Some Model Quads:
6. Larger Multi-Band Quads

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My collection of larger (more than 2 elements) multi-band quads is fairly small, consisting of about 3.5 models. However, since one of them is of a 3.5 element 5-band quad, perhaps the score is even. Let's see how this works out.

First, I have modeled one of the multi-band quads from recent editions of the *ARRL Antenna Book* (page 2-12 in the 17th Edition). The antenna is a 4- element 3-band quad on a 40' boom. I count it as 1.5 models, since I have modeled is in both #14 and #12 AWG copper wire. The results, especially in light of my notes on wire size in monoband quads, are interesting.

Next, ON7NQ has shared a number of models with me in his efforts to improve the performance of a commercial 3-element 5-band quad on an 18' boom. One model of note simply adjusts the sizes of virtually all of the loops. A second model adds 2 new elements--new drivers for 10 and 12 meters--making approximately a 3.5 element quad--all on the same 18' boom.

In looking at these models, we should note a number of things. First and most obvious is the standard set of performance parameters that we have surveyed for all of the quads: free space gain in dBi, 180-degree front- to-back ratio in dB, and VSWR to some specified resistive impedance value. In addition to these matters, we may also wish to note how 3- and 4-element quads are similar to and differ from 2-element multi-band quads in various characteristics. Finally, we may also wish to record some factors related to boom length--at least so far as this small sample of models might suggest about the question.

As in all other cases, modeling has been done on NEC-4. The conventions of segmentation used in earlier multi-band quads are repeated here. For each side of a given quad loop, there are 7 segments on 10 meters, 9 segments on 12, 11 segments on 15, 13 segments on 17, and 15 segments on 20. Within practical limits, this scheme approaches the goal of having equal length segments throughout the model. Nonetheless, at least one model will have 724 segment distributed on 68 wires. Although NEC-2 will provide results as accurate as NEC-4 for these models, some implementations are limited to 500 segments and may prove less than fully adequate for the modeling task. MININEC results are also accurate if care is taken to ensure element length segment tapering at each corner of each loop. Without the use of symmetry or core enlargement, however, some of these models may be too large for some available versions of MININEC to handle.

As with past multi-band quads, only 20, 15, and 10 meters will undergo frequency sweeps. The 2 WARC bands (17 and 12) are so narrow that antenna performance characteristics do not significantly vary from their mid-band values. Each wide band will be divided into 10 equal segments. On 20, each segment is 0.35 MHz wide, on 15 each is 0.45 MHz wide, and on 10 each is 0.1 MHz wide. Hence, the graphs cover all of 20 and 10 meters and the first MHz of 10 meters.

4-Element 3-Band Quads

In recent editions of the *ARRL Antenna Book*, there is a 3-band, 4-element quad design attributed to W0AIW. It uses a 40' boom, with all elements (20 through 10 meters) equally spaced at 10' intervals. **Fig. 67** provides an outline sketch of the antenna.

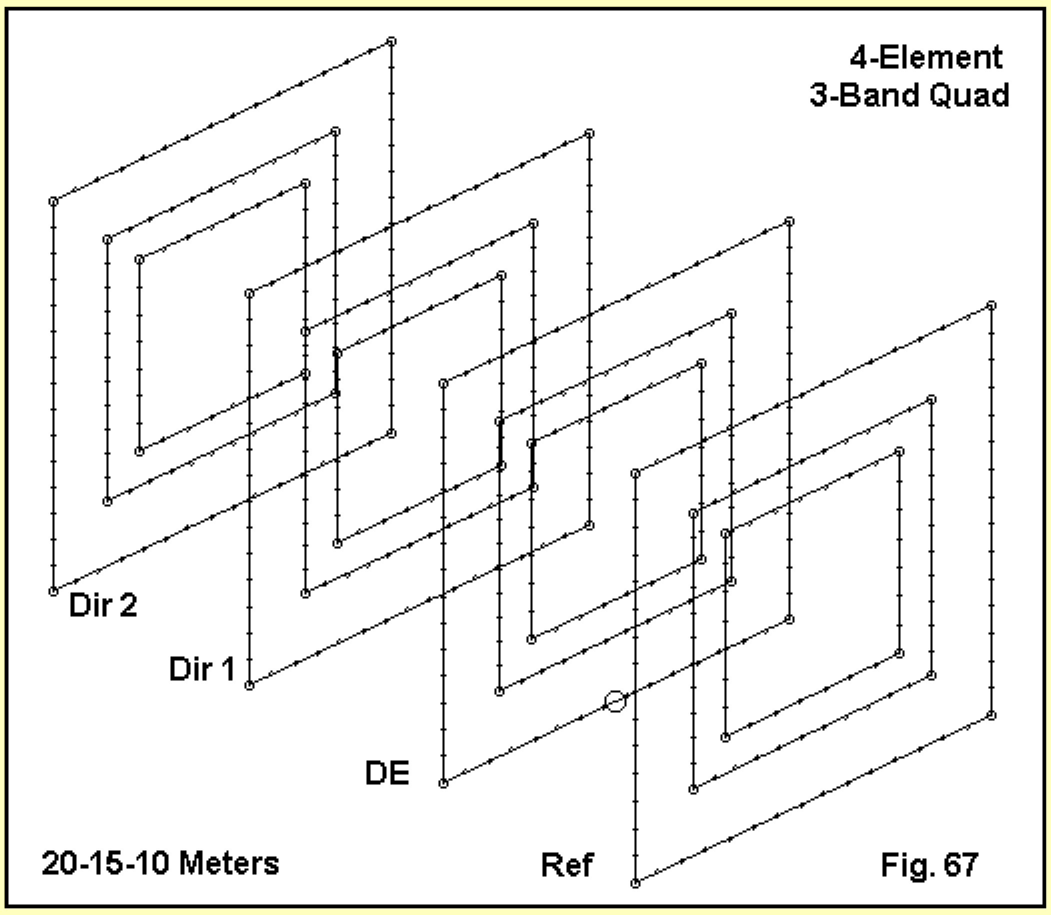

Fig. 67

The following table lists the element lengths per loop side for each of the three bands.

Band	Reflector Side L feet	Space Re-DE	Driver Side L feet	Space DE-D1	Dir. 1 Side L feet	Space D1-D2	Dir. 2 Side L feet
20	18.104	10	17.604	10	17.271	10	17.271
15	12.167	10	11.833	10	11.583	10	11.583
10	8.927	10	8.677	10	8.401	10	8.401

These loop lengths are very close to those used in one commercial quad using a shorter boom for a 3-element version. The change from band-to-band appears to be a matter of simple loop length scaling. The elements are shorter than the monoband loop lengths recommended in Orr and Cowan for 3- and 4-element quads. For reference, here is a model description.

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arrl #14                                        Frequency = 14.175  MHz.

Wire Loss: Copper -- Resistivity = 1.74E-08 ohm-m, Rel. Perm. = 1

                --------------- WIRES ---------------
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Wire	Conn.---	End 1 (x,y,z : ft)	Conn.---	End 2 (x,y,z : ft)	Dia(in)	Segs
1	W4E2	-4.200, 20.000, -4.200	W2E1	4.200, 20.000, -4.200	# 14	7
2	W1E2	4.200, 20.000, -4.200	W3E1	4.200, 20.000, 4.200	# 14	7
3	W2E2	4.200, 20.000, 4.200	W4E1	-4.200, 20.000, 4.200	# 14	7
4	W3E2	-4.200, 20.000, 4.200	W1E1	-4.200, 20.000, -4.200	# 14	7
5	W8E2	-4.200, 10.000, -4.200	W6E1	4.200, 10.000, -4.200	# 14	7
6	W5E2	4.200, 10.000, -4.200	W7E1	4.200, 10.000, 4.200	# 14	7
7	W6E2	4.200, 10.000, 4.200	W8E1	-4.200, 10.000, 4.200	# 14	7
8	W7E2	-4.200, 10.000, 4.200	W5E1	-4.200, 10.000, -4.200	# 14	7
9	W12E2	-4.339, 0.000, -4.339	W10E1	4.339, 0.000, -4.339	# 14	7
10	W9E2	4.339, 0.000, -4.339	W11E1	4.339, 0.000, 4.339	# 14	7
11	W10E2	4.339, 0.000, 4.339	W12E1	-4.339, 0.000, 4.339	# 14	7
12	W11E2	-4.339, 0.000, 4.339	W9E1	-4.339, 0.000, -4.339	# 14	7
13	W16E2	-4.464,-10.000, -4.464	W14E1	4.464,-10.000, -4.464	# 14	7
14	W13E2	4.464,-10.000, -4.464	W15E1	4.464,-10.000, 4.464	# 14	7
15	W14E2	4.464,-10.000, 4.464	W16E1	-4.464,-10.000, 4.464	# 14	7
16	W15E2	-4.464,-10.000, 4.464	W13E1	-4.464,-10.000, -4.464	# 14	7
17	W20E2	-5.792, 20.000, -5.792	W18E1	5.792, 20.000, -5.792	# 14	11
18	W17E2	5.792, 20.000, -5.792	W19E1	5.792, 20.000, 5.792	# 14	11
19	W18E2	5.792, 20.000, 5.792	W20E1	-5.792, 20.000, 5.792	# 14	11
20	W19E2	-5.792, 20.000, 5.792	W17E1	-5.792, 20.000, -5.792	# 14	11
21	W24E2	-5.792, 10.000, -5.792	W22E1	5.792, 10.000, -5.792	# 14	11
22	W21E2	5.792, 10.000, -5.792	W23E1	5.792, 10.000, 5.792	# 14	11
23	W22E2	5.792, 10.000, 5.792	W24E1	-5.792, 10.000, 5.792	# 14	11
24	W23E2	-5.792, 10.000, 5.792	W21E1	-5.792, 10.000, -5.792	# 14	11
25	W28E2	-5.917, 0.000, -5.917	W26E1	5.917, 0.000, -5.917	# 14	11
26	W25E2	5.917, 0.000, -5.917	W27E1	5.917, 0.000, 5.917	# 14	11
27	W26E2	5.917, 0.000, 5.917	W28E1	-5.917, 0.000, 5.917	# 14	11
28	W27E2	-5.917, 0.000, 5.917	W25E1	-5.917, 0.000, -5.917	# 14	11
29	W32E2	-6.083,-10.000, -6.083	W30E1	6.083,-10.000, -6.083	# 14	11
30	W29E2	6.083,-10.000, -6.083	W31E1	6.083,-10.000, 6.083	# 14	11
31	W30E2	6.083,-10.000, 6.083	W32E1	-6.083,-10.000, 6.083	# 14	11
32	W31E2	-6.083,-10.000, 6.083	W29E1	-6.083,-10.000, -6.083	# 14	11
33	W36E2	-8.635, 20.000, -8.635	W34E1	8.635, 20.000, -8.635	# 14	15
34	W33E2	8.635, 20.000, -8.635	W35E1	8.635, 20.000, 8.635	# 14	15
35	W34E2	8.635, 20.000, 8.635	W36E1	-8.635, 20.000, 8.635	# 14	15
36	W35E2	-8.635, 20.000, 8.635	W33E1	-8.635, 20.000, -8.635	# 14	15
37	W40E2	-8.635, 10.000, -8.635	W38E1	8.635, 10.000, -8.635	# 14	15
38	W37E2	8.635, 10.000, -8.635	W39E1	8.635, 10.000, 8.635	# 14	15
39	W38E2	8.635, 10.000, 8.635	W40E1	-8.635, 10.000, 8.635	# 14	15
40	W39E2	-8.635, 10.000, 8.635	W37E1	-8.635, 10.000, -8.635	# 14	15
41	W44E2	-8.802, 0.000, -8.802	W42E1	8.802, 0.000, -8.802	# 14	15
42	W41E2	8.802, 0.000, -8.802	W43E1	8.802, 0.000, 8.802	# 14	15
43	W42E2	8.802, 0.000, 8.802	W44E1	-8.802, 0.000, 8.802	# 14	15
44	W43E2	-8.802, 0.000, 8.802	W41E1	-8.802, 0.000, -8.802	# 14	15
45	W48E2	-9.052,-10.000, -9.052	W46E1	9.052,-10.000, -9.052	# 14	15
46	W45E2	9.052,-10.000, -9.052	W47E1	9.052,-10.000, 9.052	# 14	15
47	W46E2	9.052,-10.000, 9.052	W48E1	-9.052,-10.000, 9.052	# 14	15
48	W47E2	-9.052,-10.000, 9.052	W45E1	-9.052,-10.000, -9.052	# 14	15

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

Source	Wire Seg.	Wire #/Pct From End 1 Actual	(Specified)	Ampl.(V, A)	Phase(Deg.)	Type
1	8	41 / 50.00	(41 / 50.00)	1.000	0.000	V

The model has 48 wires and 528 segments. However, modeling time can be reduced by judicious use of the copy function for identical loops and by symbolic coordinate entries, if available. The source wires for each band are as follows: 20m = wire 41; 15m = wire 25; and 10m = wire 9. Source placement is at the wire center.

