

AN IMPROVED METHOD OF MEASURING AERIAL GAIN.

The gain of an aerial is normally expressed in dB as the ratio of maximum radiation intensity from the aerial to the maximum radiation intensity from a half wave dipole. The measurement is usually made by substituting a half wave dipole for the aerial under test and noting the difference in intensity of signal. An alternative method of measurement has been proposed using integration of the horizontal and vertical radiation patterns of the aerial.

This method may, however, be highly inaccurate due to the impossibility of presenting sufficient information. The radiation pattern from an aerial is essentially a three dimensional shape. For instance, lobes at 45° from both E. & H. planes cannot normally be measured and would, therefore, be ignored in the calculations. Also perhaps the most serious source of error is that losses in the aerial itself are ignored, and experience has shown that these may be considerable especially at UHF.

Pursuing, therefore, the established method of dipole substitution it is first of all necessary to consider the possible errors which may occur.

IMPEDANCE MATCHING. The normal test set up is shown diagrammatically in Fig. 1., and it will be seen that two feeders are used, one between the Signal generator and radiating aerial, and the other between the test aerial and the receiver. Both of these feeders must be accurately matched to the instruments used. The calibration and reading of the signal generator output meter is only accurate when the load on the generator is as stated by the manufacturers. This source of error can be very serious indeed if aerial test are being carried out involving changes in frequency of operation. The out put meter may

effectively be reading the voltage at a point on the transmission line to the aerial although the point of connection may be inside the instrument. Variations in frequency mean, therefore, that the effective position of measurement on the line will vary and the presence of any standing waves will result in variations in meter reading. The load on the signal generator feeder is the radiating aerial, and although it is essential that this aerial should be reasonably matched to the line, it is not always possible to provide an accurate match, therefore it is necessary to incorporate an attenuator of the correct impedance at the connection to the signal generator to provide a correct load. Standing waves and consequent errors of the receiver signal strength meter reading will occur if the input impedance of the receiver is not accurately matched to the feeder from the test aerial at all frequencies used. It is almost impossible to satisfy this condition, and it is therefore essential that another attenuator is incorporated at the receiver input to eliminate this source of error. An alternative method of dealing with this problem is to incorporate directly at the test aerial terminals a matched rectifier which converts the receiver signal to DC or audio which may then be conveniently fed to a remote meter. In either system, however, it is essential that the test aerial operates into its designed impedance.

DRIFT OF TEST EQUIPMENT. The requirement for the output of a signal generator or the sensitivity of a receiver, to stay constant throughout a day is not normally met by instrument manufacturers. The accuracy of reading of the signal generator output meter may well vary as a function of temperature, thus although throughout a series of tests the reading is held constant, the actual RF output may vary considerably. This fault has been found in both British and foreign types of test equipment, and adequate precautions to control these effects are essential. Two methods of control are available. Firstly a third aerial may be set up to provide a reference signal to which the receiver may be frequently

switched, although it is sometimes impossible to avoid this reference aerial having some effect upon the aeriels under test. A second preferable method of calibration is by means of a link via an attenuator between signal generator, and receiver. Mains voltage variations, unless catered for in the instruments used, must be eliminated by the use of constant voltage transformers etc.

MODIFICATION OF THE AERIAL CHARACTERISTICS BY THE PRESENCE OF THE FEED SYSTEM AND MOUNTING ARRANGEMENTS. The performance of an aerial may be drastically modified by the presence of feeders and mounting structures in the plane of the elements. Testing of an aerial must, therefore, be carried out on its designed mounting structure and with the feeder in its designed position. The only alternative to this, when perhaps basic research is being undertaken, is to ensure that mounting structures and feeders are at right angles to the plane of the elements for at least half a wavelength.

