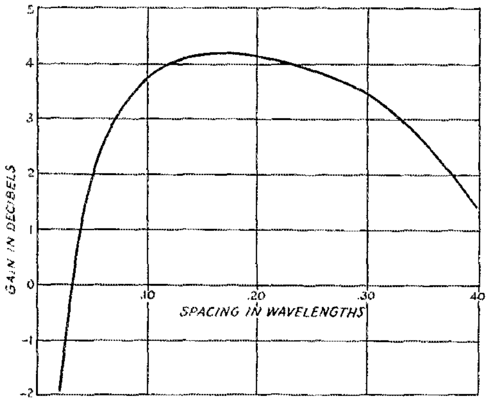

Fig. 1 — Gain in db versus spacing in wavelengths for two parallel half-wave antenna antennas fed out of phase. Gain is referred to a single half-wave antenna.

The "Q" Beam Antenna

BY LLOYD W. OLANDER*

A Two-Band Directional System With Non-Resonant Feeders

In general, a fixed antenna should have vertical and horizontal characteristics which give optimum results over a wide range of distances and directions. Antennas such as the single long-wire radiator, the "V," and the horizontal diamond restrict the radiation in the horizontal plane so that one or more sharp lobes having fairly high gain are produced. However, 15 to 20 degrees removed from the beam the signal strength is down several "S" points. To meet the average amateur requirement of wide-range long-distance transmission on the higher frequencies, the antenna should have a broad horizontal characteristic and low-angle vertical directivity, unless the system is rotatable or there is sufficient room for several antennas having sharp horizontal beams.

An antenna approaching these specifications has been developed by G. H. Brown.[1] Basically, it consists of a pair of closely-spaced elements excited with currents 180° out of phase. The resulting radiation is maximum in the plane of the elements and broadside to them, when the spacing between the elements is 0.5 wavelength or less. The maximum gain is essentially constant for spacings between 0.125 and 0.20 wavelength. The curve of Fig. 1 shows the variation of gain with spacing for a two-element beam antenna where each element is one-half wavelength long (equation 50 of Brown's article). The radiation pattern may be shifted either by changing the spacing of the elements, the phase relation between the excitation currents, or the electrical length of the elements.

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[1] G. H. Brown, "Directional Antennas," *Proc. I.R.E.*, Jan., 1937.

The "Q" Beam

The "Q" beam antenna, Fig. 2, is a two-band matched impedance antenna for two adjoining harmonically-related bands. It consists of two half-wave radiators spaced ⅛-wave apart and fed 180° out of phase by means of individual quarter-wave "Q" sections. The radiation pattern is bi-directional, maximum broadside to the radiators, and has a fairly wide horizontal angle. The gain over a half wave is approximately 4 db on fundamental operation and over 6 db on second harmonic operation.

Since the voltages or currents on opposite conductors of a balanced open-wire line are 180° out of phase, the 180° phase relation between the two elements is obtained very simply by reversing the connections at the center insulator of one element. Thus the right half of one element and the left half of the other element are connected to the right-hand tubing of the associated "Q" sections, and vice versa. The two "Q" sections are fed by a 600-ohm balanced two-wire transmission line. The bottom connection between the two sections should not be more than one or two inches at frequencies above 56 megacycles. At the lower frequencies this connection is not so critical, but should be as short as possible.

When two antennas or elements are so spaced as to have appreciable mutual reactance, the resistance and reactance of each antenna (as measured at a current loop) and the gain of the system will change with the spacing and the electrical length of the antennas. It is apparent that as the spacing approaches zero the mutual impedance approaches the self-impedance of each antenna and the directivity is the same as for one radiator alone, while at a very great spacing the mutual impedance is negligible.

The self-impedance of a half-wave horizontal radiator is 73.2 +j42.5 ohms.[2] This result indicates the necessity for decreasing the length a little (5 per cent)* to obtain a non-reactive load. The inductive reactance of each half-wave element, when two elements spaced 0.2 wavelength are used, increases from 42.5 ohms to 56.8 ohms. This increase in inductive reactance was verified during testing of the "Q" beam, as it was found necessary to decrease the length of each half-wave element to 94 per cent of the length in space instead of the usual 95 per cent.

