K8AZ 2013 10 Meter Yagi Update 1
August 8, 2013
Greg Ordy, W8WWV
V1.0

Introduction

Back on July 20th, I created a note that compared a number of 10m Yagi's through their antenna models.

Two things have happened since then to warrant an update to the information.

First, Dan, AC6LA, has added an optimizer to his AutoEZ program that drives the EZNEC modeling software. This means that we can create our own designs with some confidence of *doing a good job*.

Second, after the existing Create Yagi's were removed from the tower and stripped down, it was realized that the maximum boom length could be extended to 26' from 24'. This is all in the name of reusing existing materials in the smartest way to achieve the best results.

This update uses the AutoEZ optimizer to create new 4, 5, and 6 element designs that will be compared to the previous designs, all in the name of squeezing out the highest performance stack of 4 Yagi's on no more than a 26' boom.

When I say a 26' boom, what I really mean is a last director to reflector distance of no more than 25.5'. This leaves 3" on the ends of each boom, so that elements are not placed at the very ends of the boom.

Using an Optimizer

Although I've fooled with AO/YO, and used optimizers in general, the optimization process is partly determined by the nature of the tool, and also the creative process that is used around the tool. You might think that the word *optimizer* means that the human factor is reduced. That is probably the opposite of the truth – the human is *amplified* by the optimizer. That can be a good thing or a bad thing.

Dan did a great job of documenting his optimizer. This, and most antenna optimizers, are what could be called a *local* and not *global* optimizer. As the names imply, a local optimizer is more likely to get *trapped* in a small region of the overall design space, and not find the absolute best design in the total space. A global optimizer includes additional algorithms to attempt to pick the best of the discovered local designs. A perfect optimizer for these sorts of problems is probably impossible, unless you try every possible permutation, which would take close to forever, even on our fast computers of 2013.

One of the complaints I heard about earlier antenna optimizers is that in all of their wisdom they did not find solutions such as the OWA closely-spaced first director leading to a relatively flat and low SWR with direct 50 Ohm feed.

With Dan's optimizer, when I have specified a low SWR goal across several frequency points, that first director is pulled close to the DE, in the OWA style. So, I'm tempted to say that this optimizer, while not global, is at least a step ahead of previous antenna optimizer.

For these antennas, the variables are the element tip lengths and the element spacing. In one case, I did allow the optimizer to determine the length of a shorted transmission line which was a proxy for the length of a hairpin stub. A 5 element Yagi has around 9 variables, the 5 tip lengths, and the 4 spacings, with one element in a fixed position.

In working on these designs, and one or two others, I developed the following general approach.

1. Create a model with the desired number of elements, and reasonable lengths and spacings. This turns out to be somewhat important – the reasonable part. If you just scribble down any old random initial design, the optimizer might send the main lobe in the opposite direction, and get trapped in that local minimum. A good initial *guess* is helpful.
2. Let the optimizer run without any overall boom length constraint – with a primary goal of maximum forward gain. This means that in the name of gain, the boom will grow as long as necessary. The antenna will *take all that it can use*. I would call this the length resulting in maximum gain for the number of elements.
3. After establishing what appears to be the maximum gain for the number of specified elements, constrain or fix the last director (and reflector) to live within your physical limits. See how much gain this costs you. If it's too much, then your ideas of how many elements to put onto how long of a boom may need improvement.
4. With a constant eye on gain, start to improve the SWR performance. This could include adding an OWA element that is closer to the DE. If you are thinking of some other match, like a hairpin, add that into the model. It can be optimized too.

5. At this point, there is a lot of tweaking with the optimizer targets, trying to get a flat and low SWR without giving up too much gain. No doubt there is a trade-off to be made. Here's where you usually see the *no free lunch* rule.

I have not spent too much time on other design parameters such as front to back or front to rear performance. Within reason, high forward gain implies good front to back/rear performance, since the forward gain comes at the expense of the rear gain. If you direct the optimizer to target rear performance, it will do a great job, but I have found for this class of antenna (upper HF Yagi) that I can really focus on maximum forward gain.

When I got to the point where I think I have a decent result, I try to *kick the tires* a bit by playing with all of the goals, and look to see if I can get something for nothing. For example, if my front to rear goal has been low through the whole process, kick it up at the end, just to see if you can tweak the design in a positive direction. Try to improve even the parameters that were not that important, just so long as you don't lose what is most important.

I believe that what I just wrote is that you should first optimize the aspect of the antenna that is most important to you, and then slowly give back primary performance to gain secondary performance and end up with a balance that is acceptable.

Taper Schedule

I modeled all Yagi's using the taper schedule that has been discussed. There is a center section of 1" diameter tube that is 1' long. That tube is mainly there to be snugly grabbed by the element to boom clamps. Inside that 1' section of tube is a 6' piece of 0.875" (7/8") tube. The tips are made from 6' pieces of 0.75" tube.

The DE is a little different in that it does not have the 1" diameter tube, and is split in the middle.

Tubing for 10m Yagi's, where an element is no more than around 18' long need not be this large. This larger diameter tubing was prompted by the frequent appearance of vultures that like to land and perch on Yagi elements at K8AZ.

