Preliminary Notes on Trap Placement

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Conventional Trap Designs

Many claims have been made about trap losses in dipoles and more complex antennas made from dipoles, such as multi-band Yagis. These claims led to an interest in discovering to what degree these losses might be verified through modeling trap antennas. Other notes in this series establish that it is possible to model traps for each band of operation with quite reasonable accuracy. So a preliminary analysis was undertaken.

At the same time, alternatives to the use of a standard solenoid inductor came to my attention. Sometimes called "linear" inductors, all the alternatives consisted of the use of a shorted transmission line stub to achieve the level of inductive reactance need to resonate with the selected capacitor at the trap frequency. Since the reactance of a shorted stub does not vary with frequency in the same manner as it does in a solenoid inductor, at least some properties of the resultant trap dipole were expected to change.

The process of optimizing NEC-4 models of trap dipoles for 10 and 20 meters in free space yielded some surprising results. Conventional wisdom, for example, suggests that one place a trap at the end of a resonant antenna at the higher frequency and then extend the element for resonance at the lower frequency. This conventional wisdom is called into serious question by models, especially when the trap inductor is some form of a shorted stub.

Modeling traps is most accurate on NEC-4 with standard lumped components. Models of "linear" inductors as physical elements required the use of physically modeled lines of the same diameter (0.5") as the antenna wire in order to ensure that results would not exceed the NEC-4 limitation with parallel and right angle wires of different diameters. (See notes on limitations of NEC-4 in another entry in this series.) Moreover, physical modeling of the transmission line stub required placing it across a single segment wire loaded with the appropriate capacitive reactance. Since modeling is most accurate when segments lengths are as equal as possible, a minimum spacing of the transmission line wires was established, roughly 0.5 feet for reasonably sized models. As will be noted in appropriate places, the resultant unorthodox construction of the "linear" inductors sets limits on the direct applicability of the results of this study to real antennas. However, the results are sufficiently suggestive to call for further studies and extensive field experimentation by hams thinking of building their own trap antennas.

{The phantom second study: In order to provide a check on the work done with fat aluminum elements, I also undertook a study of trap wire dipoles using #14 copper wire for all segments, including those that are a part of linear inductors. To separate the wire results from the aluminum results, I am setting forth the wire notes within {} as addenda to any relevant segment of the study.

{The copper wire antennas will be given in inches, while aluminum dimensions will be in feet. This will distinguish the two in the intermix of the text. Additionally, the copper wire antennas are more heavily segmented than the aluminum ones, at about 4" per segment.}

The Basic Antennas

The basic models of 10- and 20-meter dipoles used for all comparative purposes in this study have aluminum elements 0.5" in diameter. The 10 meter (28.5 MHz) model used 31 segments for an approximate length of 0.5' per segment. The 20 meter (14.175 MHz) model used 61 segments for an equivalent segment length. 0.5' per segment is well within both upper and lower limits of recommended segment lengths for accurate NEC-4 modeling. These independent models had the following properties. All gain figures are for free space.

Antenna	Length (ft)	Gain (dBi)	Feed Z (R+/-jX)
10 meter	16.46'	2.13	71.92 - j0.28
20 meter	33.32'	2.13	72.22 + j0.54

Obviously, there is nothing surprising in these models. The combination of element diameter and material losses result in a net loss of 0.02 dBi relative to the ideal free space dipole of infinitely thin, but lossless wire.

It should be noted that throughout this study, antennas are resonated, where resonance is defined as a feedpoint reactance of less than +/-1 ohm. Further accuracy of resonance was deemed unnecessary, given other limitations of the modeling exercise.

In order to make comparisons as reasonable as possible, antenna wire of 0.5" diameter aluminum is used throughout the study.

{Basic #14 copper wire dipoles differ from fat aluminum dipoles in gain, with only minor differences in feedpoint impedance. Although copper is more conductive than aluminum, the losses due to the small diameter of the wire more than offset the conductivity to yield noticeably lower gains (although nothing is operationally noticeable for full-size standard dipoles).

