The Coaxial Trap Confusion (mostly resolved?)

Background

Antenna traps need an inductor and a capacitor in a parallel circuit to effectively cut off the end of the antenna for some higher frequency giving dual band capability. Inductors are easy but high voltage/current capacitors are more difficult. Mathison (77) and then Myers (80) noted that a modest length of open ended coax is a capacitance so adding as a stub across the coil proves a nice trap. Next Johns (81) took a leap and coiled up the coax stub AND connected the output center connector both to the antenna end (making the coiled coax an inductance) and back to the braid near the input thereby keeping the capacitive stub. This appears to be the first published coaxial trap. Noble (84) adds an explanation as to why the Johns circuit should be the equivalent of parallel inductance of the coiled braid and a capacitance of a coax open stub with an argument that the capacitance current will not contribute any addition inductance in spite of the fact that it flows on the center conductor.

But wait, there’s more. O’Neill (81) then went yet another step by taking the Johns configuration (although Johns is not referenced) and instead of connecting the outer antenna to the output center conductor, he connected it to the shield at the output end, but without highlighting this advance. This might be viewed as forcing the trap inductance current to take a second pass through the coiled coax, now through the braid. (Note that the braid and center conductor connections can be interchanged with no difference.) Later these two possible configurations were described clearly by Buxton (94) in figure below, as the (Johns) Low-Z and (O’Neill) High-Z mode as seen here. Buxton used both styles in in making two different multi-band trap antennas (but referenced no prior coax trap work) – more on Buxton later.

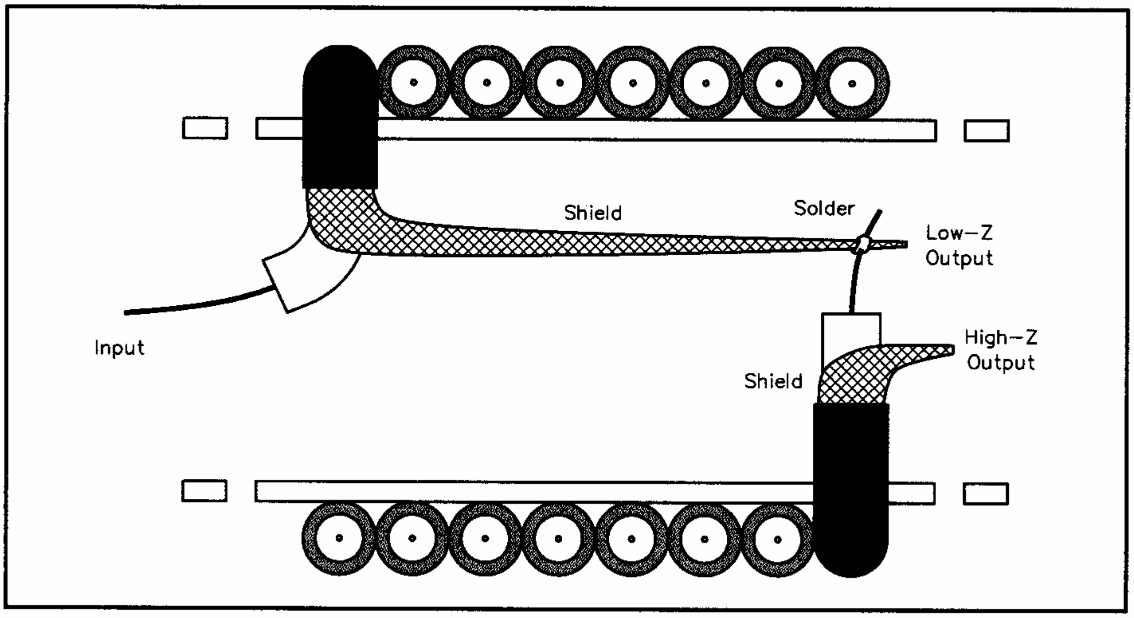


Figure 4—Construction details of the W8NX coaxial-cable trap.

And the remarkable part, hardly noted by any authors, here is that the resonance frequency of the Low-Z and High-Z modes are nearly the same.

Later Demaw (83) provided an example for coax trap use that appeared (from fuzzy sketches but also due to the quoted high peak Z value) to use the High-Z connection, while referencing both Johns and O'Neill (but noting no differences). A "Feedback" from Finley (84) indicted the Demaw had an error in the connection diagram and Finley appears to recommend the Low-Z Johns connection rather than the High-Z O'Neill connection. This "correction" is likely not correct but it was accepted and published in QST where Demaw was highly a respected technical editor However, either connection could have produced a useful trap.

Sommer (84) produced a set of examples with both experimental and analytic methods clearly picturing the High-Z connection, while referencing both Johns and Demaw (but not noting that Johns was Low-Z). Sommer provides values for L and C reactances for a set of examples where they are clearly the values for a single coil and for an open coax stub, that is the Low-Z connection that he doesn't use.

As mentioned before, Buxton (94) produced real examples of Low-Z and High-Z connected traps and provided the inductances and capacitances for each connection. He notes explicitly that the inductance for High-Z is approximately 4X that for Low-Z and attributes this to the second pass of the trap current, through the coil braid, giving twice the number of coil turns. Of course (as we are told by experts) the inductance of a coil is proportional to the square of the number of turns, thus the 4X. He also notes that the High-Z capacitance is approximately ¼ of the Low-Z capacitance. He says "This (Low-Z) mode steps the trap's impedance to approximately one-fourth of that of the high-impedance level" but provides no other explanation for the fact that the resonance is nearly the some for both configurations. [As an interesting if not fully relevant sidelight, Buxton in an earlier article (92) produces what is called a "coaxial trap" but he uses just the dielectric/center conductor core of coax (braid stripped off) to wind a rather long insulated wire into a two layer coil that apparently has enough self-capacitance to be resonant for a useful trap.]

There exists some confusion in the literature about the appropriate L, C and equivalent circuit that should be used for coax traps. The Coax Trap Design calculator software by VE6YP pictures a High-Z connection on the website (http://www.qsl.net/ve6yp/CoaxTrap.html) but the calculated values of L, C and corresponding reactances are for a single coil and the coax open stub. The resonance frequency is okay but the reactance values are inappropriate for modeling with a trap element such as you might use in EZNEC. This has been noted by others.

