

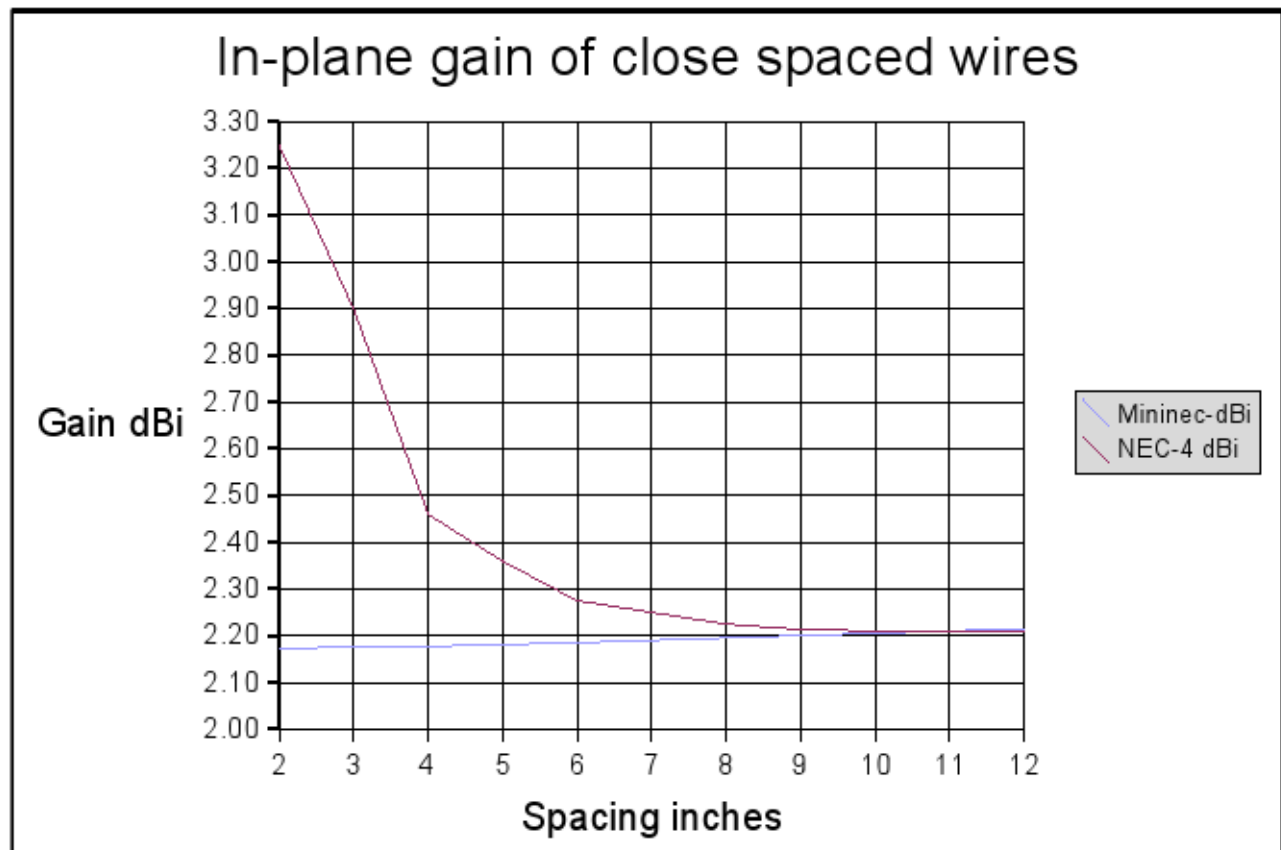
How Close Can They be Stacked?

By
K0CQ

How close can yagis for harmonically related bands be stacked? What are the consequences of close stacking?

This study has been inspired by Kent Britain's display of fairly closely stacked yagis on the antenna range at CSVHF 2010 and by stumbling on an article in the February 1947 issue of QST by W1HDQ on the topic plus having moved and its time to put up antennas for VHF and up again. In the process, I've found a handy antenna analysis program and compared program results with some experiments. I found that the choice of analysis program is critical to correct results.

NEC 2 and 4 have been used heavily in analysis for some time, but have reputations of giving misleading (though consistent) results for closely spaced wires. MININEC has not had as much publicity but though the authors conservatively warn about closely space wire errors, it seems to work much better. In QEX in May/June 1998, L. B. Cebik, W4RNK (now SK) looked at the limitations of NEC 4.1 comparing it to MININEC. The creators of MININEC also wrote an article supporting its performance in the same issue. These articles are not found on the internet and are not available from ARRL. I have scanned them and posted those scans on my web server at <http://www.geraldj.networkiowa.com/nec>.

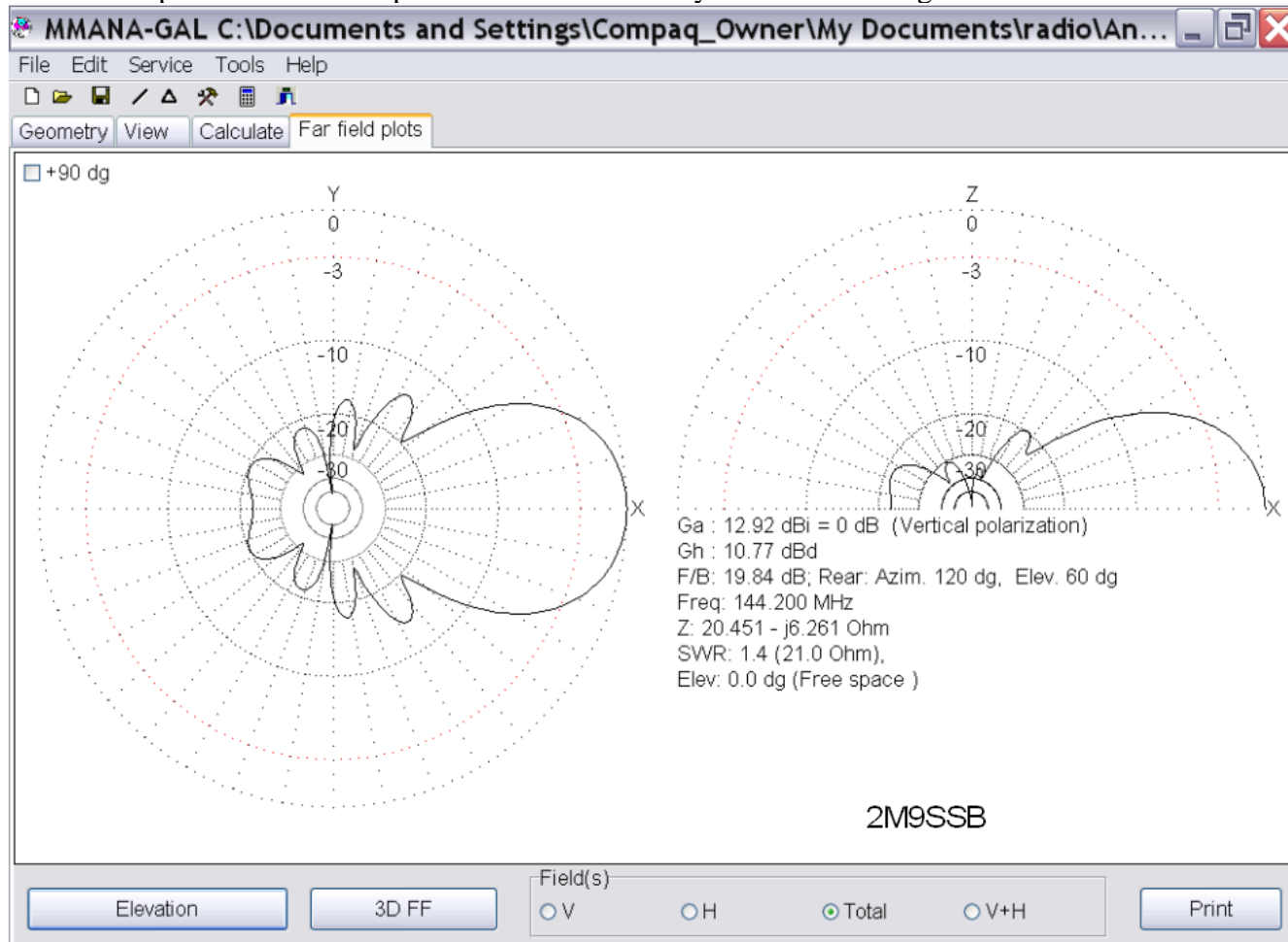


In a capsule of the comparison, the first figure is a graph of the radiation gain of two 1" diameter wires

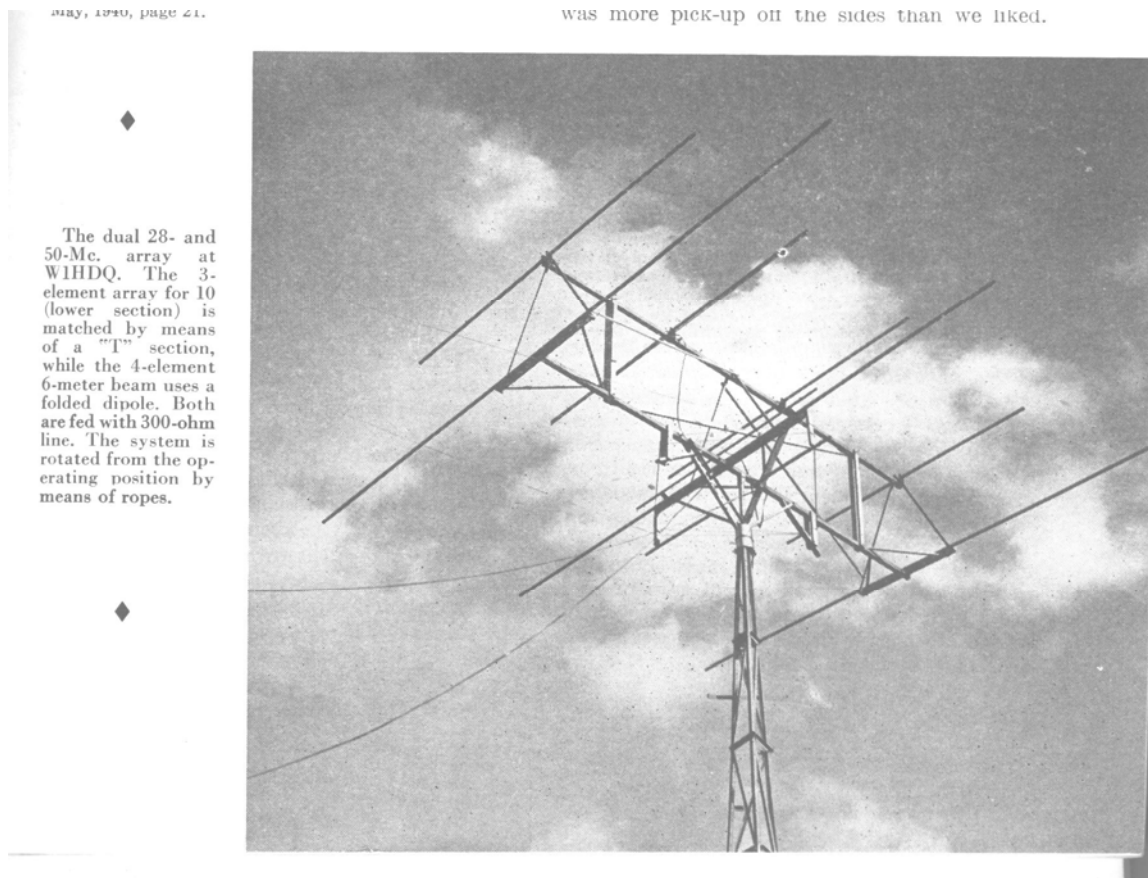
at close spacings at 14 MHz. Spacings from 2 to 12 inches. Cebik showed four graphs but this one shows the difference more dramatically. On this scale, there is practically no change from MININEC calculations and more than a dB difference between 2 and 12" for NEC 4.1 matching MININEC at 10" and wider.

