High Performance Wide-band 'self-matched' Yagi Antennas
- with a focus on pattern symmetry

by Justin Johnson, G0KSC

I must say it has been good to see some long-standing Yagi developers adopt new optimisation techniques (originally used, although not publically presented by YU7EF) which have led to a much higher standard of Ham-designed Yagis than we have seen over the last 5-10 years or so. New experimenters such as DG7YBN, UA9TC, RA3AQ (etc.) have contributed to the development of this new-style optimisation (wide-band (flat) performance, consideration to elevation plane lobes within the optimisation process, self-matching radiating elements, close spaced 'driver cell' (first 3 elements), etc.). Clearly the benefits of such methods have been understood by many as even hard-line 'traditional' Yagi developers such as DK7ZB have turned their hand to it and are now experimenting with antennas designed this way.
However, while G/T performance is generally getting better (per metre of boom) and the VE7BQH list (VH list) is becoming more populated with excellent Yagis, I believe all of what makes a good Yagi great is perhaps being missed (at least in part) by some hams selecting a suitable Yagi for themselves. So with this in mind, I would like to take this opportunity to detail some of the attributes which I believe contribute to this 'ideal' Yagi in order that better informed decisions may be made. Additionally, later in the article I would like to explore the reasons that Yagis for UHF and microwave bands have not perhaps lived up to expectations software model predictions may promise.

'Self-matched' Yagis are those would-be low impedance Yagis that have the driven element (sometimes this could be the reflector or director 1 rather than the driven element) arranged in such a way (bent elements, folded dipoles, LFA loop) as to increase the impedance to 50 Ω for direct connection to 50 Ω feed-lines. There are a number of advantages of so doing which include the fact that the Yagi can be optimised and viewed exactly as it will be built within the software model with no foreign body (matching device) being added after the software model (during the build-phase) which could affect and change performance parameters in the real world. Most important for me is the ability to add a closed loop into the Yagi arrangement which increases the feed impedance of my 12.5 Ω Yagis to 50 Ω and at the same time, can perhaps reduce the susceptibility to man-made noise, in addition to drastically increasing the power levels of that can fed to the antenna system without problems.

One of the reasons for looking at this subject in the first place was a result of a number of questions I received referring to the perceived performance of InnovAntennas Yagis against the older G0KSC (g0ksc.co.uk Yagis listed on my website) when comparing them on the VH list, which seems to be in favour of the older designs in some of the key performance indicators (KPI's).

The truth is that in the earlier days, I was guilty of shaping my designs to best suit the parameters set out with of the VH list rather than optimising for the best and most stable performance within a given Yagis primary operating section of the band. The problem with the former being the potential impact on real-world performance in changing conditions and the variation in materials used to build these antennas (more on this subject later) which could result in a shift of performance (and ultimately G/T) nearing the band edges. As the 'centre of frequency' on the VH list is 144.1 MHz and the bandwidth of each antenna is measured between 144 MHz and 145 MHz, the potential issue of the antenna moving outside of its operating range is plain to see (more on this later).

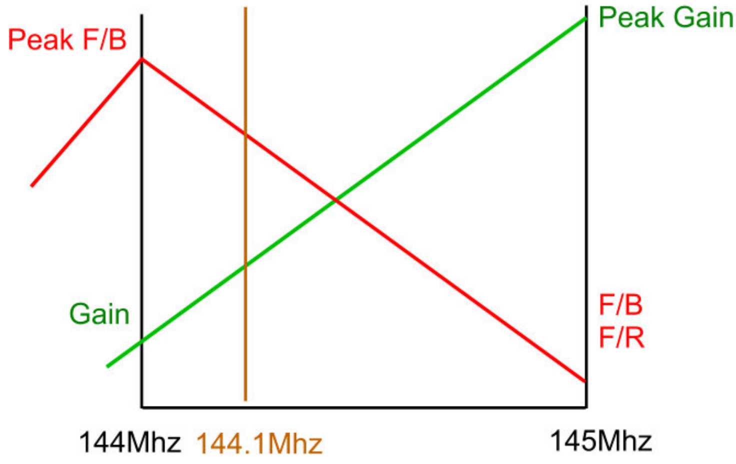

Fig. 1: Typical narrow-band Yagi performance profile

When correctly optimised, a good Yagi will have Band Pass Filter (BPF) type characteristics in terms of performance with stable and consistent performance several hundred KHz (VHF) either side of its centre frequency. Not just a nice flat SWR curve over a good range, the Gain and Front to Rear (F/R) will remain fairly constant too.

For comparison, I will use some of my newer OWL (named OWL-GT) designs which present a 12.5 Ω feed point impedance when a split dipole is used (50 Ω when a folded dipole is used) as a driven element, which have been optimised 'YU7EF style' to ensure a constant delivery of impedance where the centre frequency really is the centre of performance (contrary to the requirements to 'look good' in the VH list, more on this point later).

Let us first look at the reasons we are misled perhaps by performance characteristics and don't always see the performance (in the real world) we see in the model, despite the antenna being well replicated mechanically. Fig. 1 shows a graph of Gain versus F/R – Front to Back (F/B) in a 'typical' Yagi with a single point (frequency) of optimisation which focussed on maximum gain within the optimisation parameter setup. This is not a real plot of any Yagi and is very much exaggerated in order that the point can be well shown.

