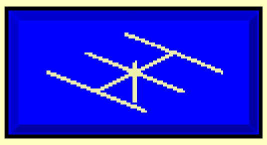

1-2-3: 1 Boom, 2 Bands, 3 Elements Each

The Evolution of a Modeling Design

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1. The Project and Its Specifications

I have long been curious about the design of multiband Yagis. Although sometimes maligned by monoband purists, these beams serve a vital function in amateur radio and elsewhere. The problems of getting a single array of elements to perform adequately on 2 or more bands is a design challenge of the first order. That the products on the market are very serviceable is a tribute to a number of fine designers around the world.

The most usual method of designing a multiband Yagi is to begin with 20 meters and then graft on elements to serve other bands. The 20-meter design remains relatively unaffected by laying in elements for 15 or 10 or other higher frequency bands, and only minor tweaking is needed to restore its original performance.

The other bands are another matter. Laying in a 15 meter Yagi within the confines of a 20 meter beam will normally cage the performance of the 15 meter antenna to less than the same antenna would do were it free and clear. Some designers add elements to restore the performance, thus getting essentially 3-element monoband performance out of 4 elements. Obviously, the weight goes up with the element count.

To counteract this trend, designers use a number of means to press elements into double duty, including traps. Traps are handy at the 20- meter driven element, since they permit the use of a single element as the driver and a single feedline for the array. However, log periodic assemblies and open sleeve coupling are alternatives that permit single feedlines, but all of the single-feed methods are implemented at the expense of design complexity, subtlety, and a certain order of finickiness.

If we can live with multiple feedlines (or a switching system at the mast), perhaps some of the complexity of multiband design might be overcome. Separate feedlines would permit placement of the driven element wherever it was needed. We might even overcome the mind set of placing driven elements for different bands in close proximity to each other.

The caging effect that requires extra elements or other design complexities might also be overcome--perhaps by sliding the upper band beams forward on the boom. If the lowest band uses only a reflector and driven element, then sliding higher frequency elements forward is simple. However, once we hit 3 elements, staggered beams become cumbersome in terms of boom length.

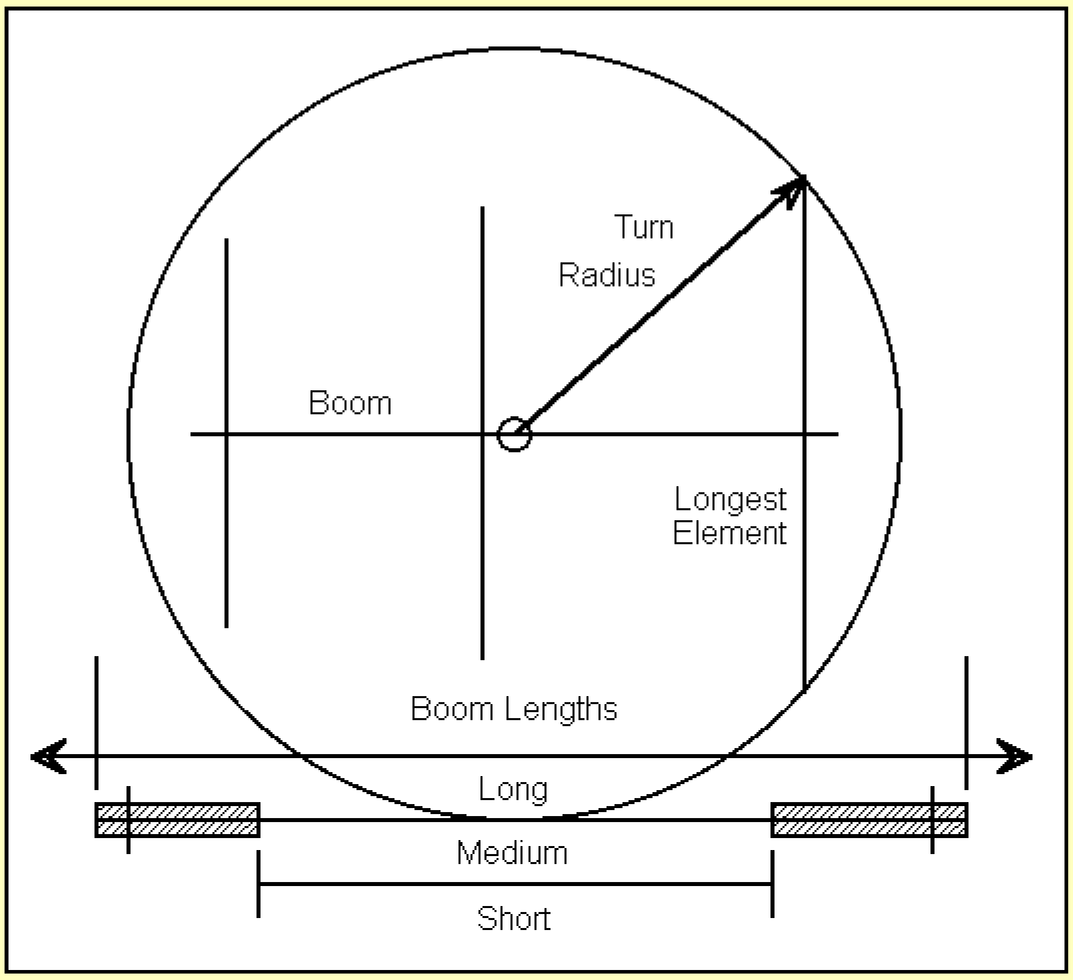
So I set myself a little modeling exercise: to develop a buildable design for a 2-band beam (20 and 15 meters) of 3-elements for each band on one medium length boom. The beams would be separately fed and, to the highest degree possible within reason, would retain their independent monoband performance.

2. The First Step: Trial Models

Beam Selection: Among my collection of models is a 3-element design for 20 meters originally supplied by Brian Beezley, K6STI, with AO-5. The model uses 1" untapered elements and provides about 8.1 dBi free space mid-band gain and better than 20 dB front-to-back ratio over the first 2/3 of the band. The intended boom length is 24 feet.

Because a seriously tapered set of elements that are mechanically sound will be equivalent to much thinner untapered elements, the beam would have to be re-tuned for that purpose. Additionally, it would require scaling to 15 meters. Finally, the beams would require conversion to tapered elements and readjusted accordingly.

Boom Length: The project goal was to use a "medium-length boom," which is a fuzzy concept unless given some definition. Using the lowest band to set parameters, we might call a medium length boom one that is generally about twice the length of the antenna turning radius, as defined by the longest elements. This measure is not precise, since the turning radius is a function of the 20-meter reflector length and the distance of the element from the boom-mast junction. However, 35' at 20 meters seems not unreasonable as a good number and is commonly used (plus or minus a foot or so) for multiband beams. Anything more than 10% longer gets into long boom Yagis (40' or so at 20 meters) and anything less than 2/3 this length (less than 24') is usually classed as a short boom at 20.



The goal was also to keep the boom length as short as feasible while retaining essentially monoband performance for the individual beams. This goal meant that I could not simply set one beam in front of the other to get a composite of 24' plus 16' plus a little extra for a 45' long antenna. Something closer to 30' seemed a decent limit, but it meant that at least some of the elements would have to interlace.

First-Things-First: The Individual Beams: Having set the project goals, the first step was to ascertain the monoband performance of the rescaled beams. I modeled the 20 meter beam using 5/8" diameter elements with the following results across 20 meters

Fq	**14.0**	**14.15**	**14.35**
Gain dBi	**8.03**	**8.18**	**8.45**
F-B dB	**21.41**	**26.33**	**16.20**
Feed Z ohms	**67.6 - j29.6**	**50.7 - j10.7**	**32.4 + j11.8**
SWR 50	**1.79**	**1.24**	**1.69**

I also scaled the antenna for 15 meters, using 1/2" diameter elements. After re-tweaking, I obtained these results across the band.

Fq	**21.0**	**21.2**	**21.45**
Gain dBi	**8.13**	**8.28**	**8.51**
F-B dB	**23.29**	**25.22**	**16.75**
Feed Z ohms	**60.4 - j27.8**	**48.8 - j9.7**	**35.3 + j11.6**
SWR 50	**1.71**	**1.22**	**1.56**

The slightly stronger performance (which shows only in decimal places that are meaningless to actual operation) on 15 is a result of the fact that the beam elements are essentially fatter on that band, relative to a wavelength.

As anticipated, front-to-back ratio fell off in the upper portion of the band, which gain continued to increase.

For reference, the wire lengths and spacings of the 2 beams are included here.

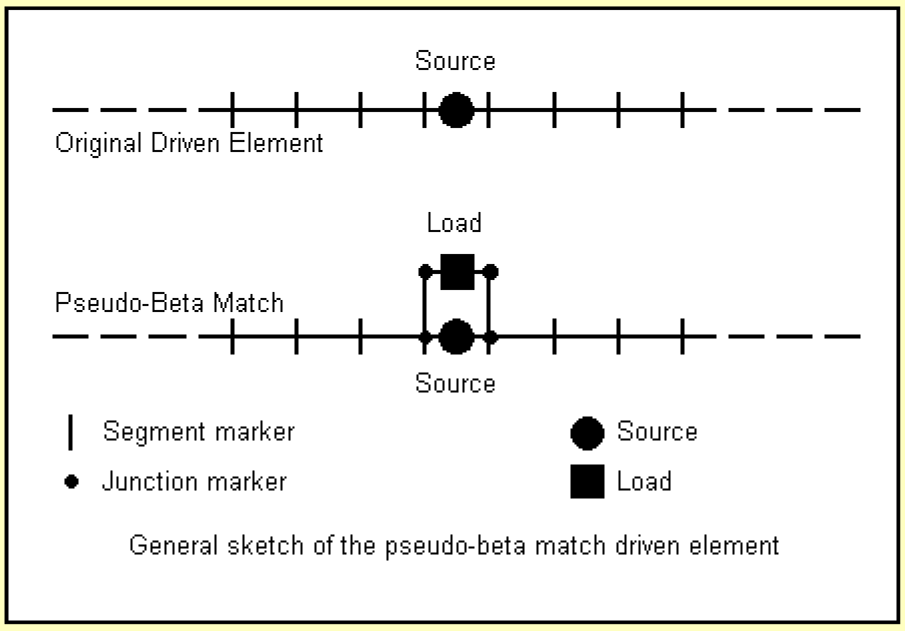
```
Frequency = 14.15  MHz.
              --------------- WIRES ---------------
Wire Conn.--- End 1 (x,y,z :in) Conn.--- End 2 (x,y,z :in) Dia(in) Segs

1    -208.00,  0.000,  0.000       208.000,  0.000,  0.000 6.25E-01  21
2    -197.00,127.000,  0.000         197.000,127.000,  0.000 6.25E-01  21
3    -188.00,275.000,  0.000         188.000,275.000,  0.000 6.25E-01  21
              -------------- SOURCES --------------
Source  Wire    Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
        Seg.    Actual      (Specified)
1         1     2 / 50.00   (  2 / 50.00)    1.000       0.000       I
------------------------------------------------------------------------
```

```
Frequency = 21.2  MHz.
              --------------- WIRES ---------------
Wire Conn.--- End 1 (x,y,z :in) Conn.--- End 2 (x,y,z :in) Dia(in) Segs

1    -138.80,  0.000,  0.000       138.800,  0.000,  0.000 5.00E-01  15
2    -131.50, 85.000,  0.000        131.500, 85.000,  0.000 5.00E-01  15
3    -125.50,184.000,  0.000         125.500,184.000,  0.000 5.00E-01  15
              -------------- SOURCES --------------
Source  Wire    Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
        Seg.    Actual      (Specified)
1         8     2 / 50.00   (  2 / 50.00)    1.000       0.000       I
```

Feedpoint Impedance: a Pseudo-Beta Match: The raw feedpoint impedances for the models actually show the standard values one might anticipate-- about 25 ohms resistive with more than 10 ohms capacitive reactance at the target center frequencies. 50-ohm performance figures were created by modeling a pseudo-beta match. The procedure is straightforward. The driven elements were subdivided into 3 wires according to the following scheme. A left end used 1/2 the total segments, as did a right half of the element. Each half element was terminated 1/2 the length of a segment within it from the center point. A single-segment wire was placed between the halves. The following sketch may be helpful here.