Setting Expectations

In the first note from a few weeks ago, I modeled most every 10m design we could find that seemed to be in the 24' boom category. The models placed each Yagi at 70' off of the ground. The maximum forward gain results, including the existing long boom Create Yagi's was:

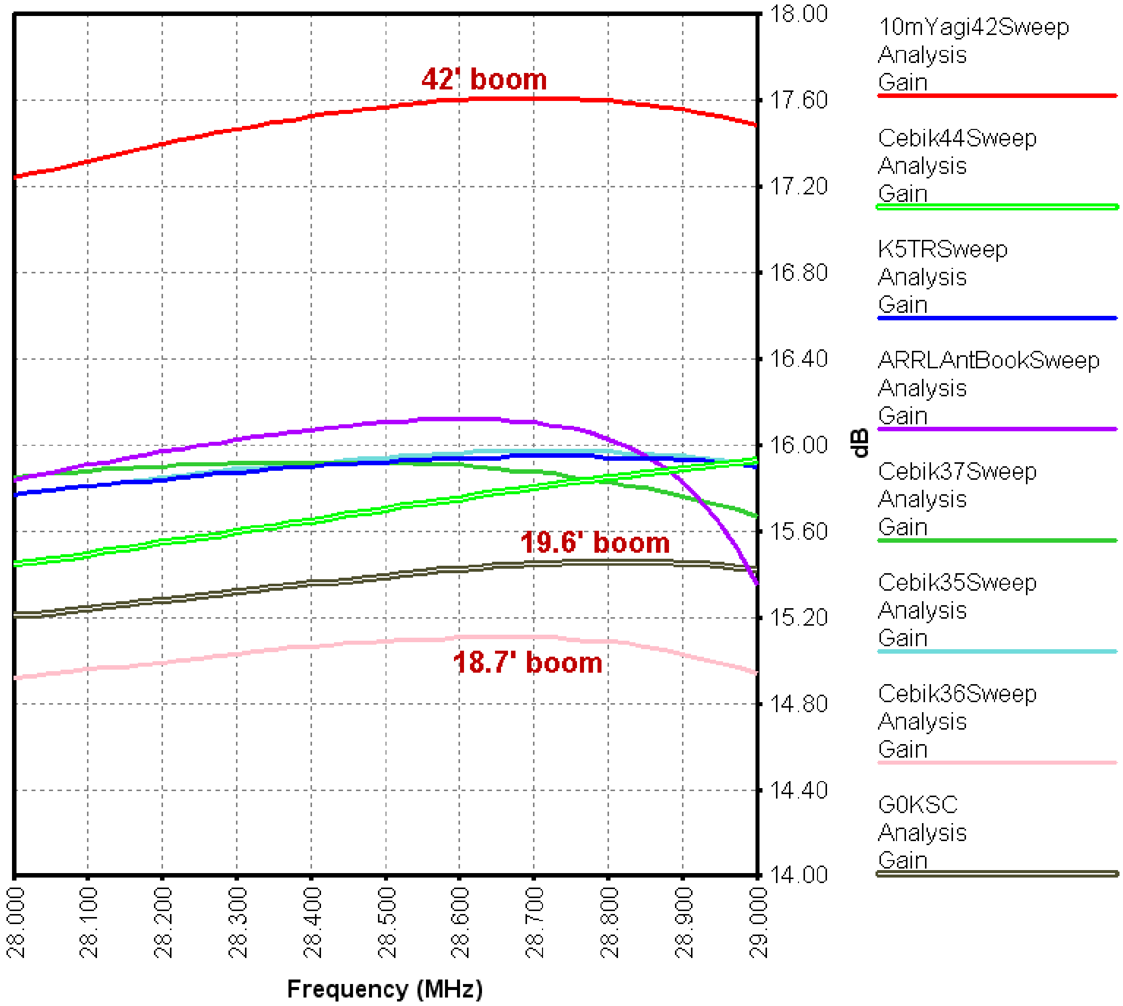


Figure 1 – Maximum Forward Gain from July 20th Note

This graph supports the conventional wisdom that the gain of a Yagi is primarily determined by the boom length. The cluster of unlabeled traces are from the Yagi's that were close to a 24' boom length.

Those 24' boom Yagi's all came in little under 16 dBi of gain. The Yagi slightly above 16 dBi, the purple trace, was the design from the ARRL Handbook (5 elements). While it had the highest gain, it was a non-OWA design with a hairpin, and, a relative small bandwidth.

What this exercise did in my mind was to set the expectation that 16 dBi is the magic number. Since we are allowing the boom length to increase by about 2 feet, this should be a target we can hit.

Conclusion: with a Yagi model at 70' off of real/high accuracy ground, with good characteristics, we are looking for gain around 16 dBi. Above would be great, and should be possible based upon the results of the 24’ boom modeling a few weeks ago. If not, then these *optimized* designs don’t really bring anything new to the party.

4 Element Design

Tom had provided me with one existing commercial 4 element design – the M^2 10M4DX. It used a 24’ boom, and has the following specifications:

Model	10M4DX	Power Handling	3 kW, Higher avl.
Frequency Range	28.0 To 28.8 MHz	Boom Length / Dia	24’ / 2” x .065 Wall
*Gain, (FS) / Over gnd	10.1dBi / 15.7dBi @35’	Element Length / Dia	18.5’ / 1” To 1/2”
Front to back	22 dB Typical	Turning Radius:	14’ 8”
Beamwidth	E=53° / H=68°	Stacking Distance	25’ To 31’
Feed type	Hair pin match	Mast Size	2” to 3 ” Nom.
Feed Impedance.	50 Ohms Unbalanced	Wind area / Survival	3.5 Sq. Ft. / 100 MPH
Maximum VSWR	1.2:1	Weight / Ship Wt	38 Lbs. / 41 Lbs.
Input Connector	SO-239, Others avl.		

