The Moxon Claw revisited (part 1)

A very compact and high performance beam for 14, 18, 21, 24 and 28MHz

PHOTO 1: The distinctive shape of the Moxon Claw antenna explains its name.

INTRODUCTION. In the second edition of his ground-breaking book *HF Antennas for all Locations* **[1]**, the late Les Moxon, G6XN, describes a highly innovative and compact beam antenna that he called the Claw, owing to its shape (**Photo 1**). The Claw covers the 14, 18, 21, 24 and 28MHz bands using two remotely-tuned loop elements.

G6XN's design is based on right-angled delta loops, which he termed small delta loops (or SDLs) because they have a perimeter of substantially less than a wavelength on the Claw's lowest band, 14MHz.

Whilst Les is perhaps best remembered for his two-element beam known as the Moxon Rectangle, in my opinion the Claw is his finest antenna design, providing gain and front-to-back rejection that is equal to or better than full-sized conventional two-element antennas on 14, 18 and 21MHz and superior to those antennas on 24 and 28MHz.

Variants of the Claw have been in use at VK6APH for about 15 years and have been tested against a variety of antennas, including a commercial full-sized three-element 14MHz Yagi and a three-element 14, 18, 21, 24 and 28MHz Yagi with motorised elements of my own design. In terms of performance, reliability and flexibility, the Claw has won hands-down.

In the late 1990s, I had the great pleasure of working with Les on some aspects of the Claw development that are not covered in his book. Les's intention was to write an article on these developments but unfortunately he passed on before completing this work. It is therefore my pleasure to perhaps introduce the reader to the Claw for the first time and document Les' final experiments.

FEATURES. In almost all respects the Claw is a remarkable antenna. It has the following features:

- Small, lightweight, inexpensive and of low wind resistance.
- Its loop elements are not critical in length/perimeter and no mechanical tuning of them is required.
- Covers all bands between 14 and 28MHz as a beam, plus useful operation on the bands below 14MHz.
- Uses two identical loops that are non-resonant on any amateur band and in which the amplitude of the currents are set to be equal using a simple variometer, which gives the Claw greater than a 30dB front-to-back ratio on all bands and the ability to instantaneously reverse its beam direction.
- The antenna's pattern and tuning is controlled from the operating position, using simple switched boom-mounted matching networks and a variometer.
- When used as a beam on 14 and 18MHz the effective height of the Claw is some five metres above its boom height, because the point of current maximum is in the top of the loops. This provides an improvement in performance over a comparable Yagi at the same boom height.
- When used on as a beam on 24 and 28MHz, the loops are larger than a wavelength so the Claw gives more gain than a conventional two-element beam antenna.
- When used on 10MHz with a suitable antenna tuning unit, the Claw shows unity gain but reduced signals off its back (front-to-back ratio) and directivity.
- Smaller than a 14MHz two-element Quad antenna (so not as beautiful, or ugly!).

BACKGROUND. I first came across Les' Claw antenna during a contact with him on 14MHz in 1996. He explained that he was testing a small two-element beam and was looking for signal reports. When Les demonstrated the ability to instantly switch the antenna's beam by 180°, along with its very impressive front-to-back ratio, I became very interested indeed.

I asked Les if he could provide me some further information on the antenna and he advised that details would shortly be available in the second edition of [1].

The book duly arrived and, with great anticipation, I set about modelling the antenna using *EZNEC* **[2]**. I must admit that these attempts at modelling proved inconclusive, but, spurred on by G6XN's reputation and excellent on-air results, I set about building a Claw.

Initially, the results were not particularly encouraging. Whilst my version of the Claw did appear to have some gain and front-to-back ratio, its performance varied daily! After some head-scratching and further experimentation, I found the performance variation to be due to salt build-up on the spreaders of the open wire feeders I was using to feed the loops. In contrast to Les, who lived well inland in the leafy environment of Surrey's North Downs, I live only a few hundred metres from the Indian Ocean and get strong on-shore winds on a daily basis.

After some discussions with Les, in order to overcome the problem I was experiencing, he offered to re-develop the feed system to use 50Ω coaxial cable rather than open wire line. About this time I had to make a business trip to the UK and was consequently – and very fortunately – able to spend a day with Les and his wife, Nancy, in order to gain a better understanding of exactly how the Claw worked.

