trapping the mysteries of trapped antennas

A quantitative treatment of antenna trap design and construction

Much information is available pertaining to antenna design and construction. Most of this information is written for a technically competent audience and addresses the problem of antenna performance under nearly ideal conditions. With 17 years in Amateur Radio, I have yet to live in a location where compromises are not required. One very popular compromise is the use of traps to achieve multiband operation with a single antenna.

The use of traps in commercial designs, such as verticals and triband beams, has been an accepted technique for many years. Although design guidelines are available, a quantitative definition of what is required and acceptable does not seem to exist. I was puzzled about trap designs and asked why a compromise in performance should be costly. Owning a transceiver that covers 160 through 10 meters, I wanted to use as many of the bands as possible. Separate antennas for each band were out of the question because of limited space. Having no previous experience with trapped antennas, I decided it was the right time to gain some.

what is required?

I began reading assorted handbooks and college texts. I reviewed back issues of magazines and queried colleagues. I was surprised to discover how little information is available about traps, much less their use in antennas. The following information was derived from my research:

1. Traps are parallel-resonant tuned circuits that provide an effective open circuit at their resonant frequency.

2. Traps become a series inductance at frequencies below resonance, electrically lengthening the antenna. This implies that the physical length of the antenna is shorter at lower frequencies because of the inductance provided by the coil component of the trap.

3. Traps must have a high Q.

4. High-Q capacitors must be used.

5. Large-diameter coils are recommended.

6. Capacitors and inductors providing 200 to 300 ohms of reactance at resonance provide good results.

7. Traps must be resonant very near the center of the band for which they are designed.

I needed answers to some basic questions to determine the requirements of a trap:

1. What is an effective open circuit?

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2. How high is high Q?

3. How large is a large-diameter coil?

4. How close to the desired frequency must a trap be resonant?

5. What effects do traps cause at the band edges?

6. How much do traps shorten an antenna?

7. How do I tune an antenna with traps?

I'd be dishonest if I claimed that I asked all these questions at once and that my initial results were where this story ends. Actually, I went through two designs before developing the trap described here and evaluated one commercially manufactured design for comparison of performance. As I progressed, I found I had questions not answered by colleagues or reference books. Some crude testing was in order.

high Q or high impedance?

I needed to know what an effective open circuit was, and my test for this was quite simple. I built a 20-meter dipole as my reference antenna and assumed that adding a high-value resistor in series with the length of wire on the end would be like adding a high-Q trap and wire for a lower band when operating on 20 meters. I assumed a quarter wavelength on 20 meters to provide a worst-case mismatch of the antenna. I cut some wire to 16.5 feet (5 meters) in length and spliced a resistor to one end; then I connected this wire onto one end of my dipole at the opposite side of the resistor and measured the VSWR. The following results were obtained:

resistor value (kilohms)	VSWR
2.7	2.8 to 1
3.9	2.6 to 1
6.8	2.2 to 1
10.0	1.7 to 1

The VSWR of the antenna before this test was less than 1.2 to 1. I conducted the test where the antenna was best matched to get a feel for the contribution to overall VSWR.

It appears that an impedance greater than 7 kilohms must be maintained to ensure a 2:1 VSWR. A lower trap impedance can be used and compensated for by adjusting antenna lengths; but in this case the loading effect would have caused an interaction and tuning for resonance on all bands would be a frustrating experience.

While studying my impedance data and considering Q, I became a bit perplexed. As losses approach zero, Q approaches infinity and bandwidth approaches zero. If this were true, the trap would be useful at one frequency only. Zero bandwidth was not my problem. Given bandwidth and center frequency, I can calculate Q, as illustrated by this example:

Given: $F_c = 14.175\,MHz$ (center of 20 meters)

$3\,dB\,BW = 0.35\,MHz$ (width of 20-meter band)

Therefore:

$$Q = \frac{F_c}{3\text{-}dB\,BW} = \frac{14.175}{0.35} = 40.5$$

It follows that high Q is 40.5 on 20 meters and is valid if, at F_c, the impedance is equal to 14 kilohms. The impedance at the band edges in this case would be 7 kilohms, which is sufficient for a 2:1 match and assumes that the antenna and traps are tuned to 14.175 MHz exactly.