Then there is an article in February 1991 QST by W7EL, titled "MININEC: The Other Edge of The Sword." His ELNEC program is based on MININEC but is very limited in antenna complexity, at least the vintage DOS version I have..

I found MMANA-GAL on the internet, based on MININEC with a fairly decent user interface with extended array sizes, and free. MMANA keeps its antenna files in plain text that can be edited in any good word processor that doesn't mess with formats. It can store far field plot data (but not in a format I've figured out yet) for recovery and comparison. I'll show many of those comparison plots. It can store readily readable files of currents, fields, and patterns for display and further analysis with other programs like spreadsheets. So far it has one design flaw that I've had to work around. In the elevation and azimuth plots it shows only the upper half of the elevation plot, even when there is no ground in the computation. It hides the lower half behind a chart of computed values. I have found the most interesting effects of close spaced stacking is in asymmetry of the elevation plot. So I have converted all my data to vertically polarized antennas in free space. Rather than manually move data, I was able to write a C program that swapped the columns for all the runs in a few seconds. I have observed that the azimuth plots in horizontal polarization have been symmetrical. A single antenna result.

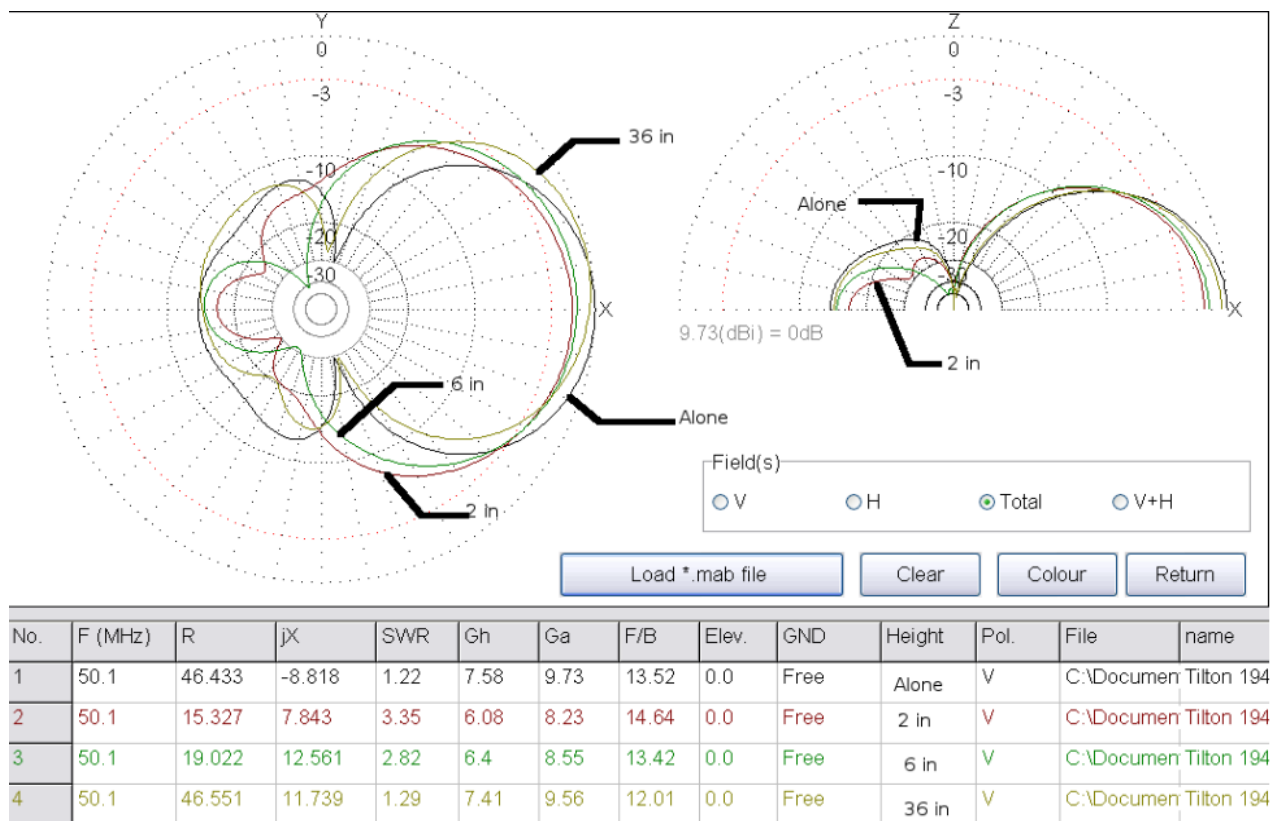


So what spacing is passable, what is adequate, what is great?

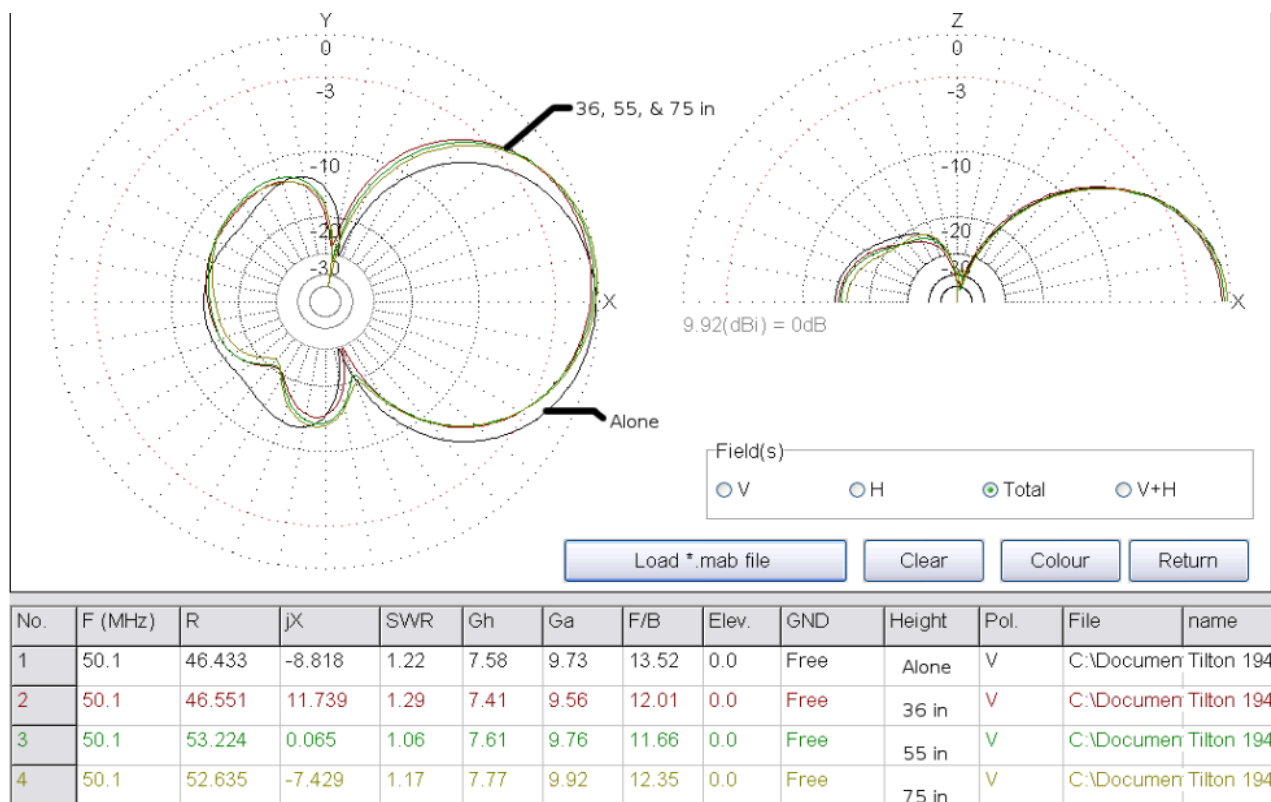


In his 1947 article, W1HDQ the ARRL's original VHF guru noted that stacking a 4 element 6m over a 3 element 10m both with 150" long (wooden) booms that he found the gain down 5 dB at 2" spacing and down about 3 dB at 6" spacing. He concluded 3 feet was a fine spacing. About 1/4 boom length. Later in the ARRL VHF Handbook that he edited it says $\frac{1}{2}$ boom length of the higher band beam is proper. I think that's based on the capture area of the beam being tangent to the lower band beam. (Directive Systems has a report based on capture area on line).