Because small changes in wire size resulted in noticeable differences in the antenna performance across the bands in question with monoband quads, I modeled this antenna using both #14 and #12 AWG copper wire. Only the #14 model is shown, since wire size is the only difference between the models.

As a handy reference, the following table lists the mid-band performance for each band of each version of the antenna.

Wire-Band	Freq. MHz	Gain dBi	F-B dB	Impedance R +/- jX Ohms
#14-20	14.175	9.60	20.8	40.8 + j 3.6
#12-20		9.74	22.0	38.0 + j 1.7
#14-15	21.225	10.10	16.8	87.6 + j 4.4
#12-15		10.16	15.9	85.3 + j 3.9
#14-10	28.5	8.93	8.3	105.0 - j35.0
#12-10		8.93	8.0	103.0 - j35.8

The differences in performance figures are almost completely insignificant. This fact suggests that element interaction among loops for the various bands may play a stronger role in determining performance characteristics in this 3-band model than modest changes in wire size. The closest loop set to an uninfluenced set is for 20 meters, and the differences in mid-band performance are greatest on that band. The performance curves across the bands bear out this suggestion.

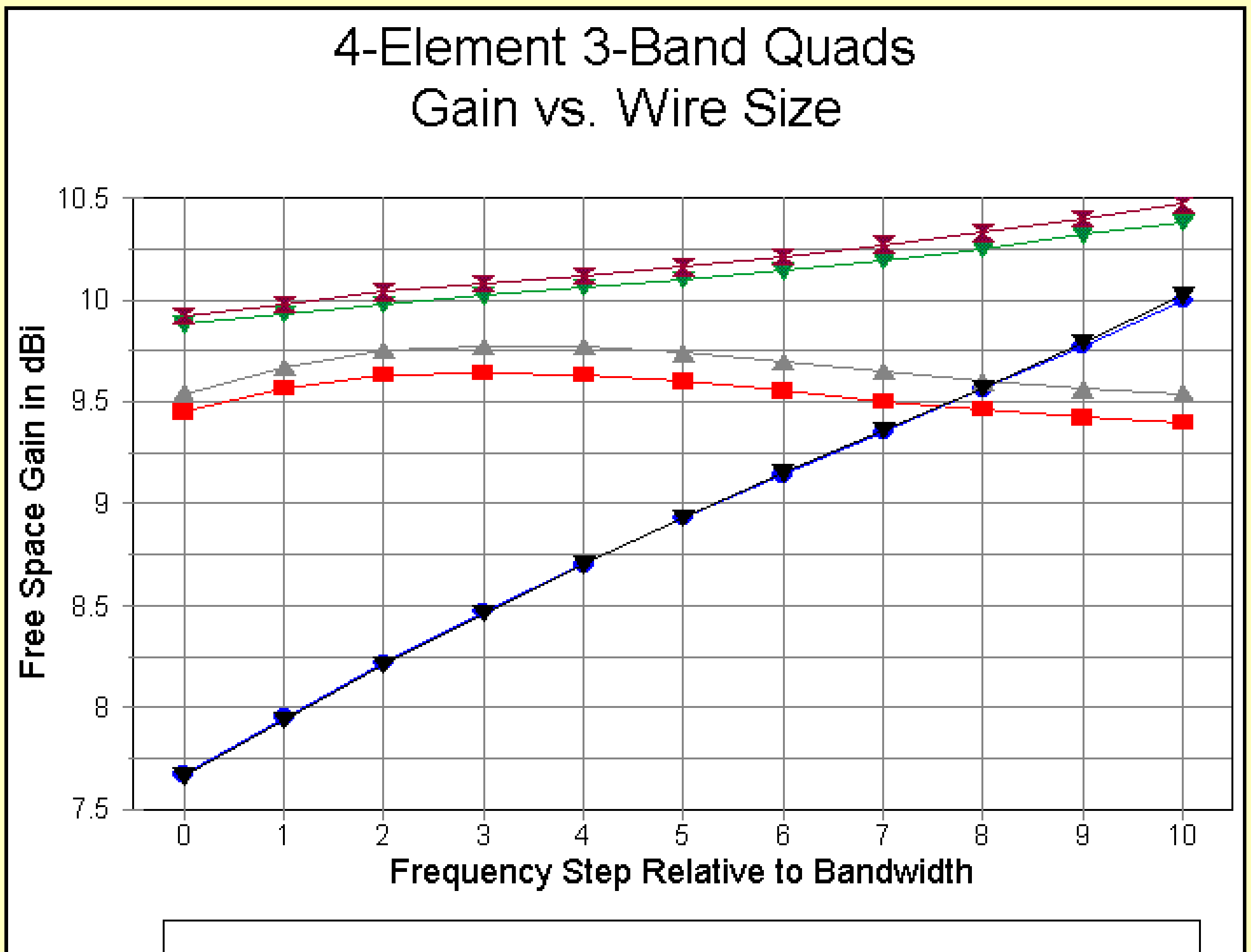


Fig. 68

The gain curves in **Fig. 68** show the virtual identity of the 10-meter gain for the two wire sizes. 15-meter gain does almost as well, and only 20-meter gain shows something interesting. The low-end increase in gain toward the peak value is slightly steeper for the fatter wire.

A rising gain curve across the band is natural for virtually any parasitic beam having a director and is the opposite trend from that shown by 2-element reflector-driver designs. However, the 10-meter curve strongly suggests that the performance for this band has not been optimized. The dimensions for 10-meters suggest that the design technique used to arrive at the dimension was simple scaling of the loop length from 20 and 15 meter. The result is, according to the model, relatively mediocre performance at the low end of 10 meters for a long-boom 4-element array.

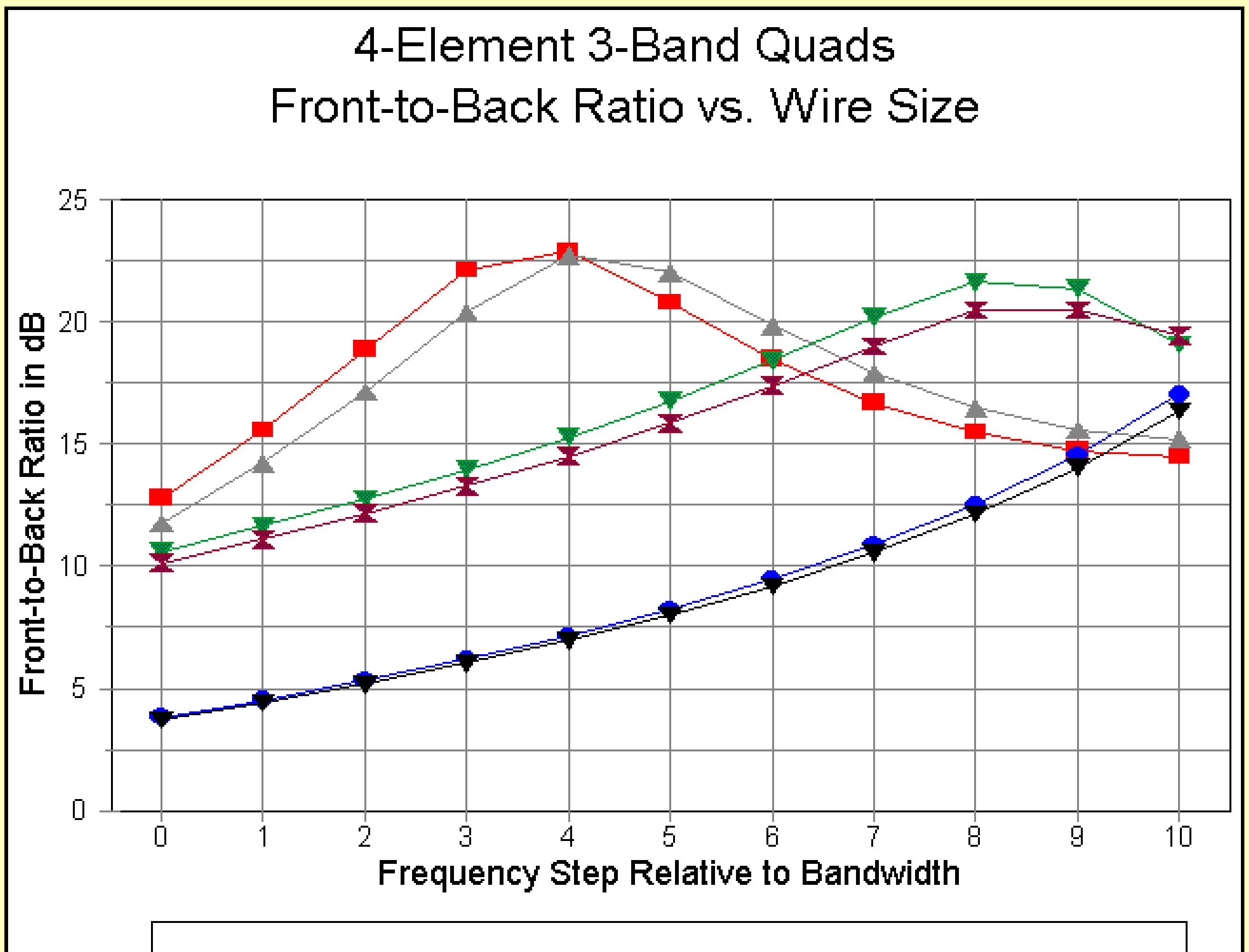


Fig. 69

The front-to-back ratio curves in **Fig. 69** tend to confirm that--if the model is reasonably accurate--inadequate attention has been paid to 10 meter dimensions. The front-to-back ratio on that band only rises above 10 dB at about 28.6 MHz and continues to climb toward the 29.0 MHz mark, where the scan ceased. In contrast, the front-to-back peaks for both 20 and 15 meters occur within the passband under study. In accord with the suggestion that the 20 meter loops are least affected by the other loops in the array--in other words, act most like a monoband array--the 20-meter front-to-back curves show a frequency displacement that is missing from the 15- and 10-meter curves.

