Some Notes on Linear Resonators
Part 1: 20 and 15 Meters

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Amateurs are always searching for ways to obtain multi-band service from a single element. Of course, we can always feed a wire with parallel feedline and an antenna tuner. However, amateurs tend to have a fetish for 50-Ohm coaxial cables. Of all the myths upon which the coax preference rests, perhaps the only valid one is that we may route a coaxial cable with less care for what surrounds the cable than we can when using parallel transmission line.

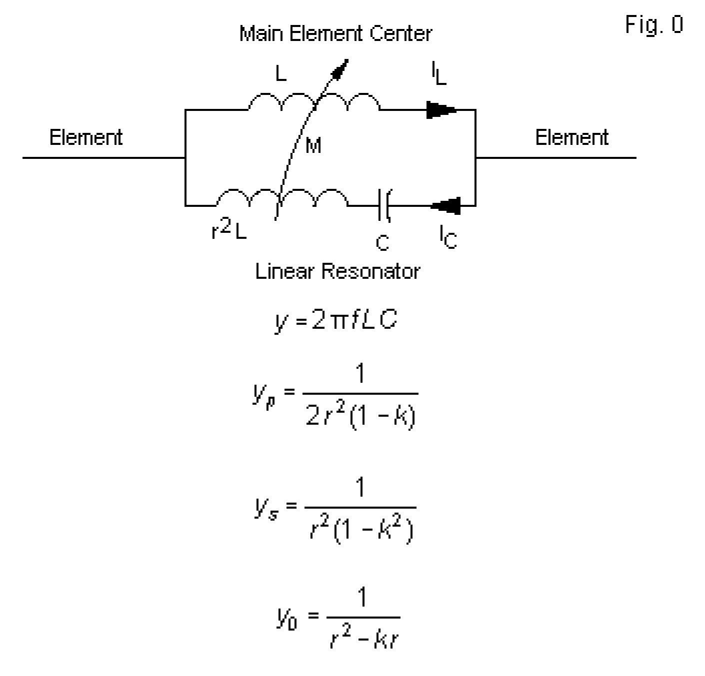
One popular multi-band technique has come to dominate all others: the trap. A high-Q trap tuned at or just below a higher operating frequency tends to terminate the antenna element length at the trap. At lower frequencies--within limits--the trap appears as a mid-element loading inductive reactance, allowing operation on a lower frequency. Trap verticals tend to outnumber trap dipoles, perhaps because they require half the number of weather-protected parallel combinations of inductance and capacitance.

In his justly well-known work, *HF Antennas for All Locations*, Les Moxon, G6XN, reported on and analyzed an alternative scheme for obtaining 2-band performance from a single element. The technique required only a single capacitor and enough wire or rod to span the center of a lower frequency element. With the right combination of ingredients, we can obtain a dipole-type near-resonant impedance at a desired higher frequency. Although Moxon makes use of the linear resonator in several projects within his book, the relevant analysis of the technique appears on page 117-120 of the 1982 edition and on pages 140-143 of the 1993 2nd edition. In a recent issue of *QEX* (Mar/Apr, 2006, pp. 46-50), Vidi la Grange, ZS1EL, reports on a use to which he put the linear resonator. However, the lack of solid technical analysis of the resonator left me curious about the technique--and why amateurs have generally failed to make use of it more widely.

Moxon's Analysis and the Amateur's Questions

A linear resonator consists of a length of wire stretching equally on each side of the center of a lower-frequency element. The ends of the new wire connect to the lower-frequency element. At the center of the new bridging wire, we place a properly sized capacitor. At the lower frequency, the added structure and component have little effect on the performance of the element. Some writers suggest that it has no effect, but that will prove wrong. However, the effect is small. At some higher frequency, the bridge wire and capacitor will form essentially a series tuned circuit that will create a low-impedance path, resulting in a second resonant point for the wire. Theoretically, we can calculate the higher frequency by knowing a few properties of the additions to the initial element. Note that I do not here specify that the element is a fed dipole. In principle, the additions would apply to parasitic elements as well as driven elements. In fact, Moxon's own analysis is independent of the element having a feedpoint or not. **Fig. 0** shows the key elements of Moxon's rendition of the key elements in the linear resonator.

Fig. 0



Fundamentals of the Linear Resonator

The equations are nearly but not quite self-explanatory. L and C, of course, are the values of inductance (of the wire length within the confines of the linear resonator) and of capacitance. The term r is the "turns-ratio" of the main or lower frequency element and the added linear resonator elements when treated as lumped components. Note that the diagram uses the term M to represent the mutual coupling between the main element and the linear resonator element. In contrast, the equations make use of a mathematically related concept, k, the coefficient of coupling. If we know the effective turns-ratio between the two wires, we can solve for r. Where we use the same diameter conductors for the element and the linear resonator, we end up with a 1:1 ratio for r, but that condition is rare in practice.

The key blockage to our ability to calculate the requisite values for a linear resonator lies in the mutual coupling, that is, the value of k. Although there are standard techniques for measuring either M or k when using lumped components, few amateurs have any inkling of how to determine the value for an antenna structure. Since we cannot effectively calculate the values that we need for a linear resonator, those who wish to try the technique do so by experimentation. They change the physical variables until they either give up in frustration or succeed in obtaining usable proportions.

Although I have no magic method of determining the coefficient of coupling within a linear resonator circuit, it may be possible to evaluate which of the physical variables that go into such an antenna are most sensitive and which are least sensitive to changes. Modeling the simplest case, a 2-band dipole--may give us some useful clues should we wish to experiment with the idea. As a start, I picked an arbitrary frequency and dipole: 20 meters or, more specifically, 14.175 MHz. The dipole of choice is 0.875" in diameter. Because we shall later explore the effect of changing the main element diameter in a dual-band dipole, I also modeled dipoles using 1.0" and 0.75" diameter wire. **Table 1** provides the data. I have purposely over-modeled the dipole to bring the resonant impedances as close together as feasible, noting the required change in dipole length to achieve this goal. Although the impedances match up to unrealistically small fractions, the length change between 0.75" and 1.0" material is over 1" or about 0.3% of the total length.

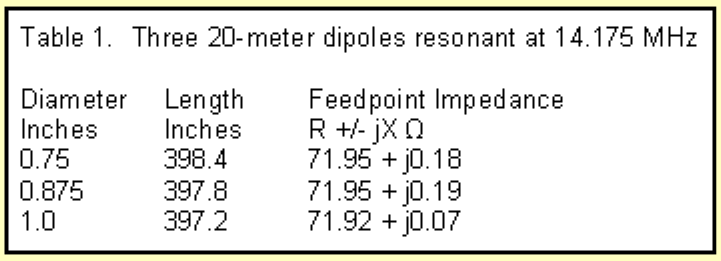


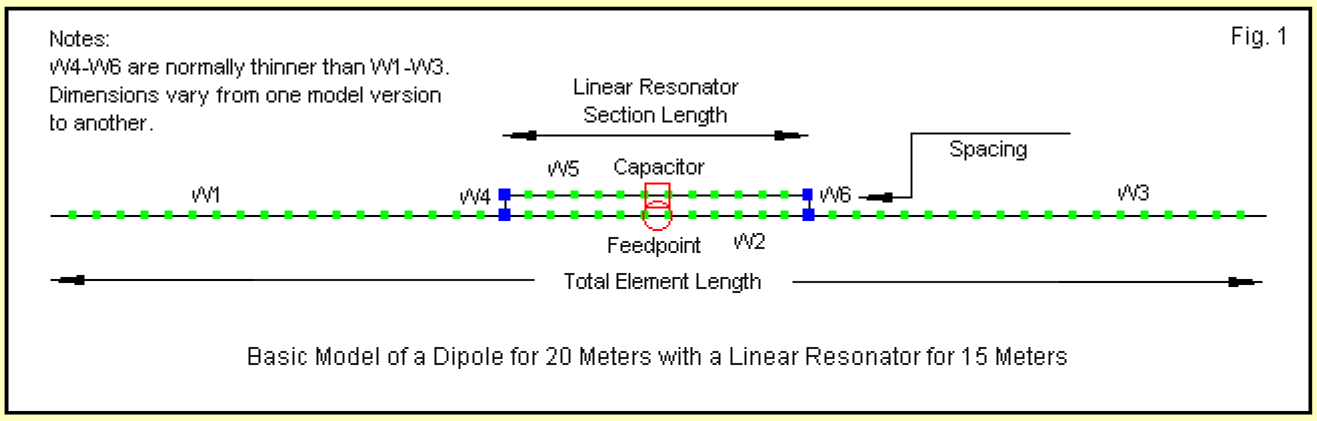
Table 1. Three 20-meter dipoles resonant at 14.175 MHz

Diameter Inches	Length Inches	Feedpoint Impedance R +/- jX Ω
0.75	398.4	71.95 + j0.18
0.875	397.8	71.95 + j0.19
1.0	397.2	71.92 + j0.07

Modeling a dual-band dipole with a linear resonator, however, is not quite so simple as modeling a mono-band dipole.

Some Modeling Issues

For the dual-band dipole, I selected 20 and 15 meters, specifically, 14.175 and 21.225 MHz. (As we shall see, I also selected structural values that showed <2:1 50-Ohm SWR across both bands.) A total of about 50-51 segments on the main element, divided into 3 wires, allows us to manipulate most of the structural variables and still maintain reasonable good equality among the segment lengths. As shown in **Fig. 1**, the linear resonator adds 3 wires to the basic dipole, along with a capacitor at the center of the linear resonator structure.



