the ground-plane antenna: its history and development

Some useful information for those interested in the design and adjustment of this popular antenna

This article will be of value to those interested in designing and adjusting ground-plane antennas. The article describes the original invention of the ground-plane antenna, points out an error in assumptions regarding radiation resistance, and includes formulas for designing a simple matching network.

background

A study of 30 - 60 MHz antennas made in 1936 by Dr. George H. Brown and J. Epstein of RCA brought to light two principal defects in most types of such antennas used at that time: the transmission line was not terminated properly, and sizable standing waves occurred on the outside of the coaxial transmission line. The J-antenna and the sleeve or coaxial antenna (both popular at that time) were found to be particularly susceptible to such standing waves.

Brown and Epstein found that the use of horizontal quarter-wavelength ground rods extending from the base of the vertical antenna established a virtual ground plane and shielded the coaxial line from the rf field of the antenna. Two types of coaxial matching networks were developed. Both supported the antenna rod mechanically, insulated it from ground at rf but grounded it at lightning and dc frequencies, and at the same time provided a good impedance match between antenna and transmission line at the operating frequency. Two patents resulted from this work: the original[1] was issued in 1941, and another was issued on an improved design[2] in 1942.

The original design, **fig. 1**, was built and tested in 1938 in Camden, New Jersey. It was my privilege to witness some of these tests. The first design used a quarter-wavelength antenna rod, four quarter-wavelength ground rods, and a quarter-wavelength coaxial support stub shorted at the bottom end. The coaxial transmission line was matched to the antenna base resistance (the reactive component was negligible when the antenna was exactly one-quarter wavelength long) by a quarter-wavelength coaxial line connected between the antenna base and the antenna end of the transmission line.

This quarter-wavelength line had a characteristic impedance of

$$Z = \sqrt{R_a Z_l} \qquad (1)$$

where

Z = characteristic impedance of the quarter-wavelength matching section (ohms)
R_a = antenna resistance (ohms)
Z_l = transmission-line characteristic impedance (ohms)

This coaxial matching section can be compared to the so-called Q-section used by many amateurs years ago as an impedance transformer between an open-wire transmission line and a center-fed antenna.

improved design

In the improved ground-plane design, **fig. 2**, the coaxial Q-section was eliminated, the transmission line was connected directly to the antenna base, the antenna was shortened to present an impedance of 19-j29.5 ohms, and the previous quarter-wavelength support section was shortened to about one-sixth wavelength. This shorted stub then had an inductive reactance of about +42 ohms which, in parallel with the capacitive antenna impedance of 19-j29.5 ohms, resulted in a parallel impedance of 65 ohms – the characteristic impedance of the coaxial transmission line used at that time. Each of the four horizontal ground rods remained a quarter wavelength long. Tests showed that their length was not too critical.

The values above were calculated as follows, as stated in Dr. Brown's article in *Electronics*:[3]

By Harold C. Vance, Sr., K2FF. (Mr. Vance became a silent key in August, 1976.)

The parallel inductive reactance of the matching stub required for parallel resonance with the capacitive reactance of the antenna is

$$X_s = \frac{R_a^{\,2} + X_a^{\,2}}{X_a} \tag{2}$$

where

X_s = stub reactance (ohms)
R_a = antenna resistance (ohms)
X_a = antenna reactance (ohms)

The parallel impedance of the antenna, a pure resistance at resonance, is

$$R_p = \frac{R_a^{\,2} + X_a^{\,2}}{R_a} \tag{3}$$

where

R_p = terminating resistance presented to the transmission line at the antenna base.

In his *Electronics* monograph[3] Dr. Brown points out that, ". . .it is practically possible to present a resistance that will match a concentric transmission line of any characteristic impedance above 25 ohms. . .but the antenna length becomes extremely critical when resistances in excess of 100 ohms are desired."

The evolution of the ground-plane antenna design is described in detail in an article by Dr. Brown and J. Epstein in the July, 1940, issue of *Communications* magazine.[4] This article also shows a ground-plane antenna with a close-spaced reflector. A gain of approximately 3 dB was obtained. The antenna and matching-stub lengths were changed slightly to maintain a match between antenna and transmission line when the reflector was added.

erroneous assumption

In an article on the ground-plane antenna, Stephens[5] refers to an article by Hassenbeck[6] giving formulas and curves that claim to be values of resistance and reactance of a vertical antenna supported above four one-quarter wavelength ground rods. Hassenbeck states that data given by King and Blake[7] was used in establishing his curves.

