Analysis of a small Inverted F PCB antenna for a 450 Mhz to 470 Mhz frequency band radio receiver using NEC2

1.0 Introduction:

A small antenna was required to be implemented on the PCB of a FM radio receiver operating between 450 Mhz and 470 Mhz. The PCB size was required to be no more than 4 inches long and 2 inches wide.

An inverted F antenna was chosen for this purpose. This antenna is printed directly on the PCB. The issues in the design of this antenna are numerous. Not the least being that not much information is available for the design of this type of antenna from an *analytical* point of view.

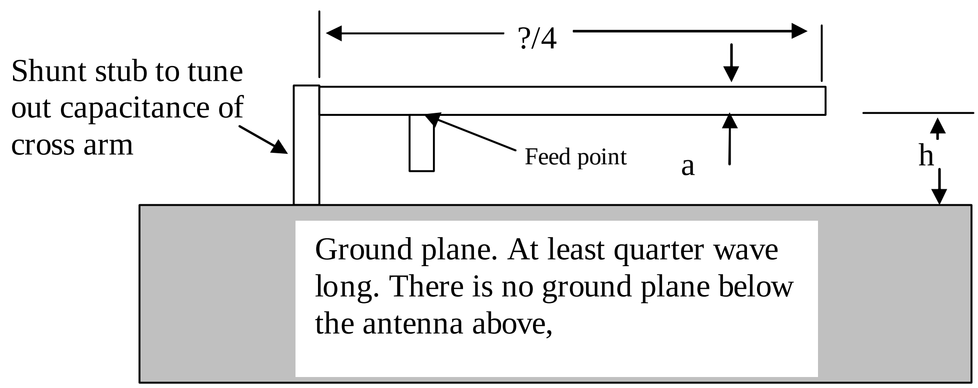
In any case even if the antenna is designed very carefully, and EM simulations are used extensively, ultimately the tuning of the antenna has to be done within the enclosure, as the performance is quite sensitive to other components on the board, the enclosure and the ground plane.

In any case, *it must be emphasized that the antenna will still have to be tuned in its final enclosure along with other components.*

2.0 The inverted F antenna configuration:

The configuration of the IFA is shown below in Figure 1.0. It is printed on a PCB using standard PCB techniques. The cross arm is a quarter wavelength (corrected for the composite dielectric constant of the PCB material and air, as detailed below.)

The vertical arm is a stub tuning device to tune out the capacitance of the cross arm at the frequency of interest. Expressions for the capacitance are given below. In addition the Agilent CAD package – APPCAD is also used to confirm calculations as needed.

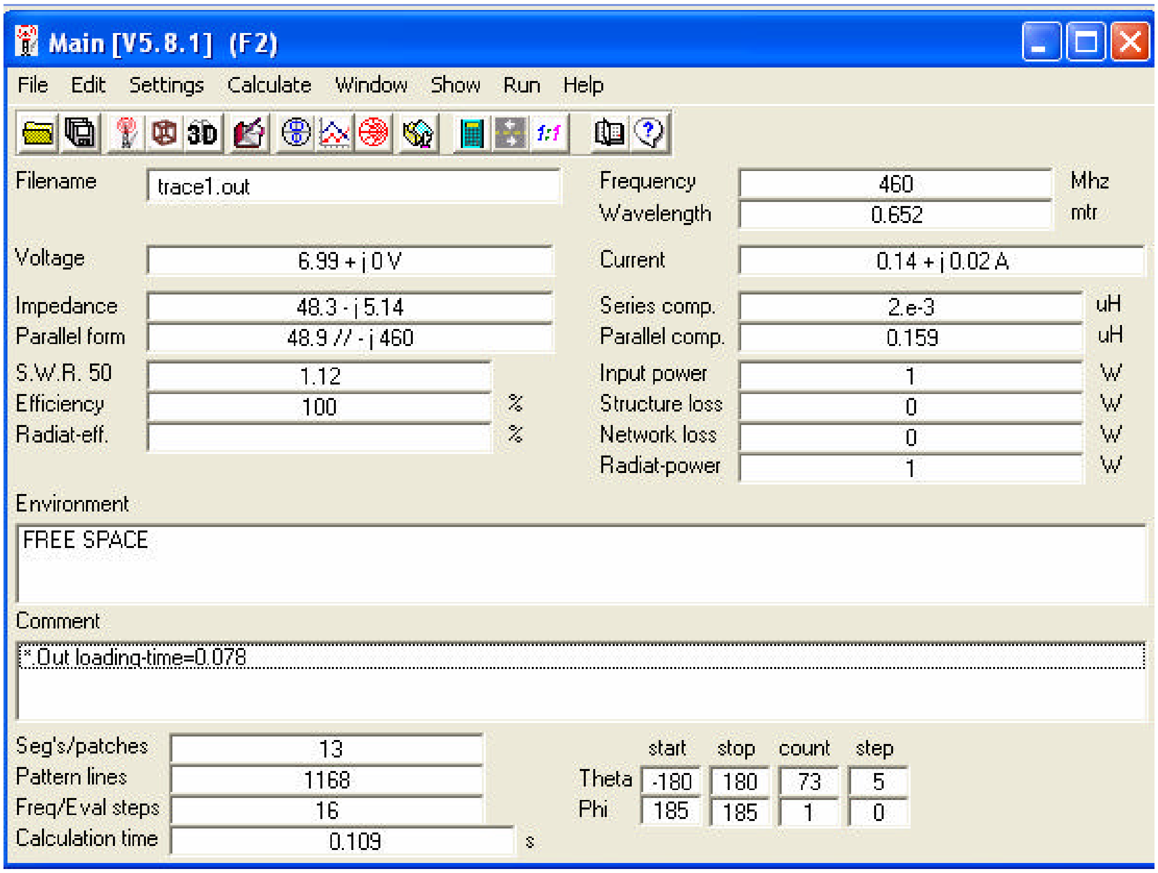


Inverted F antenna: Printed on a PCB substrate typically FR4.

