33ft Verticals and 4:1 Ununs

Following a discussion on eham relating to the use of 4:1 Unun's for multiband operation in conjunction with 33ft vertical antennas. I referred to measurements I had previously made with 10m vertical antennas fed with 4:1 Ununs. Most of this work was done as part of an investigation into the performance of the Comet CHA-250 broadband antenna, which uses a deliberately lossy 6:1 Unun to provide a good match on all bands.

As part of this investigation I discovered that the Comet antenna actually worked better than I would have expected it to. In some cases it produced similar results than those obtained with a 6.5m vertical fed via a 4:1 Unun at the base of the antenna and fed with coax from an atu-tuner in the shack. Some comparison graphs can be found here.

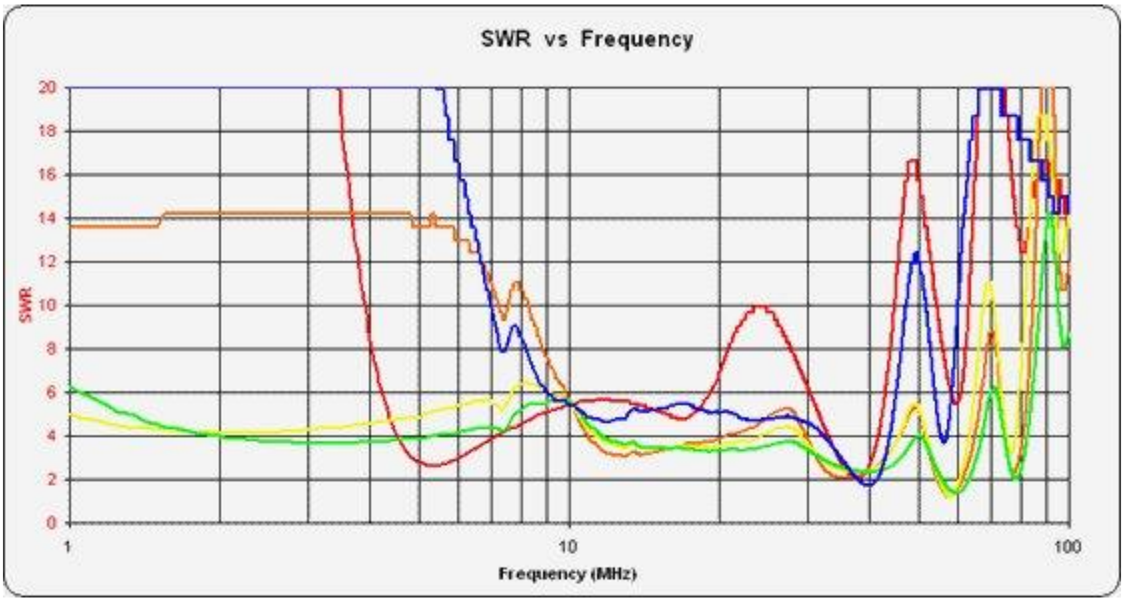
As you would guess there is a large degree of interaction between the Unun and the impedance presented to it, especially when it is being used as a multiband antenna.

The two main problems are major copper losses when feeding a vertical which is electrically too short (due to the very low resistive component presented to the Unun by the radiating element), unwanted resonances when feeding highly reactive impedances and loss in the transformer core due to too low a value of shunt impedance when presented with a very high secondary impedance.

Perhaps surprisingly the Ununs with the lowest losses are not always the best type to use in this application.

This may seem odd, but high Q designs using Type 2 powdered iron cores tend to interact badly with some of the impedances that can be encountered at the base of the vertical radiator at specific frequencies. This interaction causes very high excursions of impedance which present an even worse match to the 50 ohm coax feed than would otherwise be present. Lower Q materials can help damp these excursions to manageable proportions. However it's not a good idea to overdo this, a balance has to be achieved. In some cases a 4:1 Unun (or Balun) doesn't actually improve the match, or widen the matching range of a tuner. It's just the additional loss masking the poor match. A 6dB attenuator in the feed line will allow you to achieve better than 2:1 VSWR on any band, but the match at the other end will still be bad.

See this graph showing the VSWR of several different 4:1 Ununs connected to a 6.5m vertical.



When required, I use a 4:1 Unun which I have specially optimised for this application, it is lossy but the improvement in match to 50 ohms offsets the mismatch loss which would otherwise occur along the feedline.

Using a 4:1 balun and remote coax fed tuner typically adds about 1.5 to 2dB of loss in the best case, compared to a coax fed ATU at the base of the antenna with no Unun. In the worst case with a bad set of parameters you can lose 10dB or more.

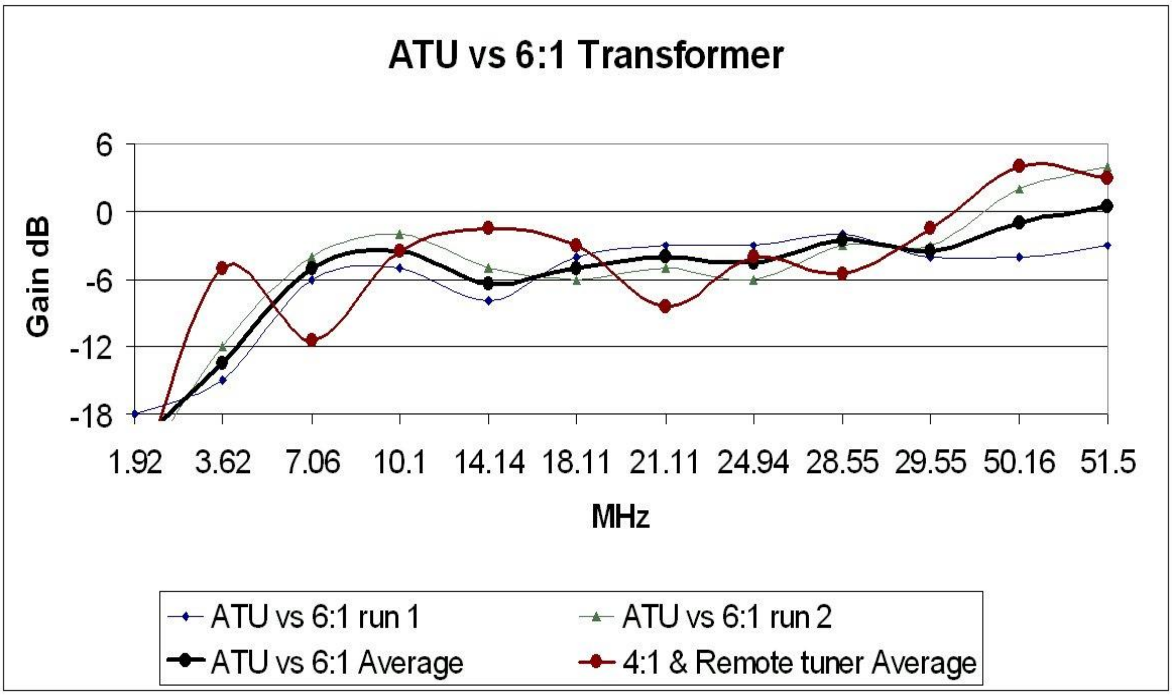
The bottom line is that you have to treat the antenna system as a whole in order to minimise losses.

Incidentally if you want or 'see' copper losses in an atu feeding low impedance load, take a look at the thermal images towards the bottom of this [page](#).

