matching:

The folded dipole may be modified to obtain impedance step-up. This is useful where the folded dipole is the driven element in a multi-element beam array, under which conditions the radiation impedance becomes greatly "compressed". The impedance transformation is obtained by selection of suitable conductor diameter ratios and conductor spacing. The behaviour of unequal-conductor folded dipoles as regards impedance step-up is somewhat complex, but the graph (Fig. 11) will provide ratios required for most normal purposes—based, as it is, on empirical data. Fig. 12 shows the construction of a typical folded dipole.

WATMOUGHS LIMITED, ENGLAND