TEST SITE ERRORS. The sources of error previously listed may be overcome by attention to detail and the problems are essentially soluble. The perfect test site however is very often a dream and it is the purpose of the proposed new method of testing to overcome the inaccuracy caused by the imperfect test site, which is the main source of error in the measurement of aerial gain. Fig.1., illustrates a typical test set up with the shape of the radiation pattern of the test aerial superimposed thereon. It will be seen that in addition to the direct signal path between the two aeriels A-C there is a reflected signal path A-B-C. The phase relationship of these signals will be a function of path length or frequency and the reflected signal may augment, or diminish the signal received. The shape of the radiation pattern of the aerial under test in this case however, will result in a considerable reduction of reflected signal, and this will thus have little effect. When however, in an attempt to measure gain, a dipole is substituted for the test aerial there will be

little or no attenuation of the reflected signal, and an entirely erroneous reading of the dipole performance will be obtained. The problem therefore, is not so much that of measuring the performance of the test aerial but of measuring the performance of a dipole with which to provide comparison.

It is a requirement of the improved method that two identical aerials of the types whose gain it is required to measure are available. These aerials are mounted facing each other in the normal way on the test site at a minimum distance apart given by $R = \frac{4W^2}{\lambda}$ where R is the spacing and W is the largest physical dimension of one aerial. The frequency response of the two aerials is now plotted by recording in graphical form a plot of frequency against amplitude of received signal as shown in C1 of Fig. 2. The response curve for one aerial will be the square root of C1 if this is plotted to linear ordinates, or if as is more convenient it is plotted in dB the response curve will be half of C1, drawn as C2. Taking due precautions to maintain a constant amplitude of transmitted signal and receiver sensitivity one of the two test aerials is now replaced by a correctly matched half wave dipole. The frequency response of one test aerial and a dipole is then measured and is shown as C3 on Fig. 2. An uncorrected curve of gain over a dipole may now be obtained by subtracting C3 from C1 and this is shown as C4. Now it is known that C2 is the response curve of one test aerial whereas C3 is that of one test aerial and a dipole. Subtraction of C2 from C3 will therefore provide the response curve of the substituted dipole under the conditions of test, and this is drawn as C5 in Fig. 1. It will be immediately noticeable that the response curve of the dipole contains considerable cyclic variation and graphically illustrates the possible error if a normal fixed frequency substitution has been undertaken. At 193 Mc/s., for example, the gain over a dipole would be 12.5 dB., and at 195 Mc/s., it would be 10.5 dB., an error of 2 dB. Having obtained the dipole response under the conditions of test it is a simple matter to

draw the average of the cyclic variations due to test site reflections and then to draw a straight line at the level of the corrected dipole curve thus obtained. It is advantageous in the interpretation of the dipole curve to use a dipole with elements as thin as possible to provide a complete response curve within the measured band which also ensures that the gain is evaluated against the dipole at resonance. Corrections may then be made to C4 by adding the amounts above or subtracting the amounts below, that the dipole curve C5 differs from the drawn in reference line. This is shown as C6, and since due care has been taken to maintain the dE ordinates at the correct amplitude, C6 represents the measured gain over a dipole of one test aerial throughout its frequency response with full compensation for site errors due to reflections.

The method may be proved algebraically as in appendix 1 and an indication is also given by the shape of the curves obtained, of the suitability of the test site for the measurement being made. An example of inadequacy of site would be shown by curve C5, the dipole resonance, being so irregular as to prevent correct interpretation. Nothing is lost should this occur since any measurement taken by any other method on the site used would be inaccurate in any event.

An assumption is made in the test that the curve C1 taken between the two test aerials is accurate and not subject to errors occasioned by the test site reflections. This is a reasonable assumption when two high gain aerials are used since the sharpness of their radiation patterns will attenuate reflected signals to negligible proportions. Where however, aerials of lower gain and consequent reduced directivity are being measured, any unwanted reflections will show as a cyclic variation of C1. It will then be known that the measuring site is not really good enough but a reasonable result may still be obtained by taking the average of this cyclic variation. This gives a modified version of C1 to be used in subsequent operations.