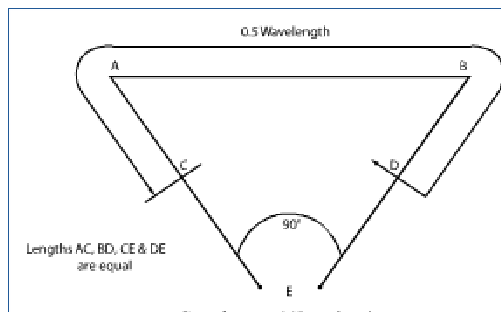

FIGURE 1: Dimensions of the Moxon Claw small delta loop element.

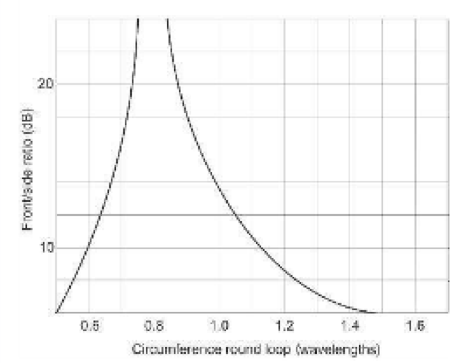

FIGURE 2: Variation in front to side ratio with loop size.

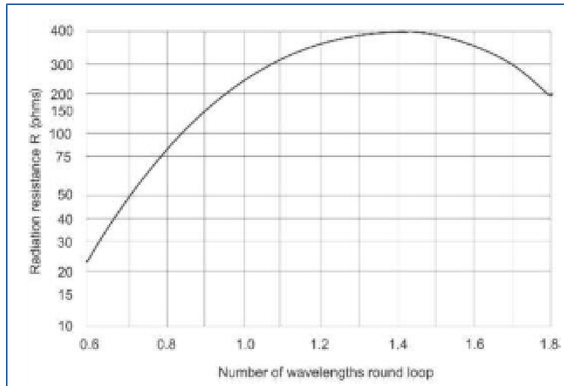

FIGURE 3: Variation of radiation resistance with loop size.

Balanced precariously on the roof of Les's house with the great man for company, there were many moments during the day when (metaphorically) light bulbs went off in my brain. For me, at least, there were a number of critical ideas that were missing from Les's amazing book but once explained in person by the author, the reasons for my lack of initial success became obvious.

As a result, with this additional information and insight I was able to both successfully model the Claw in *EZNEC* and quickly build a working 50Ω version.

THE CLAW IN DETAIL. The Claw is one of an increasingly popular class of beam antenna that is remotely tuneable from the shack. However, rather than physically/mechanically altering the length of the elements, such in the SteppIR antennas or the G3XJP PICaYAGI that was recently described in [3], the electrical properties of the Claw are altered by reflecting the appropriate impedance up the feeders to each loop.

This, together with the design of the element spacing on the Claw, eliminates the use of electric motors on an antenna of this kind and overcomes the sub-optimum element spacing on some bands that antennas with mechanically-altered elements pose. To overcome the latter problem, the loop elements in the Claw are not parallel to each other. Instead, they taper towards each other in the vertical plane, from top to bottom as you move towards their feedpoints, which optimises their spacing on the frequency of use from 14 to 30MHz.

Ironically, G6XN actually pioneered the remote tuning of Yagi-type elements over 30 years ago using his linear resonator technique, explained in detail in [1]. This allows the full length of a dipole element to be used on multiple bands without the need to mechanically alter its length.

Owing to using the full aperture on higher bands, additional gain is obtained with G6XN's linear resonator. Whilst I am sure Les would have been most interested in beams that physically alter their element lengths in order to tune them to different amateur bands, I am equally sure he would have disapproved of throwing away the additional gain that is available by using the full length of the elements on all bands.

The basic building block of the Claw is a 90° small delta loop. The circumference of the loop is approximately 0.85 wavelengths at the lowest frequency of operation – see **Figure 1**.

The reason a 'small' delta loop is used in the Claw is to keep the radiation pattern of each element sensibly constant over a 2:1 frequency range. **Figure 2** shows the variation in front-to-side ratio as the loop circumference is altered. Had a one wavelength circumference loop been used in the Claw, the pattern would be unsuitable for use as a beam element on its second harmonic.

The use of a loop element also means the radiation resistance is much higher than if a dipole element had been used. **Figure 3**, taken from [1], shows the radiation resistance versus frequency at the centre of the top wire in the SDL. Note this is not the resistance measured at the feedpoint of the loop since the 'arms' of the SDL act as transmission lines that alter the impedance at its feedpoint.

