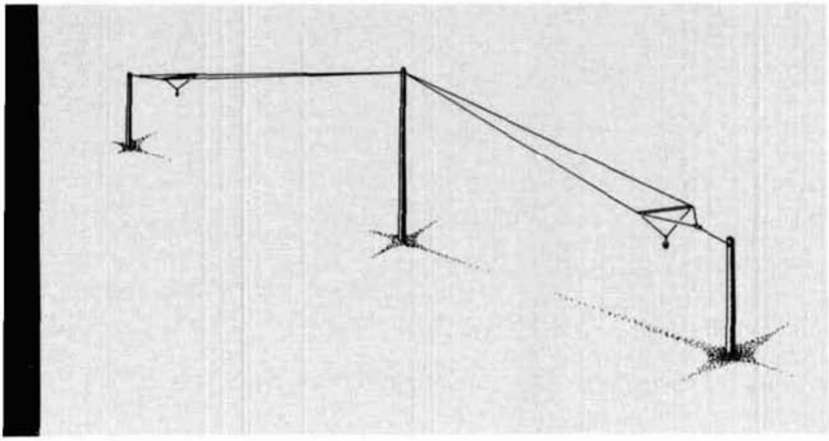


wide bandwidth bow-tie antenna for eighty meters

Discussion of a bow-tie antenna design using galvanized-steel wire that provides low swr performance over the entire 80-meter amateur band

Dwight Borton, W9VMQ, Box 93, Zanesville, Indiana

One of the problems requiring a decision when you establish a station is the selection of an antenna or group of antennas for the bands on which you want to operate. To make the best use of your environment and space available requires some study and planning.

In the case of the limited space of a city lot, especially for an 80-meter antenna, special steps may be needed for satisfactory results. A major consideration for an 80-meter antenna is the portion of the band you intend to use. The ordinary single-wire horizontal dipole, when used on this band, for example, will not work well over the entire band without some sort of antenna tuner or matching system. Verticals have the same limitations, but this article is concerned only with a horizontal antenna.

A typical horizontal dipole, resonant at 3.75 MHz, will approximate a series-resonant circuit as shown in **fig. 1**. Resistance R represents the radiation resistance which will be about 50 ohms. The inductive and capacitive reactances, X_L and X_C, with a Q of 14 will be about 700 ohms (14x50 ohms) at the resonant frequency.

Fig. 2 shows a swr vs frequency curve for a horizontal, single-wire antenna, resonant at 3.75 MHz, measured and used as a standard of comparison for the experiments that follow. Tests made at four other amateur stations show the curve of **fig. 2** to be typical for antennas of this type.

One important fact must be noted at this point: the majority of swr bridges made for amateur use will not provide accurate readings on the 80-meter band because of the non-linearity of the germanium diodes used in the simple bridge circuits. A Heath HM-102 swr bridge was used to obtain the curves presented here. This unit checked very closely with a Waters 365A reflectometer as well as with a standard Bird wattmeter. The typical, simple bridge will measure swr as much as 35% low on 80 meters.

Using the values of **fig. 1**, the inductive reactance of the antenna at 4 MHz will be (4/3.75)700 = 747 ohms; the capacitive reactance, (3.75/4)700 = 656 ohms. The net reactance is 747 - 656 = 91 ohms (inductive). At 3.5 MHz the inductive reactance will be (3.5/3.75)700 = 653 ohms; capacitive reactance is (3.75/3.5)700 = 750 ohms, and the net reactance is 750 - 653 = 97 ohms (capacitive). Neglecting the resistance change with frequency, which is small, the impedance at 4 MHz will be approximately 50 + j91 ohms; at 3.5 MHz the impedance will be approximately 50 - j 97 ohms.

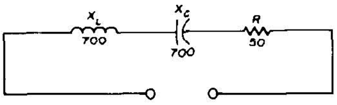


fig. 1. Equivalent circuit of single-wire horizontal dipole. Values are typical of those at resonance.

