Revolutionary 'Loop Fed Array' Yagi Antenna Feed System

by Justin Johnson, G0KSC

This is an introduction to the LFA 'Loop Feed Array' Yagi pioneered by Justin Johnson G0KSC. The LFA Yagi is not fed with a dipole as traditional Yagi antennas would be. Instead, it is fed with a rectangular loop which is laid flat on the boom of the Yagi in place of the dipole driven element. The LFA is not 'The Holy Grail' of directional antennas and will not give any additional forward gain for any given boom length. However, it has a new and unique combination of properties which can be tailored to provide improvements in many areas over a traditional dipole-fed Yagi. These will be explained fully through this article.

About this Work

Since I was first licensed in 1988 I have had a keen interest in antennas and built many basic antenna systems, mainly from wire. A rekindled interest in 50MHz two years ago led me to search for a directional antenna but I wanted to build it myself. That is when I found the website of YU7EF, Popa (www.yu7ef.com). 'Pop' has many interesting 'OWA' (Optimized Wideband Array) antenna designs with very clean patterns – for those in the know, the sidelobe suppression he has achieved from standard Yagis is second to none. I first built one of Pop's designs for 50MHz and then another for 28MHz, which both performed very well indeed. The next step for me however was designing my own. While the techniques are a subject for another time, my objectives were clear: without copying other people's designs, I wanted to achieve similar or even better results than anything I had built to date. However, after playing with designs within modelling packages and comparing my results to Pop's published designs, this was going to be a challenge! In the hope that I could achieve these goals there have been many hours of trial-and-error and 'what if' experiments, followed by many more hours of questions and discussions with Pop. I owe Pop a debt of gratitude for the many Skype hours and e-mails back and forth. Without his help, my (still limited) knowledge would not have extended sufficiently to make this new LFA design possible. Pop is one of amateur radio's finest!

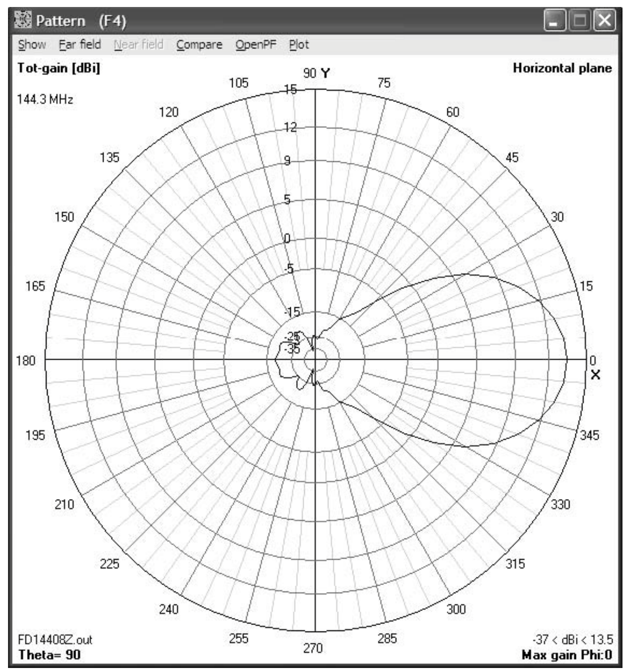

Fig. 1 Is that pattern real? First taste of the LFA Yagi comes from an 8 ele LFA for 144MHz with 13.5dBi forward gain

Stumbling upon the Loop Fed Array

This new development began from an experiment with folded dipoles within Yagis. Although I like Yagis with a 50Ω feed point, I also appreciate some of the qualities of lower impedance antennas, namely higher front-to-back ratio on smaller arrays in particular. I decided to experiment with the folded dipole to increase the feed impedance. The use of a folded dipole with 50Ω Yagis like the DL6WU series is well known; but what if I could create a Yagi with a 12.5Ω driven element impedance and again replace the simple split dipole with a folded dipole? This would step up 12.5Ω to 50Ω balanced, and then some other form of 1:1 balun could be used to give a very simple 50Ω feed system. Also, the wideband properties of the folded dipole may extend the very narrow VSWR bandwidth typically seen in a 12.5Ω Yagi, and perhaps remove some of the 'twitchy' tendencies of these lower impedance antennas.

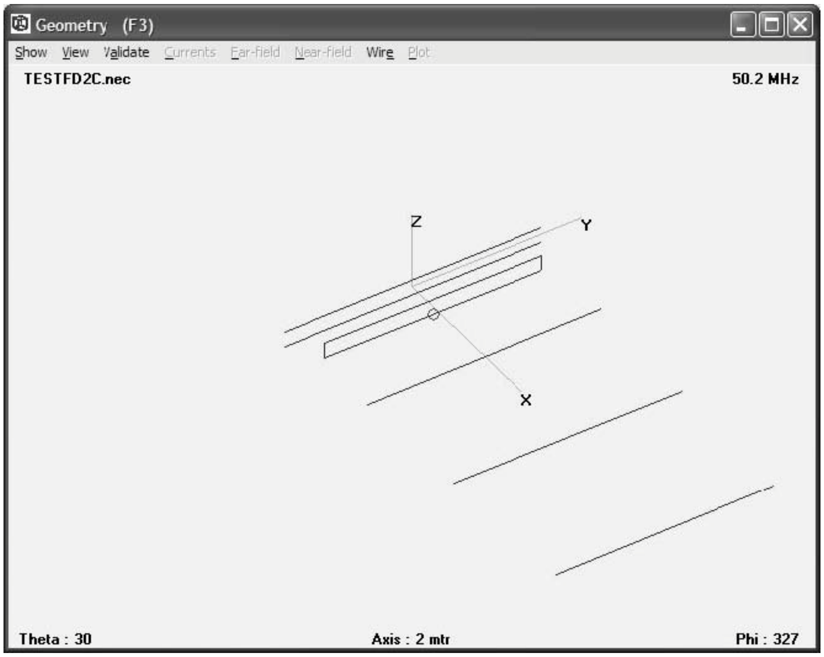

Fig. 2 One of the test designs on the way to the Loop Fed Array Yagi

I started modelling 50MHz Yagis using a folded dipole in the traditional way, but with limited results. Out of frustration, I decided to extend the vertical height of the dipole (above and below the boom) so the top and bottom elements were spaced 20cm apart. To my surprise, F/B and forward gain increased slightly and tuning became more flexible. I opened the dipole again, now 30cm. Again, I saw improvements but now the driven element had become a loop and was protruding quite a long way above and below the boom. When I achieved the optimum level of performance, the loop stood over 23cm above and below the boom (46cm in total). In experimenting with double elements front and back of this loop and placing two reflectors in-line with the top and bottom sections of the loop, I came close to re-inventing several types of antenna from before the computer age! These experiments and single director elements placed on the boom achieved good results. For example, a 5 element 50MHz Yagi with a boom of 4.6 metres in a configuration like **Figure 2** showed a forward gain of almost 11dBi (free space) and 22dB F/B ratio, along with a direct 50Ω feed requiring only a 1:1 balun. This is better than a more modern OWA style Yagi of similar boom length and the pattern looked better too. This was all well and good – but how hard was it going to be to build and test? Supporting two reflectors and holding a large loop in place was not going to fit well with the easy-to-construct Yagi designs that I already have on my website. Perhaps this needed a re-think…