Notes:
W4-W6 are normally thinner than W1-W3.
Dimensions vary from one model version to another.

Fig. 1

Basic Model of a Dipole for 20 Meters with a Linear Resonator for 15 Meters

The sketch indicates some of the structural variables in a linear resonator dipole. **Table 2** provides a more complete list.

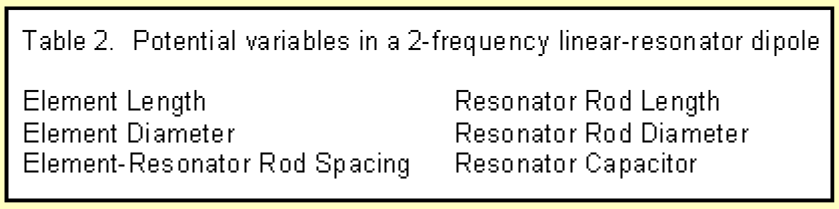


Table 2. Potential variables in a 2-frequency linear-resonator dipole

Element Length	Resonator Rod Length
Element Diameter	Resonator Rod Diameter
Element-Resonator Rod Spacing	Resonator Capacitor

My initial model required a main element that is 384" in total length, compared to about 398" for the monoband 20-meter dipole. Subsequent models maintained that length, suggesting that the idea that the linear resonator makes little or no difference to lower-frequency operation may be overstated. At 20 meters, an element length change of 14" is quite significant (about 3.5%). Both elements use 0.875" diameter wire in the model with the same total segmentation.

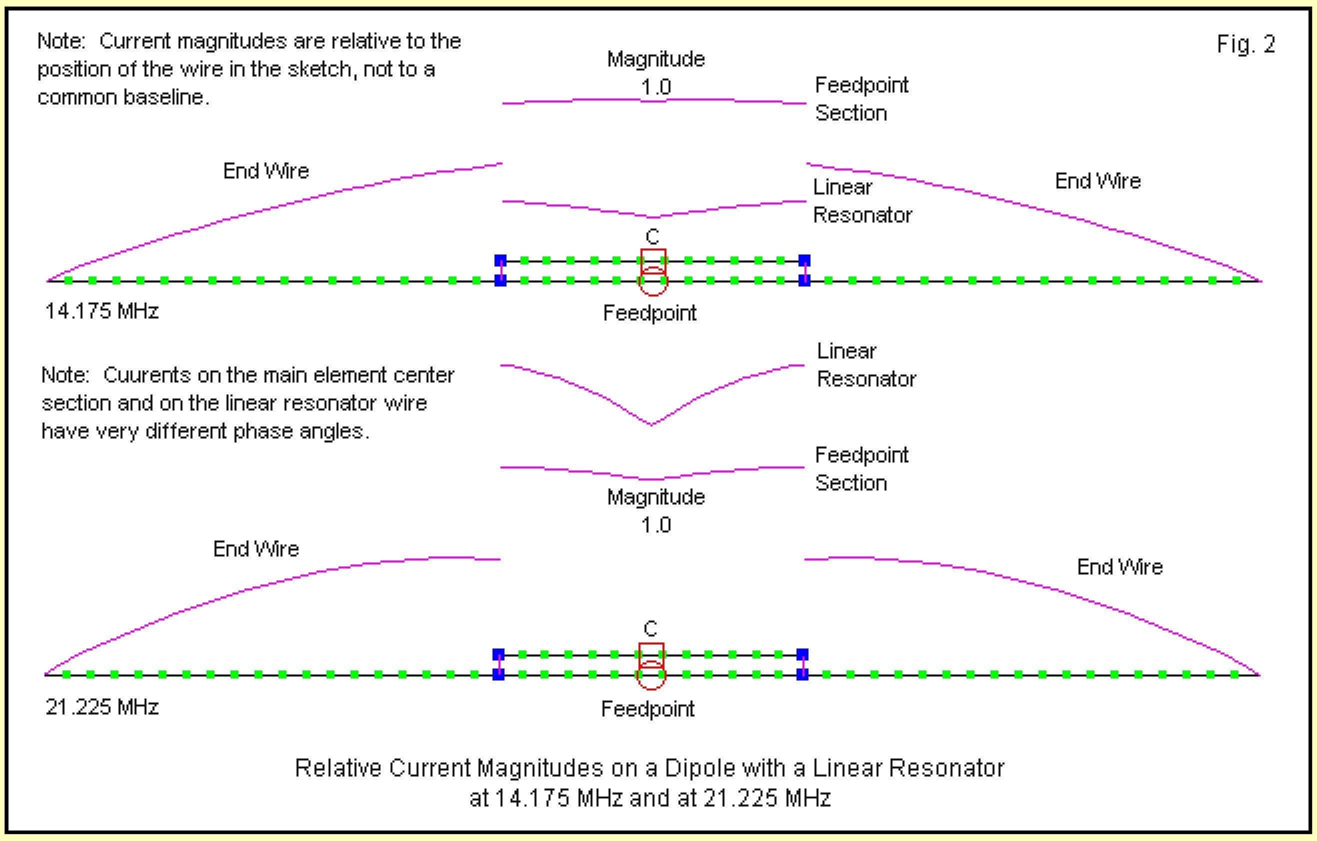
HF tubular dipoles are unlikely to use the same diameter material for the linear resonator additions as for the main element. In most cases, the linear resonator will be considerable thinner. I selected--again arbitrarily--0.25" as an appropriate diameter for rods that the main element would support. (We shall later vary that diameter to see what happens.) My initial successful models used a rod length of 96", extending 48" on either side of center. I used three wires in the main element of the antenna so that the resonator rod and the center main element tube would have the same number of segments. Single-segment wires (0.25" diameter) connect the resonator rod ends to the junctions of wires making up the main element. The spacing (center-to-center) between the rod and the main element is initially 6" (although we shall also vary that value later).

Here we encounter a modeling challenge. NEC has accuracy difficulties with junctions of wires that have different diameters. NEC-2 is worse than NEC-4. In fact, my initial NEC-4 models showed average gain test (AGT) scores of 0.971 on 20 meters and 0.963 on 15 meters. (NEC-2 models showed AGT values of 0.944 and 0.932 for the two bands, and I excluded the use of this core.)

In contrast, my best implementation of MININEC 3.13 (Antenna Model) showed values in excess of 0.998 on both bands, simply because MININEC does not respond inaccurately to junctions of wires having different diameters. However, the only critical difference between the MININEC and NEC-4 models was in the value of capacitance necessary to arrive at a successful 15-meter resonance while using identical sizes for the physical parts of the dual-band dipole. MININEC required a capacitance of 16.9 pF, while NEC-4 reported a value of 15.7 pF. Absolute values of gain and impedance are not here in question. Rather, we are more interested in trends and rates of change. Therefore, the NEC-4 models are quite usable with the understanding that the impedances and the capacitance values shown may be a bit low. My preference for NEC-4 is not a bias--the MININEC models are more accurate in this situation--but a matter of practicality. It is more convenient for me to transfer data from my NEC-4 programs to other programs, such as spreadsheets, than it is for me to do so with my extant MININEC programs. Since graphic curves will play a significant role in what follows, I opted for the easier data transport.

Some Basic Dual-Band Dipole Properties When Using a Linear Resonator

The initial model that I have just described is satisfactory for exploring some of the basic properties of a dual-band dipole for 20 and 15 meters when using a linear resonator. Perhaps foremost among the easily detectable properties is the impedance behavior. On 20 meters, the impedance will no longer be 72 Ohms, but about half that value. At 21.225 MHz, the feedpoint impedance may cover a wider range, depending on the specific values assigned to the physical variables. For the initial model, the impedance was about 60 Ohms.



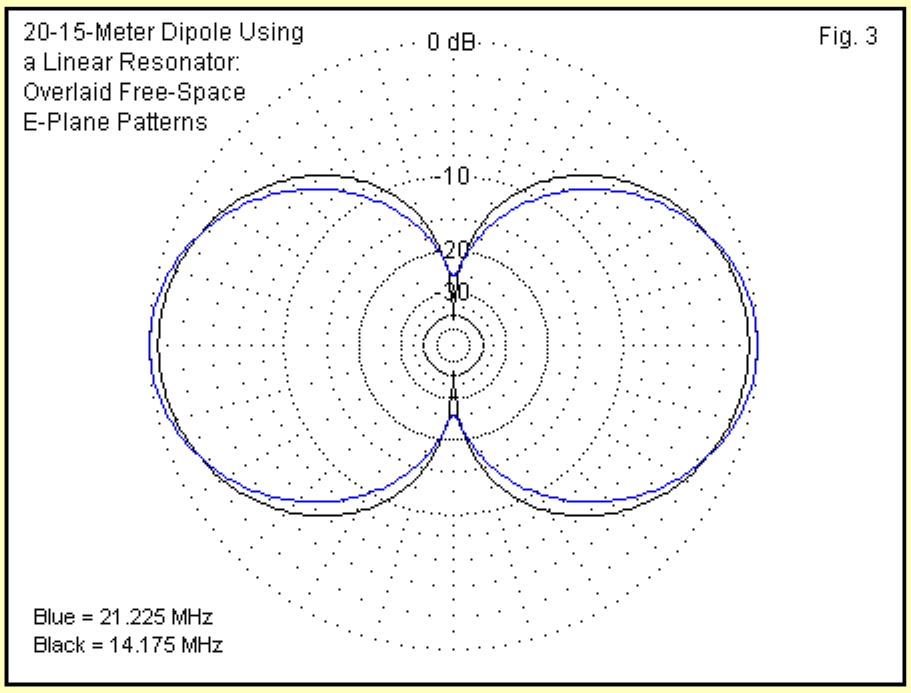
Note: Current magnitudes are relative to the position of the wire in the sketch, not to a common baseline.