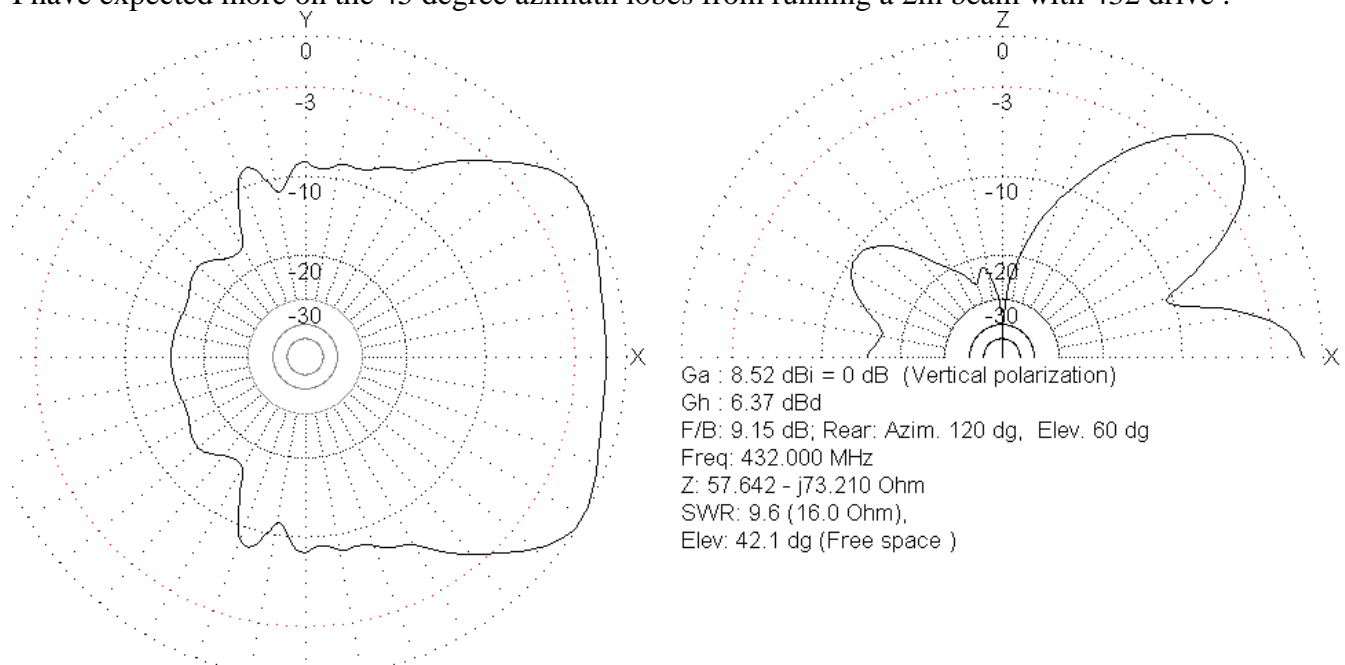
In the comparison in the next figure you can see the effects of really close spacing on the elevation pattern are more than the effects on the width of the azimuth pattern at the right. In the table, the lines are free space, 2", 6", and 36". Gh is gain dBd, and Ga is dBi. And even at 36" spacing there is a 10 degree tilt of the forward lobe causing a 0.21 dB drop at the horizon. I suspect Tilton's measurements weren't nearly that sensitive or reproducible. Note also the impedance is more reactive at the close spacings which made matching difficult and his higher gain losses I expect are from that impedance and resonance change that the computer ignored.



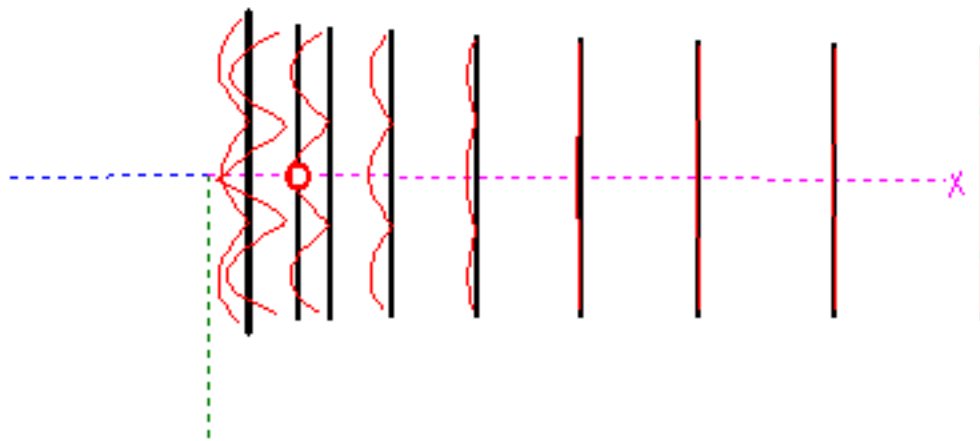
In the next comparison there isn't much difference except that the computer says (aluminum conductor losses) the gain is greater at 75" than in free space by 0.17 dB and with a few degrees tilt up at the maximum gain point. There is less difference in these than can be easily measured.



I have expected more on the 45 degree azimuth lobes from running a 2m beam with 432 drive .

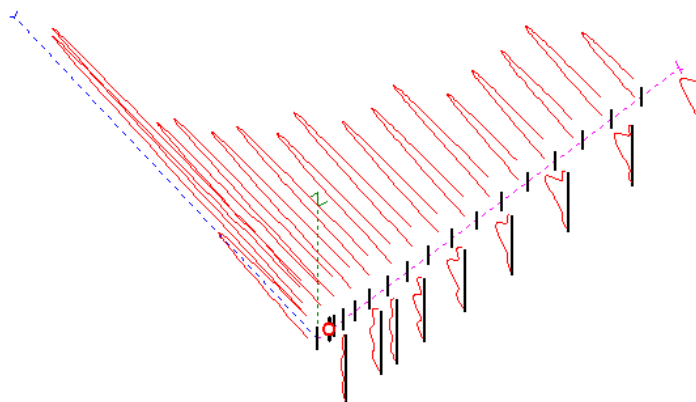


But this comes from poor coupling between the driven element and most of the parasitic elements because of their wide spacing at 432. The currents in the elements of a 2m beam driven at 432 are only in a few elements, shown in the following figure.



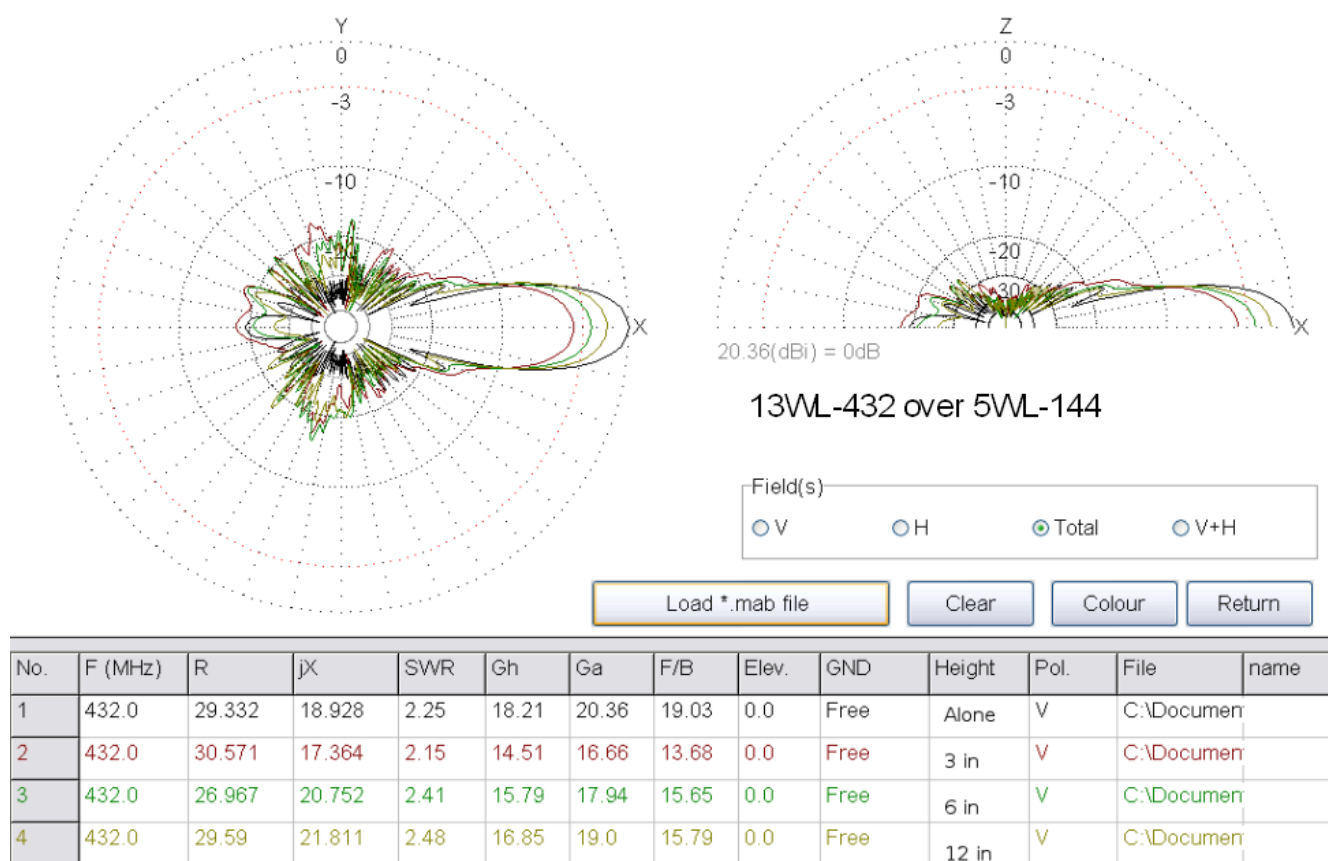
One other example that shows most of the 2m elements have current is the FO17 at 12 inch spacing from a F09-144. (vstkfo12ini.bmp). This changes the effects to be seen. MMANA doesn't seem to have an option to show the phase of the currents. The currents at the outer ends of 3/2 wave elements are out of phase with the centers leading to a weak signal at right angles to such a long dipole and a cloverleaf pattern.