A Q of 40.5 and an impedance of 14 kilohms at resonance can be achieved with a wide variety of LC combinations and assorted types of capacitors.

Now assume Q remains constant but impedance increases at F_c. The effect is a higher impedance across the band. If the impedance at F_c remains constant and Q gets larger, the impedance at the band edges is reduced. This implies a problem, since my crude measurements indicate a need to maintain greater than 7 kilohms across the band.

My point is, *high Q may not be desirable in antenna traps*. It's important to understand that the property of the trap providing isolation is its *impedance*. It is this impedance that must be kept large. Anything larger than 7 kilohms improves isolation and is therefore desirable.

A little experience will clarify the fact that, as Q increases, the impedance at F_c increases. This is perhaps the reason why high-Q traps are considered a must for good performance. I intend to show this is not true and attempt to explain the contribution of Q to losses and bandwidth rather than to impedance at resonance.

questions answered

The most helpful reference I could find for an answer to my original question suggests that high Q is approximately 100, and a Q of 50 would be considered medium. Aside from answering my original question, this information served no useful purpose. The same is true for high-Q capacitors. Strictly speaking, Q refers to losses *in this case* rather than bandwidth. And if capacitors are used, the higher the Q, the better should be your guide. High-voltage capacitors are popular but are generally expensive and difficult to find.

Large-diameter coils seem to imply 2-3 inches (5-7.5 cm), although most triband beam manufacturers do well with smaller diameters. This information, along with the recommended 200-300 ohms of reactance at resonance, have worked well in the past; and experiments with trap designs of the more conventional type tend to support these recommendations. For this reason, I will not oppose the theories on which they are based.

I attempted a number of trap designs, looking for a low-cost, easily manufactured capacitor. Gary Myers, K9CZB,[1] used coaxial cable for the capacitor in his 7-MHz trap. My tests revealed an impedance of 50 kilohms at F_C for a 15-meter version using an HP-4815A Vector Impedance Meter. Its Q was high (approximately 126); and to ensure 7 kilohms at the band edges, the center frequency had to be accurate and stable. With a bit of persistence, careful thought, and some RG-58/U, I was able to develop the trap described here.

theory

The single-element trap simultaneously uses three physical properties that can be realized with a section of coaxial cable. Using the properties of capacitance, inductance, and coupling reduces the complexity of LC networks to an appropriately configured length of coax in the form of a coil. Models have been built, tested, and evaluated in the 3.5- to 30-MHz range and calculations verified to 150 MHz with a reasonable accuracy.

A properly designed and manufactured coaxial cable has a uniform capacitance per unit length, which is predictable, between the center conductor and shield. This capacitance can be employed in an LC network such as a tank circuit, which presents a high impedance at resonance.

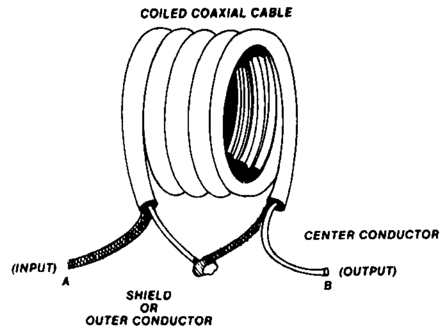

fig. 1. Single-element trap wiring detail.

A second property is that coax can be coiled. The forming of a conductor (the coax shield in this case) into a coil produces an inductance greater than that of the wire alone, due to coupling between turns. This is predictable and can serve as the inductive component in an LC network. It should be noted that only the shield is considered to be coiled and is the significant contributor to the inductive component of the trap.

Since the center conductor is shielded, the effects of coiling the cable do not influence the center conductor, which maintains a given inductance per unit length of the wire alone. Although this property has negligible effect on the operation of the trap to be described and was omitted from the calculations, one should be aware of it for applications at or near microwave frequencies. The important point is that the capacitance per unit length remains unchanged by coiling the cable due to the shielding properties of the outer conductor.

configuration

With the source of capacitance and inductance defined, the task of wiring the device remains. **Fig. 1** illustrates this requirement and shows the cable coiled as described. It is shown without a form for support as an illustrative aid. If flexible cable such as RG-58/U is used, a rigid form such as PVC plumbing stock would be required.