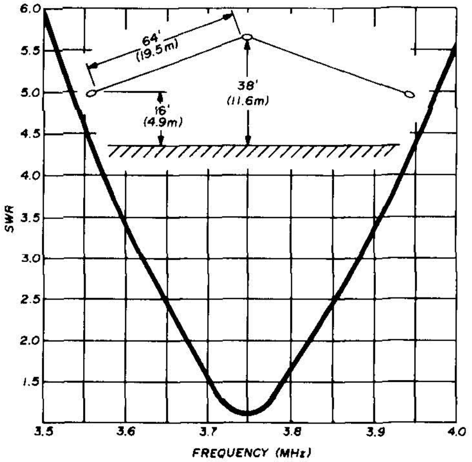


fig. 2. Swr vs frequency curve for single-wire antenna which is resonant at 3.75 MHz (radiation resistance = 45 ohms). Antenna is made from number-14 copper wire.

Fig. 2 shows the swr variations across the 80-meter band for the single copper-wire antenna with the maximum points at about 5.6:1 on the band edges. To reduce the swr (to broaden the frequency range of the antenna) you can reduce the Q by reducing the reactance or raising the radiation resistance. One method of reducing the reactance is by using a larger diameter antenna conductor. However, in most cases this is impractical at low frequencies. To reduce the Q of the single-wire antenna from 14 to 10, for example, would require a diameter of 640 mils or 0.64 inch (16mm). The use of RG-8/U coaxial cable, with the inner and outer sections connected in parallel, reduced the Q of the antenna to about 12.

A much more practical method of increasing antenna bandwidth is by using the bow-tie or fan configuration shown in **fig. 3**. With a wire separation of 7 feet (2.1 meters) or more and copper wire, the Q can be reduced to about 10. This brings the swr at the band edges down to about 3.8:1. For swr no higher than 2:1, the bandwidth is increased to 190 kHz.

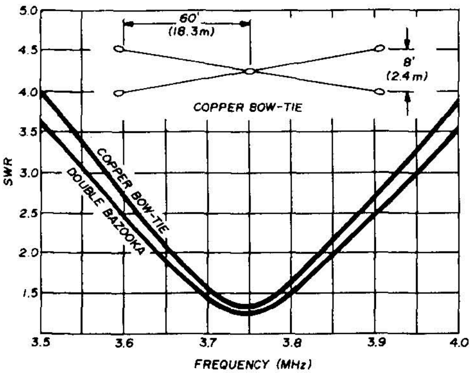


fig. 3. Swr comparison of the copper bow-tie and double bazooka antennas on 80 meters. Radiation resistance of the bow-tie is 35 ohms at 3.75 MHz; radiation resistance of the double bazooka is slightly lower.

double-bazooka antenna

The so-called double-bazooka or coaxial antenna is another modification for increasing the bandwidth of the basic horizontal dipole. However, the results were disappointing in the tests I made with this system. With new RG-58/U cable and very careful construction, with open-wire line for the end sections, the best I could obtain was an swr of about 3.5:1 at the band edges, an 8% improvement over the bow-tie (see **fig. 3**). The use of RG-8/U or RG-11/U for this antenna was not tried.

On the basis of the considerably greater cost and work required to build the double-bazooka antenna, it compares poorly with the bow-tie. The possible balun characteristic it is supposed to have is difficult to determine and of doubtful value.

galvanized wire

About two years ago, with more antenna experimenting in mind and copper wire in short supply, I obtained a roll of galvanized steel electric-fence wire at a farmers' supply store. When I built a single-wire dipole with this wire, a considerable lowering of swr was noted. The same wire in a bow-tie showed an swr of about 2.5:1 at the 3.5- and 4-MHz band edges. When I checked the radiation resistance at resonance, it was found to be about 50% higher than with copper, or about 75 ohms for a single wire and 50 ohm for the bow-tie (see **fig. 4**).

Speculation as to the reason for the increased radiation resistance, as well as how much antenna loss may have increased because of the higher resistance of this wire, led to quite a bit of research in reference books and experimenting.