{The basic dipoles in copper wire are as follows:

Antenna	Length (in)	Gain (dBi)	Feed Z (R+/-jX)
10 meter	200.4"	2.10	72.68 - j0.05
20 meter	404.0"	2.08	72.99 - j0.38

{As noted, all dimensions for wire antennas will be in inches to provide for additional segmentation in a convenient manner--and to allow you to easily know when we are working with aluminum and when with copper.}

Conventional Dipole Traps

A conventional trap consists of a parallel combination of capacitance and inductance resonated (usually) at the lower limit of the higher frequency band to be covered by the trap dipole. Past conventions suggest that a component reactance near 200 ohms (at resonance) is useful, and some measurements suggest that coil Qs of 200 and upward are possible.

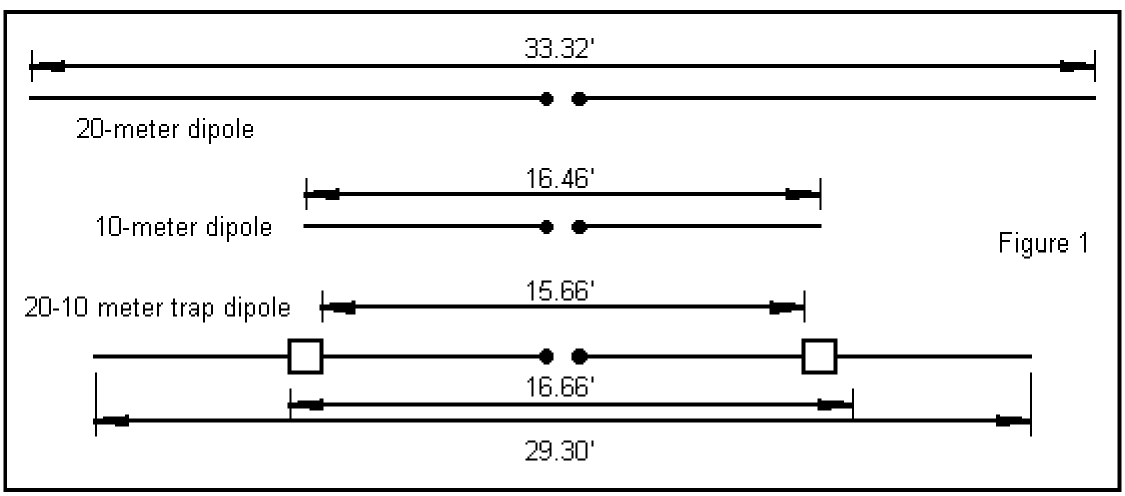
Therefore, a trap was designed using a 1.2 microH inductor and a 26.92 pF capacitor in parallel. The reactance of each component at resonance (28.0 MHz) was 211 ohms. A Q of 200 was arbitrarily assigned to the coil.

At 28.5, the 10 meter target frequency, the capacitor reactance is about 207 ohms, while the inductor reactance is about 215 ohms. At 14.175 MHz, the 20 meter target frequency, the reactance of the capacitor climbs to about 417 ohms, while the inductor reactance decreases to about 107 ohms. However, in analyzing the trap at any frequency, one cannot simply use any of these figures. Calculations of the reactance and Q at the target frequencies yielded the following results:

Frequency	Reactance	Q
28.5 MHz	-6019 ohms	7
14.175 MHz	144 ohms	149

Although the 20 meter reactance figure does not seem too far off the reactance of the inductor alone, it is in fact nearly 40% different, an amount that results in a considerable difference in the required additional linear element length needed to resonate the trap dipole at 20 meters.

Since the parallel equivalent resistance for a circuit with a coil Q of 200 differs from band to band, separate models were required for each band. In each model, a parallel R-L-C load was placed in the last segment of the 10 meter inner wire. Reiterative modeling was done until the models resonated at both target frequencies with the same inner and outer wire lengths with their appropriate loads. Figure 1 illustrates the models, with standard 20-meter and 10-meter dipoles for comparison.



The dimensions of the model in Figure 1 should draw some attention. compared to a 10 meter dipole with a length of 16.46, the 10 meter inner wire's length of only 16.66' indicates that the load is mostly within the standard 10 meter length. The segments of the antenna are roughly 0.5' each, and the loaded segment is on each end. A load is distributed throughout the segment, although often thought of as centered in the segment. In either way of thinking, the load is within the 16.46' limits of the standard unloaded dipole for all but 0.1' per end.