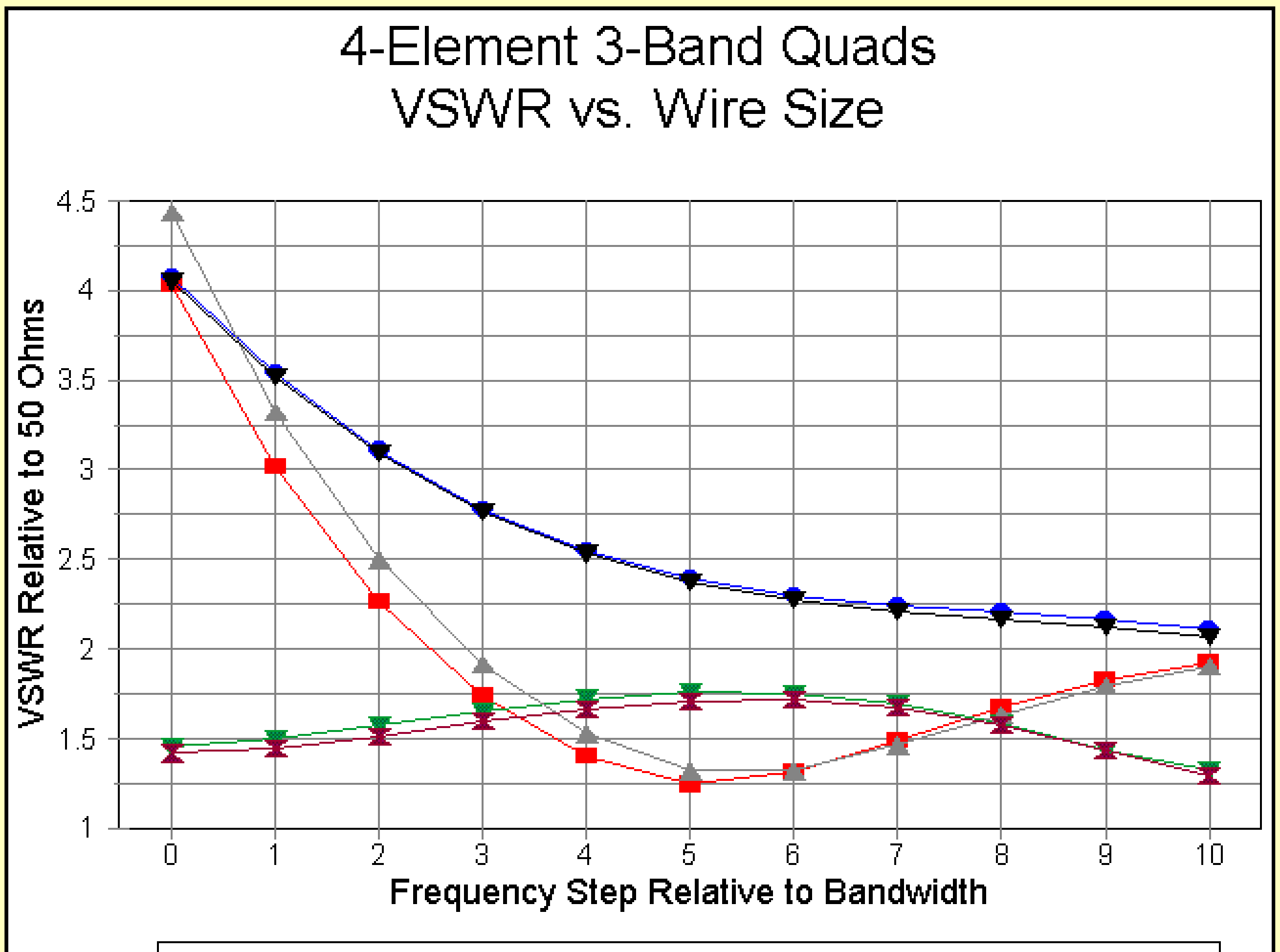


Fig. 70

The VSWR curves in **Fig. 70** are also revelatory. The 20-meter mid-band values suggested that the array might have a low SWR relative to 50 Ohms across that band. However, the curves show that SWR climbs precipitously below mid-band, as the resistive component of the source impedance approaches 20 Ohms. Although the mid-band impedance given for 15 meters suggests a better match to 75-Ohm line, the 50-Ohm SWR remains below 2:1 across that band. On 10 meters, the SWR only approaches 2:1 at 29 MHz. However, if the dimensions of all the 10 meter loops were changed to bring the performance reports within the pass band, it is likely that the 10-meter SWR would also decrease to a more acceptable set of values relative to 50 Ohms.

For reference, here is a table of source impedance values for each band, using the #14 model, recorded for the low, middle, and high points of each band.

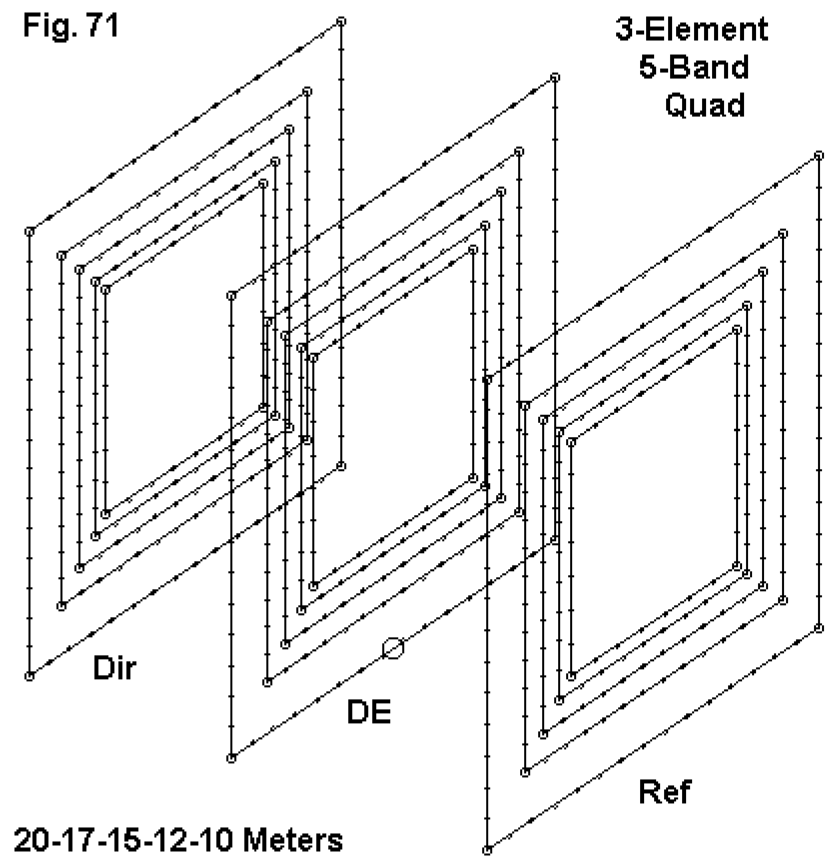
Band	Impedance at a Specified Frequency			Delta R	Delta X
20 m	14.0	14.175	14.35		
	24.2 - j45.8	40.8 + j 3.6	67.7 + j34.5	43.5	80.3
15 m	21.0	21.225	21.45		
	69.6 - j10.2	87.6 + j 4.4	60.7 + j11.3	26.9	21.5
10 m	28.0	28.5	29.0		
	92.6 - j94.6	105.0- j35.0	104.9+ j 6.7	12.4	101.3

Above 29 MHz, the 10-meter impedance descends once more. It is likely that judicious loop alteration can bring the source impedance within a 2:1 50- Ohm SWR curve that occupies most of the first MHz of 10. Likewise, adjustment to the 20 meter driver length could also move its 2:1 SWR curve lower in the band. There is no reason to touch anything on 15, except perhaps to draw the front-to-back curve more symmetrically within the band.

A 3-Element 5-Band 18'-Boom Quad Array

Correspondence with ON7NQ brought to light his efforts to improve the performance of a commercial 3-element 5-band quad he had purchased. The initial dimensions--with allowance for adding 17 and 12 meters and for dropping one element--were similar to those in the 4-element quad just studied. Improvements to 20 meter low-end performance and overall 10-meter performance were the goals of the revisions. Although ON7NQ modeled with a MININEC product, my cross checks with his numbers via NEC-4 showed a very close correlation. The results of one direction of the work yielded the 3- element array sketched in **Fig. 71**.

Fig. 71



Since the sketch gives no hint of the final dimensions of this model (only one of several we discussed), the following table may help.

Band	Reflector Side L feet	Space Re-DE	Driver Side L feet	Space DE-D1	Dir. 1 Side L feet
20	18.166	10	17.812	8	17.166
17	14.134	10	13.874	8	13.458
15	12.066	10	11.834	8	11.500
12	10.334	10	10.062	8	9.834
10	9.100	10	8.800	8	8.684

Compared to the dimensions given for the 3-band quad, 15 meters changes scarcely at all. In the case of both 20 and 10 meters, the loops have been enlarged, with the exception of the 20-meter director, which was decreased. The model for this 60-wire, 660 segment model follows.

