Development and Real World Replication of Modern Yagi Antennas (III) - Manual Optimisation of Multiple Yagi Arrays

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Within this article we will discuss optimisation of Yagi stacking distances required in order to achieve the cleanest, tightest patterns / Front to Rear (F/R). While the DL6WU formula does provide a good basis from which to work, it is my finding that this calculation is more suited to more traditionally optimised Yagis than ultra clean Yagi antennas.

Objectives

In my last article [1] I suggested we would look at stacking of OWL (Optimised Wide band Low impedance) Yagis but will start with an 11 element 144MHz LFA Yagi.

I have been asked for some large, complex stacked arrays in more recent years and in the interest of keeping radiation patterns as tight as the original single Yagi (or as close as possible), have spent time manually adjusting stacking distances in order to ensure best results. By best results, I mean to include symmetry in the final results while maintaining or bettering both F/R and F/B (Front to Back ratio) and avoiding (where possible) random 'spikes' appearing within either the elevation or azimuth planes.

It is important to note that this optimisation is not being carried out for absolute best sky temperature and/or G/T although the results prove not to be too far away from optimum in these areas. However, by achieving very high levels of F/R and reducing any 'spike' lobes to an absolute minimum, real-world experiences in terms of general noise level and/or birdies can be substantially reduced.

How Yagis really look electromagnetically?

In more recent times we have become used to seeing ARRL style antenna plot tapers which perhaps make Yagis focused more heavily on gain than pattern, look better on paper than their on-air performance would suggest. To put this into perspective, below are two plots of the same 14 element G0KSC OWL 'Gain Focused' Yagi

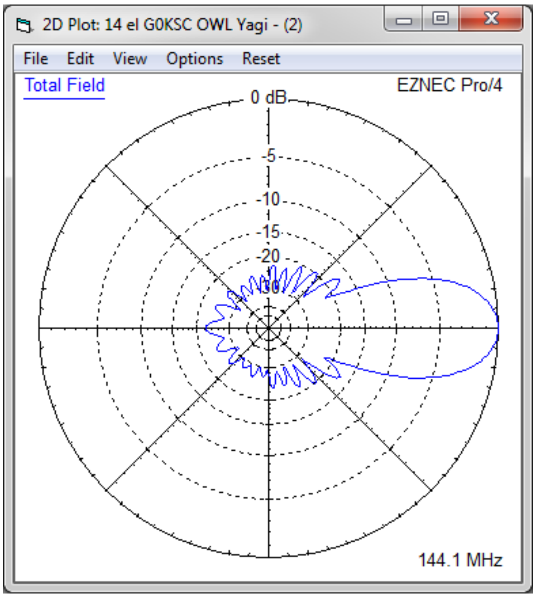

Fig. 1: 14 el. OWL Yagi ARRL style plot

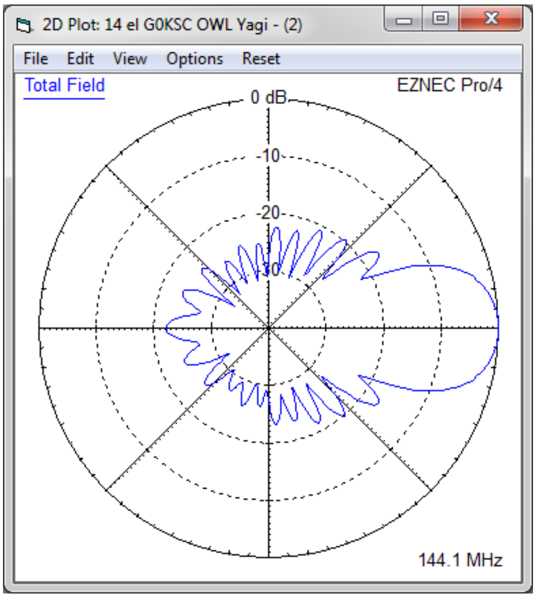

Fig. 2: Ditto, but linear scale

Fig. 1 above shows the elevation plot of this antenna in free space as we are used to viewing Yagis by means of an ARRL style plot, while fig. 2 presents the same antenna in a linear format. When comparing the forward lobe to all side lobes (in particular those beneath the antenna where these lobes will be looking at your shack, your neighbours and any other earth-side noise sources) the antenna appears to be far less impressive. However, the reverse applies when looking at lobes suppressed to levels better than 30dB. Take the following examples of an OWL with off-set folded dipole driven element where the feed point and dipole off-set has been arranged in favour of less unwanted lobes towards ground.