By making the diameter of the wire very large, or preferably using a cage dipole form of construction using two wires in parallel (as used in Les' original design [3]), the SDL can be directly connected to open wire feeders and used as a multi-band antenna.

It is interesting to model an SDL built in this manner and fed with 600Ω feeder

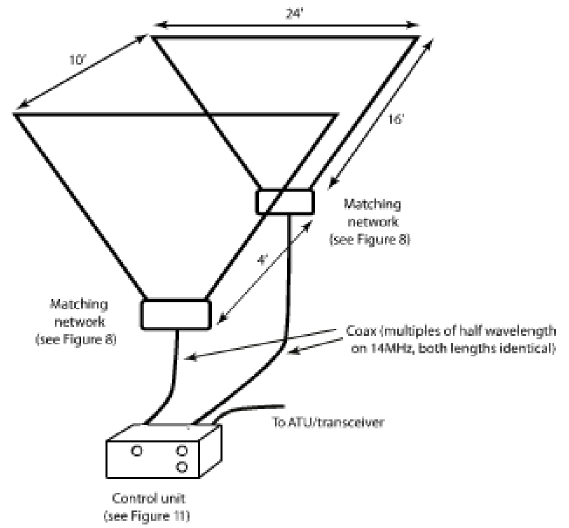

FIGURE 4: Two identical small delta loops are required to give the antenna directional properties.

using *EZNEC* (or similar) antenna analysis software. The SDL shows a remarkably constant SWR over a wide frequency range.

In order to build a directional antenna, a second SDL, of identical size to the first, is added – see **Figure 4**. For operation on the five amateur bands from 14 – 28MHz, the tops of the loops are separated by approximately 305cm (10') and the bottoms by 122cm (4').

The Claw's second loop has its own feeder that runs back to the shack. Since the loops are identical, the decision as to which is the (designated) driven element and which the reflector is made by the operator and, using a suitable change-over switch or relay, enables instantaneous beam reversal.

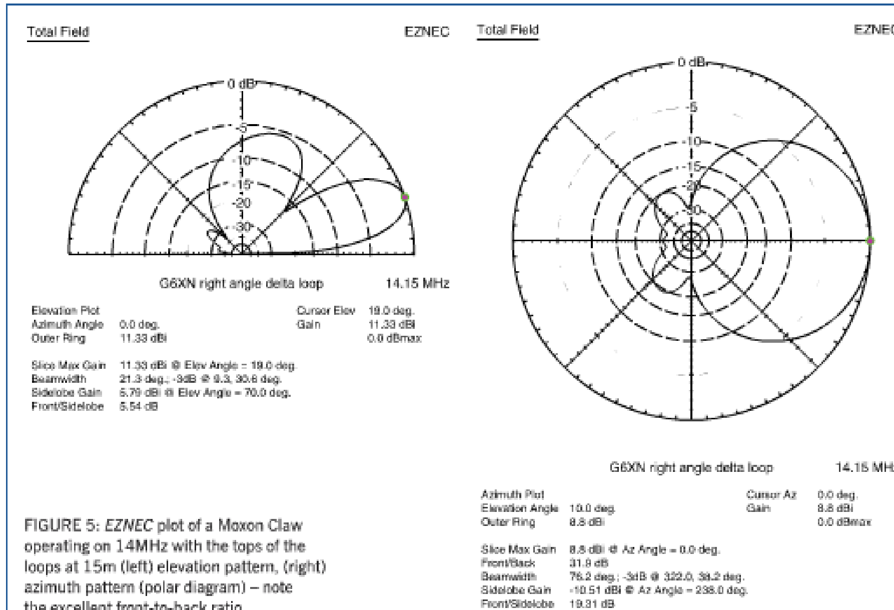

FIGURE 5: *EZNEC* plot of a Moxon Claw operating on 14MHz with the tops of the loops at 15m (left) elevation pattern, (right) azimuth pattern (polar diagram) – note the excellent front-to-back ratio.

The loop intended to be used as the Claw's reflector is bought into use by reflecting the appropriate impedance up its feeder from the shack. More information on how this is achieved is given later in the article.

It should be noted that it is not possible to tune one of the Claw's loops as a director in order to alter the beam direction. This is due to the capacitive nature of the coupling between the two loops.

The Claw is a class of beam antenna in which its elements are referred to as being 'critically coupled' **[4]**. In order to achieve critical coupling, the current flowing in each loop needs to be identical. In theory, an infinite null on the rear of the antenna can be obtained by equalising the loop currents and making the phase difference between the loop currents equal to the loop spacing in wavelengths.