The following "explanation" is a tempting one: If we look at the antenna from a different perspective, the dimension become much clearer. The load is a part of the antenna at 10 meters. Except at 28 MHz precisely, the trap offers a heavily capacitive load (more than 6000 ohms at 28.5 MHz) to each end of the antenna, thus demanding some slight lengthening--namely about 0.1' per end. (Note: although it requires only small inductive or capacitive loads at the center of a dipole to effect significant changes in the dipole's electrical length, it requires massive loads at or near the element ends to create relatively minuscule changes in electrical length. Hence, the 0.1' change of length for 6000 ohms of loading is normal.) As experience with the wire version of the trap antenna suggests, we cannot wholly accept this account.

At 20 meters, the overall length of the antenna is only 29.3' or about 4' shorter than a full size dipole. This shortening is fully expected due to the inductive loading provided by the trap at 14.175 MHz. (Note: a dipole loaded only by the 107 ohm reactance of the coils, without consideration of the full trap circuit, would have required about a 30.2' length, nearly a foot longer than the trap dipole at 20 meters.) For reference, we may note that the extensions beyond the traps are 6.32' long each.

{The dimensions of the #14 copper wire trap antenna partially adhere to the account for the aluminum version and partially deviate from it. The overall length of the wire trap dipole with identical traps is 366.4" with a 196.4" 10-meter section (including two 4" trap segments) and 85" 20 meter extensions. The reduction in 20 meter length from the standard dipole 404" is evident, due to the loading by the remnant reactance of the trap. However, the 10-meter section is 4" shorter than a standard 10-meter dipole of the same material. Although it remains true that the trap lies within the 10-meter antenna an acts as a load on it, the effects of wholly capacitive reactance on the end does not wholly account for the element length.

{Part of the explanation consists of noting that the wire diameter and the resonant frequency of the trap are not independent variables. As the resonant frequency of a trap is lowered relative to the operating frequency, the required length of the trapped section grows shorter. The resonant frequency effect is larger for smaller diameter wires than for large diameter wires, thus shortening the wire antenna more than the capacitive reactance at its end would lengthen it.}

Performance of the Q=200 trap dipole on each band is as follows:

Frequency	**Gain (dBi)**	**Feed Z (R+/-jX)**
28.5 MHz	**2.03**	**83.63 - j0.33**
14.175 MHz	**1.98**	**63.56 - j0.72**

Note that the high band feed impedance rises and the low band feed impedance falls relative to a standard dipole. The 10 meter dipole gain is down from the standard by 0.1 dB, while the 20 meter dipole gain is down by 0.15. The decrease in gain on 20 meters is due mostly to a combination of the shortening of the dipole from its standard length and to trap losses. We can roughly sort these losses. An unloaded dipole at 14.175 MHz with a length of 29.3' has a gain of about 2.03 dBi, about 0.1 dB down from a standard dipole. The remaining 0.05 dB loss stems from power losses within the Q=200 trap itself.

{Similar trends show themselves with the copper wire antenna. Its performance figures are as follows:

Frequency	Gain (dBi)	Feed Z (R+/-jX)
28.5 MHz	**1.83**	**90.40 + j0.18**
14.175 MHz	**1.94**	**66.33 - j0.96**

{The gain and feedpoint impedance differences between the 20 meter aluminum and copper trap models are fully consistent with the differences between the standard dipoles for that band. However, the losses at 10 meters are unexpectedly high. The 10-meter model was, of course, double checked for error. The figures are consistent for a variety of wire models using NEC models of R-L-C loads for the traps. The program shows nearly a 0.5 dB power loss within the loads of the wire antenna, far above the loss of less than 0.1 dB for the same traps in the aluminum dipole. The notion that "traps are traps" may be called into question, since it appears that the losses of identical traps may differ according to other factors of antenna design.}

Currents and Losses

It is also useful to examine the current distribution in a trap antenna. Figure 2 compares the current distribution for a standard dipole, the 10-20 meter trap dipole at 10 meters and the 10-20 meter trap dipole at 20 meters. Current maxima are not to scale to save drawing space and to clarify a few matters. The standard dipole shows are decrease in current away from the feedpoint in a curve that is close to sinusoidal.

