A Trap 2-Band 2-Element Beam for 17 and 12 Meters

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Over the last 2 decades, we have seen a crossroad between older and newer multi-band beam designs. Older multi-band beams tended to make heavy use of traps to achieve 2-band and 3-band performance from a minimum number of elements. Newer beam designs gave up the trap and let each element serve only one primary band, whether the element was a driver or a parasitic element. Initial feed systems, pioneered by Force12, used open-sleeve driver coupling, although later makers have tended toward forms of direct driver coupling. In the market place today, trap and non-trap beams are available both in short and simple and in long and complex designs.

In the series of articles on the rudiments of multi-band beam design, I used forms of direct coupling among the drivers. Although I made passing reference to both trap and open-sleeve designs, I did not linger on them. The time to linger has come. In these notes, we shall examine a 2-element trap beam design for 17 and 12 meters. My band selection is not accidental. Many amateurs already have commercial tri-band arrays for the wider upper HF bands. They need a 2-band beam for 17 and 12 meters, two of the younger and narrower amateur bands. Very often, they wish to use a somewhat smaller array, since the activity level on these no-contest bands seems to merit a lesser investment. In addition, the project seems more fitting to home design and construction.

The 17-12-meter combination is a good place to experiment. Materials are readily available, and the pieces are macro rather than mini or micro. Standard hardware (stainless steel, of course) works well for most tasks. If the project takes longer than anticipated, it does not disturb more regular operations on the wider bands. Therefore, let's design a 2-element beam for the 17- and12-meter bands.

Traps and Trap Beams

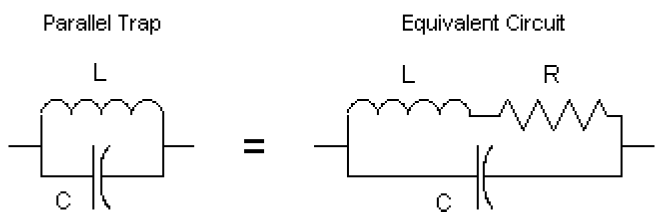
The newer Yagi technology created a phrase: the *lossy trap*. Seemingly, this phrase was synonymous with the simpler word *trap*. As a result, any antenna application for traps became almost forbidden on pain of losing most of one's signal inside the trap assembly. One consequence has been our loss of understanding of how traps work, along with how well they work.

In fact, most of the hype about lossy traps emerged from the inadequate performance of parasitic beams that used them. Indeed, some designs dating back to the 1970s and 1980s showed very little gain and only had directivity as a recommendation for use. In most cases, traps were far less culpable for poor performance than were matters of general design in the effort to reduce the number of elements to an absolute minimum. Poor beam performance resulted largely from unacceptable compromises in element spacing on each band. Consider a 3-element, 3-band trap Yagi. Each band uses traps for the upper two bands on each of the elements. At the same time, the beam had to cover with an adequate SWR value as much as possible of the 20-, 15-, and 10-meter bands. Even with zero-loss traps, the project cannot succeed and still provide standard levels of 3-element monoband performance on all 3 bands. First, the element spacing will be optimal on only one of the three bands, relative to of obtaining maximum gain and a usable feedpoint impedance. Second, on all bands below the highest covered by the beam, the elements will be shorter than normal due to residual inductive loading by one or more traps. Shortening elements inherently reduces gain relative to a full-size element. In the end, these somewhat primitive designs did not need traps to yield lower performance levels than we can easily attain today in multi-band beams. Still, rather than fully analyzing the earlier designs, almost everyone blamed the poor trap. Even today, some makers of non-trap verticals try to give competing trap vertical monopoles a bad name, simply because they use traps.

Are traps lossless? Not by a long shot. Are they as bad as much current literature tries to make us believe? Not by an equally long shot. Indeed, traps have a perfectly usable place in the array of beams that we use on the upper amateur bands, so long as our needs are suitably modest. For example, we may design a 17-12-meter driver-reflector beam that has a relatively short boom and only two elements total. Its performance will be operationally indistinguishable from monoband 2-element designs that we might put in its place using 2 separate booms and a total of 4 elements. Before we take that step, let's review some basics of traps and their use.

Traps: A trap is neither more nor less than a parallel circuit composed of inductance and capacitance. **Fig. 1** shows the basic trap circuit and its equivalent if we consider—and we must—the series RF resistance of the inductor.