Müller (04) has made an experimental and analysis effort to clarify the question of the equivalent circuit for the High-Z connection. First you must be aware that he uses the symbol "L" in a way different from others, which can be confusing. For him "L" is the inductance of doubled coil which results from the High-Z connection that sends the current through the coax braid as well as the center conductor. Therefore "L" = L_{Muller} = 4L, where L is the single coil value. (This equivalent inductance value "L" is taken as a given by Müller so it gets no discussion.) For addition discussions here we will refer to the simple coax open stub capacitance as C (which you can approximately evaluate by looking up the standard coax parameter capacitance per length and multiplying by the physical open stub length). Müller develops his "true equivalent circuit" by first notionally moving the crossover connection to the center of the coax. This seems okay. He then notes, essentially by symmetry, that the new crossover connection can be broken without any effect on the circuit. This is way less obvious and not very convincing. That leaves a circuit consisting of pair of open stubs of half the original length in series, which together then run in parallel to the inductance. The series capacitors are then C/2 each and so result in C/4 when combined. The inductance remains L_{Muller} = 4L. Therefore the High-Z connection is a parallel (4L)(C/4) circuit, while the Low-Z connection is a parallel (L)(C) circuit. Thus the two connections provide the same resonance frequency but not the some impedance.

Duffy (07 and 11, http://vk1od.net) has pointed out in more detail than others that treating the coax as a simple capacitor is limited to cases where the length is not very long. In general it must be treated as a transmission line that behaves in a more complex manner at higher frequencies - producing multiple resonances in traps. He has investigated just the High-Z connection (or "bootstrap") and offers some thoughts on Muller's work. But even though Duffy says "impedance values obtained from the (Muller's) 4L // C/4 have significant error in the region of resonance," and thus rejects Müller's circuit, the experimental differences in his plots (in the region of resonance) might appear to an outside analyst as being easily within the confines of experimental error. Duffy raises another point concerning the dual inductance current paths (center conductor and braid) by noting the skin effect (which is, of course, vital for normal coaxial cable behavior) means that there must, in reality, be a (equal) current counter to the center conductor current that runs on the inside of the braid. Therefore the result (after invoking Kirchhoff

(1845)) is that the current, I, on the center conductor results in an inductively relevant current 2I on the outer braid (since the center conductor coax current is said to be shielded). This has the effect of a 4X inductive impedance increase which is equivalent, at least in practice, to doubling the number of turns on the coil so the net effect on the apparent inductance is the same. Aside from the assertion of a 4X inductive impedance increase ("transformation"), there is no analysis to suggest that the effective capacitance should be C/4. More on this later.

Beaumont (11) has carried out a careful and extensive experimental investigation of the electrical properties of coaxial traps both for the High-Z "bootstrap" and the Low-Z "half trap" configurations. While the current note here does not do that work full justice, the upshot is that given the inductance, L, of the Low-Z coax coil (center conductor or braid alone) and the capacitance of the shunted open coax stub, C, the High-Z connection ("bootstrap") provides an equivalent LC parallel circuit with inductance of 4L and a capacitance of C/4 near the resonance while the Low-Z connection gives L and C.

High-Z Inductive Impedance "Transformation"

Some authors have made comments on the understanding of the inductive impedance multiplier associated with looping the coax center conductor back to the coax braid for a second tour through the coil. While the standard claim is that this simply doubles the number of loops in the coil, others have suggested more interesting descriptions.

O'Neill provides this diagram. While the language used in the description does not seem useful, the basic notion of feeding the inductor current back into a second parallel inductor is more useful, beyond just saying "magnetic induction." Note that the "secondary current" pictured here is the additional current forced by mutual induction, it is not the same as the second loop of current forced in the coax braid, which is in the opposite direction. While a number of O'Neill's technical assertions may be subject to additional critical review, the notion of use of a second pass of the current through the coax coil has truthiness. He mentions only a "gain in impedance" from the configuration and does not quote any L or C values explicitly so there is no direct suggestion of an X4 multiplier.

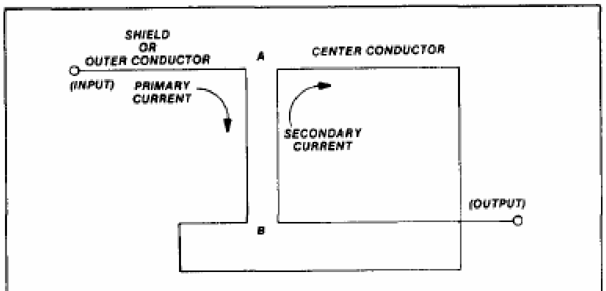
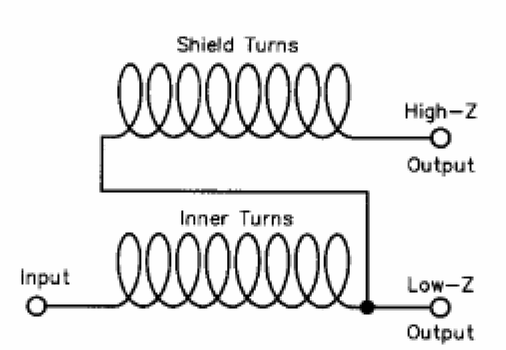


fig. 3. Electrical schematic of single-element trap as a 1:1 transformer or coupler.

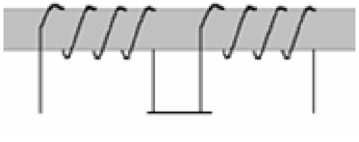
Buxton (94) shows the next picture which suggests that the High-Z trap current goes through two coils but he says nothing as to why this should give 4L rather than 2L.

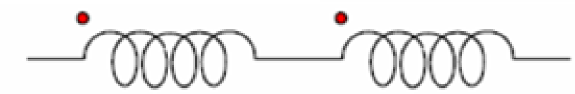


(Recall that Duffy (11) invokes the coax skin effect and thus rejects the notion of two coils, coupled or otherwise, while saying the circuit results in twice the input current appearing on the braid, so giving 4L – no need for mutual inductance of two coils.)

Consider an inductor L, followed by a separated identical second inductor. Assuming they are well separated, they have no mutual inductance, so the net inductance for the two coil series circuit is 2L.

Now if we put the two inductors close together or on a common core (so they share the other's flux) the net inductance of each will be L+/- kL where k is the coupling factor (0<k<1) and the +/- is selected according to the polarity of the coupling. If the two coils are wound the some direction and on a common core (or interlaced), the resulting total inductance is L+L <u>for each</u>. Therefore the total inductance will be 4L. The dots on the symbolic coupled inductances indicate the polarity of the coupling, dictating the +/- mentioned above as +.



