COMMONWEALTH OF AUSTRALIA

AUSTRALIAN BROADCASTING CONTROL BOARD

TECHNICAL SERVICES DIVISION

REPORT No.

TITLE: EXAMINATION OF FRINGE TYPE ANTIFADING AERIALS FOR MEDIUM FREQUENCY BROADCASTING.

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Technical Report No. 1.

Examination of "Ring" Type Antifading Aerials for Medium Frequency Broadcasting.

Work carried out in December, 1949.

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Summary.

Vertical radiation characteristics and radiation resistance values have been calculated for two types of aerial employing a ring of vertical radiating elements, and a practical application of one of the types suggested.

Introduction.

1. From time to time proposals have been made for methods of concentration of the radiation from a broadcast transmitting aerial in directions close to the horizontal, alternative to the familiar vertical radiator of height exceeding a half wavelength on the lower "loaded" vertical type, having similar radiation characteristics.

Several suggestions have been made for using a number of short vertical aerials located in one or more rings, and suitably excited and phased to reduce high angle radiation. A brief survey of the possibilities of two practicable types is given below, and sufficient details for the formulation of a practical design of one of these types have been prepared.

Summary of ring aerial types.

2. The general theory of an aerial comprising a number of concentric horizontal rings of vertical radiators has been considered by Hansen and Woodyard(1). The theory is based on a continuous distribution of such elements inside a circle of specified radius, and having a specified distribution of current

magnitude and phase. Two particular examples have been worked out. The first type is that of a central radiator, and a number of concentric rings, each with a finite number of radiator elements, all the elements being excited in phase. The number of individual elements is made sufficiently large to approximate a continuous distribution. A specific case of this type is a central radiator with a single concentric ring of radiators, all the raidators being excited in phase. The second type is that of a single ring (without a central radiator), the phase of the current in each radiator advancing uniformly, as we move round the ring. The number of radiators is made great enough to approximate a continuous distribution round the ring.

3. Page (2) has considered in more detail, and in a more practical form, the two types of radiator outlined above -

(a) The single ring with concentric central radiator with uniform phase (J_o Type)

(b) The single ring without a central radiator, with progressive phase round the ring (J_n Type)

He has worked out a number of specific examples, and has given general expressions for vertical radiation characteristic and radiator resistance.

4. The relevant expressions given by Page are

<u>J_n Type.</u>

Vertical radiation characteristic.

$$E = \frac{J_n (q \sin \theta)}{J_n (q)} \sin \theta \qquad \text{——— (1)}$$

Radiation resistance

$$\frac{R_r}{R_o} = 1.5 \left[- \frac{2n-1}{8q^2} J_{2n} (2q) + \frac{1}{4q} (2q) + \left(\frac{1}{2q} + \frac{4n^2-1}{8q^3} \right) \sum_{r=0}^{r=\infty} J_{2n+2r+1} (2q) \right] - (2)$$

J_0 Type

Vertical radiation characteristic.

$$E = \frac{k + J_0(q \sin \theta)}{k + J_0(q)} \sin \theta \qquad - (3)$$

$$\frac{R_0^1}{R_0} = 1 + 1.5 \frac{I_2}{k} \qquad - (4)$$

$$\frac{R_r^1}{R_0} = 1.5 (I_1 + kI_2) R_0 \qquad - (5)$$

$$I_1 = \frac{1}{8q} J_0 (2q) + \frac{1}{4q} J_1 (2q)$$

$$+ \left(\frac{1}{2q} - \frac{1}{8q^3}\right) \sum_{r=0}^{r=\infty} J_{2r+1} (2q) \qquad - (6)$$

$$I_2 = \frac{\sin q}{q} - \frac{\sin q}{q^3} + \frac{\cos q}{q^2}$$

For both cases.

q is the ring radius in electrical radians (equal to $\frac{2\pi r}{\lambda}$ where r is the radius, λ is the wavelength)

θ is the angle of radiation from the vertical.

E is the relative field strength at the angle θ

J_n is a Bessel function of the n^{th} order

R_0 is the radiation resistance of a vertical radiator element when isolated.

R_r is the radiation resistance of the complete ring in the J_n type.

N is the phase difference between two aerials in the ring spaced 1 radian in space - phase change round the ring = $2\pi n$ radians.

k is the ratio of the central radiator current to the total ring aerial current in the J_0 type.

R_c is the actual radiation resistance of the central radiator in the J_o type.

R_r' is the radiation resistance of the whole ring in the J_o type.