General sketch of the pseudo-beta match driven element

Then three 1-segment wires were constructed, each of the same length as the other segments and of the same diameter as the element. This latter step is necessary to overcome some inaccuracy introduced when NEC encounters angular junctions of dissimilar diameter wires. Two of the new wires are oriented vertically from the junctions with the 1-segment center wire. The third wire connects the open upper ends of the first two.

The third wire is loaded with a value of inductive reactance. This value may not be the same as the value one might calculate for a beta match, because the vertical wires present physical structures that amount to parallel transmission line lengths and which exhibit capacitance between them. The required reactance values for the independent antennas were about double what might be expected, and in all cases required lengthening the driven element to eliminate remnant inductive reactance. Nonetheless, the matching system simulates with reasonable accuracy a beta match and provides what is needed for a 50-ohm target frequency match.

Accuracy can be improved by using the maximum number of segments possible without violating the NEC limits for segment length-to-diameter ratio. This procedure will minimize the physically modeled structure and its affects on the required loading. However, in multiband beams with stepped segment diameters, a model may easily become unmanageable.

Although the resulting impedance figures may be adequately accurate to estimate operating bandwidth, the physical structure also increases gain slightly (often up to 0.1 dB). This is a false increase created by the physical structure of the pseudo-beta match.

For purposes of making operating bandwidth estimates, the inductive reactance is converted into a value of inductance placed in a parallel loading circuit. Of course, the value of capacitance for this mode of loading is left zero. I normally leave the resistance zero (recorded by NEC as missing), which produces the highest Q and narrowest operating bandwidth, so that estimates are conservative. As the sample beams show, a simple beta match has no difficulty providing full band operation with under 2:1 50-ohm SWR.

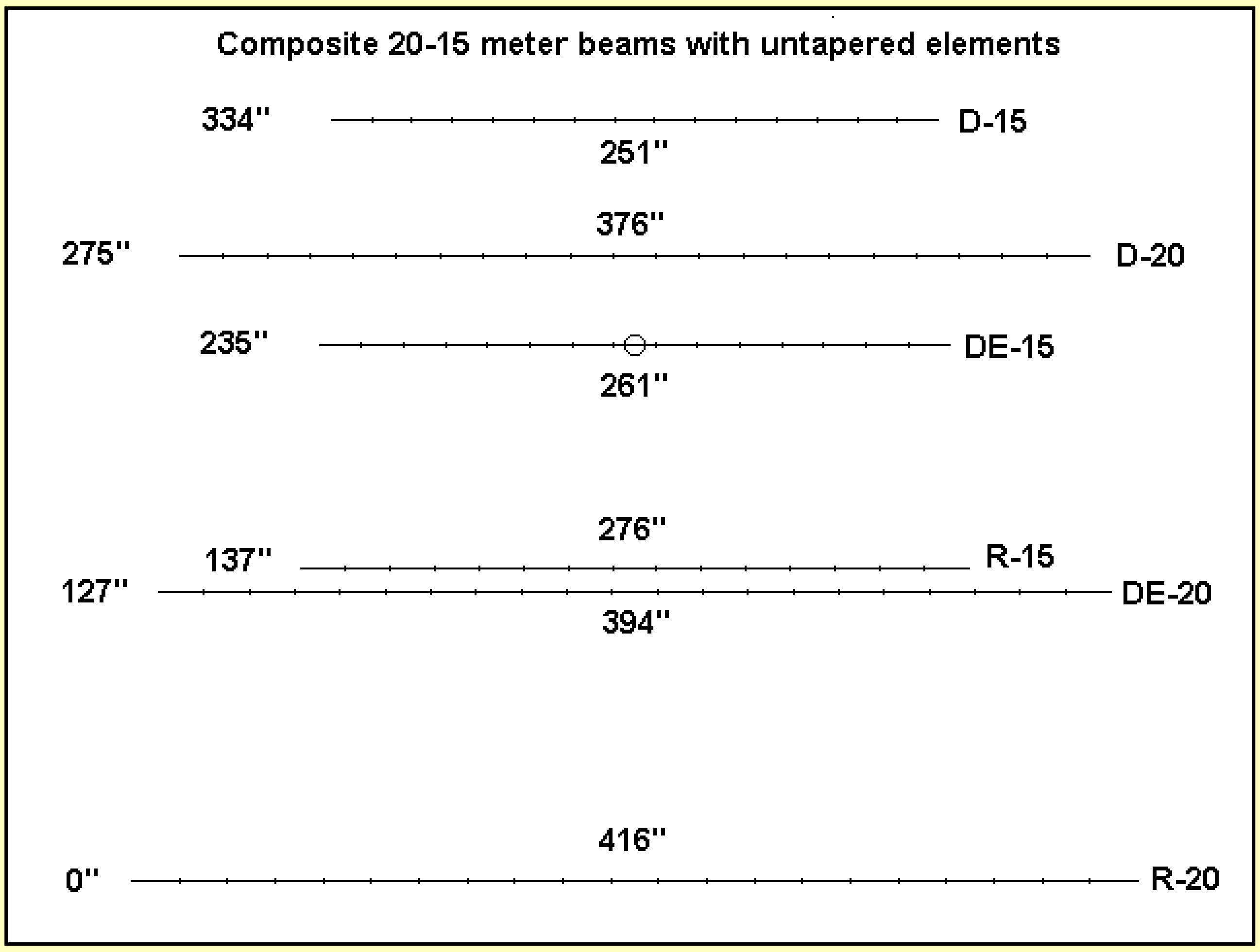
Combining the Untapered Beams: All modeling of the individual beams was done with segments about 10" long: 21 segments for the 20-meter elements and 15 segments for the 15-meter elements. These lengths were retained for the composite attempt to model the antenna on one boom. Remember that the goal was to retain, insofar as possible, monoband performance on a medium length (less than 35') boom.

The figure shows the layout. The 15-meter driver and reflector were placed forward of the 20-meter driver and reflector, so that the 15-meter director is well forward of the 20-meter reflector.

The following element chart shows the final element lengths and spacings. All 20-meter elements are 5/8" diameter, while all 15-meter elements are 1/2" diameter. The elements are grouped by bands, so that the 20 meter director is physically out of place in the chart, but electrically grouped with its cohorts.

```
              --------------- WIRES ---------------

Wire Conn.--- End 1 (x,y,z :in) Conn.--- End 2 (x,y,z :in) Dia(in) Segs
1    -208.00,  0.000,  0.000       208.000,  0.000,  0.000 6.25E-01  21
2    -197.00,127.000,  0.000       197.000,127.000,  0.000 6.25E-01  21
3    -188.00,275.000,  0.000       188.000,275.000,  0.000 6.25E-01  21
4    -138.00,137.000,  0.000       138.000,137.000,  0.000 5.00E-01  15
5    -130.50,235.000,  0.000       130.500,235.000,  0.000 5.00E-01  15
6    -125.50,334.000,  0.000       125.500,334.000,  0.000 5.00E-01  15
              -------------- SOURCES --------------
Source  Wire   Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
        Seg.     Actual      (Specified)
For 15 meters
1       8     5 / 50.00   (  5 / 50.00)      1.000       0.000       I
For 20 meters
1       8     2 / 50.00   (  2 / 50.00)      1.000       0.000       I
```



By simple calculations, you will see that minor adjustments in 15-meter element spacing and lengths were required to tweak the design in its semi- caged setting. Little or no change was necessary for the 20-meter beam. The entire assembly is under 28' long, a good fit for a 30' boom.

Although the pseudo-beta match model wires are not shown in order to maintain clarity, they were present in the runs that produced the following results for the two bands.

Fq	**14.0**	**14.15**	**14.35**
Gain dBi	**8.23**	**8.37**	**8.60**
F-B dB	**22.87**	**23.30**	**15.11**
Feed Z ohms	**87.1 - j23.7**	**57.8 - j 4.9**	**33.0 + j18.2**
SWR 50	**1.93**	**1.19**	**1.83**

Fq	**21.0**	**21.2**	**21.45**
Gain dBi	**8.39**	**8.45**	**8.67**
F-B dB	**19.57**	**20.09**	**14.70**
Feed Z ohms	**79.1 - j41.6**	**56.6 - j15.6**	**30.3 + j18.7**
SWR 50	**2.19**	**1.37**	**1.98**

Several things stand out in these results. The 15-meter operating bandwidth is just sufficient so that with any length of coax at all, it will show less than 2:1 SWR at the operating position. A beta inductance with any finite Q will also likely widen the operating band width. What the use of the pseudo-beta match in the model obscures is the actual feedpoint impedances without the match in place. The 20-meter portion of the antenna shows a normal feedpoint impedance in the mid-20s. The 15- meter feedpoint impedance is closer to 15 ohms--a low but usable figure.

Beyond the feedpoint impedance, the performance of the antennas is enhanced (although not in a major way) with respect to gain on both bands. The presence of the elements for the other band adds a modicum of gain when most of the longer elements are to the rear and most of the shorter ones are to the front. However, 15-meter front-to-back ratio is down somewhat, again not too significantly except for the very upper end of the band.

