COAXIAL CABLE CURRENTS

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In this paper I analyze and measure coaxial lines when subjected to currents on the outer shield.
The analysis may be done with simple models, no black magic being necessary.
A lab grade VNA is used to precisely measure SWR and attenuation.

The first case deals with measurements done with the split 25 Ω – 25 Ω termination.
This case was modelled at both low RF and higher frequencies, up to a coax length of two wavelengths.

Measurements and modelling results show that this method does not generate large shield currents as compared to feeding a half wave dipole with a coaxial cable.

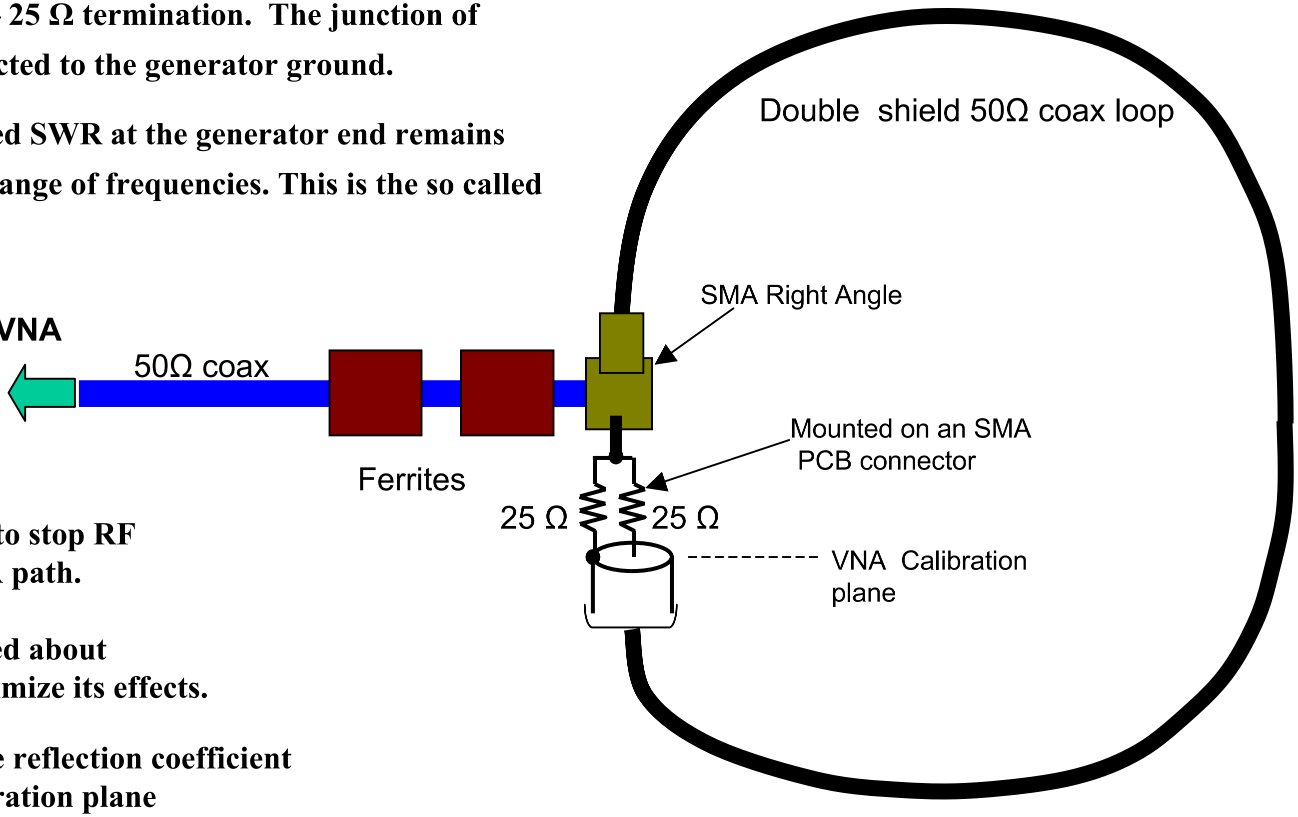
Possible transformer action of a short length of semi-rigid coax was also investigated, by forcing current to flow longitudinally along the shield. It shows that only skin effect coupling can be detected below 5 MHz, using a very sensitive detector.