ON7NQ 3 el 5 band #14 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	W4E2	-52.100, 96.000,-52.100	W2E1	52.100, 96.000,-52.100	# 14	7
2	W1E2	52.100, 96.000,-52.100	W3E1	52.100, 96.000, 52.100	# 14	7
3	W2E2	52.100, 96.000, 52.100	W4E1	-52.100, 96.000, 52.100	# 14	7
4	W3E2	-52.100, 96.000, 52.100	W1E1	-52.100, 96.000,-52.100	# 14	7
5	W8E2	-52.800, 0.000,-52.800	W6E1	52.800, 0.000,-52.800	# 14	7
6	W5E2	52.800, 0.000,-52.800	W7E1	52.800, 0.000, 52.800	# 14	7
7	W6E2	52.800, 0.000, 52.800	W8E1	-52.800, 0.000, 52.800	# 14	7
8	W7E2	-52.800, 0.000, 52.800	W5E1	-52.800, 0.000,-52.800	# 14	7
9	W12E2	-54.600,-120.00,-54.600	W10E1	54.600,-120.00,-54.600	# 14	7
10	W9E2	54.600,-120.00,-54.600	W11E1	54.600,-120.00, 54.600	# 14	7
11	W10E2	54.600,-120.00, 54.600	W12E1	-54.600,-120.00, 54.600	# 14	7
12	W11E2	-54.600,-120.00, 54.600	W9E1	-54.600,-120.00,-54.600	# 14	7
13	W16E2	-59.000, 96.000,-59.000	W14E1	59.000, 96.000,-59.000	# 14	9
14	W13E2	59.000, 96.000,-59.000	W15E1	59.000, 96.000, 59.000	# 14	9
15	W14E2	59.000, 96.000, 59.000	W16E1	-59.000, 96.000, 59.000	# 14	9
16	W15E2	-59.000, 96.000, 59.000	W13E1	-59.000, 96.000,-59.000	# 14	9
17	W20E2	-60.375, 0.000,-60.375	W18E1	60.375, 0.000,-60.375	# 14	9
18	W17E2	60.375, 0.000,-60.375	W19E1	60.375, 0.000, 60.375	# 14	9
19	W18E2	60.375, 0.000, 60.375	W20E1	-60.375, 0.000, 60.375	# 14	9
20	W19E2	-60.375, 0.000, 60.375	W17E1	-60.375, 0.000,-60.375	# 14	9
21	W24E2	-62.000,-120.00,-62.000	W22E1	62.000,-120.00,-62.000	# 14	9
22	W21E2	62.000,-120.00,-62.000	W23E1	62.000,-120.00, 62.000	# 14	9
23	W22E2	62.000,-120.00, 62.000	W24E1	-62.000,-120.00, 62.000	# 14	9
24	W23E2	-62.000,-120.00, 62.000	W21E1	-62.000,-120.00,-62.000	# 14	9
25	W28E2	-69.000, 96.000,-69.000	W26E1	69.000, 96.000,-69.000	# 14	11
26	W25E2	69.000, 96.000,-69.000	W27E1	69.000, 96.000, 69.000	# 14	11
27	W26E2	69.000, 96.000, 69.000	W28E1	-69.000, 96.000, 69.000	# 14	11
28	W27E2	-69.000, 96.000, 69.000	W25E1	-69.000, 96.000,-69.000	# 14	11
29	W32E2	-71.000, 0.000,-71.000	W30E1	71.000, 0.000,-71.000	# 14	11
30	W29E2	71.000, 0.000,-71.000	W31E1	71.000, 0.000, 71.000	# 14	11
31	W30E2	71.000, 0.000, 71.000	W32E1	-71.000, 0.000, 71.000	# 14	11
32	W31E2	-71.000, 0.000, 71.000	W29E1	-71.000, 0.000,-71.000	# 14	11
33	W36E2	-72.400,-120.00,-72.400	W34E1	72.400,-120.00,-72.400	# 14	11
34	W33E2	72.400,-120.00,-72.400	W35E1	72.400,-120.00, 72.400	# 14	11
35	W34E2	72.400,-120.00, 72.400	W36E1	-72.400,-120.00, 72.400	# 14	11
36	W35E2	-72.400,-120.00, 72.400	W33E1	-72.400,-120.00,-72.400	# 14	11
37	W40E2	-80.750, 96.000,-80.750	W38E1	80.750, 96.000,-80.750	# 14	13
38	W37E2	80.750, 96.000,-80.750	W39E1	80.750, 96.000, 80.750	# 14	13
39	W38E2	80.750, 96.000, 80.750	W40E1	-80.750, 96.000, 80.750	# 14	13
40	W39E2	-80.750, 96.000, 80.750	W37E1	-80.750, 96.000,-80.750	# 14	13
41	W44E2	-83.250, 0.000,-83.250	W42E1	83.250, 0.000,-83.250	# 14	13
42	W41E2	83.250, 0.000,-83.250	W43E1	83.250, 0.000, 83.250	# 14	13
43	W42E2	83.250, 0.000, 83.250	W44E1	-83.250, 0.000, 83.250	# 14	13
44	W43E2	-83.250, 0.000, 83.250	W41E1	-83.250, 0.000,-83.250	# 14	13
45	W48E2	-84.805,-120.00,-84.805	W46E1	84.805,-120.00,-84.805	# 14	13
46	W45E2	84.805,-120.00,-84.805	W47E1	84.805,-120.00, 84.805	# 14	13
47	W46E2	84.805,-120.00, 84.805	W48E1	-84.805,-120.00, 84.805	# 14	13
48	W47E2	-84.805,-120.00, 84.805	W45E1	-84.805,-120.00,-84.805	# 14	13
49	W52E2	-103.000, 96.000,-103.00	W50E1	103.000, 96.000,-103.00	# 14	15
50	W49E2	103.000, 96.000,-103.00	W51E1	103.000, 96.000,103.000	# 14	15
51	W50E2	103.000, 96.000,103.000	W52E1	-103.00, 96.000,103.000	# 14	15
52	W51E2	-103.00, 96.000,103.000	W49E1	-103.00, 96.000,-103.00	# 14	15
53	W56E2	-106.87, 0.000,-106.87	W54E1	106.870, 0.000,-106.87	# 14	15
54	W53E2	106.870, 0.000,-106.87	W55E1	106.870, 0.000,106.870	# 14	15
55	W54E2	106.870, 0.000,106.870	W56E1	-106.87, 0.000,106.870	# 14	15
56	W55E2	-106.87, 0.000,106.870	W53E1	-106.87, 0.000,-106.87	# 14	15
57	W60E2	-109.00,-120.00,-109.00	W58E1	109.000,-120.00,-109.00	# 14	15
58	W57E2	109.000,-120.00,-109.00	W59E1	109.000,-120.00,109.000	# 14	15
59	W58E2	109.000,-120.00,109.000	W60E1	-109.00,-120.00,109.000	# 14	15
60	W59E2	-109.00,-120.00,109.000	W57E1	-109.00,-120.00,-109.00	# 14	15

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

Source	Wire Seg.	Wire #/Pct From End 1 Actual	(Specified)	Ampl.(V, A)	Phase(Deg.)	Type
1	8	53 / 50.00	(53 / 50.00)	1.000	0.000	V

This model happens to begin with the 10-meter wires, from director to reflector, and end with the 20-meter wires. The source wires are 20m = wire 53, 12m = wire 41, 15m = wire 29, 17m = wire 17, and 10m = wire 5. Dimensions are in inches in the model description. The wire size is #14 AWG copper.

The midband performance values reported by NEC-4 for this model are as follows:

Band	Freq. MHz	Gain dBi	F-B dB	Impedance R +/- jX Ohms
20	14.175	8.08	11.31	43.6 + j 3.2
17	18.118	8.32	15.2	39.6 + j 3.5

15	21.225	8.51	21.4	45.5 + j 6.2
12	24.94	8.52	15.9	47.7 + j 8.9
10	28.5	9.33	11.3	45.0 + j14.9

Relative to the 40' boom 4-element array, gains are down, but each band shows a good match at center to a 50-Ohm feed system. A closer look at each parameter across the wide bands may be useful in understanding the design goals of this model.

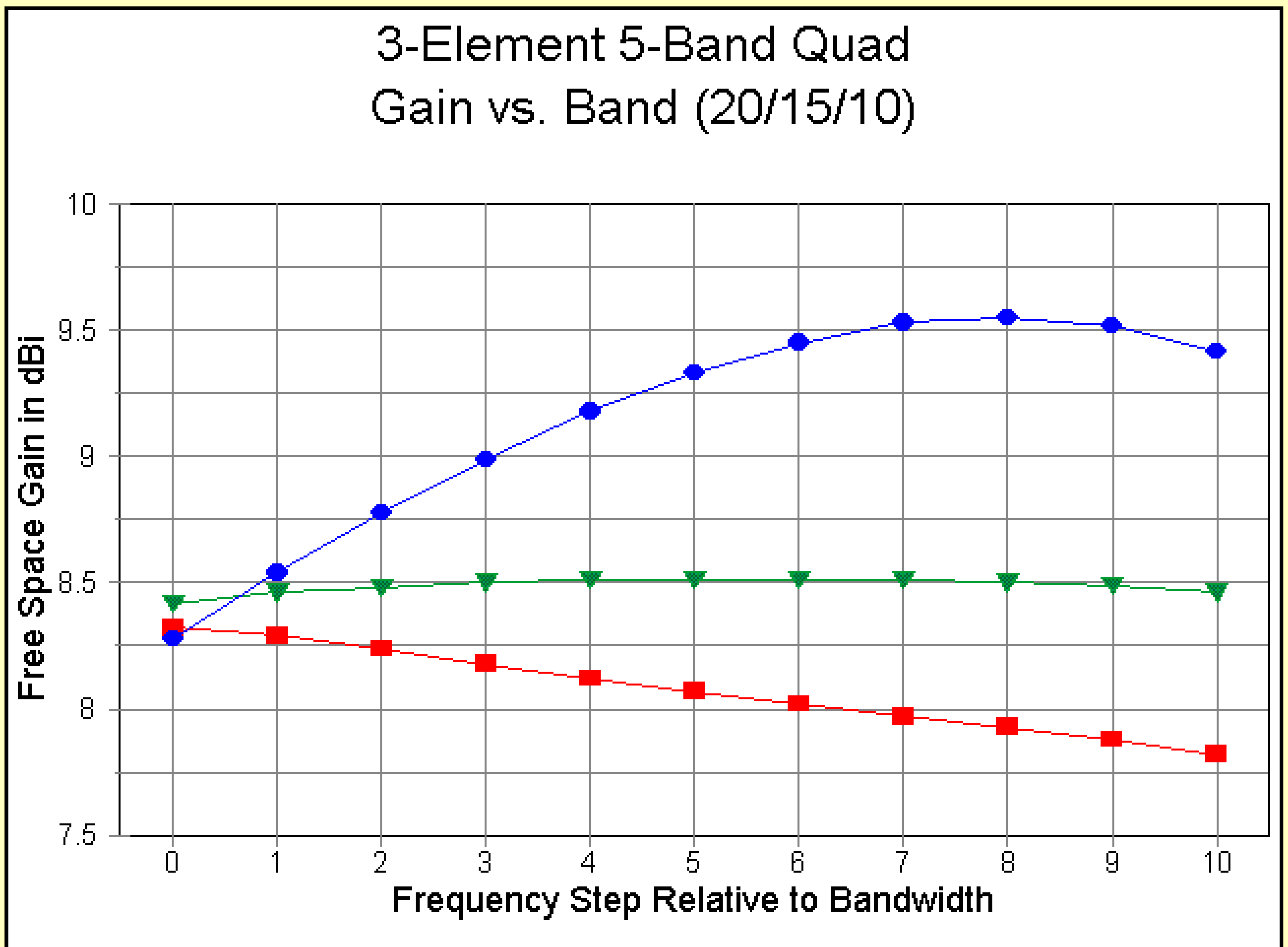


Fig. 72

As shown in **Fig. 72**, the gain across 15 meters is virtually flat. The gain across 20 meters descends, but only moderately, with design emphasis upon performance at the lower end of the band. Although the 10-meter gain curve still ascends, its peak occurs within the pass band. As we discovered with 2-element multi-band quad arrays, element interaction provides 10-meters with higher gain than might otherwise be obtained in a monoband 18' boom quad, since the elements are very widely spaced for that band. 20 meters seems to "suffer" from its relative independence, with 15 meters showing a "balance" of influence. (How to quantify the terms in "-" remains a task for the future of quad design.)