Fig. 1



The Basic Antenna Trap for Multi-Band Elements

A parallel tuned circuit resonated on any given frequency has a very high impedance on that frequency. If we insert the circuit in an antenna element and try to operate the element on the frequency to which we have tuned the trap, the active element length is restricted to the part from the feedpoint up to and including the trap. The current beyond the trap on that frequency will be very low and not contribute significantly to the radiation from the element. In general, the total length of the element should not exceed a length of about 3 times the length up to the trap or the element may act like a collinear array, a situation not especially good for use in most applications.

Trap builders are always concerned with the series RF resistance of the inductance. Commercial trap coils have Qs (the ratio of inductive reactance to RF resistance at the self-resonant frequency) of perhaps 220 to 300. Numerous alternative designs have emerged trying to raise the trap Q, some by using coaxial cables to form the coil and the capacitance together. However, for our work, we may stick with standard designs using discrete coils and capacitors. For our work on 17 and 12 meters, we shall create a 12-meter trap consisting of a 2.8-µH coil in parallel with a 15-pF capacitor. I have somewhat arbitrarily assigned a series resistance of 1.5 Ω to the coil, yielding a Q just below 300.

These values show a self-resonant frequency of about 24.55 MHz. (For reference, the resonant frequency for any combination of inductance (in µH) and capacitance (in pF) is equal to the square root of 25330 divided by the product of inductance and capacitance.) A half-century of experience has taught builders that a trap should be self-resonant on a frequency at the bottom or just below the band to which it applies. Since the 12-meter band runs from 24.89 to 24.99 MHz, our self-resonant point coincides with experience.

A trap terminates significant current flow on an element at a length suitable for resonating the element on a desired operating frequency—the upper frequency of elements intended for 2-band operation. On the lower frequency, it serves as an inductive loading coil in the element at its location. However, the residual inductive loading is not solely a function of the inductor in the parallel combination. Rather, it is a function of the complex combination of inductive and capacitive reactance yielded by the trap components when both are distant from resonance. As well, the Q of the combination is not the same as the Q of the coil alone within the trap at resonance. For further information on calculating the parameters of trap operation, see "Systematic Trap Modeling" (http://www.cebik.com/content/a10/model/trapg.html"). Among the "load" options in EZNEC is a trap selection that uses its own methods to pre-calculate traps parameters for each frequency in a sweep in a manner that fits NEC requirements. The design models that we shall use in these notes make use of this facility.

We may begin with a simple trap dipole for both bands. The sample will use the dimensions prescribed in **Fig. 2**. The diagram specifies an element diameter taper schedule consisting both of section diameters and section lengths. The trap position and the total element length are partial functions of the taper schedule and any changes will require redesign of the trap position and the tip length. The diagram shows only half the element, since the other half is a mirror image. The material is aluminum.