The bottom axis represents frequency, the left-hand side being 144 MHz and the right-hand side being 145 MHz. The grey line represents the typical gain produced while the black line shows typical F/B – F/R. There are no figures associated with this graph; its intent is to demonstrate the 'ski slope' performance parameters from opposite ends of the antennas decided bandwidth coverage. Often, the presented usable bandwidth (by the designer) is simply points within the SWR curve that exceed a certain value (1:1.5 for example) rather than carry an average of all performance parameters over a given range.
What stands out clearly is the best F/B (and/or F/R) and best forward gain are typically at opposite ends of the bandwidth of the antenna. Gain is highest at the top of this bandwidth (naturally) because of the increasing boom length (in terms of frequency/Wavelength). F/B and F/R drops off very quickly in the same direction, usually because the Yagi is too long for the number of elements the modeller has selected for this given boom length (or has let his optimiser run away with boom length) and therefore, the Yagi cannot be optimised for a balance of gain and F/B (F/R) across the desired range. This 'Ski sloping' of performance parameters is very common and often the reason why Gain and F/B figures are quoted as being 'peak gain, peak F/B'. If they were presented at spot frequencies (gain @ 144.1 MHz, F/B @ 144.1 MHz) it would be much clearer to see all the inherent flaws in the design in question. It is this spot frequency performance I would like to discuss now.

Take a look at the vertical line (Fig. 1) which denotes the performance of this hypothetical antenna at 144.1 MHz and the corresponding gain and F/B results. Shifting up and down frequency just 50 kHz or so will show very different gain – F/B combinations which will result in a large variation in temperature and G/T as well. Furthermore, it is important to note how close the centre of operation is (144.1 MHz) to the band edge (144-145 MHz according to VH list). Taking into account our BPF type characteristics and to 'look good' in the VH list (bandwidth coverage (SWR) is measured between 144 and 145 MHz rather than the more logical method of measuring 500 kHz either side of the centre frequency) although the centre of activity for any 144 MHz Yagi should more likely be focused around 144.300 MHz if modes other than just EME will be practiced by the end user, it would not take too much for narrower band antennas to move well out of their peak performance characteristic range in real-world conditions (wet weather, ice, other antennas close by etc, etc.), if they were optimised between 144 and 145 MHz and were being used at 144.100 MHz. Of course, the focus of the VH list is G/T performance on 144.1 MHz for EME applications. However, the comparison of G/T at 3 points (perhaps 144.0, 144.1 and 144.2 MHz) may give a much more accurate indication as to what the user might expect for day to day use.

Performance tends to tail off towards the edge of the range of operation (bandwidth) and it is for this reason that with InnovAntennas optimised arrays, I have chosen to optimise with 144.300MHz as the true centre of operation with a guided bandwidth of 500 kHz either side of that point (143.800 –144.800 MHz). Doing this ensures very constant performance either side of the centre frequency rather than perhaps experiencing the typical tail-off of performance at the band edges as maybe the case in the VH list scenario discussed above. This does however led to the SWR bandwidth figures (for InnovAntennas LFAs and the new OWL-GT) on the VH list appearing to be less impressive as the BPF characteristics of these antennas means the SWR tails of quickly after 144.800 MHz which results in what looks like a less impressive bandwidth when measured between 144 and 145 MHz. If an experimenter or potential antenna builder is looking for a stable design to be used in varying weather conditions, run the model of the selected antenna through Tant at least 100 kHz (as already discussed) either side of 144.100 MHz and compare the noise temperature and G/T figures, you may be very surprised by the results! The antenna which yields the most consistent results across these compared frequencies is likely to be the most stable for day to day use and/or use in extreme environments and not just for EME applications either!

Let us now take a look at a recently optimised 9 element 12.5 Ω 'Optimised Wideband Low impedance' (OWL-GT) Yagi and how this looks across the bottom end of the 2 m band.

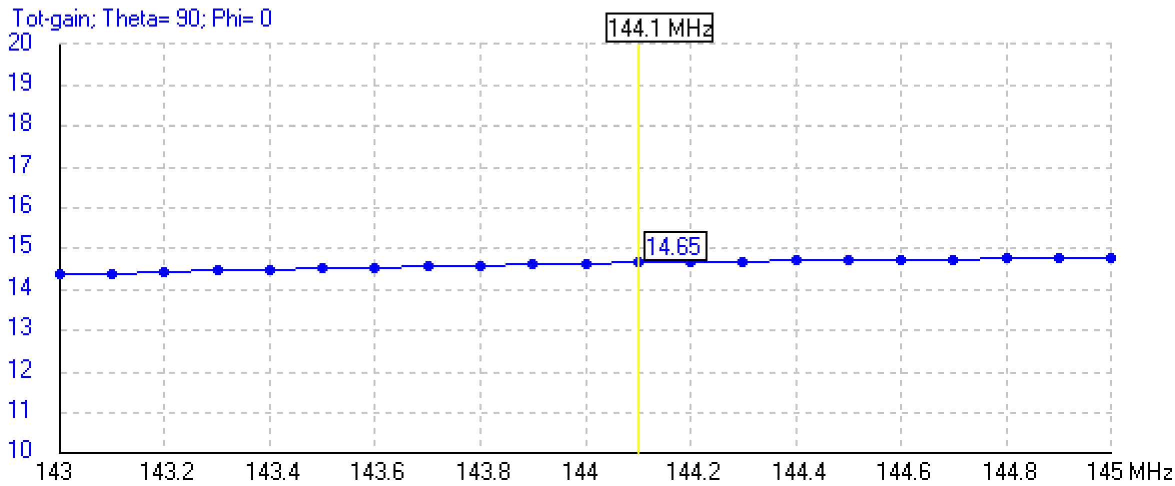

Fig. 2

Fig. 2 shows the predicted gain figure for this antenna across a 2 MHz range using the NEC4.2 engine within 4NEC2 by Arie Voors (http://www.qsl.net/4nec2/). While this antenna covers a much wider bandwidth than the expected use areas of this antenna, this plot has been created to demonstrate the slight increase in gain that occurs as a result of the boom length effectively increasing (in terms of wavelength) as we move up in frequency.