For example, with equal currents, the relative phase is given by

Phase = 180 – (d x 360) degrees

Note that d is equal to the distance between the elements as a fraction of a wavelength and one wavelength = 360 degrees. For example, for a Claw with two elements spaced 1/8th of a wavelength, the relative phase would be:

180 - (1/8 x 360) = 180 – 45 = 135 degrees

The two loops of the Claw couple together well, so in practice all that is needed to achieve equal currents is to make a slight adjustment from the shack. This is also true of a two-element Quad beam (with 1/8th wavelength spacing between the loops), where the loops are naturally well coupled with each other, providing near-equal current in the elements and the resulting high front-to-back ratio.

This also explains why the front-to-back performance of a conventional two-element Yagi beam built from dipoles is so poor – there is insufficient capacitive coupling between the two straight elements. However, bending the element's ends towards each other increases the coupling between them and hence the front-to-back ratio – this is the principle behind Les' Moxon Rectangle antenna.

When used with open wire feeders there are advantages in making each loop of the Claw from two wires in parallel, as per the original description at [4]. After using coaxial feed with parallel-wired loops for several years, I lost one of the parallel wires in a loop during some bad weather. However, despite this, using the remaining single wire, I could not determine any loss in performance. As a result, all my Claws have subsequently been built using a single wire for each loop.

At this stage those readers who are interested in computer modelling of antennas should have sufficient information to allow them to build a model of the Claw and start experimenting with it. Alternatively, a copy of my *EZNEC* file, Claw_20m EZ, is available from the *RadCom* Plus website **[5]**.

A MEETING WITH LES MOXON, G6XN

Les' wife Nancy very kindly picked me up from the nearby train station and, upon arrival at their house, I was 'called from on high' – quite literally. Les was standing on the roof of his house, working on the coaxial cable feed for the Claw. He asked me to join him.

The route to the roof was via various lengths of old wooden ladders that were lashed together with rope and thence to the chimney pot, in the best Heath Robinson tradition.

Upon my rather shaky arrival onto the roof, Les greeted me warmly as though we were both standing on the ground and proceeded to point out the finer details of the coaxial matching network. I must admit that my mind was not fully on his explanations of the Claw but rather on how – and if – I was going to get down safely off the roof!

I'd been advised prior to my visit that Les made extensive use of computer modelling tools when developing his antennas. That turned out to be far from reality – paper, pencils and a four-function calculator were his only tools of trade.

However, over many years of carrying out antenna designing, Les had memorised numerous mathematical short cuts for working out inductance, capacitive reactance and the effects of transmission lines of various lengths. His most impressive feat of mental gymnastics was an ability to actually manipulate a Smith chart in his mind's eye. To stand with Les and see him do this was a truly amazing experience and a privilege.

Les' antenna test equipment was mainly confined to an automatic SWR bridge and a RF current probe of his own design. By coincidence I had a newly-acquired Autek RF-1 antenna analyser with me, which I demonstrated to him. Les was very impressed and felt this would be an excellent tool to use when adjusting antennas on the roof. He subsequently purchased one.

To have achieved such a level of sophistication of antenna design with only these very basic aids clearly marks Les Moxon as a very special kind of genius.

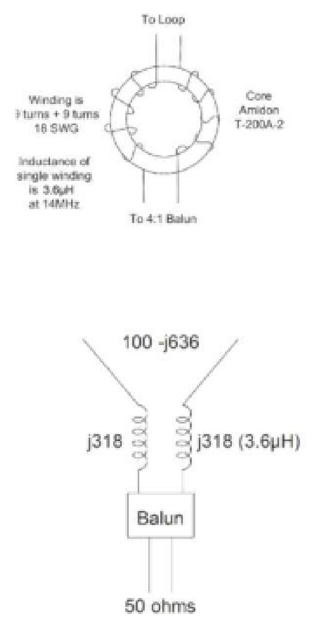

FIGURE 6: 20m matching network details – (top) method of winding the inductor, (bottom) equivalent circuit and impedances at 14MHz.

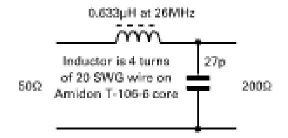

FIGURE 7: Matching network for 24/28MHz.