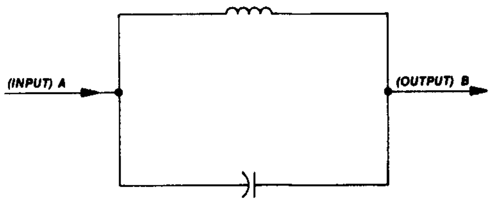

fig. 2. Electrical schematic of an antenna trap.

Fig. 2 is the schematic representation of a parallel LC network with external connections designated **A** and **B**. Notice that a dc path must be provided between terminals **A** and **B**. Also, each plate of the capacitor connects to opposite ends of the inductor. A casual look at **fig. 1** may cause some confusion since it appears that, with the center conductor connected to the shield, the cable's capacitance is short circuited. This is valid only at dc as is the case in the circuit shown in **fig. 2**. An analysis of the phase relationships required at resonance will reveal why this connection is not only valid but is also required.

The third property of the coaxial cable is the coupling between the center conductor and shield due to magnetic induction. This property (the basis of transformers) is clearly seen if viewed as a straight length of cable. **Fig. 3** shows this schematically as two parallel conductors revealing the necessary components of a 1 to 1 transformer, or more aptly, a coupler. Current injected into the primary from some source induces a secondary current in the opposite direction as indicated by the arrows. Connecting the top of the secondary to the bottom of the primary causes primary and secondary currents to oppose each other. These currents, being equal and opposite, aid the opposition of the network to current flow. At resonance, the trap has a high circulating current enhancing the coupling properties, which further improves this opposition.

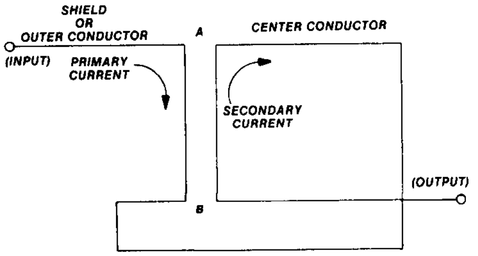

fig. 3. Electrical schematic of single-element trap as a 1:1 transformer or coupler.

With the cable configured as shown in **fig. 1** and referring to the schematic in **fig. 2**, one might assume that the input and output connections should be at the ends of the shield. This provides the tank circuit function using only the properties of inductance and capacitance. Magnetic induction is not employed when one end of the secondary remains open circuited. The connections indicated provide the return path for secondary current, and an analysis of phase relationships at resonance will validate this connection.

The inductance of the center conductor now included causes a slight shift downward in resonant frequency and was observed to be about 2.5 percent in a 15-meter trap. The significant result of this connection is the gain in impedance produced by the opposing primary and secondary currents with no detectable change in Q relative to the 3-dB bandwidth of the device. Test data provided at the end of this article illustrates the significance of this impedance gain.

Tests of traps using conventional LC configurations indicate this trap has much lower Q (wider bandwidth) but provides a comparable impedance at resonance, implying similar loss characteristics. High impedance and relatively low Q make this design superior, since the accuracy to which it is tuned and its physical stability become less critical. *The result is a trap that does not need tuning.*

In addition to these profound advantages, the cost is near zero. If you are considering erecting an antenna, you will likely have coax as your feedline. A local plumbing contractor may be a good source for discarded PVC stock sufficient for these traps.

Q versus loss

Does the low Q of the single element trap imply that it is lossy? This must be answered with another question. What is low loss? **Fig. 2** represents a tank as a capacitor in parallel with an inductor. If this were an exact representation, the impedance at resonance would be infinite. Mother nature plays her role and introduces loss represented by a resistor in parallel with the tank.

At resonance, the impedance is infinity in parallel with the resistor representing the losses, or approximately the value of the resistor alone. To determine actual losses, it's necessary to apply a voltage across the tank and solve for the power dissipated in the resistor. The power dissipated as heat in this resistor is the loss presented by the tank. It should be clear that the losses encountered are inversely proportional to the tank's impedance. If this impedance is high, the loss will be low. If Q can be reduced without decreasing the value of the resistor representing the losses, the performance in multiband antenna applications will be enhanced.