Note: This 9 el 144 MHz Yagi has a boom length of 4.939 m. Based on my findings and Critical Success Factors (CSF) for the ultimate Yagi, this boom is 'too long' for 9 elements on this band, the ideal length would be much closer to 4.5 m and as a result, the gain curve above is not as flat as it could be. However, I wanted to demonstrate that even with longer, wider-spaced Yagis, it is possible to achieve wider, much flatter results than we have become used to in wider spaced Yagis. This is only possible if the appropriate time and skill are applied during optimisation, forcing a tight, close-spaced driver-cell to be used being an important part of this optimisation strategy.

See Fig. 2a below which shows a 4.4m long 144 MHz 9 el LFA Yagi gain figure:
With the shorter boom, the gain figure could be made much flatter by forcing the optimisation process to reduce gain at the top end (nearer to 145 MHz, in exchange for an increase in gain at the bottom end nearer to 144 MHz). In so doing, the result is a balancing of gain across the antennas usable range making the resulting performance parameters much more predictable and constant. These super flat-line gain plots can be seen on many YU7EF examples (www.yu7ef.com), DG7YBN and others sites, outside of my own.

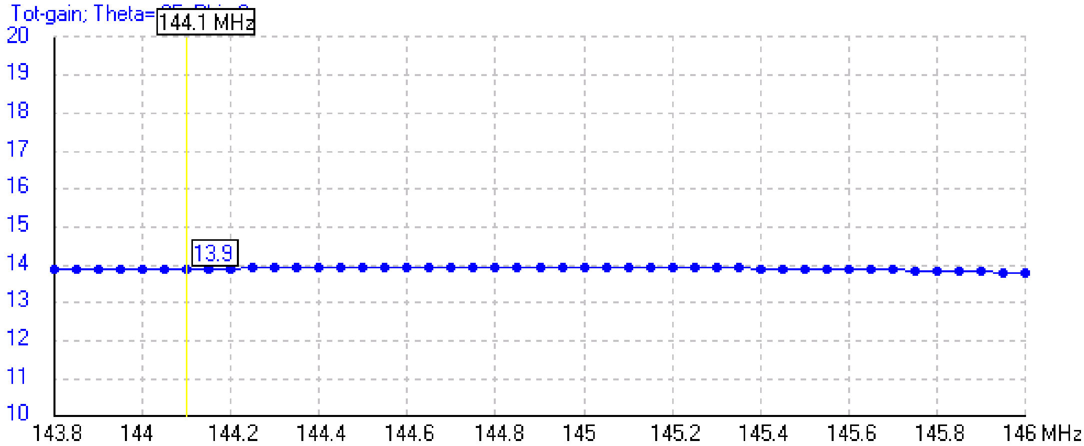

Fig. 2a: Gain for a 4.4 m long 144 MHz 9 el LFA

Now let us take a look at the F/B and F/R presented in Fig. 3 below.

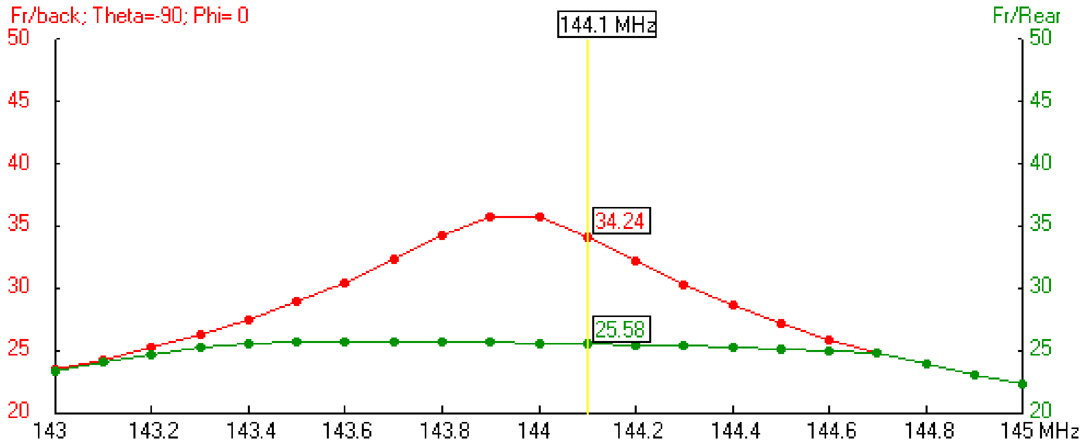

Fig. 3: F/R and F/B vs. frequency

While the F/B peaks around 144 MHz, the most important attribute (in terms of noise temperature and G/T) is F/R and we can see that F/R on this antenna remains constant (better than 25 dB) with little variation across a 1.4 MHz bandwidth with 144.1 MHz being close to the centre of this very flat curve. The resulting G/T (in combination with a similarly flat gain curve) is very flat across this range also. Therefore, when weather conditions change, when other antennas are close by (including other antennas in the same stack!) performance (including impedance) should remain within a few % of the originally suggested prediction.