The above expressions apply for the cases of an infinite number of elements in each ring. The number of elements necessary to approximate the continuous rings are

J_n case $2n + 3$

J_o case $q + 1$ to $q + 2$

<u>J_n Type</u>

5. Both Page and Hansen and Woodyard have published vertical radiation characteristics of a number of applications of the J_n type. From the point of view of extending the radius of the fading free service area the important values of the angle θ are between 0^o and 45^o corresponding to distances of the return of the indirect ray up to 135 miles, for a reflecting layer height of 68 miles. For a high value of n (up to 10) and a low value of q the vertical radiation characteristic of a J_n type is much superior in the range 0^o - 60^o (up to 230 miles) than any height of vertical aerial. The case of n equal to 10 and q equal to 3 is shown in figure 1 in comparison with vertical aerials of heights 0.56 wavelength and 0.64 wavelength. Unfortunately such an aerial would have an impossibly low radiation resistance. The radiation resistance would be increased by increasing the radius q. The case considered of q=3 however corresponds to a radius of 590 feet at 670 kc. and as a considerably larger radius would be necessary to appreciably increase the radiation resistance, there is little practical possibility in this direction. A further practical although not insuperable disadvantage of this J_n type is the large number of radiator elements required, namely 23 for n=10. A value of n of as low as 4 still gives a radiation resistance for a reasonable radius which would be impracticably low, while giving a vertical radiation characteristic inferior to that from a suitable J_o type. For example the vertical radiation characteristic for the case of n=2 q=2.5 has been plotted in Figure 1. This would involve a value of radiation resistance R_o' given by R_o'/R_o = 0.16. This would be inferior in earth losses to the case of a J_o aerial, whose vertical radiation characteristic is shown in Figure 1, and it will also be seen that the J_n case is inferior in vertical radiation characteristic. It would involve a total of 8 radiator elements.

<u>J_o Type.</u>

6. A brief examination of one or two cases of the J_o type indicated that the best vertical radiation characteristic is obtained with a low value of q and a value of k approaching -1.

Such an array would have a very low value of radiation resistance. Further the value of the numerator in (3) $k \div J_0 (q \sin \theta)$ as well as the denominator $k \div J_0 (q)$ is the small arithmetical difference between two large quantities one of which is k the ratio of the currents in the central radiator and the ring. Consequently this ratio would need to be kept to its desired value within very close limits.

7. A further brief arithmetical analysis of the expression (3) was therefore undertaken, to determine the effect of increasing q. Six arbituary values of q between 0.3 and 2.5 were selected. In each case a value of k was selected about midway between $J_0(q \sin \theta)$ for 20° and θ=45°. Thus values of E are obtained at θ=20° and θ =45° of the same order, and opposite sign, giving approximately the minimum overall value of E between θ=0° and θ=45°. Table 1 below shows the situation.

TABLE 1.

Characteristics of J_0 Type aerial for various calues of q and k.

Radius q radians	Current ratio k	$k \div J_0(q)$	10°	20°	30°	40°	45°	50°	60°	70°	80°	Rad^n resistance R^1_0/R_0	$R_{\frac{1}{2}}/R$
.3	-.993	-.016			.10	.05	.10	.20	.55				
.4	-.987	-.027			.10	.05	.10	.19	.55				
.0	-.92	-.155			.11	.06	.09	.19	.55				
.5	-.83	-.317			.11	.05	.07	.21	.56			0.270	-0.12
.0	-.72	-.496	.09	.11	.05	.12	.23	.35	.56	.81	.96	0.507	-0.10
.5	-.59	-.638	.10	.15	.04	.14	.25	.38	.62	.83	.96	1.33	+0.16

It will be seen that up to q=2.5 the overall value of E between θ = 0° and θ = 45° increases only by a small amount. The value of $k \div J_0 (q)$ is reasonably large above q=1.5 and the radiation resistance becomes satisfactory only at q=2.5. The case of a self excited ring that of $R_{\frac{1}{2}}/R_0$ = o could easily be arranged at a value of q between 2.0 and 2.5. It is felt however, that an array could be more confidently adjusted if the ring radiators are fed, and have a small positive resistance. Alteration of the values of k from those selected would be such that a decrease in the arithmetical value of k would increase the magnitude of the high angle lobe, and increase the value of θ at which the null occurs.

Practical Considerations.

8. The case of q=2.5 and k=0.59, is considered to be as good a compromise as can be attained, having regard to the necessity of keeping the radius of the array within reasonable proportions. The radius for 670 kc would be 590 feet, not including the earth system.

The array would involve the use of one central mast and five masts in the ring. Some reduction in earth losses would undoubtedly be effected by the use of top loading in the form of horizontal tee sections suspended between the 5 masts. It is considered that these in addition to their mechanical untidiness, might cause stray high angle radiation. The following brief analysis indicates that by the use of ⅛ wave towers (180 feet at 670 kc) and a good earth system, the losses are not excessive.