The loop is a bit big standing upright, so what happens if I lay it down on the boom? It will now be on top of the reflector and first director, so I will need to make the boom a little longer. If I make the reflector and first director the same distance away from each side of the loop that they had been with a simple dipole, I could give that a try. Yes, I needed to re-model… but boy, was it worth it!

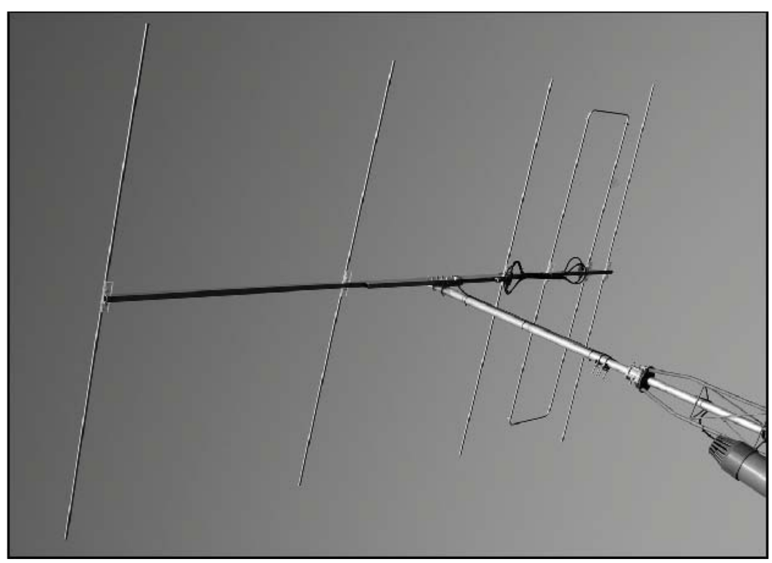

Fig. 3 The FD0605H 50MHz 5el LFA Yagi installed on the G0KSC tower

Eureka!
The patterns were so clean and the front to back ratio increased dramatically. Furthermore, I could model more and more front to back without getting any unwanted lobes! Although the gain was still a little down on Pop's benchmark antennas, I seemed to have found something new and very worthwhile.

Having had an additional month or two of experimentation, and having now been able to build and test one of these designs, I have a much better understanding of the associated benefits of the antenna. I have listed my findings to date below. I am sure I have only scratched the surface so far, and hope that others will help to extend the experimentation with this design to reach its full potential.

But first, here is a taste of what can be achieved with the LFA concept, on three different bands. **Figure 3** is the 5 element LFA Yagi for 50MHz. This antenna is now built and in use at G0KSC. The design will be explained and analysed in some detail later, but as an example of its performance, **Figure 4** shows the excellent 50Ω match across a very wide bandwidth. Return loss is better than 30dB across 500kHz.

Figure 5 shows a 3 element LFA Yagi for 70MHz, optimized for forward gain rather than F/B, and exhibiting more than 9.3dBi forward gain on a short boom. **Figure 6** is an 11 element LFA Yagi for 144MHz exhibiting good gain and an extraordinarily clean pattern.

LFA Yagi Advantages
The advantages of the LFA concept that I would like to identify and discuss in more detail are:

- Superior front to back ratio
- Exceptionally clean patterns
- Ultra-wideband gain and matching characteristics
- A new definition of the 'ideal' boom length
- Flexible feed point arrangement
- Direct 50Ω feed
- Optimization of loop dimensions. In the following sections I will discuss each of these points in turn. Then I will describe a practical LFA Yagi for 50MHz, followed by details of further designs for 144MHz and 70MHz.

Superior Front to Back Ratio
Quad beams are renowned for their readily achievable clean patterns, with superior front to back properties over Yagis (when comparing like numbers of elements in small arrays). The LFA Yagi seems to have picked up this desirable characteristic. In models created so far, front to back figures of between 3040dB have been readily achieved in Yagis of 7 and 8 elements without distorting the forward pattern or indeed creating any unwanted sidelobes. In addition, 3 and 4 element patterns look very similar in shape and performance to quad alternatives. This is one of the benefits of the LFA, as traditionally fed OWA antennas tend not to model well unless at least 4 elements are used.

Exceptionally Clean Patterns
Another very nice 'quad-like' characteristic of the LFA Yagi is side lobe suppression. This is of particular importance when short boom, multi-antenna arrays are being used for EME work. It can be quite a challenge to eliminate rearward lobes in the elevation plane which will lead to noise being picked up from residential locations (and perhaps causing interference in these locations too). The LFA Yagi provides the best benefits of both small quad and Yagi antennas in one design. The LFA concept also offers more design variables that can be used to tailor the

performance to suit individual requirements. Although it may require much more antenna modelling, there is also a good possibility that the design objectives can be surpassed rather than merely achieved.

Ultra Wideband Characteristics

In modelling of both 10 and 11 element LFA Yagis for 2m I have achieved over 15dBi forward gain along with more than 34dB front to back ratio, with no significant sidelobes or unwanted forward lobes and a VSWR of less than 1.1. This is exceptional performance indeed, but even more exceptional considering how well this performance is maintained across a very wide bandwidth between 144MHz and 145MHz. This Yagi provides the nucleus of a very effective array for the serious DXer and EME enthusiast. **Figure 4** shows similar wideband VSWR performance for the 50MHz LFA Yagi.