Before discussing more about G/T, let us now take a look at Fig. 4 and Fig. 5 which provide Azimuth (Az) and Elevation (El) performance plots of an early 9 el 144 MHz OWL to see what control methods have been applied to ensure absolute best results can be obtained from this antenna. First, examine the side lobes seen in the Az plane which while well down on the main lobe, are much more pronounced than some might be used to seeing from my antennas, so why are they there? By allowing these lobes to form (but not allowing them further back than the 55° line (a predetermined maximum marker for side lobes on a boom of this size on this band) marked with a bar in Fig. 4) the rear bubble is greatly reduced in size. Not just ultimate F/B but also the size and shape of any lobes that exist after the 55° line, the rear 'bubble' as I like to call it.

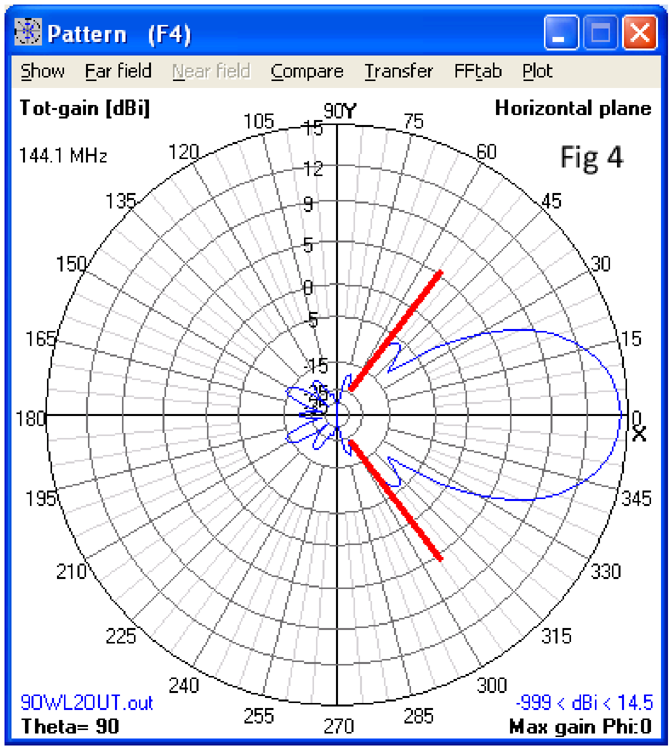

Fig. 4: Az plot 9 el OWL

The Az plane looks OK and certainly gain is good but it is the El plane pattern which is much more important than the Az plane in terms of G/T but more so than this, (and before we can even begin to think about G/T) the collection and pick-up of real world noise is dependent on the lack of side lobes in the Elevation (El plane. If lobes in the El plane are prominent and down-facing, regardless of how quiet you believe you location to be, you will receive higher levels of noise in certain directions (direction of the shack and/or house for example) than you otherwise would if any lobes were much more highly suppressed. When measuring and comparing G/T within Tant, rear-facing lobes from the 90° line back are what are considered for calculation and measurement. However, real-world operation by hams requires us to pay equal consideration to more forward and down facing lobes in this plane but it is at this point it starts to become more complicated. '***An optimal antenna on 144 MHz does not provide the basis of an optimal antenna on 432 MHz when scaled'***.

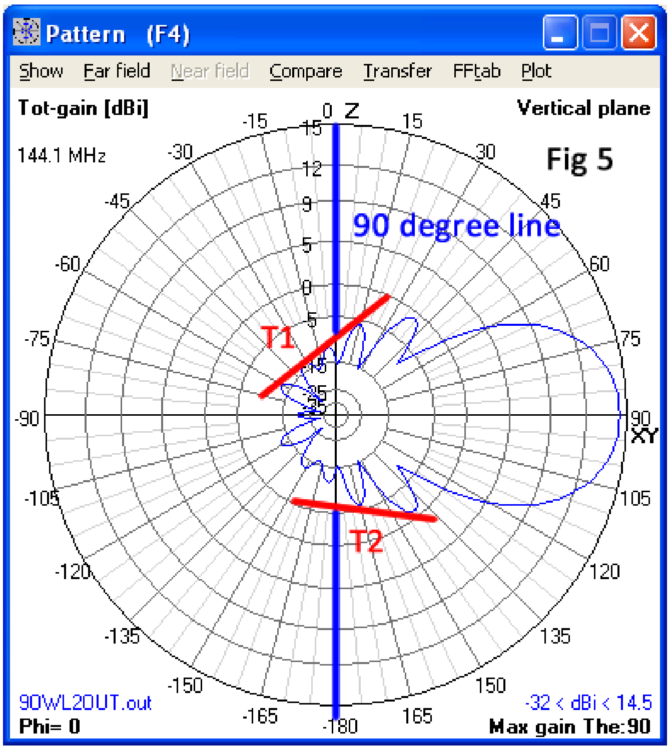

Fig. 5: El plot 9 el OWL

Different levels of consideration/attributes have to be taken into account and considered at the design phase when switching from designing a Yagi on one band and then looking to do the same on another band. Quiet Yagis are very much band specific so note that what is being discussed here carries relevance when optimising on 144 MHz only.