My experience is that most atu losses occur when trying to match to low impedance capacitive loads, usually when using short verticals on the LF bands.

Big external coils can help to improve this situation so that the atu doesn't have to work so hard.

If you take a look at this graph



It shows field strength measurements I made some time ago, which compare a 30ft vertical fed with an auto-tuner at the base vs. the same antenna fed a 4:1 balun wound with 75 ohm coax on two separate type 43 ferrite cores and a remotely sited tuner fed via 200ft of low loss LDF2-50 coax vs. a broadband antenna of the same element length.

To summarise the results WRT to reference antenna consisting of 30ft wire vertical fed with auto-tuner at base.

The 4:1 balun and coax fed remote tuner and also the broadband antenna Ununs produced signal levels about 20dB down on 160m, 6dB down on 80m and an average of about 3db down with dips of > 6dB on 40m through to 10m.

Obviously these parameters will change with differing designs of balun, length coax and vertical radiator, but it gives a good ballpark indication of the relative performance of each type.

As a result of these earlier investigations I was prompted to spend further time making comparisons between different methods of feeding a 33ft vertical wire. I wished to ensure that the previous measurements were still valid.

I was particularly concerned that the radial system I used for the first set of tests may not have been good enough, and that the additional earth loss would have influenced the results to favour the lossy broadband Ununs.

As before, measurements were made using a remote controlled Icom PCR-1000 receiver fed from a Datong Active antenna. This was vertically polarised and mounted at approx. 20m (66ft) AGL. The distance between TX and Rx site was approx. 4.5Km (2miles).

For the 4:1 Unun, I chose to use 13 bifilar turns on a T200A-2 core configured as a Ruthroff voltage Unun.

There are a number of problems associated with the use of iron power cores for this application, take a look at this document

In this case I decided to use them for the test in order to emulate a commonly chosen design.
The main problem is not always associated with the choice of core material; it's the coax mismatch loss, especially when the resistive component of the antenna impedance is very low. Adding a 4:1 balun into the equation makes things even worse.

In the past I have used other core materials for Unun's which have been used to feed vertical antennas, including type 61, 31 and 43 but it doesn't make much difference to the overall performance. You improve the results on some frequencies, but loose it on others, sometimes by 2 or 3dB either way. A lot depends upon the interaction with the rest of the system.

To put this into perspective, I find that day to day changes in the weather and propagation conditions can make +/- 1dB or so difference in measurements over the 2 mile path measurement path. When I perform these measurement runs, I try to complete them all within an hour and usually repeat the first tests a second time at the end of the runs as an overall confidence check.

As I stated before the main source of system losses is the mismatch between antenna feed impedance, Unun and coax at the low frequencies. This is predicted by graphs on L.B. Cebik and Owen VK1OD's websites.

For these tests as a reference point, I used a CG-3000 auto-tuner at the base of the wire (typically 1dB loss through the tuner when presented with moderate load impedances), which was fed against 10 random length buried radials.

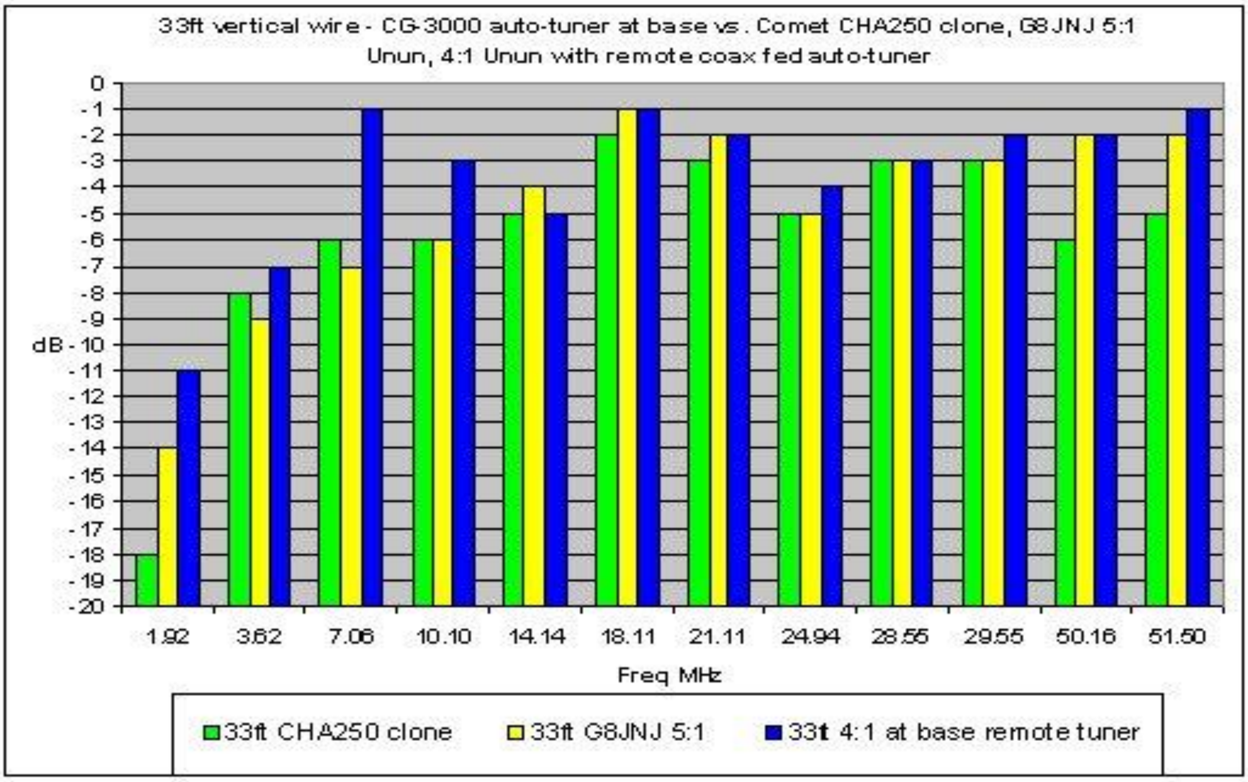
The antenna wire was 2mm tinned copper with PVC insulation suspended via a rope from a tree branch and spaced approx. 1m (3ft) away from the trunk. The wire was resonant on 7.1MHz with a measured Rs value of approximately 55 Ohms. The field strength on 7.1MHz with no tuner connected was exactly the same as with the tuner in circuit. I could not determine any difference between the two.

All measurements were made using the same wire in exactly the same position for each test run.

For the series of tests the 33ft wire was fed at the base with a copy of the Broadband Comet CHA-250 Unun, my improved version of the Comet the G8JNJ 5:1 Unun and finally a 4:1 Unun fed with an auto-tuner at the far end of the 62m (200ft) LDF2-50 coax feed cable. The tuner was connected directly to the transceiver, and all cables were kept the same during the series of tests.

If the tuner was connected directly to the 4:1 Unun at the base of the antenna wire, I would expect it to be within a fraction of a dB of the auto-tuner.

As you can see from the graph shown below there is very little difference between feeding the antenna with any of the Ununs. They all produce results which are worse than using an auto-atu at the base.



Note that both the Comet copy and G8JNJ Ununs were used without any tuner attached. They both rely upon losses in the Unun to provide a good match to the TX.

The loss is much less at 7 MHz where the antenna impedance is low compared to 14 MHz where the antenna impedance is very high and the impedance of the UNUN is too low. This is likely to be due to the type 2 iron powder core material used for the 4:1 which is not suited for this application due to the low value of shunt inductance presented across the load.