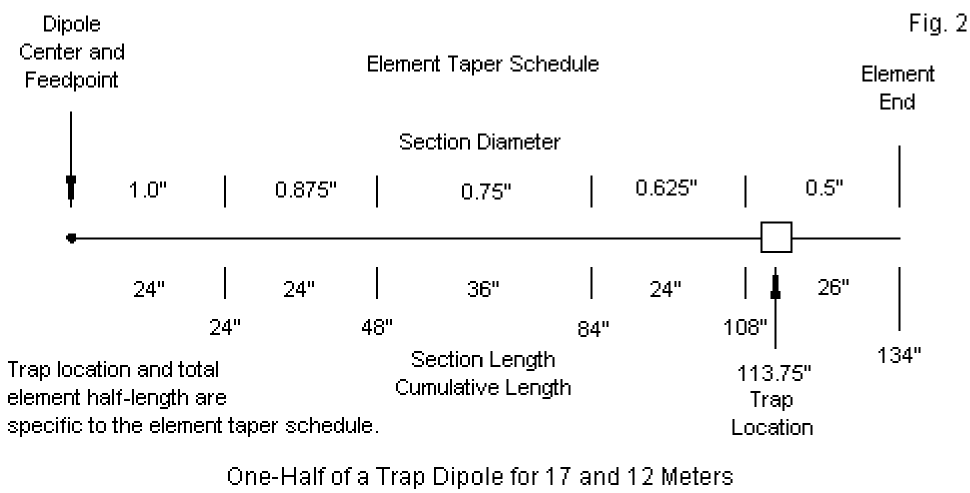
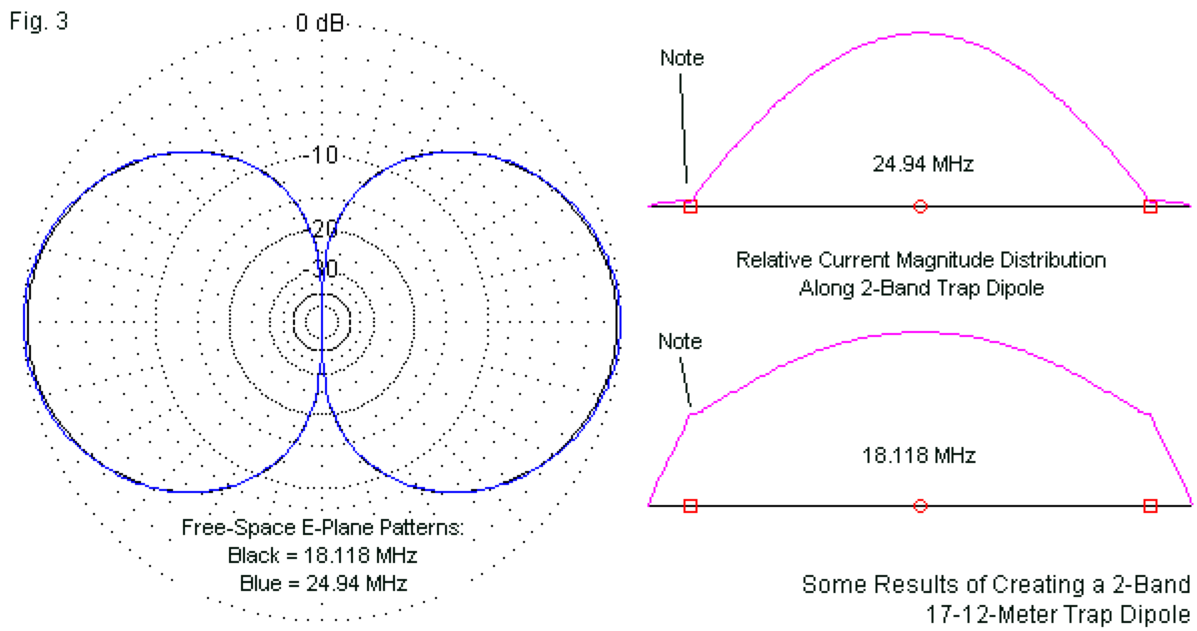


Table 1 provides us with the free-space performance of the dipole on both bands, using our trap design placed as specified.

Table 1. Mid-band performance of a 17-12-meter trap dipole in free space

Frequency	Gain	Feedpoint Impedance
18.118 MHz	1.93 dBi	70.9 + j4.1 Ω
24.94	2.13	73.4 – j5.0

The difference between the gain numbers for the 2 bands (0.2 dB) may lead us to some hasty conclusions. Therefore, let's examine the situation a few steps further. **Fig. 3** can assist us in this effort. It presents the overlaid E-plane free-space patterns of the 2-band performance, and also shows the distribution of current magnitude along the element on both bands. We need all of this information to reach even preliminary conclusions.

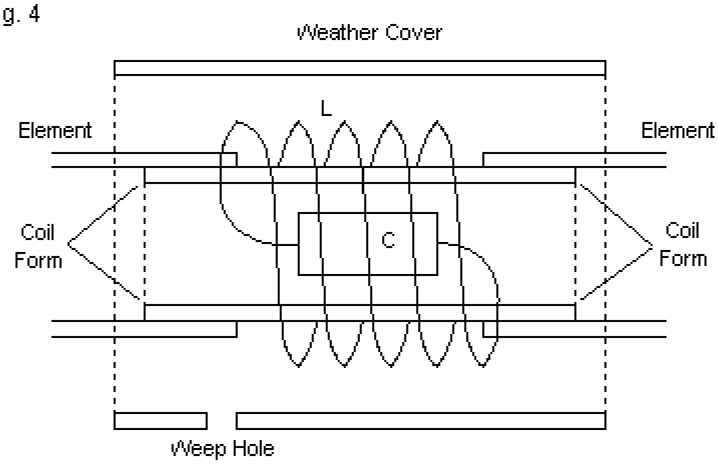


Perhaps the first thing that should strike us is the difficulty of discerning the 0.2-dB difference in free-space gain between the two E-plane patterns. The lower band (17 meters) has the weaker of the two patterns, but the deficit in gain is not wholly due to the trap. The element on 17 meters is only 134" per side (256" overall). A full-length 17-meter element—without the traps either side of center) requires 160" per side (320" overall) for resonance, and such a dipole yields 2.13 dBi free-space gain. If we shorten the trapless element to the smaller size, a reduction of over 16%, then the gain drops to 2.03 dBi. Fully half the gain decrease in the trap dipole is due to element shortening, and only half due to trap losses.

