ANTENNA FACTOR

Antenna Correction Factor, or simply Antenna Factor (A.F.), is a performance characteristic for antennas which is important primarily in receiving applications such as EMI and field strength measurement. It relates terminal voltage to incident field strength, taking into account the antenna directivity, all internal dissipative losses, mismatch loss, frequency, and effects of any integral electronics circuitry. Knowledge of the A.F., antenna pattern shape and threshold sensitivity are all that are needed with respect to the antenna for receiving system performance considerations. A.F. is very simple in concept, but it is so often misunderstood and mis-applied that a discussion is in order.

A.F. is defined as that number by which the voltage appearing across a specified terminating impedance of a given receiving antenna must be multiplied to obtain the strength of the field to which the antenna is exposed. The terminating impedance is usually a 50-ohm resistor, or equivalent, and the A.F. is ordinarily expressed in dB, with its dimensions understood.

Some limitations must be observed in using A.F. to determine field strength. One is that the field to be measured must be reasonably constant in magnitude over the active physical structure of the antenna. This means that if the field itself is not uniform, the antenna must either be small compared to a wavelength in the case of strong standing wave distributions, or to the radius of the curvature of the field contours in the case of close proximity to sources or scatterers, or to both in more complicated environments such as the inside of shielded enclosures. A directive beam-type antenna, for example, cannot be used in ordinary probe fashion to explore standing wave field distributions. It will, instead, respond more nearly in proportion to the strength of the traveling wave field component incident upon it from its forward beam direction.

Finally, and almost obviously, the antenna must be substantially pure in type, either E-field or H-field, in order to be able to measure exclusively the desired field component. This last requirement includes attention to practicalities such as excellence of electrical balance and careful dressing out of harness and feed lines which may impair the purity of field sensitivity. The accuracy obtainable in measurement through the use of A.F. depends heavily upon the degree of compliance with these restrictions. In a strongly perturbed region, the relative magnitudes of E and H may be quite different from their free-space ratio of 120π ohms. Where large standing waves exist, the ratio of E to H may vary from nearly zero to very high values (theoretically from zero to infinity), depending upon the Q of the region (enclosure or cavity).

An antenna is generally catagorized either as an E-field (electric) type or an H-field (magnetic) type to indicate which electromagnetic field component it is that produces the voltage at the terminals. Antennas made of metallic rod elements are almost invariably of the E-field type, while those with small loops and ferrite rods are just as consistently of the H-field type. Under the above restrictions, each antenna responds only to the field component of its type, and in proportion to the strength of the field, regardless of the strength of the associated component of opposite type. It follows that the A.F. for an E-field antenna must yield the existing E-field in volts per meter, regardless of the strength of the associated H-field, and the A.F. for an H-field antenna must yield the existing H-field in ampere-turns per meter (or, more commonly, amperes per meter) independently of the strength of the associated E-field. Because of the dimensional differences between the units of E and H, there have to be two kinds of A.F., and it is quite proper to differentiate between them, say by subscript. Thus, one should say

$$E = \mathrm{A.F.}_E \times V \quad \text{volts/meter} \qquad (1)$$

and

$$H = \mathrm{A.F.}_M \times V \quad \text{ampere-turns/meter,} \qquad (2)$$

where V is the voltage developed across the terminating impedance of the antenna. It will be shown below that $\mathrm{A.F.}_E$ and $\mathrm{A.F.}_M$ are simply related, for a plane-wave field.