◦Source
×Load

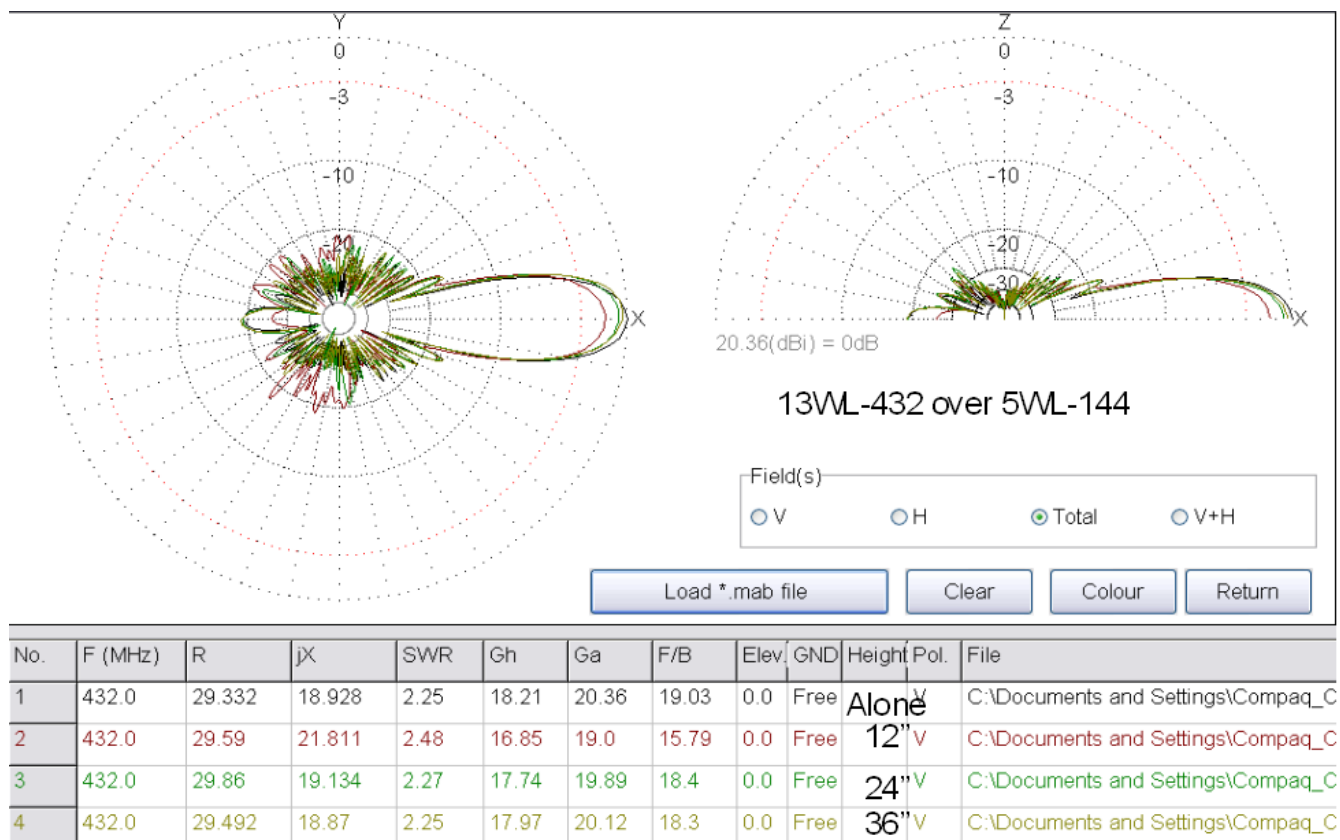


Wire No.1	
X1	: 0.104 m
Y1	: 0.0 m
Z1	: -0.167 m
X2	: 0.104 m
Y2	: 0.0 m
Z2	: 0.167 m
R	: 2.38 mm
Length	: 0.333 m
Azim.	: 90.0 deg
Zenith	: 0.0 deg

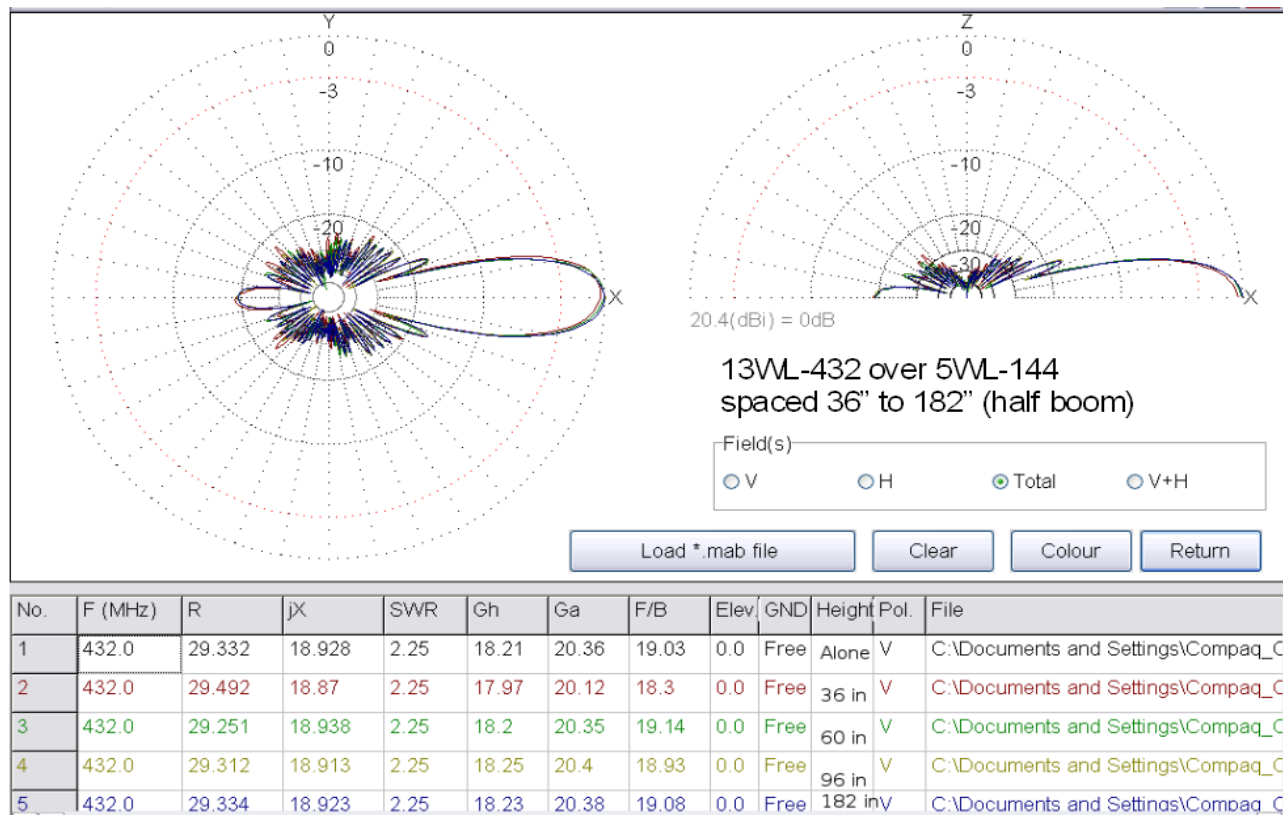
Then I went an opposite extreme family of long yagis, 13wl at 432 over 5 wl at 2m both made by M^2 . 30.2 feet of boom over 33' of boom. I've had a 5wl on 2m for several years. Its going to become pieces for my next array, but nothing nearly as long and as hard to aim and hold (breaking rotors and slipping on the mast). The comparison (spaced free space, 3, 6, and 12") shows a gain reduction of 3.7 dB at 3".



Might as well throw away half the 13 wl yagi and have easier to build structure with a bit wider spacing. The gain loss is accompanied by many more side and rear lobes, mostly in the elevation pattern on the left. The next comparison at mid range spacings of 12, 24, and 36" (1/10th boom length) shows only 0.24 dB gain loss with a main lobe tilt of about a degree. That tilt might be significant when the main lobe is only 18 x 19 degrees at 3 dB down.

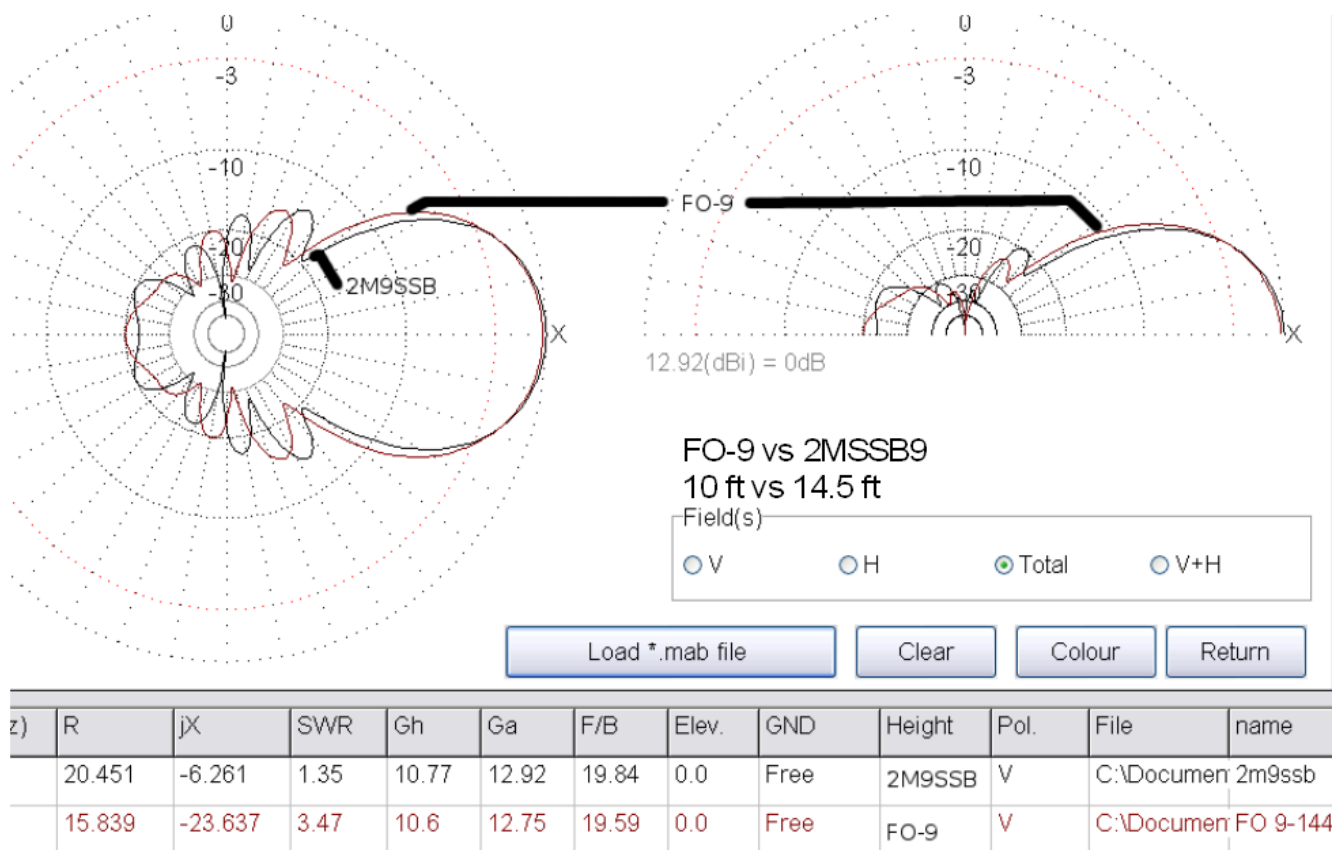


Going to classical spacings of 36, 60, 96, and 182 inches (13wlov5wl36-60-96-182.bmp) there isn't much change in gain or patterns for all these spacings from 1/10th boom to 1/2 boom.