The right side of **Fig. 3** goes some distance in both explaining and evaluating the performance of the dipole. At 12 meters, the trap resonance is below the lower end of the band. However, the current distribution curve in the upper right suggests that the trap is highly effective. Relative to peak current along the element, the current magnitude beyond the traps is quite negligible. On 17 meters, we may note the "corners" in the current curve. Beyond the trap assembly, the current drops very rapidly, indicating the missing section of element relative to a full-size dipole with its nearly sinusoidal distribution. The corner also indicates a limitation of the method by which NEC models RLC loads. They do not have a physical dimension. Hence, in the load, we do not have the normal mixture of inductive and wire-length phenomena. Inductors distant from a peak current feedpoint do not encounter equal current levels on both ends of the coil. Hence, in an antenna, they do not act at those positions as pure inductors. Their inductive effects extend only so far as we have equal current magnitudes on both ends of the solenoid. To the degree that there is a current differential, the coil wire acts like antenna wire, but arranged so that it does not radiate significantly. The chief consequence of the difference between pure (mathematical) NEC inductors and physical inductors at a distance from the feedpoint is that the model will fall short of precision with respect to both the required trap position and the component values required in the trap. In most cases, the component values will be close enough to allow effective trap operation, but the position may require careful adjustment to arrive at upper band resonance. Since every small change of position of the trap will also affect the lower band by the revised placement of the residual reactance, the tip length must also change. Therefore, in creating any trap element, the builder must be prepared for careful field adjustment before declaring the element ready for operation.

We should combine these structural notes with a review of **Fig. 2**, noting that the position of the trap is on the 0.5"-diameter section of the element. One reason for using the element taper schedule shown is to provide sufficient support for the trap assembly, which is considerably heavier than a simple length of tubing filling the space. Suppose that we determine to give the trap inductor a 0.75" diameter. The required 2.8-μH inductance requires just over 27 turns of AWG #14 wire using 8 turns per inch for adequate spacing. The total coil is about 3.4" long. Of course, there is inter-turn capacitance, which may reduce the required parallel capacitance to about 13.5 pF for resonance on about 24.55 MHz. As well, any necessary leads contribute further inductance. Therefore, the builder must resonate traps independently of their placement in the element to ensure their adequacy to the trapping task.

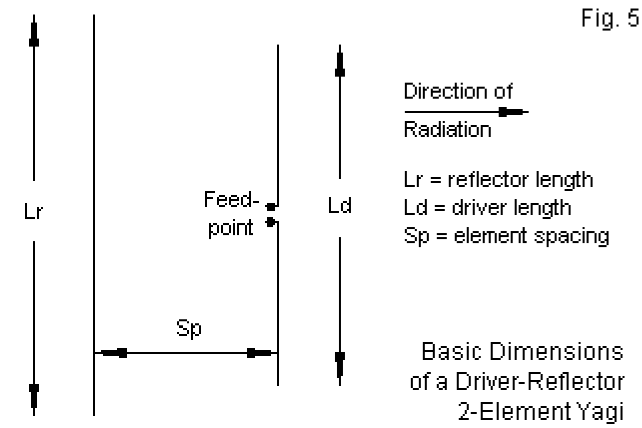
Fig. 4



General Construction Features of a Standard
Antenna Trap Using Discrete Components

Fig. 4 shows some—but not all—of the construction details of a typical trap using discrete components. The sketch assumes the use of stainless steel hardware to firmly hold the assembly together and to the cut element in which we insert it. A weather cover is normally necessary to keep out both moisture and nesting small bugs. (Inspect and clean traps annually for continued effective performance.) Use wire large enough to handle the current levels on both bands. As well, the capacitor should be able to handle both the current and the voltage levels involved. In addition to the details suggested directly by the sketch, both sides of the trap should be adjustable. The trap position is movable for 12-meter tuning by changing the insertion distance of the half-inch tubing into the next 5/8" section. To adjust the tip length for resonance on 17 meters, one might replace some of the outermost end section of the element with a moveable length of 3/8" tubing. Of course, once you have located the exactly proper positions for each band, be sure to secure the sections for durable operation.