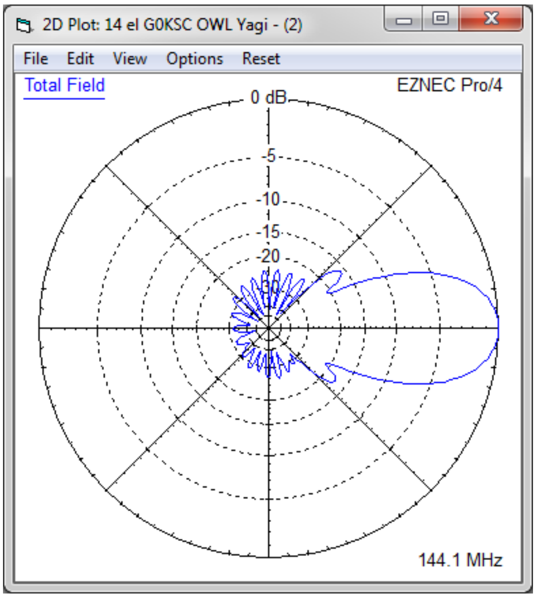

Fig. 3: 14 el. OWL high suppression, ARRL style

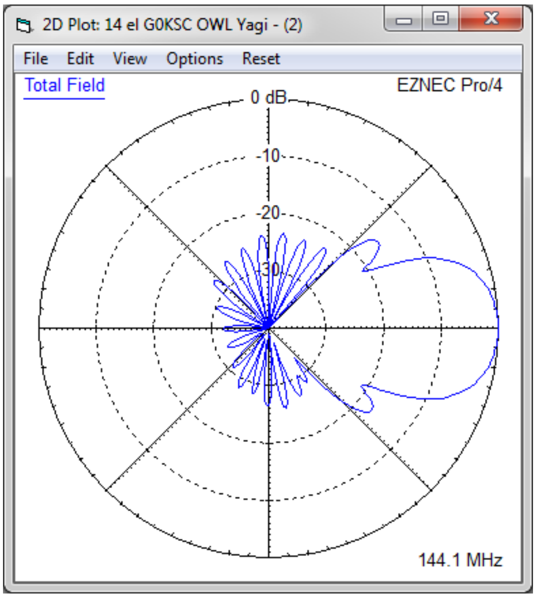

Fig. 4: Ditto, linear scale

When comparing the above plots (fig. 3 and fig. 4), a much more impressive level of suppression is seen from 45 degrees backwards in both examples, but when directly comparing the linear results of fig. 2 and fig. 4, we can begin to understand why hams see much lower 'real world' noise levels when using Yagi antennas optimised for minimum unwanted lobes.

Stacking more than 2 antennas in any direction

As mentioned above I have had many request both commercially and self-build for multiple Yagi arrays which extend with more than 2 antennas per plane. I had previously found that using the well regarded DL6WU formula produced interesting results with my Yagis. In many cases, going above the suggested stacking distance for a given array resulted in increased G/T figures (and in most cases, reduced sky temperature too) although side lobes became very large indeed. 'Under-stacking' (2 Yagis) from the DL6WU suggested measurements often drastically reduced side lobes without too much of a compromise in both sky temperature and G/T.

The first result above was puzzling to me until I went back to basics on the output that Tant produces when predicting sky temperature and G/T figures. The standard method of comparison used within Tant (and the VE7BQH list) is taken at 30 degrees elevation angle and therefore, if any larger side lobes (at this angle) do not point towards ground, a fair representation of assessment or comparison may not be seen. It is for this reason, when asked my opinion on stacking distances, I tend to ask the requirement and location of the suggested array, establish boom length and the purpose of use and then manually optimise. Ultimately, a tighter (than DL6WU suggested figures) stacking distance is the result although to maintain the levels of suppression (along with the avoidance of unwanted lobes or 'spikes') the stacking distance between each antenna needs to increase, the more Yagis are added.