In both series of tests I have I have observed the same trends, so I'm fairly confident that they represent real world conditions.

Following feedback from Peter, HB9PJT, I decided to build a 4:1 Unun wound on an FT240-61 core. In theory this should provide much higher shunt impedance than a similar Unun wound on a much lower permeability material such as type 2 Iron powder. This is particularly important at frequencies where the radiating element of the antenna is ½ wavelength long, and so presents a high impedance (in the region of 5K ohms) to the secondary of the Unun. If the shunt impedance of the Unun secondary is too low, loss will occur.

Peter suggested a design which is documented on Phil, AD5X's website

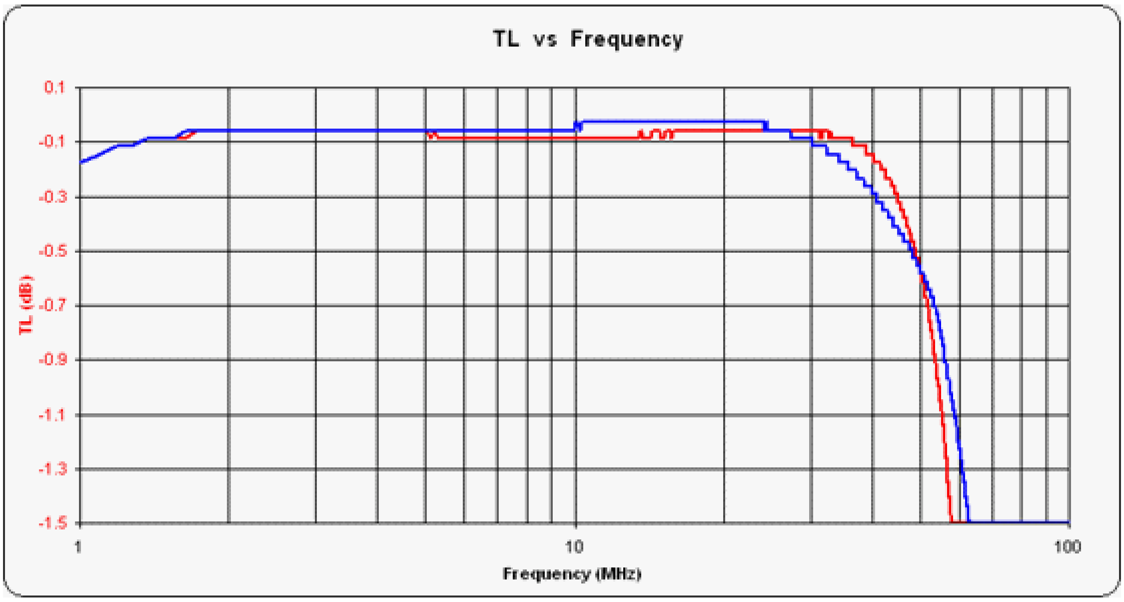
I made a similar version; of the 4:1 Unun consisting of 12 bifilar twisted turns of 18AWG silver plated stranded wire. PTFE insulation, 1.85mm outer dia (CPC part number CB10433) wound on single FT240-61 core.

This gave good performance from 1.8 to 52MHz, with less than 0.1dB loss over most of the range up to 30MHz, and approx. 0.5dB at 50MHz. This was measured with a miniVNA by halving the loss of two Ununs connected back to back I could have added more turns without affecting the performance over 1.8 to 30MHz (I started at about 15 turns) but I found could achieve sufficient bandwidth to include 50MHz by sacrificing a bit of additional loss at each end of the operating range.

I also tried a ceramic microwave trimmer cap across the 50 ohm input and found a value of 22pF gave the flattest response when looking at the secondary impedance with the AIM, with the Unun input terminated with 50 ohms. I didn't have any high voltage caps so I used a 15" open circuit PTFE coax stub across the 50 ohm input to provide the required capacitance. Fortunately this length is short enough that it doesn’t affect the overall performance.

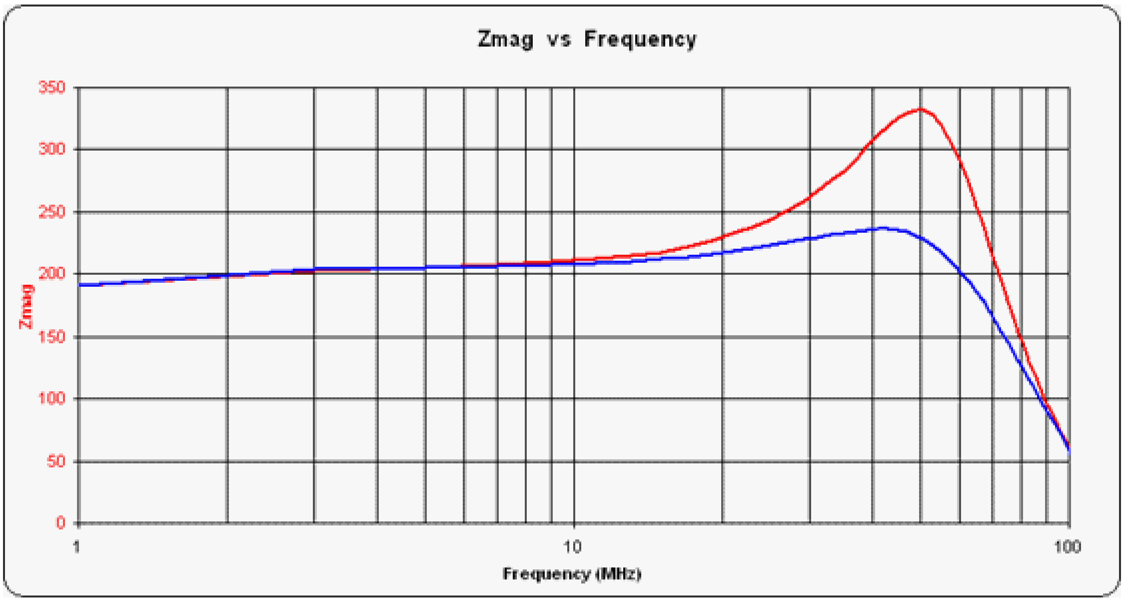
Adding the cap or stub introduced approx. 0.1dB additional loss at 40MHz, the rest of the performance was unaltered, apart from a shift in the reactive impedance of the secondary from being inductive up to about 33MHz, moved down to a cross over at about 10MHz.

The graph below shows the measured loss.



The red trace is without the compensation capacitor, the blue trace is with it fitted.