When aerials of considerable bandwidth are being tested the frequency coverage may be great enough to necessitate correction of the response curves for the increase in effective path length which occurs as the frequency is increased. This form of correction is not normally required since if a normal dipole substitution test had been carried out at say 400 Mc/s., and at 600 Mc/s., then in each case the dipole would also have been receiving over the same path lengths and the subtraction of dipole gain from aerial gain would have automatically removed the error. In the new method when C_3 (the curve of one aerial and a dipole) is subtracted from C_1 (the curve of two aerials,) the inherent slope of the curves due to increasing path length at the HF end is automatically eliminated, and C_4 (the uncorrected gain over a dipole,) does not require correction. However, when C_1 is halved to provide C_2 , the slope due to increasing path length is also halved, and since it is intended to subtract C_2 from C_3 which has a full amplitude attenuation slope, it is necessary to correct C_2 by replacing the half of the attenuation slope which was lost due to the halving process. This source of error is perhaps made clearer with a hypothetical example as shown in Fig.3. It is given that the response is flat from 400-600 Mc/s., and the gain 2 dB over a dipole. C_6 therefore, is drawn and must be a straight line at the 2 dB level. When, however, a measurement of two of these aerials is considered to provide C_1 the theoretically flat response will not appear due to the increase in attenuation over the increasing effective path length. The difference in attenuation A between f_1 and a second higher frequency f_2 is given by $A = 10 \log 10 \left\{ \frac{f_2}{f_1} \right\}^2$ dB. Over an interval less than a frequency ratio of 3:2 an error not greater than 0.1 db will occur if this increase is taken as linear. C_2 is obtained by halving C_1 and it will be apparent that the attenuation slope has also been halved. This will provide an erroneous result if subsequently subtracted from C_3 which has an unmodified attenuation slope. The correct curve is

shown as C2¹ to which the full slope has been restored. Thus C4 and C5 are obtained by subtraction of curves with the full attenuation slope thereon, and are therefore fully corrected.

See appendix 2 for proof.

Fig. 4 is an actual test result of a 12 element yagi designed for wideband application at UHF. It will be seen that even at UHF with a highly directive aerial there is a 3.5 dB swing on the normally measured gain over a dipole, as shown at 450 and 460 Mc/s., on C4 the uncorrected gain curve.

Exhaustive tests have been conducted utilising this method and it has been found that gain measurements on the same aerial may be repeated with identical results on different days with different operators, and with different sites. Additionally changes have been made to the aerials under test such as altering the number of directors to give a theoretically predictable alteration in gain, and the measured results have always been as theory dictates.

The method not only provides an accurate means of measuring the gain of an aerial, but also shows immediately and unmistakably when the inaccuracies of the measuring site are too great to prevent a correct result. In practice of course only C5 and C6 need be drawn as a curve, previous calculations being carried out in tabular form. The drawing of all the curves does, however, provide a check on accuracy since C6 must be of similar shape to C2 and any errors will thus be immediately apparent.

APPENDIX 1.

Algebraic Confirmation of the Method.

True gain of test aerial = $G(f)$ = Y , ordinates in dE.

Apparent gain of probe dipole = $H(f)$ = D , ordinates in dE.

Curve 1 = $C_1(f)$.

Curve 2 = $C_2(f)$ etc.

$$C_1 = 2Y + 2a, \text{ Where 'a' is an arbitrary number which depends on the output level.}$$

$$C_2 = \frac{C_1}{2} = Y + a.$$

$$C_3 = Y + D + 2a,$$

$$\therefore C_4 = C_1 - C_3 = 2Y + 2a - (Y + D + 2a)$$

$$= Y - D. \quad \text{Note that 'a' is not superimposed on } C_4.$$

$$C_5 = C_3 - C_2 = Y + D + 2a - (Y + a)$$

$$= D + a.$$

Now C_5 contains errors due to site factors, and due to 'a' the zero shift. If a smooth curve is drawn through the mean of the undulations in C_5 , then this will represent the real gain of the dipole. This should be zero at resonance and will fall off at either side of the resonance. Variations of C_5 above and below this zero line represent the imperfections in the dipole pickup and the site. The choice of the resonance point for zero relative gain removes the factor 'a'.

$$C_5 - a = C_5' = D.$$

$$\therefore C_6 = C_4 + C_5' = Y - D + D$$

$$= Y = G(f).$$

As C_6 is necessarily identical in shape to C_2 , varying from it by a constant amount, it may be thought unnecessary to produce C_6 ,

APPENDIX 1 cont'd.

as the desired factor 'a' is determined in the transformation of C_5 to C_5' ; however, an exact correspondence between C_2 and C_6 is a convenient check that no calculation error has been made.