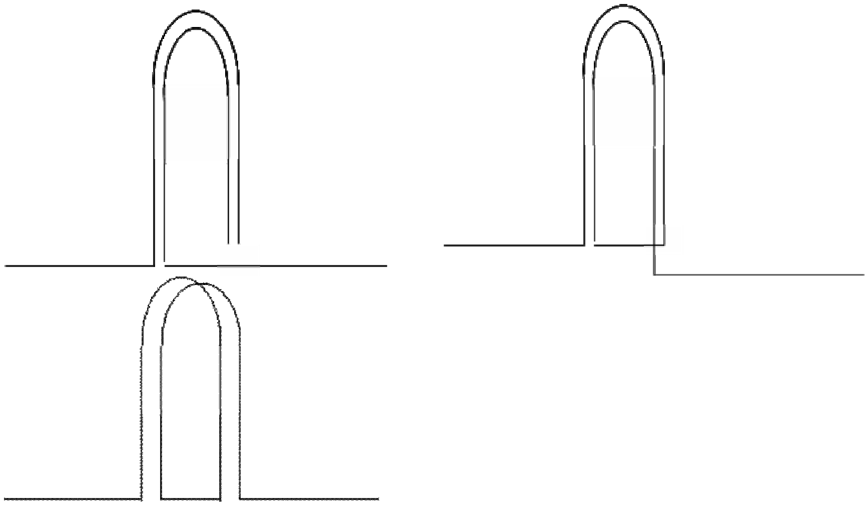


The (effectively) two coils for a High-Z connected coax trap are mutually coupled in just this way and that accounts for the 4L. Again, if Duffy's argument is correct, this is not needed since there is then a single coil but with twice the input current leading to the same 4L. But one could use a two parallel wire transmission line, rather than the coaxial cable, and the mutual coupling of the two coils would then be clear. Note that this is consistent with Buxton's diagram given before provided the mutual coupling is complete with the shield and inner turns interlaced on a common core. It is also consistent with O'Neill's circuit. However, all this has little to do with impedance transformation, 1:1 transformers or couplers. There is nothing remarkable about this last illustration of getting 4L from 2 coils of L each. It is exactly the effect that causes the inductance of a coil to be (approximately) proportional to the square of the number of turns. (Proof left as an exercise for the student.)

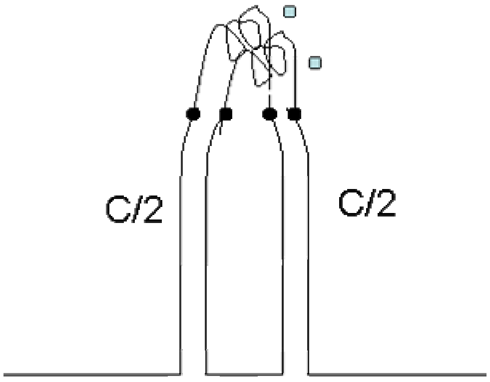
High-Z Capacitive Impedance "Transformation"

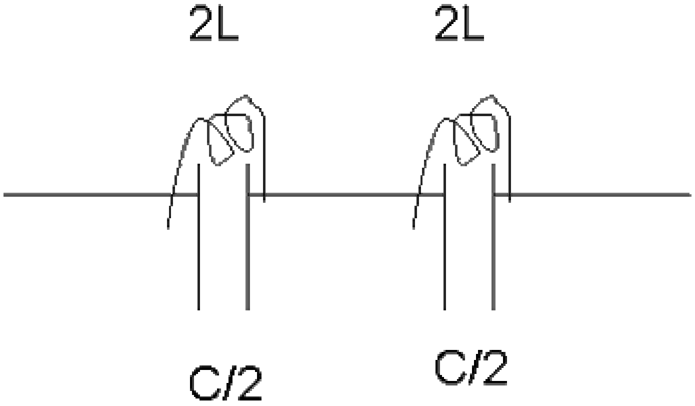
Of the Coax Trap authors, only Muller has really ventured into the question of why, for a High-Z connection, the equivalent parallel circuit capacitance is ¼ of the capacitance of the open coax stub alone. Consider this variation as an alternate to Muller's approach:

Assume we have a two parallel wire transmission line with a high capacitance per length and no significant inductance. This is connected first in the Low-Z and then in the High-Z type mode and finally the far left side is the High-Z version given a half twist (but the top loops do not touch).

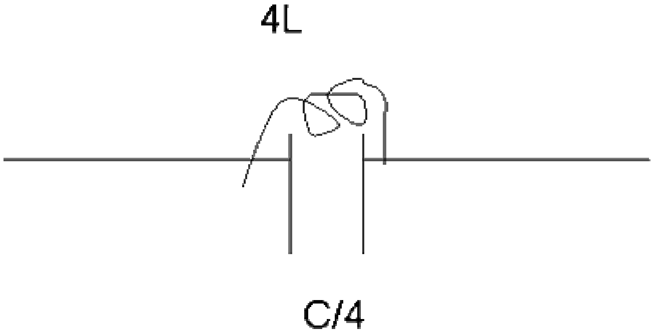


Then we admit there is some inductance and add two (coupled) coils (individually with inductance L) to the tops of the loops (maintaining the symmetry since coaxial traps are symmetrical). The capacitance of each leg is now (maybe) C/2 since it is half the length. Then noting that the two coils are fully positively coupled, the effective inductance of each is 2L. So it might then be argued that the result is equivalent to the circuit on the right.





If that is true, it is then easy so show this in-series pair of parallel LC circuits is the same as the following.



Therefore the High-Z “twin lead” trap can be claimed to be equivalent to a (4L)(C/4) parallel circuit (in the region of the resonance). Making the same story for the coax trap is less evident if you accept the skin effect story that implies the equivalent to a single coil with twice the input current.