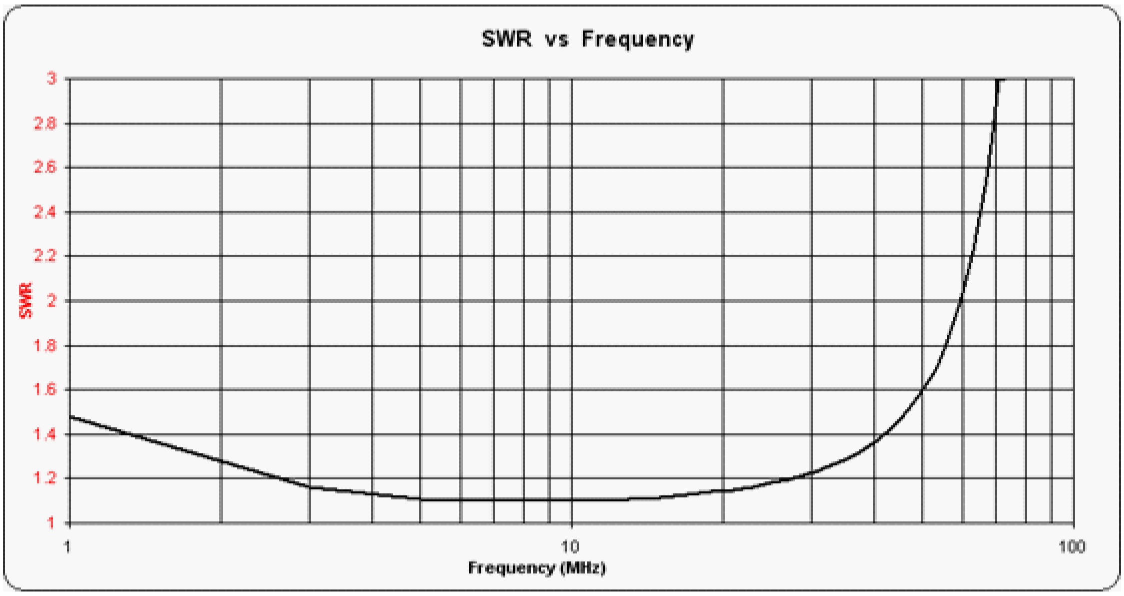
The next graph shows the secondary impedance with the input terminated in 50 ohms. Note that 200 ohms is the target impedance.



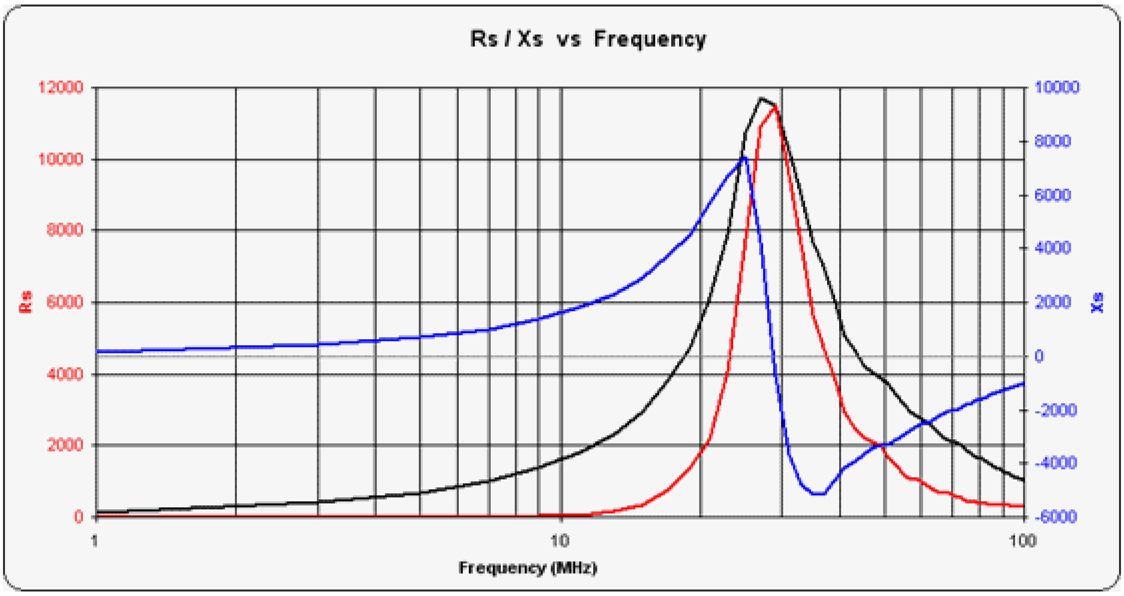
As before the red trace is without the compensation capacitor, the blue trace is with it fitted.

I'm not sure that the capacitive compensation is actually required when used as a tuner Unun. It makes the graphs look good on the plots, but in the real world it's not going to be connected to a true 200 ohm resistive load anyway. I think the cap just adds a further complication to the design. So I may just connect the coax stub across the input with a BNC Tee so that I can add it when required for test purposes.

Here is a plot of the input SWR with the secondary terminated with 220 ohms.



Here is a plot of the common mode impedance, with both bifilar wires connected in parallel at each end of the winding. The black trace shows the overall value of Z.



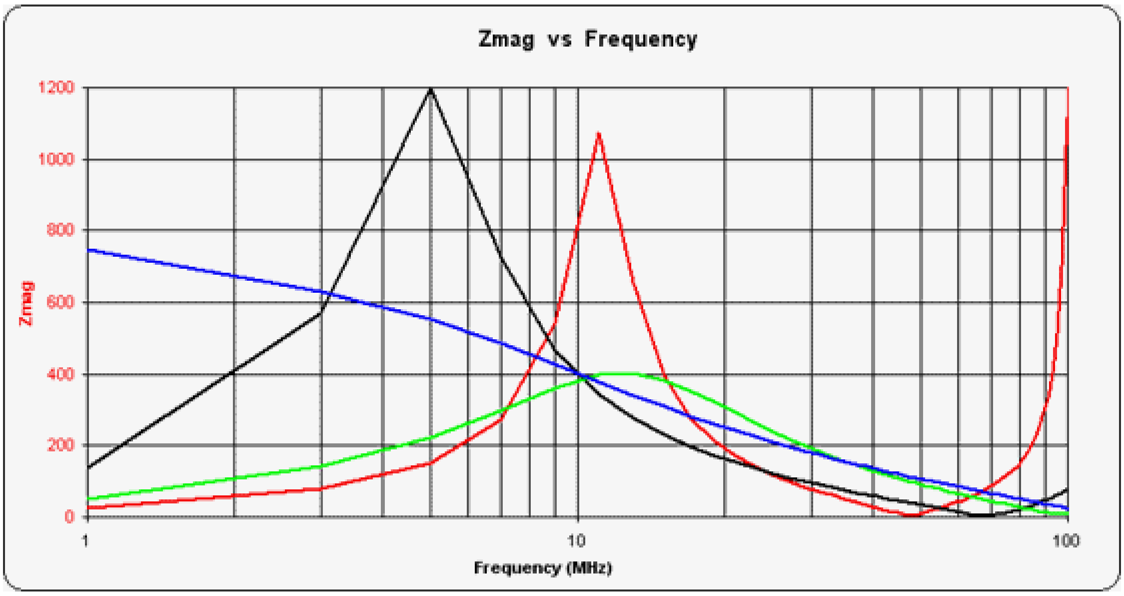
The next stage of the tests was to measure the input impedance of the Unun when the secondary was terminated in a 5K ohm load. The intention of this test was to simulate the performance of the Unun when presented with the sort of load impedance that was likely to be encountered when attached to a ½ wave antenna.

The initial results obtained with the FT240-61 core were somewhat surprising, so I repeated the same measurements with some other 4:1 Ununs I had previously wound on different types of core material.

In order to better observe any differences between the Ununs, I selected two different types of Ferrite and Iron Powder cores, one type of each being much higher loss material than the other.