The Results So Far: The exercise using simple models proved the principle that two 3-element beams for separate bands can be placed on a single moderate length boom in such a way as to preserve for all practical purposes the performance of each beam when used as a monobander. Although the assembly requires separate feedlines for each antenna, it is otherwise a model of simplicity, using no extra elements or components. Thus it is, in principle, amenable to straightforward construction techniques by the home builder. Incidentally, a 4-element monobander for 20 meters of about the same boom length will have a center-band gain of about 8.5-8.6 dBi, but will hold a front-to-back ratio of about 23 dB across the band. The present design places two antennas in the same space with reasonably competitive performance.

3. From Principle to Practicality

A Buildable Model: The initial simplified (untapered-element) model was developed to prove a principle (luckily, it was provable). However, the untapered elements are generally unsuitable for construction. Hence, the next step was to adopt a set of element tapers and redo the project. Although some readjustment of element length and spacing was anticipated, the untapered-element models provided initial guidelines on which to rapidly develop something approaching a buildable model.

The Element Taper: For purposes of the exercise, a fairly standard set of element tapers was selected from other Yagis. The following table shows the taper chosen and represents the lengths each side of the boom the all the elements of each band:

Band	**1"**	**.875"**	**.75"**	**.625"**	**.5" (tip section)**
20	**72"**	**20"**	**42"**	**20"**	**35-62"**
15	**--**	**30"**	**36"**	**18"**	**40-60"**

Although other taper schedules can certainly be used, the one above will suffice for the exercise. The 20-meter schedule can be strengthened if the inner 4' of tubing is increased to 1.125" stock. As given, simple models of the individual antennas required 27 wires on 20 and 21 wires on 15, while the eventual composite model involves 48 wires. In all cases, to the degree permitted by the segmentation, individual segment lengths were equalized as much as possible, with 10" being the average segment length.

The Individual Antennas: Relative to the untapered models, both the 20- meter and 15-meter Yagis required adjustment both to elements lengths and to spacing. Since tapering yields an element which has a quite small effective diameter, element lengths grew. Moreover, as the performance charts below show, the front-to-back ratio available in the untapered versions could not be sustained, although the decrease is not large. Here are the wire tables and performance figures from the tapered models of individual antennas.

Frequency = 14.15 MHz.

```
             --------------- WIRES ---------------

Wire Conn.--- End 1 (x,y,z : in) Conn.--- End 2 (x,y,z : in) Dia(in) Segs
1      -215.00,  0.000,  0.000  W2E1 -154.00,  0.000,  0.000 5.00E-01   5
2 W1E2 -154.00,  0.000,  0.000  W3E1 -134.00,  0.000,  0.000 6.25E-01   2
3 W2E2 -134.00,  0.000,  0.000  W4E1 -92.000,  0.000,  0.000 7.50E-01   4
4 W3E2 -92.000,  0.000,  0.000  W5E1 -72.000,  0.000,  0.000 8.75E-01   2
5 W4E2 -72.000,  0.000,  0.000  W6E1  72.000,  0.000,  0.000 1.00E+00  11
6 W5E2  72.000,  0.000,  0.000  W7E1  92.000,  0.000,  0.000 8.75E-01   2
7 W6E2  92.000,  0.000,  0.000  W8E1 134.000,  0.000,  0.000 7.50E-01   4
8 W7E2 134.000,  0.000,  0.000  W9E1 154.000,  0.000,  0.000 6.25E-01   2
9 W8E2 154.000,  0.000,  0.000       215.000,  0.000,  0.000 5.00E-01   5
10     -201.00,129.000,  0.000 W11E1 -154.00,129.000,  0.000 5.00E-01   5
11W10E2 -154.00,129.000,  0.000 W12E1 -134.00,129.000,  0.000 6.25E-01   2
12W11E2 -134.00,129.000,  0.000 W13E1 -92.000,129.000,  0.000 7.50E-01   4
13W12E2 -92.000,129.000,  0.000 W14E1 -72.000,129.000,  0.000 8.75E-01   2
14W13E2 -72.000,129.000,  0.000 W15E1  72.000,129.000,  0.000 1.00E+00  11
15W14E2  72.000,129.000,  0.000 W16E1  92.000,129.000,  0.000 8.75E-01   2
16W15E2  92.000,129.000,  0.000 W17E1 134.000,129.000,  0.000 7.50E-01   4
17W16E2 134.000,129.000,  0.000 W18E1 154.000,129.000,  0.000 6.25E-01   2
18W17E2 154.000,129.000,  0.000       201.000,129.000,  0.000 5.00E-01   5
19      -188.00,300.000,  0.000 W20E1 -154.00,300.000,  0.000 5.00E-01   5
20W19E2 -154.00,300.000,  0.000 W21E1 -134.00,300.000,  0.000 6.25E-01   2
21W20E2 -134.00,300.000,  0.000 W22E1 -92.000,300.000,  0.000 7.50E-01   4
22W21E2 -92.000,300.000,  0.000 W23E1 -72.000,300.000,  0.000 8.75E-01   2
23W22E2 -72.000,300.000,  0.000 W24E1  72.000,300.000,  0.000 1.00E+00  11
24W23E2  72.000,300.000,  0.000 W25E1  92.000,300.000,  0.000 8.75E-01   2
25W24E2  92.000,300.000,  0.000 W26E1 134.000,300.000,  0.000 7.50E-01   4
26W25E2 134.000,300.000,  0.000 W27E1 154.000,300.000,  0.000 6.25E-01   2
27W26E2 154.000,300.000,  0.000       188.000,300.000,  0.000 5.00E-01   5
             -------------- SOURCES --------------
Source    Wire    Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
         Seg.     Actual      (Specified)
1         6    14 / 50.00   ( 14 / 50.00)      1.000       0.000       I
```

Fq	14.0	14.15	14.35
Gain dBi	8.00	8.08	8.23
F-B dB	18.36	20.75	16.44
Feed Z ohms	27.2 - j24.0	28.0 - j12.7	27.7 + j 3.1

Frequency = 21.2 MHz.

```
             --------------- WIRES ---------------

Wire Conn.--- End 1 (x,y,z : in) Conn.--- End 2 (x,y,z : in) Dia(in) Segs

1      -142.50,  0.000,  0.000  W2E1 -84.000,  0.000,  0.000 5.00E-01   6
2  W1E2 -84.000,  0.000,  0.000  W3E1 -66.000,  0.000,  0.000 6.25E-01   2
3  W2E2 -66.000,  0.000,  0.000  W4E1 -30.000,  0.000,  0.000 7.50E-01   3
4  W3E2 -30.000,  0.000,  0.000  W5E1  30.000,  0.000,  0.000 8.75E-01   7
5  W4E2  30.000,  0.000,  0.000  W6E1  66.000,  0.000,  0.000 7.50E-01   3
6  W5E2  66.000,  0.000,  0.000  W7E1  84.000,  0.000,  0.000 6.25E-01   2
7  W6E2  84.000,  0.000,  0.000       142.500,  0.000,  0.000 5.00E-01   6
8      -134.00, 86.000,  0.000  W9E1 -84.000, 86.000,  0.000 5.00E-01   6
9  W8E2 -84.000, 86.000,  0.000 W10E1 -66.000, 86.000,  0.000 6.25E-01   2
10 W9E2 -66.000, 86.000,  0.000 W11E1 -30.000, 86.000,  0.000 7.50E-01   3
11W10E2 -30.000, 86.000,  0.000 W12E1  30.000, 86.000,  0.000 8.75E-01   7
12W11E2  30.000, 86.000,  0.000 W13E1  66.000, 86.000,  0.000 7.50E-01   3
13W12E2  66.000, 86.000,  0.000 W14E1  84.000, 86.000,  0.000 6.25E-01   2
14W13E2  84.000, 86.000,  0.000       134.000, 86.000,  0.000 5.00E-01   6
15      -125.50,200.000,  0.000 W16E1 -84.000,200.000,  0.000 5.00E-01   6
16W15E2 -84.000,200.000,  0.000 W17E1 -66.000,200.000,  0.000 6.25E-01   2
17W16E2 -66.000,200.000,  0.000 W18E1 -30.000,200.000,  0.000 7.50E-01   3
18W17E2 -30.000,200.000,  0.000 W19E1  30.000,200.000,  0.000 8.75E-01   7
19W18E2  30.000,200.000,  0.000 W20E1  66.000,200.000,  0.000 7.50E-01   3
20W19E2  66.000,200.000,  0.000 W21E1  84.000,200.000,  0.000 6.25E-01   2
21W20E2  84.000,200.000,  0.000       125.500,200.000,  0.000 5.00E-01   6
             -------------- SOURCES --------------
Source    Wire    Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
         Seg.     Actual      (Specified)
1         4    11 / 50.00   ( 11 / 50.00)      1.000       0.000       I
```

Fq	21.0	21.2	21.45
Gain dBi	8.05	8.14	8.27

F-B dB	**18.96**	**20.78**	**17.29**
Feed Z ohms	**26.8 - j19.1**	**27.4 - j9.3**	**27.1 + j 3.5**

To decrease model complexity and because the beta matches are too similar to those of the untapered models to need rerunning with this pair of models, the raw feedpoint impedances are shown in the tables. They are typical, well-behaved mid-20s values.