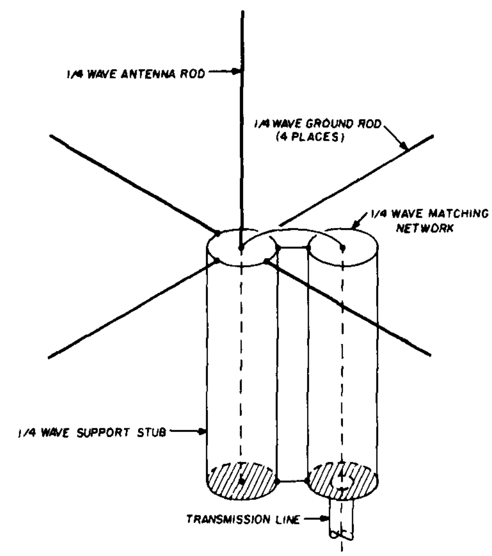


fig. 1. Original ground-plane antenna design, which was built and tested by RCA in Camden, New Jersey in 1938. The coax matching section may be compared to the familiar Q-section transformer used by amateurs years ago to match open-wire transmission lines to center-fed wire antennas.

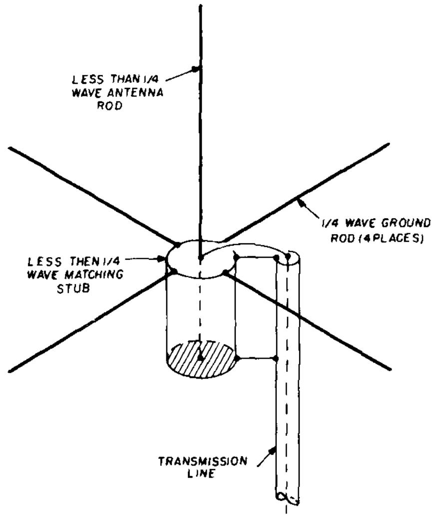


fig. 2. Improved ground-plane antenna. The coaxial Q-section was eliminated, and other innovations resulted in an antenna that was easier to match and adjust.

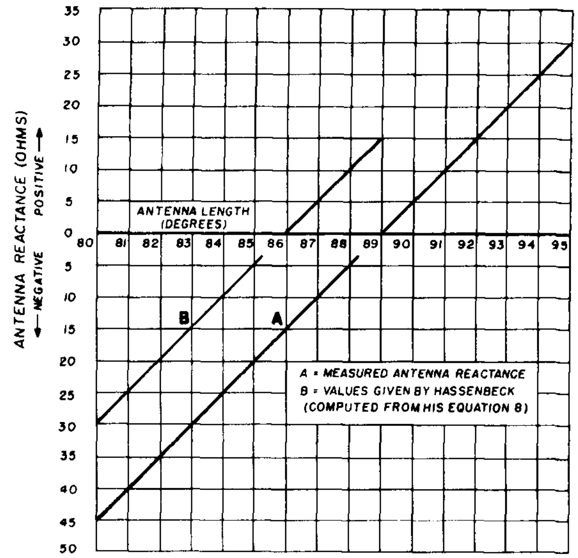
Dr. Brown pointed out[3] that, "the data given by King and Blake apply to a symmetrical antenna fed at its center or to a vertical antenna operating against an infinite metal sheet. . .there is a fundamental difference in the impedance of an antenna operating with four ground rods and an antenna operating over a semi-infinite sheet."