Note: Cuurents on the main element center section and on the linear resonator wire have very different phase angles.

Relative Current Magnitudes on a Dipole with a Linear Resonator
at 14.175 MHz and at 21.225 MHz

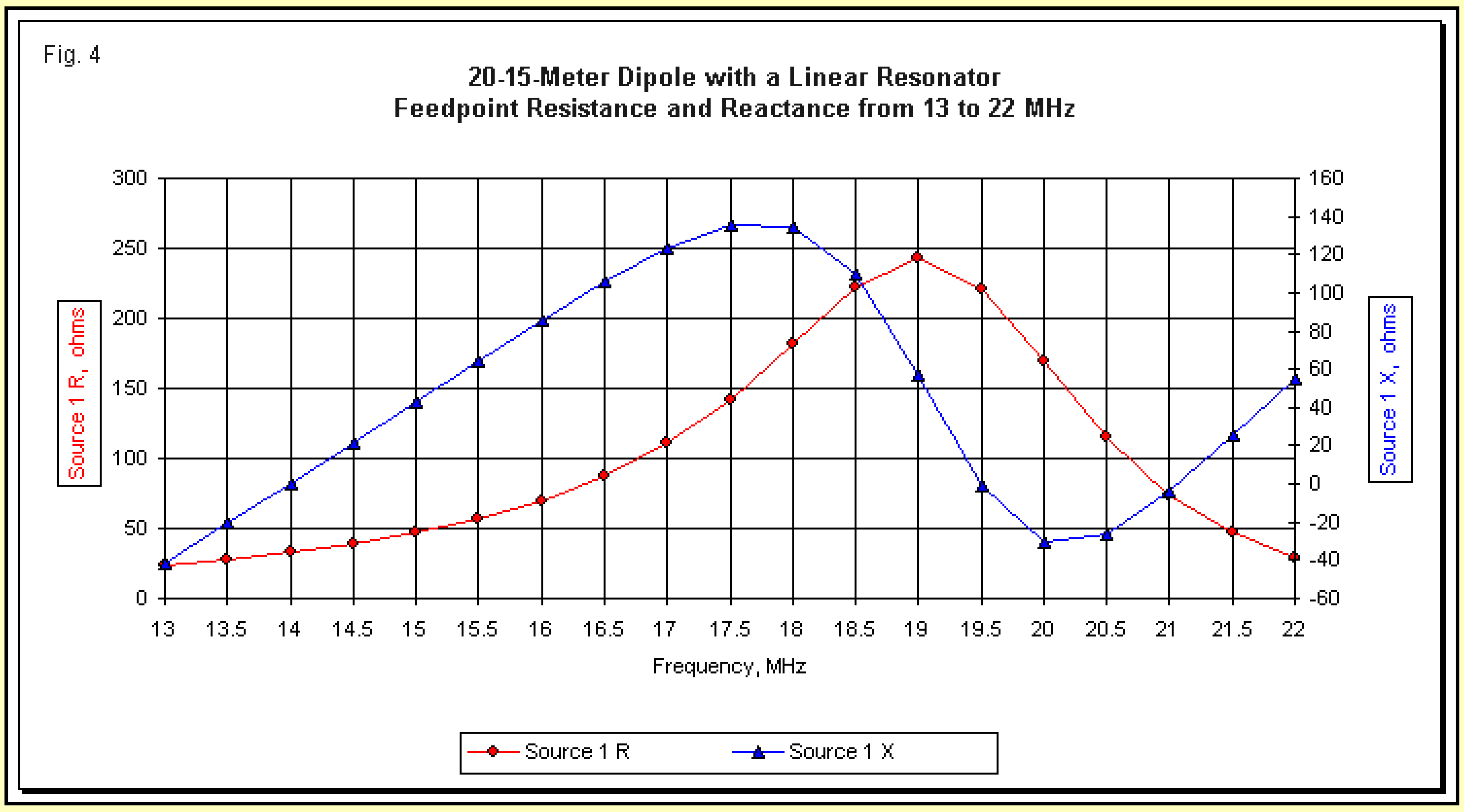
Fig. 2 shows the current magnitude distribution on the antenna at the two selected frequencies. On 20 meters, the center-section current is much higher (by a factor of about 5) than the current on the linear resonator. On 15 meters, we have a reversal, with the linear resonator wire having a higher current magnitude than the main element (even allowing for the curve displacement, which is relative to the wire to which it applies, not to a common baseline). The reason that both magnitudes on the 15-meter representation are higher than the currents at the inner ends of the outer wires is that the currents are almost out of phase with each other. If we assign an arbitrary phase angle of 0 degrees to the actual feedpoint, on 15 meters the center of the linear resonator shows a phase angle in the range of -160 to -165 degrees. (NEC counts from 0 to +180 degrees and to -180 degrees when it comes to phase angles.) Essentially, Moxon's representation of current directions in **Fig. 0** is correct--within 15 to 20 degrees.)

One popular statement about linear resonator dipoles is that we obtain essentially dipole patterns at both frequencies. The truth of this statement depends on the degree of precision upon which we might insist. In very loose terms, the statement is correct. However, as we lengthen a center-fed wire beyond 1/2 wavelength, the gain increases steadily, and the dual-band dipole with a linear resonator shows this increase. **Fig. 3** overlays free-space patterns for the model at the two frequencies. We can clearly see the slightly higher gain and narrower beamwidth at the higher frequency.

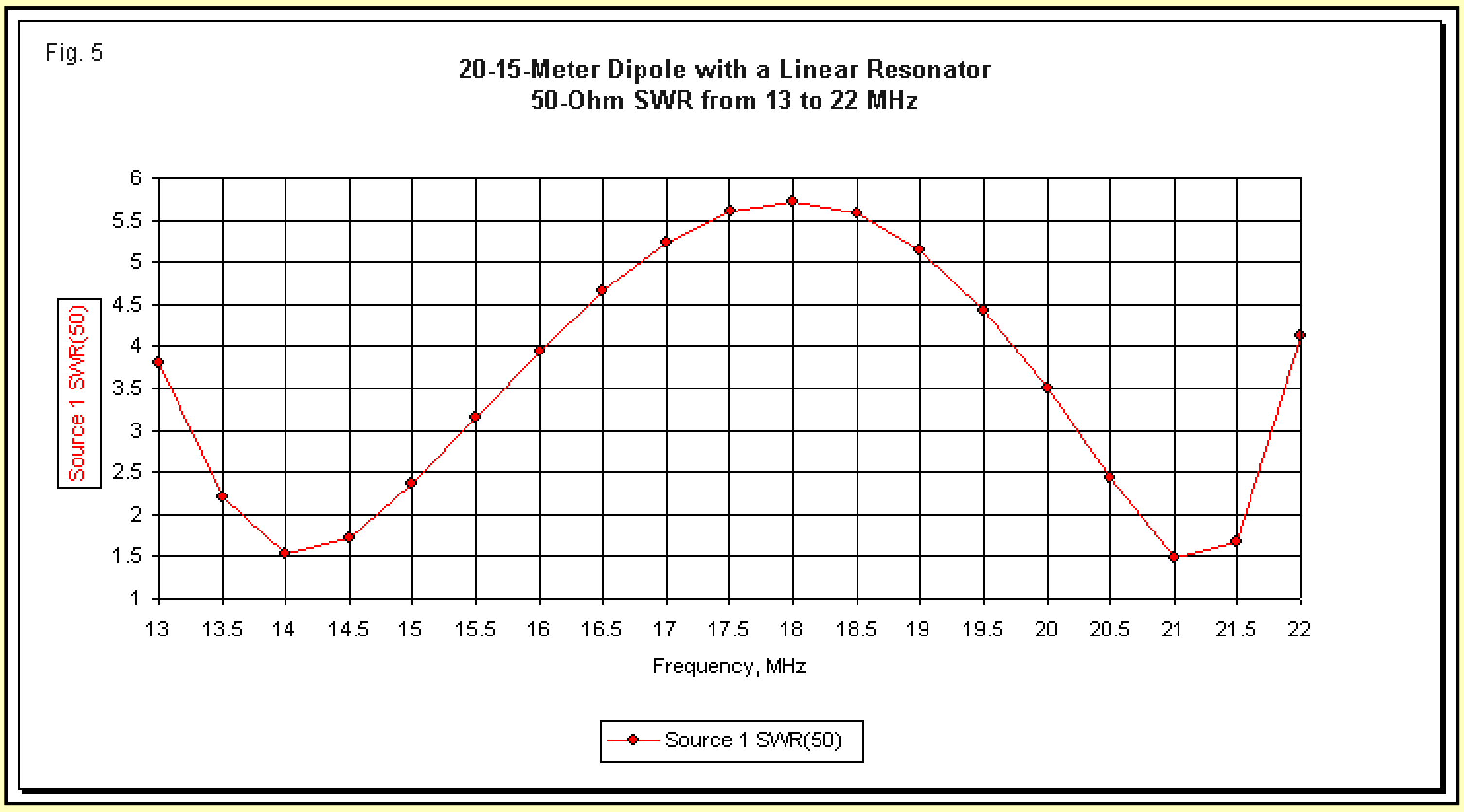


The gain difference is about a half-dB, while the beamwidth difference is about a dozen degrees. These differences may have little effect on the performance of our antenna as a simple dipole. However, they may have more significant effects if we attempt to apply them to multi-element parasitic or phased arrays.