J. Mathison (77) QST Feb 77, Inexpensive Traps for Wire Antennas

G. Myers (80) June 1980 QST, A Two Band Half Sloper
R. Johns (81) Coaxial Cable Antenna Traps, QST, May 1981 pp. 15-17
F. Noble (84) Mar 84 QST, pp46-47, Coaxial Antenna Trap Design
G. O'Neill (81) Trapping the mysteries of trapped antennas, Ham Radio Oct 1981
A. Buxton (94) Two New Multiband Dipoles Buxton Aug 94 QST
D. Demaw (83) Lightweight Trap Antennas, Some Thoughts, QST June 1983 pp-15-18
J. Finley (84) June 84 QST Feedback
R. Sommer (84) Optimizing Coaxial-Cable Traps, QST Dec 1984 pp 37-42
A. Buxton (92 Jul 92 QST, Build a Space-Efficient Dipole Antenna for 40, 80 and 160 Meters
VE6YP A. Field, Coaxial Trap Design software, http://www.qsl.net/ve6yp/CoaxTrap.html
K.-O, Müller (04) Coaxial Traps for Multiband Antennas, the True Equivalent Circuit,QEX, Nov/Dec 2004
O. Duffy (07 and 11) Impedance of a Coaxial Trap http://vk1od.net/antenna/coaxtrap/CoaxTrapImpedance.pdf and Comment on QEX article - "Coaxial Traps for Multiband Antennas, the True Equivalent Circuit" http://vk1od.net/antenna/coaxtrap/QexKom.htm
G. Kirchhoff (1845)
R. Beaumont (11) Coaxial Traps for HF Antennas, Tech Report 011-ARv2, http://vk1od.net/antenna/coaxtrap/CoaxialTrapsforHFAntennas.pdf

Appendix on Practical Effects of Traps from EZNEC and Equivalent Circuits

There is some discussion among trap authors about the best values of the impedances of the L and C components and the Q of the equivalent LCR circuit (taken here as R in series with L and C in parallel with RL while Q is XL/R where XL is the inductive reactance).

One version of conventional wisdom (O'Neill) is that the value of XL (and XC) at the resonant frequency should be 200-300 ohms and that the impedance of the trap should be > ~7000 ohms across the band near where the trap is resonant. For examples, the various traps shown in the ARRL Antenna Handbook are calculated to be 360, 225, 175 and 650 ohms and some examples for Q are ~100.

This can be investigated using the EZNEC trap load to see the effects of traps of different parameters. In this case we look at a dual band (3.7 and 7.15 MHz) trap dipole. The lengths of the dipole halves are about 33 ft and 60 ft but are somewhat variable with the trap properties. The L, C and R (in series with L) parameters can be easily calculated analytically and the examples used are shown in the following table in pairs for the Hi-Z or Lo-Z trap connections. The last two columns are to address the issue of having the resonance out of band.

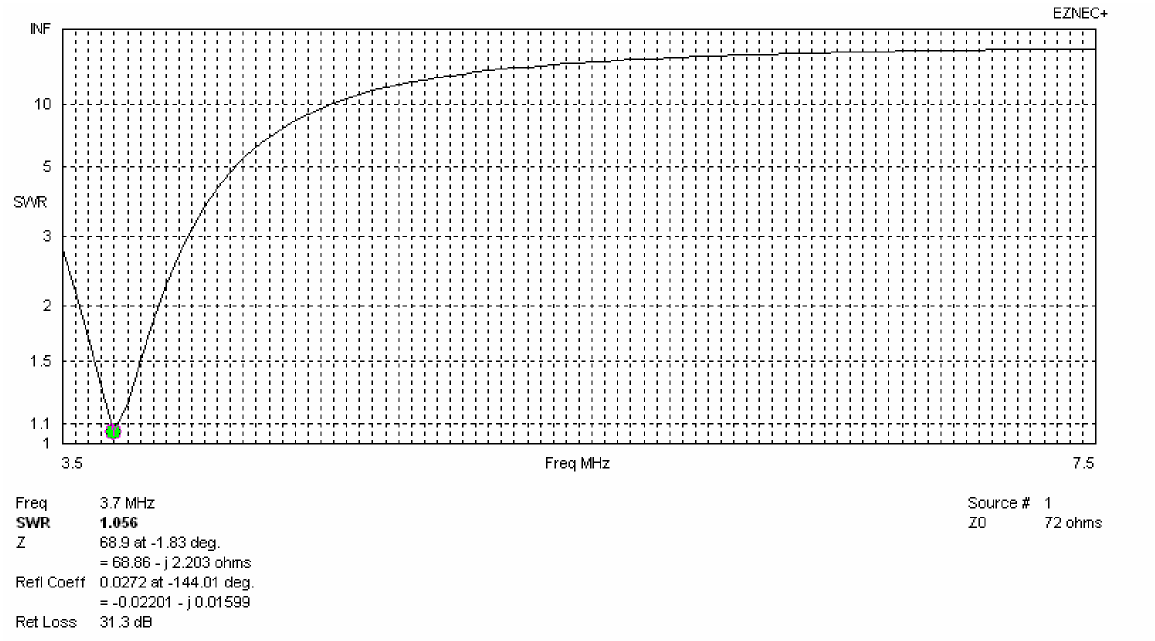
Freq Hz	Q100 R8 Hi 800Ω 7.15MHz	Q100 R2 Lo 200Ω 7.15MHz	Q25 R32 Hi 800Ω 7.15MHz	Q25 R8 Lo 200Ω 7.15MHz	Q400 R025 Lo 100Ω 7.15MHz	Q100 R8 Hi 800Ω **6.9 MHz**	Q100 R2 Lo 200Ω **6.9 MHz**
Figure#	3	4	5	6	7	8	9
7.00	17848	4462	13518	3379	2285	27510	6877
7.05	25716	6429	16121	4030	3382	18722	4680
7.10	43718	10929	18698	4674	6439	14141	3535
715	79374	19843	20014	5003	35519	11358	2839
7.20	49653	12413	19093	4773	7763	9494	2373
7.25	28270	7067	16695	4174	3760	8160	2040
7.30	19304	4826	14117	3529	2482	7159	1790
3.70	15+j565	4j+141	60+j563	15+j141	0.5j+71	16+j601	4+j150

In the upper portion the variation of the magnitude of the trap impedance |Z| is given across the 40m band for various selections of L and C impedance (at the stated approximate resonance frequency) for several Q values and coax trap connections (Hi or Lo). All this will remain true for any trap, coax or otherwise. The last line gives the complex equivalent impedance of the trap at the 3.7 MHz low frequency dual band antenna resonance.