Now let us take a look at Fig. 5 and the design considerations taken in order to not just show a good G/T figure within Tant, but to also reduce the likelihood of man-made noise pick-up from beneath the antenna within the near-field to an absolute minimum.

First of all and as mentioned at the beginning of the article, our subject antenna should have a closed loop feed arrangement. Over many years closed loops have been proven to be much less susceptible to noise, man-made and otherwise so logic suggests that when looking to produce a Yagi that is as quiet as possible, all possible quietening attributes should be considered and where possible employed.

Within Fig. 5 are two bars marked 'T1' and 'T2'. 'T1' shows a sharp taper from the back towards the front. This level of taper right at the back of the antenna and forward is important to ensure good G/T results as tighter suppression from the 90° line backwards will yield much better results within Tant. However, to continue this level of taper for the first side lobes would be disastrous for near-field noise pick-up but also, from having very wide side lobes in the Az plan which would be not much more than 12 dB down (2 S points) on the main lobe additional noise sources could be detected and interfere with signals in the desired capture direction from noise sources either side of centre. The ability for this antenna to hear weak signals (real-world) would be greatly reduced by having what in effect would be 3 forward lobes in both planes, all receiving whatever was beneath or either side of the antenna. It is for this reason that an amount of suppression has been applied to the first lobe to arrive at the best compromise between the overall size of the 'rear bubble' and outright forward gain.

Earlier I made this statement: *'A predetermined maximum marker for side lobes on a boom of this size on this band'* and this is a very detailed subject to cover which probably needs several thousand words to describe fully. However, I will summarise what I refer to in this statement and the practice and procedure I follow to achieve the best from the antenna in terms of performance while at the same time, keeping the El pattern as clean as possible.

Basically, this is a control which can be achieved within software optimisation that is not so easily achieved when optimising manually. Some software packages allow the point at which F/B is measured (normally 90°) to be moved forward of this point towards the forward lobe. The advantage of so doing is this F/B start point can be moved forward until it covers the angle from the forward lobe where forward lobes would start to increase in size. However, while this sounds simple, in practice, getting excellent results take a lot of time and work.

Antennas of typical length up to around 6 elements tend not to produce any side lobes of any consequence, at least not in the Az plane. For weak signal and EME work, the desire is to have much longer antennas than those carrying 6 elements and normally they would have booms of multiple wavelengths were if left unattended (during optimisation), the natural course of gain-focused optimisation would see very large side lobes at quite large angles away from the centre of the forward lobe upon optimisation completion. Simply moving the F/B point (within software) further forward than the point of these lobes will result in 2 side-effects. The first, a reduction in forward gain and the second, a 'blown' rear bubble, back facing lobes while held in-check to a certain degree, F/R would typically be much worse than the starting point with odd small lobes or 'spikes' appearing in the rear bubble as a by-product.

As the boom gets longer, the forward lobe becomes narrower and in-turn, the side lobes get closer to one another either side of the main forward lobe but exactly how close they sit to the main lobe can be controlled, to a point.

I have found in order to achieve the best overall gain results and to ensure the rear bubble can be minimalistic, an antenna is best optimised (assuming computer optimisation now) with F/B parameters being set just behind the side lobe position. For example, if the side lobes on a subject antenna are at 50°, the F/B point would be set at 55°. The antenna can then be optimised for bandwidth and gain several times until no further improvements can be made. At this point, I would move the optimisation point from 55° to 54° and re-optimise then 53° then 52° and so on. Improvements should be seen in terms of gain and bandwidth by doing this method of controlling the elevation lobes in addition to (hopefully) pushing the side lobes closer to the main lobes resulting in less significance or negative consequences (for best results, computer optimisation/controlling of side lobes should only be done in the El plane, so doing will see the Az lobes kept in-check automatically. The same does not happen in reverse should you optimise in the Az plane).

Each time the optimisation results should be saved individually as there will become a point where the gain starts to drop and the rear bubble starts to 'blow'. At this point you know you are trying to compress the side lobes too tightly and you should go back to your last improvement optimisation for your best useable result. Like I said above, the whole optimisation process is much more detailed than the explanation given in these few lines but at least now an understanding of the levels of attention and time taken to optimise this antenna can be perhaps much more appreciated.

Performance

We have paid attention to pattern until now in addition to a high-level view of optimisation techniques but what about the results, how do these look? I tend to disagree with suggestions that overall G/T is the most important attribute on this band (2 m). I believe that elevation lobe suppression is the key and an antenna with far greater suppression and slightly less G/T performance will yield better results in terms of signal to noise ratio for real-World applications. However, the LFA Yagi designs I have produced until now fill my favoured niche and therefore, I have optimised these OWL-GT Yagis for optimum G/T performance (hence their name). The results are interesting, a more average noise temperature figure has resulted with a large increase in Gain (in most cases far exceeding gain figures of any traditional straight, 1/2 λ parasitic element (wideband) Yagi on the VH list. This combination of average noise temperature with exceptional gain has resulted in class-leading G/T results as future VH lists will show. Combined with a good 1 MHz (flat) bandwidth and near-constant performance parameters across their bandwidth, I believe these new OWL-GTs will be the choice of many when installing new antenna systems moving forward.