Figure 2 – 10M4DX Specifications

A few things to note. The Yagi reaches 15.7 dBi gain when mounted at 35’ above ground. As I did in the previous note, all of my single Yagi models are located at 70’ off of read/high accuracy good quality ground. The antenna uses a hairpin (shunt inductor) match, and is on a 24’ boom.

The 4L new design naturally consumed the target boom length of 25.5’. So, the 10M4DX is really not unreasonable. The feed point impedance is well under 50 Ohms, and I used a hairpin match, allowing AutoEZ to both shorten the DE and adjust the shorting stub. I ended up with the following performance:

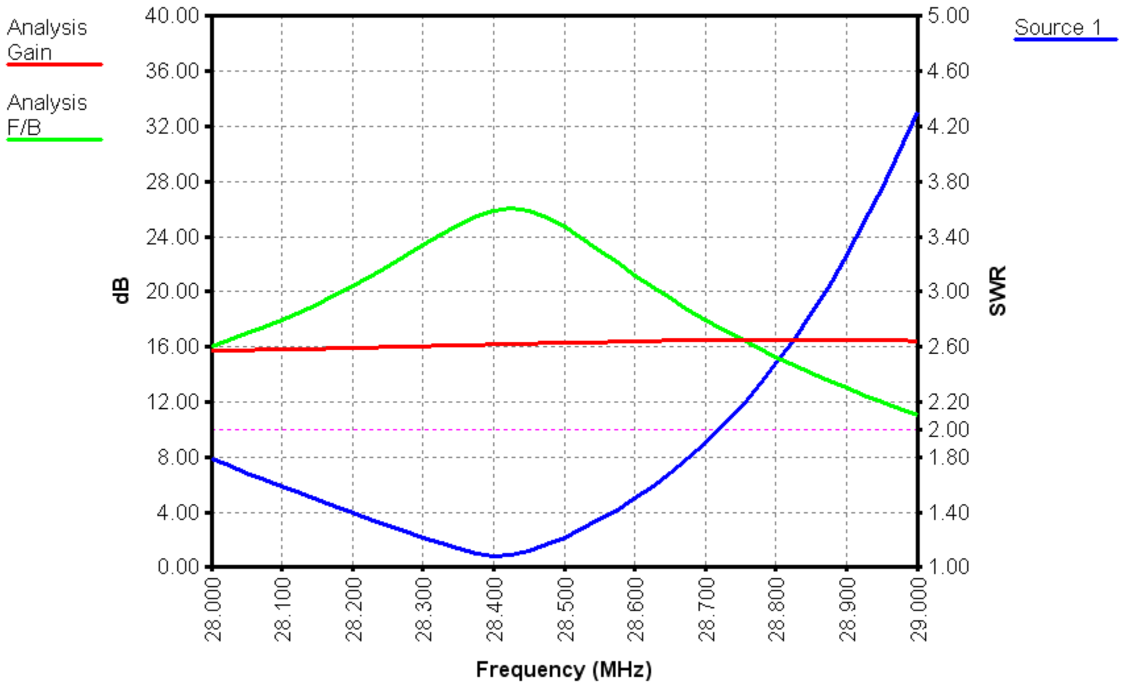


Figure 3 – 4L Performance

The gain (red) starts off slightly under 16 dBi at the bottom of the band, but ends up over 16 dBi. The F/B (green) peaks in the low SSB portion of the band, around the same frequency were the SWR (blue) dips to very close to 1.0.

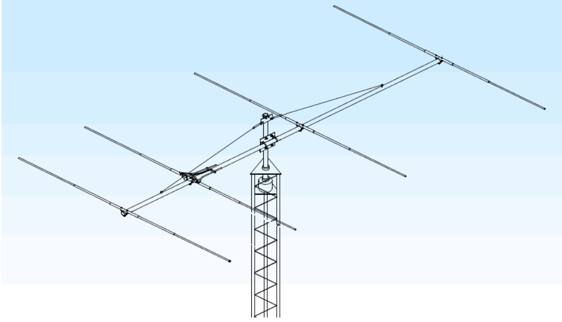
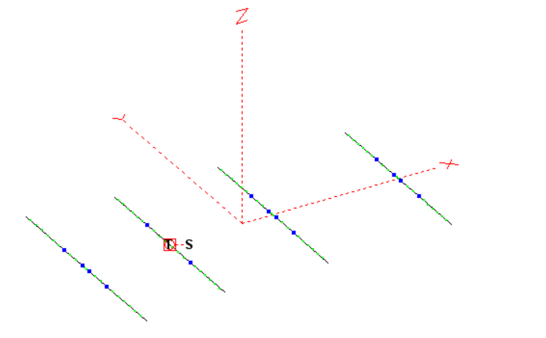
About all you could complain about with this antenna is the SWR, since it starts at 1.8 at 28.0 MHz, dips at 28.4, and is again at 1.8 around 28.7 MHz. Otherwise, this 4L design, like the 10M4DX, has pretty much the same gain as the 5L and 6L designs, and it productively consumes the full 25.5’ boom.