SPLIT 25 Ω – 25 Ω TERMINATION

The first case analyzed has recently been much discussed at AntenneX. A coax cable is connected to a generator with its end terminated in a split 25 Ω – 25 Ω termination. The junction of these two resistors is connected to the generator ground.

It is found that the measured SWR at the generator end remains very low over a very wide range of frequencies. This is the so called "current balance" test.

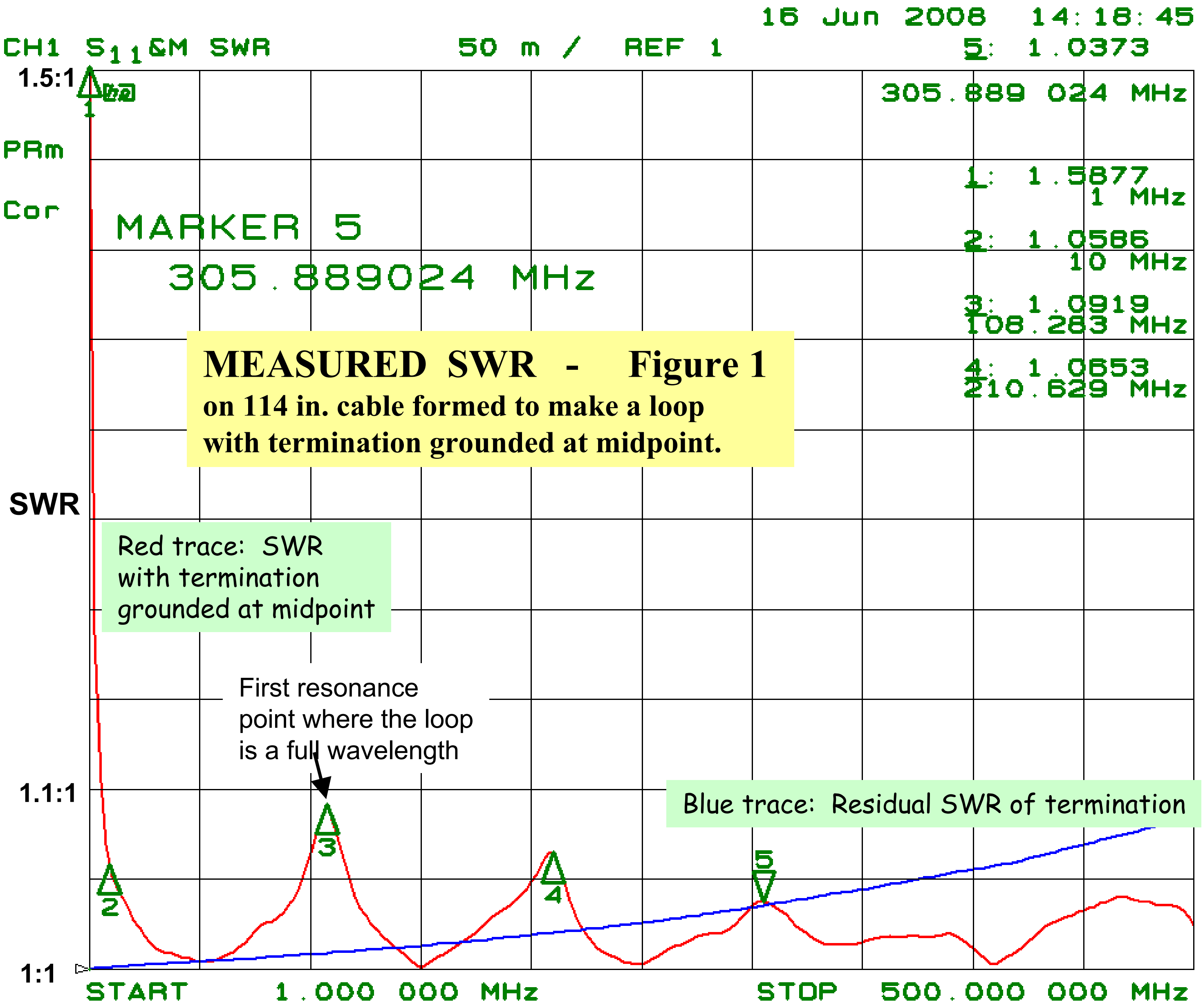
SETUP USED



Note the ferrite cores used to stop RF at the loop junction to VNA path.

Here the coax loop was lifted about 4 feet above ground to minimize its effects.