The Driver-Reflector Yagi for 2-Band Operation: Before we design a trap 2-band driver-reflector beam, we should fully understand a monoband beam of this design. In these notes, we shall not review all of the material in *2-Element Horizontal Beams, Volume 2, Parasitic Arrays* (available from *antenneX*), but the volume is available for anyone who wishes to develop a more thorough grounding in the subject. Here, we need to cover some basics and to avoid some misunderstandings. **Fig. 5** provides us with a sketch of the basic antenna.



The three critical dimensions are the reflector length (Lr), the driver length (Ld), and the element spacing (Sp). We shall develop our sample for 17 meters (18.118 MHz), but the performance will not vary significantly for any band with appropriate element adjustments. If we use the same element taper schedule that we assigned to the trap dipole, then we need a driver that is 156" each side of center and a reflector that is 169" each side of center. These dimensions will be longer than a uniform-diameter element set due to the tapering of the element from the center outward. Different taper schedules using other element diameters or even individual section lengths will call for other total half-element lengths to achieve the same performance.

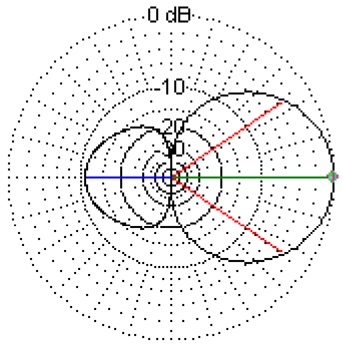
The element spacing for the sample is 81.6", a figure based on 0.125 λ at the operating frequency. Driver-reflector performance reaches a peak at this distance. In addition, the feedpoint impedance will be in the low-30-Ω range, which allows the builder to use either a matching section or a direct connection to 50-Ω coaxial cable. The 1.5:1 SWR is not a problem over such a narrow operating bandwidth (100 kHz). With these constraints, we may derive from NEC-4 the free-space performance reports shown in **Table 2**. NEC software presumes that the elements are well insulated and isolated from any conductive support boom.

Table 2. 17-meter 2-element driver-reflector Yagi performance

Frequency	18.068	18.118	18.168	Δ
Free-space Gain dBi	6.39	6.27	6.25	0.14
Front-to-back ratio dB	10.99	10.99	10.96	0.03
Feedpoint Z (R +/- jX Ω)	33.2 – j0.7	34.6 + j2.5	36.0 + j5.6	2.8 + j6.4
50-Ω SWR	1.51	1.45	1.42	

Over the narrow bandwidth of 17 meters (0.55%), the changes in values across the band—shown in the column marked "Δ"—make no operating difference at all. However, we shall use them as rough standards to better understand the operation of a trap 2-band Yagi. In addition, the radiation pattern does not change noticeably across 17 meters. **Fig. 6** shows a single free-space E-plane pattern, which suffices for the entire band. The rearward lobe shape is typical of the driver-reflector type of Yagi.

Fig. 6



Free-Space E-Plane Pattern
2-Element Driver-Reflector
Yagi for 18.118 MHz

More significant than the data so far shown are some other aspects of the antenna, including some common misconceptions. One common bad idea for designing a 2-element Yagi is to start with a dipole and then make a reflector about 5% longer. In fact, the Yagi driver is shorter than a resonant dipole to yield a resonant beam. The reflector for this version is 8% longer than the driver. The precise measures depend on the element taper schedule, among other design considerations.

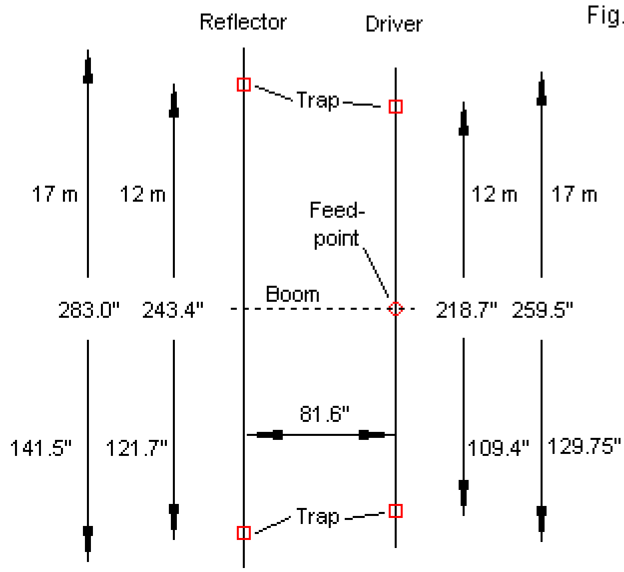
The sample model uses a spacing of 0.125 λ for peak performance. However, by lengthening the spacing to values between 0.145 λ and 0.165 λ, we can increase the feedpoint impedance from the low-30-Ω range to values closer to 50 Ω. The increase in both the spacing and the resonant feedpoint resistance costs us about 0.1 dB in forward gain and about 0.25 dB in front-to-back ratio. I know of no operator who could detect such differences, although these facts will assist us in designing a trap 2-band Yagi.