This is often the case only when 2 Yagis are used (in either direction which could include an H frame with 4 antennas). If using these stacking distances with 4 or more of the same Yagi in any direction, in order to maintain pattern symmetry and cleanliness, the stacking distance between each antenna needs to increase; the more Yagis are added, the greater the distance required between each Yagi.

The results vary from one Yagi style/size to another and there is no fixed guideline to be used but the importance of manual optimisation should be considered when looking at multiple stacked Yagi configurations. Generally, if a single large spike sticks out from an otherwise clean pattern, the spacing between Yagis is not optimum. As an example, I have provided some plots for 11 element 144MHz LFA Yagis.

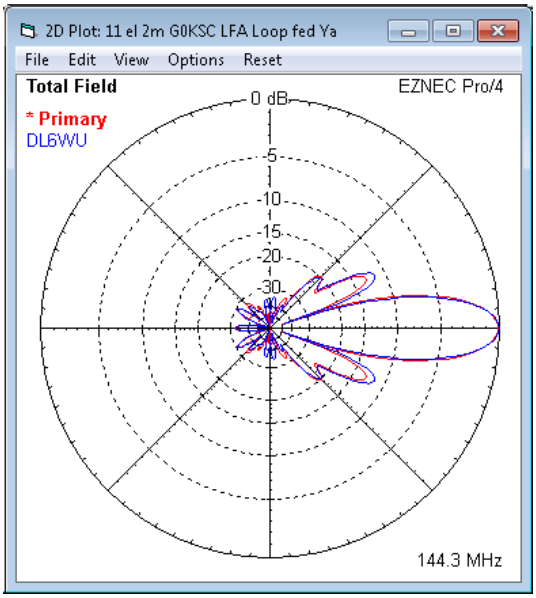

Fig. 5: 2x11 el. 3,35m vs. 3,2m stack

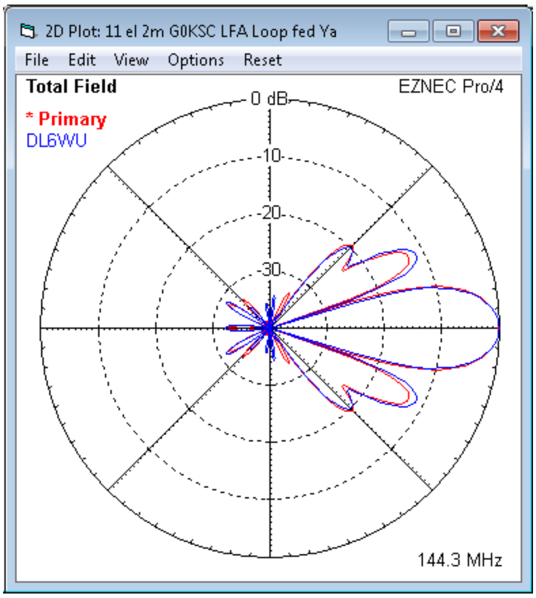

Fig. 6: Ditto, linear scale

Fig. 5 shows two plots overlaid using the typical ARRL style plots. The first example is 2 x 11el LFAs stacked at the DL6WU calculated 3.35m (vertical stack) versus the G0KSC calculated 3.2m spacing. The difference in unwanted lobes is quite marked (although forward gain is virtually identical). Not so much in the forward lobes, but those above and beneath the array. Fig. 6 shows the linear plot for the same arrangement which really highlights the difference in the two configurations. The lobes directly pointing upwards from the array would not be so troublesome but certainly the lobes pointing straight down could cause problems with unwanted noise. If this array with a 3.35m stacking distance was installed on your shack, these lobes could be susceptible to picking up shack noise. If being a part of a H frame with 4 antennas and being elevated, even at very high angles this array could still have Earth directed side lobes and thus susceptible to picking up unwanted noise. One note to make is the single antenna is extremely quiet to start with and therefore, with less quiet Yagis, the potential exists for more/larger unwanted lobes. Therefore, it is always good to experiment with various stacking configurations in software, before selecting an antenna for use as a part of a station. Now let us take a look at 4 antennas stacked using these same two sets of spacing.