A New Definition of the 'Ideal' Boom Length

As any Yagi experimenter will know, for any given frequency and number of elements there is an 'ideal' boom length that provides the best balance between forward gain and front to back ratio. Shorter boom lengths will generally provide higher F/B but at the expense of forward gain (though if the boom is made even shorter the F/B will begin to drop as well). With longer booms, forward gain increases but F/B ratio drops away or becomes much harder to achieve. An interesting characteristic of the LFA is that the 'ideal' boom length is greater than for a conventionally fed Yagi with a similar director structure, and this tends to give both more gain and improved F/B ratio. This is in part due to the size of the loop and the extra space it takes up on the boom – behind and in front of the loop, the spacings of the reflector and first director remain similar to those of traditional Yagis. When the loop is made more square in shape, so that it occupies even more space along the boom, both the forward gain and the F/B capabilities increase together. Using the 50MHz 5 element Yagi as an example, the loop length (along the boom, the X-axis dimension in the models) is around 45cm and therefore this extra length must be added to the boom. I have achieved 11.3dBi forward gain and over 20dB front to back from a boom length of a little over 5 metres, which thus becomes the new 'ideal' boom length for such an antenna. [Editor: the Addendum to this article explores some possibilities for making boom lengths even longer.]

Flexible Feed Point Arrangement

Another powerful aspect of the LFA is the flexibility of the feed arrangement and how it can alter performance of the Yagi. From the limited experiments made so far, it has been established that if the loop is fed at the rear centre (nearest to the reflector, as shown in Figure 7), better wideband performance can be achieved than by feeding at the front centre. Although the feed point cannot simply be switched from one position to the other without re-optimization, a front feed can provide a slight increase in forward gain and F/B; the VSWR bandwidth is narrower than for rear feed but still better than seen in comparable traditional Yagis. As stated above, the length of the loop along the boom can also be varied to change the LFA's operational characteristics. More experimentation is required to establish which is the best way to feed this antenna.

Direct 50Ω Feed

As with all of my designs for the amateur builder, there is no need for any matching unit, coaxial stubs or any other tuning arrangements at the feed point. A simple 1:1 balun or coaxial choke is enough. Fine tuning can be achieved by moving the ends of the loop in or out (very much as one would to tune a folded dipole). Figure 8 shows another example of the LFA's excellent VSWR bandwidth. Note that the narrow dip which is so characteristic of the dipole fed Yagi has gone. For the practical version of the FD0605H 50MHz 5el Yagi (Figure 3) I tried a 1:1 voltage balun (branch feed with ¼ wave and ¾ wavelengths of coax). This was successful but the ends of the balun must terminate upon the loop itself. Any connecting wires will de-tune the antenna and increase the VSWR.

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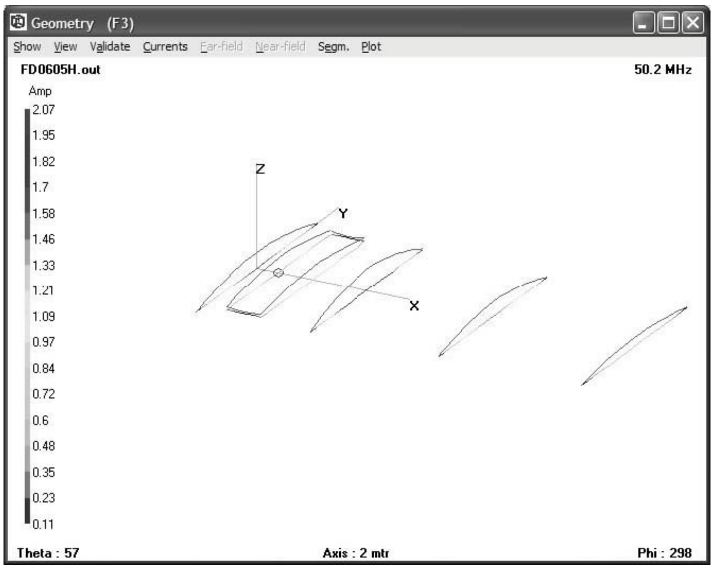


Fig. 7 The FD0605H showing current distribution and magnitude within the model. Note that the loop is rear fed giving greater bandwidth than a front fed version.

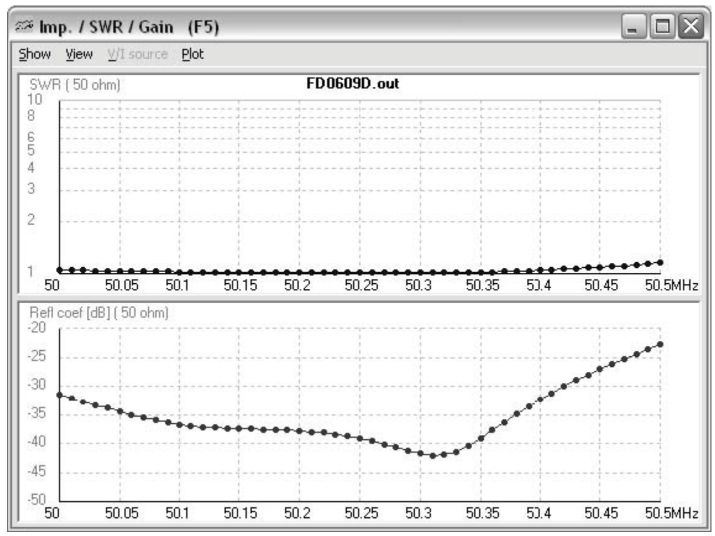


Fig. 8 The VSWR and return loss plot for a 9 element 50MHz LFA Yagi.

Optimized Loop Dimensions

As already noted, the loop dimensions offer more design variables that can be used to help optimize the entire Yagi array. There are still many more tests to be conducted. The loop circumference is close to a full wavelength, but modelling experiments have already established that by altering the shape of the loop, the F/B ratio and forward gain can be balanced one against the other. The typical width of a loop (the Y dimension, parallel to the parasitic elements) for 50MHz would be around 10cm shorter than the first director and the loop length (X axis, along the boom) between 35cm and 60cm for best results. When starting a model for 50MHz, I typically use 2.5m width and around 45-50cm length, although with certain boom lengths a smaller loop length of 35cm has also returned good results. Scaling those dimensions for other bands will