With fundamental operation the radiation resistance at a current loop decreases from 73.2 ohms to approximately 21 ohms, which was determined by evaluating equations 33 and 34 of Brown's article. The proximity of surrounding objects and the height of the antenna will change the value to some extent. The radiation resistance of the elements will be equal only when 0° or 180° phasing is used and the power is divided equally between the elements.

The Matching Section

The "Q" sections, a quarter wavelength long, which feed the individual half-wave elements at a high-current point, must match the 21-ohm impedance at the center of the elements to 1200 ohms at the opposite end of each "Q" section. The 600-ohm transmission line is then correctly matched, since the two "Q" sections are connected in parallel.

By solving the following equation:

$$Z_o = \sqrt{Z_A Z_L}$$

where

Z_o = Characteristic impedance of "Q" sections

Z_A = Resistance of each half-wave element (21 ohms)

Z_L = Twice characteristic impedance of transmission line (1200 ohms)

it is found that the "Q" section characteristic impedance must be 158 ohms. The characteristic impedance of a "Q" section having ½-inch conductors spaced 1 inch center to center is 158 ohms. It may be computed from the formula

$$Z_o = 276 \log_{10} S/d + \sqrt{\frac{S^2-1}{d^2}}$$

where

S is the distance between centers of the conductors (1 inch)

d is the diameter of the conductors (½ inch)

[2] P. S. Carter, "Circuit Relations in Radiating Systems and Applications to Antenna Problems," *Proc. I.R.E.*, June, 1932.

Except in the case of large long-wire antennas (the "V" or diamond) harmonic operation of an antenna entails the use of tuned feeders, since the ordinary impedance-matching systems go badly out of adjustment when the frequency is doubled. Here is a scheme which permits two-band operation, at least, with the transmission line closely matched on both bands. The radiating portion resembles the popular W8JK arrangement, giving low-angle radiation with a rather broad horizontal beam.

Second Harmonic Operation

When the antenna is operated on the second harmonic it becomes a two-section system, since the electrical length doubles and each element now consists of two half-wave sections fed at the ends (high-voltage points). Since the half-wave sections in one element connect to opposite sides of the "Q" matching section, they are effectively fed in parallel but 180° out of phase. The electrical spacing between the two elements also becomes twice as great and increases to 0.4 wavelength.

There is an interesting change in the matching characteristics of the "Q" sections, which become ½ wavelength long at the second harmonic. A line which is exactly ½ wavelength long has identical voltage-current relationships at each end, regardless of the characteristic impedance. Since an impedance is simply the ratio of voltage to current at a point in a circuit, the ½-wavelength line therefore has the relation

$$Z_L = Z_A$$

and the property of one-to-one transformer. If the line is terminated at either end by 600 ohms, for

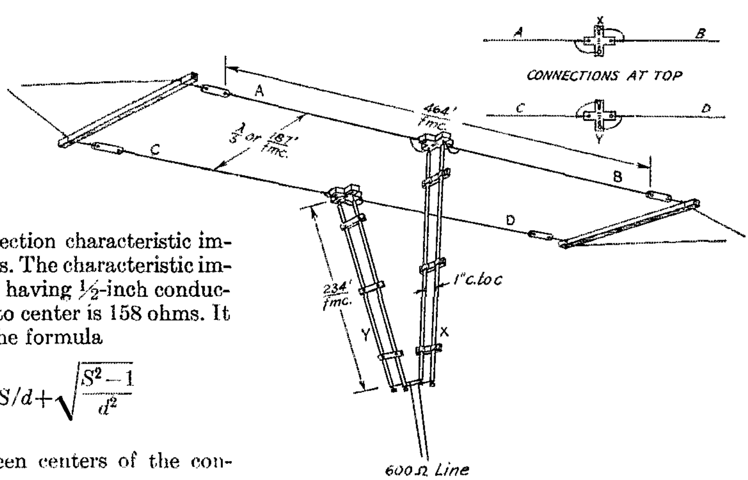

Fig. 2 — The "Q" beam antenna, using two "Q"-bar matching sections to feed out-of-phase antenna elements. The 600-ohm line will be closely matched at the termination on both fundamental and second harmonic of the system.

example, measuring equipment will indicate 600 ohms at the opposite end.