Although most design work focuses narrowly on the two frequencies of interest, we may take a larger look at the feedpoint behavior of the dipole and its linear resonator. **Fig. 4** shows the resistance and reactance from 13 to 22 MHz. The two components of the feedpoint impedance do not peak at the same frequency. In fact, the reactance peaks about 1.5 MHz lower and has a relatively steep curve of value change as the resistance crosses the 50-Ohm mark. Hence, the 15-meter resistance value is not ideal relative to 50-Ohm cable, although it is certainly usable. At the lower end of the swept frequencies, the resistance is well below 50 Ohms as the reactance cross the zero-point and becomes significantly inductively reactive. As we change some of the physical structure, we shall see that the most profound effects occur at the upper end of the swept band, while the lower end remains relatively stable.



The 50-Ohm SWR curve for the dual-band dipole also focuses on the entire span from below 20 meters to above 15 meters, as shown in **Fig. 5**. Although this curve is typical for all variations in physical structures, we shall find some small but significant variations along the way. In general, the curve shows two narrow but adequate SWR windows for use of the antenna. Like a trap dipole, the antenna is useful only on the frequencies for which the structural elements are designed.



These notes have so far shown what we may call the typical performance of a dual-band dipole with a linear resonator. Immediately, the experimenter wonders if changing any of the variables in **Table 2** might give us some advantage--perhaps a better feedpoint impedance at one or both test frequencies, perhaps a wider SWR curve. . .. The only way to find out--without having to build and rebuild many dual dipoles--is to do some systematic modeling.

Varying the Dual-Band Dipole Physical Structure

If we cannot easily determine the mutual coupling between the inductances represented by the center length of the main element and the resonator rod, we can at least explore how the operating conditions change as we systematically vary some of the structure features of the dual-band dipole equipped with a linear resonator. From the outset, we should be aware of the restrictions of this exploration. First, we are working with two frequencies that have close to a 1.5:1 ratio. Experience by past experimenters has suggested to others that frequency ratios below about 1.4:1 are unlikely to allow successful linear-resonator treatment. How far upward in frequency spread we might successfully go seems to be unexplored territory.

As well, we are working with relatively fat elements, that is, elements that are not thin wires. Hence, any dimensional scaling is likely to be limited in success, although scaling the dimensions used here might serve as a starting point for a series of more specific models. As well, the main element is fixed at a uniform diameter. Stepped diameter elements will likely be longer for the same frequencies used, although the length difference between a mono-band dipole and a dual-band dipole will be similar.

Third, we are using NEC-4 for the study. Hence, the impedance values might be a bit low relative to reality. The required capacitance values may also be a bit low. However, the progressions of values and the rates of change will be close to correct.

The bottom line, then, is that the following notes are indicators of what to expect from a 20-15-meter linear-resonator dipole, but not a set of building plans.

Varying the Length of the Resonator Rod

Perhaps the most reasonable physical dimension to vary initially is the length of the linear resonator rod. In this exercise, we shall retain the initial dimensions for all other structures. The main element will use a 0.875" diameter wire and be 384" long overall. The linear resonator rod will be 0.25" in diameter and spaced 6" from the main element.

For the exercise, I varied the length of the linear resonator rod in 4" increments from 78" to 102". (Our initial model used a 96" rod.) **Table 3** shows the feedpoint impedance values at 14.175 MHz and at 21.225 MHz. In addition, the table shows the capacitance value necessary to produce the most acceptable 50-Ohm SWR values within each of the two bands. The final column shows the relative current phase at the center of the linear resonator rod at 21.225 MHz, where the feedpoint current has a presumed current phase of 0 degrees.

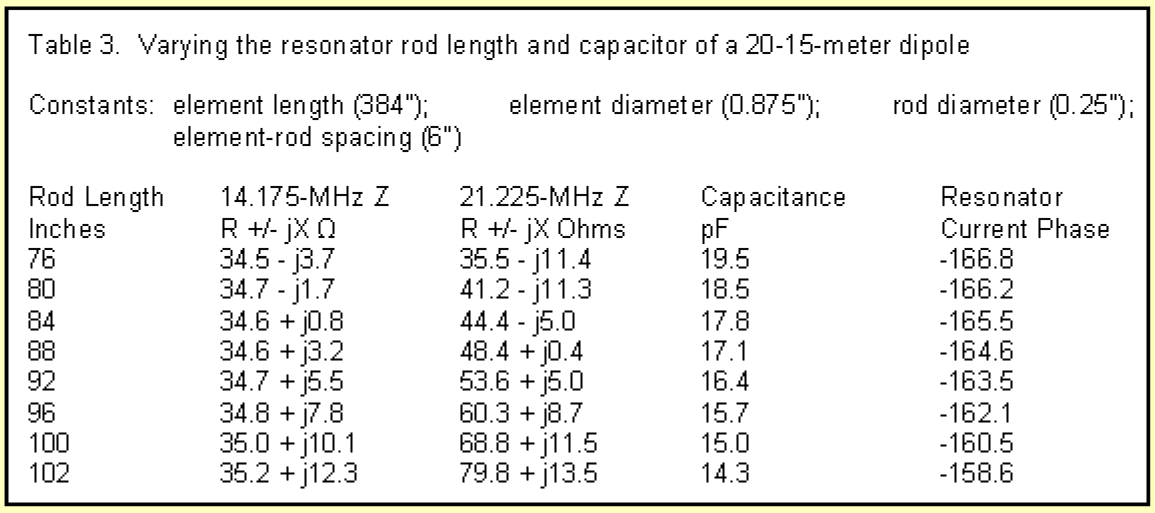


Table 3. Varying the resonator rod length and capacitor of a 20-15-meter dipole

Constants: element length (384"); element diameter (0.875"); rod diameter (0.25"); element-rod spacing (6")

Rod Length Inches	14.175-MHz Z R +/- jX Ω	21.225-MHz Z R +/- jX Ohms	Capacitance pF	Resonator Current Phase
76	34.5 - j3.7	35.5 - j11.4	19.5	-166.8
80	34.7 - j1.7	41.2 - j11.3	18.5	-166.2
84	34.6 + j0.8	44.4 - j5.0	17.8	-165.5
88	34.6 + j3.2	48.4 + j0.4	17.1	-164.6
92	34.7 + j5.5	53.6 + j5.0	16.4	-163.5
96	34.8 + j7.8	60.3 + j8.7	15.7	-162.1
100	35.0 + j10.1	68.8 + j11.5	15.0	-160.5
102	35.2 + j12.3	79.8 + j13.5	14.3	-158.6

The table provides some relevant performance numbers at two specific interesting frequencies. However, it does not show the overall performance characteristics, which are also interesting. For example, if we sweep frequencies between 13 and 22 MHz, we obtain the gain curves shown in **Fig. 6**.