The |Z| peaks at the trap resonance frequency and falls off on either side. Both the peak value and the rate of decrease with frequency and they depend on the component impedance (XL=XC=800, 200 or 100) and Q. If the Q is high and the XL is low the trap impedance may get be too small at band edges. Low Q and high XL makes the impedance at 3.7 MHz become high, including the resistive component. The input impedance of an ideal dipole is about 72 ohms and this is a standard against which the resistive component at 3.7 MHz can be judged. A high reactive (inductive) component means more loading so the ends of the dual band antenna will be shorter.

These examples were run for a free space dipole in EZNEC using the trap load model from the above table using the resistance the gives the desired Q=XL/R. The interior portion of the dipole was dictated by the desired approximate 7.15 MHz resonance and the overall length was chosen to get the 3.7 MHz resonance. The SWR plots are against a 72 ohm standard.

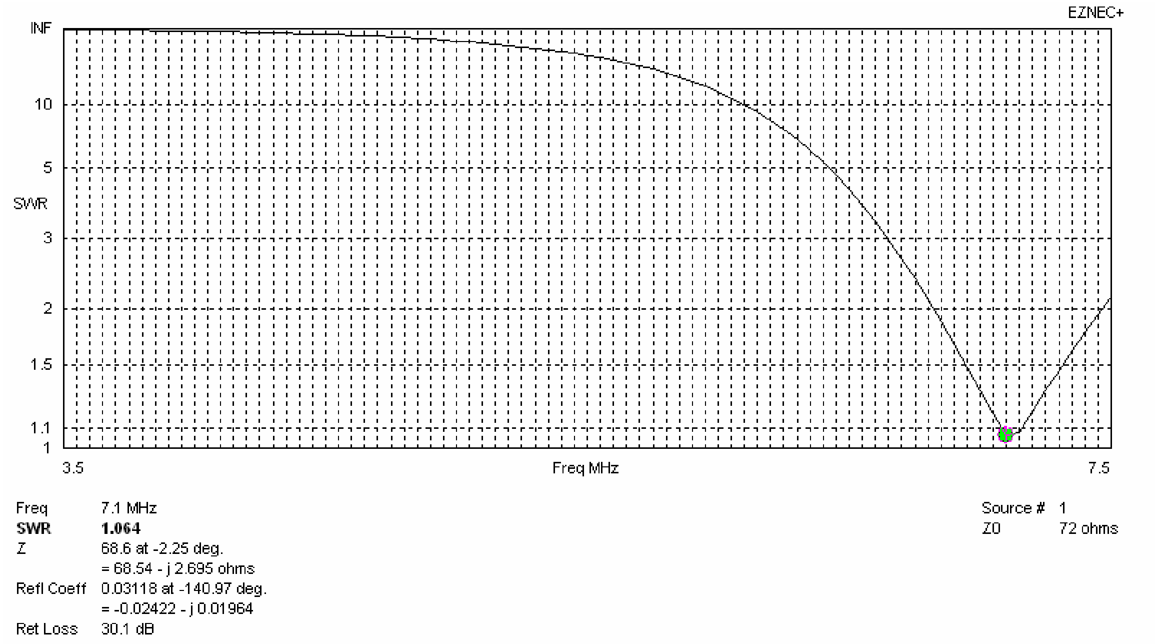
First we show the SWR for a simple full size dipole at 7.15 MHz and then for another at 3.7 MHz to allow a comparison with the various cases.



Freq 3.7 MHz
SWR 1.056
Z 68.9 at -1.83 deg.
= 68.86 - j 2.203 ohms
Refl Coeff 0.0272 at -144.01 deg.
= -0.02201 - j 0.01599
Ret Loss 31.3 dB

Source # 1
Z0 72 ohms

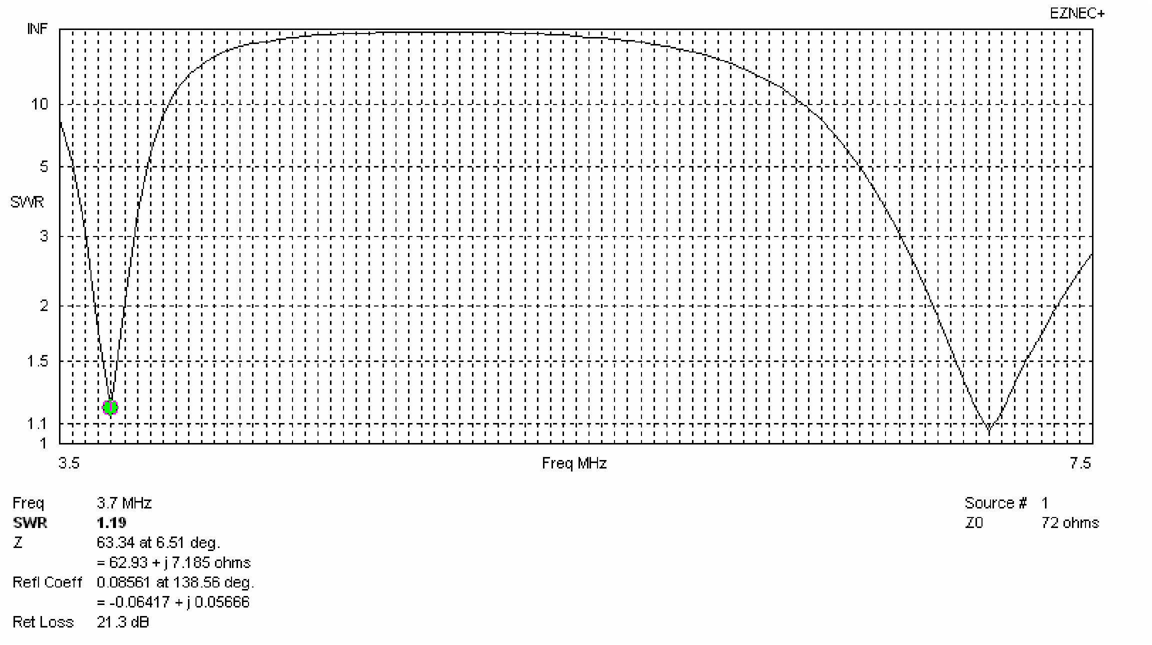
Figure A1. pure 7.1 MHz dipole



Freq 7.1 MHz
SWR 1.064
Z 68.6 at -2.25 deg.
= 68.54 - j 2.695 ohms
Refl Coeff 0.03118 at -140.97 deg.
= -0.02422 - j 0.01964
Ret Loss 30.1 dB