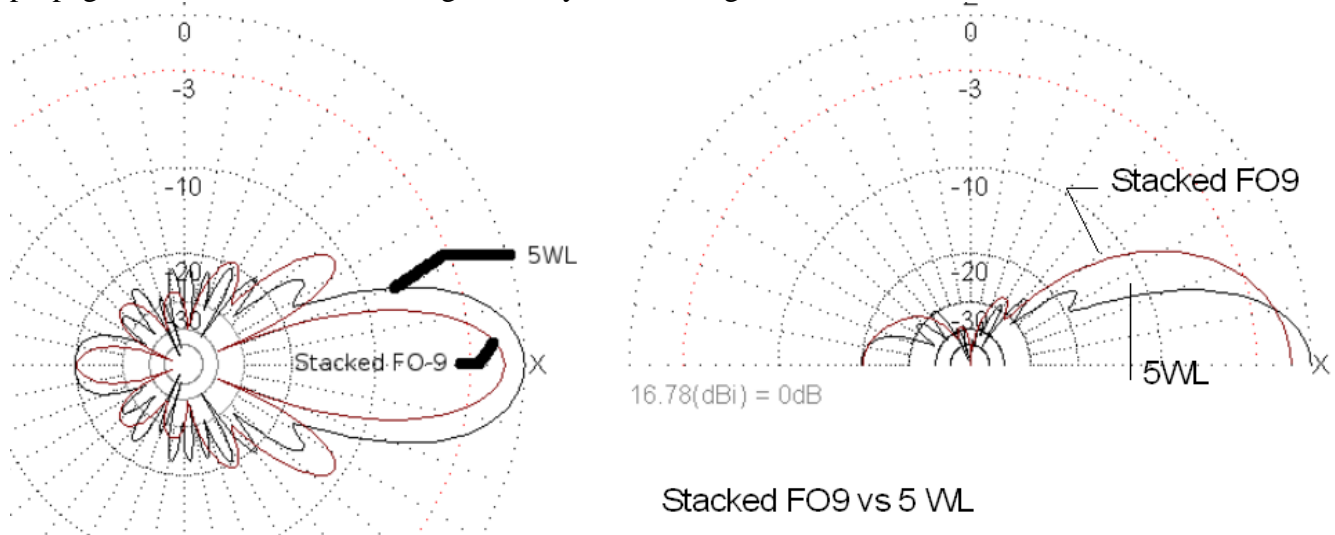


It appears that the traveling wave on the long yagi sticks close to the yagi though the capture area is wide and so the effects of the nearby 2m beam are small at spacings far closer than the 1/2 boom rule of thumb based on capture area.

With the propensity of the 5wl to be pointed in the wrong direction for making contacts, I'm leaning toward shorter antennas, stacking a couple for making up the gain. Sacrificing elevation beamwidth for keeping a wider azimuth beamwidth. The K1WHS Large Vertical Array goes to a stack of 4, 8, or 16 5 element yagis that are 10 dB down at 90 degrees beamwidth. At 2m (the only band commercially available the last I checked) the stack of 4 takes 16.5 feet of mast and leaves little space for mixing in antennas for other bands. I've settled on the 9 element 2m yagi as being a compromise between the 2wl and the VLA. That a pair of 2m 9 element yagis will give less wind load, need only 8 or 9.5 feet of mast and leave room between them for antennas for 6 and 432. Comparing an FO9 (the first 9 elements of the optimized K1FO yagis in some ARRL handbooks) and an M2 2M9SSB is interesting.

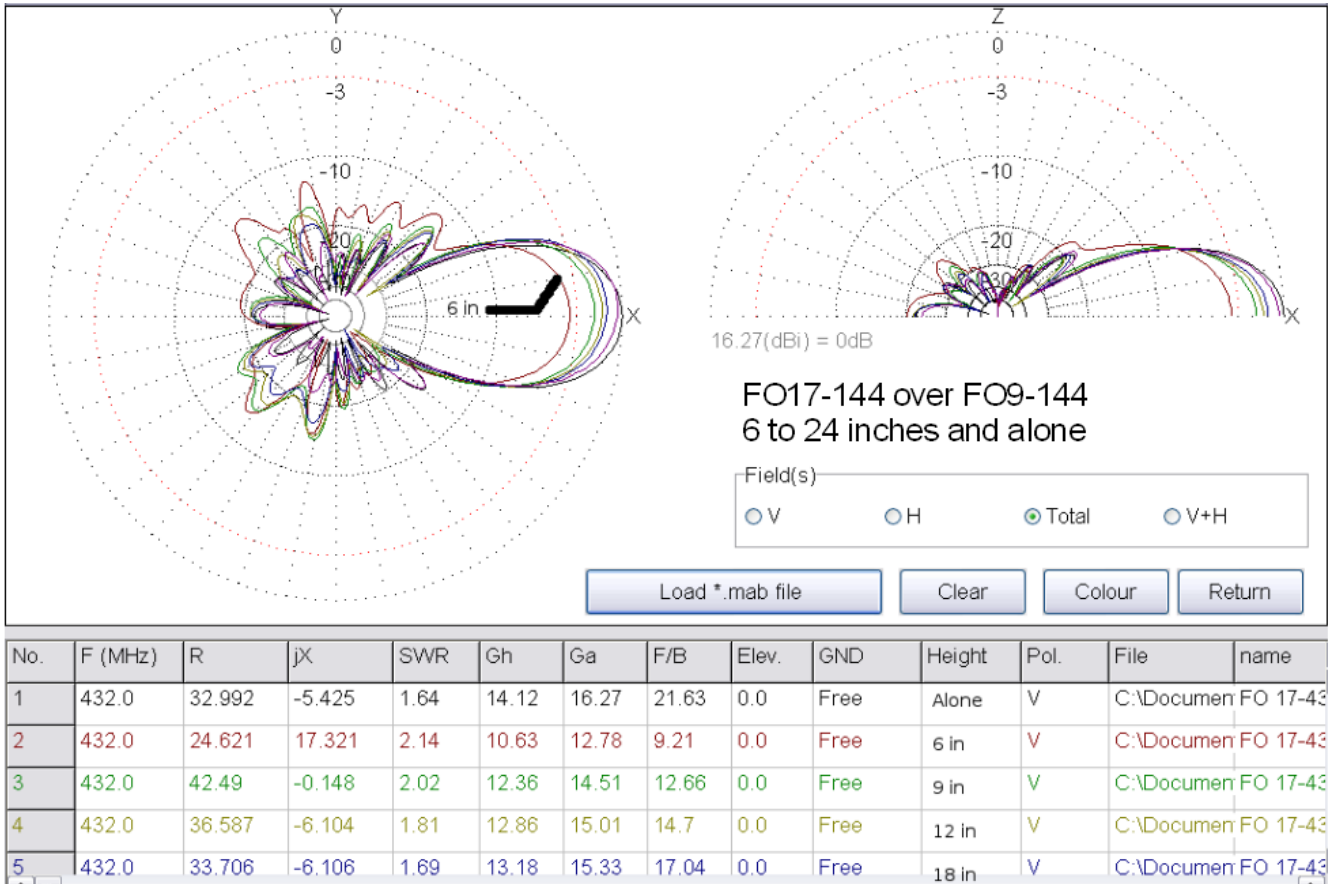


While K1FO says taking such a short yagi out his long yagi design isn't optimized, it sure has a decent pattern giving 0.17 dB less gain with a 10' boom than the M2 with a 14.5' boom. And about 72 degrees beamwidth at 10 dB down, 42 degrees beamwidth at 3 dB down. Comparing a pair stacked at 9' vs a 5wl shows 1 dB less gain and much easier azimuth aiming. And I believe that the thin atmosphere as seen from 200 miles is still illuminated adequately by the relatively sharp elevation pattern for tropo propagation. This would not be a great array for catching satellites at the horizon.

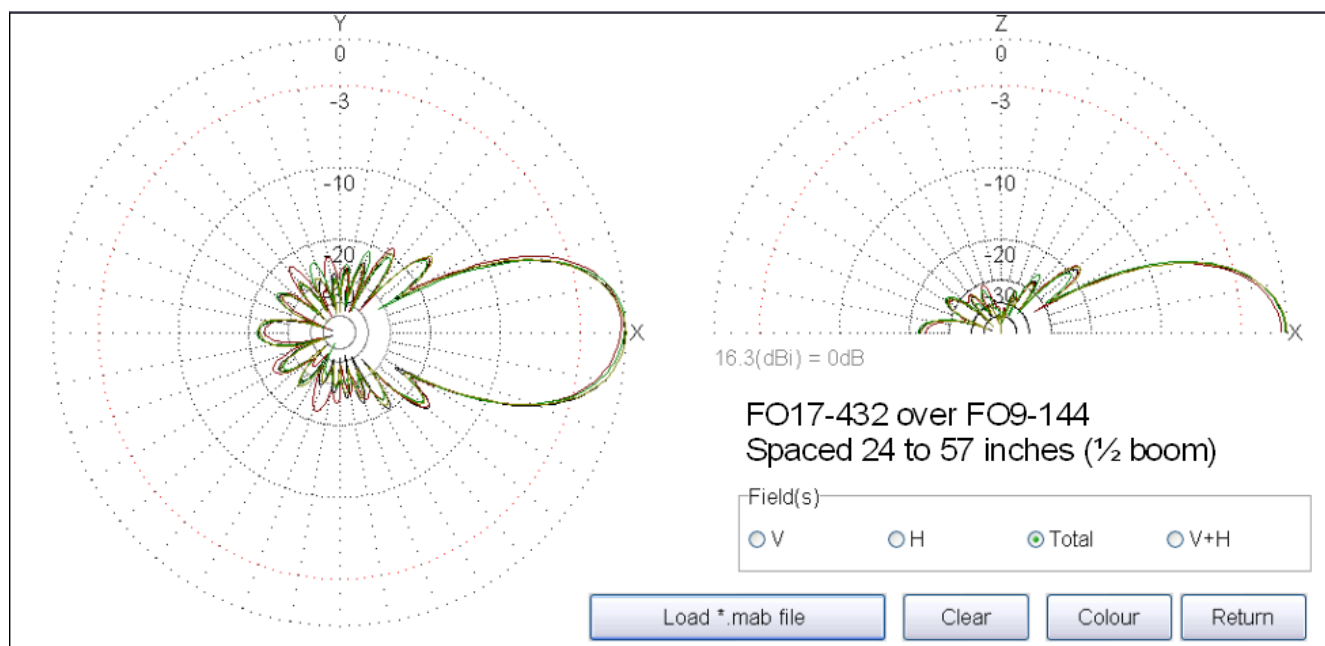


The next to look at are FO-17 over FO9. 9.5' of boom on 432 vs 10' at 144. A compact and logical array. Comparing at spacings of 6 to 24 inches shows a similar gain loss of 3.49 dB at 6" spacing but

not much (not in the table) at 24” (¼ boom length).