The impedance to ground at the end of a half-wave antenna is approximately 2200 [3] to 2900 [4] ohms [5] and, disregarding the mutual coupling, it is to be expected that since the two half-wave sections of each element are connected in parallel

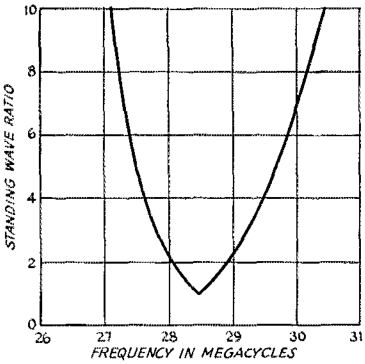

Fig. 3 — Standing-wave ratio on the 600-ohm transmission line plotted against departure from resonance of a "Q" beam designed for a fundamental of 28.5 Mc. The mismatch is small over the low-frequency half of the band.

the impedance at the high voltage point where the "Q" sections are connected will be around 1200 ohms. The 1200-ohm load is reflected through the half-wave "Q" section, which means that the impedance at the transmission-line end of the "Q" section is identical to the impedance at the antenna end. Since the two 1200-ohm impedances are connected in parallel at the ends of the "Q" sections, the 600-ohm transmission line is again terminated in to its characteristic impedance. It is probable that the impedance of each half-wave element due to the mutual coupling of the other three elements changes, although a satisfactory mathematical solution was not obtained. The standing-wave ratio on a transmission line for second harmonic operation was 1.4 to 1, which indicates that impedance at the center is not far from 1200 ohms.

The radiation resistance of each half-wave section at the second harmonic increases from 2½ to 3 times the value at the fundamental due to the increased spacing.

[3] *The Radio Antenna Handbook*, second edition.

[4] *Electronics*, Aug. 1935 (calculated from information available).

[5] The literature shows no general agreement on this figure, probably because it is subject to considerable variation with local conditions. It has been placed as high as 12,000 ohms (Romander, *QST*, June, 1938). In any event, when several closely-associated antenna elements are concerned the impedance between any two adjacent antenna ends depends principally on the mutual impedances between elements. In the practical case considered here the mismatch is small, which is the important thing regardless of whether or not the assumptions are valid. — EDITOR.

Effect of Frequency Shift

Because of QRM conditions, variable-gap crystal holders and variable frequency oscillators often are employed to change the transmitter frequency, thus permitting a satisfactory QSO. With this thought in mind, the curves of Figs. 3 and 4 were taken. These curves indicate the standing-wave ratio on the transmission line as the frequency is varied from the resonant frequency of the antenna. Referring to Fig. 3, for fundamental operation (28 Mc.), the transmitter frequency may be varied over a band of 0.5 megacycle on either side of the resonant frequency with satisfactory results. This curve is rather sharp because of the low resistance of each element. As the antenna resistance is increased the curve becomes broader, which is verified by the curve Fig. 4, for second-harmonic operation. The standing-wave ratio was indicated by a sensitive thermocouple meter connected in a tuned circuit and coupled to the transmission line by a single-turn loop. The entire assembly was mounted on the

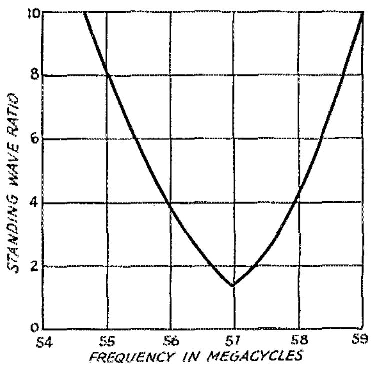

Fig. 4 — Standing-wave ratio with changes of frequency when the antenna is operated at twice the fundamental frequency.

end of a bakelite rod and the coupling held constant by means of an insulated hook.

The ratio of maximum to minimum current or voltage on a mismatched transmission line is proportional to the ratio of the load impedance to the surge impedance of the transmission line. Thus a standing-wave ratio of 4 means that the load resistance Z_L is either four times or one-fourth the surge impedance Z_O of the transmission line. Mismatching a transmission line by a certain impedance and then by the reciprocal will displace the maxima and minima of current and voltage by 180°. Thus in the former condition a maximum current indication will be found at the same position as minimum current in the latter case.