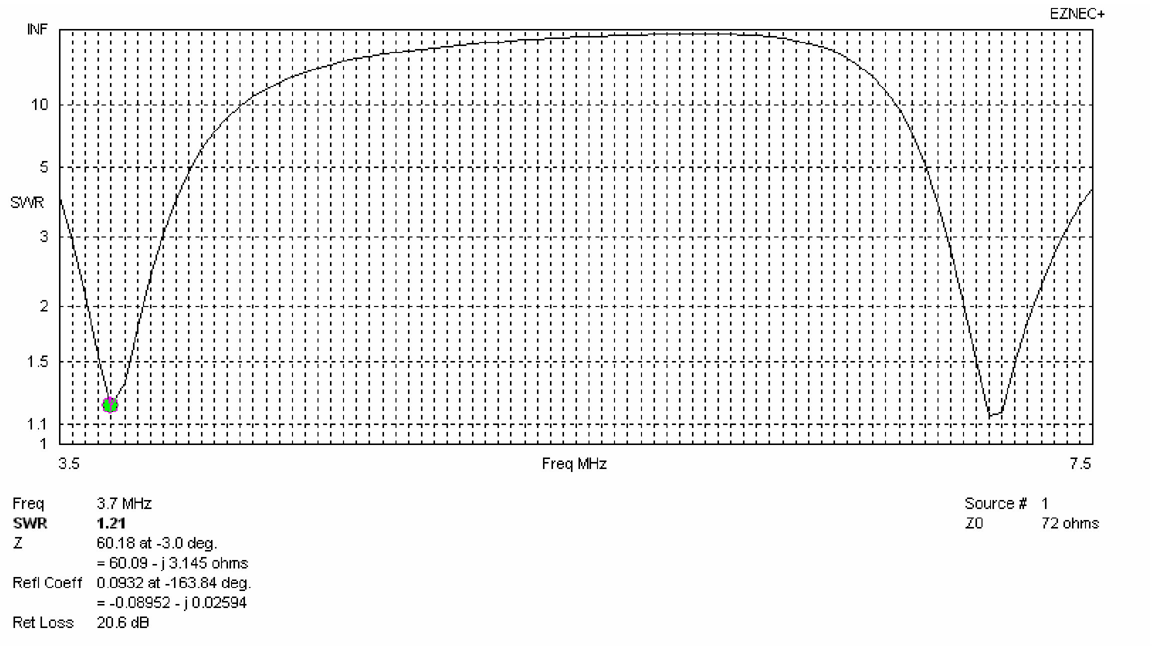
Source # 1
Z0 72 ohms

Figure A2. pure 3.7 MHz dipole



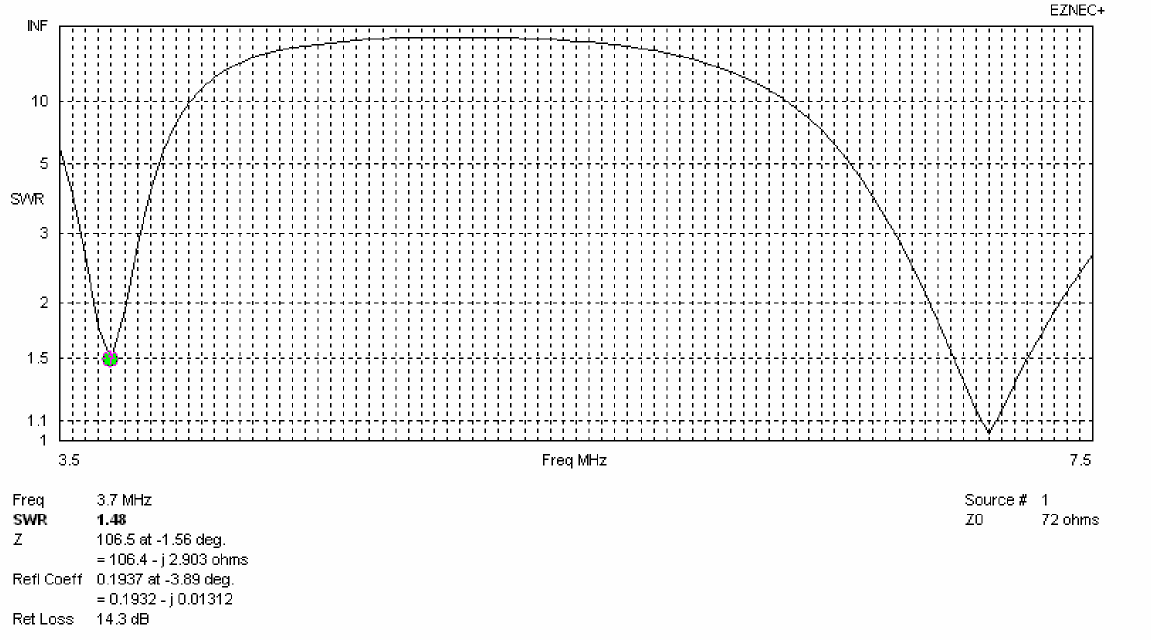
```
Freq        3.7 MHz                                   Source #   1
SWR         1.19                                      Z0         72 ohms
Z           63.34 at 6.51 deg.
            = 62.93 + j 7.185 ohms
Refl Coeff  0.08561 at 138.56 deg.
            = -0.06417 + j 0.05666
Ret Loss    21.3 dB
```

Figure A3. free space f0 7.15 MHz 72 ohm SWR
HiZtrap 800 ohms Q 100 27.8pF /17.8micH R=8



```
Freq        3.7 MHz                                   Source #   1
SWR         1.21                                      Z0         72 ohms
Z           60.18 at -3.0 deg.
            = 60.09 - j 3.145 ohms
Refl Coeff  0.0932 at -163.84 deg.
            = -0.08952 - j 0.02594
Ret Loss    20.6 dB
```