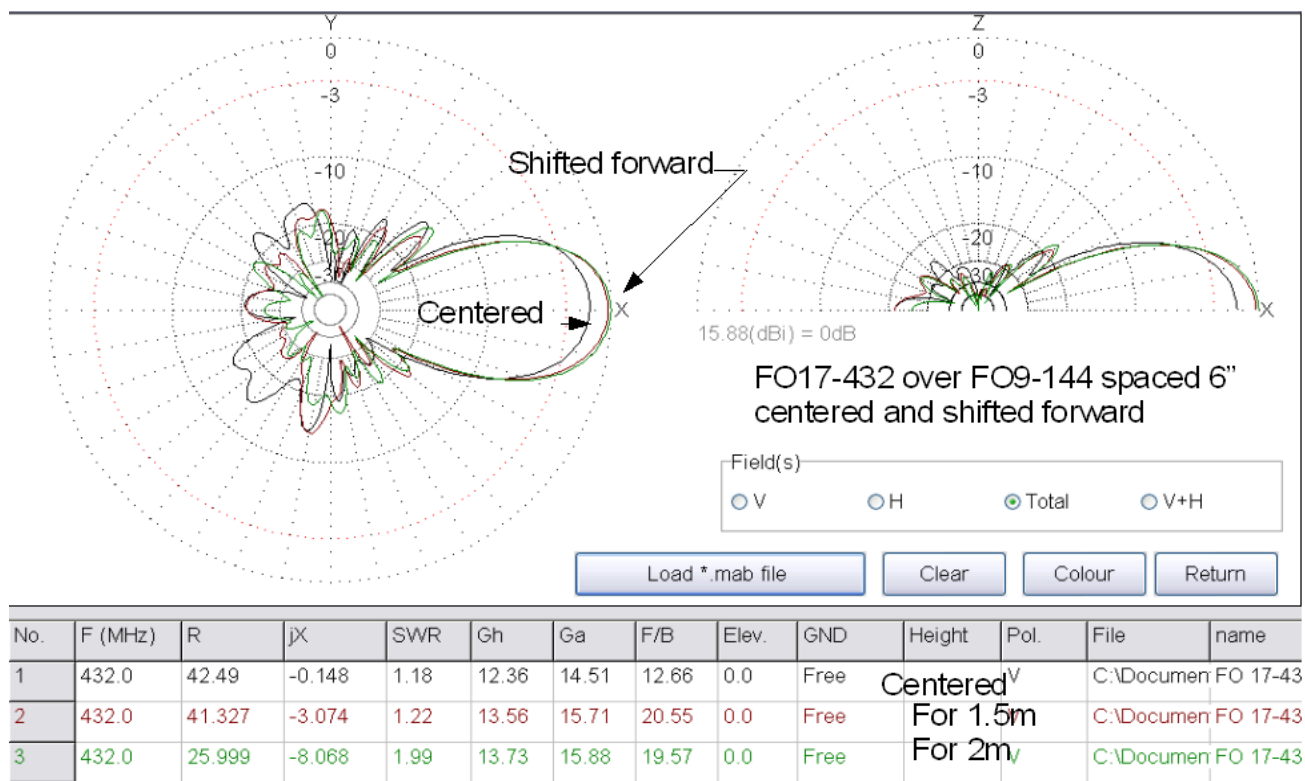


This collection is for spacings of 6, 9, 12, 18, and 24”. Another collection at 24, 36, and 57 inches (¼ to ½ boom) shows little variation in patterns but a change in gain of a whole ¼ dB.

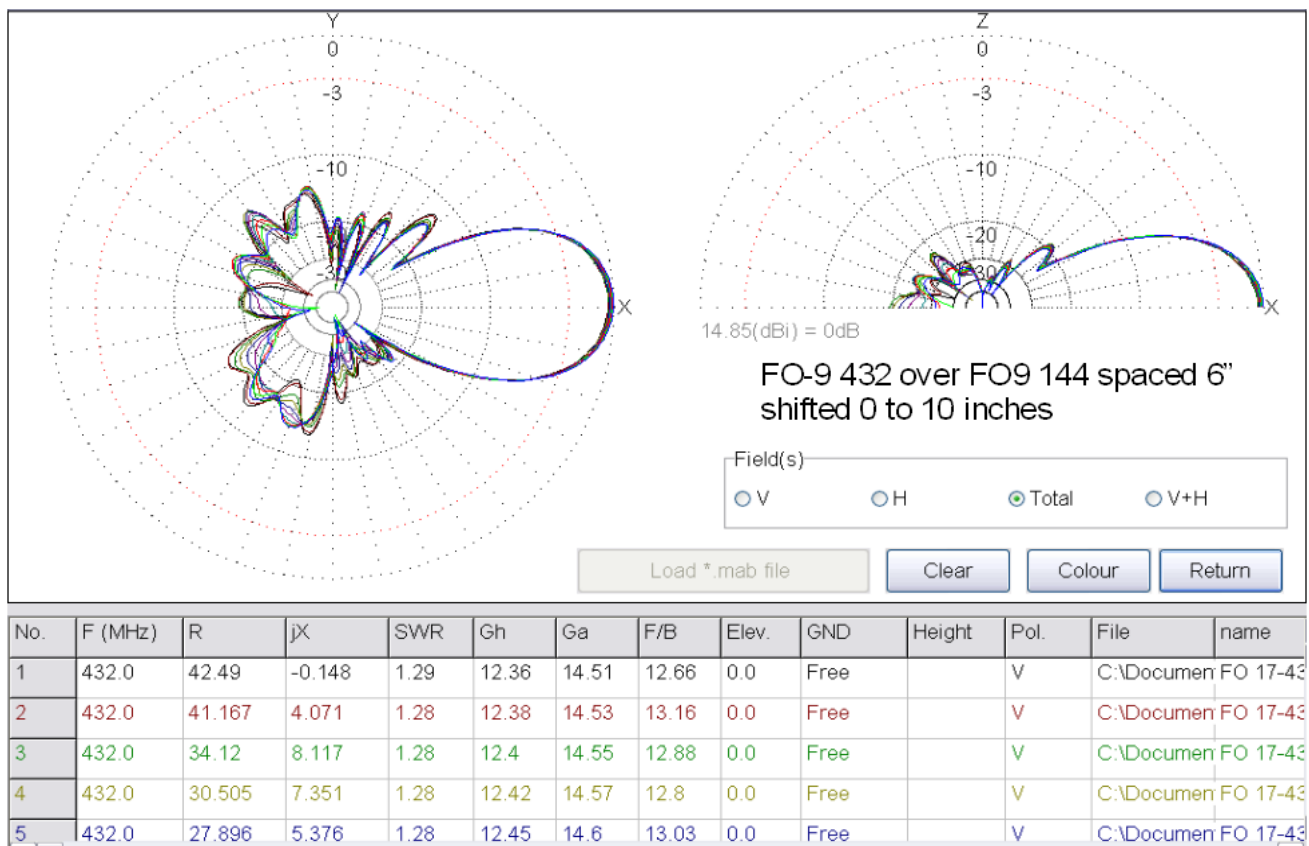


No.	F (MHz)	R	jX	SWR	Gh	Ga	F/B	Elev.	GND	Height	Pol.	File	name
1	432.0	32.992	-5.425	1.55	14.12	16.27	21.63	0.0	Free	Alone	V	C:\Document FO 17-43	
2	432.0	32.797	-5.613	1.56	13.87	16.02	21.38	0.0	Free	24 in	V	C:\Document FO 17-43	
3	432.0	32.758	-5.428	1.56	14.1	16.25	21.29	0.0	Free	36 in	V	C:\Document FO 17-43	
4	432.0	32.985	-5.424	1.55	14.15	16.3	21.81	0.0	Free	57 in	V	C:\Document FO 17-43	

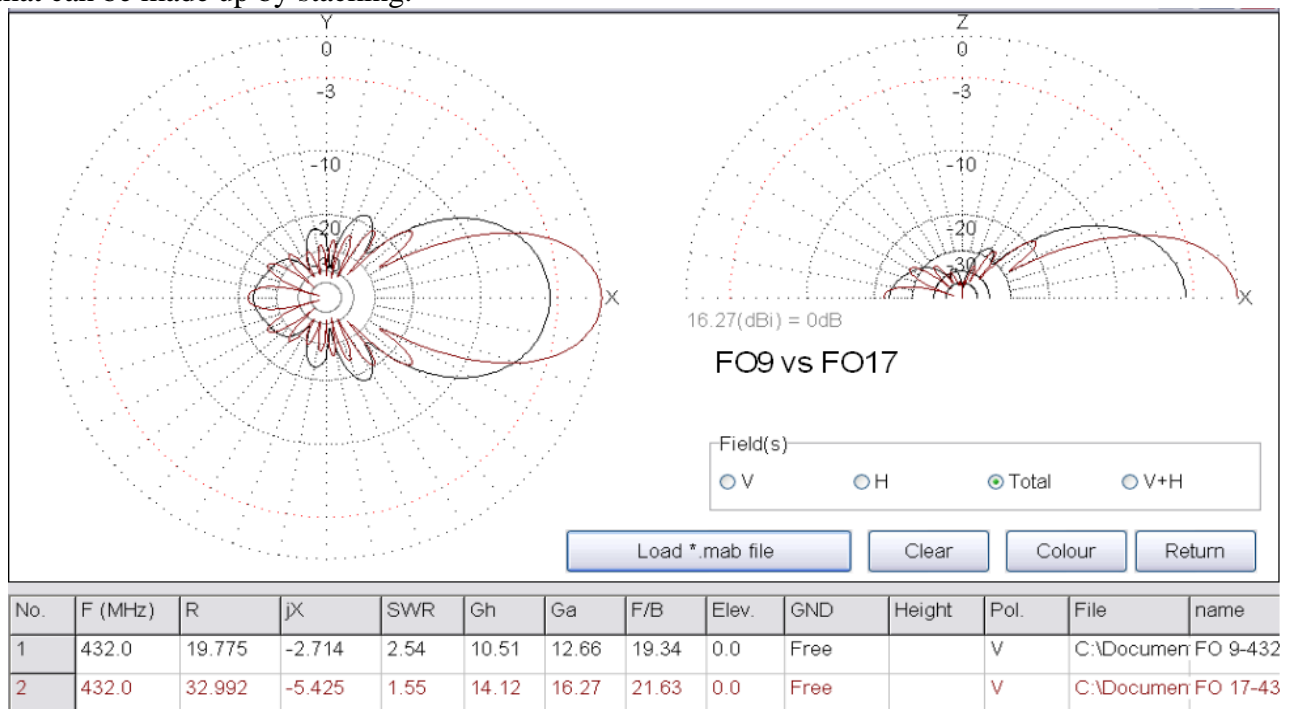
I ran a series of tests at 6" spacing moving the 432 yagi away from centered over the center of the 2m yagi to see if there were effects from driven element proximity. There were, but small until the 432 yagi extends out front of the 2m yagi. In the practical array this means wind load asymmetry.