APPENDIX 11.

If the ratio of maximum frequency (f_2) to minimum frequency (f_1) is small, the error caused by ignoring the greater electrical path length at the higher frequency is small. For example when $\frac{f_2}{f_1} = 1.12$, the electrical gain measured will be 0.5 dE down at f_2 compared with the gain at f_1 .

The change in attenuation over a fixed path when the frequency changes from f_1 to f_2 is given by:

$$dA = 10 \log_{10} \left(\frac{f_2}{f_1} \right)^2 dE = P(f)$$

Then using the symbols defined above:

$$C_1 = 2Y + 2a - P(f)$$

$$\therefore C_2 = \frac{C_1}{2} = Y + a - \frac{P(f)}{2}$$

$$\therefore C_2' = C_2 - \frac{P(f)}{2} = Y + a - P(f)$$

$$C_3 = Y + D + 2a - P(f)$$

$$\begin{aligned} \therefore C_4 &= C_1 - C_3 = 2Y + 2a - P(f) - (Y + D + 2a - P(f)) \\ &= Y - D. \end{aligned}$$

$$\begin{aligned} C_5 &= C_3 - C_2 = (Y + D + 2a - P(f)) - (Y + a - \frac{P(f)}{2}) \\ &= D + a. \end{aligned}$$

$$C_5' = C_5 - a = D,$$

$$\therefore C_6 = C_4 + C_5' = Y - D + D$$

$$= Y = G(f), \text{ which is the quantity required.}$$

Thus the true gain of the test aerial over a wide bandwidth is given by C_6 if half the attenuation function $P(f)$ is subtracted from C_2 , and the modified form of C_2 is used in place of C_2 itself.

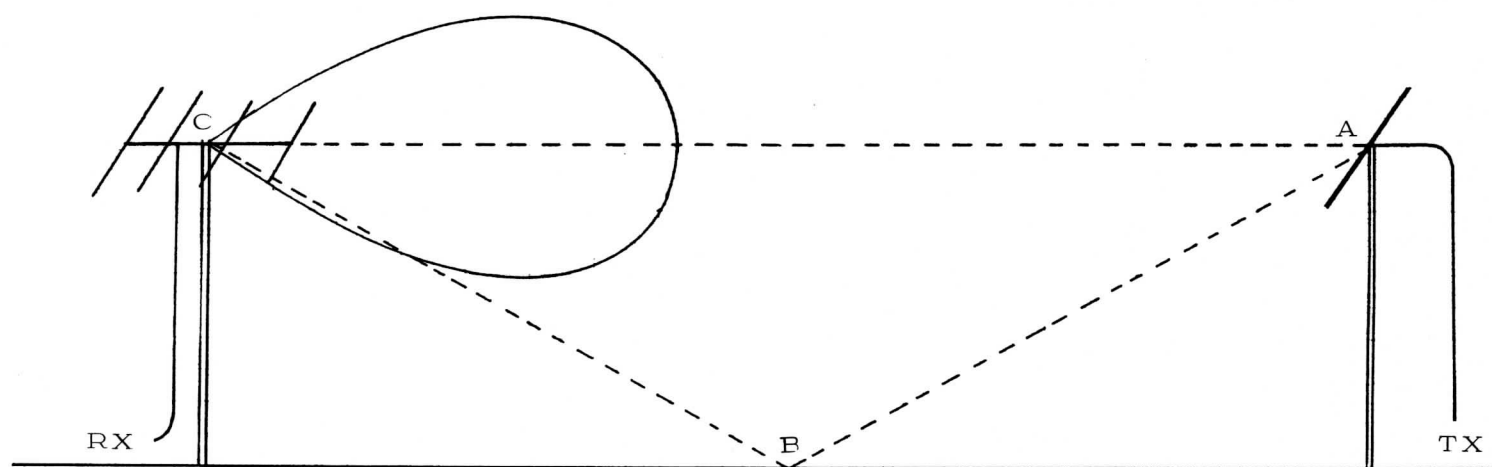


Fig. 1.