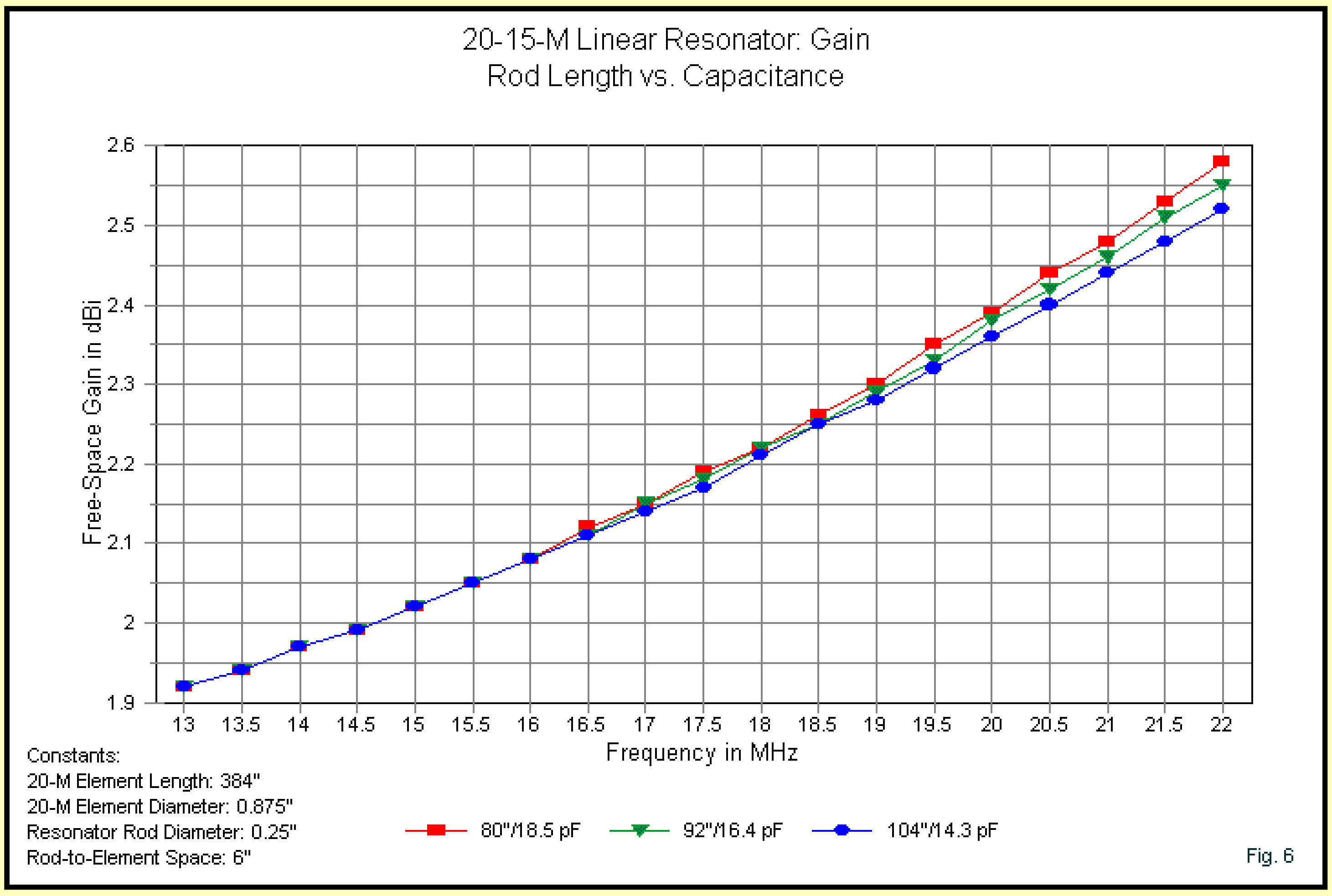


Fig. 6

The curves use only 3 widely spread resonator rod lengths because using all of them would have yielded a single wide blurry line. The result is clear: varying the rod length has no significant effect on the gain of the dual-band dipole. The curve shows a normal rise in gain with increasing length when measured as a function of a wavelength. In fact, we shall not bother with gain curves for the remaining variations in physical structure, since they would all show the same result. Since the gain curve does not vary with the physical variations, so too the beamwidth does not change relative to our initial model.

Perhaps the most significant changes occur with respect to the dipole feedpoint impedance. As shown in the table, the required linear resonator capacitance for acceptable SWR curves within 20 and 15 meters changes by about 0.35 pF per 2" change in resonator length. The rate of change is nearly linear. **Fig. 7** shows the swept 50-Ohm SWR curve for 3 widely separate samples from the table.

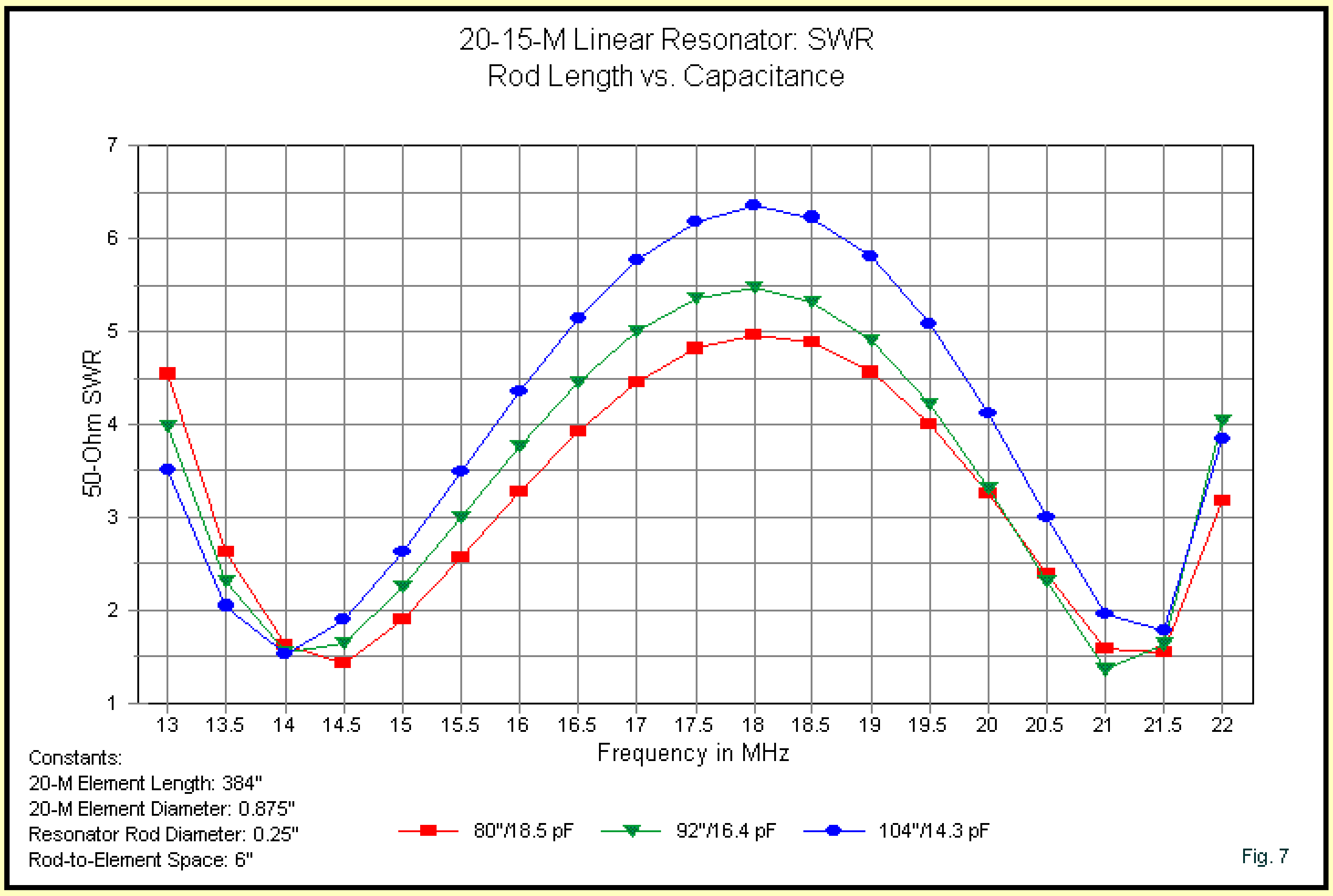


Fig. 7

There is not much difference in the curves, although the shorter resonator rods show the lowest peak SWR value between the bands. However, far more significant to the builder are the SWR values within the bands of interest and the reasons for those values. The table shows that the 20-meter feedpoint impedance changes very little despite the 40% variation in rod length (once we readjust the capacitance). However, the 15-meter impedance changes considerably. **Fig. 8** graphs the resistance variation for the same cases shown in the SWR graph.

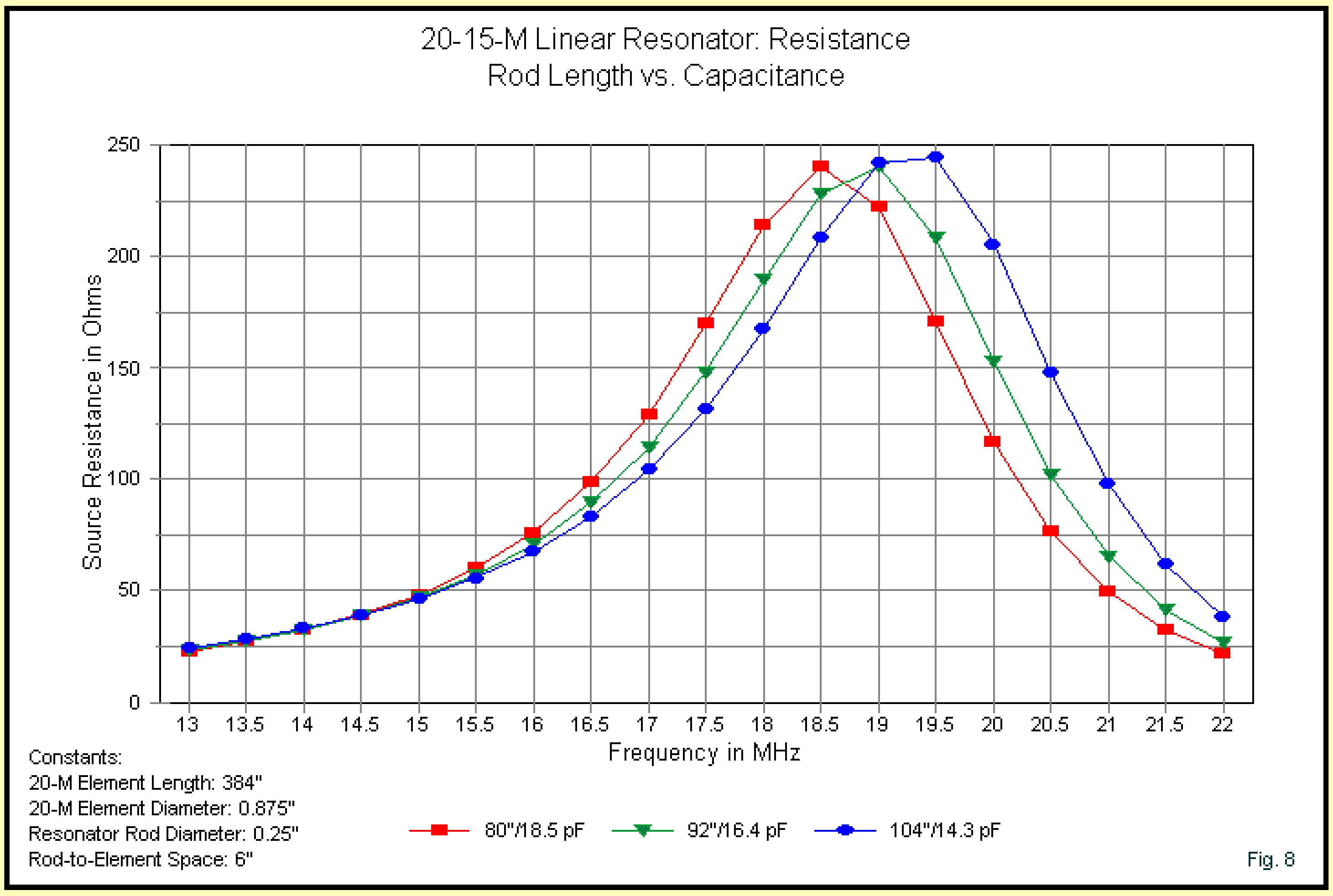


Fig. 8

Between 13 and 16 MHz, the resonator rod length makes very little difference to the feedpoint resistance. It does have a slightly more noticeable effect on the feedpoint reactance, as shown by the transition from capacitive to inductive reactance as we increase the resonator rod length. In contrast, the resonator rod length makes a much larger difference on the 15-meter feedpoint resistance. As we increase the rod length, the feedpoint resistance reaches its peak value at ever-higher frequencies so that the value is higher at 21 MHz.