This results from using the single-element trap described and is supported by data collected on four 15-meter traps. Trap A was a commercially manufactured unit; B is the single-element trap built as I have described; C, similar to trap A, is my first attempt at a compact, low-cost design; D was a K9CZB[1]-style trap. The data as measured on an HP-4815A:

trap style	inductor	capacitor	impedance at resonance (kilohms)	Q
A	1.7 inch (4.3 cm) dia. 14 AWG (1.6 mm) wire	concentric tubing	40	142
B	1.7 inch (4.3 cm) dia. RG-58U	RG-58/U coax cable	41	56
C	1.7 inch (4.3 cm) dia. 14 AWG (1.6 mm) wire	concentric tubing	27.5	75
D	1.7 inch (4.3 cm) dia. 14 AWG (1.6 mm) wire	RG-8/U coax stub	54	126

When compared with the commercial design, the single-element trap has approximately the same impedance at resonance (equal losses) but nearly three times the bandwidth. This means the accuracy and stability can be three times worse and still achieve equal results. The traps I use were built in a hurry and are resonant out of band. There was no detectable interaction during adjustment, and the performance of the antenna has been excellent on all bands.

pros and cons

A brief review of the relative advantages and disadvantages of trap antennas compared with separate antennas per band is offered here:

advantages:

1. Multiband operation achieved with a good match on all bands.

2. Automatic bandswitching.

3. Antenna length reduced.

4. No compromise operation on highest band(s) since a full-size antenna is employed there.

5. Lower cost than separate antennas.

disadvantages:

1. Lower radiation efficiency due to trap losses on lower bands.

2. Narrowing of bandwidth due to the inductive loading presented by the traps.

3. Loss of second-harmonic rejection if bands are so related.

The first two disadvantages, though not severe, are the compromise that is made in any trapped antenna design. This is also true of the third, but this compromise deserves more comment. Single-band antennas provide second-harmonic rejection due to mismatch losses, and in a simple test nearly 20 dB of rejection was achieved. This compromise affects all of us, not just the user of the antenna, and to keep interference minimal, antenna matching systems are recommended. If a matching system is not used, careful tuning of the transmitter, and application of U.S. Regulations Part 97.67b[2] will go a long way in maintaining peace and friendship within the Amateur fraternity and among other services as well.

construction

Table 1 provides the dimensions for traps below 30 MHz. These dimensions assume RG-58/U and 1.25 inches (3.2 cm) PVC stock are the materials used. Form lengths given permit 1 inch (2.5 cm) to extend beyond each side of the coiled coax. This facilitates using the form as a support for each antenna section and can be adjusted to suit personal preferences. All traps must be close wound and should be as tight as possible to ensure mechanical stability. The coax lengths permit 3 inches (7.6 cm) to extend beyond each side of the coil, permitting antenna-section splicing and the wiring of the trap itself.

With the form and coax cut as indicated in **table 1**, assembly can begin. An 0.2-inch (0.5-cm) drill was selected to allow a snug fit for the coax.

1. Begin construction of the trap by drilling one hole approximately 1 inch (2.5 cm) from the end of the form.

2. Strip 3 inches (7.6 cm) of insulation off one end of the coax, and separate the shield and center conductor.

3. Strip 2 inches (5 cm) of insulation off the center conductor. Insert this end of the coax into the hole drilled in the PVC form until the coax jacket extends into the inside of the form no more than 0.25 inch (0.6 cm).

4. Very tightly wrap the coax around the form the specified number of turns and locate the point where the coiled coax should end. Mark this spot.

5. Move the coax end away, and drill a second hole at the marked location as near as possible to the next turn of the coil without cutting the jacket.

6. Tightly rewrap the coil to take up the slack that may have been introduced, and mark the end of the coax 0.25 inch (0.6 cm) beyond the hole just drilled.

7. With a sharp knife cut approximately half way through the jacket material only, then completely around the coax at this location.

8. In a similar fashion make a cut lengthwise along the cable from the first cut to the end of the coax. Do not remove the jacket material at this point. Again, tightly rewind the coil and insert the prepared end of the coax through the second hole.

9. Pull the coax from the inside of the form until it lies flat at both ends. (Some massaging of the end of the coax where it passes into the form may be required.) The jacket may be easily removed from the coax at this point and shield and center conductor separated.

10. Remove all but about 1 inch (2.5 cm) of insulation from the center conductor. Twist together the center conductor of one side and the shield of the opposite side. This connection should be internal to the coil form and tightly twisted to keep the leads as short as possible.