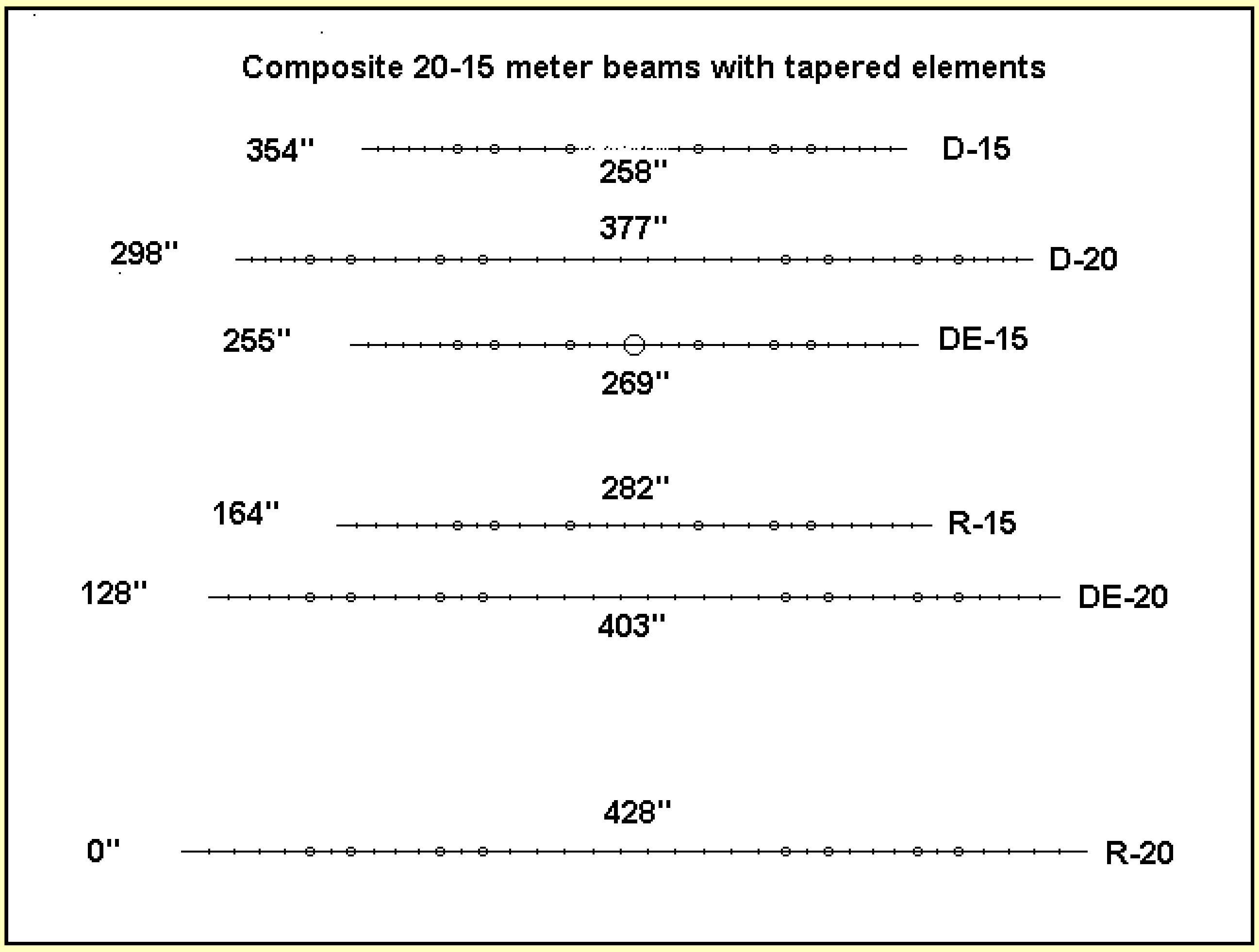
Again, the 15-meter model surpasses by amounts detectable only in models the 20-meter model because the effective diameter of the elements is slightly greater.

More significant are the required changes in element spacing necessary to optimize performance. The 15-meter boom grew by 16" while the 20-meter boom is over 2' longer than the untapered model boom. Moreover, the element placement for the 15-meter antenna will have to be changed from that used for the untapered model in order to set its rear 2 elements between the forward 2 20-meter elements.

These changes show up clearly when the antenna is modeled using the proposed element taper schedule for actual construction. Had a tapered model been built from the composite untapered model, performance would likely have been disappointing unless one were willing to spend endless hours physically juggling elements.

The Composite Tapered-Element 2-Band Beam: With a little tweaking here and there, the final composite model emerged. The chief mechanical difference is that the boom is now 29.5' long, barely under the 30' goal. Differences in element lengths and spacing will be clear with a little comparison with the individual tapered-element models. Similarly to the untapered-element composite model, elements are grouped by band and therefore are not in physical order. Here is the wire table for the antenna:

```
               --------------- WIRES ---------------
Wire Conn.--- End 1 (x,y,z : in)  Conn.--- End 2 (x,y,z : in) Dia(in) Segs
1       -214.00,  0.000,  0.000  W2E1 -154.00,  0.000,  0.000 5.00E-01   5
2  W1E2 -154.00,  0.000,  0.000  W3E1 -134.00,  0.000,  0.000 6.25E-01   2
3  W2E2 -134.00,  0.000,  0.000  W4E1 -92.000,  0.000,  0.000 7.50E-01   4
4  W3E2 -92.000,  0.000,  0.000  W5E1 -72.000,  0.000,  0.000 8.75E-01   2
5  W4E2 -72.000,  0.000,  0.000  W6E1  72.000,  0.000,  0.000 1.00E+00  11
6  W5E2  72.000,  0.000,  0.000  W7E1  92.000,  0.000,  0.000 8.75E-01   2
7  W6E2  92.000,  0.000,  0.000  W8E1 134.000,  0.000,  0.000 7.50E-01   4
8  W7E2 134.000,  0.000,  0.000  W9E1 154.000,  0.000,  0.000 6.25E-01   2
9  W8E2 154.000,  0.000,  0.000       214.000,  0.000,  0.000 5.00E-01   5
10      -201.50,128.000,  0.000 W11E1 -154.00,128.000,  0.000 5.00E-01   5
11W10E2 -154.00,128.000,  0.000 W12E1 -134.00,128.000,  0.000 6.25E-01   2
12W11E2 -134.00,128.000,  0.000 W13E1 -92.000,128.000,  0.000 7.50E-01   4
13W12E2 -92.000,128.000,  0.000 W14E1 -72.000,128.000,  0.000 8.75E-01   2
14W13E2 -72.000,128.000,  0.000 W15E1  72.000,128.000,  0.000 1.00E+00  11
15W14E2  72.000,128.000,  0.000 W16E1  92.000,128.000,  0.000 8.75E-01   2
16W15E2  92.000,128.000,  0.000 W17E1 134.000,128.000,  0.000 7.50E-01   4
17W16E2 134.000,128.000,  0.000 W18E1 154.000,128.000,  0.000 6.25E-01   2
18W17E2 154.000,128.000,  0.000       201.500,128.000,  0.000 5.00E-01   5
19      -188.50,298.000,  0.000 W20E1 -154.00,298.000,  0.000 5.00E-01   5
20W19E2 -154.00,298.000,  0.000 W21E1 -134.00,298.000,  0.000 6.25E-01   2
21W20E2 -134.00,298.000,  0.000 W22E1 -92.000,298.000,  0.000 7.50E-01   4
22W21E2 -92.000,298.000,  0.000 W23E1 -72.000,298.000,  0.000 8.75E-01   2
23W22E2 -72.000,298.000,  0.000 W24E1  72.000,298.000,  0.000 1.00E+00  11
24W23E2  72.000,298.000,  0.000 W25E1  92.000,298.000,  0.000 8.75E-01   2
25W24E2  92.000,298.000,  0.000 W26E1 134.000,298.000,  0.000 7.50E-01   4
26W25E2 134.000,298.000,  0.000 W27E1 154.000,298.000,  0.000 6.25E-01   2
27W26E2 154.000,298.000,  0.000       188.500,298.000,  0.000 5.00E-01   5
28      -141.00,164.000,  0.000 W29E1 -84.000,164.000,  0.000 5.00E-01   6
29W28E2 -84.000,164.000,  0.000 W30E1 -66.000,164.000,  0.000 6.25E-01   2
30W29E2 -66.000,164.000,  0.000 W31E1 -30.000,164.000,  0.000 7.50E-01   3
31W30E2 -30.000,164.000,  0.000 W32E1  30.000,164.000,  0.000 8.75E-01   7
32W31E2  30.000,164.000,  0.000 W33E1  66.000,164.000,  0.000 7.50E-01   3
33W32E2  66.000,164.000,  0.000 W34E1  84.000,164.000,  0.000 6.25E-01   2
34W33E2  84.000,164.000,  0.000       141.000,164.000,  0.000 5.00E-01   6
35      -134.50,255.000,  0.000 W36E1 -84.000,255.000,  0.000 5.00E-01   6
36W35E2 -84.000,255.000,  0.000 W37E1 -66.000,255.000,  0.000 6.25E-01   2
37W36E2 -66.000,255.000,  0.000 W38E1 -30.000,255.000,  0.000 7.50E-01   3
38W37E2 -30.000,255.000,  0.000 W39E1  30.000,255.000,  0.000 8.75E-01   7
39W38E2  30.000,255.000,  0.000 W40E1  66.000,255.000,  0.000 7.50E-01   3
40W39E2  66.000,255.000,  0.000 W41E1  84.000,255.000,  0.000 6.25E-01   2
41W40E2  84.000,255.000,  0.000       134.500,255.000,  0.000 5.00E-01   6
42      -129.00,354.000,  0.000 W43E1 -84.000,354.000,  0.000 5.00E-01   6
43W42E2 -84.000,354.000,  0.000 W44E1 -66.000,354.000,  0.000 6.25E-01   2
44W43E2 -66.000,354.000,  0.000 W45E1 -30.000,354.000,  0.000 7.50E-01   3
45W44E2 -30.000,354.000,  0.000 W46E1  30.000,354.000,  0.000 8.75E-01   7
46W45E2  30.000,354.000,  0.000 W47E1  66.000,354.000,  0.000 7.50E-01   3
47W46E2  66.000,354.000,  0.000 W48E1  84.000,354.000,  0.000 6.25E-01   2
48W47E2  84.000,354.000,  0.000       129.000,354.000,  0.000 5.00E-01   6
              -------------- SOURCES --------------
Source    Wire    Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
          Seg.     Actual      (Specified)
For 15 meters
1         4    38 / 50.00   ( 38 / 50.00)      1.000       0.000        I
For 20 meters
1         4    14 / 50.00   ( 14 / 50.00)      1.000       0.000        I
```



As with the individual models, the pseudo-beta matches have been omitted from both the wire table and the impedance figures below. The following table will illustrate the range of impedances to be matched, by whatever means a given builder prefers.

Fq	**14.0**	**14.15**	**14.35**
Gain dBi	**8.19**	**8.29**	**8.42**
F-B dB	**17.64**	**20.47**	**16.50**
Feed Z ohms	**24.5 - j26.5**	**25.8 - j14.5**	**26.4 + j 2.0**

Fq	**21.0**	**21.2**	**21.45**
Gain dBi	**8.25**	**8.37**	**8.60**
F-B dB	**17.59**	**19.39**	**15.44**
Feed Z ohms	**14.0 - j17.6**	**14.8 - j 7.6**	**14.1 + j 5.1**

Just as before, the array slightly enhances gain and detracts by a comparable amount from the front-to-back ratio compared to the individual beams. 15-meter feedpoint impedance is low but manageable.

This model--or some variant of it--appears to be a very buildable dual 3- element Yagi, for someone so inclined.

The Result: The staggered array is not a new idea; rather, it is an idea that needed a little refreshing. In the search for means of using a single feedline and then complicating the sequence of elements on the way to a multiband beam that approximates 3-element Yagi performance, we often forget that there may be more direct routes to a goal, especially if one does not have access to an engineering department for all the hours of design work needed. The 2-band composite beam shown here may be one practical solution within the reach of a home builder.