First off, the wire I used is designated as number-16, but this refers to the

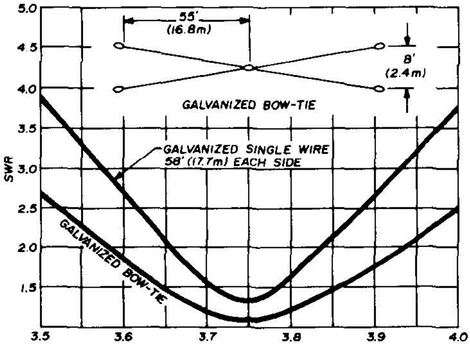


fig. 4. Swr performance of a galvanized single-wire dipole and a galvanized-wire bow-tie. Both antennas are resonant at 3.75 MHz. Radiation resistance of single-wire dipole is 75 ohms; radiation resistance of bow-tie is 50 ohms.

size before the zinc galvanizing is applied. Checking the wire table shows the diameter of number-16 as 50.8 mils (1.3mm). When checked with a micrometer, the wire measured 62 mils (1.5mm). The diameter of number-14 wire is 64 mils (1.6mm) so this wire is very nearly the equivalent. Although the use of galvanized wire for an antenna is by no means anything new, information on its rf characteristics is difficult to find. After failing to find anything in the antenna reference books, some experimenting led me to results that indicate, I think, a loss figure that is not too high when compared to copper.

The resistance tables show zinc with two to three times the dc resistance of copper. And, because of skin effect, most of the antenna rf current will be in the zinc coating. In an effort to get a comparison, equal lengths of number-14 copper wire and number-16 galvanized-steel wire were wound on identical forms and checked for Q at 3.75 MHz with a Q-meter. This test showed the copper-wire coil had a Q about six times that of the galvanized-wire coil. From this data it was assumed that a 6-to-1 ratio of rf resistance was fairly correct at 3.75 MHz.

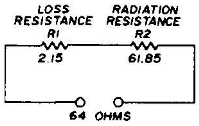


fig. 5. Relationship of loss resistance, R1, and radiation resistance, R2.

The actual loss resistance of a copper-wire antenna at 3.75 MHz is another thing that is very hard to find in the reference books. The loss resistance is usually considered to be "extremely low" or "negligible," and the only book I could find with anything like a definite statement was *Transmission Lines, Antennas and Waveguides*.[1] On pages 113 and 114 the authors stated that, when using 80-mil (2mm) copper wire at a frequency of 3 MHz, a dipole with 64 ohms load resistance at resonance will have 3% of the 64 ohms as loss resistance. This works out to be 1.92 ohms, and should be nearly the same at 3.75 MHz as the shorter length would just about balance the effect of the higher frequency. For number-14 copper wire, the smaller diameter should raise this to about 2.15 ohms ($1.92\sqrt{80/64}$).

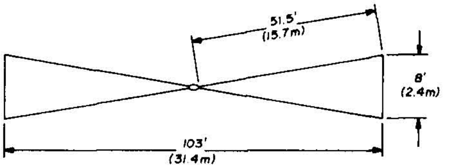


fig. 6. In this modification of the basic bow-tie antenna, the ends are tied together. Bandwidth is affected little by spreads from 6 to 16 feet (1.8 to 4.9 meters). Radiation resistance of this antenna is 50 ohms at 3.75 MHz.

Fig. 5 shows the relationship of the loss resistance and the radiation resistance. The percentage of power lost in heating the wire, of the total applied to the antenna, would be R1/(R1 + R2) = 2.15/64 = 3.4%; the percentage radiated would be 100−3.4 = 96.6%. For the galvanized-steel wire, we can assume the loss resistance to be six times 2.15 or 12.9 ohms. It is assumed that this figure for the single galvanized wire will remain substantially the same with average variations in antenna height and inverted-vee angle. For the single galvanized wire, the loss ratio is 12.9/75 = 17.2%, yielding an efficiency of 82.8%.