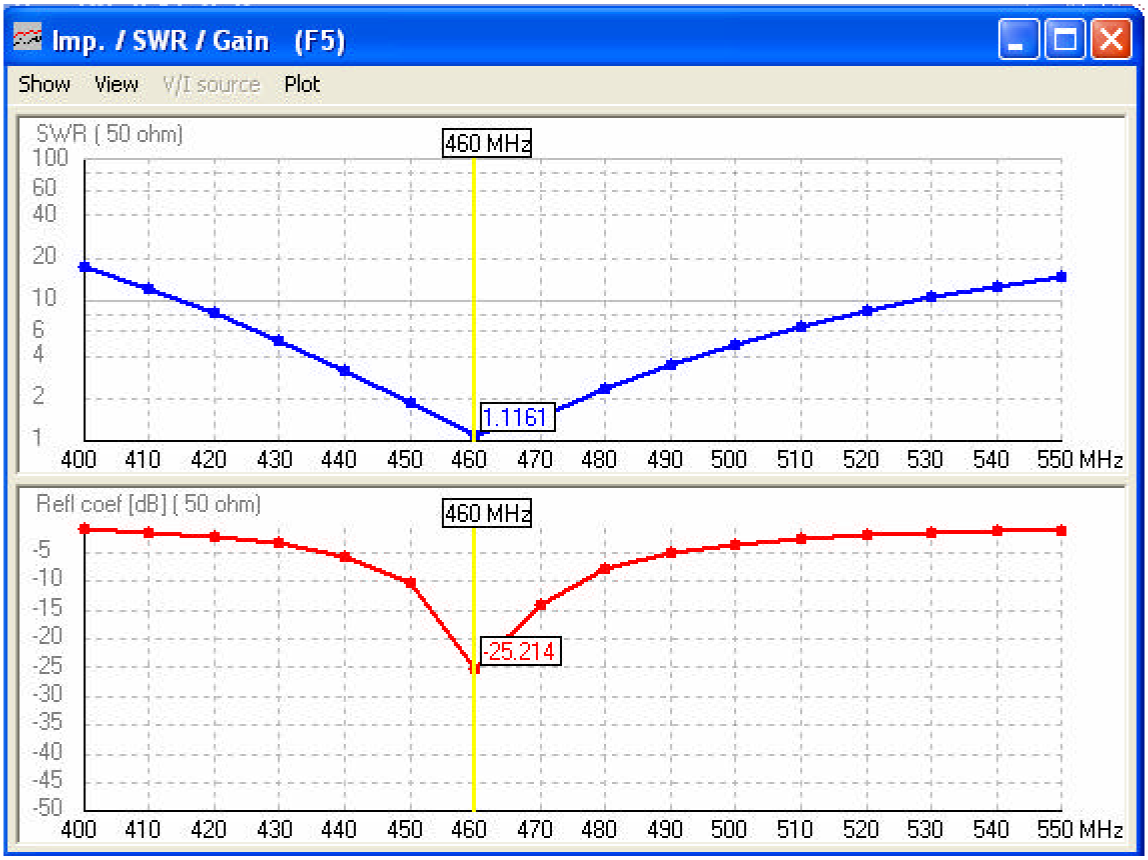
Figure 1.0

Simulation results of an inverted F antenna using NEC2

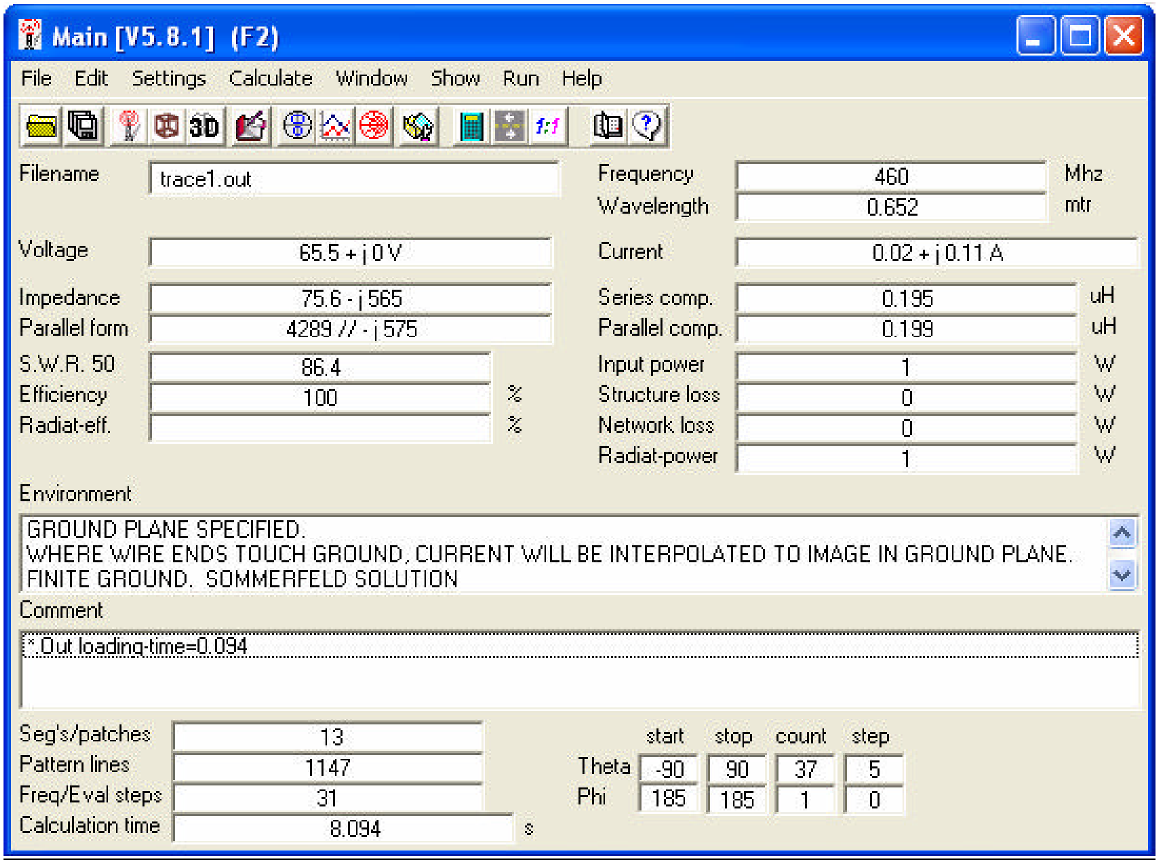
Frequency = 460 Mhz, Length of wire = 0.16 (cross arm) meter, radius = 1mm free space wavelength = 0.652 meter. Parallel stub = 0.16 meter Radius = 0.1mm, real ground. Feed point is 0.055 m from shorted end.


Main [V5.8.1] (F2)
File Edit Settings Calculate Window Show Run Help
3D
Filename trace1.out
Frequency 460 Mhz
Wavelength 0.652 mtr
Voltage 6.99 + j 0 V
Current 0.14 + j 0.02 A
Impedance 48.3 - j 5.14
Parallel form 48.9 // - j 460
Series comp. 2.e-3 uH
Parallel comp. 0.159 uH
S.W.R. 50 1.12
Efficiency 100 %
Radiat-eff. %
Input power 1 W
Structure loss 0 W
Network loss 0 W
Radiat-power 1 W
Environment
FREE SPACE
Comment
*.Out loading-time=0.078
Seg's/patches 13
Pattern lines 1168
Freq/Eval steps 16
Calculation time 0.109 s
start stop count step
Theta -180 180 73 5
Phi 185 185 1 0