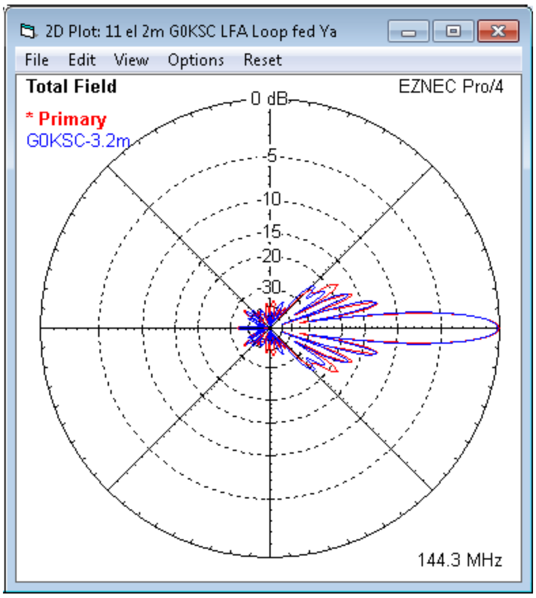

Fig. 7: 4x11 el., 3,35m vs. 3,2m stack

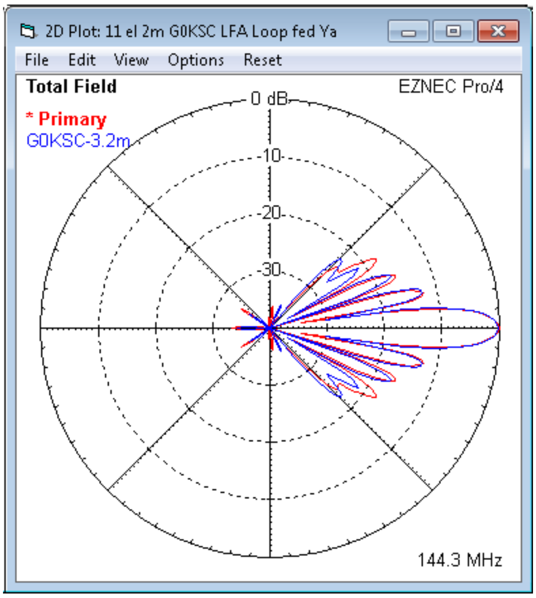

Fig. 8: Ditto, linear scale

Again it is the linear plot were we can see how much more linearity and symmetry the side lobe progression has with the 3.2m stack. So is this under-stacking or not?
I mentioned above that the more antennas there are in the stack, the greater the distance needed between them. To prove this point, I would like to conduct two experiments. The first plot below (fig. 9) shows 4 x 11el stacked at just 3.1m apart. The second plot (fig. 10) provides data for 2 antennas stacked at just 3.1m apart.