Despite the relatively wide range of 15-meter impedance values that occur as we change the resonator rod length, the current phase angle changes very slowly. A linear resonator tends not to give the builder any sudden performance changes to indicate when a varied structure has gone too far in one or another direction.

Interestingly, the most optimal version of the dual-band dipole occurs with a rod length of 92", only a bit shorter than our initial model. Although this model does not change the relatively low 20-meter feedpoint impedance, it does provide a 15-meter value that most closely approximates the best match to a 50-Ohm coaxial cable. Therefore, we shall use this model as the starting point for exploring other variations that we may impose on the dual-band dipole.

Varying the Spacing between the Resonator Rod and the Main Element

If we freeze the rod length at 92", we may vary one of the other dimensions of the physical structure. The initial model used a 6" space between the rod and the main element. Let's vary this spacing in 2" increments between 2" and 10" to see what emerges. The basic results of this exercise appear in **Table 4**. Remember that in this exercise, we are holding constant the main element length and diameter and the resonator rod length and diameter.

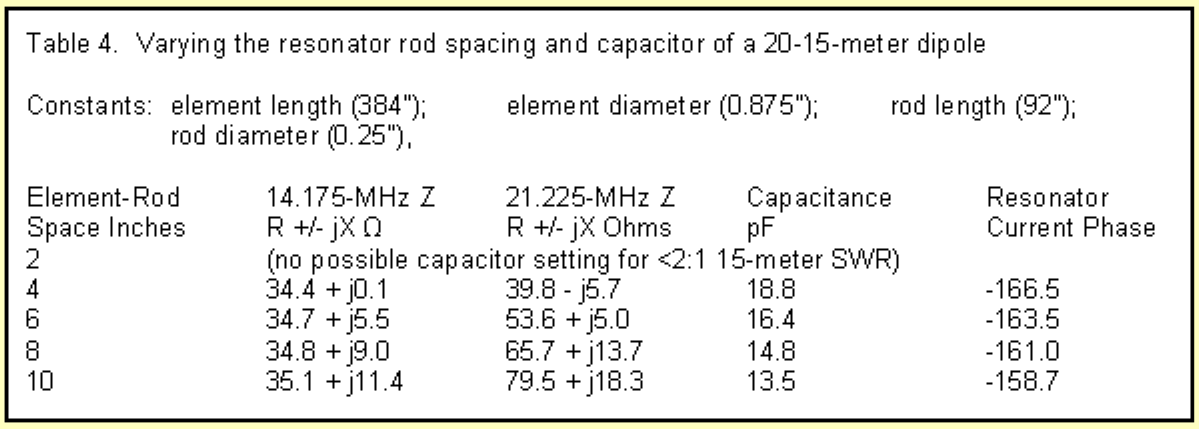


Table 4. Varying the resonator rod spacing and capacitor of a 20-15-meter dipole

Constants: element length (384"); element diameter (0.875"); rod length (92"); rod diameter (0.25"),

Element-Rod Space Inches	14.175-MHz Z R +/- jX Ω	21.225-MHz Z R +/- jX Ohms	Capacitance pF	Resonator Current Phase
2	(no possible capacitor setting for <2:1 15-meter SWR)			
4	34.4 + j0.1	39.8 - j5.7	18.8	-166.5
6	34.7 + j5.5	53.6 + j5.0	16.4	-163.5
8	34.8 + j9.0	65.7 + j13.7	14.8	-161.0
10	35.1 + j11.4	79.5 + j18.3	13.5	-158.7

The change in resonator rod spacing once more has only a small effect on the 20-meter impedance. The reactance tends to become more inductive as we increae the spacing. The key differences appear on 15 meters. As we increase the spacing, the 15-meter impedance increases in both resistance and inductive reactance. **Fig. 9** shows what happens to the wide-band SWR curves.

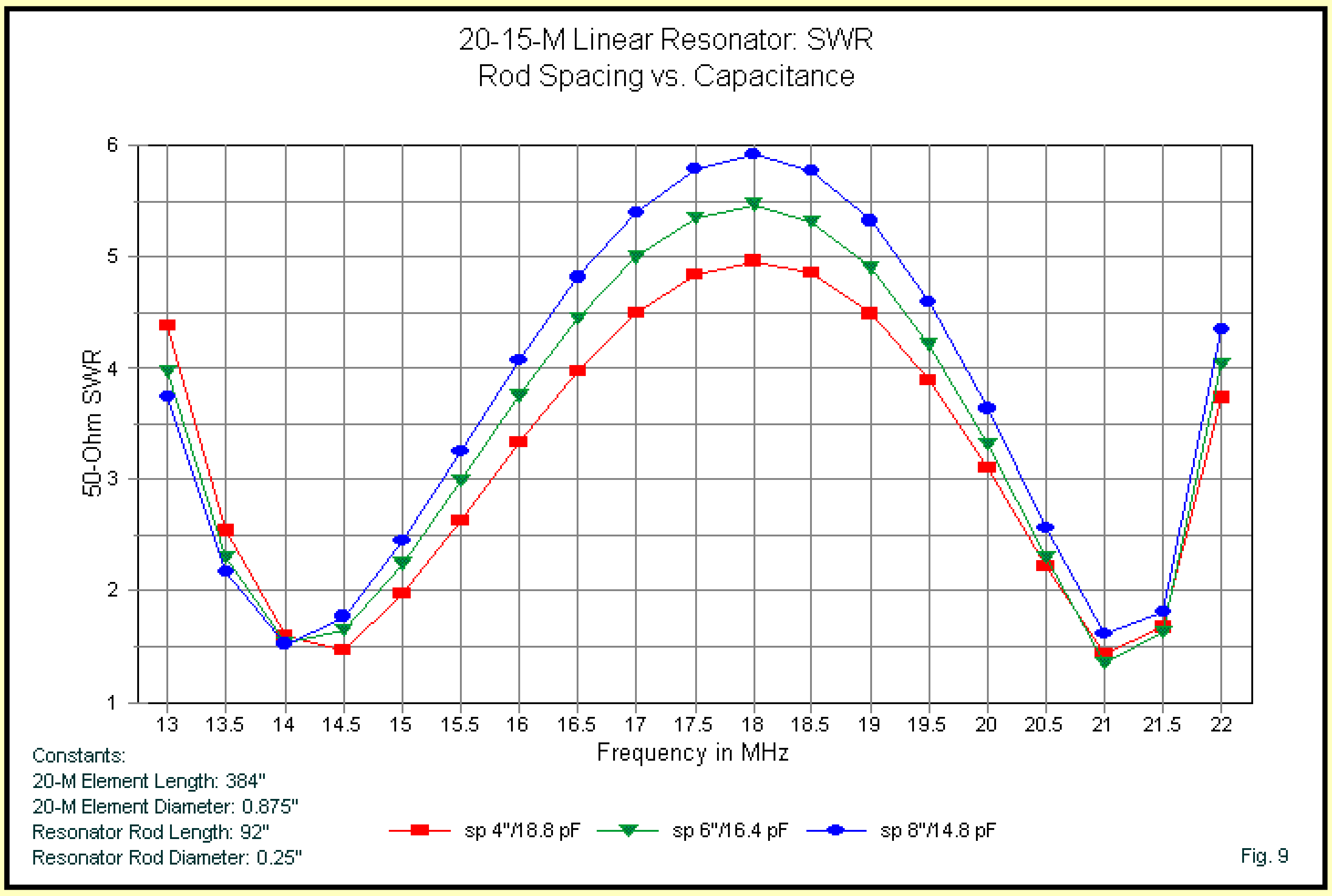


Fig. 9

Although all of the 3 curves shown are usable, close spacing reduces the feedpoint resistance to a low value, while wide spacing increases it. Both extremes raise the 50-Ohm SWR on 15 meters.

The 2" spacing value did not yield a value of capacitance that would produce an SWR of less than 2:1 on 15 meters. However, this result is uncertain. The wires that form the connections between the main element and the resonator rod have become seriously shorter than the segment lengths on the two parallel elements. Hence, it is not wholly clear whether the result emerges from the spacing or from modeling limitations.