SWR and reflection coefficient

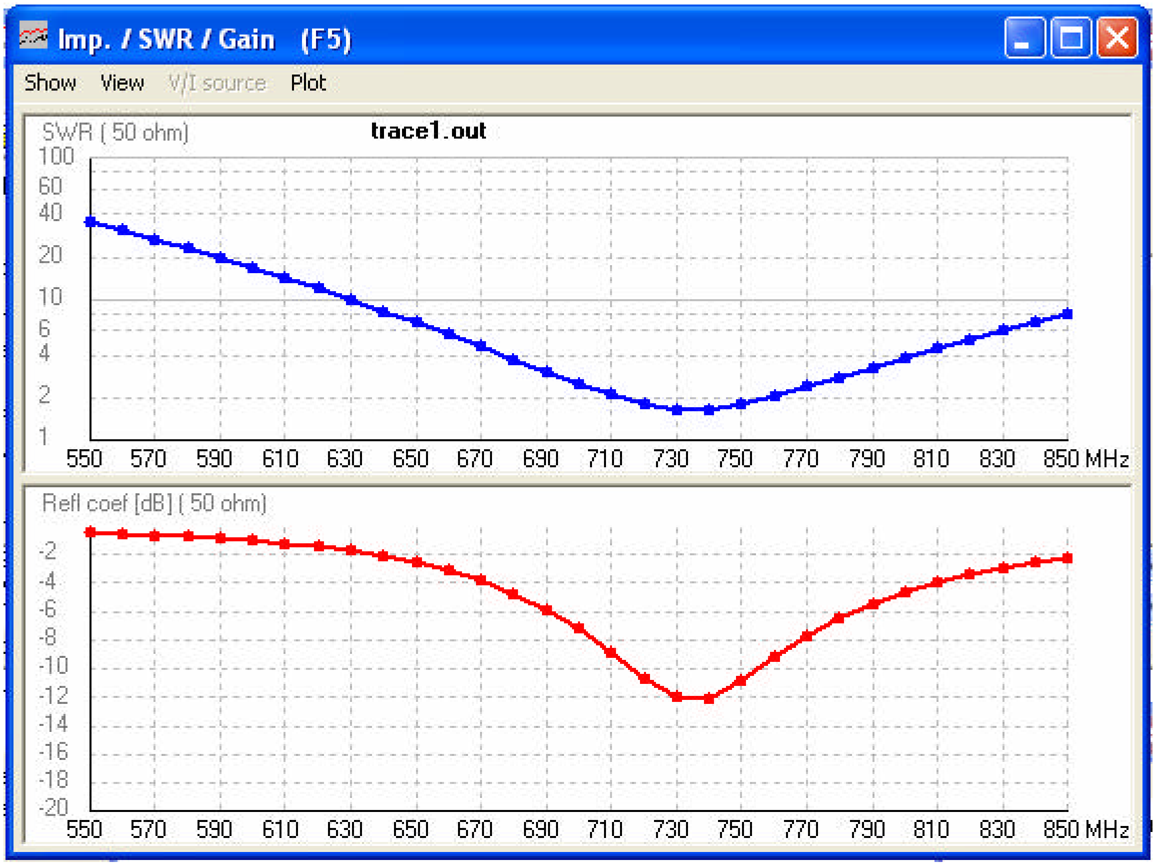


Antenna over a copper ground plane
No other changes from above



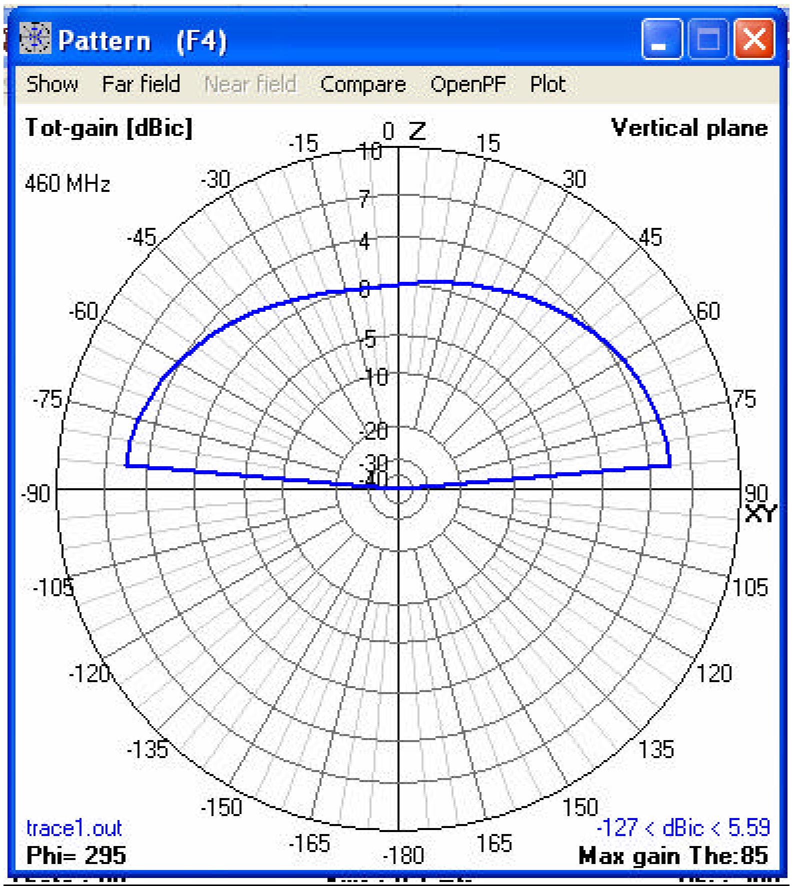
Note the change in input impedance from as an effect of the copper ground plane.

SWR and reflection coefficient with copper gnd plane

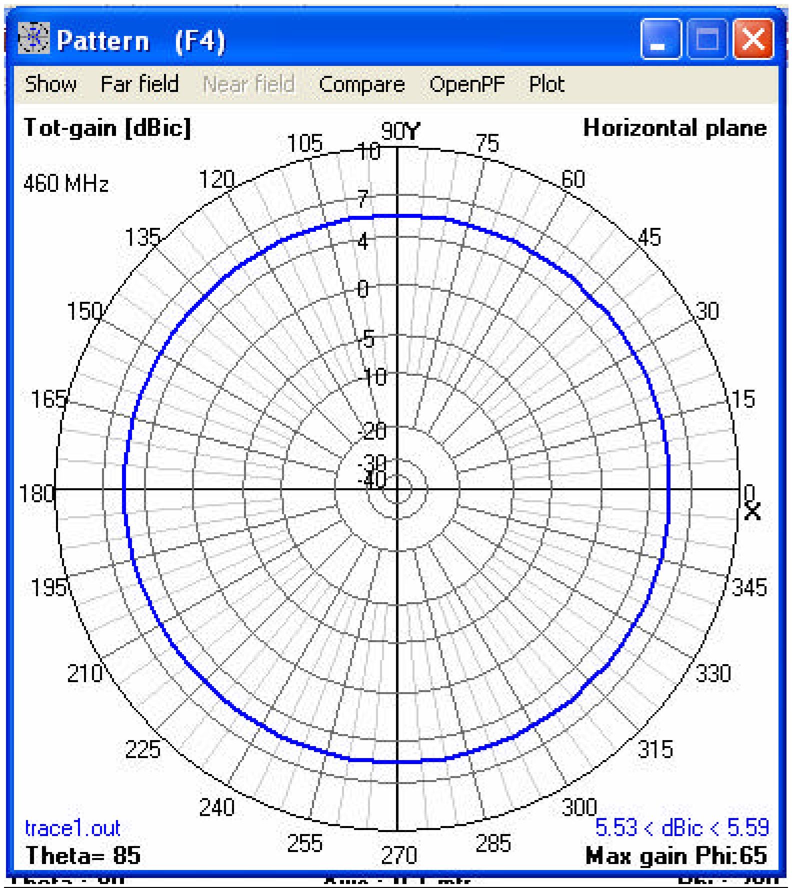


Resonant frequency shifts to 730 Mhz from 460 Mhz. as an effect of the copper ground plane. The SWR and the reflection coefficient also changes upwards.