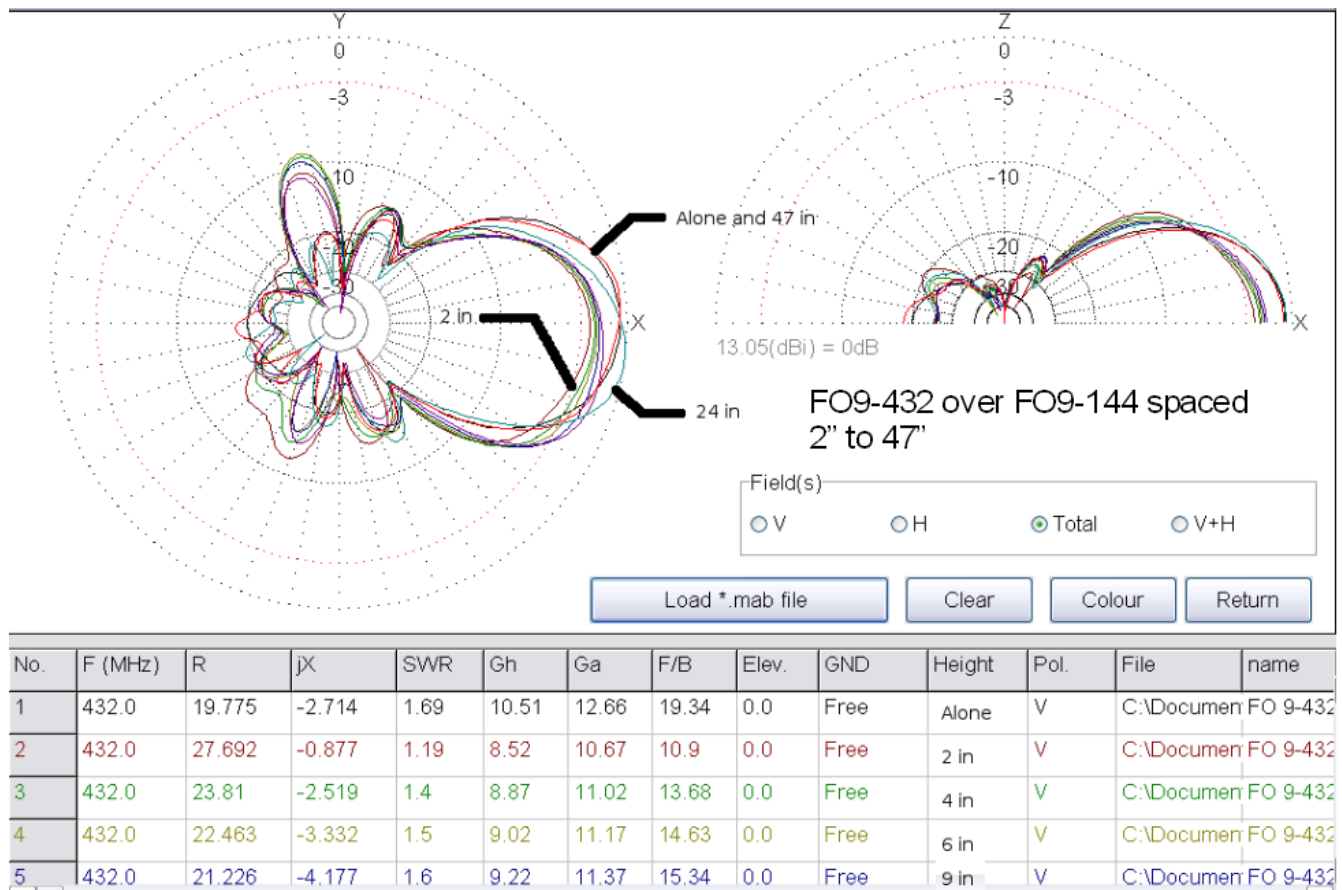
I compared fo9 over fo9 at 6" spacing for shifts front of 0 to 10" or so. There are some detail differences in the rear elevation lobes but nothing significant in gain or impedance matching differences.



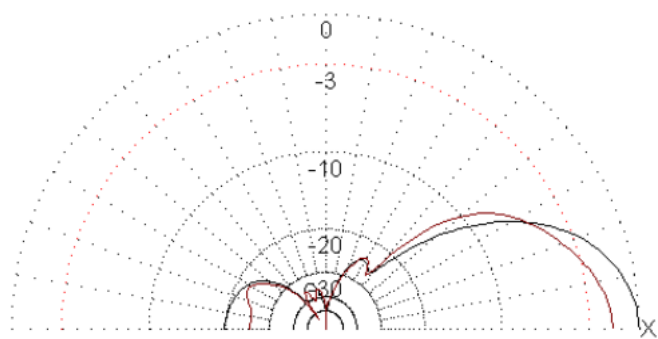
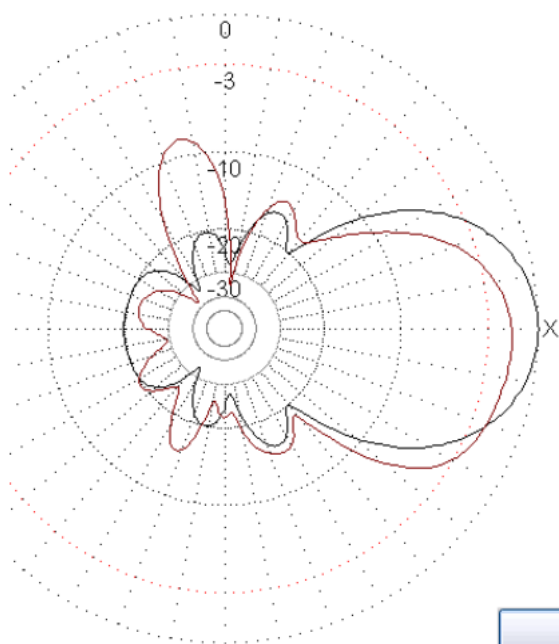
Comparing the FO9 to the FO17 at the same band, I see easier aiming for the FO9 but a loss of gain that can be made up by stacking.



Comparing FO9 over FO9 (fo9overfo9variousspacings.bmp) the maximum gain loss is 2 dB and the close spacings do widen the azimuth front lobe while making the elevation lobes considerably stronger.



At 6 inches, the gain is only down 1.5 dB and the back lobes aren't as big as they were at closer spacings.



12.67(dBi) = 0dB

FO9-432 over FO9-144 spaced 6 inches

Field(s)

☐ V

☐ H

☒ Total

☐ V+H

Load *.mab file

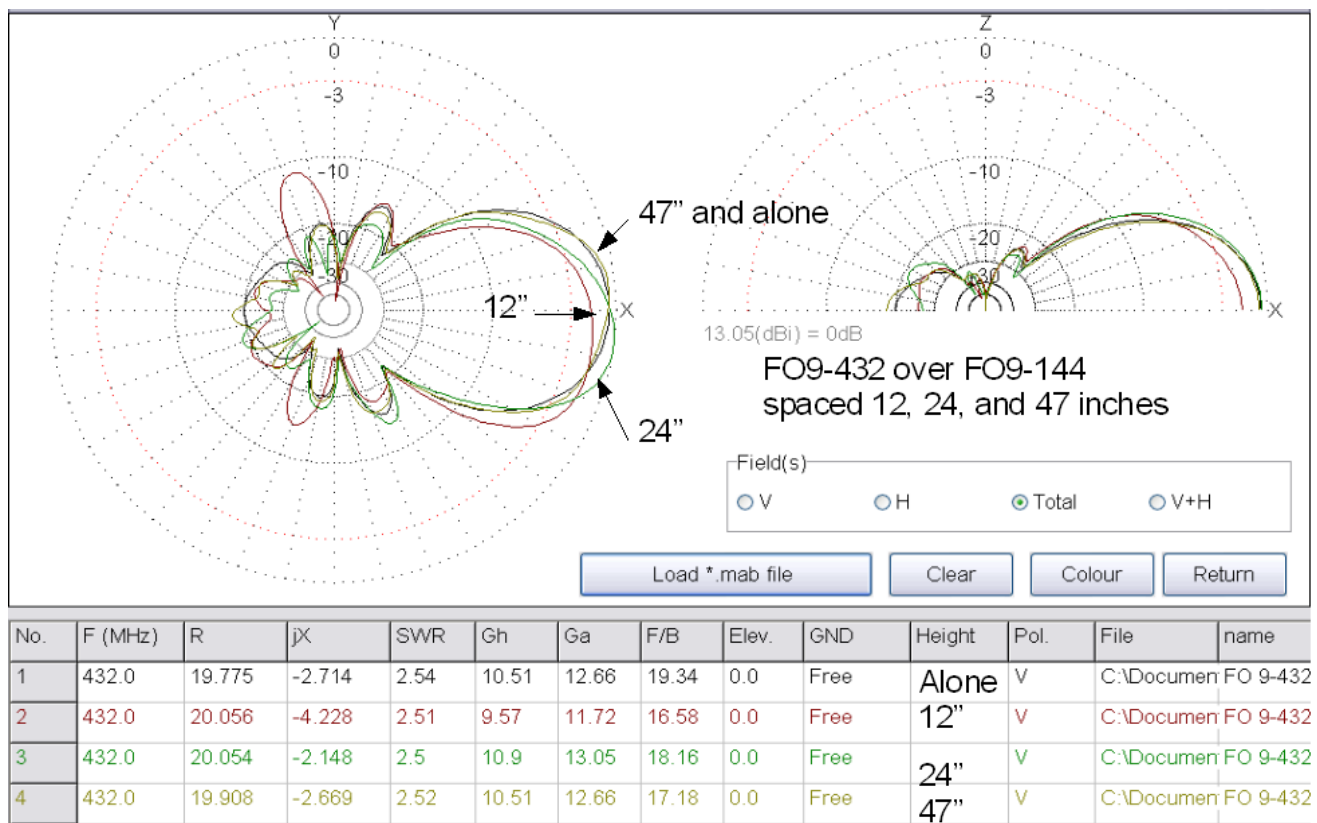
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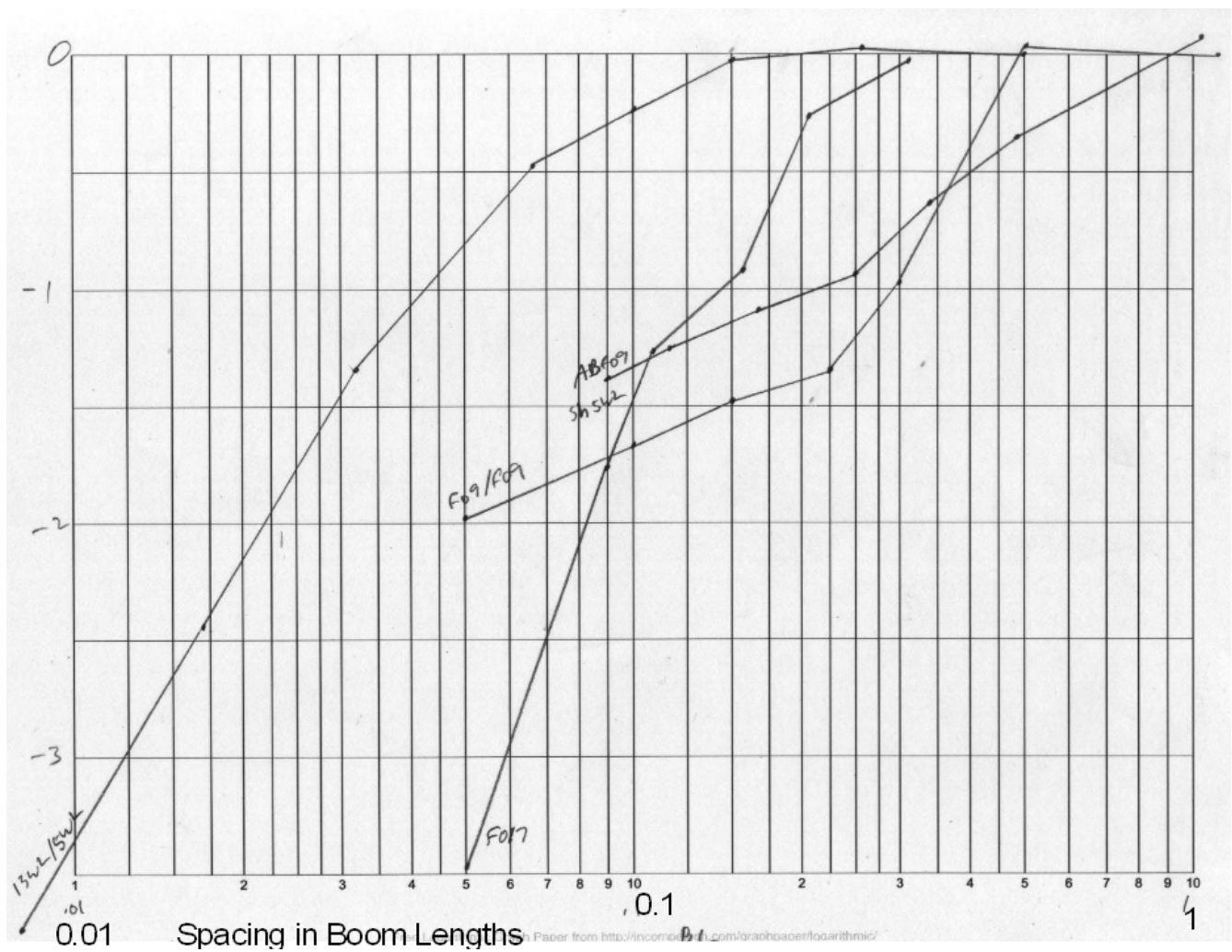
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z)	R	jX	SWR	Gh	Ga	F/B	Elev.	GND	Height	Pol.	File	name
	18.285	7.906	1.52	10.52	12.67	19.48	0.0	Free	Alone	V	C:\Document	As built F
	22.463	-3.332	1.2	9.02	11.17	14.63	0.0	Free	6 in	V	C:\Document	FO 9-432