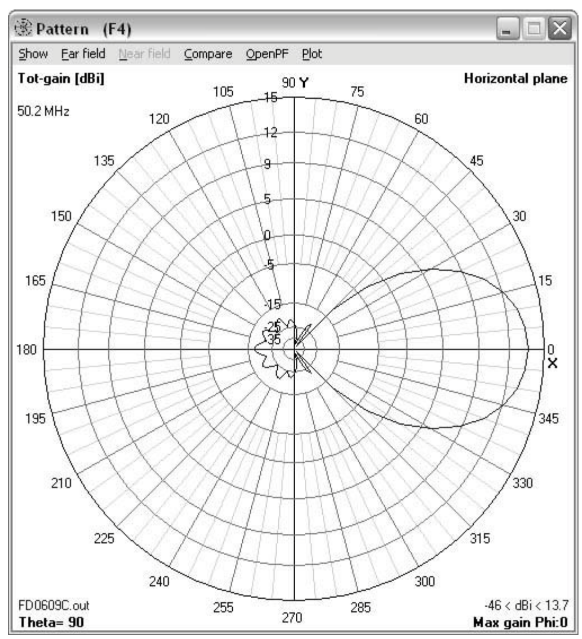


Fig. 9 The 9 element 50MHz LFA Yagi has a very clean pattern

give a good starting point. For example, with 5mm wires at 144MHz, the loop length I am using is around 16-18cm along the boom.

To fine tune the antenna once it is in place, I recommend making the end sections of the loop from a smaller size of telescoping tubing, so it can be slid in and out to alter the total circumference of the loop. However, it is important to note that part of the side lobe suppression is delivered by the anti-phase currents along the ends of the loop. To reproduce the computer models as accurately as possible, the corners of the loop should be formed as small radius bends (Figure 3). If these ends are formed as half circles (to look like a large folded dipole), the side lobe and unwanted forward lobe suppression would be worse.

5-Element 50MHz LFA Yagi

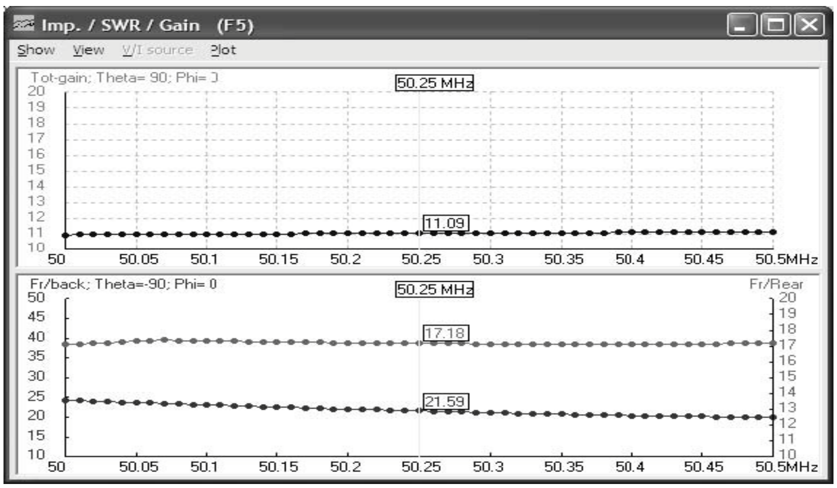


Fig. 10 Both gain and front to back are relatively flat throughout the band

I decided first to build an ultra wide-band, low return loss 5 element LFA Yagi for 50MHz. One reason for building an antenna with such a flat VSWR curve was to ensure that if the computer model was not accurate, it would be easy to see where to make any adjustments. As it turned out, the Yagi when built was absolutely spot-on! Many details of this antenna have already been shown in Figures 3, 4 and 7, and continuing with Figures 10 and 11. The double-dip VSWR characteristic (Figure 4) is thanks to further optimization by Pop, YU7EF. I decided to construct an antenna that would stand up to the weather and any birds etc, so for the elements I used single pieces of ⅝-inch (15.9mm) tubing, completely insulated from the boom. The driven loop is tuned by sliding end sections made from ½-inch (12.7mm) tubing. As mentioned earlier, it is important that the loop has straight sides and sharply bent corners. Use hose clips when fine tuning for the best return loss/VSWR, but the ideal would be to weld these joints once optimum performance has been achieved. This will ensure no performance degradation later in the antenna's lifetime.

Metric sized tubing of 16mm and 13mm could also be used, which will shift the antenna's resonance slightly LF. Although I have not tested this (due to not having those materials) it is likely that any difference will not be noticeable in practice due to the wideband characteristics of this antenna. Perhaps at most, 1mm will need to be moved from the element ends to compensate. The boom is made from a 4.8m section of 1¼inch box section aluminium tube with a second 1.5m boom section bolted beneath the main boom for additional support. The boom is then bolted to a 4-inch (100mm) wide aluminium plate, ⅜-inch (9.6mm) thick, which is U-bolted to the 2-inch supporting mast.

On-air performance

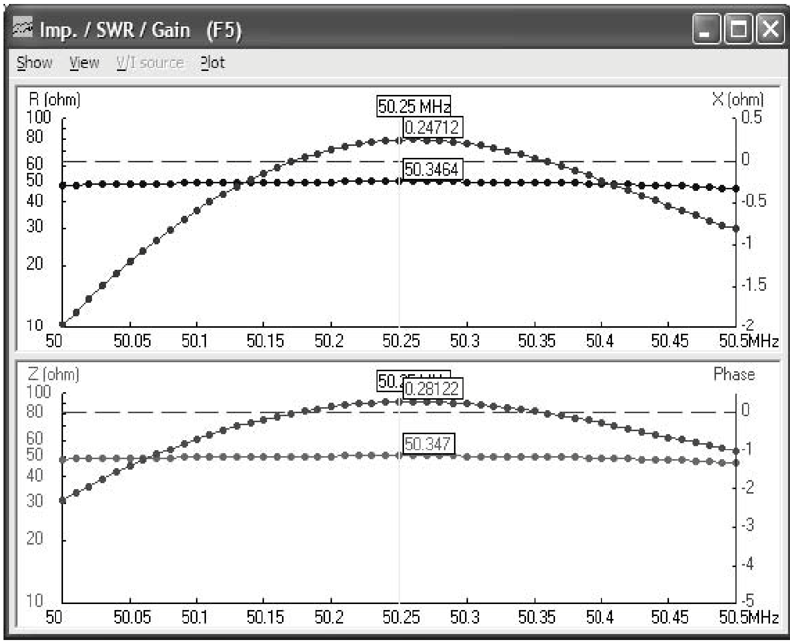
The antenna shows 1:1 VSWR at both 50MHz and 50.5MHz, rising to 1.15 around 50.25MHz. The first thing I noticed was very low noise pickup. I was a little concerned as this is what I would normally associate with an antenna not designed for the band of operation. However, any apprehension swiftly moved on when I was listening to a nearby contest station G0VHF/P. While they were calling CQ, I quite clearly heard EA3TI calling them back and let them know. A little later while calling CQ myself, the same station spotted me on the clusters so it is working! There is still no real Es to speak of as I write. My front to back tests came in a few different forms. The first was with the Oxford beacon, GB3BAA, which I could completely remove from hearing if I pointed the beam in the opposite direction. I was able to conclude my on air front to back tests with local stations sending JT6M data for 30 seconds at a time. This allowed me to spin the beam from one side to the other during this period and check the results. I am now looking forward to making further measurements and building higher suppressed, longer boom versions of this antenna!