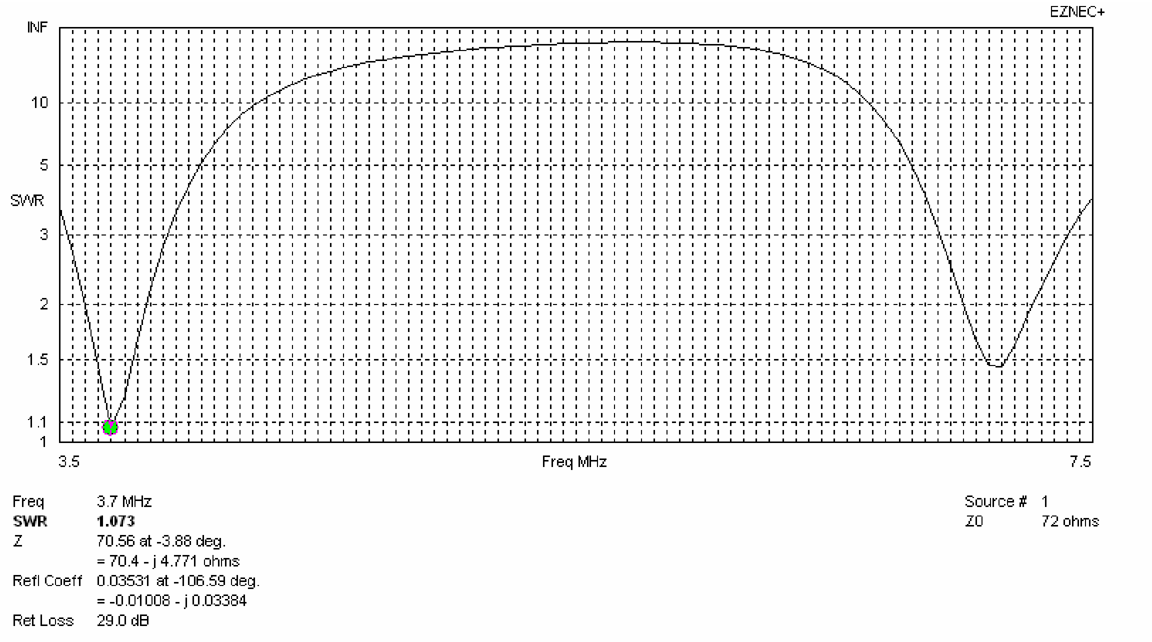
Figure A4. free space f0 7.15 MHz
LoZtrap 200 ohms Q 100 111.2pF /4.45micH R=2



Freq 3.7 MHz
SWR **1.48**
Z 106.5 at -1.56 deg.
= 106.4 - j 2.903 ohms
Refl Coeff 0.1937 at -3.89 deg.
= 0.1932 - j 0.01312
Ret Loss 14.3 dB

Source # 1
Z0 72 ohms

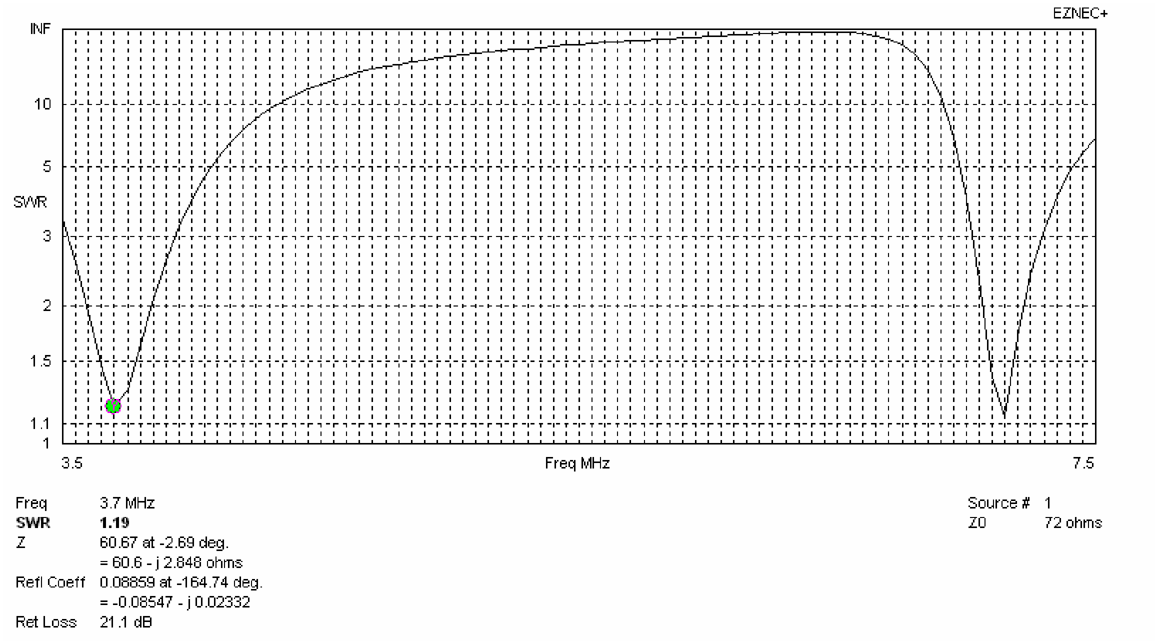
Figure A5. free space f0 7.15 MHz
HiZ trap 800 ohms Q 25 27.8pF /17.8micH R=32



Freq 3.7 MHz
SWR **1.073**
Z 70.56 at -3.88 deg.
= 70.4 - j 4.771 ohms
Refl Coeff 0.03531 at -106.59 deg.
= -0.01008 - j 0.03384
Ret Loss 29.0 dB