Far field patterns for antenna over copper ground plane
Vertical plane

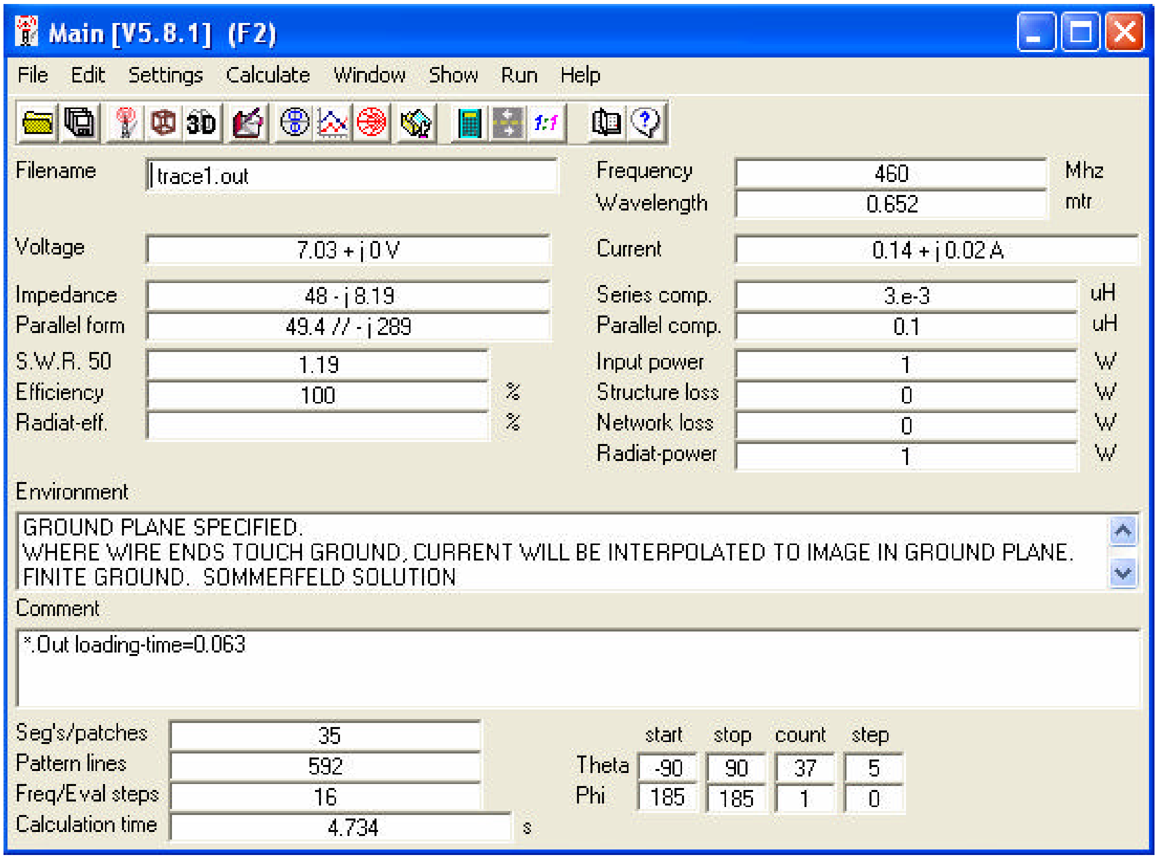


Far field pattern for antenna over a copper gnd plane
Horizontal pattern

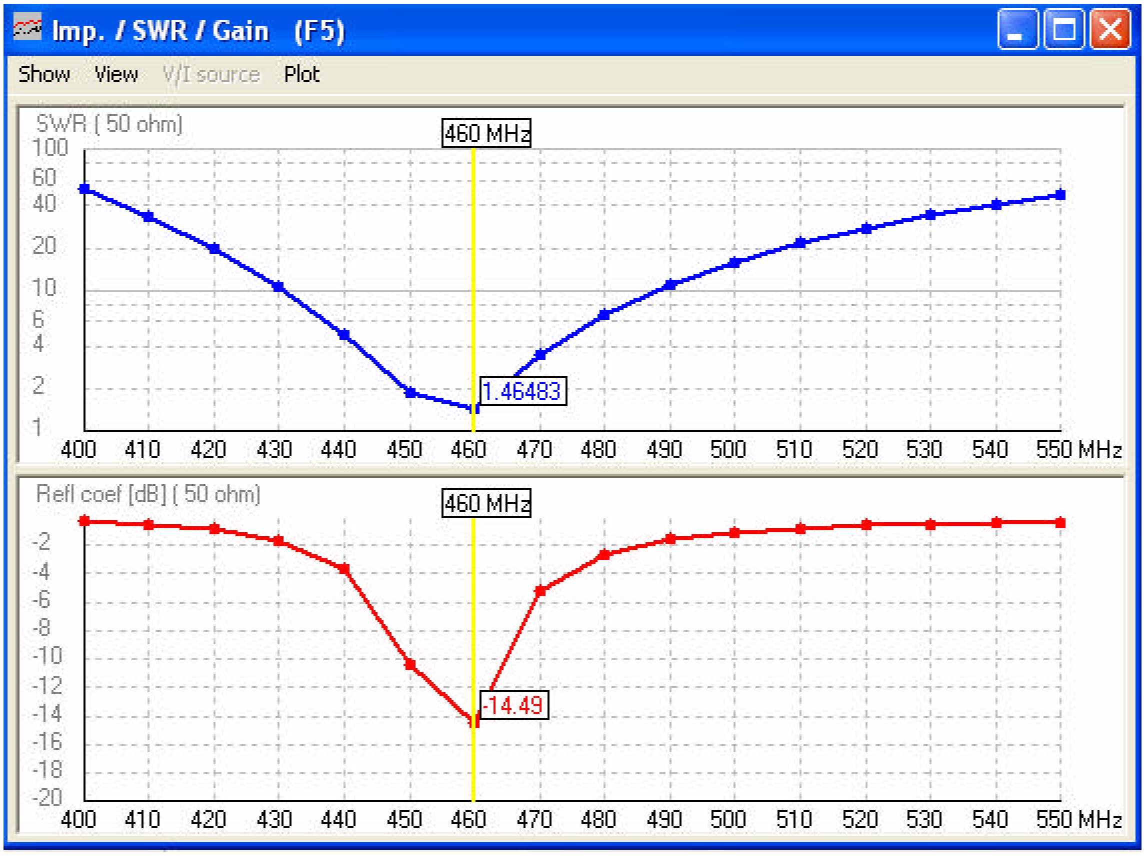


Adjustments made to get the resonant frequency and impedance close to where I want it.

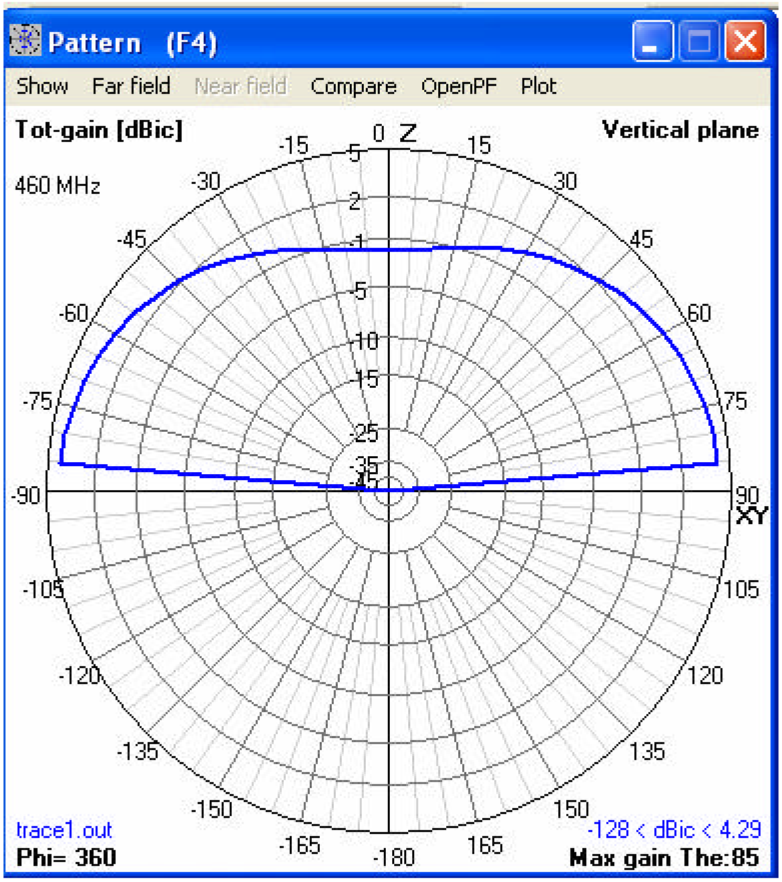
Height of the stub = 0.06 , the length of the cross arm is 0.105. Cross arm radius 0.1mm
Stub radius = 0.1 mm.