Here the VNA measures the reflection coefficient and SWR at the VNA calibration plane



MEASURED SWR - Figure 1

on 114 in. cable formed to make a loop with termination grounded at midpoint.

Red trace: SWR with termination grounded at midpoint

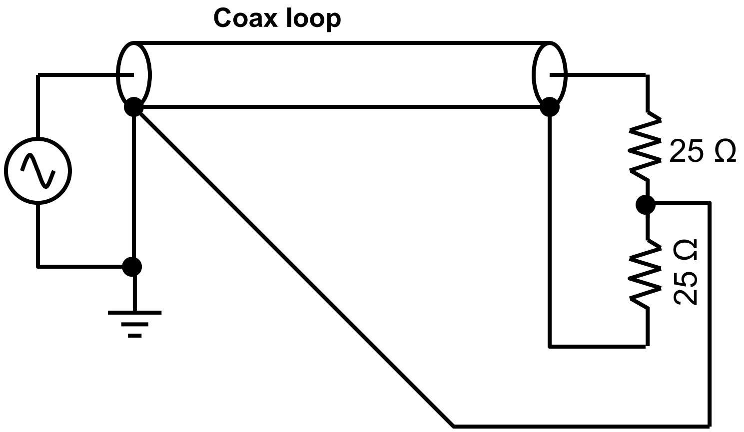
First resonance point where the loop is a full wavelength

Blue trace: Residual SWR of termination

EQUIVALENT CIRCUITS

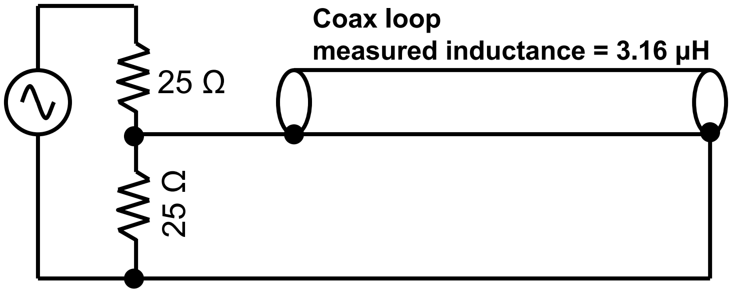
Basic circuit as connected

The generator output impedance equals the coax impedance (50 Ω).



Equivalent circuit at RF frequencies.

- **Here the source is "pushed" on the right side of the coax, since it operates in TEM mode internally.**
- **The source now appears across the two 25 Ω resistors in series.**
- **The lower 25 Ω resistor sees a wire made of the outer coax shield (the coax loop across it). This is the common mode path.**
- **Skin depth is such that internal coax currents are negligible. There is no interaction of outside currents with the inner shield currents.**



ANALYSIS OF RESULTS

When the loop is series resonant, it will present the lowest impedance across the lower 25 Ω resistor.

Here we have a rather lossy line since it radiates. The reflected resistance across the lower 25 Ω resistor will be rather high: in the case of the full wave resonant loop, the loop impedance is ~120 ohms. Computing the SWR with 120 ohms in parallel with 25 ohms gives SWR = 1.094. This is in good agreement with the measured SWR of 1.092 at 108.3 MHz at the first resonance. See figure 1.
Note that the loop is an efficient radiator and presents a minimum impedance of 120 Ω, which only cause a small change SWR change. In this case the ratio of loop current to the generator current is about 15.3 dB.

At frequencies removed from (series 1λ, 2λ… modes) resonance, the loop impedance is higher and this explains the lower SWR values measured.

At low frequency, where the loop reactance starts to shunt the lower 25 ohm resistor, the SWR will start to rise, up to a max of 2:1. Using the measured value of the loop inductance of 3.16 µH, the computed SWR is 1.5936 at 1 MHz. I measured 1.5877.

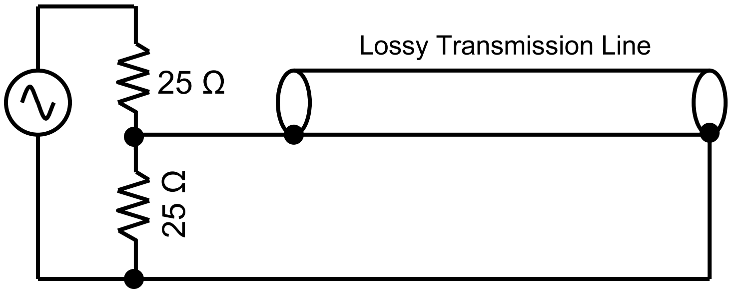
The resonant frequency (MHz) of a full wave loop may be calculated as: 1032 / length (ft.)
We get 108.6 MHz, while the measured resonant frequency was 108.28 MHz.