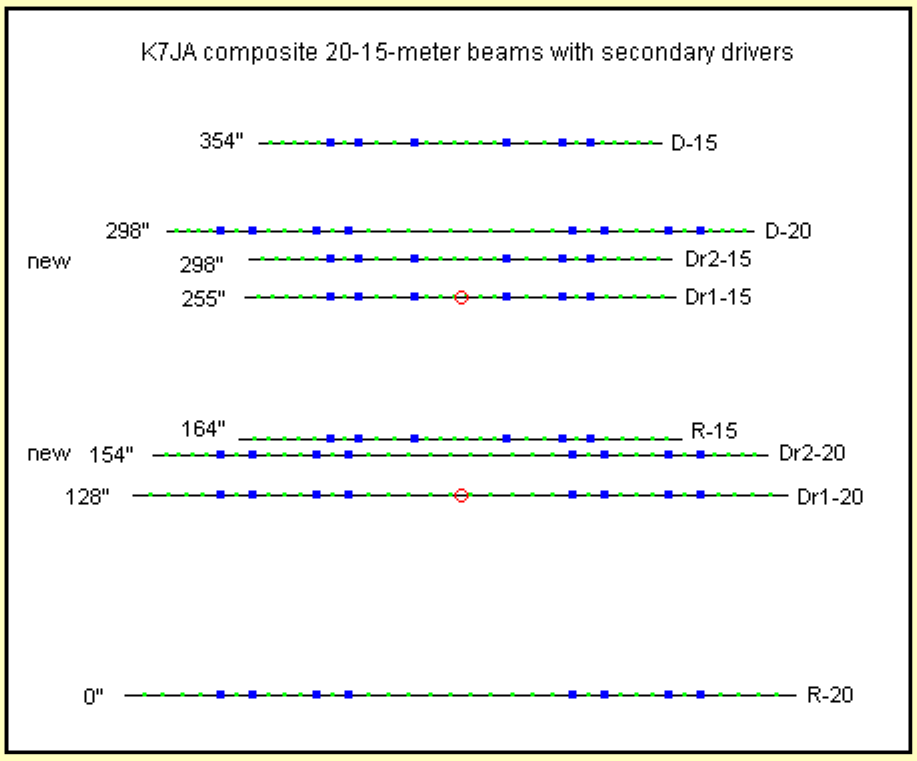
Although the beam itself is highly interesting and instructive with respect to the question of uncaging Yagi performance in a multiband array, this note has primarily recorded an exercise in the progression of modeling from developing a potential project through proving the principle to finalizing a buildable antenna. By letting the surprises and major adjustments be functions of the model, construction time and "What-do-I- do-next?" time for such an antenna as this is minimized.

However, do not expect models to be precision plans for an actual antenna. Unless you take steps to eliminate all factors that can interfere with the translation of the model into physical reality, further adjustments will be needed during the building and tuning process. Indeed, eliminating the bumps and couplings natural to the use of real materials is rarely possible without weakening the antenna structure. Nonetheless, a modeling exercise like this one--applied to your own pet project--can maximize productive time and minimize the frustration of not knowing what to do next to peak the antenna performance.

The result of the exercise is also a quite feasible antenna for the home builder. Both bands ought to compete well with any 3-element Yagi monobander and with most tri-banders (on two of the bands). The 6 simple elements ought to hold up for years--although annual maintenance is always to be recommended.

Addendum 1: A 2007 Update from K7JA

In April, 2007, Chip Margelli, K7JA, sent me information on an interesting variation of the original 2-band, 3-element/band staggered Yagi design. Chip had a few local goals. First, he wanted to re-use some materials from a commercial beam with which he was dissatisfied. Second, he wanted to overcome the somewhat finicky matching requirements on 15 meters in the original design. One way to do this was to achieve a 50-Ohm feedpoint on each of the two bands. Since he had the materials, he added to each beam a secondary driver (or, if you wish, a new first director) closely spaced to the original driver to control both the operating bandwidth and the impedance. It is a technique that appears in other designs in these pages and derives ultimately from the OWA work of KW3Z. Chip's redesign makes use of the original design's elements and simply adds 2 new secondary drivers, as indicated in the outline below.



The model for Chip's new beam appears in the EZNEC description that follows. The element diameters and individual element section lengths are a function of re-using existing materials.

```
              EZNEC/4 ver. 4.0
Dipole in free space              4/16/2007     9:20:44 AM

       --------------- ANTENNA DESCRIPTION ---------------
Frequency = 14.175 MHz
Wire Loss: Aluminum (6061-T6) -- Resistivity = 4E-08 ohm-m, Rel. Perm. = 1

           --------------- WIRES ---------------
No.       End 1    Coord. (in)          End 2    Coord. (in)       Dia (in)  Segs      Insulation
       Conn.     X       Y      Z      Conn.     X       Y      Z              Diel C  Thk(in) Loss Tan
1              -215,     0,    840     W2E1    -154,     0,    840     0.5   5      1      0      0
2      W1E2    -154,     0,    840     W3E1    -134,     0,    840     0.625   2      1      0      0
3      W2E2    -134,     0,    840     W4E1     -92,     0,    840     0.75   4      1      0      0
4      W3E2     -92,     0,    840     W5E1     -72,     0,    840     0.875   2      1      0      0
5      W4E2     -72,     0,    840     W6E1      72,     0,    840       1   11      1      0      0
6      W5E2      72,     0,    840     W7E1      92,     0,    840     0.875   2      1      0      0
7      W6E2      92,     0,    840     W8E1     134,     0,    840     0.75   4      1      0      0
8      W7E2     134,     0,    840     W9E1     154,     0,    840     0.625   2      1      0      0
9      W8E2     154,     0,    840              215,     0,    840     0.5   5      1      0      0
10             -210,   128,    840     W11E1   -154,   128,    840     0.5   5      1      0      0
11     W10E2   -154,   128,    840     W12E1   -134,   128,    840     0.625   2      1      0      0
12     W11E2   -134,   128,    840     W13E1    -92,   128,    840     0.75   4      1      0      0
13     W12E2    -92,   128,    840     W14E1    -72,   128,    840     0.875   2      1      0      0
14     W13E2    -72,   128,    840     W15E1     72,   128,    840       1   11      1      0      0
15     W14E2     72,   128,    840     W16E1     92,   128,    840     0.875   2      1      0      0
16     W15E2     92,   128,    840     W17E1    134,   128,    840     0.75   4      1      0      0
17     W16E2    134,   128,    840     W18E1    154,   128,    840     0.625   2      1      0      0
18     W17E2    154,   128,    840              210,   128,    840     0.5   5      1      0      0
19           -188.5,   298,    840     W20E1   -154,   298,    840     0.5   5      1      0      0
20     W19E2   -154,   298,    840     W21E1   -134,   298,    840     0.625   2      1      0      0
21     W20E2   -134,   298,    840     W22E1    -92,   298,    840     0.75   4      1      0      0
22     W21E2    -92,   298,    840     W23E1    -72,   298,    840     0.875   2      1      0      0
23     W22E2    -72,   298,    840     W24E1     72,   298,    840       1   11      1      0      0
24     W23E2     72,   298,    840     W25E1     92,   298,    840     0.875   2      1      0      0
25     W24E2     92,   298,    840     W26E1    134,   298,    840     0.75   4      1      0      0
26     W25E2    134,   298,    840     W27E1    154,   298,    840     0.625   2      1      0      0
27     W26E2    154,   298,    840            188.5,   298,    840     0.5   5      1      0      0
28             -142,   164,    840     W29E1    -84,   164,    840     0.5   6      1      0      0
29     W28E2    -84,   164,    840     W30E1    -66,   164,    840     0.625   2      1      0      0
30     W29E2    -66,   164,    840     W31E1    -30,   164,    840     0.75   3      1      0      0
31     W30E2    -30,   164,    840     W32E1     30,   164,    840     0.875   7      1      0      0
32     W31E2     30,   164,    840     W33E1     66,   164,    840     0.75   3      1      0      0
33     W32E2     66,   164,    840     W34E1     84,   164,    840     0.625   2      1      0      0
34     W33E2     84,   164,    840              142,   164,    840     0.5   6      1      0      0
35             -139,   255,    840     W36E1    -84,   255,    840     0.5   6      1      0      0
36     W35E2    -84,   255,    840     W37E1    -66,   255,    840     0.625   2      1      0      0
37     W36E2    -66,   255,    840     W38E1    -30,   255,    840     0.75   3      1      0      0
38     W37E2    -30,   255,    840     W39E1     30,   255,    840     0.875   7      1      0      0
39     W38E2     30,   255,    840     W40E1     66,   255,    840     0.75   3      1      0      0
40     W39E2     66,   255,    840     W41E1     84,   255,    840     0.625   2      1      0      0
41     W40E2     84,   255,    840              139,   255,    840     0.5   6      1      0      0
42             -129,   354,    840     W43E1    -84,   354,    840     0.5   6      1      0      0
43     W42E2    -84,   354,    840     W44E1    -66,   354,    840     0.625   2      1      0      0
44     W43E2    -66,   354,    840     W45E1    -30,   354,    840     0.75   3      1      0      0
45     W44E2    -30,   354,    840     W46E1     30,   354,    840     0.875   7      1      0      0
46     W45E2     30,   354,    840     W47E1     66,   354,    840     0.75   3      1      0      0
47     W46E2     66,   354,    840     W48E1     84,   354,    840     0.625   2      1      0      0
```

48	W47E2	84,	354,	840		129,	354,	840	0.5	6	1	0	0
49		-136,	280,	840	W50E1	-84,	280,	840	0.5	6	1	0	0
50	W49E2	-84,	280,	840	W51E1	-66,	280,	840	0.625	2	1	0	0
51	W50E2	-66,	280,	840	W52E1	-30,	280,	840	0.75	3	1	0	0
52	W51E2	-30,	280,	840	W53E1	30,	280,	840	0.875	7	1	0	0
53	W52E2	30,	280,	840	W54E1	66,	280,	840	0.75	3	1	0	0
54	W53E2	66,	280,	840	W55E1	84,	280,	840	0.625	2	1	0	0
55	W54E2	84,	280,	840		136,	280,	840	0.5	6	1	0	0
56		-198,	154,	840	W57E1	-154,	154,	840	0.5	5	1	0	0
57	W56E2	-154,	154,	840	W58E1	-134,	154,	840	0.625	2	1	0	0
58	W57E2	-134,	154,	840	W59E1	-92,	154,	840	0.75	4	1	0	0
59	W58E2	-92,	154,	840	W60E1	-72,	154,	840	0.875	2	1	0	0
60	W59E2	-72,	154,	840	W61E1	72,	154,	840	1	11	1	0	0
61	W60E2	72,	154,	840	W62E1	92,	154,	840	0.875	2	1	0	0
62	W61E2	92,	154,	840	W63E1	134,	154,	840	0.75	4	1	0	0
63	W62E2	134,	154,	840	W64E1	154,	154,	840	0.625	2	1	0	0
64	W63E2	154,	154,	840		198,	154,	840	0.5	5	1	0	0

Total Segments: 264

-------------- SOURCES --------------

No.	Specified Pos. Wire #	Specified Pos. % From E1	Actual Pos. % From E1	Seg	Amplitude (V/A)	Phase (deg.)	Type	
1	14	50.00	50.00	6	1	0	I	20-meter feedpoint
(1	38	50.00	50.00	6	1	0	I	15-meter feedpoint)

The modeled performance is equal to the performance of the original with two exceptions. First, the re-design improves the front-to-back ratio across both bands. Second, we can add 50-Ohm SWR values to the performance table to show the smooth curves that promise relatively easy initial tune-up of the beam. The values suggest that high-power amplifiers with sensitive fold-back circuits will not encounter power-reducing SWR values.