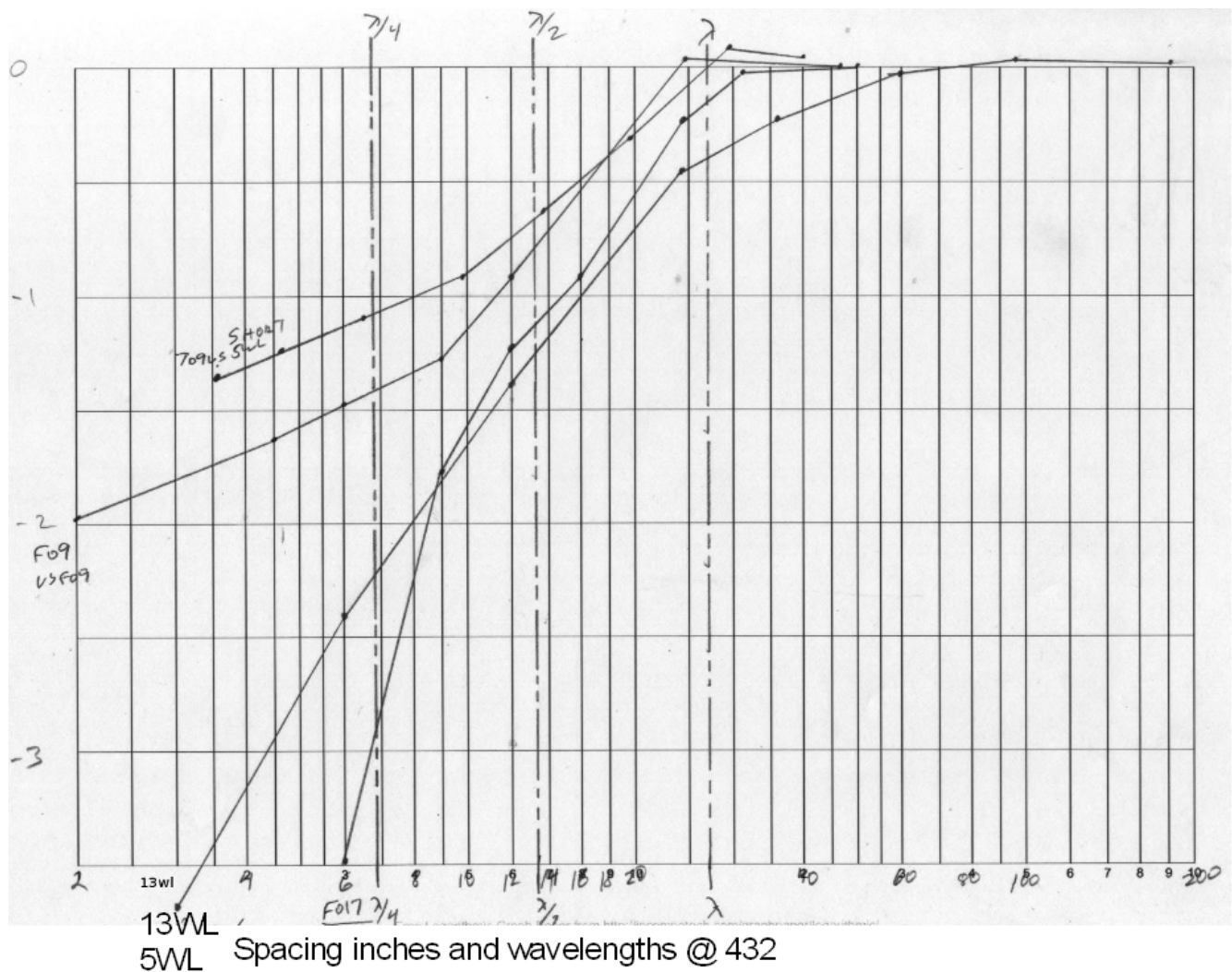
At wider spacings of 12, 24, and 47 inches the gain (though tilted) at 24" spacing (41" boom length) is slightly above free space. At 12" about 1/3 boom length the gain is down 0.94 dB. Compared to the 13wl and FO17 I conclude that the lower gain antenna isn't keeping the traveling wave as close to the elements and so is affected a bit more than the longer yagi by close spacing.



Based on these I conclude that the capture area concept is good for stacking an array for the same band but that closer spacing doesn't damage the performance seriously until its very close, under a quarter wave, and its interesting that the longer the yagi the closer the acceptable spacing. This is all summed up in the chart. It appears to me that the critical element in this stacking exercise is coupling between that active band yagi elements and those of the band with 3 times the wavelength that acts like its dependent only on distance between the elements of the two bands, far less on the directivity of either yagi. And the data appears to show the long yagi is more tolerant of close spacing while it has a larger capture area than the short yagi. And that spacing based on boom length works fine at $\frac{1}{2}$ boom length spacing though for long yagis closer spacing has little cost in either gain or pattern destruction. However in the following plot of gain loss vs spacing in boom lengths, there are no clusters.



Next the same data plotted vs spacing in inches or wavelengths.



This plot bunches up. Looks to me as if the gain loss is from simple coupling to the $3/2$ wave elements of the 2m beam and is strictly a function of distance. Remember that directors in a yagi are hardly ever spaced more than 0.4 wavelength because they don't couple well enough to make good gain. That shows here too that at spacings just a bit more than 0.4 wavelength the gain loss is small pretty much independent of the boom length.

That is not to say that the element arrangement of the 2m beam has no effect. It does as shown by the different loss curves of the FO-9 vs FO-9 and FO-9 vs the back 7 elements of the 5WL.

Now I have spent an afternoon trying to measure the gain loss by close spacing a bit of a 5WL (the rear 7 elements) next to a new constructed FO9 for 432. The numbers I recorded are in the next table.

Field measurements in the order taken, K0CQ

Spacing	Signal dB	Modeled	Apparent Error	Proposed Correction	Corrected For drift	Error with Correction
FO9 alone	0	0				
1m	-0.28	0.09	0.37	0.2	-0.08	-0.17
75 cm	-0.2	0.14	0.34	0.2	0	-0.14
50cm	-0.46	-0.3	0.16	0.28	-0.18	0.12
35cm	-0.97	-0.63	0.34	0.37	-0.6	0.03
25cm	-1.08	-0.95	0.13	0.45	-0.63	0.32
17cm	-1.2	-1.13	0.07	0.53	-0.67	0.46
12cm	-1.68	-1.26	0.42	0.62	-1.06	0.2
9.2cm	-2.1	-1.37	0.73	0.7	-1.4	0.03
FO9 alone	-0.7	0	0.7	0.7	0	0

There is 0.7 dB drift between the first and last measurements. At this point I don't know if the drift is linear with time (shown in the proposed correction column) or if its due to irregular changes in feedline position and the loose SMA connection I found once. Since the last two measurements were made within a couple minutes and the equipment had been on the longest I have greater confidence in them. There the 9.2 cm spacing data (as close as the boom to mast clamps allowed) the agreement with the model is outrageously great. And based on that pair alone, I claim MININEC and MMANA-GAL appear to be accurately modeling the effects of these close spaced yagis.

K0CQ