Antenna Dimensions (m):	**Spacing**	**Element half length**
Reflector	0	1.482
DE1 (rear of loop, feed point)	0.287	1.251
DE2 (front of loop)	0.828	1.251
D1	1.380	1.383
D2	3.026	1.324
D3	4.732	1.299

The remaining designs in this article are optimized models, not constructed yet. Dimensions are as they come from the optimizer, and have not yet been rounded to practical sizes. Most models do not include resistive losses in the element materials, but these will lose only a small fraction of a dB in forward gain. All the LFA Yagi designs are relatively wideband and the predicted performance is not sensitive to small changes in dimensions, so we can expect the real-life antennas to achieve very similar performance to the computer models.

11-Element Low Temperature 144MHz LFA Yagi

This design is the one shown in Figure 6, further optimized for low temperature, and once again it benefits from contributions by Pop, YU7EF. Figures 12 and 13 show the exceptionally clean pattern, and according to the TANT software by YT1NT (www.geocities.com/va3ttn/Tant.zip) this antenna is lower in noise temperature than any 11 element Pop has produced to date… though maybe I was lucky with this one, and future designs may need a little more work! One benefit with the LFA concept is that the loop dimensions give extra degrees of freedom when designing. Altering the length of the loop along the boom is one such factor which alters side lobe suppression, unwanted forward lobes and F/B ratio – though sadly, not all at the same time. Like any Yagi design, you need to trade one performance parameter against the others to arrive at your chosen goals for optimum performance. This antenna has been designed using 5mm elements and therefore should be more 'Euro friendly' for obtaining the materials in metric sizes. The original design was based on a continuous loop of 5mm tubing with no provision for practical adjustments. If you decide to use the same kind of telescoping end sections as I did on 50MHz, I suggest you use 8mm tubing for the main parts of the loop and 5mm for the end sections, and have included both sets of dimensions below.



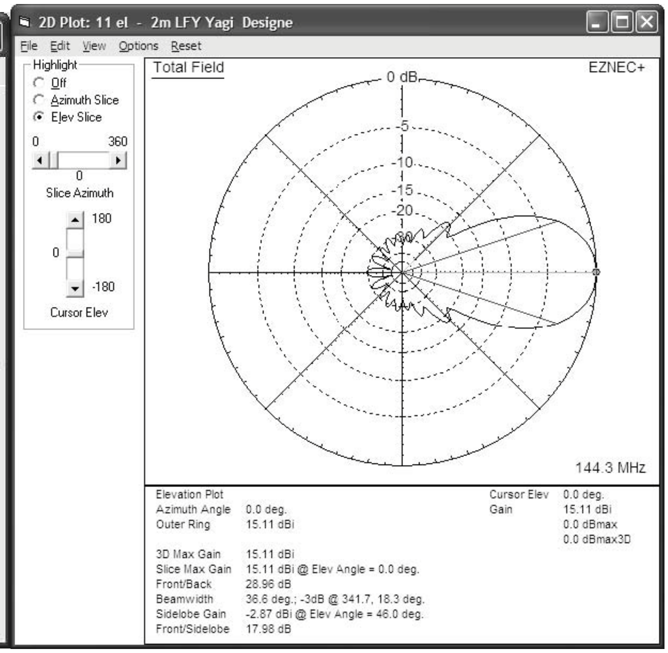


Fig. 11 Very little reactance with two points of resonance help ensure a very wideband antenna

Fig. 12 The 11 element 144MHz low temperature LFA Yagi has a nice clean pattern

Antenna Dimensions (m): Reflector	**Spacing** 0	**Element half length** 0.5135
DE1 (rear of loop, feed point)	0.150	0.4365 (5mm) or 0.438 (8mm, with 5mm ends)
DE2 (front of loop)	0.310	0.4365 (5mm) or 0.438 (8mm, with 5mm ends)
D1	0.528	0.4845
D2	0.922	0.467
D3	1.396	0.462
D4	2.012	0.4575
D5	2.754	0.452
D6	3.577	0.446
D7	4.430	0.442
D8	5.295	0.4335
D9	6.100	0.425

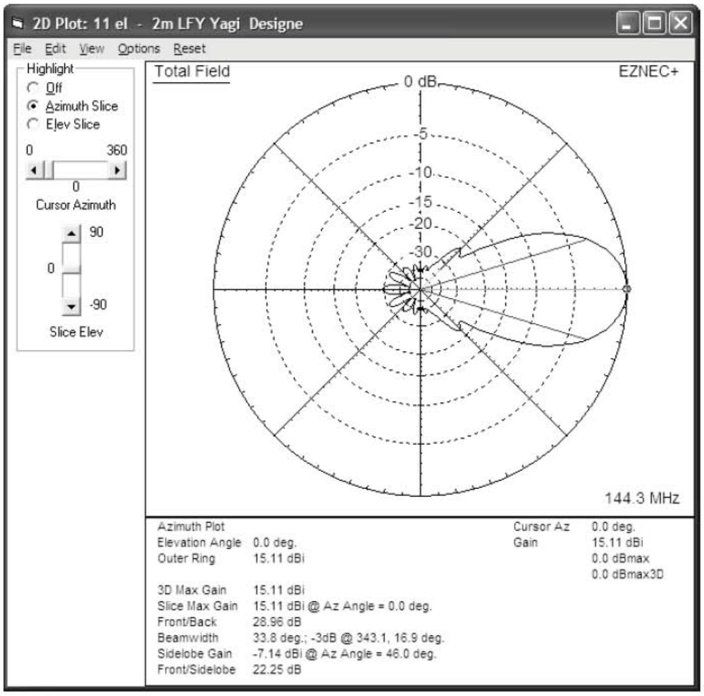


Fig. 13 (left) The elevation pattern looks good too – better than the horizontal pattern of most yagis