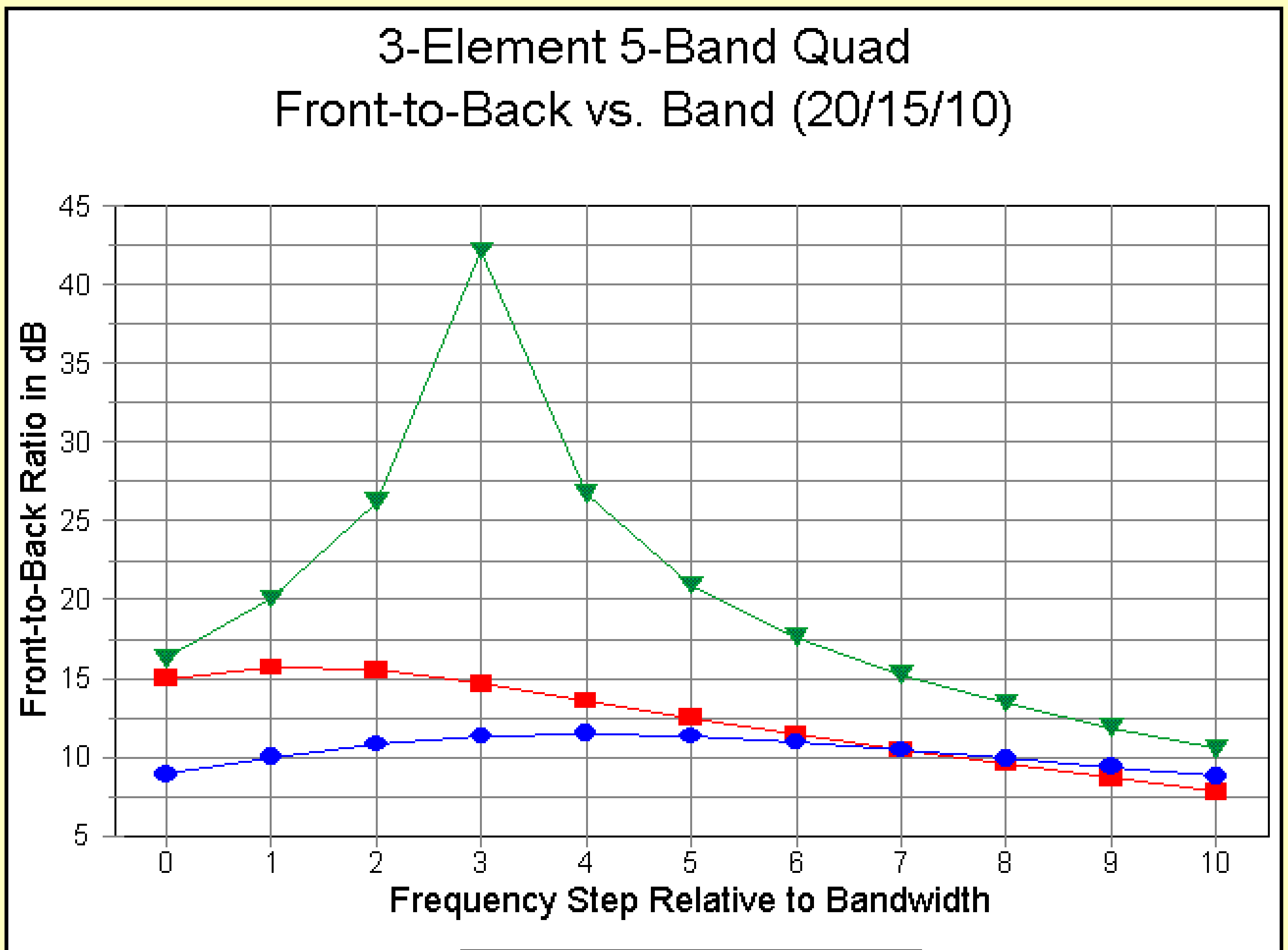


Fig. 73

The front-to-back curves (**Fig. 73**) tell us that the antenna was largely designed for gain, with the source impedance the most important second factor. Front- to-back ratio was largely accepted for what it turned out to be. On 15 meters, where gain performance is exceptionally stable, the front-to-back peak can easily be moved within the passband. 20 and 10 are harder nuts to crack, and their numbers are relatively poor, except for the low end of 20 meters, where they approach being adequate. On 10, the front-to-back performance across the band is similar to a 2-element reflector-driver Yagi.

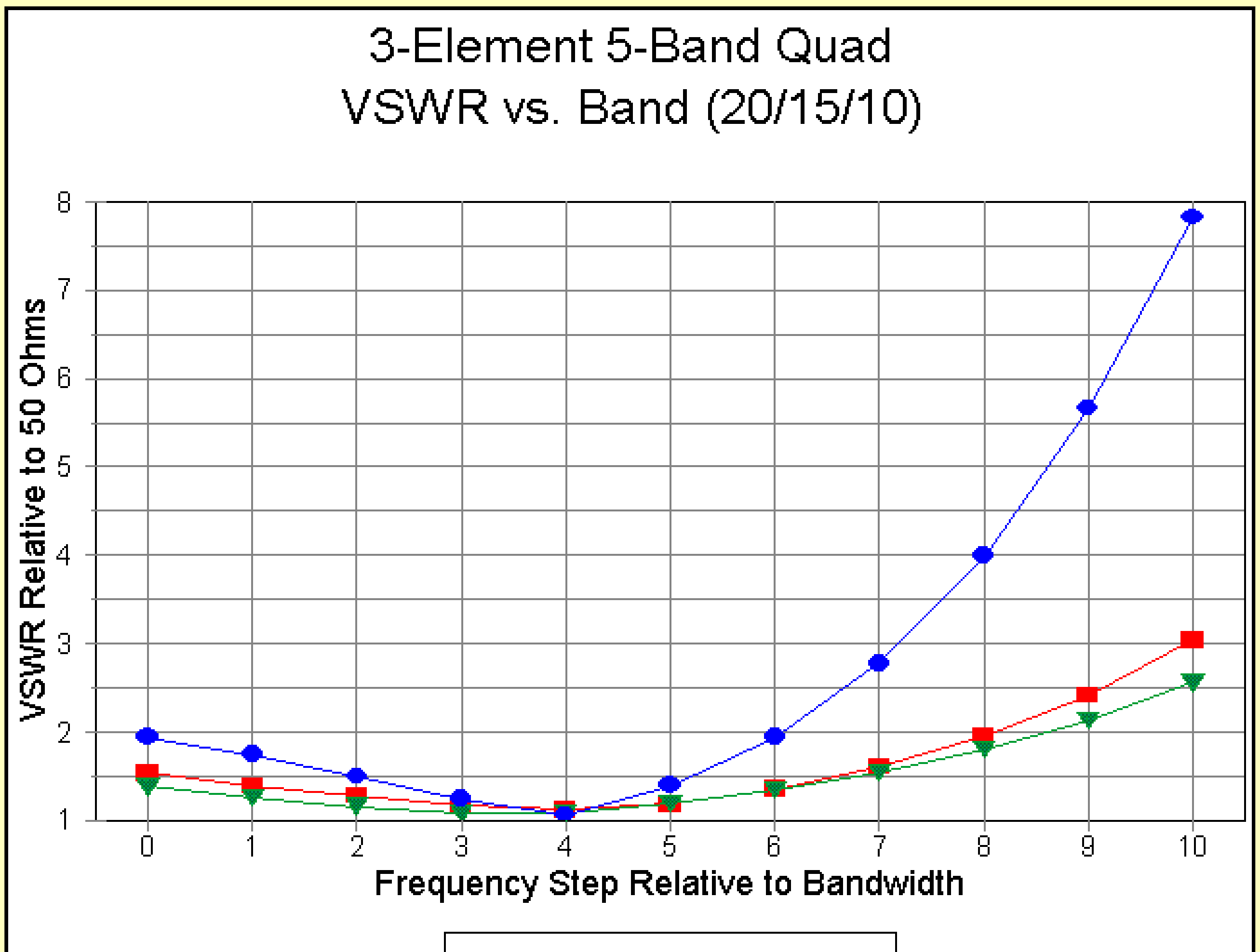


Fig. 74

The 50-Ohm SWR performance of the antennas has also been optimized for the low ends of the bands, as is readily apparent in **Fig. 74**. On 20 and 10, the SWR is below 2:1 for at least 80% of the pass bands, but that figure goes down to 60% on 10 meters. For reference, here are the standard figures across each of the wide bands.

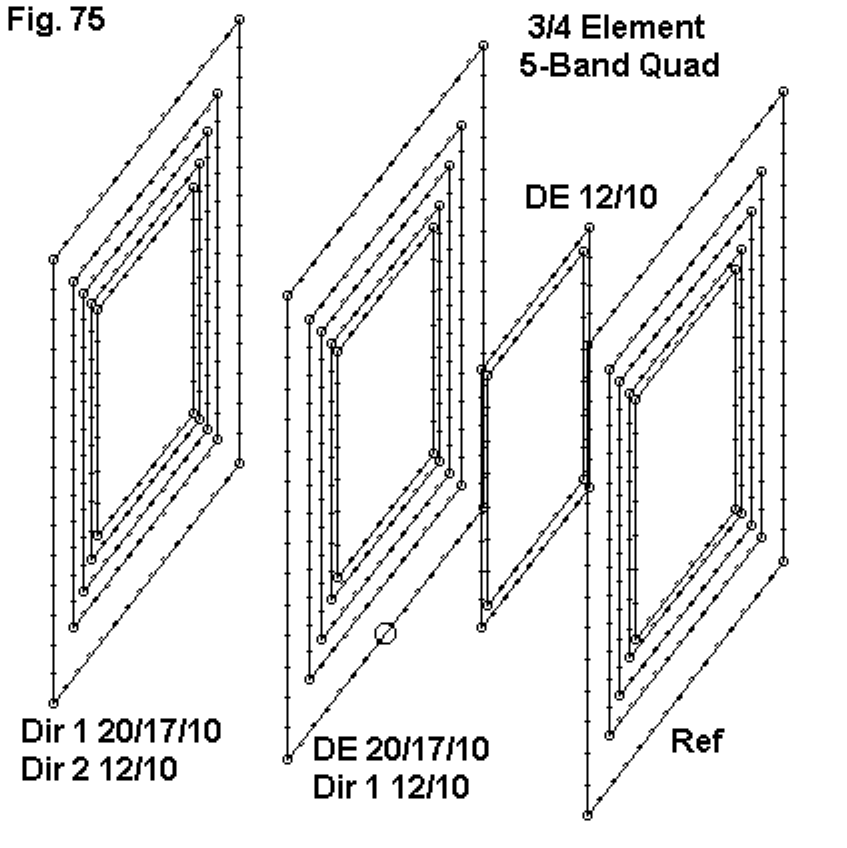
Band	Impedance at a Specified	Frequency		Delta R	Delta X
20 m	14.0	14.175	14.35		
	45.3 - j19.9	43.3 + j 4.0	32.0 + j43.2	13.3	63.1
15 m	21.0	21.225	21.45		
	48.1 - j15.6	45.4 + j 6.8	35.4 + j38.3	12.7	53.9
10 m	28.0	28.5	29.0		
	76.9 - j32.2	45.0 + j14.9	27.0 + j86.7	49.9	118.9

Optimizing gain within the pass band for each of the wide bands has resulted in an expansion of the range of reactance across the bands. Like most 3-element parasitical arrays, the lowest impedance is at the upper end of the band.

We might accept the 20-15 meter performance as not likely to be improved by more than a small amount due to the limitations of the boom length on those bands. Compared to Yagis, the boom length is short for 20 meters and about right for 15 meters, relative to maximizing gain through the use of three elements. Extending and improving 10 meter performance seems the only further development possible, since the boom is long for 3 elements on that band. The 10' reflector-driver spacing seems especially long.

A 3/4-Element 5-Band 18'-Boom Quad Array

ON7NQ added a new spreader midway between the old reflector and driver spreaders. To this, he attached what became driver loops for 10 and 12 meters, with the old drivers becoming first directors. The result is a hybrid 3- and 4-element quad, where the element spacing on the highest two bands more closely resembles that used with comparable Yagis. The overall 18' boom length was retained. The result looks something the sketch in **Fig. 75**.