The relationship between A.F., frequency and over-all power gain will now be derived. Since gain, G, enters without bound or restriction upon type, size or kind of antenna, it is appropriate to hypothesize a traveling plane wave having a power flow density of S_o watts per square meter incident in free space upon an antenna having an effective capture area of A_e square meters. If the antenna is terminated in a fixed pure resistance R, the power delivered to this resistance is

$$V^2/R = S_o A_e \text{ watts,} \qquad (3)$$

where V is the voltage across R. But S_o is determined by the electric field intensity, E (volts per meter), of the incident wave and the characteristic impedance, $Z_o = 120\pi$ ohms, of free space, namely

$$S_o = E^2/120\pi \text{ watts/meter}^2. \qquad (4)$$

The effective capture area can be expressed[1] in terms of the gain, G, relative to an isotrope, *for a given fixed terminal impedance,* and the wavelength λ. Thus,

$$A_e = G\lambda^2/4\pi \text{ meter}^2. \qquad (5)$$

Since

$$\lambda = 300/f_{MHz} \text{ meter,} \qquad (6)$$

where f_{MHz} is the frequency in megahertz, one can combine (1), (3), (4), (5) and (6) to obtain

$$(A.F._E)^2 = (E/V)^2 = \frac{480\pi^2}{300^2 R} \cdot \frac{f^2_{MHz}}{G} \text{meter}^{-2}, \quad (7)$$

which, for R = 50 ohms, becomes

$$(A.F._E)^2 = 1.05275 \times 10^{-3} f^2_{MHz}/G \text{ meter}^{-2}. \quad (8)$$

Upon taking ten times the logarithm to base 10 of both sides of (8), one obtains the desired result,

$$A.F._E(dB) = 20 \log f_{MHz} - 10 \log G - 29.777. \quad (9)$$

For an ideal matched isotrope (G = 1) at 1 MHz, the $A.F._E$ is -29.777 dB or approximately -30 dB.

It remains to show the relation between $A.F._E$ and $A.F._H$. Since the A.F. permits the accurate measure of the true field strength in any qualified situation (i.e., restrictions met), it must apply also for the ideal case of a plane wave in free space. For the plane wave, one has

$$E = 120\pi H, \quad (10)$$

which, upon substitution in (1) and comparing with (2), gives

$$A.F._E = 120\pi A.F._H, \quad (11)$$

or

$$A.F._H(dB) = A.F._E(dB) - 51.527. \quad (12)$$

The dimensions of $A.F._H$ are ampere-turns volts^{-1} meter^{-1}.

The $A.F._E$ of an antenna for a specified terminating impedance can be related to the effective height, h, by computing the limiting value of (7) as the terminating impedance becomes infinite (open circuit). Antenna height[2] relates open-circuit (or induced) voltage to electric field strength by the definition,