Modeled free-space performance of the K8JA revised staggered 2-band beam

Fq	14.0	14.15	14.35
Gain dBi	8.21	8.30	8.44
F-B dB	22.30	22.98	17.99
Feed Z ohms	53.8 - j 5.7	61.4 - j 1.6	75.2 - j 4.1
50-Ohm SWR	1.14	1.23	1.46

Fq	21.0	21.2	21.45
Gain dBi	8.11	8.20	8.33
F-B dB	21.53	24.73	18.33
Feed Z ohms	45.5 + j 4.8	55.5 - j 0.7	51.7 - j17.7
50-Ohm SWR	1.15	1.11	1.42

Chip's re-designed staggered Yagi for 20 and 15 meters also makes a handsome addition to his tower of beams, as shown in the photo. The guardian bird apparently is optional--with the whim of the bird.

K7JA's revised stagger design not only proves the principles behind the original design, but makes significant improvements. Amateurs are reticent to use more aluminum than the absolute minimum. However, Chip's addition of secondary drivers confirms that we may often profitably add an element to improve performance. The improvement may not show up in terms of gain--largely a function of the boom length--but may allow us to achieve a broader operating bandwidth in all categories of performance.

Addendum 2: Can It Be done With 4 Elements Each?

The Basic Beams: Yes, it is possible to create a similar combination beam using 4-element Yagis as the basis. Once more I began with a K6STI design for a 26' boom, not much longer than the 24' boom used for the basic 3- element 20-meter beam. I set up the Yagis using 0.75" tubing for 20 and 0.5" tubing for 15. (What this means is that I scaled the 20-meter antenna to 15 meters and accepted the resulting dimensions without further ado.) Here are the wire tables and performance numbers.

20 Meters

```
            --------------- WIRES ---------------
Wire Conn.--- End 1 (x,y,z : in)  Conn.--- End 2 (x,y,z : in) Dia(in) Segs
1       -208.50,  0.000,  0.000       208.500,  0.000,  0.000 7.50E-01  21
2       -197.00, 72.000,  0.000       197.000, 72.000,  0.000 7.50E-01  21
3       -195.40,132.000,  0.000       195.400,132.000,  0.000 7.50E-01  21
4       -183.10,306.000,  0.000       183.100,306.000,  0.000 7.50E-01  21
            -------------- SOURCES --------------
Source    Wire      Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
        Seg.     Actual      (Specified)
1         11     2 / 50.00   (  2 / 50.00)      1.000       0.000       I
```

Fq	14.0	14.15	14.35
Gain dBi	8.41	8.49	8.62
F-B dB	21.31	23.48	21.73
Feed Z ohms	25.2 - j32.7	28.0 - j30.3	19.8 - j25.2

---

15 Meters

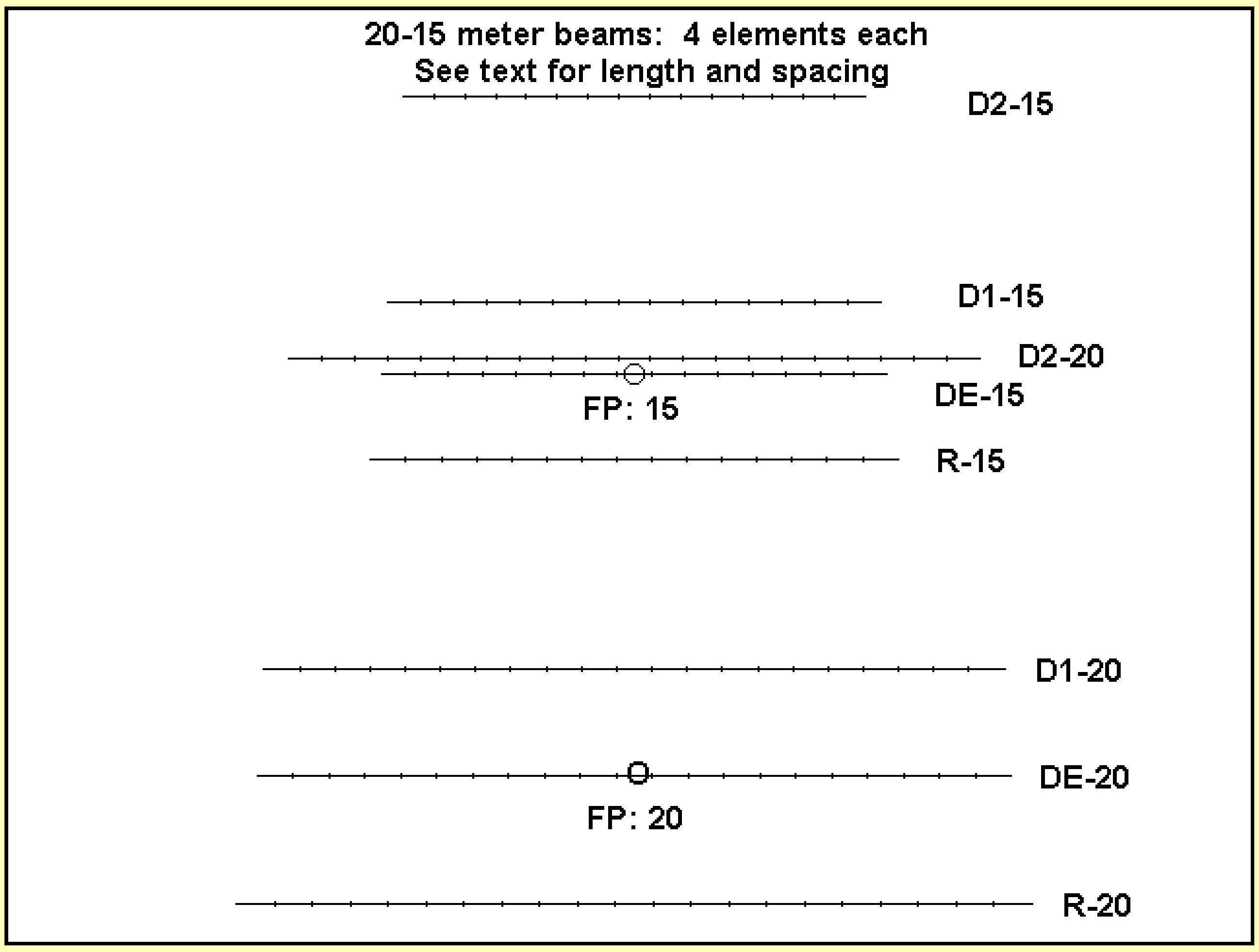
```
            --------------- WIRES ---------------
Wire Conn.--- End 1 (x,y,z : in)  Conn.--- End 2 (x,y,z : in) Dia(in) Segs
1       -139.00,  0.000,  0.000       139.000,  0.000,  0.000 5.00E-01  15
2       -131.33, 48.000,  0.000       131.333, 48.000,  0.000 5.00E-01  15
3       -130.27, 88.000,  0.000       130.267, 88.000,  0.000 5.00E-01  15
4       -122.07,204.000,  0.000       122.067,204.000,  0.000 5.00E-01  15
            -------------- SOURCES --------------
Source    Wire      Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
        Seg.     Actual      (Specified)

1         11     2 / 50.00   (  2 / 50.00)      1.000       0.000       I
```

Fq	21.0	21.2	21.45
Gain dBi	8.41	8.48	8.58
F-B dB	21.32	23.67	21.71
Feed Z ohms	25.2 - j32.7	28.0 - j29.9	23.0 - j27.2

The chief advantage of these antennas over the 3-element models is a smoother performance across the bands of interest, both in terms of gain and front-to-back ratio. Notice also from the wire charts that these beams concentrate the three rear-most elements together, with the most forward director well-spaced from the other elements.

The Combination: I only checked these antennas at the level of principle, so the following scheme might require significant variation before achieving a workable beam with stepped-diameter elements. Nonetheless, the combination works well in principle, preserving most of the front-to-back ratio and enhancing the forward gain slightly.



The largest drawback to this configuration is the very low feedpoint impedance imposed on the 15-meter beam.

The required configuration places 2 of the directors forward of the forward-most 20-meter director, creating a beam needing a 38' boom. Whether the gains over the dual 3-element array outweigh the disadvantages of the longer boom and lower 15-meter feedpoint impedance is a builder decision.

Here is the wire table:

```
              --------------- WIRES ---------------
Wire Conn.--- End 1 (x,y,z : in)  Conn.--- End 2 (x,y,z : in) Dia(in) Segs
1       -139.00,250.000,  0.000       139.000,250.000,  0.000 5.00E-01  15
2       -133.50,298.000,  0.000       133.500,298.000,  0.000 5.00E-01  15
3       -130.27,338.000,  0.000       130.267,338.000,  0.000 5.00E-01  15
4       -122.07,454.000,  0.000       122.067,454.000,  0.000 5.00E-01  15
5       -210.00,  0.000,  0.000      210.000,  0.000,  0.000 7.50E-01  21
6       -199.00, 72.000,  0.000       199.000, 72.000,  0.000 7.50E-01  21
7       -195.40,132.000,  0.000       195.400,132.000,  0.000 7.50E-01  21
8       -182.00,306.000,  0.000       182.000,306.000,  0.000 7.50E-01  21
             -------------- SOURCES --------------
Source    Wire      Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
          Seg.     Actual      (Specified)
1           8     2 / 50.00   (  2 / 50.00)      1.000       0.000       I
(15-meter source shown--20-meter source is 2/50.)
```

In this table, the 15 meter elements appear first.

The performance of the model is as follows:

Fq	14.0	14.15	14.35
Gain dBi	8.61	8.66	8.77
F-B dB	20.92	20.30	21.29
Feed Z ohms	30.0 - j22.1	32.4 - j21.6	20.95- j17.8

Fq	21.0	21.2	21.45
Gain dBi	8.42	8.51	8.66
F-B dB	22.69	21.66	20.33
Feed Z ohms	9.83 - j22.5	8.18 - j14.6	10.0 - j 7.4

Remember that all performance numbers are subject to variations, with gains varying as much as 0.1 dB and front-to-back ratios changing by as much as 1 dB, depending upon the particular modeling software used (assuming that the models are comparable to begin with).