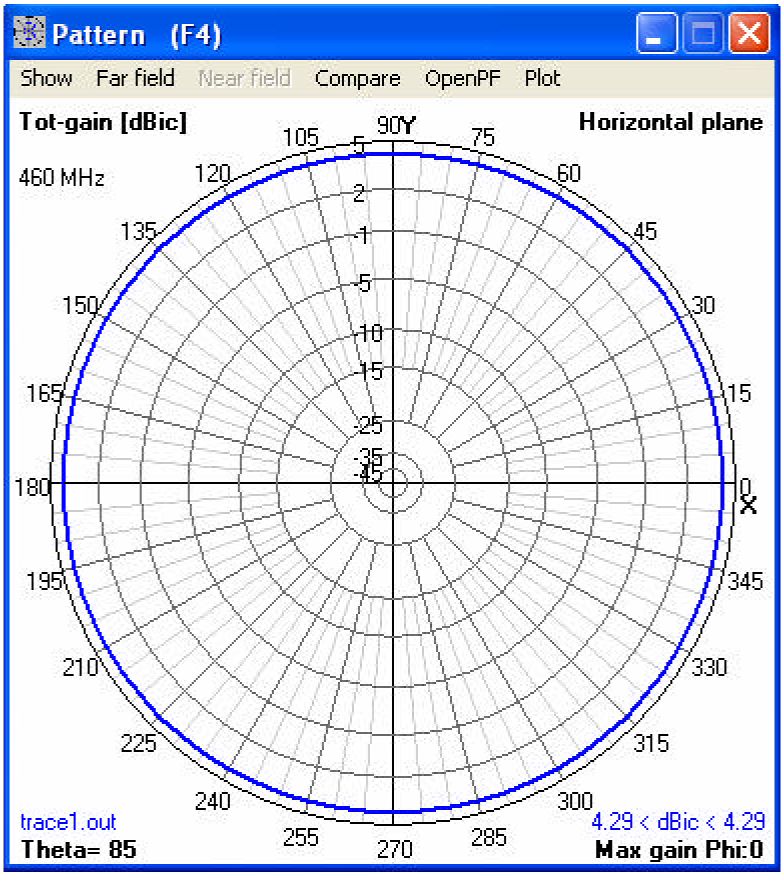


SWR and reflection coefficient

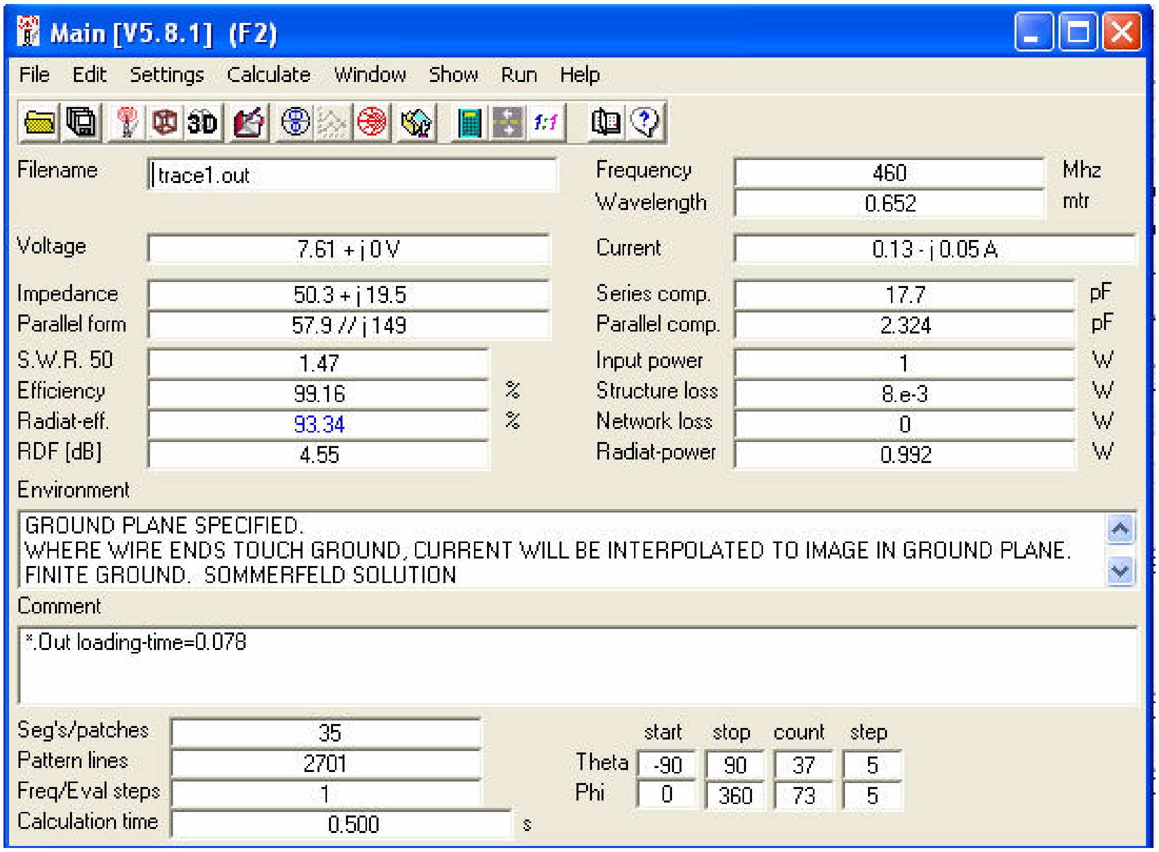


Far field

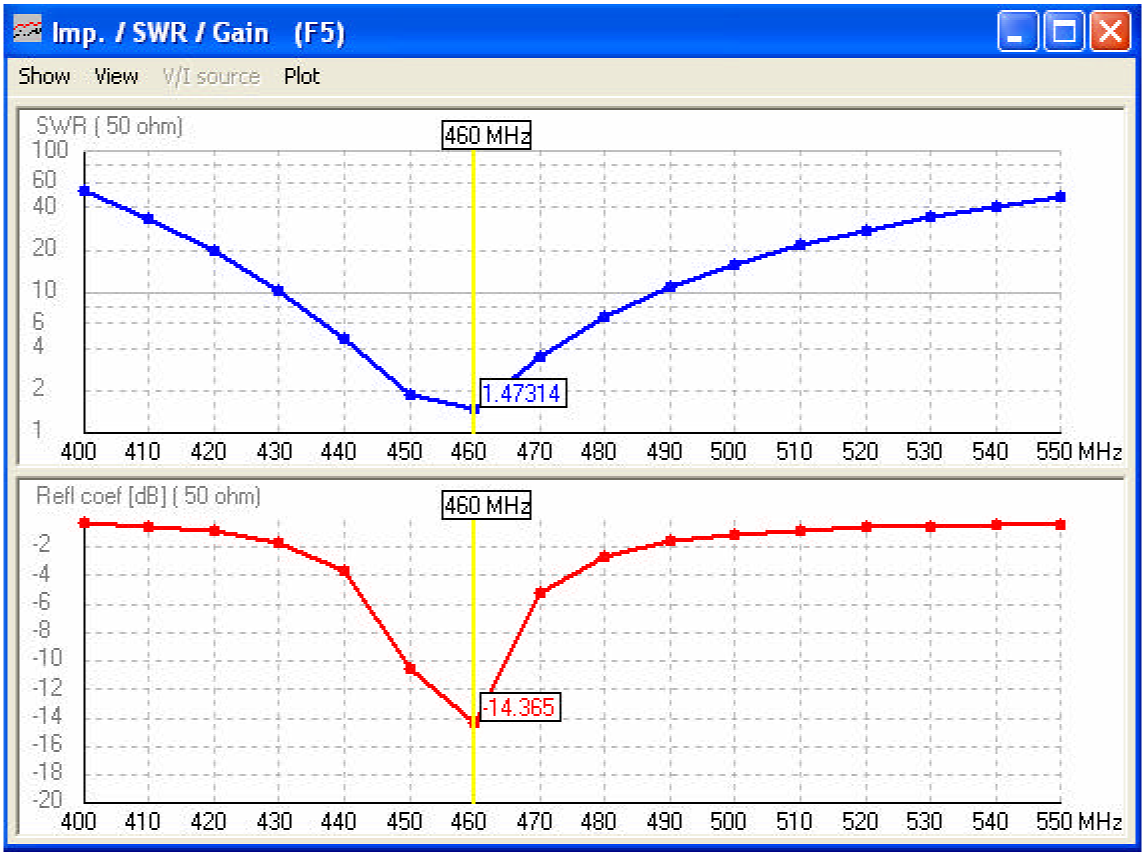

Pattern (F4)
Show Far field Near field Compare OpenPF Plot
Tot-gain [dBic]
460 MHz
Vertical plane
Z
XY
trace1.out
Phi= 360
-128 < dBic < 4.29
Max gain The:85


Pattern (F4)
Show Far field Near field Compare OpenPF Plot
Tot-gain [dBic]
Horizontal plane
460 MHz
trace1.out
Theta= 85
4.29 < dBic < 4.29
Max gain Phi:0

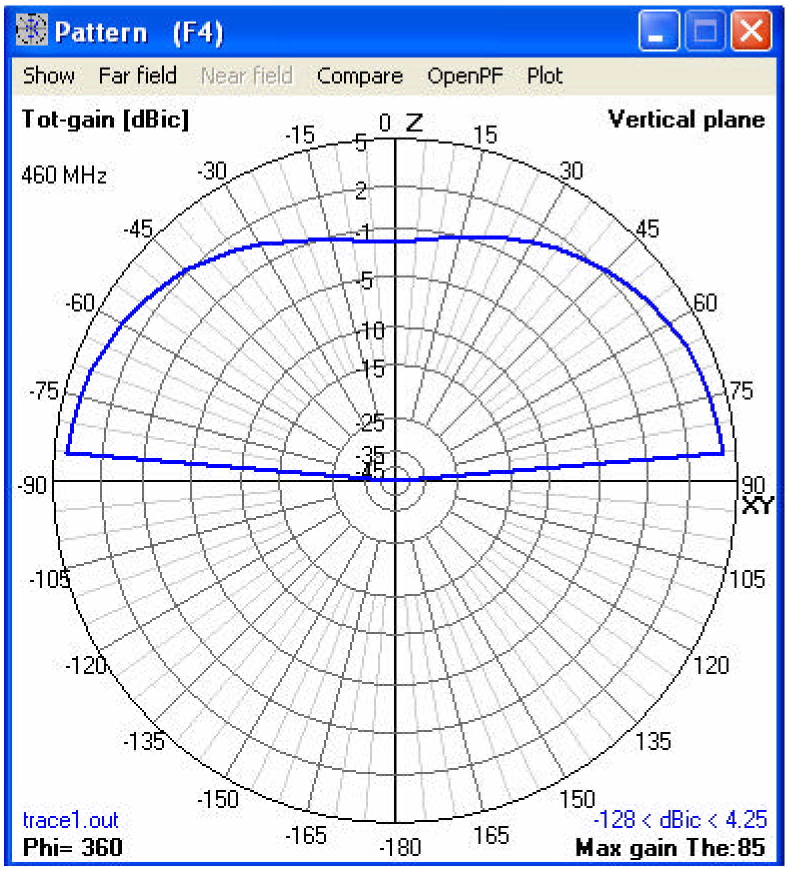
The above results were obtained with ideal conductors. The following results are with actual copper conductors.