The design is:

4L Optimized Design (4L22.weq)		
Element	**Spacing**	**½ Length**
REF	0’	8.58’
DE	6.81’	7.91’
D1	15.26’	7.86’
D2	25.50’	7.56’

Not too bad for probably about 45 minutes of work, most of that waiting for the optimizer to run EZNEC.

These are not OWA designs. The 10M4DX and new 4L antennas have a similar look:

	
10M4DX View	**4L Optimized View**

Since we have hit 16 dBi of gain with 4 elements and a 25.5' boom, I don't think we should be expecting a whole lot more gain even if we add more elements. At this point, adding element will probably be about achieving flat and low SWR, or perhaps an improved front to rear response.

5 Element Designs

I started off by emphasizing gain far over SWR, and turned loose the 5 element beast on an unconstrained boom length. The results were:

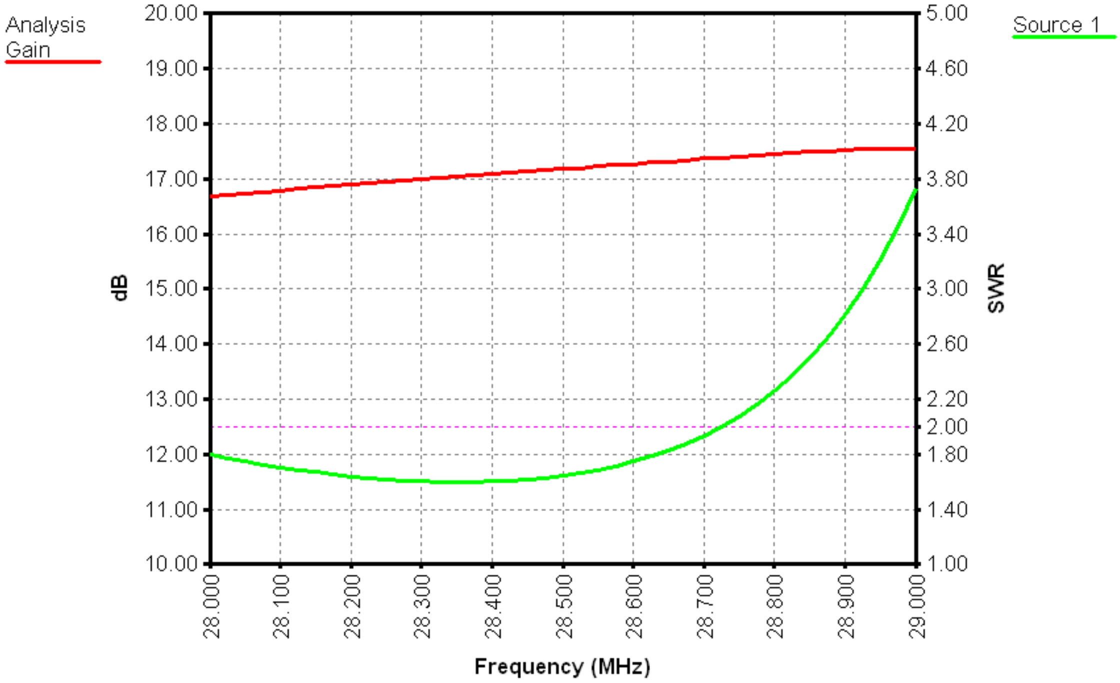


Figure 4 – 5L Initial Design

The gain crossed over 17 dBi at 28.3 MHz, which is quite nice, a full dB above what we have been talking about. But, the SWR dip is a rather poor 1.6 at best. More telling are the design dimensions:

5L Optimized for Gain Design		
Element	**Spacing**	**½ Length**
REF	0’	8.53’
DE	7.20’	8.16’
D1	14.31’	7.84’
D2	**26.12’**	7.77’
D3	**35.13’**	7.62’

The last two directors both exceed the 25.5’ target boom length. So, while we achieved a whole lot of gain, the boom is 10’ too long. But, it does suggest that if the goal is a high gain 5 element 10m Yagi, without concern for bandwidth, expect about 17 dBi and a 35’ boom length.

Note that this 35’ boom 5L Yagi is almost the same gain as the long boom Create (although this one has a very narrow bandwidth).

Ok, so at this point in the process, I will pin the D3 element to the 25.5’ position, and get as much gain as I can, knowing it will be around 16 dBi, and also target a low and flat SWR. After some trial and error, the results are:

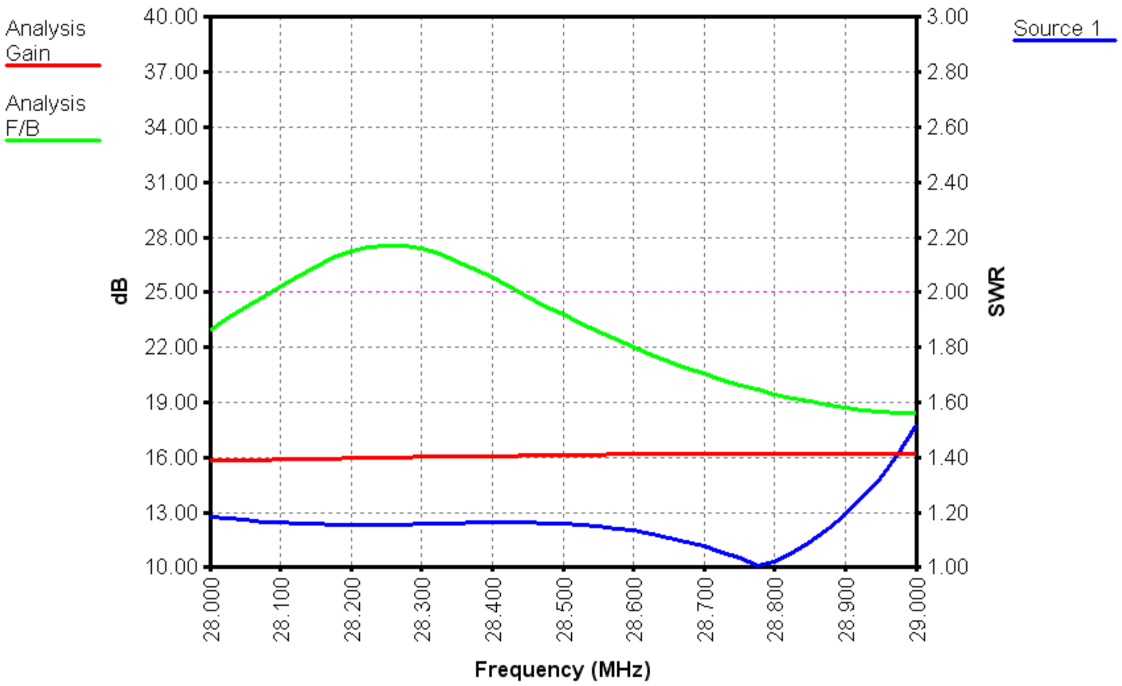


Figure 5 – 5L24.weq Model Results

The gain is almost exactly 16 dBi, with the F/B peak in the useful part of the band, and an SWR under 1.2 for the first 900 KHz of the band.

5L Design (5L24.weq)		
Element	**Spacing**	**½ Length**
REF	0’	8.71’
DE	5.51’	8.48’
D1	8.45’	8.04’
D2	15.75’	7.87’
D3	25.5’	7.41’

By the way, the name **5L24.weq** is a file name, and the 24 means nothing other than a version number.

The antenna *looks like* an OWA design, with the first director relatively close to the DE.

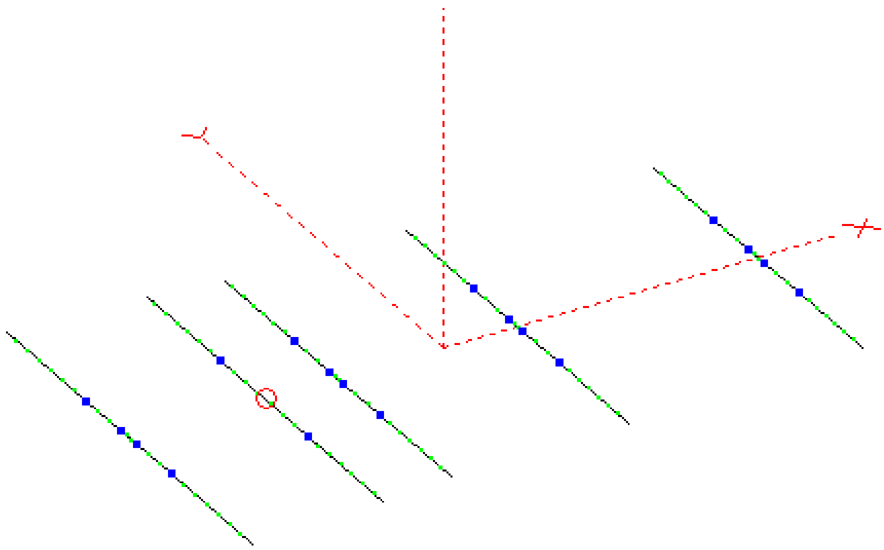


Figure 6 – 5L24.weq View

Since we are at the 16 dBi gain level, and have a low and flat SWR, a lot has been accomplished. But, since many of the previous designs use 6 elements, let’s give that one a whirl too.

6 Element Designs

As in the case of the 5 element designs, I started off modeling without a boom length constraint, and an over emphasis on gain.

The gain and SWR of the results are:

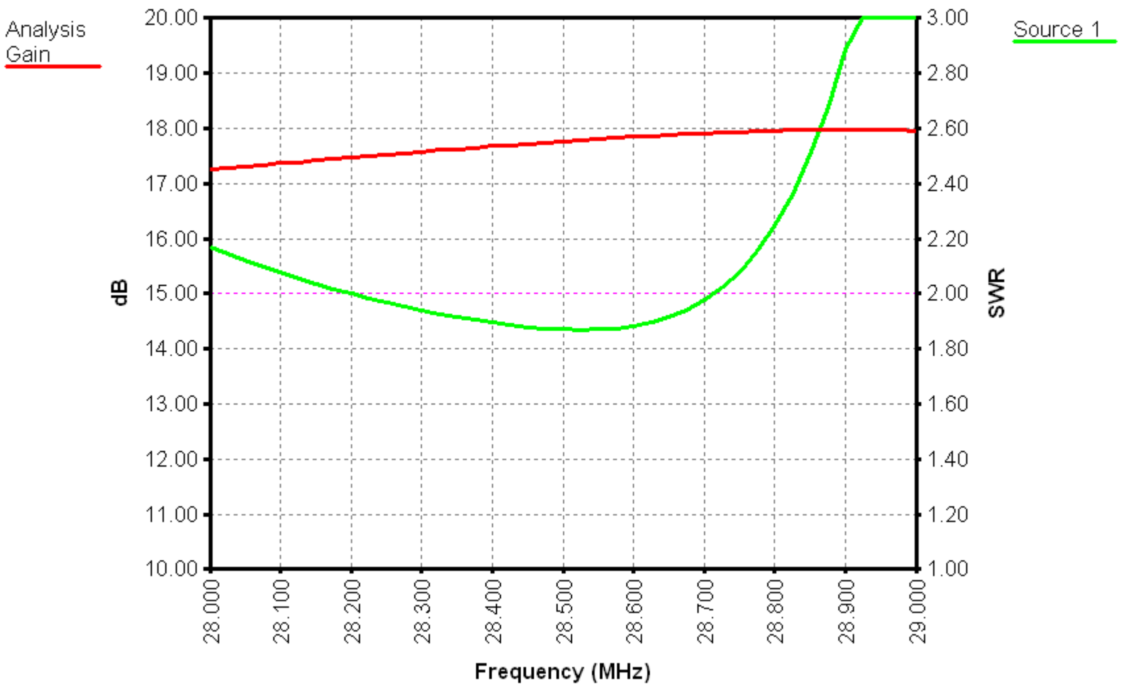


Figure 7 – 6 Element 41.7' Boom (6L29.weq)

The gain starts at 17.25 dBi, and rises to 18 dBi at 28.8 MHz. Unfortunately, this 6 element 10m Yagi has a boom that is 41.7' long! This makes it very close to the Create boom length. The performance is similar, although the Create has an extra element that apparently helps with the SWR. This antenna requires some form of matching. Here is the dimension table:

6L Design (6L29.weq)		
Element	**Spacing**	**½ Length**
REF	0'	8.73'
DE	4.16'	8.29'
D1	9.44'	7.97'
D2	19.66'	7.75'
D3	**31.05'**	7.71'
D4	**41.71'**	7.43'

D3 and D4 are too far down the boom for this project. I pinned D4 to 25.5', and moved D3 inside of D4, and started looking for a balance of gain and low and flat SWR.

The result is:

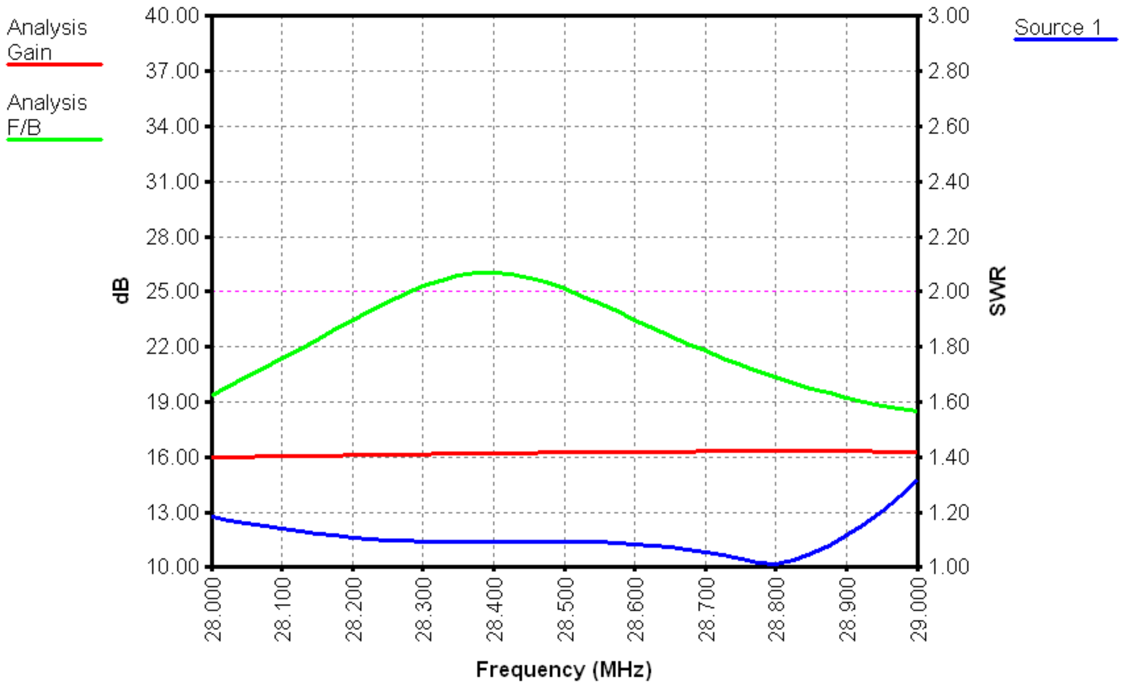


Figure 8 – 6 Element 25.5' Boom (6L28.weq)

The antenna gain is a little above 16 dBi for the entire first 1 MHz of 10m. The SWR is no higher than 1.2, and spends most of the range at 1.1.