$$h = V_{oc}/E \text{ Meters}, \quad (13)$$

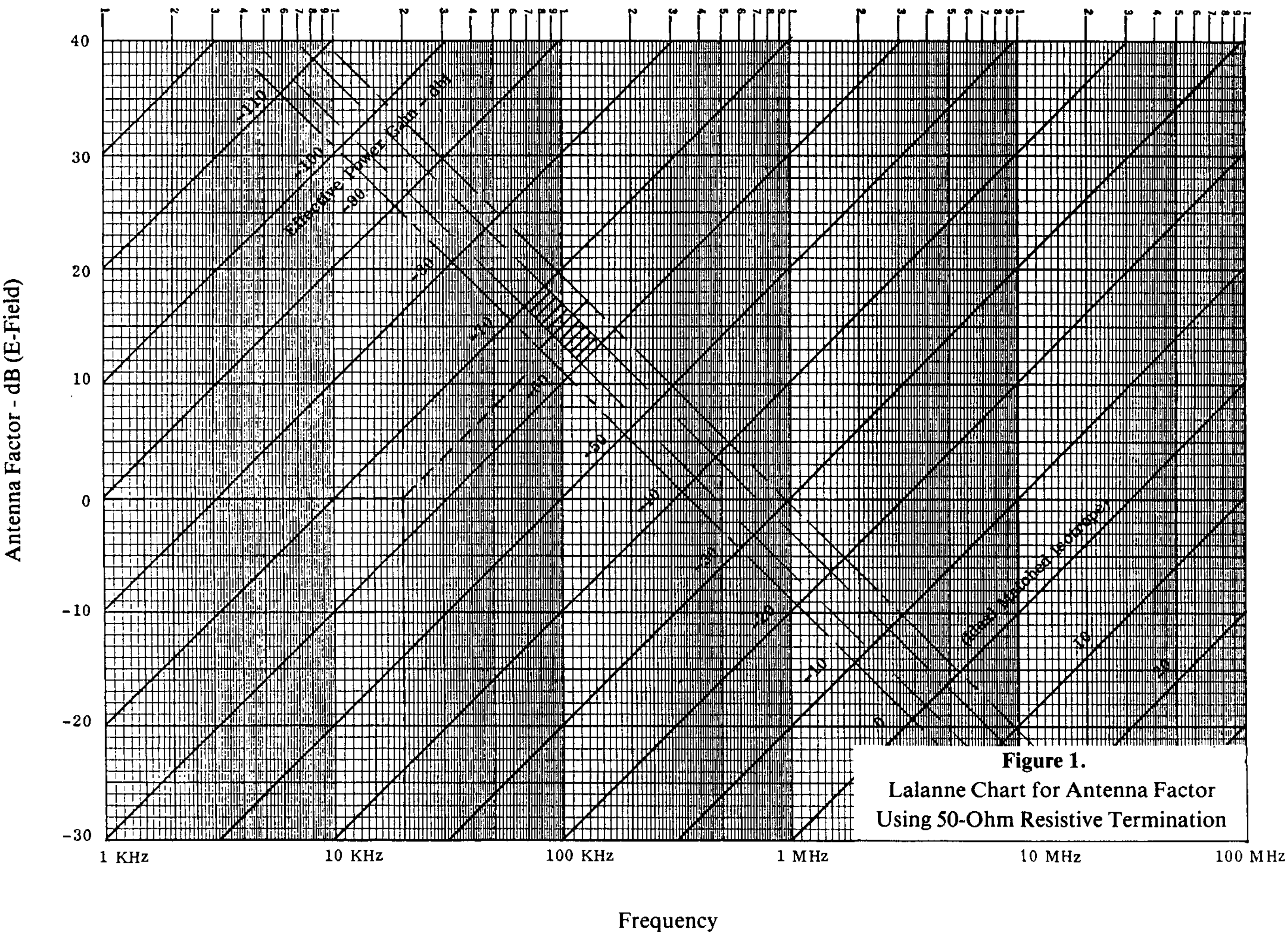

Figure 1.
Lalanne Chart for Antenna Factor
Using 50-Ohm Resistive Termination

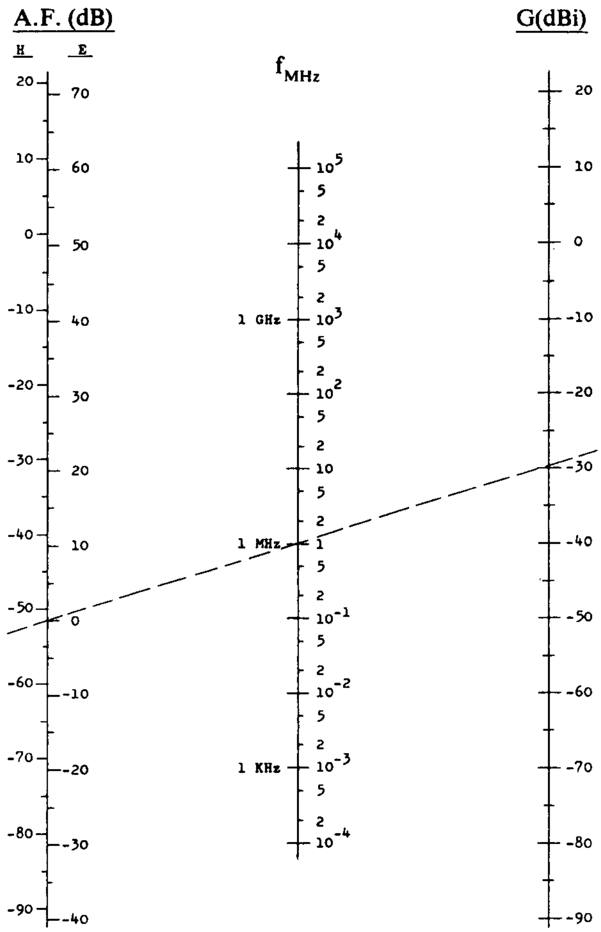

Figure 2. Alignment Chart for Antenna Factor Using 50-Ohm Resistive Termination

which is reciprocal open-circuit antenna factor. The gain, G, used in the derivation of (7), (8) and (9) is the maximum available gain, G_o, reduced by the reflection loss due to any impedance mismatch at the terminals. In practice, this loss is usually much less than 1 dB, for a well designed antenna of the same nominal impedance as R. If the antenna impedance is $Z_i = R_i + jX_i$, the complex voltage reflection coefficient at the terminals is

$$K = \frac{1 - Z_i/R}{1 + Z_i/R}, \tag{14}$$

and the reflection loss factor applicable to G_o is

$$L = (1 - |K|^2), \tag{15}$$

whence $G = G_oL$ (16)

Let us assume for example, that the antenna impedance is the same as the terminating resistor for which the A.F.$_E$ is known, that is, $Z_i = R_i = R$. Then L = O, and (7) becomes

$$(A.F._E)^2_m = \frac{480\pi^2}{300^2 R_i} \cdot \frac{f^2 MHz}{G_o}. \tag{17}$$

Now substitute from (14), (15) and (16) into (7) and let R increase without bound. The result is

$$(A.F._E)^2_{oc} = \frac{480\pi^2}{300^2 R_i} \cdot \frac{f^2 MHz}{4\, G_o} = \frac{1}{h^2} \tag{18}$$

Upon comparing (17) and (18) it is evident that

$$h = 2/(A.F._E)_m \text{ meters.} \tag{19}$$

$$\approx 2/A.F._E \quad \text{meters.} \tag{20}$$

This is exactly what one would expect, since the voltage across the conjugate impedance load of the equivalent Thevenin generator is just one half the open circuit voltage. The equations hold good when both the antenna and terminating impedances are complex. Eq. (20) is reasonably accurate for all antennas having VSWR in the order of 2:1 or less with respect to a fixed terminating resistance.