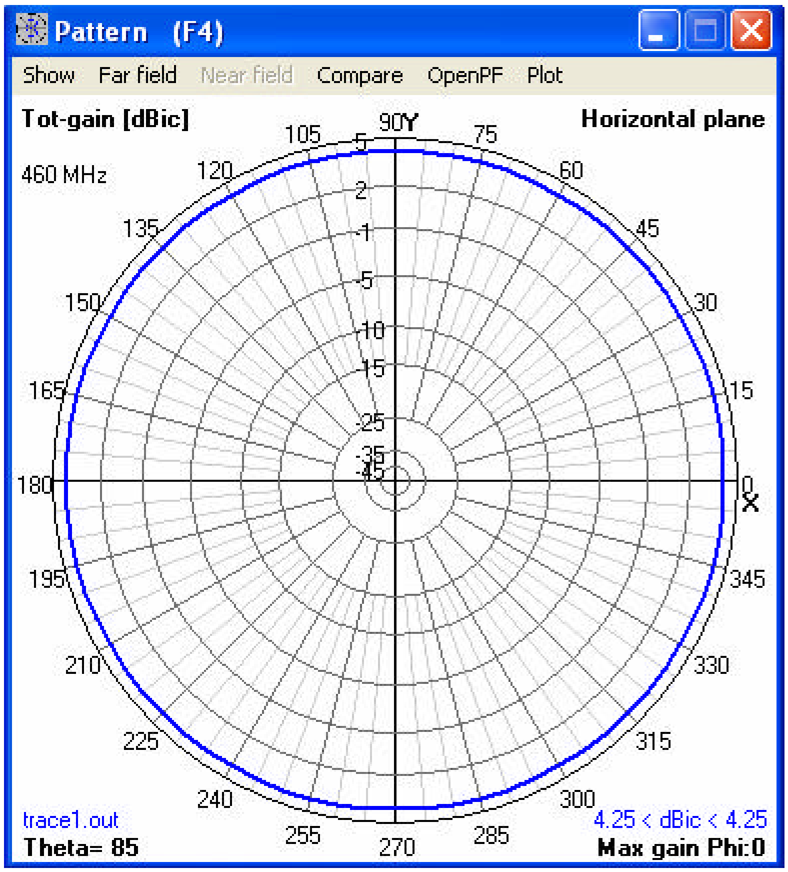


SWR and Reflection Coefficient



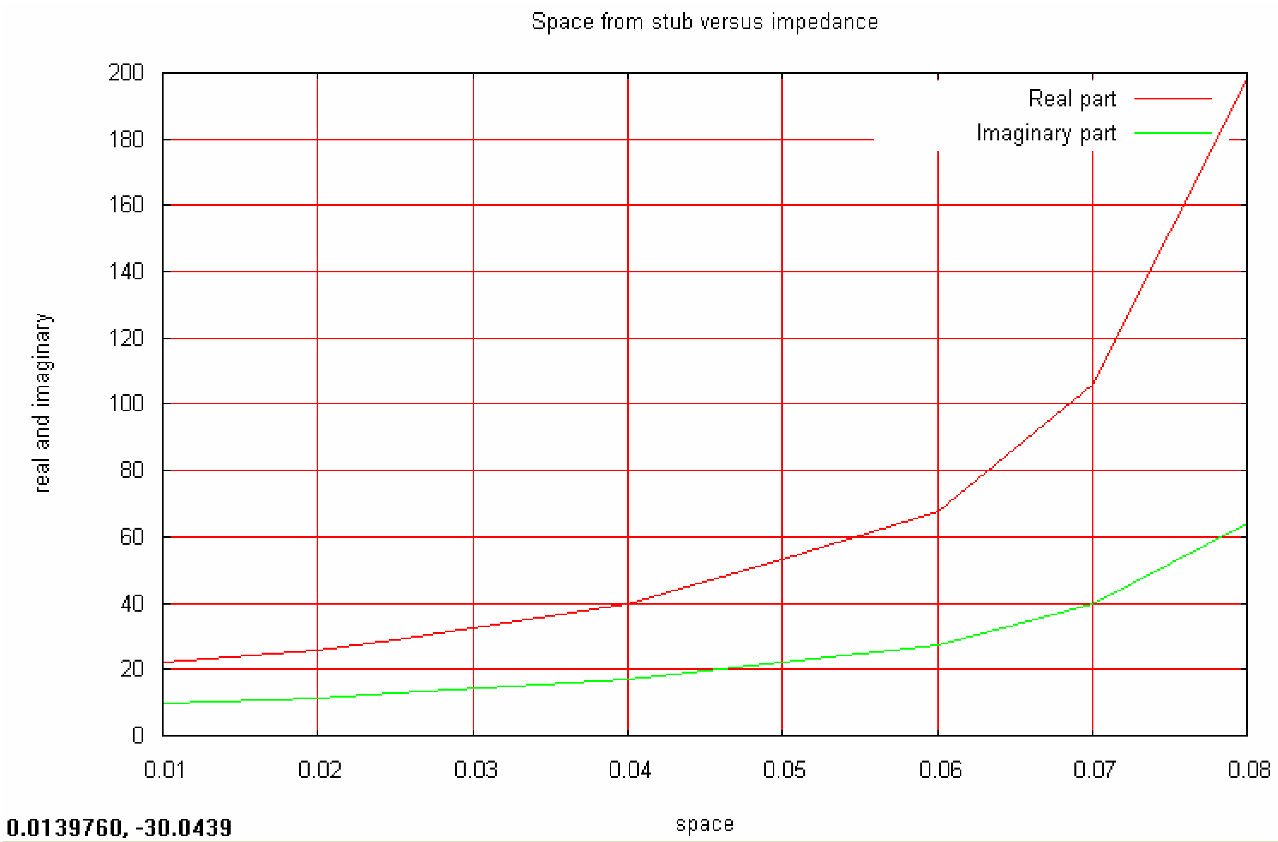
Far Field


Pattern (F4)
Show Far field Near field Compare OpenPF Plot
Tot-gain [dBic]
Vertical plane
460 MHz
trace1.out
Phi= 360
-128 < dBic < 4.25
Max gain The:85

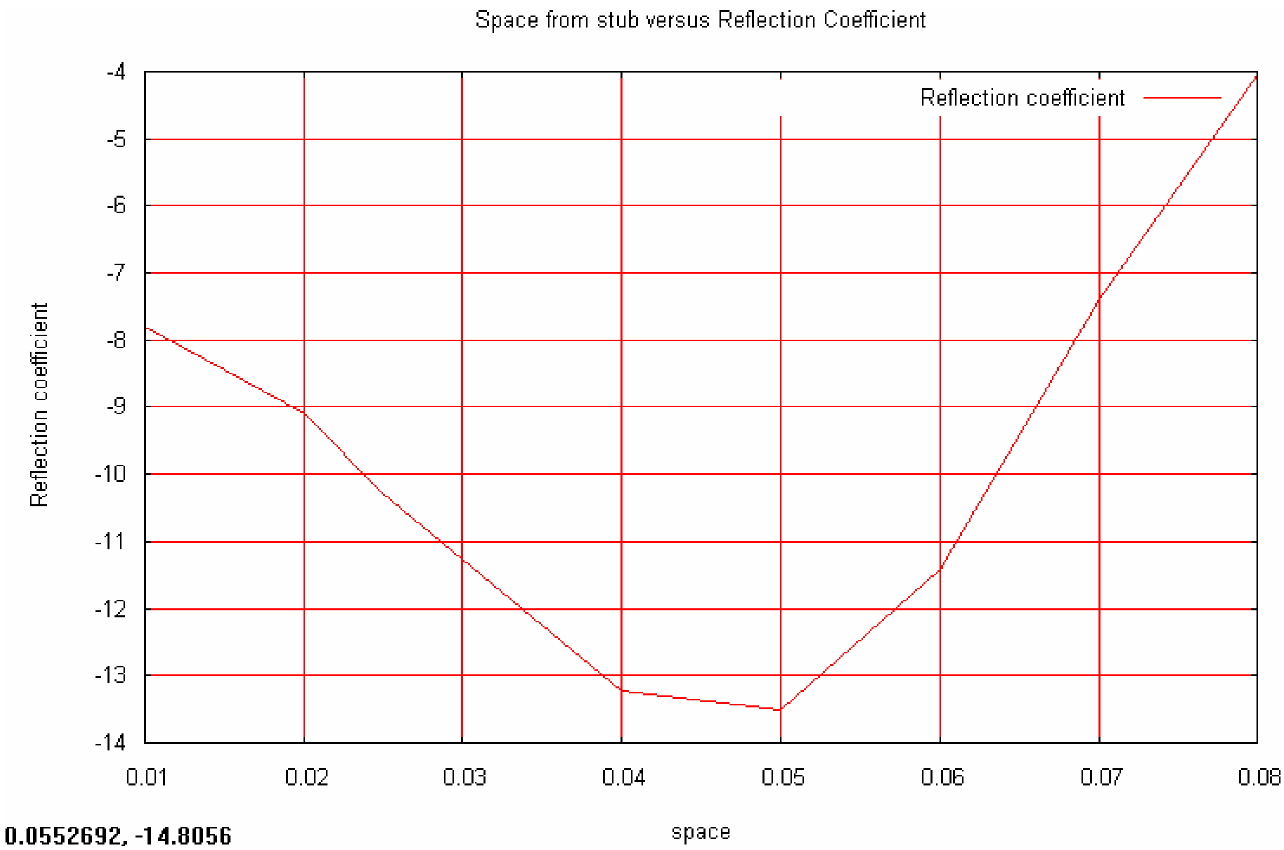


To conclude this exercise it must be mentioned that the copper ground plane makes a significant difference to the SWR, reflection coefficient and so on. However, changes in the composition of the conductors seem to make less of a difference.