The dimensions for this 6 element Yagi are:

6L Design (6L28.weq)		
Element	**Spacing**	**½ Length**
REF	0'	8.61'
DE	6.07'	8.42'
D1	9.15'	8.02'
D2	16.12'	7.78'
D3	17.25'	7.27'
D4	25.5'	7.56'

It's interesting to note that D3 is much shorter than D2, and also shorter than D4. The spacing from D2 to D3 is only about 1 foot, which seems a little odd. The view of the antenna is:

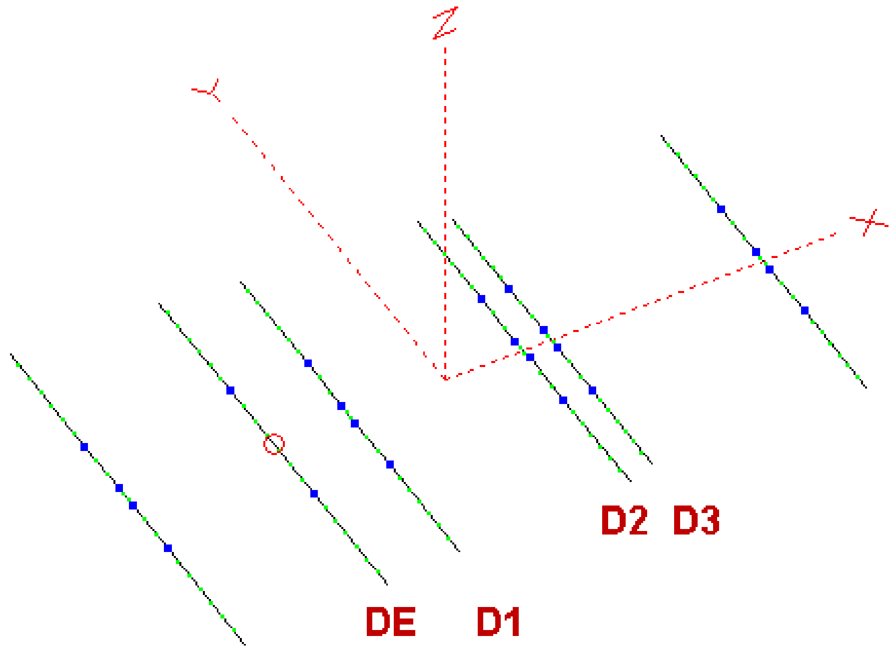


Figure 9 – 6L28.weq View

DE and D1 look like a normal OWA design. D2 and D3, with D3 much shorter than D2, appear to be an extension of that concept, where two closely spaced but different length elements provide a wider bandwidth rather than more gain.

Perhaps the reason is that there is no more gain to be had once you fix the boom length at 25.5', so all that elements can do is improve the match.

Anyway, this is what the 6 element Yagi looks like.

Comparing 5L and 6L Designs

The two alternatives are the 5 element 5L24.weq and 6L28.weq. Their gain comparison is:

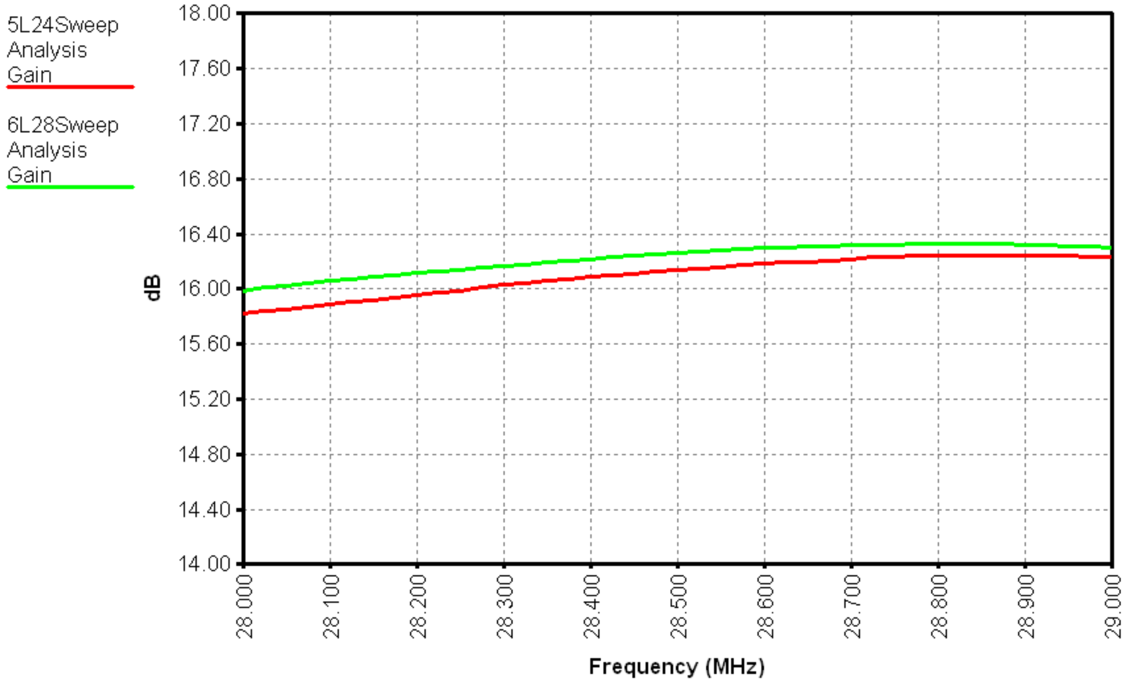


Figure 10 – Gain Comparison

The 6 element Yagi does have the higher gain, but by no more than 0.2 dB.