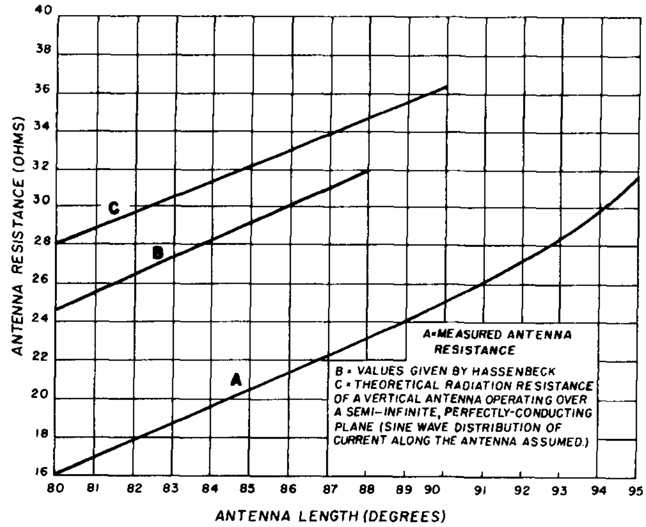
Actual measurements made by Dr. Brown showed that an antenna using four ground rods "has an appreciably lower radiation resistance than is generally assumed for the same antenna operating over a semi-infinite conducting plane." He stated that, "with an antenna exactly one-quarter wave in length, replacing the four ground rods by a metal disc one wavelength in diameter changed the actual measured radiation resistance from 25 ohms with the ground rods to 37 ohms with the one-wavelength-diameter disc."[3] Measurements of an earlier experimental unit[4] showed an antenna resistance of 21 ohms with ground rods.

The actual antenna resistance and reactance values shown in **fig. 3** were measured at 60 MHz. The ground rods were one-quarter wavelength at 60 MHz. The antenna-rod diameter was 0.625 inch (16mm), and its length was varied to those shown in the curves.

In Hassenbeck's article[6] the characteristic impedance of the support stub was assumed to be 70 ohms. In the RCA MI-7823-A antenna,[3] Dr. Brown used a stub having a characteristic impedance of only 41 ohms "to lengthen the support section when low frequencies requiring long antenna sections were used, and to make the adjustment of the shorting plug less critical."

In the case of the MI-7823-A antenna the length, S, of the inductive matching and support stub in electrical





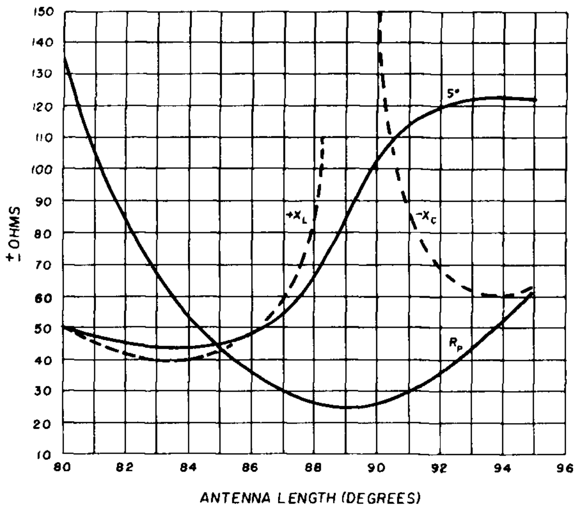


fig. 3. Actual resistance and reactance values of the ground-plane antenna measured at 60 MHz compared with values given by Hassenbeck in reference 6 (top two graphs). Bottom set of curves shows characteristics of the RCA MI-7823-A ground-plane antenna including parallel-resonance resistance, R_p; shunt reactances, X_L and X_C, required for resonance; and matching-stub length, S^o, required for the various values of reactance and resistance.

degrees (360° = one wavelength) is given as:

$$tan\ S^{\circ} = \frac{X_{stub}}{41} \qquad (4)$$

where X_{stub} is the reactance of the matching stub (ohms) and 41 is the characteristic impedance of the MI-7823-A matching stub (ohms).

In more general terms,

$$tan\ S^{\circ} = \frac{X_{stub}}{Z_{stub}}, \quad or\ S^{\circ} = arctan\frac{X_{stub}}{Z_{stub}} \qquad (5)$$

where Z_{stub} is the characteristic impedance of the stub (ohms).

That is, the stub length, S, in electrical degrees equals the angle whose tangent corresponds to the value obtained when X_{stub} is divided by Z_{stub}.

conclusion

The need for actual experimental measurements is well illustrated by the error of Hassenbeck's assumption that the radiation resistance of the ground plane antenna would be the same as that of an antenna operating over a semi-infinite sheet. Many factors such as proximity of other objects, incorrect assumptions, and structural differences can cause actual values to vary widely from calculated values. An R + jX bridge, such as those described in *QST*[8] and *ham radio*[9,10] will prove invaluable for this purpose.

acknowledgement

I wish to thank Dr. Brown for furnishing me with copies of the referenced articles by him and J. Epstein.

references

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ham radio