Placing the coax to form a loop sets the maximum impedance across the lower 25 Ω resistor.
On the other extreme, if the coax is closely folded to make a parallel wire shorted transmission line, then it will reflect a short across the lower 25 Ω resistor at its λ/2 resonance modes.
In this case, the line is prevented from radiating and the SWR seen at the generator will reach 2:1.

If the loop is set on or close to the ground, then its losses will increase and the SWR at 1λ resonance will be lower than the measured value of 1.09.

MODELLING THE LOOP AS A TRANSMISSION LINE

I have modelled the loop as a lossy, high impedance transmission line. Currents only flow on the outside of the shield. There is no interaction with the inner shield currents.



Based on measured curve of figure 1, the following line parameters were adjusted to fit the measured curve:

- **Line impedance (600 Ω, not critical).**
- **Line length (adjusted for first resonance at ~108.28 MHz)**
- **Line attenuation (~1.795 dB at 108.3 MHz). Value adjusted to match the measured SWR at 108.3 MHz.**

Note that the high attenuation (~18.9 dB/100 feet at 108.3 MHz) comes mostly from radiation.

The coax loop has its first resonance at 1λ while the shorted line here has its first resonance at 0.5λ. (However counting the return wire/plane gives 1λ total length).

MODELLING RESULTS

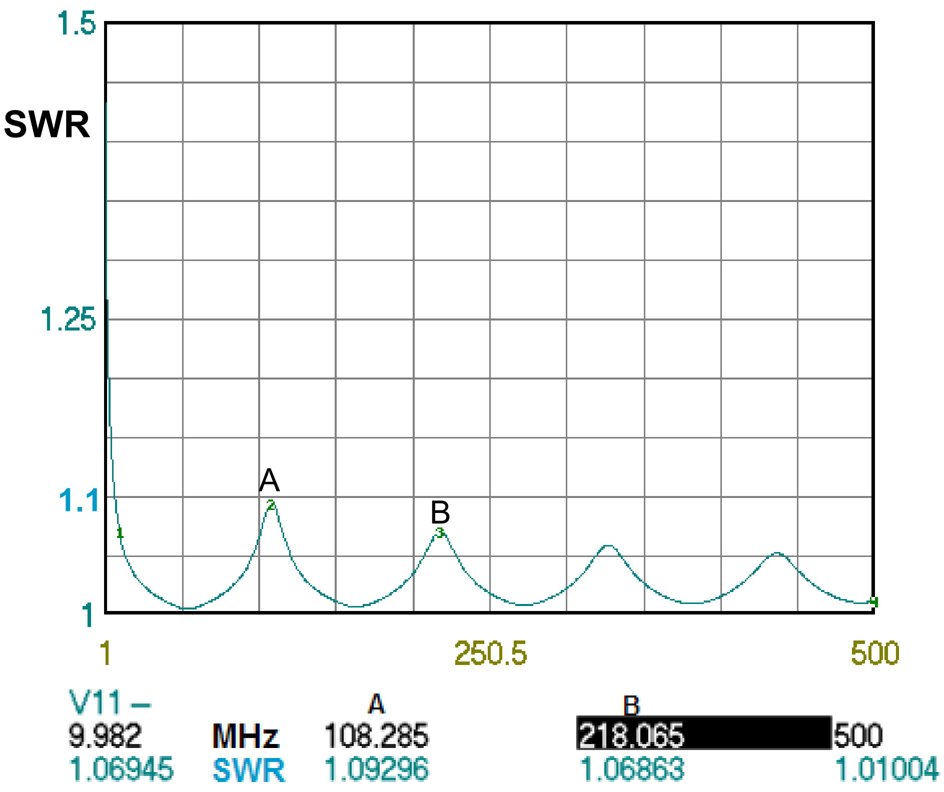
Note the first resonance at point A:
It occurs at 108.28 MHz

Compare this to the measured curve of figure 1.