As we increase the spacing, we shall also need to change the element lengths to restore both peak performance and antenna resonance. Both the resistance and the reactance at the feedpoint will rise, so we shall need to shorten the driver, but only by a small amount. Adjusting the reflector length will yield conflicting results relative to gain and the front-to-back ratio. Lengthening the reflector will tend to reduce gain but increase the front-to-back ratio, while shortening the reflector will have the opposite effects. Since we have only two elements, adjustments to the reflector may require a further small adjustment to the driver, depending on the perfection of feedpoint impedance that we demand at the design frequency. A shorter reflector tends to yield lower feedpoint resistance values and more capacitive reactance, while a longer reflector raises the feedpoint resistance and tends to add inductive reactance. Understanding these trends can speed the work of making field adjustments when translating a 2-element Yagi design into a physical antenna.

The development of a reference 2-element Yagi for 17 meters is not an idle exercise. Rather, it is an important step in the development of our 2-band trap Yagi. Not only did we develop some performance standards against which to measure the more complex antenna, we also developed a methodology of design. For example, if we can accept the feedpoint impedance for the 0.125-λ spacing at 17 meters, even though we shall use a direct connection to a 50-Ω feedline, then we can use the same spacing for 12 meters. On that band, the spacing (81.6") will be about 0.17 λ. We should be fairly close to 50 Ω at 24.94 MHz once we add traps to the assembly. In addition, we can simply use the trap that we designed for the dipole. In fact, all that we need to do is to place the traps correctly and adjust the tip lengths to arrive at our final (or at least semi-final) beam.

A 2-Band Trap 2-Element Yagi: The 2-band trap 2-element Yagi for 17 and 12 meters simply combines all that we have learned along the way into one antenna. **Fig. 7** shows the outline of the array. The individual elements use the same element taper schedule that we used on both simpler antennas. The traps are identical to those used in the initial sample trap dipole, with only position adjustments for the Yagi context.

Fig. 7



Outer Dimensions of a 2-Band Trap 2-Element Yagi for 17 and 12 Meters

The arrowed dimensions show the total element lengths from tip to tip. The half-lengths—from the center to a single tip—appear lower down. The spacing remains at 81.6", which is about 0.125 λ on 17 meters and 0.17 λ on 12 meters. The smaller dimension for each element is the distance between the traps, essentially the lengths of the elements on 12 meters. The outer or larger dimensions for the elements amount to the 17-meter element lengths, taking into account two factors. One factor is the residual inductive reactance of the trap assembly at the lower frequency. The other factor is the decreased element spacing on 17 meters when measured in terms of a wavelength. The different spacing values require different proportions between the driver and reflector element lengths for each band. Therefore, the ratio of inner (trap-to-trap) dimension to outer (tip-to-tip) dimension for each element differs naturally.

The performance of the array on each of the two bands is very close to the values that one might obtain from a monoband beam for each band. The date in **Table 3** shows the 17-meter values, while **Table 4** presents the 12-meter information. In both cases, the forward gain is down a bit from the values we derived for **Table 2**. However, at less than a half-dB maximum, the difference is not operationally detectable, since a 1-dB difference in signal strength is the least value a human operator can notice.

Table 3. 2-band trap 2-element Yagi: 17-meter performance

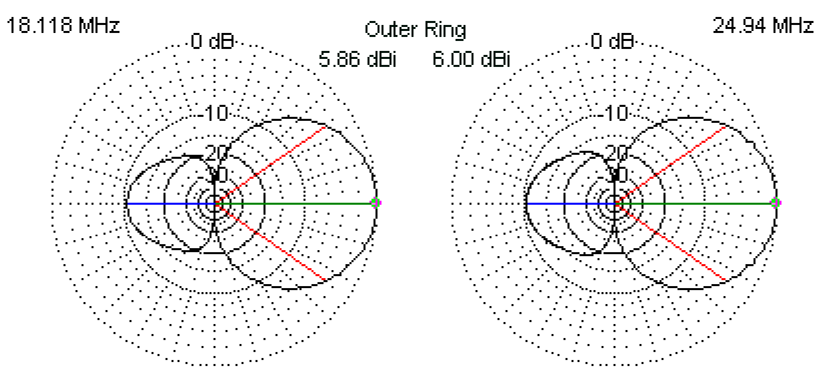
Frequency	18.068	18.118	18.168	Δ
Free-space Gain dBi	5.99	5.86	5.72	0.27
Front-to-back ratio dB	9.86	10.67	11.05	1.19
Feedpoint Z (R +/- jX Ω)	29.0 – j6.4	33.4 + j1.9	36.0 + j10.2	7.0 + j16.6
50-Ω SWR	1.77	1.55	1.50	