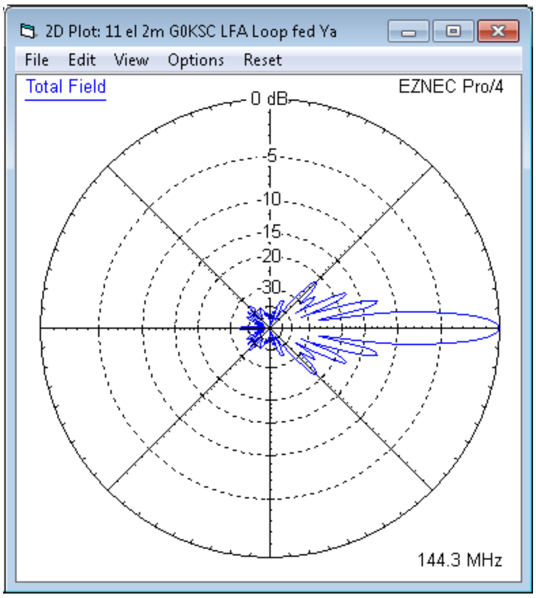

Fig. 9: 4x11 el., 3.1m stack

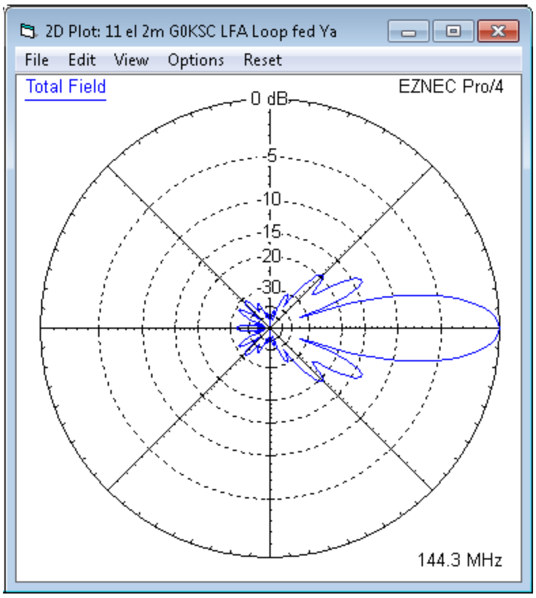

Fig. 10: 2x11 el., 3.1m stack

Within fig. 9, a clear 'spike' lobe appears at the back end of the lobe stack (at +/- 45 deg) which is not there on the 4 stacked 11els that were stacked at 3.2m, where as the 2 antennas stacked at 3.1m look perfectly reasonable (in fig. 10) and as you would expect from a well stacked pair of 11 element Yagis. From this, I would draw the conclusion that the 4 x 11els are under stacked to the point of detriment at this spacing while the 2 x 11els, even though the same stacking distance is applied, are not.

Let us now take a look at the results, if we were to stack 8 of these antennas, one above the other.

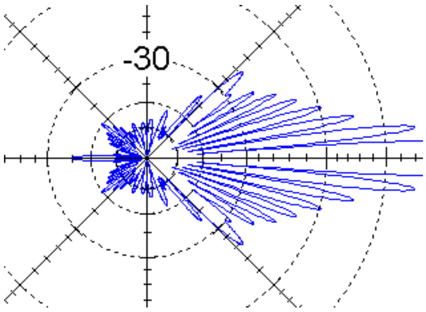

Fig. 11: 8x11 el., 3.2m

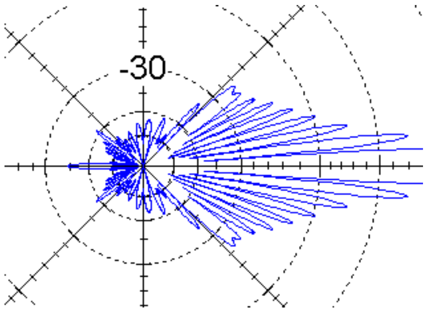

Fig. 12: 8x11 el., 3.25m

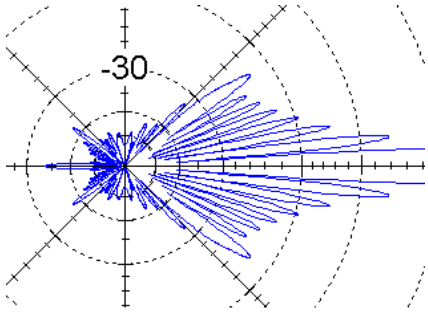

Fig. 13: 8x11 el., 3.35m DL6WU

This time, due to the size of the lobes from such a quiet array being so small, I have zoomed in on the centre section of the plot in order to best analyse them. Fig. 11 shows the plot as would be is we used the previously successful (for 4 antennas) 3.2m spacing. Note that linearity of the side lobes has been lost due to the extra-long final side lobe. Fig. 13 shows 8 of these antennas stacked at 3.35m (DL6WU) spacing between each antenna and a similar level of pattern loss is observed in addition to a loss in F/B. The plot in the middle (fig. 12) shows the results should we extend the individual antenna spacing from 3.2m per antenna to 3.25m per antenna. This time, symmetry and linearity has been restored to the plot along with the F/B of fig. 11 being retained.

We are half way towards the huge stack I designed and built for 9A2AE of 16 x 11el 144MHz LFA so I will conclude this experiment by adding a second bank of 8 x 11el next to the first set. The DL6WU formula suggests a side spacing of 3.61m. Fig. 14 below compares the azimuth plot of 16 x 11el spaced using this spacing, with the 2.7m I finally selected to recommend.