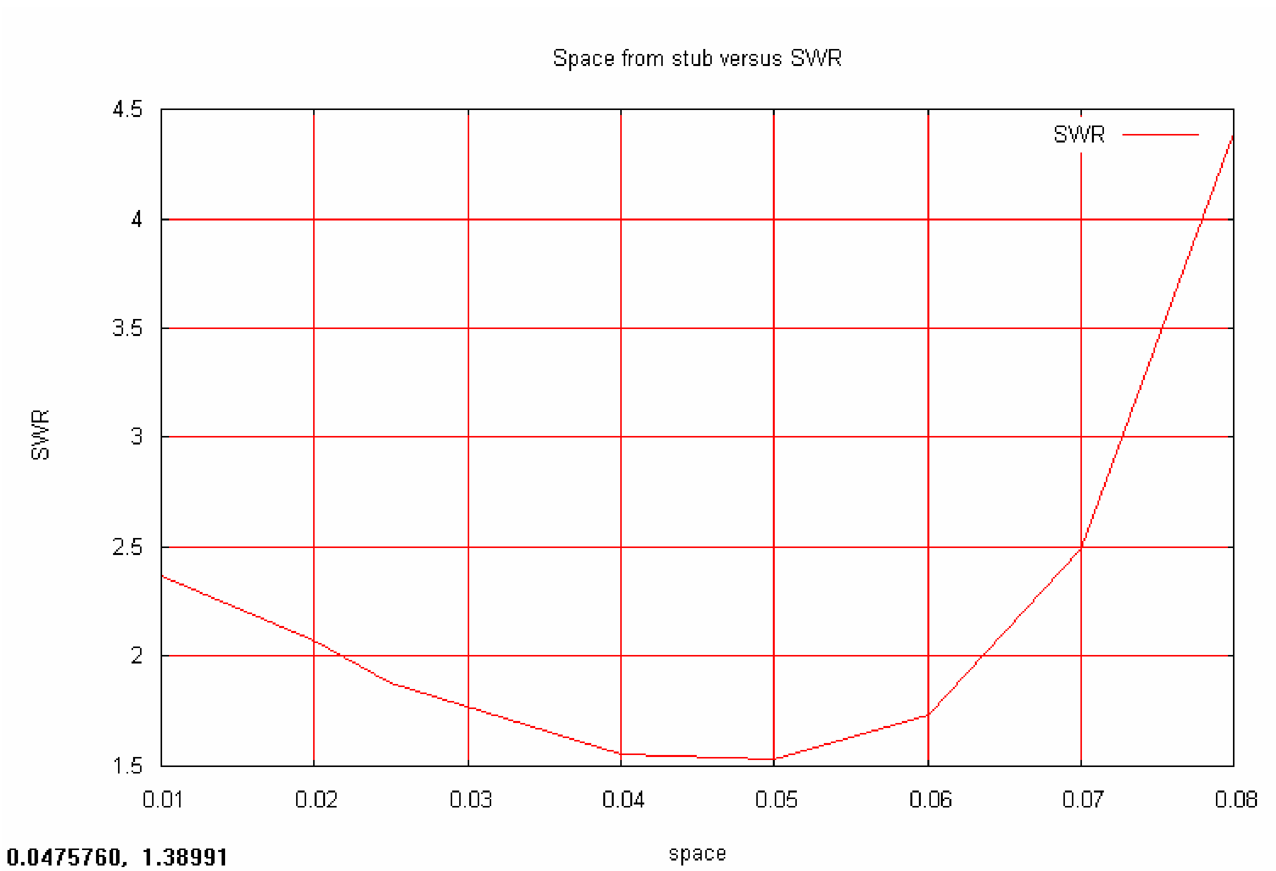
The next set of results show the change of feed point impedance with the spacing of the feed point from the stub end of the antenna. In addition the dependence of the SWR and reflection coefficient is also analyzed.


Space from stub versus impedance
Real part
Imaginary part
real and imaginary
space
200
180
160
140
120
100
80
60
40
20
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.0139760, -30.0439

Reflection coefficient versus space from stub



SWR with respect to space from stub end for feed point



The next table shows the effect of varying the height of the cross arm above ground.

The starting values are: h= 0.058 meter, f_R=460 Mhz, Zin = 47.3 – j5.24, ? = -24.2, SWR = 1.12 Reference impedance = 50.0 Ohms.

	h (m)	**Zin**	**f_R**	**SWR**	**?**
Going down	0.057	44.6 – j18.2	460	1.49	-14.0
	0.056	42.0 – j30.8	470	1.97	-16.4
	0.055	39.6 – j42.9	470	1.13	-24.0
	0.054	37.1 – j55.8	470	1.0403	-15.0
Going up	0.059	50.2 + j8.18	460	1.17	-21.8
	0.060	53.3 + j22.1	460	1.53	-13.5
	0.061	56.6 + j36.4	450	1.31	-17.4
	0.062	60.1 + j51.4	450	1.06	-30.4

Note:

1.0 Change of reactance from capacitive to inductive as height changes
2.0 Resonant frequency change. Percentage = Approximately ± 2.2%
3.0 Impedance change: Real = -20% to +27%, Imaginary = 1900% (approximately)

With *very small changes* in height above ground (for the cross arm) the impedance at a particular point changes significantly. The resonant frequency change is fairly small. i.e. antenna is very sensitive to changes in height above ground to impedance.

The next set of results shows the effect of varying **the radius** of the wires. The first table is the effect of varying the radius of the stub. **Starting values radius = 0.1mm Zin = 47.3 – j5.24, f_R = 460 Mhz, SWR = 1.12, ? = -24.4.**

Radius (mm)	**Zin**	**f_R**	**SWR**	**?**
0.09	47.5 – j0.54	460	1.05	-31.57
0.08	47.4 – j4.79	460	1.11	-25.3
0.07	48.1 + j11.0	460	1.25	-18.9
0.06	48.6 + j18.2	460	1.44	-14.7
0.05	49.3 + j27	455	1.09	-27.2
0.11	47.2 – j9.4	460	1.22	-19.9
0.12	47.1 – j13.2	460	1.32	-17.2
0.13	47.1 – j16.6	465	1.13	-23.7
0.14	47.0 – j19.8	465	1.06	-29.8
0.15	47.0 – j22.7	465	1.00	-51.2

Note:

1.0 The switch-over of the reactance type from capacitive to inductive.
2.0 Frequency changes very little
3.0 Very high return loss at about h = 0.15

The following table shows the effects of varying the radius of the cross arm. The starting point was:
Radius = 0.1mm, Zin=47.3-j5.24, f_R = 460 Mhz, SWR = 1.04, ? = -32.9

Radius	Zin	f_R	SWR	?
0.09	47.6 – j9.86	460	1.23	-19.7
0.08	47.9 – j15.1	465	1.19	-20.9
0.07	48.3 – j21.2	465	1.06	-29.5
0.06	48.8 – j28.4	465	1.08	-28.11
0.05	49.3 – j37.1	468	1.10	-26.13
0.11	47.1 – j1.14	460	1.06	-29.7
0.12	46.8 + j2.53	460	1.08	-27.5
0.13	46.6 + j5.83	458	1.12	-24.7
0.14	46.4 + j8.83	458	1.10	-26.1
0.15	46.2 + j11.6	458	1.12	-24.7

Notes:

Most parameters seem to be fairly insensitive to change of radius of the cross arm. However, from the results above it may be a good way to fine tune the parameters.

The next set of simulations results present the change in parameters with a change in the length of the cross arm. The starting values are:

Legth = 0.105 (m), Zin = 47.3 – j5.24, f_R , SWR = 1.04, ? =-32.9

L	**Zin**	**f_R**	**SWR**	**?**
0.095	39.6 – j138	491	1.11	-25.4
0.085	33.5 – j274	525	1.31	-17.38
0.075	28.6 – j419	564	1.57	-12.9
0.065	24.6 – j583	609	1.95	-9.8
0.115	57.3 + j129	434	1.2	-20.5
0.125	70.6 + j271	411	1.35	-16.5
0.135	88.7 + j427	390	1.51	-13.8
0.145	114 + j606	370	1.69	-11.8
0.155	152 + j820	353	1.85	-10.5