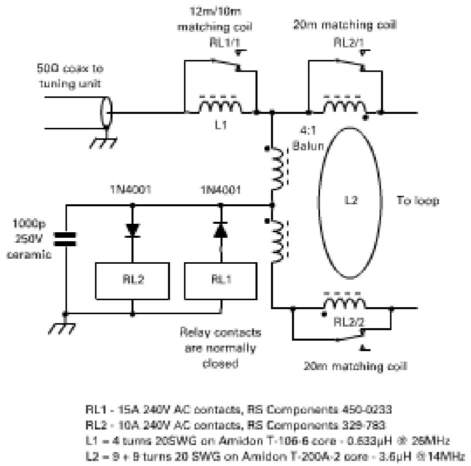

FIGURE 8: Final matching network (see text).

It is debatable as to the exact nature of the Claw operation – parasitic or driven. The reflector is certainly parasitically excited from the driven element but the actual reflector current is fine tuned, such that it matches that flowing in the driven element, by also driving it from current flowing in the driven element. In which case, in order to model the Claw, two generators, one on each loop's feedpoint, are required in order to equalise the loop currents.

Another item to note when computer modelling is that the feedpoint impedance of one of the loops (the one tuned as the reflector) may show a negative resistive component. This is of no concern and simply indicates that one of the loops is actually returning power to the generator.

An *EZNEC* plot of a Claw operating on 14MHz with the tops of the loops at 15m (50') is shown in **Figure 5**.

MATCHING NETWORKS. A number of relay-switched matching networks are mounted on the boom of the Claw. These networks are enclosed in IP65-rated plastic enclosures and identical ones are used for each element.

G6XN's concept was not to exactly match the loops to 50Ω but rather to provide broadband matching that would reduce the SWR to 3:1 or less in order to minimise feeder losses. The final match to 1:1 would be done using an ATU located in the shack.

For the experimentally-inclined, this is a rich area for optimisation; for the rest of us, the networks described form both a simple and reliable starting point and a practical solution when coupled with a simple antenna unit such as Z-match or T-match. In my case I use a refurbished KW Electronics KW-109 Z-match unit.

On the 14MHz band, a 90°, 0.85 wavelength circumference SDL has a feed impedance of 100Ω in series with 18pF. If an inductance of 7.2μH is placed in series with the loop, then the feed impedance becomes purely resistive and, when reflected via a 4:1 balun, results in a 2:1 SWR at the feedpoint.

Since the drive to the SDL needs to be balanced, the inductor is split in half and connected as shown in **Figure 6**. The inductor is wound on an Amidon T-200A-2 toroidal core, which is fine for operation at 400W PEP.

The 4:1 balun is constructed as per Les' instructions **[6]** on a short length of ferrite rod, completing the Claw's matching for 14MHz.

As the presence of the inductor impedes the matching on the HF amateur bands above 14MHz, it is shorted out using a relay. However, note that both Les and I found that leaving the inductor in circuit on 28MHz actually increases the SWR bandwidth on this band. Neither of us found the reason for this, which again opens the door to potential experimentation and improvement of the Claw design.

With just the 4:1 balun in circuit, the Claw provides a good match on the 18 and 21MHz bands. For the purist experimenter, it may be possible to optimise the match by making the loops resonant at the geometric mean of the two bands, ie

$$f = \sqrt{(18 * 21)} = 19.44\text{MHz}$$

However, the exact resonant frequency of the Claw is non-critical and, in practice, much more effort needs to be put into making sure the two loop elements are mechanically and electrically identical, in order that retuning is not required when switching between them to reverse the beam direction.

The feed impedance of the Claw increases to approximately 800Ω on the 24 and 28MHz bands. As a result, an inductor/capacitor network consisting of a series inductor and a shunt capacitor is switched into circuit on these bands – see **Figure 7**.

In practice, the shunt capacitor is formed from the input capacitance of the 4:1 balun. Initially I was cautious in using this capacitance, owing to being concerned about how repeatable this would be in terms of balun construction. However, after making a number of 4:1 baluns using different gauges of wire and scrap pieces of ferrite, the value of input capacitance seems to be remarkably consistent.

This means the matching network for the 24 and 28MHz bands simply uses just a single series inductor, which is shorted out using a single relay contact on 14, 18 and 21MHz.

When initial testing of the Claw is carried out at ground level, the turns of the inductor are spaced closer or further apart so as to achieve an SWR of 3:1 or less on both the 24 and 28MHz bands.

The final matching network configuration for the Claw is shown in **Figure 8**. 12V DC to control the relay on each loop is fed up the coaxial feeders and, by either its absence or change in polarity, the appropriate relay contacts are operated for each band.

NEXT MONTH. The concluding part of this article will cover the remote tuning head and constructional information for the antenna itself.