Notice the huge lobes in Fig. 14 using the standard DL6WU calculated spacing? Should the two banks of 8x11el be spaced at 3.61m, signals within either side lobe would be less than 2 S points down on the main lobe. However, using the much closer spaced example in fig. 15 (2.7m spacing) a much tighter (and for me more acceptable) overall pattern is achieved.

Conclusion

I have not conducted these experiments with DL6WU antennas, only my own designs and therefore, I cannot validate if the same kind of results will be seen using DL6WU or other Yagi designs.

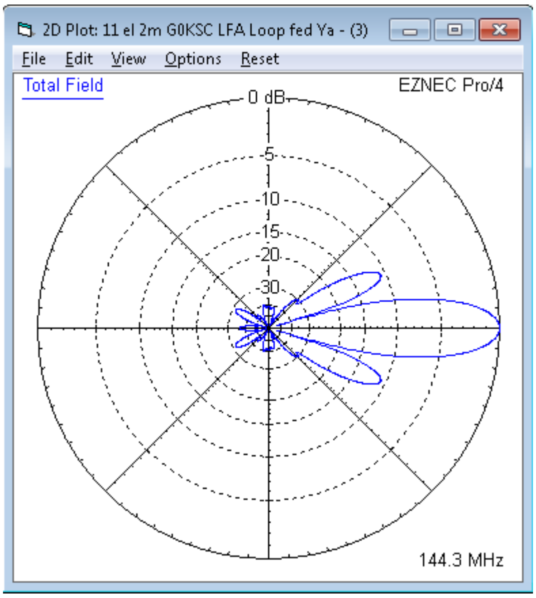

Fig. 14: Azimuth plot, 16x11 el., 3.61m (H) stack (DL6WU)

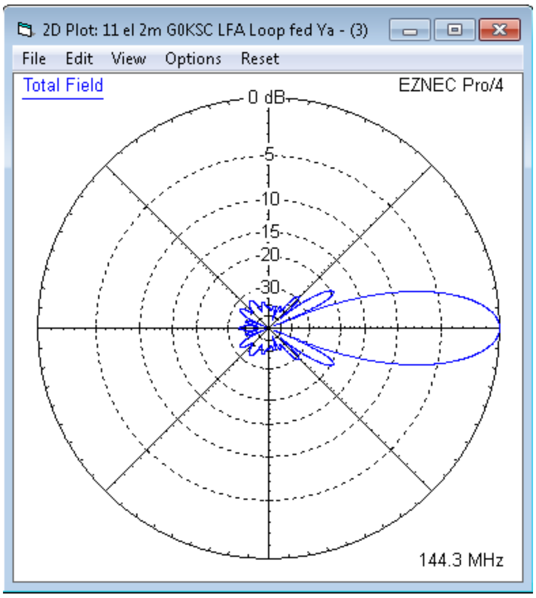

Fig. 15: Ditto, 2.7m (H) stack

However, I can conclude that by applying manual optimisation to more complex stack arrays, a cleaner final pattern may result than from using 'stock' DL6WU formula.

9A2AE installed the above array this summer and has had excellent results. He previously had installed 8 very long commercial Yagis and has noted a marked drop in unwanted noise from directions other than where the antennas are facing. Sky temprature and G/T are an excellent method of comparison when looking at Yagi antennas for weak signal working. However, this should not be the first and final aspect when selecting an antenna. Before you can expect to see differences in receive weak signals as a result of warm earth, you need to over-come man-made noise sources which are likely to be a far greater issue.

If unsure wether giving up a few 10ths of a dB gain is worth the extra dBs of suppression of unwanted noise, it might be worth building 2 small antennas of the same size. One optimised for gain, the other for heavily suppressed side and rear lobes and comparing them in your environment. You just might be very pleasantly surprised.

Reference

[1] Justin Johnson, G0KSC, Development and Real World Replication of Modern Yagi Antennas (II), DUBUS 3/2012, pp. 91

Fig. 16: The 9A2AE 16 x 11 el. 2m array