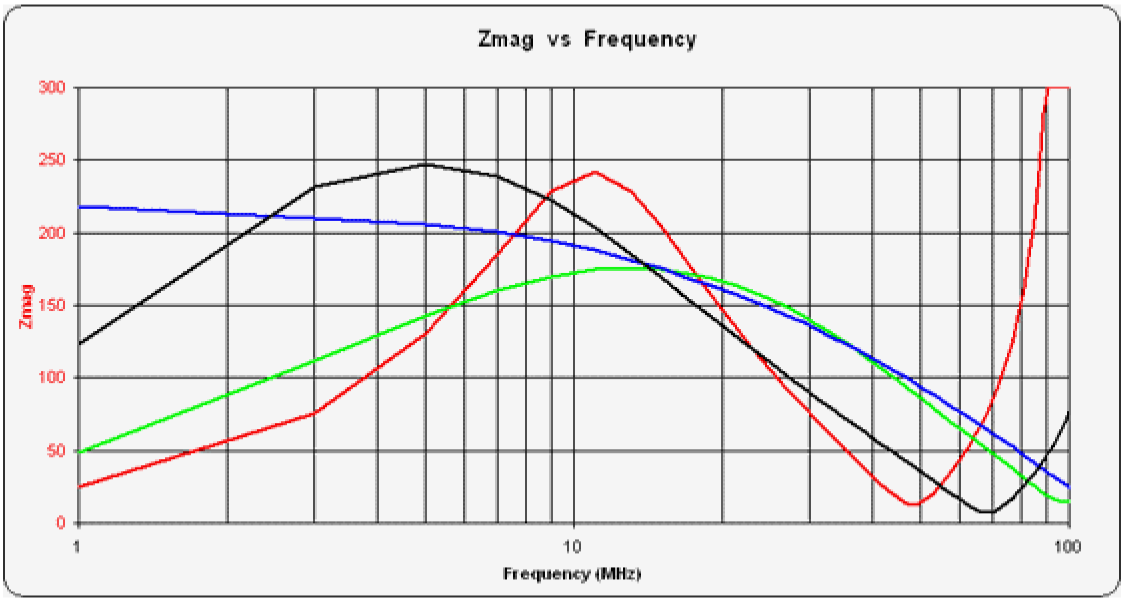
FT240-61ferrite (loss), an unknown ferrite type (high loss), T200A-2 Iron powder (low loss) and T200-52 Iron powder (high loss).

As can be seen from the graph below none of the Ununs were able to provide the required 4:1 impedance transformation (should be 5,000 divided by 4 = 1,250 ohms). Only the FT240-61 core gets close to this value, but only at frequencies around 5MHz.

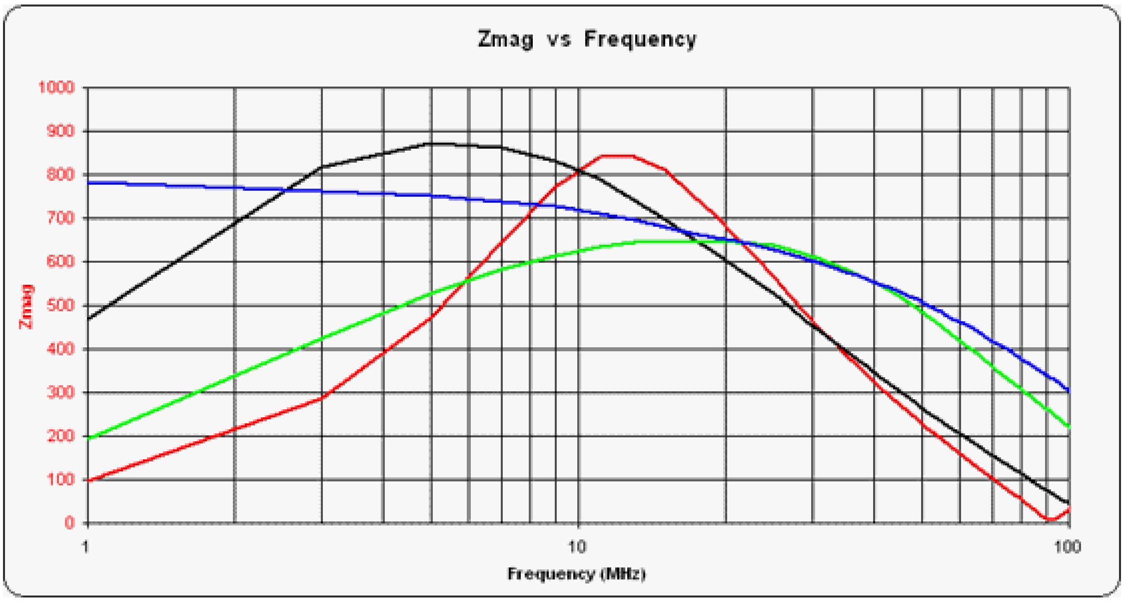


Black trace - FT240-61ferrite
Blue trace - Unknown ferrite core (high loss)
Red trace - T200A-2 Iron powder
Green trace - T200-52 Iron powder (high loss)

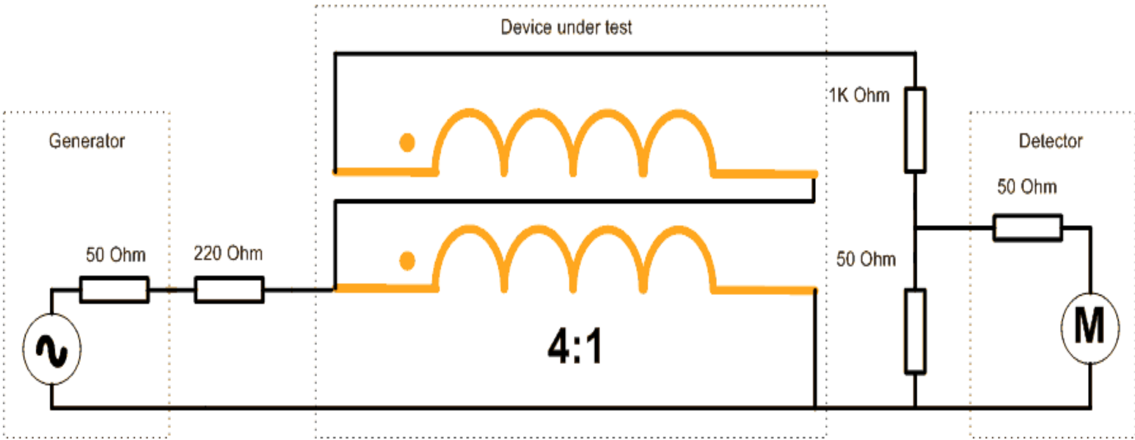
The same measurements, but this time with a 1K ohm secondary load. Target impedance is 250 ohms.