So how does this 9 element look when comparing typical stats?
Below are the results of this 9 el when optimised with a folded dipole in place:

Data at 144.100 MHz for a single Yagi:

Gain:	**14.74 dBi**
F/B:	**25.03 dB**
Temperature:	**244.3 K**
G/T:	**-9.14 dB**

Below is a selection of antennas from the VH list either side of the boom length of this 9 el OWL-GT in order comparisons can be made.

VH List Extract

Antenna	Length (λ)	Gain single antenna (dBd)	Temperature (K)	G/T (dB)	SWR 1 MHz
Flexa 224	2.34	11.52	254.6	-4.44	1.09:1
RA3AQ 9	2.35	12.38	234.3	-3.24	1.10:1
G0KSC 9 (DL6WU)	**2.37**	**12.50**	**239.4**	**-3.10**	**1.20:1**
G0KSC 9 (G0KSC)	**2.37**	**12.50**	**241.0**	**-3.08**	**1.20:1**
CT1FFU 9	2.38	12.23	226.8	-3.33	1.14:1
ZL1RS 9	2.38	12.24	227.2	-3.28	2.19:1
Eagle 10	2.38	12.28	243.0	-3.43	1.33:1
DK7ZB 9	2.39	12.41	250.5	-3.39	1.23:1

The above results (G0KSC 9...) show the single antenna gain, the 4 antenna temperature and G/T results with both DL6WU spacing (3.196 x 3.480 m) and my manually optimised spacing (3.280 x 3.480 m).
I mentioned above that this is the folded dipole version of this antenna because unlike what has traditionally been the case, I do not simply swap a split dipole (12.5 Ω) for a folded dipole (50 Ω). As discussed in my last DUBUS article [1] antennas employing off-set feed points (the exception being the LFA Yagi where the feed point remains in-line with all elements) have distortion within the elevation plane, a loss of symmetry. However, I use this to my advantage while selecting the position of the feed point (above or below the parasitic elements) and during the optimisation phase to ensure the most distorted side of the elevation plane is up-facing resulting in the least distorted (smaller side lobes) point in a downward direction and this results in a better final G/T.

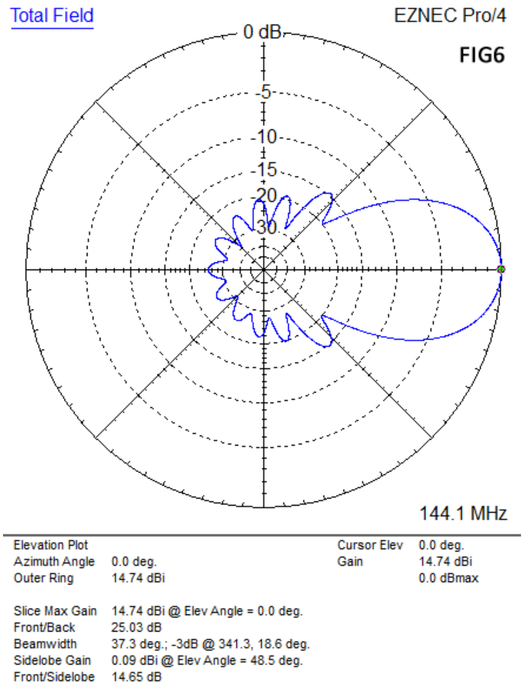

Fig. 6: El plot

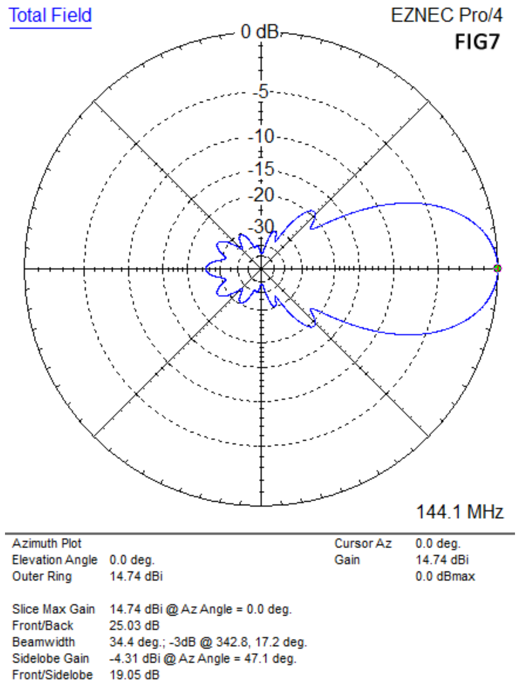

Fig. 7: Az plot

Fig. 6 shows the elevation plane lobes and while the loss of symmetry is small, if you look closely you will note the smaller side lobes in a downward direction. Fig. 7 shows the azimuth plane pattern which remains symmetrical.

I stress again that while this antenna fares well on the VH list, I am quite convinced that for most users, a 144 MHz antenna with much better noise temperature (at the detriment of gain and ultimately a worse G/T figure) would provide a better signal to noise ratio due to the subsequent smaller elevation lobes which will be subject to the reception of 'real world' noise sources from below and near the antenna. The Antenna is the most important part of the receiver chain. Any noise or unwanted noise generated in the antenna or picked-up here is much harder to remove further down the receiver chain and thus, signal to noise ratio is of the utmost importance at the antenna as well as elsewhere in the receiver itself.