In many cases, the linear resonator rod would not by fully self-supporting. Instead, it would likely have a center non-conductive support extending between the main element and the rod. Some builders might use the support as a means of flexing the resonator rod at the center to either increase of decrease its distance from the main element. I have not modeled this situation, although the technique may serve as a method for fine tuning the assembly.

We may note in passing that spacing occasions a small variation in the resonator current phase. As well, the capacitor value required to achieve the acceptable SWR curves does not change in a linear manner. The closer the spacing, the larger the capacitor must be. It is likely that the capacitor value changes according to changes in the mutual inductance between the rod and the main element center, and that value is also not linear with distance between the coupled lengths.

Varying the Diameter of the Linear Resonator Rod

Changes in resonator rod length and spacing from the main element produce clear and significant differences in the impedance performance of the dual-band dipole. If we confine ourselves to practical building dimensions, other structural dimensions that we might vary produce less dramatic effects. Most builders who begin with a tubular structure for a 20-meter dipole would likely choose a smaller diameter for the linear resonator rod in order to hold the total element weight to the minimal practical level. That reasoning underlies the initial choice of a 0.25" diameter resonator rod. However, we might have as easily selected rods or tubes ranging from 1/8" to 1/2". Let's survey the sizes readily available in the U.S.. All the while we shall hold constant the main element length and diameter, and employ the 92" resonator rod spaced 6" from the main element. For our efforts, we obtain the results shown in **Table 5**.

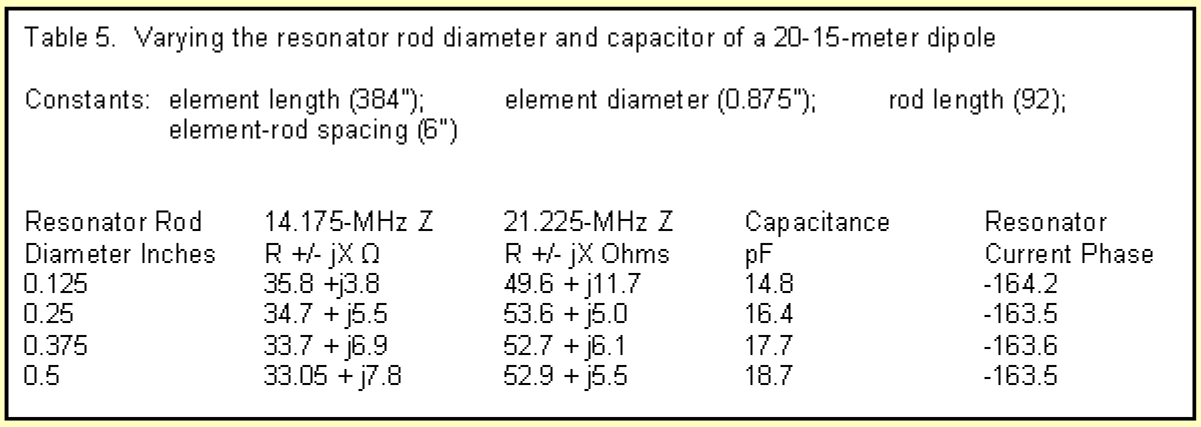


Table 5. Varying the resonator rod diameter and capacitor of a 20-15-meter dipole

Constants: element length (384"); element diameter (0.875"); rod length (92); element-rod spacing (6")

Resonator Rod Diameter Inches	14.175-MHz Z R +/- jX Ω	21.225-MHz Z R +/- jX Ohms	Capacitance pF	Resonator Current Phase
0.125	35.8 +j3.8	49.6 + j11.7	14.8	-164.2
0.25	34.7 + j5.5	53.6 + j5.0	16.4	-163.5
0.375	33.7 + j6.9	52.7 + j6.1	17.7	-163.6
0.5	33.05 + j7.8	52.9 + j5.5	18.7	-163.5

Altough the 0.125" rod is a bit difficult to tame, we may obtain essentially the same 15-meter performance with any diameter of resonator rod. In fact, the 15-meter performance--with only small changes in the required capacitance--shows almost identical feedpoint impedances and current phase angles at 21.225 MHz from 0.25" through 0.5", a 2:1 diameter ratio. In addition, the ratio of main element to resonator rod diameter changes considerably over the range of rod diameters. **Fig. 10** shows the resulting wide-band SWR curves.

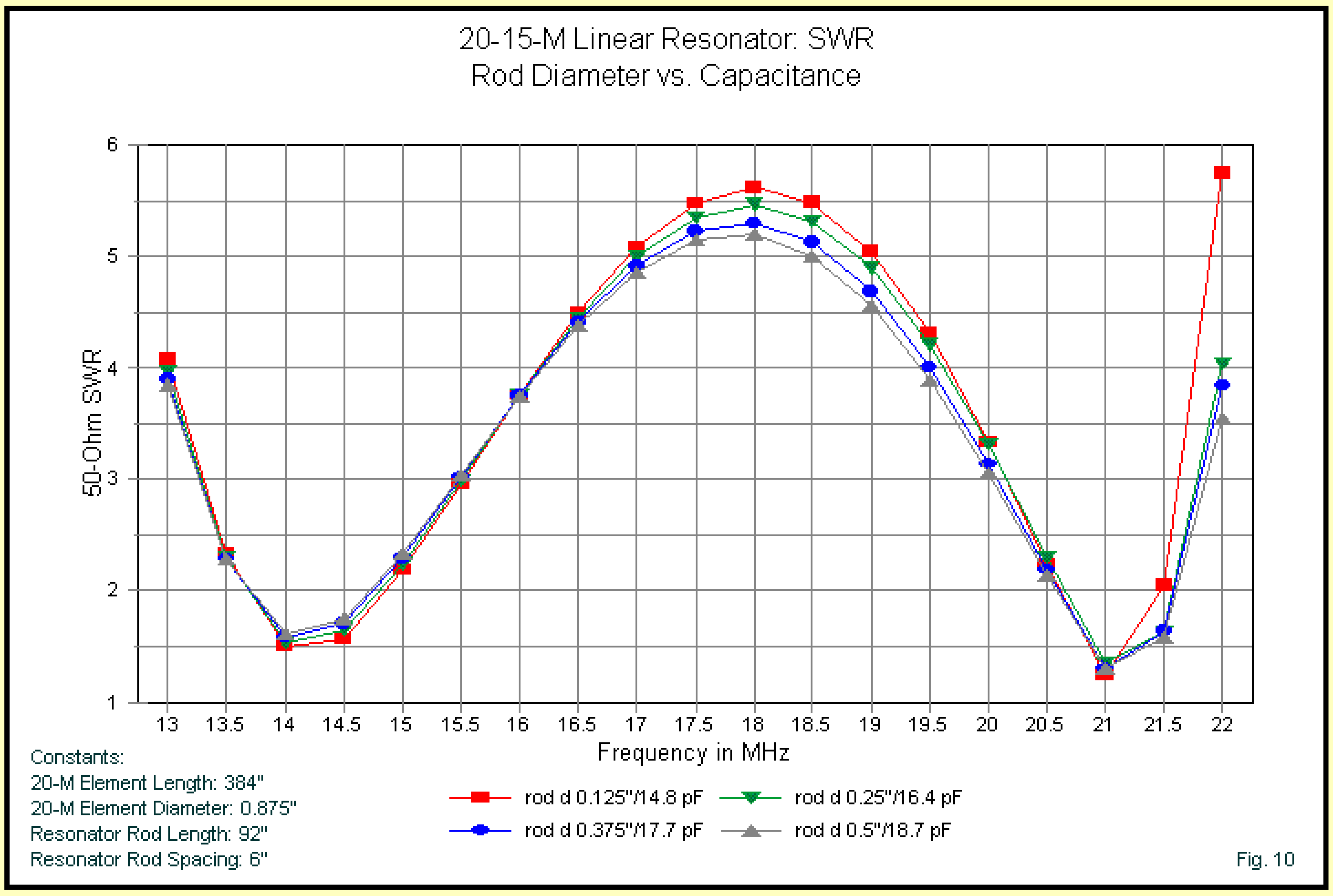


Fig. 10

At the 20-meter end of the scale, we may note some warning signals. Although all of the rod diameters produce acceptable values, increasing the rod diameter does show a downward trend in an already low feedpoint resistance value. With a 6" spacing, raising the diameter of the rod to parity with the main element might press our ability to obtain an acceptable 20-meter SWR curve.

Varying the Main Element Diameter

The final dimensional variation that we shall explore is changing the main element diameter. We shall use the 92" long, 0.25" diameter resonator rod that is 6" from the main element. I began this exercise prepared to change the main element length as I changed diameter, but within the narrow limits of practical size changes, the 384" main element length proved to be a constant. Because we are working with tubular elements at 20 meters, the range of practical tubing sizes is limited. I examined only 0.75" and 1.0" diameter tubes for comparison with the original 0.875" size. The results appear in **Table 6**.