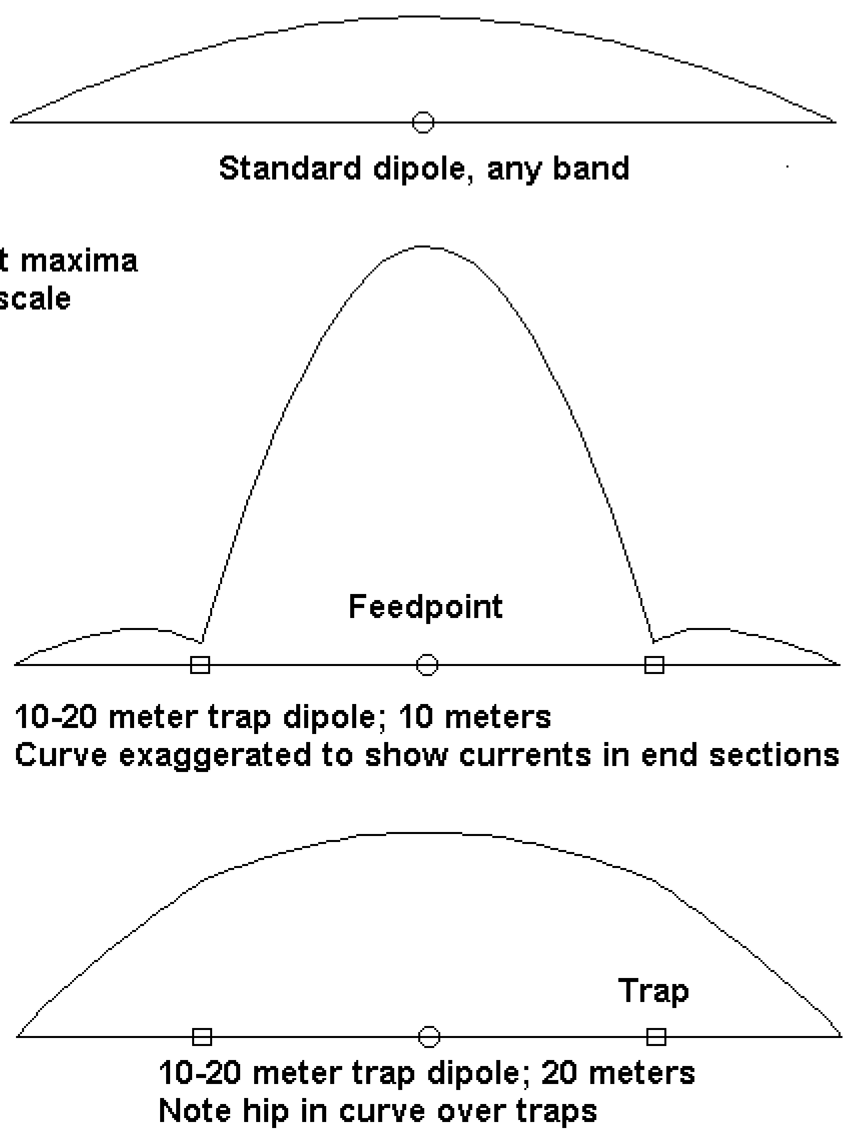


Figure 2: Current Distribution on Standard and Trap Dipoles

The trap dipole at 10 meters also shows a roughly sinusoidal curve outward to the traps. The feedpoint current maximum is exaggerated to reveal the small but real current magnitude curves on the outer parts of the elements. The curve on each extension is not a sine curve, but reaches a maximum about 1/4th the way outward on the extension. Depending on trap design, current levels can reach 8 to 10% of the feedpoint current. Although this current is small, it is not negligible. It does contribute to the overall radiation of the antenna at its higher frequency.

The 20-meter curve is also exaggerated, this time to reveal the slight "hip" in the current curve at the trap point. If we think of the antenna as divided into segments, each about 0.5' long, we may note that the segment of the trap antenna just inside the trap has a current level (relative to 1) of .79. The corresponding current in the standard dipole is about .77. In the segments just beyond the trap, the current levels for the trap and standard dipoles are both .71. However, the current decreases to zero in 15 segments for the standard dipole, while the curve is steeper for the shorter trap dipole--only 12 segments.

The more rapid decrease in current in the trap dipole results in a slightly weaker radiation field than for the standard dipole, as reflected in the slightly lower gain figure. The Q=200 trap at roughly one-half its resonant frequency has regained 3/4ths of its Q (about 148), and hence its losses are low. Had the models used here been for 10-15 meters or for 15- 20 meters, trap Q at the lower frequency would have been lower, with a somewhat higher loss. However, for relatively high-Q traps, design losses are low, as reflected in the earlier division of loss calculation.