Fig. 75


The following table lists the side lengths for the elements in this revised array.

Band	Reflector Side L feet	Space Re-DE	Driver Side L feet	Space DE-D1	Dir. 1 Side L feet	Space D1-D2	Dir.2 Side L feet
20	18.084	10	17.808	8	17.084		
17	14.042	10	13.858	8	13.316		
15	12.066	10	11.834	8	11.500		
12	10.200	5	9.932	5	9.850	8	9.892
10	9.224	5	8.816	5	8.716	8	8.666

Due to the difference in space on 12 and 10 in terms of fractions of a wavelength, the forwardmost director on 12 is actually larger than the first director. Many of the loop size changes are small on the lower bands, and the 15 meter dimensions did not change at all. Here is the model description for this 68-wire, 724-segment model.

```
ON7NQ 3/4 el 5 band #12                     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   W4E2 -108.50,  0.000,-108.50  W2E1 108.500,  0.000,-108.50    # 12   15
2   W1E2 108.500,  0.000,-108.50  W3E1 108.500,  0.000,108.500    # 12   15
3   W2E2 108.500,  0.000,108.500  W4E1 -108.50,  0.000,108.500    # 12   15
4   W3E2 -108.50,  0.000,108.500  W1E1 -108.50,  0.000,-108.50    # 12   15
5   W8E2 -106.85,120.000,-106.85  W6E1 106.850,120.000,-106.85    # 12   15
6   W5E2 106.850,120.000,-106.85  W7E1 106.850,120.000,106.850    # 12   15
7   W6E2 106.850,120.000,106.850  W8E1 -106.85,120.000,106.850    # 12   15
8   W7E2 -106.85,120.000,106.850  W5E1 -106.85,120.000,-106.85    # 12   15
9  W12E2 -102.50,216.000,-102.50 W10E1 102.500,216.000,-102.50    # 12   15
10  W9E2 102.500,216.000,-102.50 W11E1 102.500,216.000,102.500    # 12   15
11 W10E2 102.500,216.000,102.500 W12E1 -102.50,216.000,102.500    # 12   15
12 W11E2 -102.50,216.000,102.500  W9E1 -102.50,216.000,-102.50    # 12   15
13 W16E2 -84.250,  0.000,-84.250 W14E1  84.250,  0.000,-84.250    # 12   13
14 W13E2  84.250,  0.000,-84.250 W15E1  84.250,  0.000, 84.250    # 12   13
15 W14E2  84.250,  0.000, 84.250 W16E1 -84.250,  0.000, 84.250    # 12   13
16 W15E2 -84.250,  0.000, 84.250 W13E1 -84.250,  0.000,-84.250    # 12   13
17 W20E2 -83.150,120.000,-83.150 W18E1  83.150,120.000,-83.150    # 12   13
18 W17E2  83.150,120.000,-83.150 W19E1  83.150,120.000, 83.150    # 12   13
19 W18E2  83.150,120.000, 83.150 W20E1 -83.150,120.000, 83.150    # 12   13
20 W19E2 -83.150,120.000, 83.150 W17E1 -83.150,120.000,-83.150    # 12   13
21 W24E2 -79.900,216.000,-79.900 W22E1  79.900,216.000,-79.900    # 12   13
22 W21E2  79.900,216.000,-79.900 W23E1  79.900,216.000, 79.900    # 12   13
23 W22E2  79.900,216.000, 79.900 W24E1 -79.900,216.000, 79.900    # 12   13
24 W23E2 -79.900,216.000, 79.900 W21E1 -79.900,216.000,-79.900    # 12   13
25 W28E2 -72.400,  0.000,-72.400 W26E1  72.400,  0.000,-72.400    # 12   11
26 W25E2  72.400,  0.000,-72.400 W27E1  72.400,  0.000, 72.400    # 12   11
27 W26E2  72.400,  0.000, 72.400 W28E1 -72.400,  0.000, 72.400    # 12   11
28 W27E2 -72.400,  0.000, 72.400 W25E1 -72.400,  0.000,-72.400    # 12   11
29 W32E2 -71.000,120.000,-71.000 W30E1  71.000,120.000,-71.000    # 12   11
30 W29E2  71.000,120.000,-71.000 W31E1  71.000,120.000, 71.000    # 12   11
31 W30E2  71.000,120.000, 71.000 W32E1 -71.000,120.000, 71.000    # 12   11
32 W31E2 -71.000,120.000, 71.000 W29E1 -71.000,120.000,-71.000    # 12   11
33 W36E2 -69.000,216.000,-69.000 W34E1  69.000,216.000,-69.000    # 12   11
34 W33E2  69.000,216.000,-69.000 W35E1  69.000,216.000, 69.000    # 12   11
35 W34E2  69.000,216.000, 69.000 W36E1 -69.000,216.000, 69.000    # 12   11
36 W35E2 -69.000,216.000, 69.000 W33E1 -69.000,216.000,-69.000    # 12   11
37 W40E2 -61.200,  0.000,-61.200 W38E1  61.200,  0.000,-61.200    # 12    9
38 W37E2  61.200,  0.000,-61.200 W39E1  61.200,  0.000, 61.200    # 12    9
39 W38E2  61.200,  0.000, 61.200 W40E1 -61.200,  0.000, 61.200    # 12    9
40 W39E2 -61.200,  0.000, 61.200 W37E1 -61.200,  0.000,-61.200    # 12    9
41 W44E2 -59.950, 60.000,-59.950 W42E1  59.950, 60.000,-59.950    # 12    9
42 W41E2  59.950, 60.000,-59.950 W43E1  59.950, 60.000, 59.950    # 12    9
43 W42E2  59.950, 60.000, 59.950 W44E1 -59.950, 60.000, 59.950    # 12    9
44 W43E2 -59.950, 60.000, 59.950 W41E1 -59.950, 60.000,-59.950    # 12    9
45 W48E2 -59.100,120.000,-59.100 W46E1  59.100,120.000,-59.100    # 12    9
46 W45E2  59.100,120.000,-59.100 W47E1  59.100,120.000, 59.100    # 12    9
47 W46E2  59.100,120.000, 59.100 W48E1 -59.100,120.000, 59.100    # 12    9
48 W47E2 -59.100,120.000, 59.100 W45E1 -59.100,120.000,-59.100    # 12    9
49 W52E2 -59.350,216.000,-59.350 W50E1  59.350,216.000,-59.350    # 12    9
50 W49E2  59.350,216.000,-59.350 W51E1  59.350,216.000, 59.350    # 12    9
51 W50E2  59.350,216.000, 59.350 W52E1 -59.350,216.000, 59.350    # 12    9
52 W51E2 -59.350,216.000, 59.350 W49E1 -59.350,216.000,-59.350    # 12    9
53 W56E2 -55.340,  0.000,-55.340 W54E1  55.340,  0.000,-55.340    # 12    7
54 W53E2  55.340,  0.000,-55.340 W55E1  55.340,  0.000, 55.340    # 12    7
55 W54E2  55.340,  0.000, 55.340 W56E1 -55.340,  0.000, 55.340    # 12    7
56 W55E2 -55.340,  0.000, 55.340 W53E1 -55.340,  0.000,-55.340    # 12    7
57 W60E2 -52.900, 60.000,-52.900 W58E1  52.900, 60.000,-52.900    # 12    7
58 W57E2  52.900, 60.000,-52.900 W59E1  52.900, 60.000, 52.900    # 12    7
59 W58E2  52.900, 60.000, 52.900 W60E1 -52.900, 60.000, 52.900    # 12    7
60 W59E2 -52.900, 60.000, 52.900 W57E1 -52.900, 60.000,-52.900    # 12    7
61 W64E2 -52.300,120.000,-52.300 W62E1  52.300,120.000,-52.300    # 12    7
62 W61E2  52.300,120.000,-52.300 W63E1  52.300,120.000, 52.300    # 12    7
63 W62E2  52.300,120.000, 52.300 W64E1 -52.300,120.000, 52.300    # 12    7
64 W63E2 -52.300,120.000, 52.300 W61E1 -52.300,120.000,-52.300    # 12    7
65 W68E2 -51.995,216.000,-51.995 W66E1  51.995,216.000,-51.995    # 12    7
66 W65E2  51.995,216.000,-51.995 W67E1  51.995,216.000, 51.995    # 12    7
67 W66E2  51.995,216.000, 51.995 W68E1 -51.995,216.000, 51.995    # 12    7
68 W67E2 -51.995,216.000, 51.995 W65E1 -51.995,216.000,-51.995    # 12    7

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

Source    Wire      Wire #/Pct From End 1    Ampl.(V, A)  Phase(Deg.)  Type
          Seg.     Actual      (Specified)

1           8     5 / 50.00   (  5 / 50.00)      1.000       0.000       V
```

This model is listed by bands from 20 through 10 meters, with wires within a band given from the reflector forward. Consequently, the source wires are 20m = wire 5, 17m = wire 17, 15m = wire 29, 12m = wire 41, and 10m = wire 57. Dimensions are in inches, and the wire size is #12 AWG copper.

To see what basic improvements the addition of the two new drivers has made, let's look at the midband performance reports from the model.

Band	Freq. MHz	Gain dBi	F-B dB	Impedance R +/- jX Ohms
20	14.175	8.30	15.2	44.4 + j 3.6
17	18.118	8.42	25.5	43.5 - j 0.1
15	21.225	8.52	21.6	46.6 - j 0.6
12	24.94	9.22	18.5	42.2 + j 2.9
10	28.5	9.74	27.9	56.1 + j11.3

Overall, gain and front-to-back ratios are up across the board, although only marginally on the lowest bands. Mid-band gain and front-to-back ratio are better on 10 meters especially. 15-meters remains virtually unchanged.