Table 4. 2-band trap 2-element Yagi: 12-meter performance

Frequency	24.89	24.94	24.99	Δ
Free-space Gain dBi	6.05	6.00	5.95	0.10
Front-to-back ratio dB	10.50	10.52	10.52	0.02
Feedpoint Z (R +/- jX Ω)	50.0 – j10.2	51.6 – j7.3	53.1 – j4.4	3.1 + j5.8
50-Ω SWR	1.23	1.16	1.11	

The reduction in gain that we find when comparing the 12-meter values with the reference values results primarily from the increased spacing between the elements. Otherwise, 12-meter operation is quite normal, including smaller values of Δ in every catalog category. As predicted, the increased boom length as a fraction of a wavelength results in at 50-Ω feedpoint impedance with a very smooth—if modest—front-to-back ratio across the band.

In past notes on non-trap multi-band beams, we noticed compressed curves for the upper of the 2 bands covered due to a greater rate of change in virtually every performance area. Due largely to the shortening of the elements, a trap array exhibits the compression on the lower band. Compare the amount of change in values in the trap beam on 17 compared to the reference antenna. Nevertheless, the average gain and front-to-back values are down by less than a half-dB in each area. The decrease is also consistent with the gain drop for a single trap dipole on the lower band, which we roughly divided in two, half of the decrease belonging to the shortened elements and half due to losses in the trap assemblies acting as a loading inductive reactance. The SWR values—while less than ideal—still fall within acceptable limits for virtually all amateur applications.



Free-Space E-Plane Patterns: 2-Band Trap
2-Element Yagi for 17 and 12 Meters

Fig. 8

Fig. 8 provides a sample E-plane free-space pattern for each band. The 17-meter pattern is indistinguishable in shape from the pattern in **Fig. 6** for the reference 2-element Yagi, despite the slight difference in forward gain. The 12-meter pattern is very similar, but shows a slightly wider rearward lobe beamwidth, a natural function of the longer boom length.

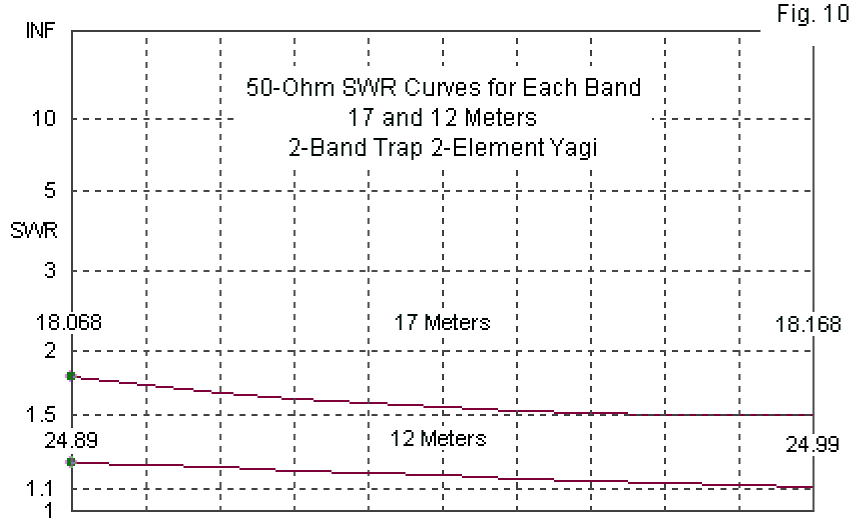
Evidence for normal operation of the array shows up perhaps most clearly in **Fig. 9**, a pair of current distribution curves for the array, one for each band. In both cases, the ratio of peak driver current magnitude to peak reflector current magnitude is similar, with a slightly lower reflector current level on 12 meters, where the boom is longer. Both elements of the 12-meter curves show the effect of the traps to limit current beyond them to virtually negligible levels. On 17 meters, both elements show the “corners” in the current magnitude curves, with a rapid decrease in current from the trap (as an inductively reactive load) to the element tips.