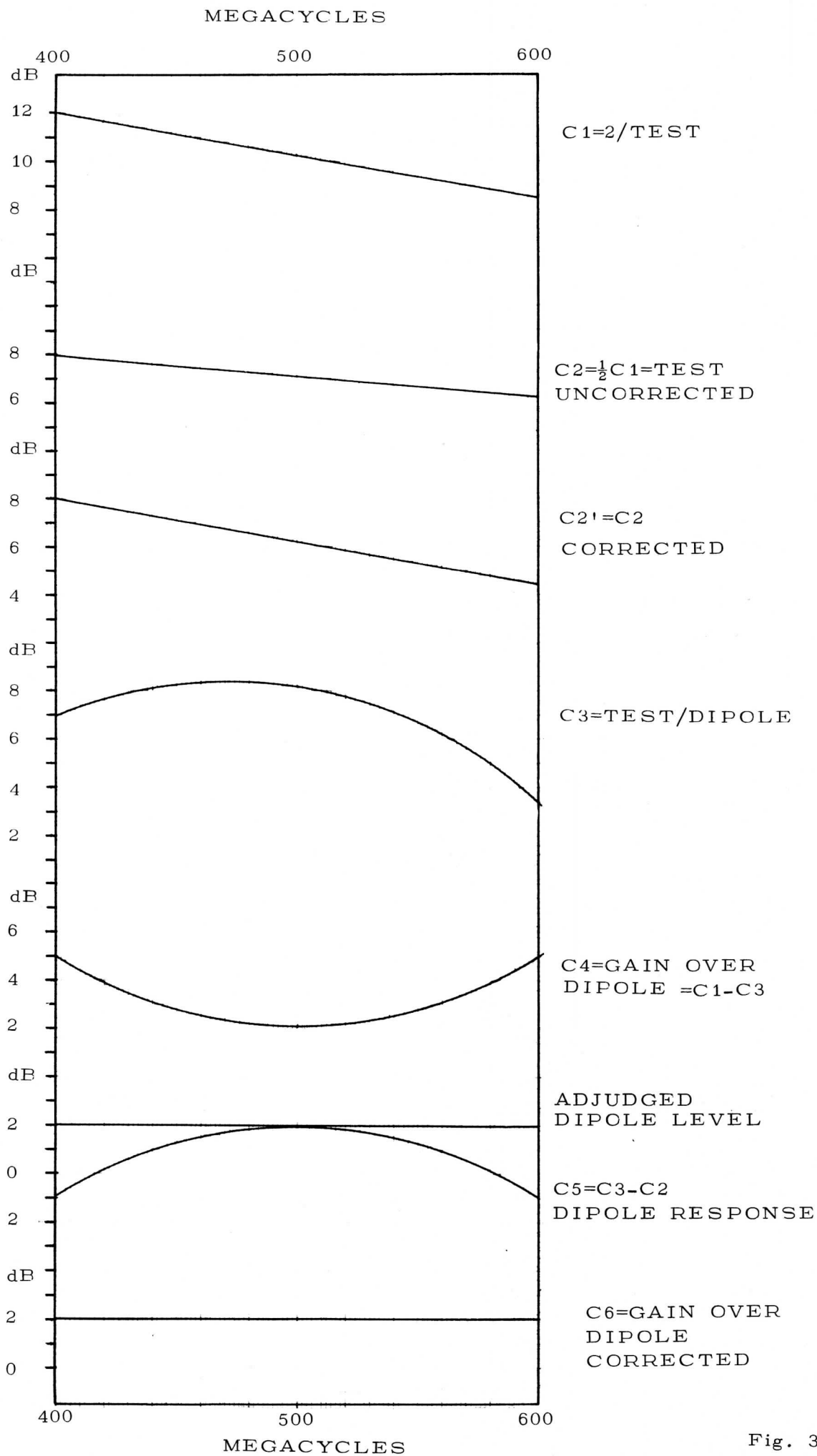


Fig. 3.

MEGACYCLES