Stacking the OWL-GT

Fig. 8 and fig. 9 show the azimuth and elevation plots of 2 x 9 el OWL-GT stacked at 3.3 m apart vertically and it is clear to see that just a fraction over 3 dB additional gain (over one antenna) has been achieved. The two antennas are stacked for maximum gain (this is a gain antenna; low temperature antennas would be stacked for least noise). Secondary lobes are also decreased with this stack along with F/B having increased too. Let us now take a look at a box of 4 antennas both in accordance with DL6WU calculations and my manual 'optimum G/T' spacing.

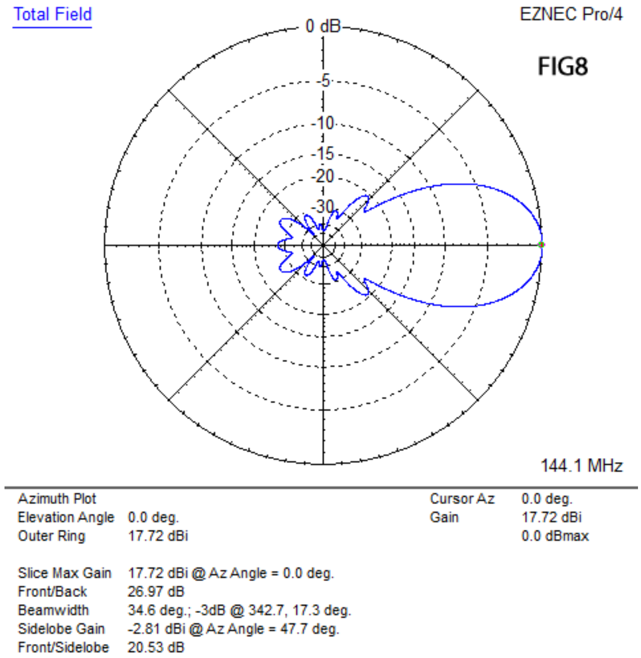

Fig. 8: Az plot 2 x 9el

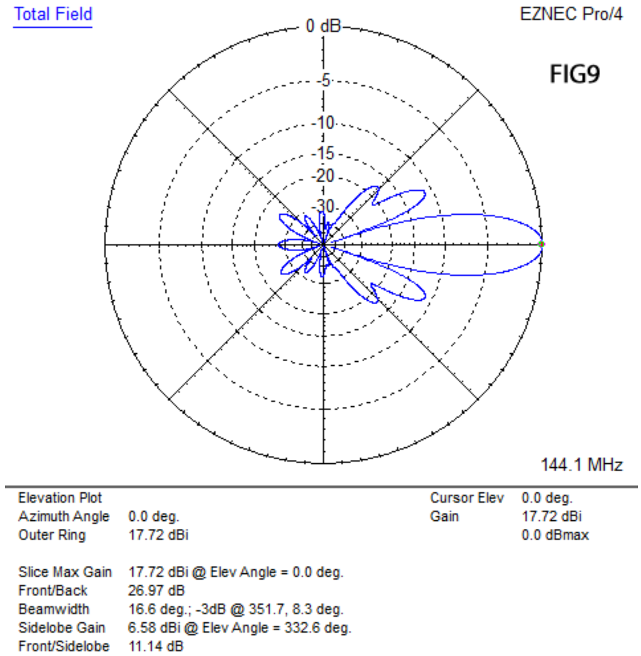

Fig. 9: El plot 2 x 9el

- DL6WU Calculated results
As always DL6WU calculated results give an excellent starting point and are sometimes right on the nail. However, while time consuming it is often worth manually optimising if your target is to achieve a peak in one performance parameter in particular. Increasing the vertical spacing as I have, provided the above mentioned pattern improvements and subsequently an overall improvement in G/T.

- G0KSC Optimum G/T spacing
Manual finalisation of any stack is always important in my view. Odd lobes can be taken care of with careful alteration in both H and V planes which ultimately improve G/T. Sometimes, surprising results can be seen from increasing or decreasing spacing from suggested spacing of the DL6WU spacing with this antenna demonstrating such results from the former.

New OWL-GT range and Design Parameters

I have added a new range of OWL-GT antennas to the G0KSC website for self-build which is currently limited to 2 m. However, I will be adding a limited number of smaller, high-gain 6 m and 4 m versions too. These antennas will also be available from InnovAntennas directly; no other company has permission to build these commercially. These are all produced with thick elements (1/2'' and 12 mm for the 2 m versions) and there are two main advantages in so doing. The first is well-known and this is an increase in average gain which certainly has helped the OWL-G/T range achieve its class-leading G/T numbers (for a wideband antenna). The second is perhaps not so obvious or well-known and this is the break-up of sub or non-primary lobes. With thicker elements any sub-lobes are wider with bigger, deeper nulls between them while with thinner elements, the opposite occurs in much the same way as primary forward lobes break-up if an antenna is raised 'too high' above ground for its given boom length (which again is another subject for discussion!).
Whether this 'sub-lobe break-up' has an impact on overall noise temperature and G/T figures is still to be determined (I have not spent enough time on it until now to decide this). However, the deep wide nulls between these lobes are certain to have a positive impact with real-world noise reduction at certain angles of elevation or distances from the antenna (when not elevated).

There are no 70 cm versions of the OWL-GT at the time. Firstly, pattern cleanliness is much more important at 70 cm than at 144 MHz as raised early in this article, so the same models produced on 144 MHz would not be acceptable performance-wise on 432 MHz.