Fig. 9

Current Magnitude Distribution on 17 and 12 Meters
2-Band Trap 2-Element Yagi

Perhaps no description of a beam is complete without the obligatory SWR curve set. **Fig. 10** satisfies this requirement. It is possible by judiciously small adjustments in the driver length to obtain curves better centered in the passbands, and to do so without disrupting overall beam performance on wither band. However, that step takes us to a final set of reminders about multi-band trap beams.

Fig. 10



From Model to Physical Reality: The beam as designed provides as good an approximation of monoband driver-reflector Yagi performance on both bands as we can expect from a trap design. Losses are far from excessive. Indeed, on 12 meters, the performance reaches monoband levels within the traps. On 17, where elements are shortened and loaded, we find a small drop in performance, but one that we might be hard pressed to detect in operation.

The design dimensions for the beam result from NEC-4 models and other calculation aids. In earlier sections, we enumerated some of the limitations of the design process that make field adjustment an expectation. First, as noted, the trap design, with a self-resonant frequency of about 24.55 MHz, does not account for inter-turn capacitance. Therefore, each trap needs to be resonated before installation in its element. The precise resonant frequency is not especially critical, and values up to the lower edge of the 12-meter band are usable. However, each trap should resonate at the same frequency to reduce the number of variables to think about during adjustment.

Second, each trap position, along with its lower-band tip section, needs to be initially adjustable, since the NEC models of trap loads vary slightly from physical reality when such loads are distant from the feedpoint. The model values are only starting points for the adjustment. For the average amateur, who usually lacks sophisticated measuring instruments and a good antenna range, the process comes down to establishing an acceptable SWR value. In physical reality, there may be many trap and tip settings that may yield good SWR values and poor performance.

Fortunately, the models provide a second form of guidance in the relative proportions of the inner and outer sections of the elements. When making adjustments, begin with the modeled dimensions. Start the adjustments on 12 meters. The goal—if only impedance measurements are possible—is to arrive at values very close to the modeled values with each element having the same proportions to the other as in the model. If the proportions drift excessively out of line with the model, then one may need to go back and start the process again. Once the 12-meter work is initially done, the 17-meter tips call for final adjustment, aiming both for the modeled impedance region and for final tip-to-tip lengths proportional to the model. Normally, this procedure will not call for a revision in the 12-meter adjustments beyond a fractional change in the inner driver length. Of course, the use of local assistance to confirm a reasonable front-to-back ratio (relative to the type of beam in question) is an invaluable aid to moving from the field adjustment phase to the operating phase of the beam's life.

Conclusion: A 2-band trap Yagi is a viable alternative to other designs for these bands in terms of having modest but solid 2-element performance. Since the entire array uses only 2 physical elements, the boom length is just under 7' (or perhaps just over 7', depending upon the methods used to secure the elements to the boom). The element structure for beams using traps should be somewhat robust to ensure both strength and minimum sag from the weight of the traps. The structure that the design uses is rated for over 100 mile-per-hour winds, but requires de-rating in this application. Not only do the traps add weight near the element ends, they also increase the element wind loading due to their larger diameter.

The potential performance that we may obtain from the trap array should lay to rest the simplistic equation of *trap* with *lossy trap*. One may in fact design a very lossy trap, but that is an option (or an accident) and not inherent to standard trap design. Traps are not lossless, but may be nearly lossless on the upper band where they serve as traps. On a lower band, they inevitably show some loss. However, as the design samples have shown, much of the gain loss also stems from the shortening of the elements. In terms of radiated energy relative to supplied energy, the array on 17 meter shows a NEC report of 85% efficiency.

Much of the excessively low gain shown by some past Yagis using traps is due to the use of unacceptable design compromises, not to losses in the traps. The present design, for all of its modest goals, makes use of established design principles on both bands to achieve reasonable performance on both bands. The results might well have been quite different had I chosen to design a three-element Yagi for both bands with traps in each of the elements. Three-element designs generally call for different spacing values on each band for each pair of elements. Such a design might be possible, but its advantage over a 2-element design might be debatable. We shall explore 3-element trap design in the next episode.

The reason that a 2-element trap design, such as the one discussed here, is suitable for 17 and 12 meters is that for many amateurs, smaller beams are more acceptable and even desirable on these bands. Despite the challenges that it presents, the trap design is perhaps one of the most compact possible and uses the fewest physical elements for the performance level that it attains on both bands.