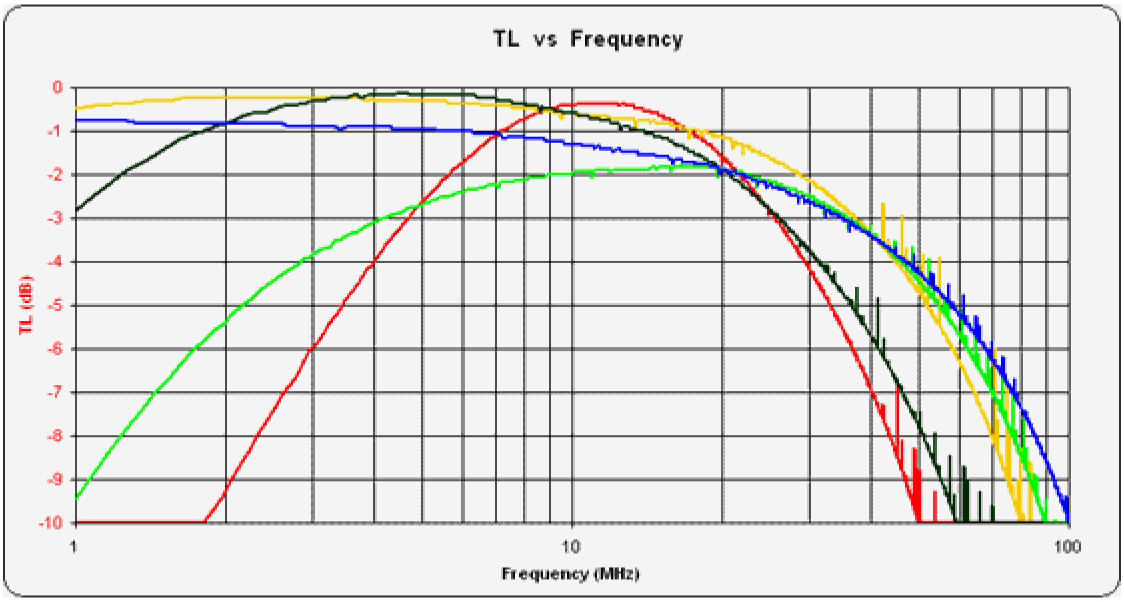
This time I have also measured the output when the input is terminated with 220 ohms. The target impedance is 880 ohms.



I also made an attempt at measuring the loss when terminated with a 1K ohm load and fed from a 200 Ohm source. In order to do this I used the test circuit shown below. I didn't have exact values of non-inductive resistors, so I had to make do with standard values.



Once I had made the measurements, I normalised the graph so that all the curves are relative to the Unun which displayed the lowest loss figure. As expected the general trend follows that of the pervious impedance curves.



Black trace - FT240-61ferrite
Blue trace - Unknown ferrite core (high loss)
Red trace - T200A-2 Iron powder
Green trace - T200-52 Iron powder (high loss)
Brown trace – FT240-K

However this graph doesn't tell us much more than the impedance curves did. It only provides an indication of the frequencies at which the internal shunt impedance of the Unun is sufficiently high, that it can provide a 4:1 impedance transformation when terminated in a 1 K ohm load. When used as part of an antenna system the Atu would always attempt to match to whatever Unun input impedance it was presented with. Some of the applied power would be lost in the Unun and the rest would reach the antenna.

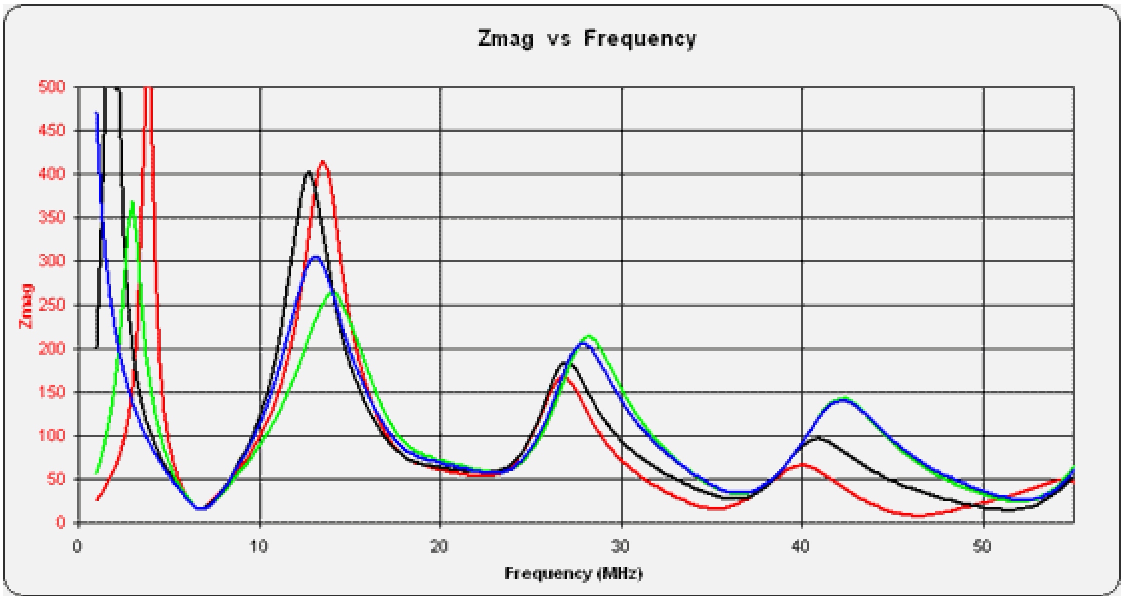
In order to determine the losses Owen, VK1OD, has constructed a mathematical model of a 4:1 Unun.

Details can be found here

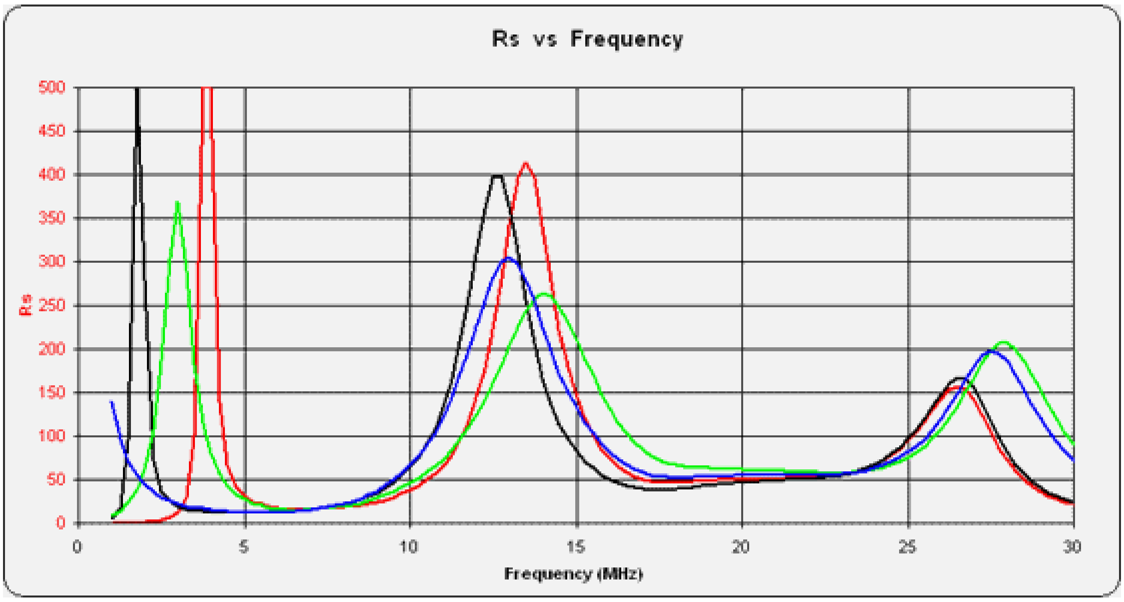
Owen sent me a spreadsheet that I could use with of some S parameter measurements on the Unun's I had constructed. The intention was to plug the values I obtained into the spreadsheet, calculate the losses and then compare the results against the field strength measurements I had made previously. However the accuracy of the miniVNA I used to measure S11, S21, S12 and S22 does not seem to be good enough for this purpose, as the calculated results were wildly inaccurate. This was very disappointing as I had hoped that the results would qualify my previous observations.

Another set of tests involved connecting the various Unun's to the vertical wire and measuring the Unun input impedance. This was in order to try an observe any slight differences in Impedance transformation that may occur when using Unun's with differing core materials.