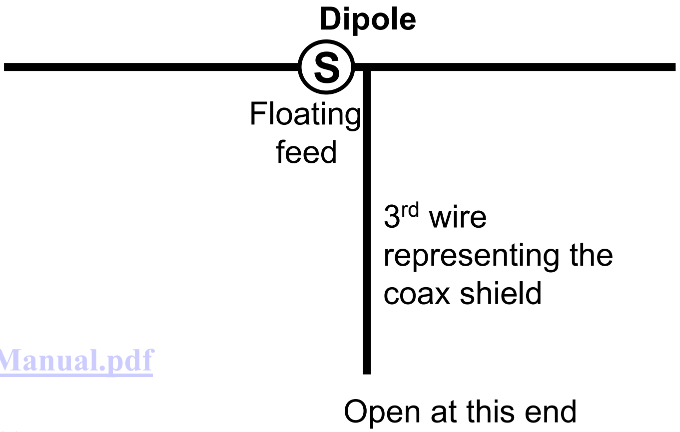
Note that the residual SWR on the measured curve prevents making accurate measurements above ~ 250 MHz
See figure 1.

At 10 MHz, the SWR is 1.0694 while I measured 1.0586.

At the second peak point B, the SWR is 1.0686 while I measured 1.0653.
The predicted frequency is 218.065 MHz, while I measured frequency is 210.629 MHz.
The error may be caused by the residual SWR of the termination.



MODELLING A HALF WAVE DIPOLE FED WITH A COAX



As suggested by Roy Lewallen and others, for modelling purposes, an ideal floating source "S" is placed at the feedpoint.
The coax shield is represented by a third, single wire, of the proper size.
See: http://eznec.com/misc/EZNEC_Printable_Manual/5.0/EZW50_User_Manual.pdf

The third wire is part of the antenna. In general it will change its impedance, resonant frequency and radiation pattern.

Depending on the length of this third wire, the induced currents will vary.
For instance, a quarter wavelength will greatly modify the normal dipole currents.
It was found that adding 1000 Ω of RF resistance at the third wire junction with the dipole will be sufficient to restore the normal dipole radiation pattern.

The simulation allows for computing the shield currents with respect to the dipole currents.
With the third wire in resonance, the magnitude of the shield current can be as high as the left side dipole current.

See: http://ve2azx.net/technical/BALUNS2006-ang.pdf pages 17-26

EXCITING THE OUTSIDE OF THE COAX LINE AT RF

This was done to investigate possible transformer action by common flux coupling between the inner and the shield of a coax cable at RF frequencies.
I used semi-rigid coax and forced RF current on its outer sheet, in a longitudinal manner.
I then measured the attenuation between the outside loop and the current picked up by the inner conductor/shield.