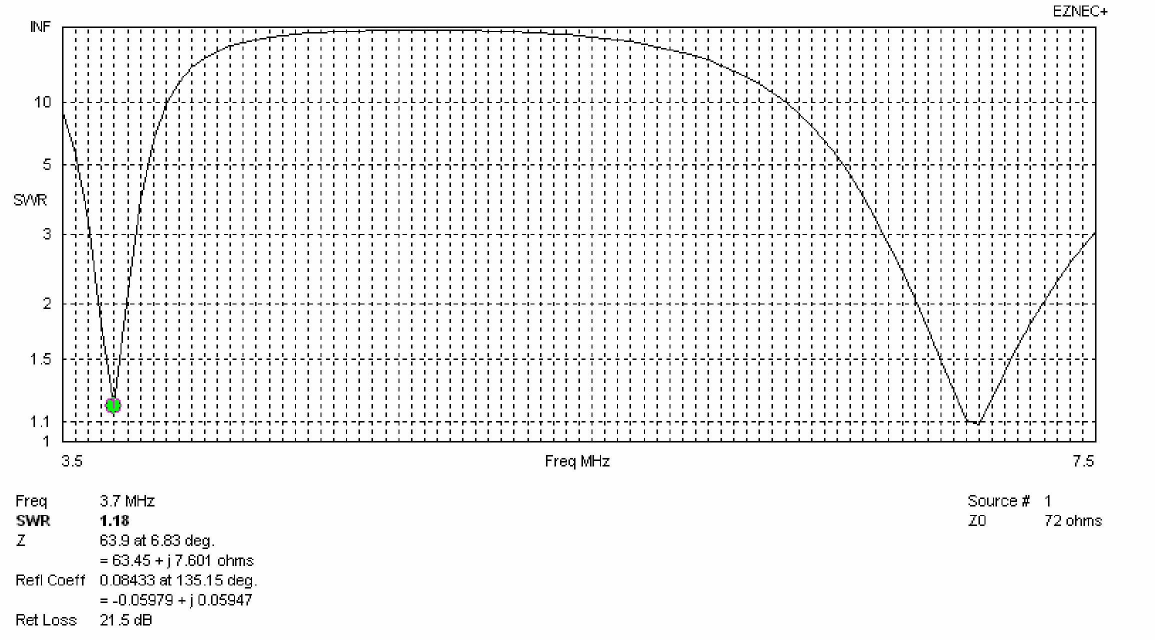
Source # 1
Z0 72 ohms

Figure A6. free space f0 7.15 MHz
LoZtrap 200 ohms Q 25 111.2pF /4.45micH R=8



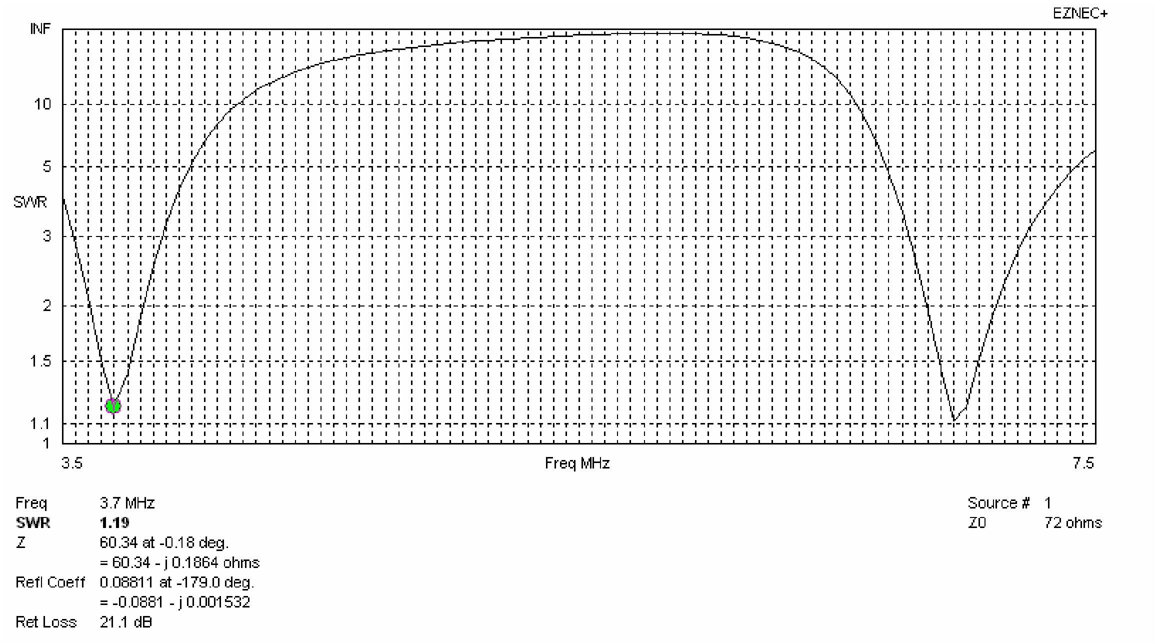
Freq	3.7 MHz	Source #	1
SWR	**1.19**	Z0	72 ohms
Z	60.67 at -2.69 deg.		
	= 60.6 - j 2.848 ohms		
Refl Coeff	0.08859 at -164.74 deg.		
	= -0.08547 - j 0.02332		
Ret Loss	21.1 dB		

Figure A7. free space f0 7.15 MHz
LoZtrap 100 ohms Q 400 222.4pF /2.225micH R=8



Freq	3.7 MHz	Source #	1
SWR	**1.18**	Z0	72 ohms
Z	63.9 at 6.83 deg.		
	= 63.45 + j 7.601 ohms		
Refl Coeff	0.08433 at 135.15 deg.		
	= -0.05979 + j 0.05947		
Ret Loss	21.5 dB		

Figure A8. Hi800 6900 Q100 note f0 at 7 is low and would be corrected but the shape is okay



```
Freq        3.7 MHz                                      Source #  1
SWR         1.19                                         Z0        72 ohms
Z           60.34 at -0.18 deg.
            = 60.34 - j 0.1864 ohms
Refl Coeff  0.08811 at -179.0 deg.
            = -0.0881 - j 0.001532
Ret Loss    21.1 dB
```

Figure A9 Lo200 6900 Q100 note f0 at 7 is low and would be corrected but the shape is okay.

Summary

For 3.7 MHz resonance:

Fig 3, 5 and 8 with high Zs show a narrower BW which can be associated with the high loading inductance and consequent shorter antennas

Figures 4, 6, 7 and 9 with Lo Z have wider BW but still not as good as the pure dipole since they are also shortened, but less

For 7.15 MHz resonance:

Fig 7 for LoZ plus high Q is the worst BW case, likely due to the relatively low trap impedance at the band edges

Fig 9 for LoZ and below band resonance also appears to suffer from the low trap impedance at the upper band edge

Fig 3 5 8 for HiZ shows a mildly reduced BW compared with the pure dipole

Figures 4 6 LoZ, 4 has a more significantly reduced BW compared to the HiZ cases while 6 with the lower Q has lower trap impedance across the band that has a more serious impact on the BW

For the 6.9 MHz resonance:

Fig 8 vs 3 HiZ, shows little difference in moving the resonance from 7.15 to 6.9

Fig 9, the loZ case produces low trap impedances at the upper edge of the band that narrows the BW.

Trap impedances less than ~ 5000 ohms in band cause BW performance reductions – worst case is too LoZ and high Q

Downside of HiZ is narrowed BW on the lower band

IF losses in the lower band can be judged by the effective resistance of the trap in that band, then HiZ is worse than LoZ and low Q makes it yet worse.

Losses in the resonance band are unclear.