This model suggests that a dual 4-element Yagi system is feasible, but may be approaching the limits of the technique. The boom has grown significantly, and the 15-meter feedpoint impedance has decreased to a level where physical connection losses begin to counteract gain improvements. Increasing the 15-meter feedpoint impedance requires element placement or dimensions that either reduce 15 meter gain or narrow the performance bandwidth on that band.

Further optimizing is possible and would certainly be necessary for a set of stepped-diameter elements.

A Tapered-Element Test: For some time after working with the 4-element Yagis with uniform element diameters, I hesitated to devote the time to exploring what might happen with Yagis using tapered-diameter elements. However, Gene, UA4RZ, asked me to look into some beam designs he was working on, so the time was right to try the staggered system on some designs one might really build. The beams employ, in good and traditional ham fashion, element materials that are accessible to the builder.

First, the models: It was necessary to make two minor modifications to Gene's models. I eliminated a 0.1" section of 0.85" diameter tubing from the 20 meter reflector and director, absorbing the 0.1" length in the adjacent section. This allowed me to use segments just about 10" long, which is close to the length of the center section. I also reduced the center section diameter to 2" diameter, because NEC-4 still has some limitations when the diameter of an element changes too much too abruptly.

20 meter antenna:

```
Frequency = 14.175  MHz.
Wire Loss: Copper -- Resistivity = 1.74E-08 ohm-m, Rel. Perm. = 1
              --------------- WIRES ---------------
Wire Conn. --- End 1 (x,y,z : in)  Conn. --- End 2 (x,y,z : in)   Dia(in) Segs
1          -217.63,  0.000,  0.000  W2E1 -164.10,  0.000,  0.000 7.00E-01   5
2     W1E2 -164.10,  0.000,  0.000  W3E1 -89.000,  0.000,  0.000 1.20E+00   7
3     W2E2 -89.000,  0.000,  0.000  W4E1  -4.000,  0.000,  0.000 1.50E+00   8
4     W3E2  -4.000,  0.000,  0.000  W5E1   4.000,  0.000,  0.000 2.00E+00   1
5     W4E2   4.000,  0.000,  0.000  W6E1  89.000,  0.000,  0.000 1.50E+00   8
6     W5E2  89.000,  0.000,  0.000  W7E1 164.100,  0.000,  0.000 1.20E+00   7
7     W6E2 164.100,  0.000,  0.000       217.634,  0.000,  0.000 7.00E-01   5
8          -201.30, 71.995,  0.000  W9E1 -189.00, 71.995,  0.000 8.50E-01   1
9     W8E2 -189.00, 71.995,  0.000 W10E1 -89.000, 71.995,  0.000 1.20E+00  10
10    W9E2 -89.000, 71.995,  0.000 W11E1  -4.000, 71.995,  0.000 1.50E+00   8
11   W10E2  -4.000, 71.995,  0.000 W12E1   4.000, 71.995,  0.000 2.00E+00   1
12   W11E2   4.000, 71.995,  0.000 W13E1  89.000, 71.995,  0.000 1.50E+00   8
13   W12E2  89.000, 71.995,  0.000 W14E1 189.000, 71.995,  0.000 1.20E+00  10
14   W13E2 189.000, 71.995,  0.000       201.302, 71.995,  0.000 8.50E-01   1
15         -197.00,131.990,  0.000 W16E1 -189.00,131.990,  0.000 8.50E-01   1
16   W15E2 -189.00,131.990,  0.000 W17E1 -89.000,131.990,  0.000 1.20E+00  10
17   W16E2 -89.000,131.990,  0.000 W18E1  -4.000,131.990,  0.000 1.50E+00   8
18   W17E2  -4.000,131.990,  0.000 W19E1   4.000,131.990,  0.000 2.00E+00   1
19   W18E2   4.000,131.990,  0.000 W20E1  89.000,131.990,  0.000 1.50E+00   8
20   W19E2  89.000,131.990,  0.000 W21E1 189.000,131.990,  0.000 1.20E+00  10
21   W20E2 189.000,131.990,  0.000       197.003,131.990,  0.000 8.50E-01   1
22         -183.53,305.977,  0.000 W23E1 -164.10,305.977,  0.000 7.00E-01   2
23   W22E2 -164.10,305.977,  0.000 W24E1 -89.000,305.977,  0.000 1.20E+00   7
24   W23E2 -89.000,305.977,  0.000 W25E1  -4.000,305.977,  0.000 1.50E+00   8
```

```
25   W24E2  -4.000,305.977,  0.000 W26E1   4.000,305.977,  0.000 2.00E+00   1
26   W25E2   4.000,305.977,  0.000 W27E1  89.000,305.977,  0.000 1.50E+00   8
27   W26E2  89.000,305.977,  0.000 W28E1 164.100,305.977,  0.000 1.20E+00   7
28   W27E2 164.100,305.977,  0.000       183.529,305.977,  0.000 7.00E-01   2
              -------------- SOURCES --------------
Source    Wire      Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
          Seg.     Actual      (Specified)
1          1    11 / 50.00   ( 11 / 50.00)      1.000       0.000       V
```

Gain: 8.77 dBi free space
F-B: 23.26 dB
Source impedance: 25.96 - j21.76 ohms (about right for a beta match)

15 meter antenna:

```
Frequency = 21.224  MHz.
Wire Loss: Copper -- Resistivity = 1.74E-08 ohm-m, Rel. Perm. = 1
              --------------- WIRES ---------------
Wire Conn. --- End 1 (x,y,z : in)  Conn. --- End 2 (x,y,z : in)   Dia(in) Segs
1          -142.01,  0.000,  0.000  W2E1 -114.00,  0.000,  0.000 7.00E-01   3
2     W1E2 -114.00,  0.000,  0.000  W3E1   -4.000,  0.000,  0.000 1.00E+00  11
3     W2E2  -4.000,  0.000,  0.000  W4E1    4.000,  0.000,  0.000 2.00E+00   1
4     W3E2   4.000,  0.000,  0.000  W5E1 114.000,  0.000,  0.000 1.00E+00  11
5     W4E2 114.000,  0.000,  0.000       142.013,  0.000,  0.000 7.00E-01   3
6          -133.99, 48.000,  0.000  W7E1 -114.00, 48.000,  0.000 7.00E-01   2
7     W6E2 -114.00, 48.000,  0.000  W8E1   -4.000, 48.000,  0.000 1.00E+00  11
8     W7E2  -4.000, 48.000,  0.000  W9E1    4.000, 48.000,  0.000 2.00E+00   1
9     W8E2   4.000, 48.000,  0.000 W10E1 114.000, 48.000,  0.000 1.00E+00  11
10    W9E2 114.000, 48.000,  0.000       133.995, 48.000,  0.000 7.00E-01   2
11         -129.89, 82.000,  0.000 W12E1 -114.00, 82.000,  0.000 7.00E-01   2
12   W11E2 -114.00, 82.000,  0.000 W13E1   -4.000, 82.000,  0.000 1.00E+00  11
13   W12E2  -4.000, 82.000,  0.000 W14E1    4.000, 82.000,  0.000 2.00E+00   1
14   W13E2   4.000, 82.000,  0.000 W15E1 114.000, 82.000,  0.000 1.00E+00  11
15   W14E2 114.000, 82.000,  0.000       129.888, 82.000,  0.000 7.00E-01   2
16         -119.54,198.000,  0.000 W17E1 -114.00,198.000,  0.000 7.00E-01   1
17   W16E2 -114.00,198.000,  0.000 W18E1   -4.000,198.000,  0.000 1.00E+00  11
18   W17E2  -4.000,198.000,  0.000 W19E1    4.000,198.000,  0.000 2.00E+00   1
19   W18E2   4.000,198.000,  0.000 W20E1 114.000,198.000,  0.000 1.00E+00  11
20   W19E2 114.000,198.000,  0.000       119.539,198.000,  0.000 7.00E-01   1
              -------------- SOURCES --------------
Source    Wire      Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
          Seg.     Actual      (Specified)
1          1     8 / 50.00   (  8 / 50.00)      1.000       0.000       V
```

Gain: 8.76 dBi free space
F-B: 22.97 dB
Source impedance: 31.7 - j16.41 ohms

Combination: I staggered the 15 meter antenna interlaced with the 20. Initially, I placed the reflector at 177" from the 0-point of the 20 meter reflector. This placed all but the forward director between the two 20- meter directors. I then moved the 15 meter assembly forward in 10" increments (reference to the reflector) until the inner director on 15 and the outer director on 20 were nearly touching. Here is what I got:

15 Ref	**20 meters**			**15 meters**		
from 0	**Gain**	**F-B**	**Feed Z**	**Gain**	**F-B**	**Feed Z**
177	**8.96**	**20.64**	**26.5-19.5**	**8.26**	**15.73**	**58.5-2.0**
187	**8.98**	**20.46**	**26.9-19.5**	**8.38**	**15.74**	**46.5+11.7**
197	**8.99**	**20.33**	**27.3-19.5**	**8.47**	**15.63**	**30.1+15.6**
207	**9.00**	**20.28**	**27.6-19.6**	**8.51**	**15.30**	**16.7+11.6**
217	**9.01**	**20.40**	**27.7-19.9**	**8.50**	**14.55**	**8.0+4.4**

Here, I ran out of room, but the 15 meter F-B is still low, while the 15 meter feed Z goes very low. 20-meters is hardly affected at all. So I moved the 15 meter antenna 20" forward, which places the two directors in front of the 20 meter forward director.

237	**9.05**	**20.02**	**28.7-20.4**	**8.67**	**17.46**	**6.8-5.8**
247	**9.07**	**19.98**	**29.1-20.9**	**8.75**	**19.86**	**5.8-13.9**
250	**9.08**	**19.92**	**29.1-21.1**	**8.78**	**20.49**	**4.7-17.0**

Here I again ran out of room. The 15 meter gain is up, and the F-B is climbing, but the feed Z is very very low. So I moved all but the reflector ahead of the 20-meter forward director.