This modeling exercise cannot, of course, address construction losses that may be present in poorly designed traps. Connection losses, inadequate sizing of coil wire, coil wire material losses, and container/shield- induced losses may all contribute to trap losses not included in these models. However, with a frequency separation of at least 2:1, a well- design trap appears to reduce gain on the lower frequency mostly by shortening the resonant length of the antenna.

As a comparison, the same values for trap inductance and capacitance were run for 28 MHz traps with a Q of 75. The result was an antenna of almost the same dimensions as the Q=200 trap dipole for 10 and 20 meters. The 10- meter element was lengthened by 0.2' and the overall length increased by the same amount. (The performance table for the Q=200 trap is repeated to make the contrast more evident.)

Trap Coil Q=200

Frequency	**Gain (dBi)**	**Feed Z (R+/-jX)**
28.5 MHz	**2.03**	**83.63 - j0.33**
14.175 MHz	**1.98**	**63.56 - j0.72**

Trap Coil Q=75

Frequency	**Gain (dBi)**	**Feed Z (R+/-jX)**
28.5 MHz	**1.63**	**91.81 - j0.70**
14.175 MHz	**1.85**	**65.49 - j0.65**

The performance difference at 20 meters is most readily explicable. Reduced length has already been shown to contribute approximately 0.1 dB loss of gain relative to a full size standard dipole of the same materials, the gain loss due to the trap design and construction is 0.05 dB in the Q=200 model and 0.18 dB in the Q=75 model. Power losses in traps are inversely proportional to relative Qs for any two proposed designs. Although these figures do not translate directly into accurate assessments of gain loss, they are indicative of those losses.

The losses at 28.5 MHz are more dramatic: 0.4 dB. These are losses of power wholly within the trap assemblies themselves.

In multi-element antennas, losses due to loading and shortening of elements tend to be additive. Therefore, one might expect about three times the gain reduction of a single dipole in an optimized 3-element trap Yagi relative to a similarly optimized 3-element Yagi with full-length elements. This feature holds apart from any other design factors that may also affect antenna performance.

{The same comparison with Q=200 models was run with the #14 copper wire antenna, again using the same trap design at Q=75. Like the aluminum antenna, slight dimensional adjustments were made to achieve resonance. However, for this table, the dimensions were left identical to those for the Q=200 model to show the amount of frequency shift at both 10 and 20 meters, as indicated by the remnant feedpoint reactance. The comparison is as follows:

Trap Coil Q=200

Frequency	**Gain (dBi)**	**Feed Z (R+/-jX)**
28.5 MHz	**1.83**	**90.40 - j0.18**

14.175 MHz	**1.94**	**66.33 - j0.97**

Trap Coil Q=75

Frequency	**Gain (dBi)**	**Feed Z (R+/-jX)**
28.5 MHz	**1.15**	**105.3 - j3.52**
14.175 MHz	**1.83**	**68.15 - j1.18**

{At 20 meters, where the trap acts as an inductive load, the decrease in gain due to the lower Q trap is 0.11 dB, comparable to the drop in the aluminum antenna. The same inverse relationship between Q and power loss in the trap applies to the wire antenna model as well.

{The drop in gain at 10 meters for the Q=75 model is 0.68 dB relative to the Q=200 model, with the power loss in the trap also inversely proportional to the ratio of Qs. However, the drop is less than double the drop in the aluminum antenna. It would appear that the rate of drop depends in part upon the relative Qs of the antenna and the traps. The aluminum antenna is fairly low-Q, with something like 10 times the circumference and surface area of the wire antenna. Not until the descending trap Q reaches a certain value relative to the antenna Q does the power loss in it increase at an initially rapid but then a tapering rate. For the higher-Q wire antenna, this relative value is reached at trap Qs higher than 200; for the aluminum antenna, the critical value region may lie between trap Qs of 75 and 200.}

{A test of this perspective on the relationship of antenna Q to trap Q would require the use of traps of very high Q relative even to the wire antenna. It is possible to artificially specify impossibly low-loss coils for conventional traps. However, a more realistic alternative is also open to us. We may physically model the trap inductor as a parallel transmission line shorted stub. Such stubs would have Qs in the high hundreds, if not higher yet, and are also one of the construction alternatives used in practical antennas. If the proposed perspective on 10-meter trap losses is correct, then there ought to be no significant gain difference on 10 meters between comparable fat aluminum model and thin copper models.