Whether the load impedance presented by the "Q" section to the transmission line is higher or lower than the characteristic impedance of the transmission line can be determined readily by means of a low-scale r.f. meter or neon bulb which is moved along the wire from the junction of the transmission line and the "Q" section toward the transmitter. If the load impedance is low the meter reading will decrease or the neon bulb become brighter as they are slid along the line. For a higher load impedance, the indications will be reversed.

It is general practice to attempt to fulfill the condition $Z_L/Z_O = 1$. At this condition the line copper loss is minimum. The power lost in a well constructed line, when $Z_L/Z_O = 1$, is a very small percentage of the power delivered to the load. Considering a 600-ohm line of No. 12 copper wire 100 feet long, terminated in its characteristic impedance, the power at the receiving end will be approximately 97 per cent of the power delivered to the transmission line at 14 megacycles. Fig. 5 compares the power losses in unmatched and matched transmission lines for various ratios of mismatch.[6] P_m = the power lost in the line when $Z_L/Z_O = 1$; P_{um} = power lost in the unmatched line when the same amount of power is delivered to the load as in the matched case; Z_L = load impedance; Z_O = transmission line impedance. When the transmission line is mismatched as much as 2 to 1 the increase in power loss over the matched condition is negligible. A mismatch as much as 4 to 1 can be tolerated. The foregoing discussion applies only to the power dissipated in the copper losses and neglects the radiation losses. A properly-balanced transmission line will radiate a small amount of power, which is increased if the transmission line is not balanced.

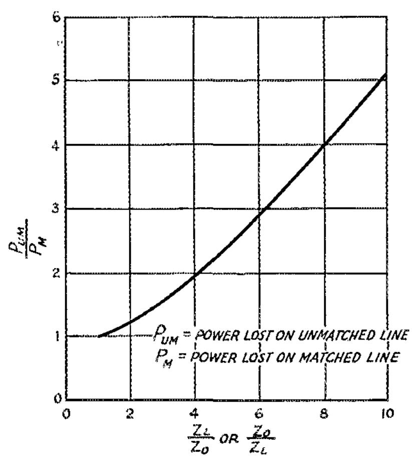

Fig. 5 — Power loss ratio in a transmission line as a function of the extent of mismatch between line and load; radiation losses not included. Constant power in load.

[6] From an unpublished paper by G. H. Brown.

The maximum radiation from the "Q" beam is at 90 degrees to the axis of the radiators in the horizontal plane. The nulls off the ends (along the line of the antenna) are very pronounced. On the second harmonic, the gain over a single half-wave antenna is still 5 db 15 degrees off the line of maximum radiation, as compared with over 6 db in the optimum direction; on the fundamental, the gain is still 3 db at 30 degrees from the maximum, or only 1 db down. The useful width of the beam is probably about 35 degrees in each direction broadside in the former case, and about 70 degrees in the latter.

The radiation in the vertical plane varies with the height above ground, but with the "Q" beam is maximum at a lower angle than in the case of a single half-wave antenna because of the out-of-phase currents; the antenna may be placed at heights of a half- to a full-wave above ground with satisfactory results. The lower angle of radiation results in more consistent DX reports. A "Q" beam has been used at W9LFU for almost a year with excellent results.

The "Q" beam can be operated on the fourth harmonic although the gain is reduced due to the wider spacing (0.8 wavelength) of the elements, and it is probable that the radiation pattern is multi-lobed. Each element then consists of two full-wave sections fed at the ends. The end impedance to ground of a horizontal full-wave antenna is of the same order as that of a half-wave antenna, and it is to be expected that the impedance at the receiving end of the "Q" section will be in the neighborhood of 1200 ohms.

Since the "Q" sections at the fourth harmonic have an electrical length of one wavelength, they function as two one-to-one transformers in series. The 1200-ohm impedance, therefore, is reflected to the transmission line end of the "Q" section as explained under second harmonic operation. Fourth harmonic operation was not attempted, and no calculations were made of either the gain or field pattern.

Acknowledgment

Considerable credit is due Fred Hager, Jr., W9DRG, for doing the experimental work, checking the original calculations and determining the radiation patterns.

Strays

— Said the electron to the amplifier grid, "Greetings and excitation." — *W4DZB*

According to a news item found by W1KTX in a small Mass. newspaper, one of the local citizens "was recently granted a license for an *amateur broadcasting station* and *assigned a wavelength for his special use.*"

No poaching, boys!