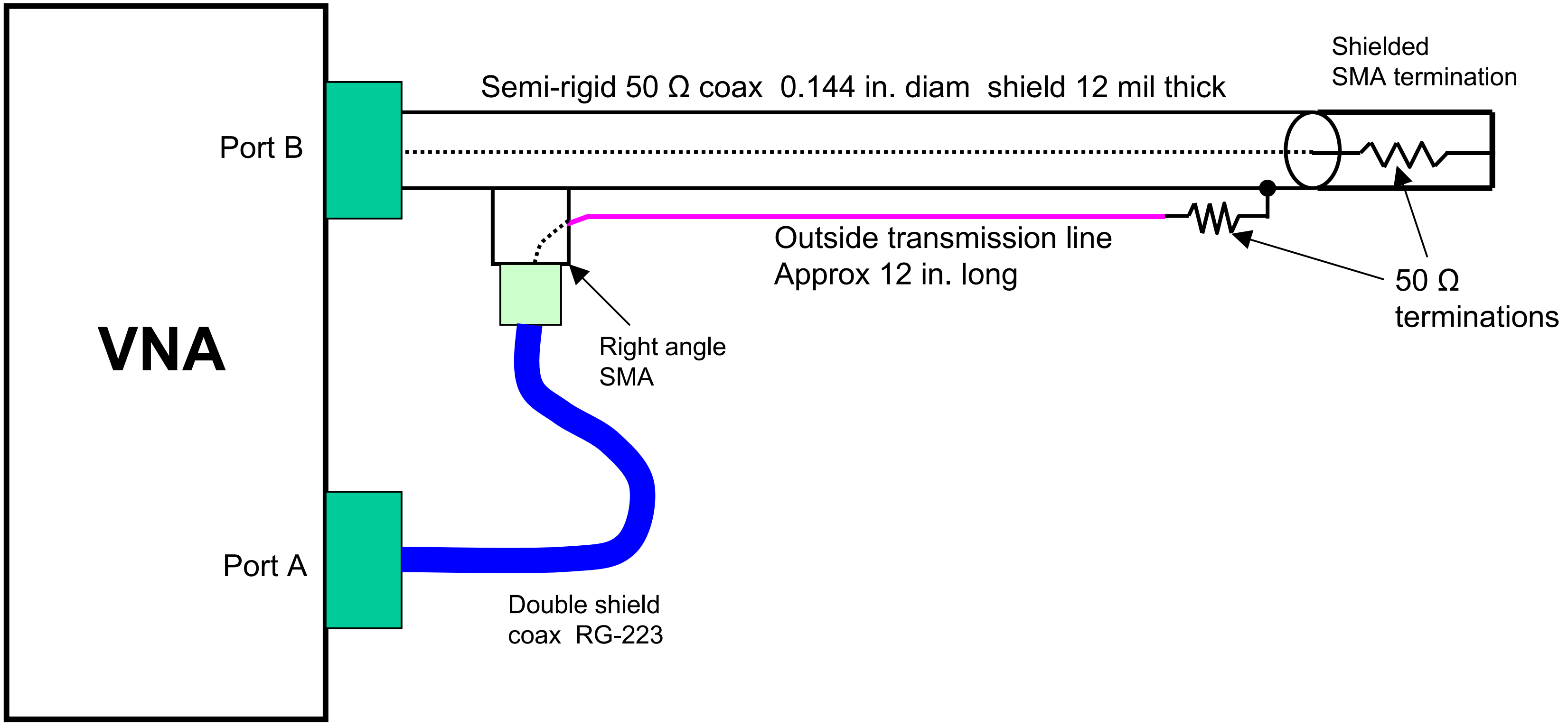
Results show that some leakage is measured at the –100 dB level at 1 MHz, for a 1 foot long cable. See figure 2.
The leakage is unmeasurable from 5 – 400 MHz. (below –120 dB). However leakage above 400 MHz is unexplained.

The shield does its job at RF of blocking RF fields. The measured isolation is very high due to the skin depth (0.066 mm at 1 MHz for copper) being 4.5 times less than the shield thickness (~ 0.3mm). Remember that the skin depth is the depth at witch the RF field (magnetic or EM) decreases by the factor 1/e (~37%). The decrease is exponential, so that at 3 times the depth, the field drops to 5%. At 4.5 times the skin depth, it drops to 1.1%.
Note also that the skin depth varies as the inverse of the square root of the frequency. For example, at 100 MHz, the skin depth will be 10 times smaller. It is the same skin effect that governs the largest part of the attenuation in coaxial cables. The attenuation in dB increases as the square root of the frequency.

Skin effect starts to be observable below 5 MHz, but at very low levels. However the magnetic coupling will increase with longer cables. From 100 KHz up to 5 MHz, the leakage decreases with increasing frequency, indicating that the skin depth decreases. This occurs even if the coupling increases (from 100 KHz up to 5 MHz), since the cable length (measured in wavelengths) represents a larger fraction of a wavelength.