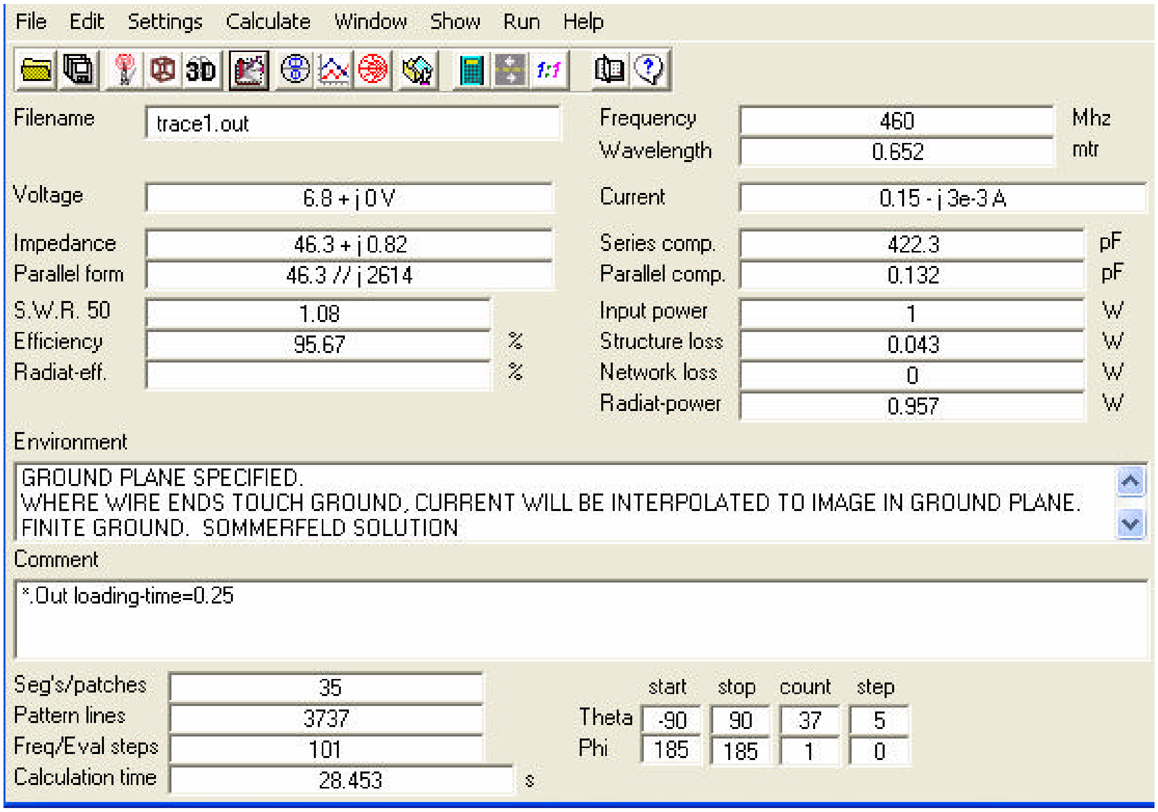
Notes:

1.0 Resonant frequency is a sensitive function of cross arm length
2.0 Impedance is likewise
3.0 SWR seems to be much more muted in response.

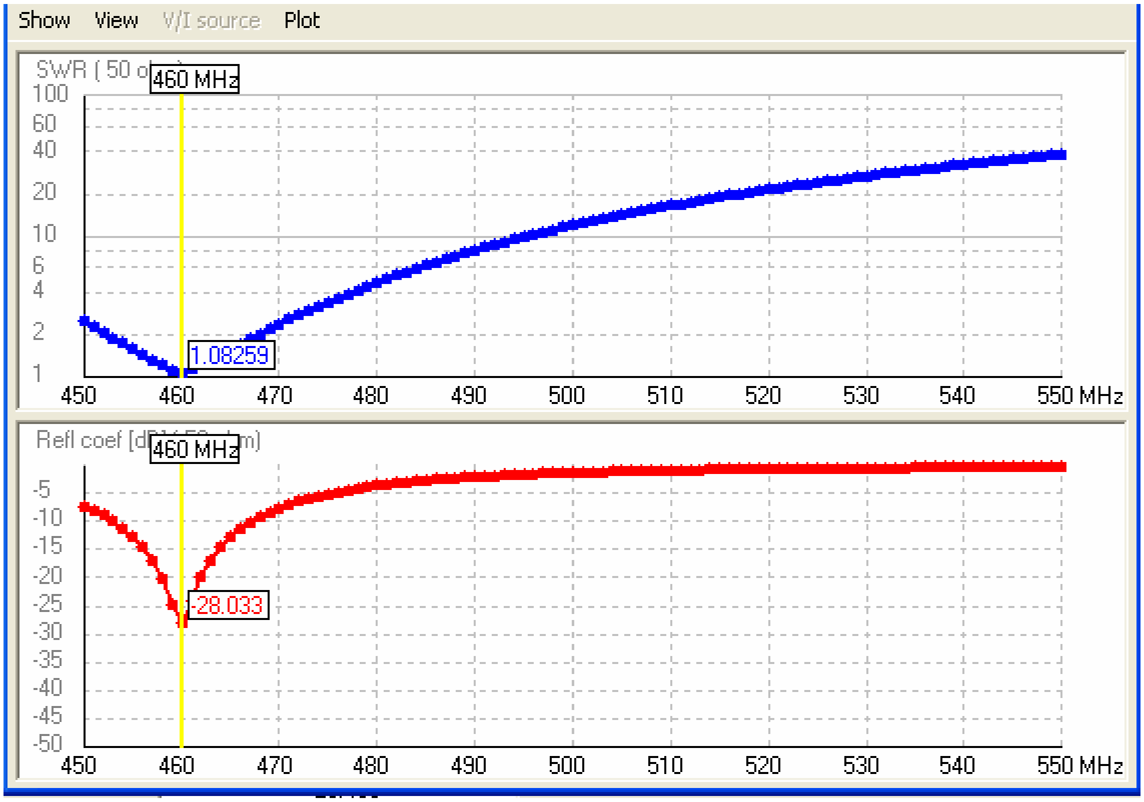
In practical terms this means that one has to be prepared to trim the cross arm length for gross frequency trims.

This concludes the NEC2 simulation results presentation. A follow – up paper presents the EM simulation results using ADS.

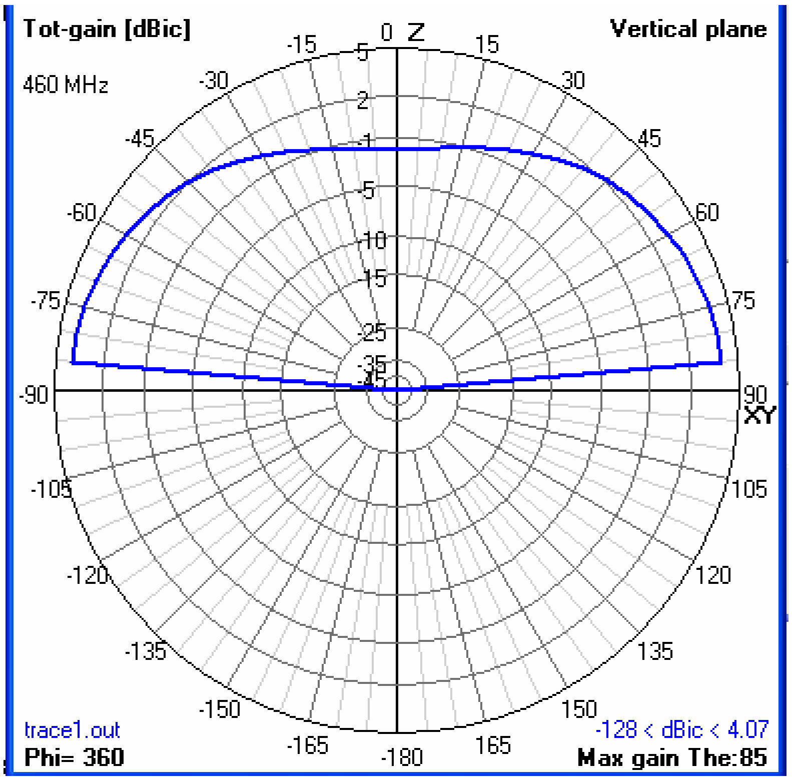
Appendix: The following results are presented for an optimized 460 Mhz antenna that I designed to increase the trace widths to 24 mil.


File Edit Settings Calculate Window Show Run Help
Filename trace1.out
Frequency 460 Mhz
Wavelength 0.652 mtr
Voltage 6.8 + j 0 V
Current 0.15 - j 3e-3 A
Impedance 46.3 + j 0.82
Series comp. 422.3 pF
Parallel form 46.3 // j 2614
Parallel comp. 0.132 pF
S.W.R. 50 1.08
Input power 1 W
Efficiency 95.67 %
Structure loss 0.043 W
Radiat-eff. %
Network loss 0 W
Radiat-power 0.957 W
Environment
GROUND PLANE SPECIFIED.
WHERE WIRE ENDS TOUCH GROUND, CURRENT WILL BE INTERPOLATED TO IMAGE IN GROUND PLANE.
FINITE GROUND. SOMMERFELD SOLUTION
Comment
*.Out loading-time=0.25
Seg's/patches 35
Pattern lines 3737
Freq/Eval steps 101
Calculation time 28.453 s
start stop count step
Theta -90 90 37 5
Phi 185 185 1 0

Reflection coefficient and SWR



Far field patterns



Far field pattern (contd)