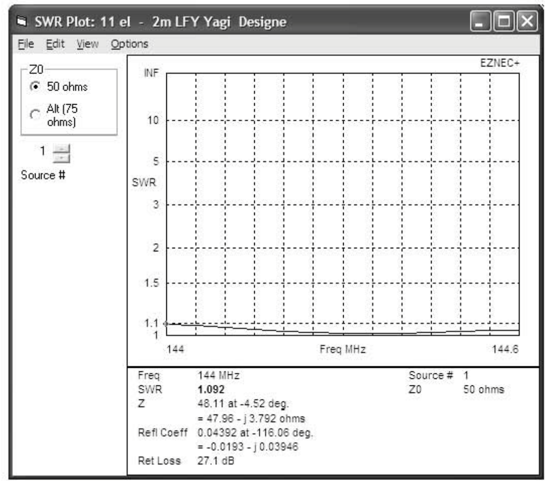


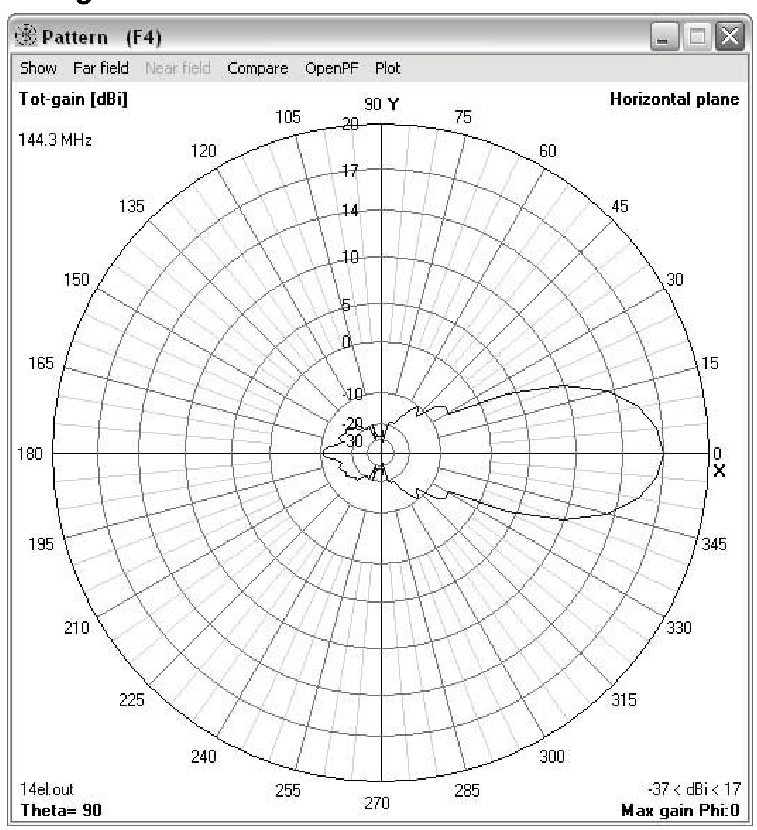
Fig. 14 (right) VSWR with 5mm loop driven element. The 8mm/5mm loop gives a slightly lower and broader curve

Predicted Performance:

Forward gain 15.1dBi @ 144.3MHz F/B 29dB @ 144.3MHz F/R 27.6dB @ 144.3MHz VSWR Better than 1.1 from 144.0MHz to 144.6MHz Return loss Better than 27dB from 144.0MHz to 144.6MHz

14-Element Low Temperature 144MHz LFA Yagi

This time I have modelled using ¼-inch elements for the UK, US and Australasia regions using inch sized tubing. As with the 11 element version, a 4-part loop should be constructed using ⅜-inch (9.6mm) tubing for the long sections and ¼inch (6.4mm) for the sliding end sections. As with the other designs, a very similar antenna could of course be constructed using metric sized tubing.



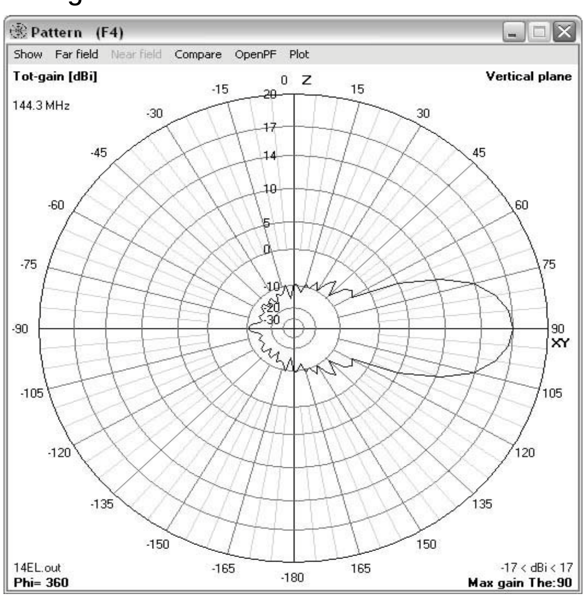


Fig. 15 (above) Again unwanted side lobes are strongly suppressed in the horizontal pattern

Fig. 16 (left) A nice clean elevation pattern too. This antenna should be an exceptional EME performer

Antenna Dimensions (m):	Spacing	Element half length
Reflector –	0.068	0.516
DE1 (rear of loop)	0.149	0.458 (¼-inch) 0.462 (⅜-inch)
DE2 (front of loop, feed point)	0.308	0.458 (¼-inch) 0.462 (⅜-inch)
D1	0.448	0.4895
D2	0.908	0.475
D3	1.533	0.464
D4	2.298	0.456
D5	3.106	0.4505
D6	3.974	0.4435
D7	4.873	0.438
D8	5.802	0.432
D9	6.747	0.4265
D10	7.686	0.425
D11	8.621	0.427
D12	9.397	0.4375

Predicted Performance:
Forward gain 17.0dBi @ 144.3MHz F/B 27.2dB @ 144.3MHz F/R 25.7dB @ 144.3MHz
VSWR Better than 1.1 from 144.0MHz to 144.6MHz
Return Loss Better than 29dB from 144.0MHz to 144.6MHz