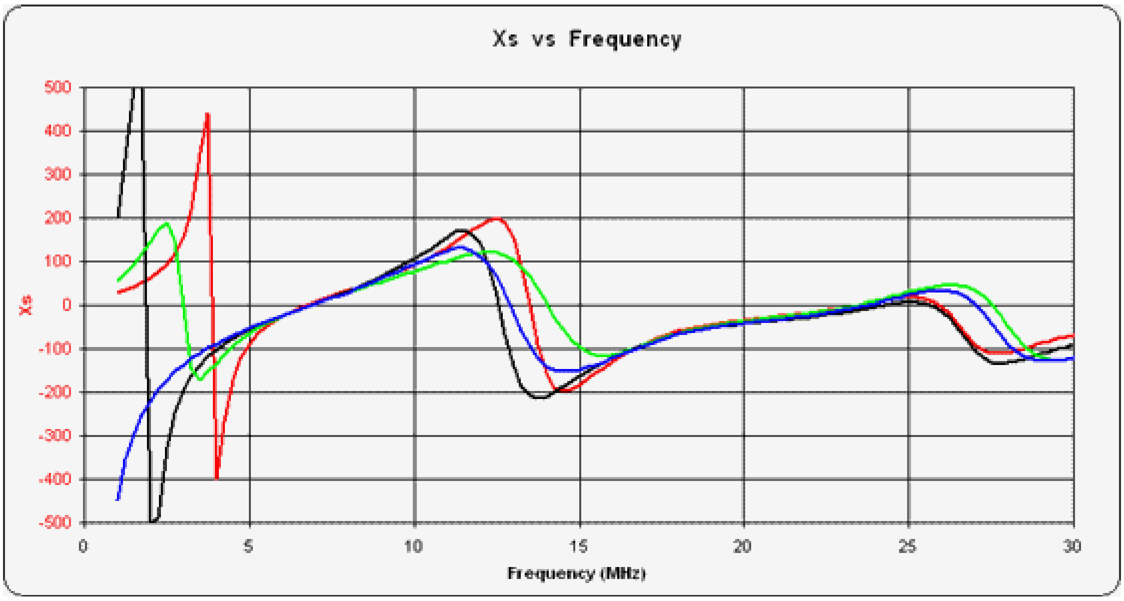
Here is a graph showing the input impedance of various Unun's connected to a 10m vertical wire.



And another, this time showing the Resistive component at the input of various Unun's connected to a 10m vertical wire. I've just selected the 0 to 30MHz range, so that the detail around 14 and 28MHz is easier to see.



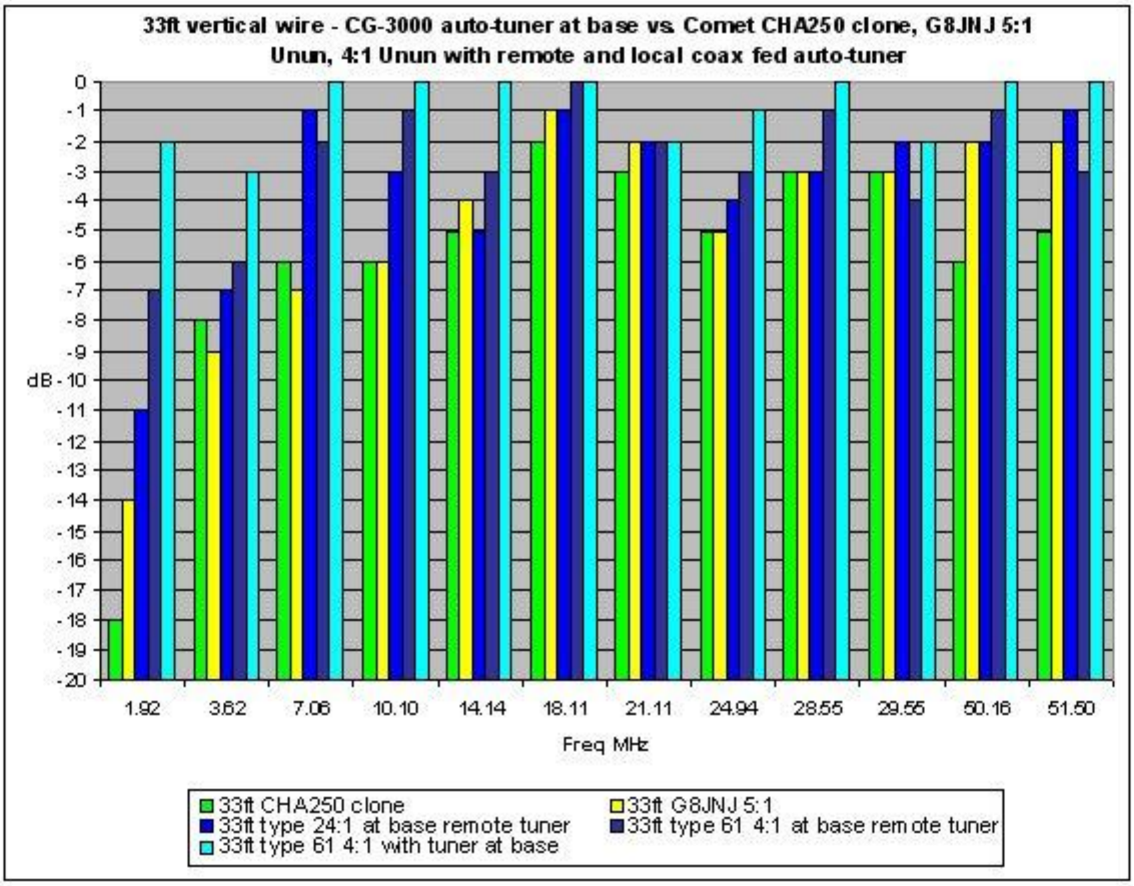
And yet another, this time showing the Reactive component at the input of various Unun's connected to a 10m vertical wire.



So at frequencies where the 33ft radiator presents a high feed impedance (14 MHz and 28MHz) the very rapid change in Reactive impedance causes an observable difference between the curves. The FT40-61 and T200A-2 cores have practically the same values, and as expected the lossier Ferrite and Iron powder cores present a slightly lower impedance, except at 28MHz.

I believe all of these measurements support my previous observations that I couldn't find much practical difference between lossy broadband designs such as the Comet CHA-250 or G8JNJ optimised version and a 4:1 Unun with remote tuner.

In order to test this theory still further I made another series of field strength measurements, but this time I included the type 61 4:1 Unun with a coax fed remote tuner (as per the previous tests) and I also performed another measurement run with the tuner connected to the 4:1 Unun at the base of the antenna. This should have produced very similar results to the tests with just the Auto-Atu connected.



Once again there are some dips in the response, particularly around 21 and 24MHz which may be due to Unun losses. Also note the poor performance on 1.9 and 3.6MHz which is primarily due to copper losses in the ATU and Unun, because the already low resistive component of the antenna feed impedance, is being transformed down to an even lower value by the Unun. In fact the Atu had great difficulty in matching antenna via the type 61 Unun when it was connected directly to the Unun at the base of the antenna. The loss becomes even worse when the atu is remotely feeding the Unun via a long length of coax.
Peter, HB9PJT performed these calculations for an ideal Unun and 62m of LMR-400 which was close to the characteristic of the LDF2-50 I used.