Because the two wires of the bow-tie are in parallel for the antenna current, the effective loss resistance should be about one-half that of the single wire. For the copper and galvanized bow-ties, therefore, the loss resistance should be about 1.08 ohms and 6.45 ohms, respectively. The relative frequency response of the antennas that have been checked can be expressed by the bandwidth over which they can be used with no more than a 2:1 swr (see **table 1**). The figure of 2:1 is used because this is the maximum swr specified by many manufacturers for their transmitters or transceivers. An swr of 2:1 is also the value above which line loss begins to mean something.

table 1. Bandwidth of different 80-meter antennas for maximum swr or 2:1 (antenna resonant at 3.75 MHz).

antenna type	load resistance	loss resistance	percent loss	bandwidth
Single copper wire	45 ohms	2.15 ohms	4.8%	165 kHz
Single galvanized wire	75 ohms	12.90 ohms	17.2%	188 kHz
Copper-wire bow-tie	30 ohms	1.08 ohms	3.6%	190 kHz
Double bazooka	35 ohms	—	—	206 kHz
Galvanized-wire bow-tie	50 ohms	6.45 ohms	12.9%	325 kHz

bow-tie antennas

A useful modification to the basic bow-tie antenna is that of tying the two wires together at the ends as shown in **fig. 6**. This shortens each side by about one-half of the end separation as shown. The overall length of 103 feet (31.4 meters) is very desirable where space is limited. The end connection can be made by using light-weight aluminum spreaders, a wood spreader with wire connector, or any other method that provides the mechanical spread and the electrical connection.

table 2. Losses of copper and galvanized bow-tie antenna systems with RG-8/U coaxial feedlines.

antenna type	frequency	antenna loss	feedline loss	total loss
Copper-wire bow-tie	3.75 MHz	0.17 dB	0.50 dB	0.67 dB
Galvanized-wire bow-tie	3.75 MHz	0.65 dB	0.28 dB	0.93 dB
Copper-wire bow-tie	4.00 MHz	0.17 dB	0.88 dB	1.05 dB
Galvanized-wire bow-tie	4.00 MHz	0.65 dB	0.40 dB	1.05 dB

The spread of the wires can be either horizontal or vertical. A variation of spread from 6 to 16 feet (1.8 to 4.8 meters) makes very little difference in the swr characteristic. A very wide spreader, however, results in a proportionate reduction in overall length. **Fig. 7** shows one arrangement that worked very well with swr performance slightly better than the standard spread.

A simple and economical L-network tuner, as in **fig. 8**, will allow an antenna cut for resonance at 3.75 MHz to be used over the entire 80-meter band with no more than 1.5:1 swr at the transmitter terminals. The maximum swr on the feedline is only about 2.6:1 so with RG-8/U feedline, the line loss due to swr would be about 0.34 dB at 3.5 MHz and 0.44 dB at 4 MHz, practically negligible amounts.

A comparison of the associated feedline loss of the two bow-tie antennas (no tuner) is presented in **table 2**. The larger feedline loss of the copper bow-tie is the result of the low radiation resistance of 30 ohms which results in considerably higher line current. This effect was checked out experimentally with a dummy antenna on the bench.

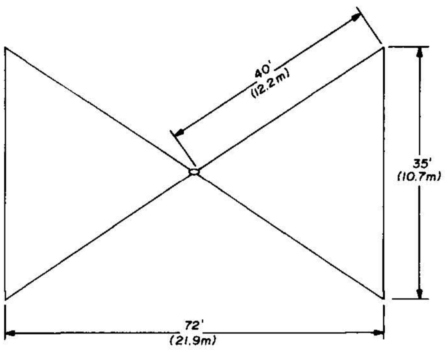
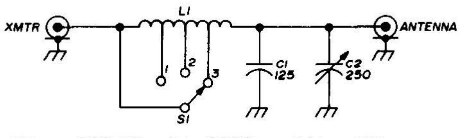


fig. 7. Bow-tie antennas can also be built with a very wide spread as shown here. As well as shortening the overall length of the antenna, this slightly improves the swr performance. Radiation resistance of this antenna is 50 ohms at 3.75 MHz.