It may be assumed that a self supporting tower ⅛ wavelength in height has a self impedance

$$Z = 5 - j\,150 \text{ ohms}$$

using the figures of Table 1

$$R_2^1 = 5.7 \text{ ohms}$$

$$R_3^1 = 0.82 \text{ ohms}$$

Using for each radiator an earth system of 113 radials 0.274 wavelength long G.H. Brown indicates a reduction in signal strength of 10% below the theoretical. This gives a total resistance for such an isolated ⅛ wavelength aerial of

$$1.1^2 \times 5 = 6 \text{ ohms}$$

which may be empirically inferred to include an earth resistance of 1 ohm. In addition the aerial loading coil will have a reactance of 150 ohms (neglecting mutual reactance between radiators) and assuming a Q of 300 will have a resistance of 0.5 ohm. The total loss resistance is thus approximately 1.50 ohm per ring radiator or 0.3 ohm total.

For a current I in the central radiator.

$$\text{Aerial output} = 5\,(1.55\,I^2 + 0.164 \times .59^2\,I^2)$$
$$= 7\,I^2 \text{ watts.}$$

$$\text{Loss in earth system} = (1.5\,I^2 + 0.3 \times .59^2\,I^2)$$
$$= 1.6\,I^2$$

$$\text{Loss} = \frac{1.6}{8.6} = 19\% \text{ in power}$$
$$9\% \text{ in field strength.}$$

It is considered that this is indicative of the loss which would occ in practice and is not unreasonable.

Method of Feed and Adjustment.

9. For a 10 kw transmitter the power fed into the central radiator would be approximately 9.5 kw, and into each radiator in th ring 100 watts. The ring radiators could each be fed by means of underground coaxial lines terminating in small L type matching networks. The feeders to ring aerial could be commoned at the central aerial tuning hut, and fed in parallel with the central aerial coupling network through a coupling network of sufficient impedance to draw the correct power from the main line. A suitable phasing network would be incorporated in the input to each ring aeri feeder. There would be other equally suitable methods of feed. It would be necessary to install some device to measure phase differenc between the various elements, and this could take the form of a phas meter (3) as described by G.H. Brown, and employing a cathode ray oscillograph and phase shifter. This could be located when necessar at the central element, and coaxial lines permanently laid between the outer elements and the central one.

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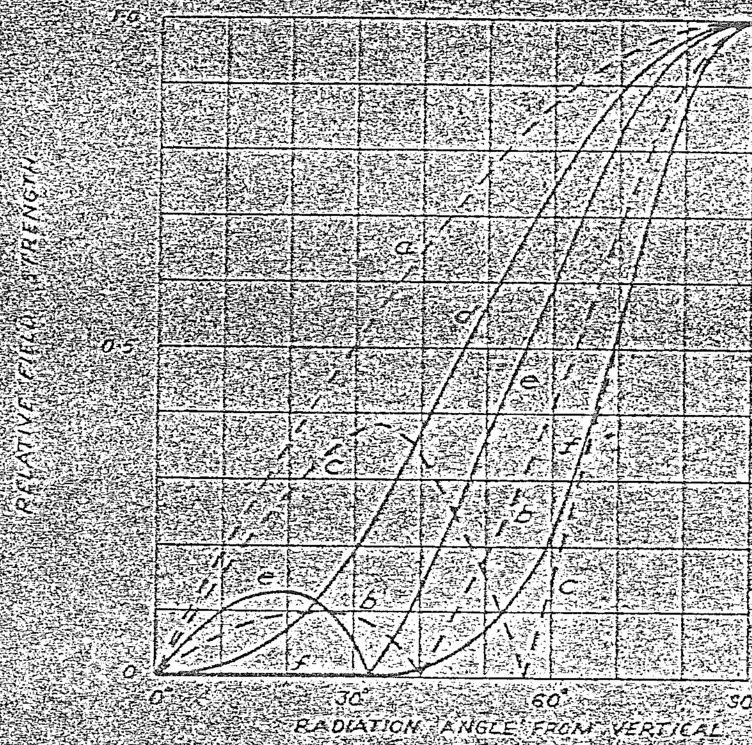

REFERENCE :-

a VERTICAL – VERY SHORT.

b VERTICAL – ·56 WAVELENGTH.

c VERTICAL – ·64 WAVELENGTH.

d Jn TYPE q = 2·5 n = 2

e Jo TYPE q = 2·5 k = –0·59

f Jn TYPE q = 3 n = 10

NOTE :- TYPE f HAS AN IMPRACTICABLY LOW RADIATION RESISTANCE

FIG. 1

ISSUES					
DRAWN	ORDER	NO.	DATE	APPD.	AMENDMENTS
S.W.R.	3F/50	1	19-1-50	A.J.M.	

COMMONWEALTH OF AUSTRALIA
AUSTRALIAN BROADCASTING CONTROL BOARD

VERTICAL RADIATION CHARACTERISTIC
COMPARISON OF RING AND VERTICAL AERIALS

DRAWN S.W.R. 5-1-50
EXAMINED A.J.M.
APPROVED A.J.M.
DATE 19-1-50

DRAWING NO. RC-3-A

FORM C.D. 150

A