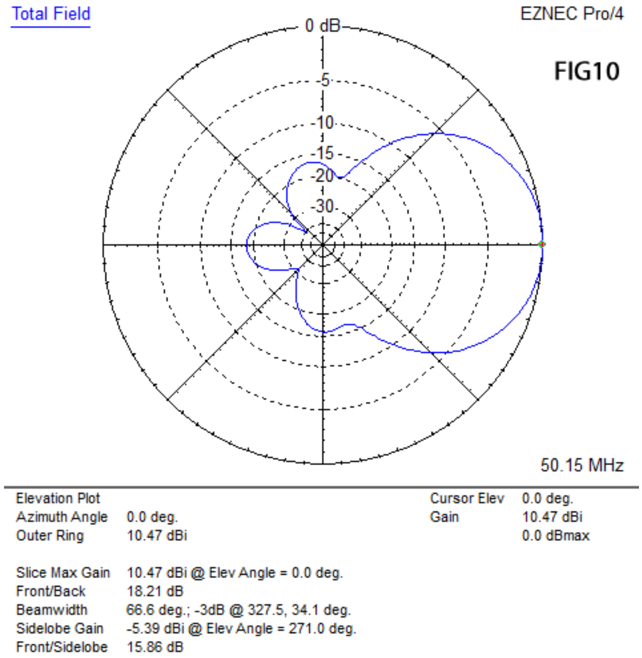

Fig. 10: El plot 5 el OWL for 50 MHz with 46 mm FD

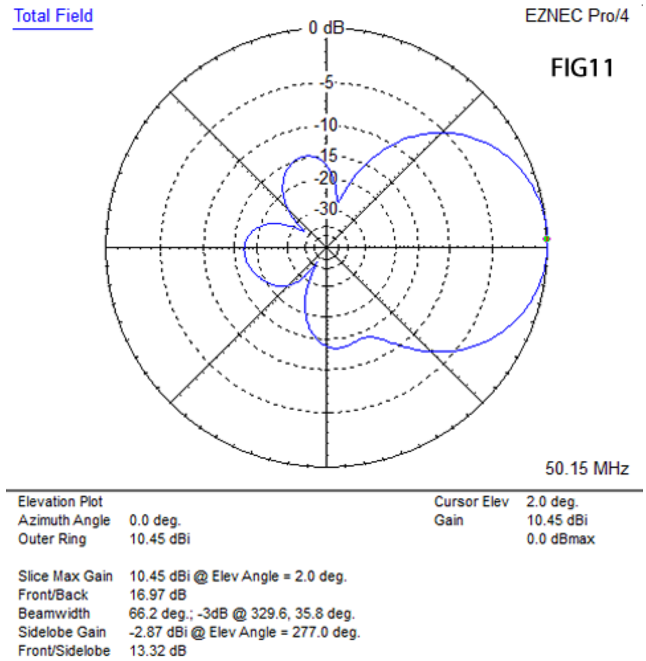

Fig. 11: Ditto with 363 mm FD

Second and most important of all, a folded dipole is not suitable for use on 432 MHz antennas. At least not with the size it has to be with the mechanical constraints we have when building antennas for this band.

Last time in DUBUS we discussed the effects of off-set feed points and of course the folded dipole falls in this category. In Fig. 10 we see the elevation plot for a 5 element 50 MHz OWL on a 3.8 m long boom. Note the marked distortion in this antenna with folded dipole being just 46 mm between top and bottom. It is important to note that I have arranged the feed point in order that the highest levels of distortion are up-facing and for most (including me) this level of distortion (especially at 50 MHz on an antenna this short) is acceptable. However, this 46 mm wide folded dipole translates to a dipole with just 6mm of spacing at 432 MHz, hardly practical for this band as both sides of the element would be inside the boom, only when Yagis with non-metallic booms were in use might this size of folded dipole be practical enough for consideration.

To put this into perspective, should we have installed a 46 mm wide folded dipole on 432 MHz, this would translate to a folded dipole with a width of 363 mm at 50 MHz. This would simply never be considered for obvious reasons and without question, it is the off-set of these folded dipoles (and matching devices on Yagis at UHF which extend well away from the drive element) which lead to the poor performance we have become accustomed to on these bands. Fig. 11 shows the same 5 el 50 MHz OWL with a 363 mm wide folded dipole inserted. Can you imagine the impact this would have on the noise temperature of a longer Yagi at 432 MHz, or 1296 MHz even and yet there are commercial antennas out there with folded dipoles which scale to much wider/larger parameters than this one?
In future articles I would like to discuss and explore the impacts of such distortions at 432 MHz and above and how perhaps these issues could be over-come mechanically in order that antennas with much more acceptable performance can be produced both by the home constructor and commercial builder alike.

Conclusion

Certainly the best is yet to come as far as the optimum 144 MHz Yagi is concerned and certainly while there are impressive Yagis at 432 MHz and above, the mechanical issues which start to show at 144 MHz are major hurdles still to be overcome on the upper bands. G/T is without question an important parameter and means of comparison for 144 MHz antennas but when selecting antennas, the location of any array and long with consideration of any elevation lobes should be of equal importance. Even in the quietest locations, man-made (perhaps shack-made?) noise will be an issue at some stage or other that could have perhaps been reduced or removed by a more detailed selection process.
Until next time. Justin G0KSC

Reference

[1] Justin Johnson, G0KSC: Achieving pattern symmetry within stacked Yagi arrays with off-set feed points. DUBUS 1/2013, pp 98-100.