1:4 at Antenna Base and Antenna Tuner at TRX

Band	ANT	1:4	Cable loss	At Tuner	Tuner Loss	Total Loss, dB
2	4.4-1352	1.1-338	20	1084-365	0.3	20
3.5	9.6-661	2.4-165	12	7+56	1	13
7	34-38	8.5+9.5	1.7	95+99	0.1	1.8
10	109+430	27+108	3	11+25	0.2	3.2
14	3152+171	788+43	4.3	13+35	0.2	4.5
18	134-587	34-147	4.6	15+38	0.1	4.7
21	72-119	18-30	2	22-18	0.2	2.2
25	172+411	43+103	3	49+67	0.1	3.1
28	1313+1057	328+264	4.3	13-18	0.2	4.5
50	101-167	25-42	2.8	49-41	0.3	3.1

Antenna Tuner at Antenna Base

Band	ANT	Cable 50 Ohm	Tuner Loss	Total Loss	
2	4.4-1352	0.3	tune failed		
3.5	9.6-661	0.45	3.4	3.9	
7	34-38	0.64	0.3	0.95	
10	109+430	0.77	0.1	0.87	
14	3152+171	0.9	0.4	1.3	
18	134-587	1	0.6	1.6	
21	72-119	1.1	0.2	1.3	
25	172+411	1.2	0.1	1.3	
28	1313+1057	1.3	0.2	1.5	
50	101-167	1.7	0.2	1.9	

Antenna, Difference

Band	Difference calculated by HB9PJT	Difference measured by G8JNJ
2		7
3.5	9	6
7	0.9	2
10	2.3	1
14	3.2	3
18	3.1	0
21	1	2
25	1.8	3
28	3	4
50	2.2	3

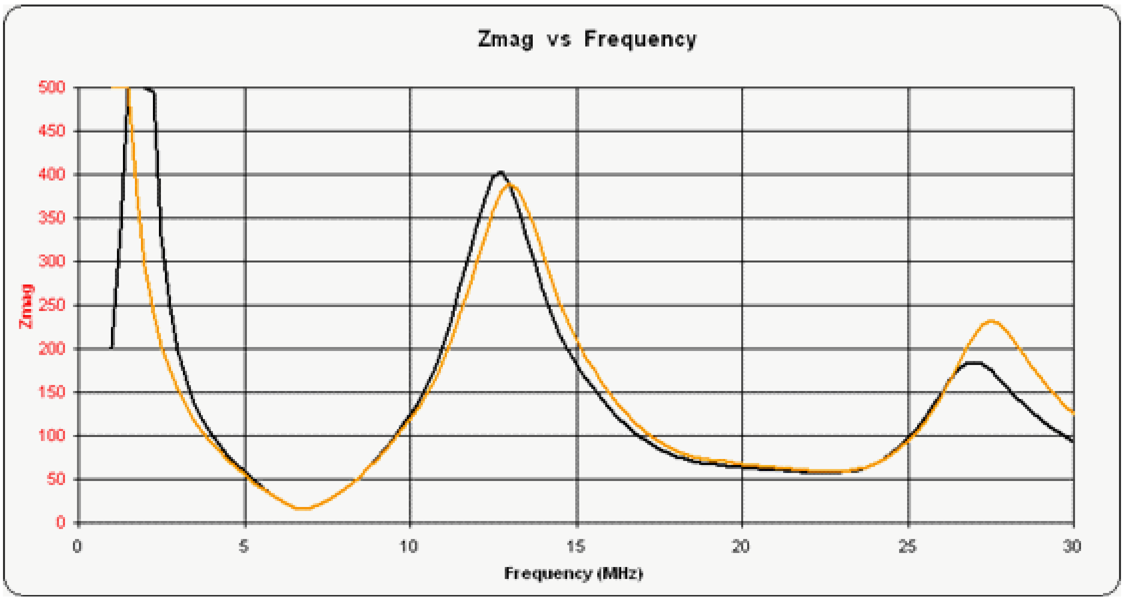
Das Kabel hat 11 mm Durchmesser und 1.1 dB Verlust bei 30 MHz und 62 m
http://www.rfparts.com/heliax_LDF250.html (RG213 = dB)

Für die Berechnung LMR-400, da anderes nicht in Software
Antenna Calculation: EZNEC v4.0 (Antenna 10 m and 8 radials, each 10 m, average ground)
Tuner calculation: http://fermi.la.asu.edu/w9cf/tuner/tuner.html
Coax calculation: “Transmission Line Details – v1.1” (TLD)

As a result of these tests it was suggested, that I should try another material, type K ferrite with a permeability of about 290, which was used in a commercially produced balun.

I found the type K Unun to be 2dB better than the type 61 Unun on 14.1MHz and 2dB worse at 29MHz. Both types were within +/-1dB of each other at all other frequencies, which is about the best resolution I can achieve with my measuring system.

Here is a comparison of the FT240-61 and FT240-K 4:1 Unun input impedance when connected at the base of the 10m wire.



Black trace - FT240-61ferrite
Brown trace - FT240-K ferrite

In practise when the Atu is connected to the Unun by a length of coax, the differences between all the Unun's I have tested could be considered to be almost negligible. The complex interaction between ATU, type and length of coax, Unun construction and antenna length will define the overall efficiency (within a few dB) at any given frequency. The coax cable introducing the largest proportion of the additional loss.

Even with the Unun connected directly to the Atu at the base of the antenna, the difference in measured field strength is not simply due to the type of core material used to construct the Unun. It is the interaction between Atu, Unun and antenna forming the entire system. Changing any of the component parts will modify the overall results.

The most probable explanation for the differences in measured filed strength is the slight variation in load impedance presented to the Atu by each Unun at a specific frequency. The loss through the Atu will vary significantly depending upon the 'difficulty' of the load presented to it. This is likely to be the dominant factor rather than the loss through the Unun (except perhaps at the lower frequencies where the antenna presents impedance with a very low value of resistive component).

Peter, HB9PJT, modelled this in his calculations using an ideal Unun and tuner simulation. In the real world additional stray impedances will modify the results significantly. Just because have obtained better results on one specific frequency, with one particular type of Unun, this does not mean that exactly the same results will apply when using a different antenna and Atu.

However, it apparent that the losses associated with using a 4:1 Unun and tuner are significant, especially when the tuner is remotely sited.

So, It seems to me that it would be better to choose a length of radiating element which is not ¼ wave on any amateur band, but which is optimised to present a moderate impedance (in this case around 200 ohms) on as many bands as possible.

I need to perform further modelling with EZNEC, but my first thought is a resonant frequency of something around 8.5MHz.

Whatever length is used I would suggest that the worst case impedance should not be allowed exceed 1K ohm, in an attempt to keep losses to a minimum.

The bottom line is that a 33ft vertical (even ‘magic’ ones) fed with a 4:1 Unun (or Balun) at the base and remote coax fed tuner, may not always perform significantly better than a Broadband Comet CHA-250 (regarded by many as a dummy load) or G8JNJ antenna.

One other option may be to feed a resonant 1/4 vertical with a tuned section of 450 ohm line, say something like 1/4 wave at 2 x the 1/4 resonant frequency of the radiating element. This would provide a frequency selective impedance transformation, which may be a better option than using a compromise design of 4:1 Broadband Unun.

Time permitting I will conduct a further set of tests using a more suitable length of radiating element and model further options with EZNEC.

On-going investigation

M. Ehrenfried - G8JNJ - V1.9 - 01/07/2009