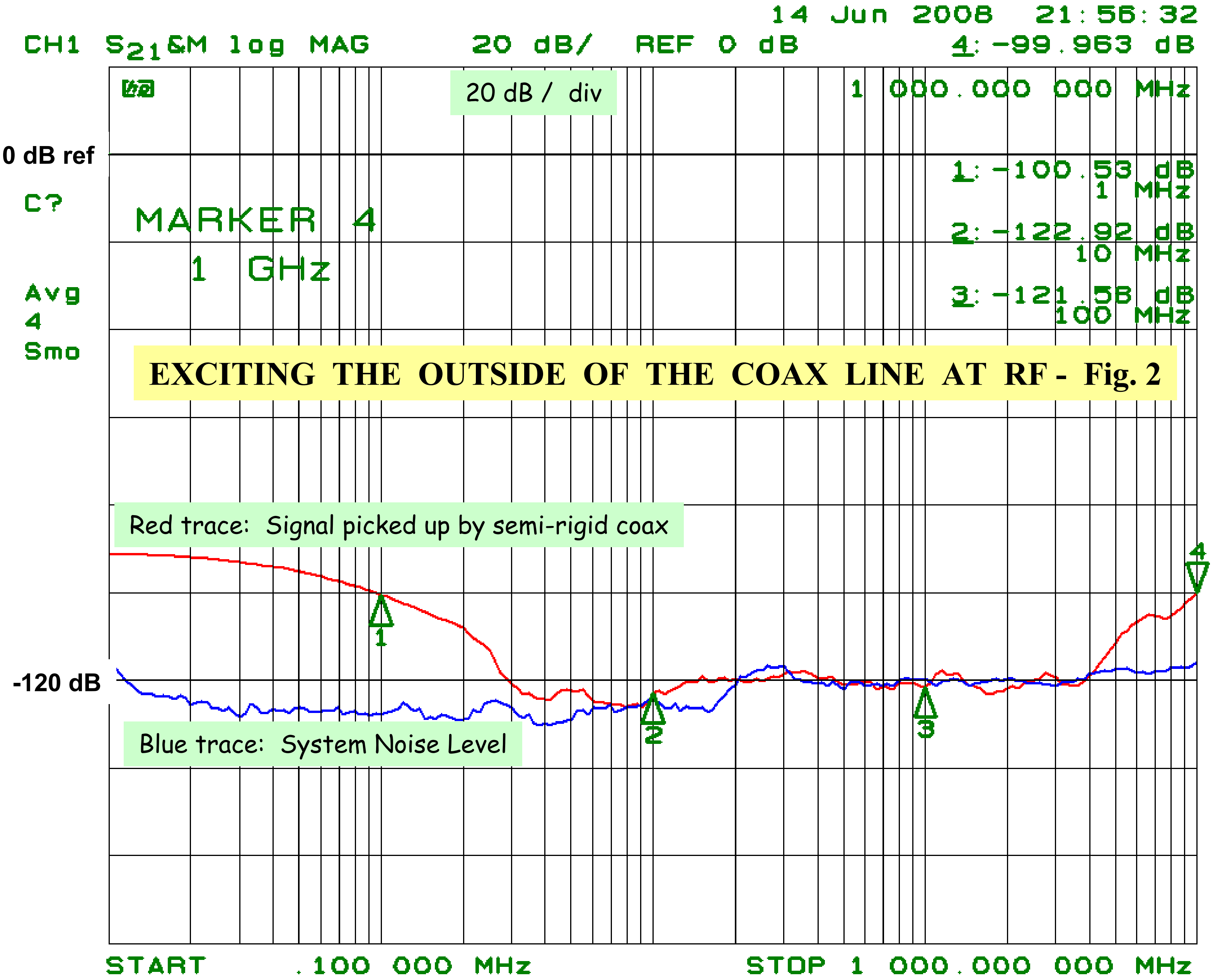
Normal leakage tests measure the isolation between two similar coax cables. If the leakage value is 90 dB, then each cable is assumed to provide 45 dB of isolation. Here we have an unshielded cable leaking into a very well shielded semi-ridgid cable. It appears that the isolation between two similar semi-ridgid cables would be ~200 dB at 1 MHz.

SET – UP USED



Here the VNA measures the attenuation between ports A and B as S21 in dB

EXCITING THE OUTSIDE OF THE COAX LINE AT RF - Fig. 2



20 dB / div

0 dB ref

-120 dB

Red trace: Signal picked up by semi-rigid coax

Blue trace: System Noise Level

CONCLUSION

The outside shield currents generated with the split 25 Ω – 25 Ω termination generate small amounts of current, which are typically 15 dB below the generator current at the first resonance and much lower outside resonance.
The coax cable shield is effectively connected in parallel with the grounded 25 Ω resistor.
Measurements show that the coax shield shows its first resonance at one wavelength and its multiples. This explains the very low SWR measured, since the coax loop formed presents a minimum impedance of ~120 ohms at resonance, and much higher outside resonance. At very low frequency, the loop inductance/reactance shunts the grounded 25 Ω resistor and causes the SWR to rise up to a maximum of 2:1.

Connecting a coax to a half wave dipole may generate currents of a similar magnitude as the dipole arm connected to the inner conductor, from NEC simulations.

Modelling the radiating loop was done using a high impedance transmission line. Measurements show that the resonance modes may be predicted in this manner, up to at least 2λ.

RF currents circulating on the outside of the shield will set potential differences on the outside of the cable. However the inside is not affected, besides the skin effect, which is very low and only detectable at the lower RF frequencies.