11. Cut off all but 0.5 inch (1.3 cm) and solder this connection.

12. Drill a hole 0.5 inch (1.3 cm) from each end and on the same side of the form. These holes are used to support the elements when used in a dipole or wire vertical.

13. Wrap a turn or two of the remaining end of the center conductor through the hole on its end of the form, and do likewise with the remaining end of the shield through the opposite hole.

table 1. Dimensions for constructing traps for frequencies between 3.75 and 29 MHz.

F_c (MHz)	form length (inches)	form length (cm)	coax length (inches)	coax length (cm)	number of turns	effective length (inches)	effective length (cm)
3.750	6.0	15.2	123.06	312.6	19.79	120	305
7.150	4.2	10.7	70.70	179.6	10.94	65	165
10.075	3.6	9.1	53.70	136.4	8.06	48	122
14.175	3.2	8.1	41.47	105.3	6.00	36	92
18.118	3.0	7.6	34.80	88.4	4.87	29	74
21.225	2.8	7.1	31.24	79.3	4.27	26	66
24.940	2.8	7.1	28.09	71.3	3.74	22	56
28.850	2.6	6.6	25.61	65.0	3.32	20	51

The trap is now complete and ready for installation in an antenna. A silicone-base caulk may be used to seal the traps against weather. I chose not to seal mine and they have been in service for more than a year without degradation in performance.

tuning an antenna

The last column in **table 1** provides the effective length of wire in the trap used. This length should be subtracted on all bands where the trap looks like an inductor to provide a reasonable starting length before tuning.

Start with the highest band used and construct a halfwave dipole using the traps for that band as end insulators. Tune the antenna as desired with the traps connected before going any further. Once tuned, any lower band can be added by connecting more wire to the opposite sides of the traps and extending the antenna from this point. Calculate the length of a quarterwave section on the desired lower band, subtract half the length of the dipole just built, and finally subtract the trap's effective length provided in **table 1**. The result is the length of wire required on the opposite ends of the traps.

Adjust the added sections only to tune the antenna so as not to affect the higher-band antenna that you have already tuned. Traps may be used as the end insulators for this new lower band, and another band (lower still) can be added using the same procedure. When completed, recheck VSWR on all bands. There should be little or no difference from where they were initially tuned.

test data

Fig. 4A is the antenna configuration I chose and is a combination of horizontal trapped dipoles. This provides five-band coverage with optimum bandwidth while remaining a simple construction task. A slight interaction was detected on 10 meters when 15 meters was added (the 10-meter center increased about 200 kHz). This was caused by the connection of the combined dipoles; not by the traps. **Fig. 5** shows the VSWR curves of this antenna. The VSWR of an antenna built as shown in **fig. 4B** is plotted in dashed lines to illustrate the loss of bandwidth by using this approach.

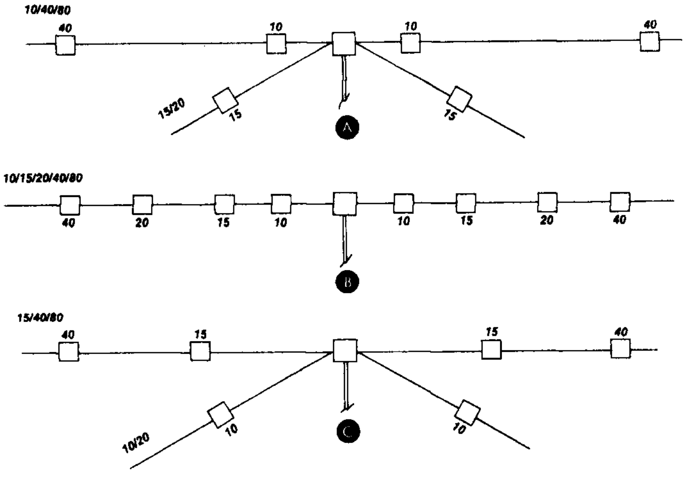

fig. 4. Trap antenna designs. Configuration in use by the author is a combination of horizontal trapped dipoles (A). Single dipole trapped antenna has narrow bandwidth (B). Recommended optimum multiband dipole is shown in C.