Table 2 shows that the price paid in increased loss from the use of the galvanized steel wire is small enough to justify its use for the resultant broadband characteristic of the antenna. Its lower cost, compared to copper, is a fringe benefit. The durability of this wire, if my case is typical, is very good. The same wire has been up for two years with no visible rust. A coating of varnish or lacquer could be applied before putting the antenna up, if desired.



C1	125 pF mica, 1000 working volts
C2	250 pF air variable, 0.030" (0.8mm) spacing or greater
L1	9 turns no. 16, 1-7/8" (48mm) diameter, 1" (25mm) long, tapped at 2, 5 and 7 turns

fig. 8. Simple L-network antenna tuner which can be used to match the bow-tie antenna to 50 ohms over the entire 80-meter band (swr - 1.5:1 or less). Inductor L1 is 9 turns no. 16 airwound on 1-7/8" (48mm) diameter, 1-inch (25mm) long, tapped at approximately 2, 5 and 7 turns. Capacitor C2 should have spacing of 0.03" (0.8mm) or more.

operating Q

The operating Q of the bow-tie antenna can be reduced further by using the parallel compensating circuit shown in **fig. 9**. This circuit is simple, inexpensive and will work with any dipole to some extent. It makes use of the principle that a parallel tuned circuit has the opposite reactance variation on each side of resonance as that of a series resonant circuit. When connected as shown in **fig. 9**, the parallel network will cancel some of the series reactance exhibited by the antenna on each side of resonance. The values of inductance and capacitance were determined by experiment for best results. The capacitance is 2500 pF and the coil is adjusted by means of a grid dipper to resonate with the capacitor at 3.75 MHz.

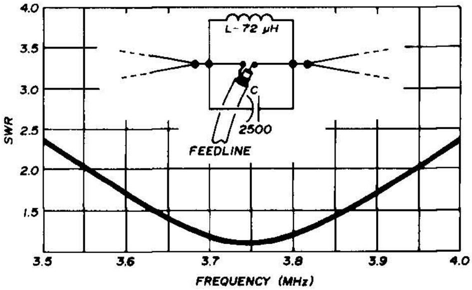


fig. 9. The bandwidth of the galvanized-wire bow-tie antenna can be increased still further by the addition of the parallel L-C circuit shown here (see text). Feedline is 88-feet (24.4m) long.

By shortening or lengthening this antenna, the resonant point can be moved higher or lower to obtain the desired coverage. Eight inches (20.3cm) of change, in each wire, will produce about 80 kHz frequency shift.

Considerable time and effort have been spent to answer two obvious questions: Why does the bow-tie antenna exhibit broader response than a single wire, and why does the use of galvanized steel wire show the same effect? As for the first question, one reference book indicated that the bow-tie arrangement effectively increased the conductor size. That does not satisfy me. The most logical explanation seems to be that the two parallel wires reduce the inductance while at the same time increasing the capacitance between the halves of the antenna and the ground. The reduction in reactance is great enough to more than compensate for the reduction in radiation resistance, resulting in lower Q.

As to why galvanized steel wire increases the bandwidth of the antenna, it is thought that the 60% increase in feedpoint resistance at resonance (in the bow-tie), as indicated by an antenna noise bridge, must be the reason for the lowered Q. Part of this increase is due to the higher loss resistance, of course, and this has been calculated to be about 6.45 ohms while the actual increase is 20 ohms. This would require a ratio of 20/1.08 or about 18.5 times as much rf resistance in the galvanized as the copper antenna. Even considering the limits of the Q meter for making coil comparisons, this is much too great an error to believe possible.

It has been noticed, however, that the galvanized wire, for a given resonant frequency, is about 4% shorter than the copper wire. This could be explained, as suggested by WB0BHG, by a "velocity factor" effect of the current flow slowing down on the higher resistance wire.