A Lalanne chart has been constructed in Figure 1 to show the relationships expressed in (9) for A.F.$_E$. Antennas of constant gain with respect to an ideal matched isotrope are represented by the set of diagonal lines, while A.F.$_E$ (dB) and f_{MHz} are the ordinary dependent and independent Cartesian coordinates. The same relationships can also be presented in the familiar form of an alignment chart having three parallel line scales, as shown in Figure 2. This chart includes a scale for A.F.$_H$. Given any two of the quantities, the charts readily yield the third. Dashed lines on the charts show how the chart is used. The scales on either chart can easily be shifted to accommodate values lying outside the range. One can extend the A.F.$_E$ scale in either direction by adding algebraically any convenient multiple of 10 dB to the numbers already there if he also subtracts algebraically the same number of dB from the gain scale values. The frequency scale can be extended by adding or subtracting 20 dB from the A.F.$_E$ scale each time the frequency scale is multiplied or divided by 10.

As to choice between the two charts, there is little. The alignment chart, once constructed, is less congested and easier to use. The Lalanne chart is easily constructed because standard semilogarithmic coordinate paper is generally available. Some degree of interpolation is inevitable with either type of nomogram. One obvious advantage of the Lalanne chart is that either the A.F. or the effective power gain can be plotted directly on it as a function of frequency. Since the trace for either characteristic is the same thing on the chart, read-out is a matter of choosing the proper set of coordinates. Conversion from A.F. to effective power gain is automatic.

REFERENCES

1. Samuel Silver, "Microwave Antenna Theory and Design", McGraw-Hill Co., New York, 1949, p 51.
2. John D. Kraus, "Antennas", McGraw-Hill, New York, 1950, p 44.

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