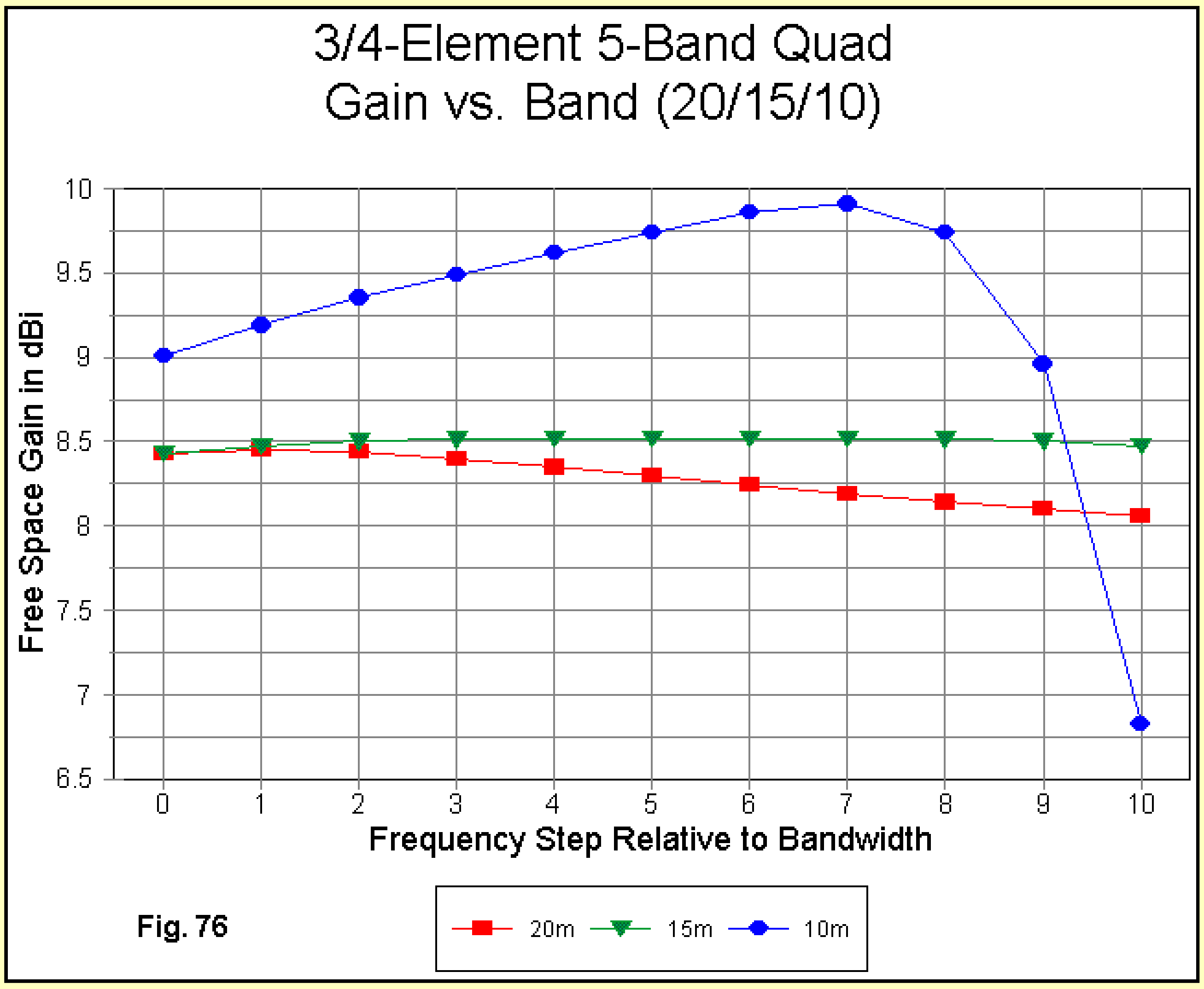


Fig. 76

In the gain curves in **Fig. 76**, we may note that 15 remains unchanged in its flat curve, while the decrease in gain at the upper end of 20 meters has decreased. The gain curve for 10 meters remains at about 9 dBi or better for 90% of the pass band, before taking a nose dive.

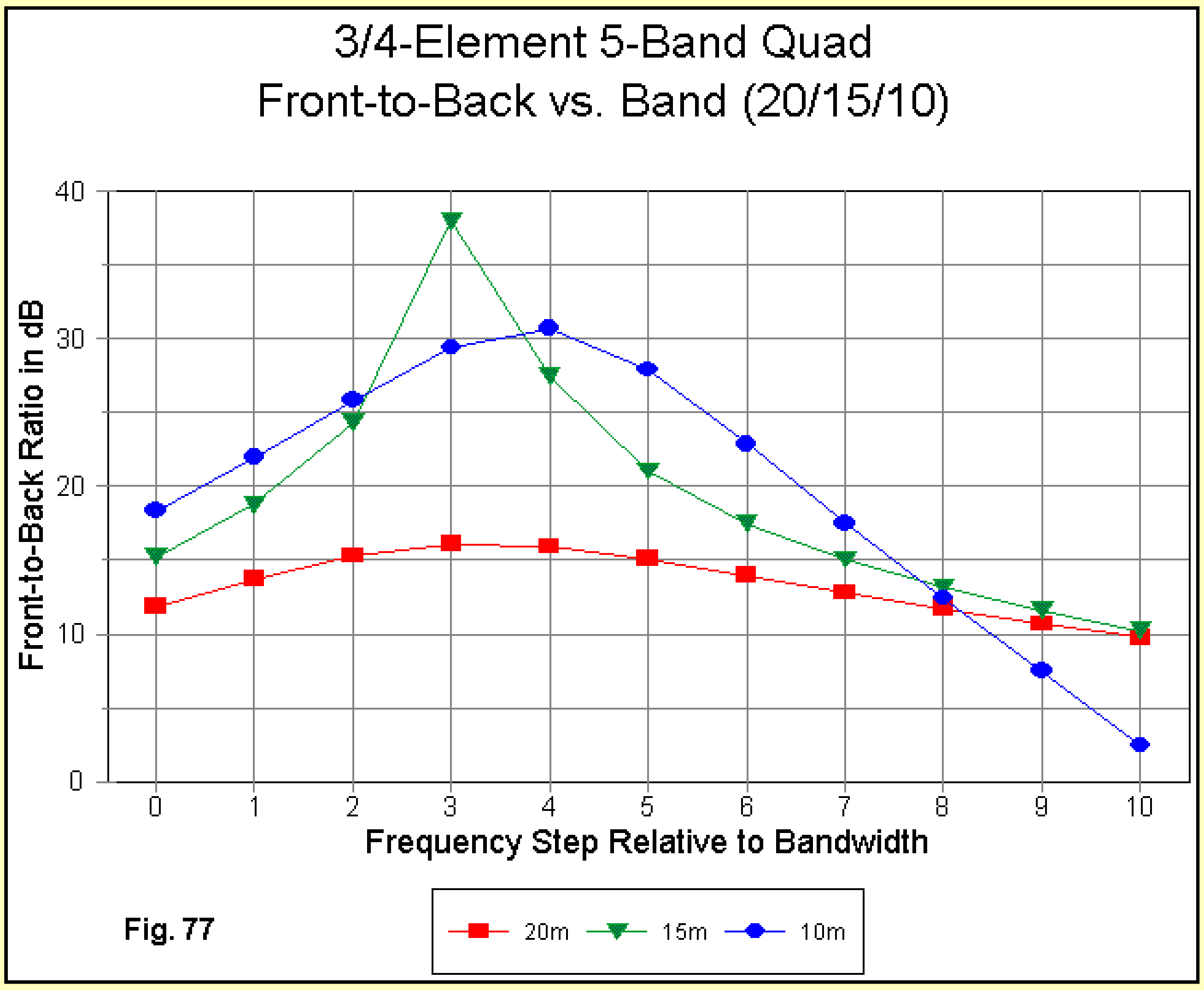
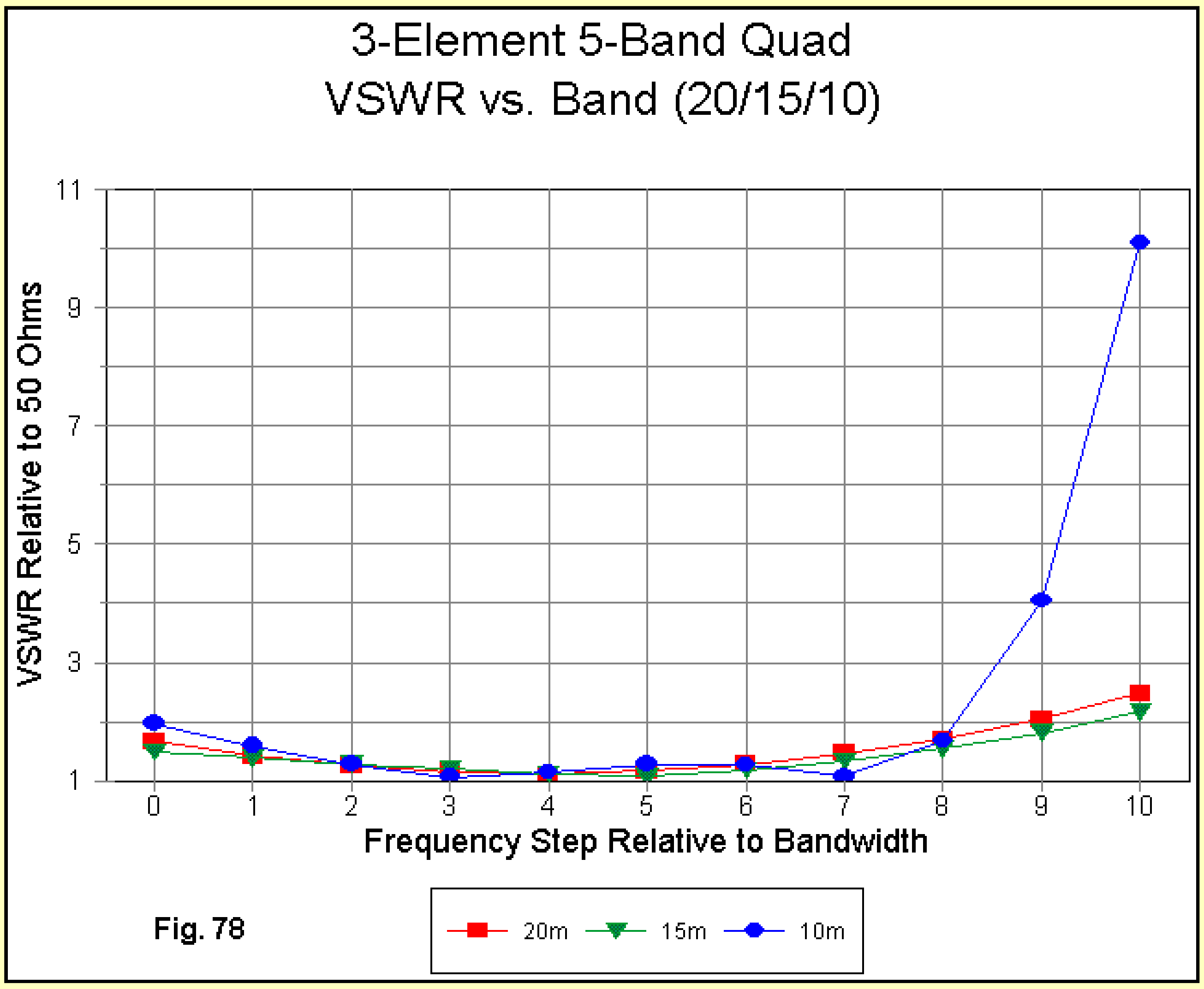


Fig. 77

In **Fig. 77**, we can see the unchanged 15-meter front-to-back curve, which serves as a back drop for the other curves. 20 meters shows a movement of the curve to better center it within the band and give better upper band- edge performance. The biggest improvement occurs on 10 meters, where the front-to-back value is at least 15 dB for more than 3/4 of the pass band. As with the gain, we get a steep slope downward as the frequency approaches 29 MHz.



The small adjustments to the lower bands yield 50-Ohm SWR curves (**Fig. 78**) that are below 2:1 for 90% of 20 and 15 meters. The 10-meter 2:1 curve has been extended to over 80% of the pass band and is consistent with the patterning of the gain and front-to-back figures. 28.8 to 29 MHz has been sacrificed for optimized performance at the low and middle regions of the pass band. You may compare this figure with **Fig. 74** to more clearly see the improvement in the 50-Ohm SWR category.

It is also noteworthy to compare the performance figures of the 3/4-element 5-band quad with those of the traditional design in **Fig. 68** through **Fig. 70**. Although the 4-element, 40' boom design provides more gain on 15 and 10 meters, the 18' boom 3/4-element design is superior in all other categories, except perhaps 20-meter front-to-back ratio--which was obtained at the cost of a relatively low gain figure over most of the band. The 18' 3/4-element design is also a better match on every band.