The F/B comparison is:

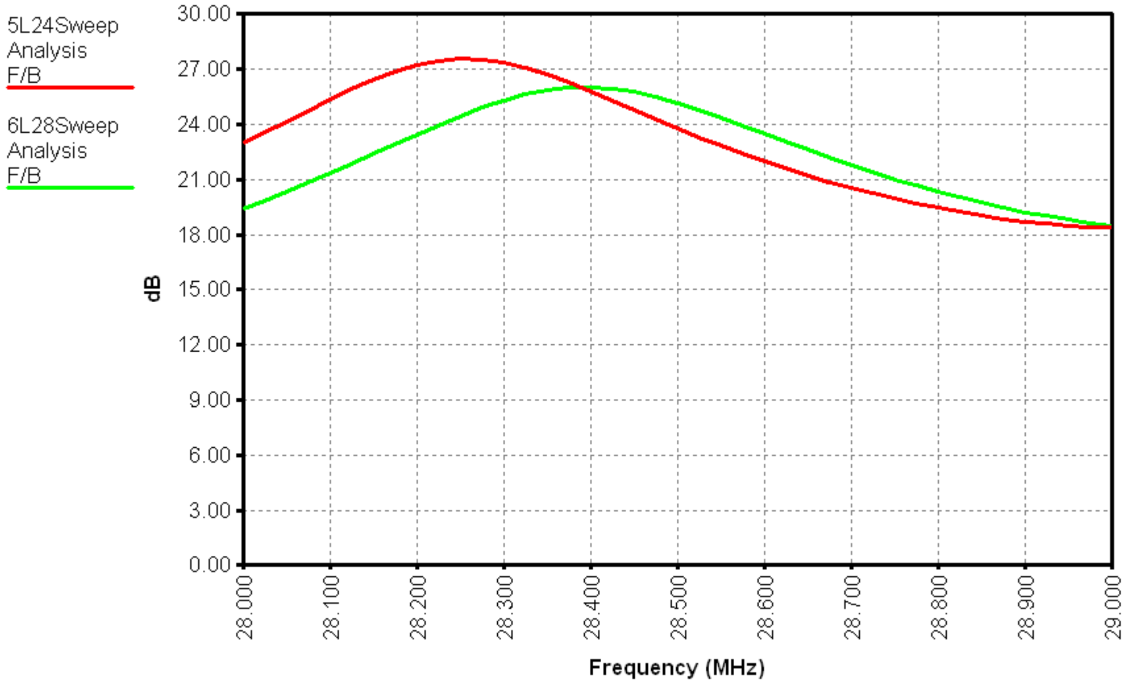


Figure 11 – F/B Comparison

Not a lot of difference, perhaps the 5 element is better positioned in the band.

The SWR comparison is:

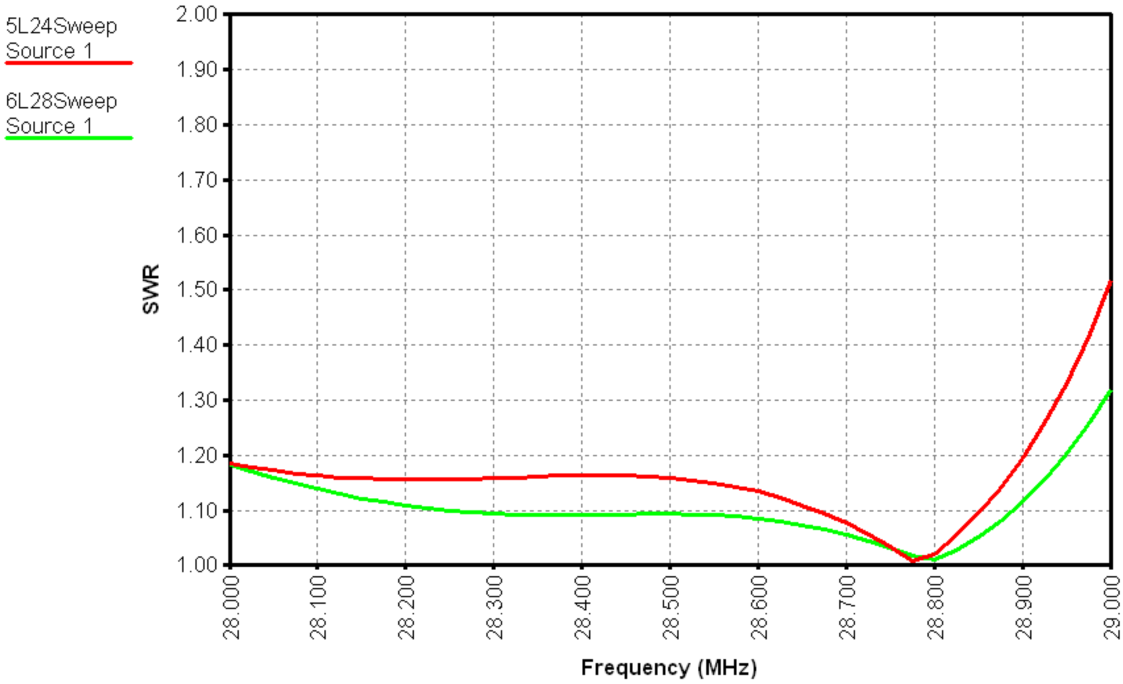


Figure 12 – SWR Comparison

The 6 element SWR is lower, but both are under 1.2 for most of the range.

The higher performance goes to the 6 element design, but the difference is about 0.2 dB of gain and 0.1 SWR unit.