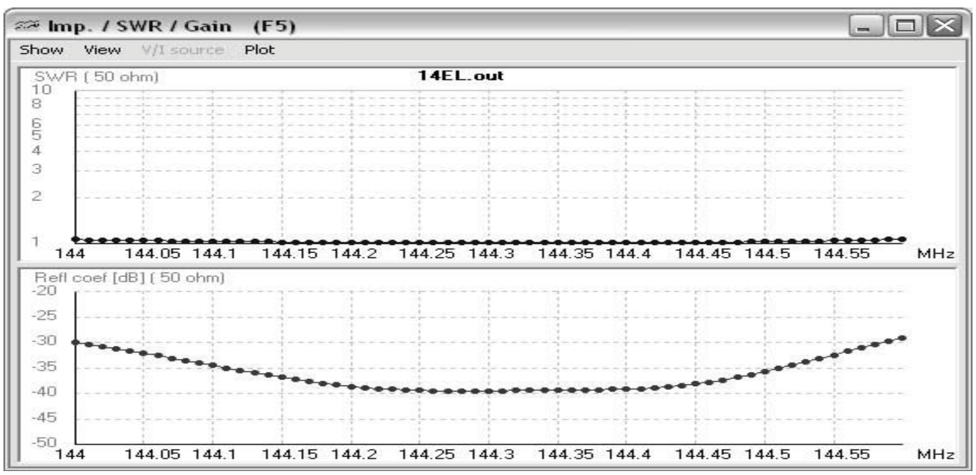


Fig. 17 This antenna has been optimized for VSWR and return loss as well as an excellent pattern

4-Element 70MHz LFA Yagi

This final example shows more clearly what I describe as the 'quad like' characteristics of the LFA Yagi. This antenna provides almost 10dBi forward gain (Figure 18) while delivering quad-type F/B ratio within a compact design. That is achieved by trading off some of the LFA's broad VSWR bandwidth (Figure 19). This antenna was designed for inch-sized tubing and has tapered elements. A single 600mm piece of ⅝inch (15.9mm) tube forms the centre of each element, giving a half-length of 300mm each side. The outer sections of each element are made from ½-inch tube (12.7mm) and the loop ends are ⅜-inch (9.6mm).

AntennaDimensions (m)	Spacing –	Element half length
Reflector	0.271	1.073
DE (rear of loop, feed point)	0.115	0.899
DE2 (front section)	0.474	0.899
D1	0.983	0.977
D2	2.43	0.864

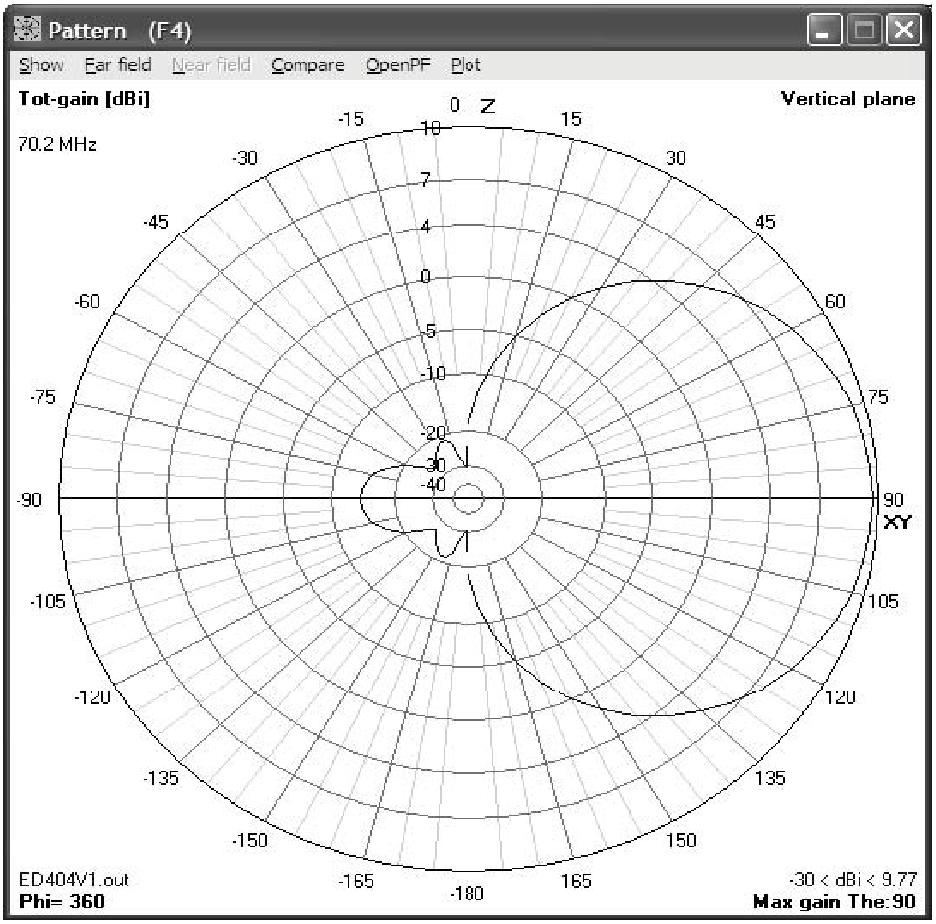


Fig. 18 Remarkable gain and front to back ratio from a 4 element LFA Yagi

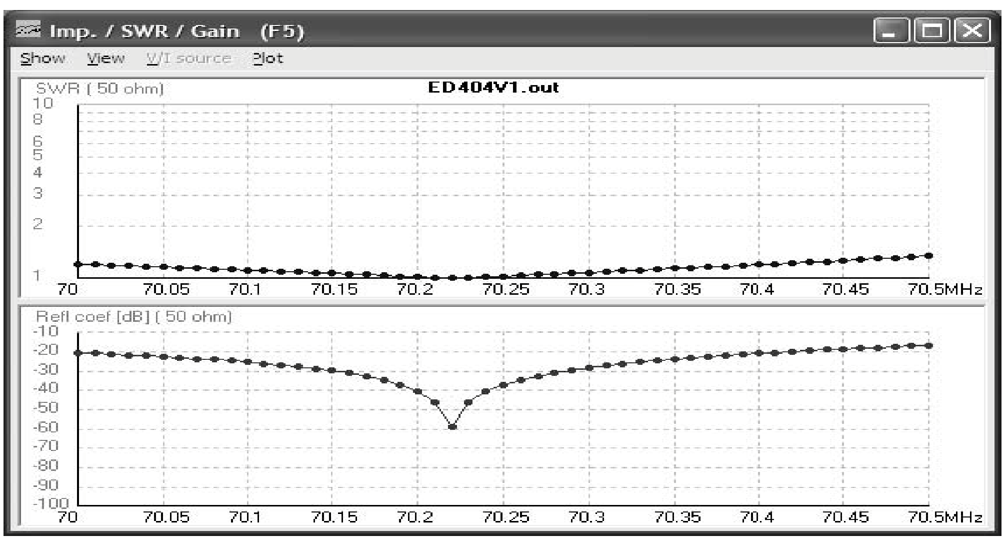


Fig. 19 VSWR bandwidth has been traded for extra gain, but is still better than many conventionally fed Yagis