Fig. 4C is an alternative approach that has not been verified but is included as an improvement suggestion to reduce the VSWR observed on 15 meters. My assumption here is that the 40-meter and 15-meter dipoles are at or near resonance on 15 meters, thus reducing the feedline impedance by a factor of 2; hence a 2:1 VSWR. I will have verified this assumption as this article goes into print, so watch the letters to the editor for a report of my findings.

Fig. 6 illustrates the impedance bandwidth gained by the wiring technique described, which uses the coupling properties of the coaxial cable.

calculator program

In the interest of expanding the single-element trap applications into areas other than antennas, and accommodating those who have suitable materials other than those that have been described, I can provide a TI-58/59 calculator program that computes the number of tight-wound turns required for a given resonant frequency when the physical properties of the desired materials are specified. In addition, I have described in detail the mathematical derivation of the trap and have provided a step-by-step procedure for building and tuning the antennas described in this article. For copies, send an SASE to the author with a check or money order for $1.50 to cover photo-copy fees. TI-59 owners providing a blank magnetic card will receive a recorded copy of the program.

conclusion

The purpose of, requirements for, and effects of using traps have been explored and supported by comparative test data. In addition, a trap design has been presented that is extremely simple to build (a pair of traps can be built in less than half an hour), costs less than half a dollar per band, and by design requires no tuning. With nothing more than an SWR meter and your transmitter for test equipment, you can have an antenna performing on 80 through 10 meters in a single afternoon.

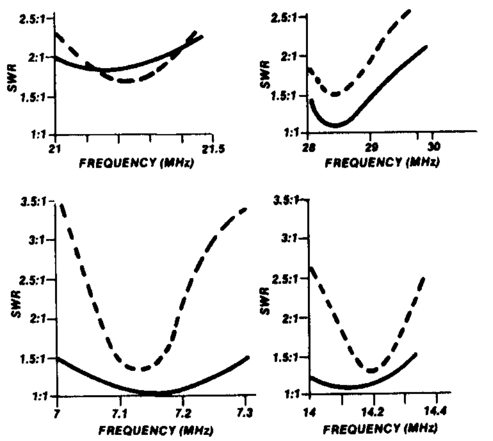

fig. 5. SWR plots of antennas in figs. 4A and 4B (dashed lines) illustrating effects of traps on antenna bandwidth.

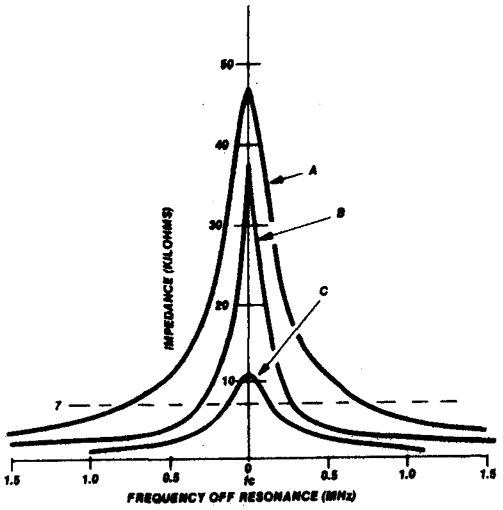

fig. 6. Comparison of relative rejection of 15-meter traps. A represents the single-element trap connected as described in the text. B represents the commercial trap of conventional design that was evaluated by the author. C represents the single-element trap's rejection if improperly connected as discussed in the text. Note the 7 kilohm bandwidth improvement over the conventional design. The rejection is plotted versus frequency away from resonance (f_c).

I hope I have been successful in my attempt to unveil the secrets of antenna traps and instill confidence in those who heretofore have been hesitant, puzzled, or otherwise afraid to pursue trap antenna designs.

acknowledgments

At this point I would like to thank Joe Williams, N2GU, for his editorial and moral support, and Ray Avery, WA2RRS, for the use of his grid-dip oscillator and his support during testing and evaluation of my trap antennas for harmonic radiation. I would also like to thank Ed Lancki, N2BHD, for the use of his commercial antenna traps in my evaluation.

references

1. Gary E. Myers, "A Two-Band Half Sloper Antenna," *QST*, June, 1980, page 32.
2. *The Radio Amateur's License Manual*, 71st edition, ARRL, April, 1974, page 98.

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