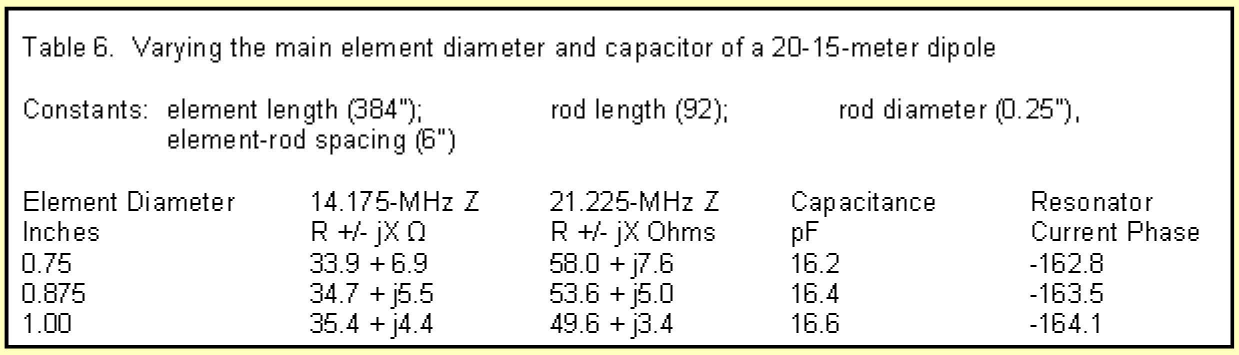


Table 6. Varying the main element diameter and capacitor of a 20-15-meter dipole

Constants: element length (384"); element-rod spacing (6"); rod length (92); rod diameter (0.25"),

Element Diameter Inches	14.175-MHz Z R +/- jX Ω	21.225-MHz Z R +/- jX Ohms	Capacitance pF	Resonator Current Phase
0.75	33.9 + 6.9	58.0 + j7.6	16.2	-162.8
0.875	34.7 + j5.5	53.6 + j5.0	16.4	-163.5
1.00	35.4 + j4.4	49.6 + j3.4	16.6	-164.1

The table suggests that the wide-band SWR curves will show little difference among them. **Fig. 11** confirms our suspicions.

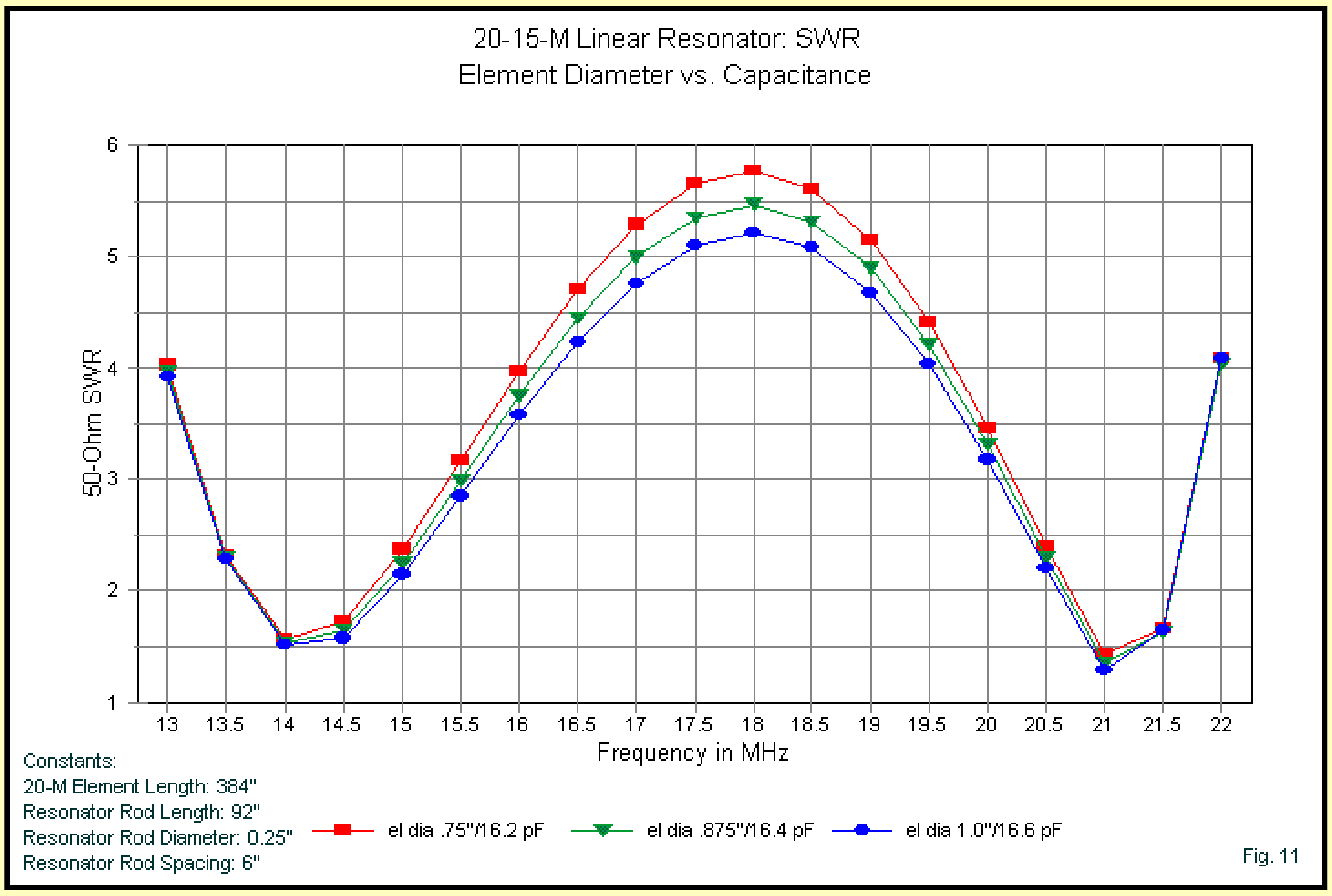


Fig. 11

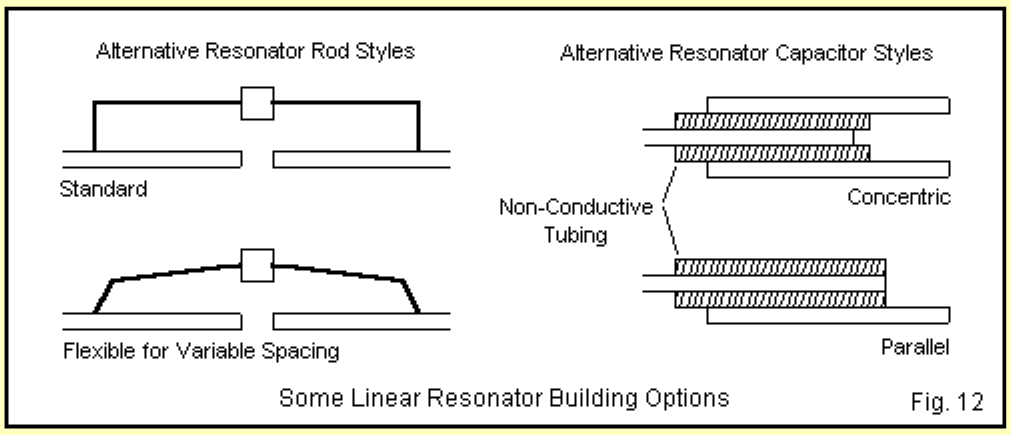
The changes in main element diameter yield only minuscule changes in the required capacitance and the resultant 15-meter resonator rod current phase. As we increase the element diameter, we find a rising 20-meter feedpoint resistance and a decreasing 15-meter feedpoint resistance. However, both changes are small. In general, a 1.3:1 change in main element diameter produces no performance change that rises above the level of construction and field testing variations that we are likely to encounter if we translate a model into a physical antenna.

Concluding Thoughts

These notes have not aimed at producing a buildable design for a dual-band 20-15-mter dipole with a linear resonator. Instead, they have had as their goal an examination of some of the basic properties of such an antenna, along with an exploration of the effects of varying parts of the structure. The numbers are less important than the trends, which an experimenter may use with almost any frequency combination and with any materials. Indeed, the ultimate goal is to make linear-resonator techniques sufficiently familiar to encourage further experimentation and exploration.

Much remains yet to be done in detail. Linear resonators on wire antennas offer an open region for both modeling and actual building of experimental antennas. Although there are reports of directional antennas using drivers with linear resonators, they are so few and scattered that the backyard builder has few resources for guidance.

In most instances, linear resonators are the province of the experimenter. Hence, it is wise to do the initial work with scrap or dispensable materials--to account for initial unsuccessful tries. As well, you might consider giving yourself maximum flexibility. For example, compare the standard (modeled) resonator structures at the top left in **Fig. 12**. The lower sketch shows a more flexible design that allows for fine adjustment by the size of the spacer at the center of the assembly.



Some Linear Resonator Building Options

Fig. 12

The right side of **Fig. 12** shows two practical capacitors. The upper view shows concentric tubes (or a tube and a center rod) with a non-conductive sheathing on the center rod. The system offers maximum capacitance per inch due to the maximizing of facing surfaces. However, the system requires a mounting system for connection to the rod presumed to be at the right. The lower sketch shows paralleled rod lengths, with a non-conductive sheath on one rod. The system offers less capacitance per inch, but may be useful in fine-tuning. As well, the parallel capacitor does not require a physical connection between the capacitor leads and plates, since they are the same. Both systems require a means of securely fixing the final settings and perhaps heat-shrink tubing to protect against weathering effects.

These are but starter thoughts toward further experimentation that is possible with linear resonators. As well, there is considerable design work yet to be done. For example, one might consider other frequency spreads to see what linear resonators might require for success. Wire antennas require design work relative to both dimensions and fabrication. Future parts of these notes will explore some--but by no means all--of these directions.

How useful linear resonators may become and how easily we may work around some of their limitations depends upon how much ingenuity we are willing to devote to their development.

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