Conclusion

I believe I have only scratched the surface of the LFA Yagi concept. In a relatively short time it has enabled me to create some very good models which are now beginning to show proven practical results, so I am sure that with more time and many more minds, the LFA concept can produce some remarkable antennas. I am also working on a number of models for 70cm and 23cm that have equally impressive predicted performance – perhaps these will be the topic of a later article! By offering more design variables than a traditional Yagi (the width, length, positioning and feed point of the driven loop), the LFA Yagi offers much more flexibility in design and optimization, so that more of the desirable performance objectives can be achieved simultaneously. Overall, this will result in superior performance. At last it seems possible to achieve more of the characteristics of the legendary quad antenna within the compact and more visually pleasing outline of a Yagi, while also losing some of the less desirable properties of traditional Yagis. I am sure that, like me, many hams will see the LFA Yagi as a viable alternative to both the quad and traditional Yagi, and equally I believe the LFA will become a common feature within DX and EME stations. If you have any comments, suggestions or findings relating to the LFA, please let me know and I will be happy to share these results on my website, which in the near future will have a section dedicated to the LFA designs.

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Addendum: Modelling extra-wide spaced arrays

We have already touched upon the ability to extend the 'ideal' boom length beyond what we would expect in a dipole-fed Yagi. What if we were to push this ability to the limits? I have had some excellent results with opening up the spacing on the elements. No additional gain is achieved per metre of boom, but the same gain can be achieved with fewer elements. On bands where wind loading plays an important role in the design criteria, this model may be for you. During testing, I managed to achieve more than 12.2dBi forward gain from a 5 element 50MHz Yagi – albeit with a 7 metre long boom! This said, the pattern was not as clean as the closer spaced LFA Yagis featured above, and had started to move towards what is typically found with DL6WU style Yagi designs.

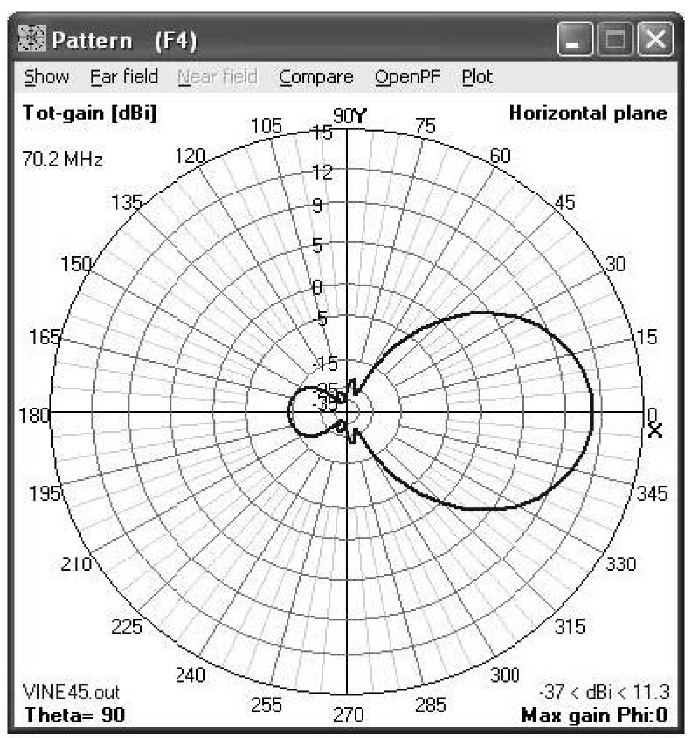

Figure 20 (right) is a 5-element ultra-wide spaced LFA Yagi for 70MHz which exhibits both 11.3dBi forward gain and 25dB front to rear (across the whole rear sector, not just front to back). The 3D pattern shows a very tight 'collar' around the centre and rearward lobes, a typical characteristic of the LFA. How long is it? 4.4 metres is the total boom length, so this ultra-wide spaced LFA Yagi for 70MHz is almost as long as a conventional 5 element 50MHz Yagi – but with extra gain and F/R as a result. I have optimized this design to achieve excellent F/R in addition to good forward gain; some may want to optimize only for forward gain and perhaps 0.3 or 0.4 dB additional gain could be achieved. However, I have learned to value the cleaner patterns with a very high F/R, as local noises and other QRM can be more easily removed from the received signal, so I can enjoy working stations that were not possible previously.

Additionally, early tests of the LFA in stacked and 4X form show an exceptionally low sky temper-ature. In fact, when comparing 4x9, 4x13 and 4x18 element LFA arrays, no other 4 bay array comes close (same number of elements). While the 4x18 element array had the lowest temperature out of any other array listed (including M2 arrays of some 8 wavelengths long on 144MHz where the LFA array is 2 wavelengths shorter), second on the VE7BQH list of arrays was the 4X13 element array!

None of the LFA arrays have been added to the VE7BQH list yet. However, I am starting to list the design files on my site for these arrays so if you are a keen EME fan, these maybe worth taking a look at! **-30-**

Brief Biography of Author

Justin Johnson, G0KSC of the UK has been involved within security, test and measurement of the mobile/Cell phone industry for over 20 years. He is currently working from Stockholm, Sweden for a provider of the above mentioned systems at C level management. He has been a keen ham since childhood which led him into the industry in which he works today.

In more recent times, Justin has become more involved in the development of directional antennas for ham radio providing many free to build Yagi and quad designs online. However, several commercial companies now build and sell his antenna designs too. I pioneered the LFA design in late 2008. It has been patented (for commercial use only, if building for you own use, there is no issue) and now several antenna manufacturers around the World build and market my LFA Yagi designs.

The LFA provides quad like performance from a Yagi Antenna. I provide many LFA designs upon my website for Hams to build themselves for free. More info at www.g0ksc.co.uk

The two antennas now installed at G0KSC a 6.6-meter 50MHz LFA and a 4.4-meter 70MHz LFA

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Send mail to webmaster@antennex.com with questions or comments.