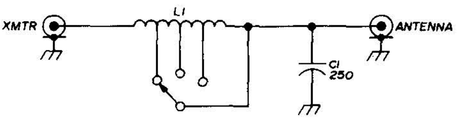
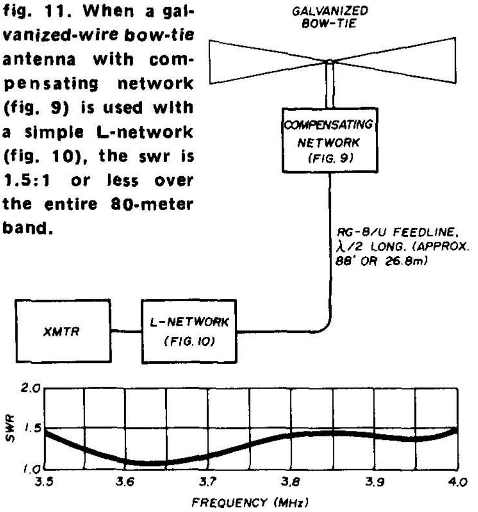


fig. 10. L-network for use with the bow-tie antenna with compensating network shown in fig. 9. Resultant swr curve is plotted in fig. 11. L1 is 9 turns no. 16, 1-7/8" (49mm) diameter, 1" (25mm) long, tapped at 2, 5 and 7 turns. Capacitor C1 is a 250 pF mica, 1000 working volts.

fig. 11. When a galvanized-wire bow-tie antenna with compensating network (fig. 9) is used with a simple L-network (fig. 10), the swr is 1.5:1 or less over the entire 80-meter band.



This might raise the radiation resistance and lower the Q.

One experiment was tried using number-26 copper wire instead of galvanized steel. The swr at the band edges of 80 meters was about 3.2:1 and the radiation resistance about 65 ohms. The rf resistance of number-26 copper, according to the wire table, should be about 85% of the single galvanized-steel wire.

The transmission line used for all tests and swr curves was 88 feet (26.8 meters) long, checked out with a noise bridge for one-half wavelength at 3.75 MHz. It was found experimentally that the circuit of **fig. 10**, with the values shown, when inserted between the transmitter and feedline, modified the swr curve to that shown in **fig. 11**. For this result, however, the transmission line must be close to one-half wavelength long. To obtain the averaging out effect the transmission line should be within 5% of one-half wavelength long.

The simple circuit of **fig. 10** replaces that of **fig. 8** when the parallel compensating circuit at the antenna and a half-wave feedline are both used. This brings the system to the point where no tuning is needed at all, with very low swr at the transmitter output terminals.

operation

The ability to work across the entire band with no more than 1.5:1 swr, as shown in **fig. 11**, provides very smooth operation. A variable antenna tuner with a coax fed copper antenna will also cover the 80-meter band but with a much more complicated tuner and with much higher line loss.

Swr curves were run with and without a balun at the center of the antenna. Both straight-core and toroid types were tried. The only observed difference was a downward shift in resonant frequency by about 50 to 75 kHz. Substitution of number-14 galvanized wire with an actual diameter of 75 mils (1.8mm) resulted in a very small change as compared to number-16 wire. A third wire, strung between the two wires of the basic bow-tie, was tried with very little change.

One thing I did notice was that twisting the two wires together at the center, even for 2 or 3 feet (61 to 91cm), raised the swr about 6%. This effect led me to try bracing the two wires about 10 inches (25.4cm) apart at a point about 18 inches (45.7cm) out from the meeting point, but no improvement was observed.

I experienced no difficulties from the wires getting twisted or tangled after the antenna was installed. Winds up to 60 mph (97 kmh) have given no trouble.

All experimental work was carried on jointly with W8URR who first suggested the use of the bow-tie arrangement with which he had already done considerable experimenting. Both he and W8SAY are using the antenna with very satisfactory results.

reference

1. King, Mimnow and Wing, *Transmission Lines, Antennas and Waveguides*, McGraw-Hill, New York, 1945.

ham radio