The results of looking at these models are a few suggestions rather than judgments. First, element interaction in a multi-band quad array remains a strong candidate for being the source of some of its performance. The fact that the current ON7NQ model achieves the performance it does with a boom less than 50% the length of the more traditional models suggests that some of the element interactions can be beneficial.

The achievements of the short boom quad also suggest that those interested in quad design may wish to rethink some of presumptions underlying traditional designs. Element spacing taken in terms of fractions of a wavelength plays a role in optimizing performance, although not necessarily in a simple way. Simply adding element collections at somewhat arbitrary points along the boom may be less effective than optimizing the spacing for each major band and then working out whatever compromises may be needed. A 40' boom may be both useful and necessary for higher gain on 20 and 17, but without intermediate elements somewhere along the line, the boom length may be wasted for 10- and 12-meter performance.

Even within the realm of these design suggestions, it appears that a quad can be designed for a relatively uniform source impedance for all of the bands covered. Although this feature may not improve absolute performance, it can ease the task of installation, band-switching, and other functions of a more practical nature in constructing and using a large quad array. It also appears possible to better center the SWR curve within both the 20- and 15-meter bands.

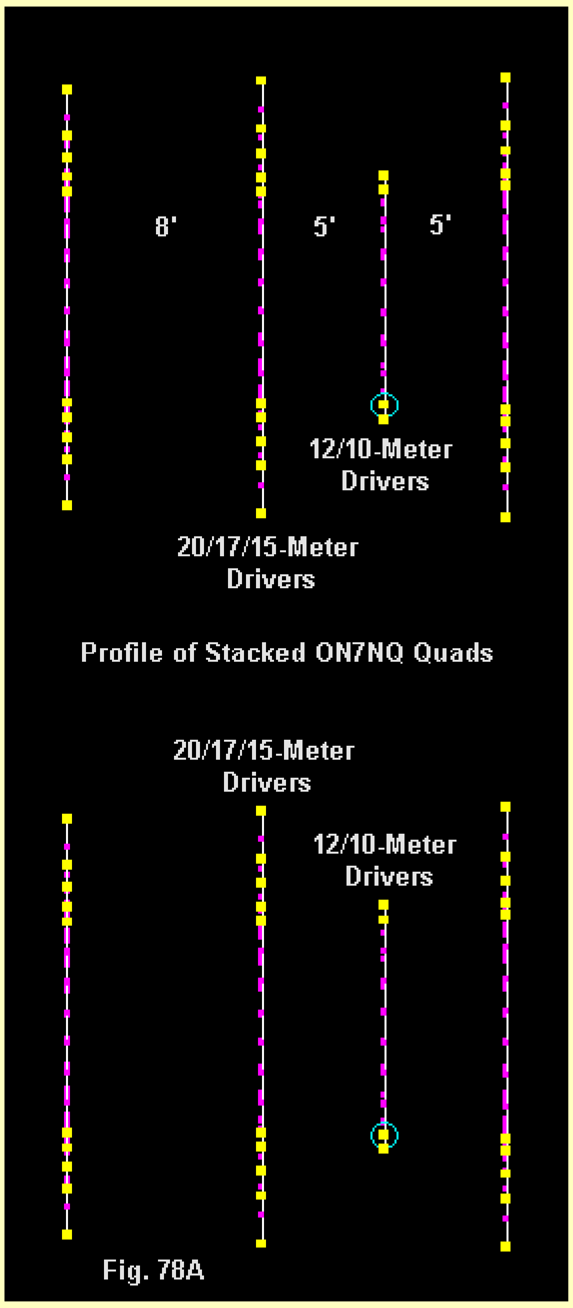
There may in fact be designs available that achieve all of this. My small sample of models can make no claim to being exhaustive or even representative. However, if those designs are not available at present, then multi-band quad designers have a fertile field of endeavor for some time to come. If someone is going to erect something of the mechanical complexity of a many-element, many-band quad, he deserves to have the optimal performance to be gained from the array--and from the investment he has made in it and in its supporting structure.

Stacking the 3/4-Element 5-Band 18'-Boom Quad Array

The ON7NQ 3/4 element quad on an 18' boom has attracted a bit of attention, along with questions about stacking a pair of them. Stacking quads is not quite the same as stacking Yagis. For identical monoband Yagis, the best stacking distance tends to increase with individual array gain. Once you find--via models--the best distance apart for maximum gain, then the next hunt is for the distance that gives adequate front-to-back ratio--unless one wishes to redesign the antennas in the array. The higher the gain of the individual Yagis, the more likely it is to be able to find a distance that maximizes front-to-back ratio while only robbing about 0.1 dB from the maximum gain.

For quads, we have a different ball game. Although array gain does play a role in the determination of the best stacking distance, this criterion tends to be overridden by considerations of array isolation. By isolation, I mean a stacking distance that allows each array on all bands covered to shows the least changes in feedpoint impedance on each band relative to a single array. Planar arrays tend to show more isolation at close spacings (5/8 to 2/3 wavelength on 20 meters, or about 24') than spider designs. 2-element 5-band spiders tend to achieve satisfactory isolation with a center-to-center spacing of about 30'--at least in the models explored so far. (Remember that all of this work is exploratory.)

The ON7NQ array is planar in design, but has more gain than the 2-element planar designs examined so far. Hence, it was likely that the best stacking distance might be more than 24'. In fact, a 30' spacing produced adequate isolation (and convergence of the feedpoint impedances with the single array values). However, 36' proved to be a bit far apart, as the lower-band front-to-back ratio began to decreae--or shift off of the design frequency. Therefore, the following preliminary figures for the single array and the stack in free space use a 30' stack spacing, as measured from the hub of one array to the hub of the other. **Fig. 78a** shows a profile of the stack.



The data consists of gain in dBi, TO angle (where relevant), F-B, beamwidth, feed Z(s) and 50-Ohm SWR (for which the original array had been set). Since the array was designed for 28.0 to 28.8 MHz coverage on 10 meters, The values for that band follow the designer's plan.

ON7NQ 3/4-Element Quad in Free Space

Fq	Gain	F-B	B/W	Feed Z	SWR-50
14.0	8.4	11.8	66	37.5-18.4	1.66
14.175	8.3	15.1	67	44.3+ 4.3	1.16
14.35	8.1	9.8	67	34.9+36.2	2.48
18.118	8.4	25.5	68	43.5- 0.3	1.15
21.0	8.4	15.2	69	49.6-20.2	1.50
21.225	8.5	21.0	68	46.4- 0.0	1.08
21.45	8.5	10.3	65	36.2+30.7	2.17
24.94	9.2	19.0	59	40.9+ 2.2	1.23
28.0	9.0	18.4	65	43.8-31.7	1.97
28.4	9.6	30.7	59	51.3+ 6.7	1.14
28.8	9.7	12.4	52	31.2+ 8.0	1.67

2 ON7NQ Quads stacked 30' apart in Free Space: Z1 (upper entry) = lower quad; Z2 (lower entry) = upper quad. Since both quads are fed on the lower element, some differentials in values are normal.

Fq	Gain	F-B	B/W	Feed Z 1/2	SWR-50 1/2
14.0	10.2	13.5	65	38.7-20.9	1.71
				38.4-20.5	1.70
14.175	10.2	14.7	65	42.5+ 9.3	1.30
				42.2+ 9.4	1.30
14.35	9.9	9.4	64	36.9+45.7	2.88
				36.3+45.7	2.92
18.118	10.9	23.3	67	43.9+ 1.5	1.14
				43.9+ 1.5	1.14
21.0	11.2	14.6	68	49.8-19.7	1.48
				49.8-19.7	1.48
21.225	11.3	21.3	67	49.4+ 2.3	1.05
				49.4+ 2.3	1.05
21.45	11.1	10.1	64	41.5+32.1	2.04
				41.5+32.2	2.04
24.94	12.0	17.4	59	44.7- 0.9	1.12
				44.8 -0.9	1.12
28.0	12.1	18.9	65	46.0-31.9	1.93
				46.0-31.9	1.93
28.4	12.6	25.1	59	53.2+ 5.1	1.12
				53.3+ 5.1	1.12
28.8	12.6	12.2	52	31.9+ 8.4	1.64
				31.9+ 8.4	1.64

Stacking Gain averaged by bands:

20	17	15	12	10
1.8	2.4	2.7	2.9	3.0 dB

2 ON7NQ Quads stacked 30' apart in 50' and 80' above average ground: Z1 (upper entry) = lower quad; Z2 (lower entry) = upper quad. Since both quads are fed on the lower element, some differentials in values are normal.

Fq	Gain	F-B	B/W	Feed Z 1/2	SWR-50 1/2	TO
14.0	14.7	13.5	65	38.7-20.6	1.70	14
				38.4-20.7	1.71	
14.175	14.7	14.5	65	42.5+ 9.5	1.30	13
				42.1+ 9.2	1.30	
14.35	14.4	9.3	65	40.0+45.7	2.88	13
				36.2+45.6	2.92	
18.118	15.7	22.7	67	44.1+ 1.4	1.14	11
				43.8+ 1.5	1.15	
21.0	16.1	14.7	68	49.8-19.9	1.49	9
				50.0-19.6	1.48	
21.225	16.2	20.9	67	49.3+ 2.2	1.05	9
				49.6+ 2.3	1.05	
21.45	16.0	10.0	64	41.6+32.2	2.04	9
				41.5+32.2	2.04	
24.94	17.0	16.5	58	44.8- 1.3	1.12	8
				45.1 -0.9	1.11	
28.0	17.1	19.0	65	45.8-32.1	1.94	7
				46.0-32.1	1.94	
28.5	17.6	24.7	59	52.9+ 5.0	1.12	7
				53.2+ 5.1	1.12	
29	17.6	12.2	52	31.6+ 8.8	1.66	7
				31.7+ 8.5	1.65	

The two quad arrays show good isolation with a 30' spacing in free space, shifting the feedpoint impedance by only a very few Ohms on 20 and much less as the frequency goes up. Front-to-back figures remain roughly centered in the design frequencies. The stacking gain shows a relatively standard progression. Consequently, the stacking process may in some cases--considering mast stresses, mechanical complexity, and weather effects--be a worthwhile project. Greater spacing will show increased array isolation on 20 meters, but greater skewing of the performance curves. Less spacing shows decreased isolation between arrays and higher differentials between feedpoint impedance values for the two feedpoints. For reference, the forward gain of a 5-6 element Yagi on a 0.7 wavelength boom (48' on 20 meters, 24' on 10 meters) is about 10.1 dBi in free space.

Above ground, as we might expect, the values of impedance diverge more than in free space (where Z1 is the lower quad and Z2 is the upper and both quads are fed on the bottom wires of their respective drivers). With 30' spacing, the values--even on the lowest bands--do not diverge enough to materially affect a junction. 75-Ohm quarter-wavelength sections might be used on each band and join at a Tee prior to connection to a single remote band switch installed on the mast. If connection length is a problem, the lower quad might be fed at its top wire, and 75-Ohm 3/4-wavelength sections are also usable, although with greater losses. Alternatively, but with some complexities of switching, 75-Ohm parallel line can be used to transform the 50-Ohm individual feed impedances to the 100 Ohms needed at each Tee-junction for the stack common feedline.

The stacking exercise is shown only as a representative example of possibilities and to illustrate the importance of independence or isolation in quad stacking.

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