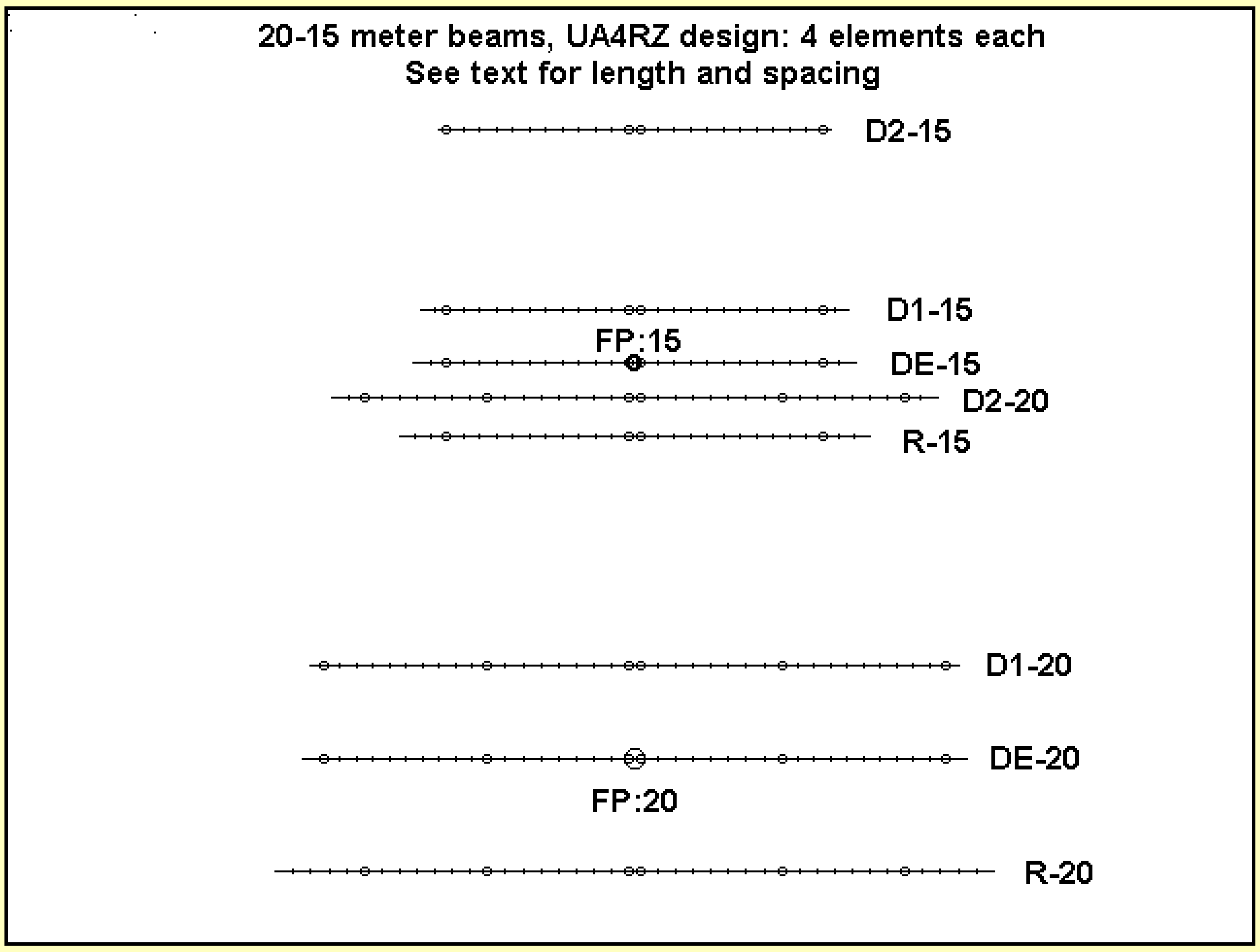
270	**9.13**	**19.53**	**30.0-22.1**	**8.62**	**24.42**	**14.9-17.1**
275	**9.15**	**19.42**	**30.2-22.4**	**8.62**	**24.38**	**19.8-16.2**
280	**9.16**	**19.36**	**30.3-22.8**	**8.62**	**24.24**	**23.6-16.1**

This last position or two (15 meter reflector at 275 or 280 inches forward of the 20-meter reflector) appear to be the best compromise for both antennas. However, the total assembly is longer than the monotapered version in the original study. Nonetheless, if a 40' boom is feasible, the pair of antennas would just about fit and give a very good account of themselves. Of course, one can always select one of the intermediate settings, going all the way back to the 177" mark, if slightly lower gain and F-B is acceptable on 15.

For reference, here is the description of the model in the final position:

```
Frequency = 14.175  MHz.
Wire Loss: Copper -- Resistivity = 1.74E-08 ohm-m, Rel. Perm. = 1
              --------------- WIRES ---------------
Wire Conn. --- End 1 (x,y,z : in)  Conn. --- End 2 (x,y,z : in)   Dia(in) Segs
1          -217.63,  0.000,  0.000  W2E1 -164.10,  0.000,  0.000 7.00E-01   5
2     W1E2 -164.10,  0.000,  0.000  W3E1 -89.000,  0.000,  0.000 1.20E+00   7
3     W2E2 -89.000,  0.000,  0.000  W4E1  -4.000,  0.000,  0.000 1.50E+00   8
4     W3E2  -4.000,  0.000,  0.000  W5E1   4.000,  0.000,  0.000 2.00E+00   1
5     W4E2   4.000,  0.000,  0.000  W6E1  89.000,  0.000,  0.000 1.50E+00   8
6     W5E2  89.000,  0.000,  0.000  W7E1 164.100,  0.000,  0.000 1.20E+00   7
7     W6E2 164.100,  0.000,  0.000       217.634,  0.000,  0.000 7.00E-01   5
8          -201.30, 71.995,  0.000  W9E1 -189.00, 71.995,  0.000 8.50E-01   1
9     W8E2 -189.00, 71.995,  0.000 W10E1 -89.000, 71.995,  0.000 1.20E+00  10
10    W9E2 -89.000, 71.995,  0.000 W11E1  -4.000, 71.995,  0.000 1.50E+00   8
11   W10E2  -4.000, 71.995,  0.000 W12E1   4.000, 71.995,  0.000 2.00E+00   1
12   W11E2   4.000, 71.995,  0.000 W13E1  89.000, 71.995,  0.000 1.50E+00   8
13   W12E2  89.000, 71.995,  0.000 W14E1 189.000, 71.995,  0.000 1.20E+00  10
14   W13E2 189.000, 71.995,  0.000       201.302, 71.995,  0.000 8.50E-01   1
15         -197.00,131.990,  0.000 W16E1 -189.00,131.990,  0.000 8.50E-01   1
16   W15E2 -189.00,131.990,  0.000 W17E1 -89.000,131.990,  0.000 1.20E+00  10
17   W16E2 -89.000,131.990,  0.000 W18E1  -4.000,131.990,  0.000 1.50E+00   8
18   W17E2  -4.000,131.990,  0.000 W19E1   4.000,131.990,  0.000 2.00E+00   1
19   W18E2   4.000,131.990,  0.000 W20E1  89.000,131.990,  0.000 1.50E+00   8
20   W19E2  89.000,131.990,  0.000 W21E1 189.000,131.990,  0.000 1.20E+00  10
21   W20E2 189.000,131.990,  0.000       197.003,131.990,  0.000 8.50E-01   1
22         -183.53,305.977,  0.000 W23E1 -164.10,305.977,  0.000 7.00E-01   2
23   W22E2 -164.10,305.977,  0.000 W24E1 -89.000,305.977,  0.000 1.20E+00   7
24   W23E2 -89.000,305.977,  0.000 W25E1  -4.000,305.977,  0.000 1.50E+00   8
25   W24E2  -4.000,305.977,  0.000 W26E1   4.000,305.977,  0.000 2.00E+00   1
26   W25E2   4.000,305.977,  0.000 W27E1  89.000,305.977,  0.000 1.50E+00   8
27   W26E2  89.000,305.977,  0.000 W28E1 164.100,305.977,  0.000 1.20E+00   7
28   W27E2 164.100,305.977,  0.000       183.529,305.977,  0.000 7.00E-01   2
29         -142.01,280.000,  0.000 W30E1 -114.00,280.000,  0.000 7.00E-01   3
30   W29E2 -114.00,280.000,  0.000 W31E1  -4.000,280.000,  0.000 1.00E+00  11
31   W30E2  -4.000,280.000,  0.000 W32E1   4.000,280.000,  0.000 2.00E+00   1
32   W31E2   4.000,280.000,  0.000 W33E1 114.000,280.000,  0.000 1.00E+00  11
33   W32E2 114.000,280.000,  0.000       142.013,280.000,  0.000 7.00E-01   3
34         -133.99,328.000,  0.000 W35E1 -114.00,328.000,  0.000 7.00E-01   2
35   W34E2 -114.00,328.000,  0.000 W36E1  -4.000,328.000,  0.000 1.00E+00  11
36   W35E2  -4.000,328.000,  0.000 W37E1   4.000,328.000,  0.000 2.00E+00   1
37   W36E2   4.000,328.000,  0.000 W38E1 114.000,328.000,  0.000 1.00E+00  11
38   W37E2 114.000,328.000,  0.000       133.995,328.000,  0.000 7.00E-01   2
39         -129.89,362.000,  0.000 W40E1 -114.00,362.000,  0.000 7.00E-01   2
40   W39E2 -114.00,362.000,  0.000 W41E1  -4.000,362.000,  0.000 1.00E+00  11
41   W40E2  -4.000,362.000,  0.000 W42E1   4.000,362.000,  0.000 2.00E+00   1
42   W41E2   4.000,362.000,  0.000 W43E1 114.000,362.000,  0.000 1.00E+00  11
43   W42E2 114.000,362.000,  0.000       129.888,362.000,  0.000 7.00E-01   2
44         -119.54,478.000,  0.000 W45E1 -114.00,478.000,  0.000 7.00E-01   1
45   W44E2 -114.00,478.000,  0.000 W46E1  -4.000,478.000,  0.000 1.00E+00  11
46   W45E2  -4.000,478.000,  0.000 W47E1   4.000,478.000,  0.000 2.00E+00   1
47   W46E2   4.000,478.000,  0.000 W48E1 114.000,478.000,  0.000 1.00E+00  11
48   W47E2 114.000,478.000,  0.000       119.539,478.000,  0.000 7.00E-01   1
              -------------- SOURCES --------------
Source    Wire      Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
          Seg.     Actual      (Specified)
1          1    11 / 50.00   ( 11 / 50.00)      1.000       0.000       V
20-meter Source location shown.  15-meter (21.224 MHz) source is Wire 36.
```

The size of this file suggests why I hesitated to place something this size on line. (On the other hand, compared to some models, this one is rather small.) However, the opportunity to work with a model of a beam someone might actually build seemed worth the effort. As the following figure of the final version of the model shows, the untapered 4-4 model was optimistic in its length, since it did not show quite so severe a reduction in feedpoint impedance with two of the 15-meter elements inside the forward 20-meter director. With tapered elements of the types proposed, a workable feedpoint impedance only occurs if three of the 15-meter elements are forward of the forward-most 20-meter director.



Is this the only way to get full performance from a dual-band beam? Not necessarily. What this study has shown is simply one way to get virtually the full performance of individual beams of a given boom length and number of elements when combined in-line and at least somewhat interlaced. There are other approaches, such as changing the relative element spacings and element lengths, and possibly ending up with tighter interlacing with full performance for the boom length assigned to each band. These days, such beams are produced largely with reiterative optimizing techniques rather than the simplified technique used here of simply moving the elements as a group. The optimizing techniques, however, do not always guarantee success in achieving full boomlength-number of elements performance for the Yagis interlaced.

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