Small transmitting loop – ground loss relationship to radiation resistance

This article documents a series of NEC-2 models at 7.2MHz of a lossless small transmitting loop near ground for the insight that they might provide about underlying loss mechanisms.

Key model details:

- lossless conductor 25mm diameter;
- octagon of sides 403mm, has same enclosed area as a 1m diameter circle;
- three ground types;
- height varies from 1.5-10m to centre of loop.

Impedance elements discussed in this article are referred to the main loop.

Radiation resistance

Radiation resistance Rr (Rrad) is taken to mean that quantity that relates the total power radiated in the far far field to the feed point current, Rr=Pr/I^2.

Above is a plot of Rr (Rrad) vs height for the three ground types and perfect ground. All curves oscillate at increasing height but converge on the free space radiation resistance Rrfs which is 6.4mΩ for the subject loop.

Rr increases with the fourth power of diameter, and this usually dramatically increases radiation efficiency (even though conductor resistance and capacitor resistance have increased).

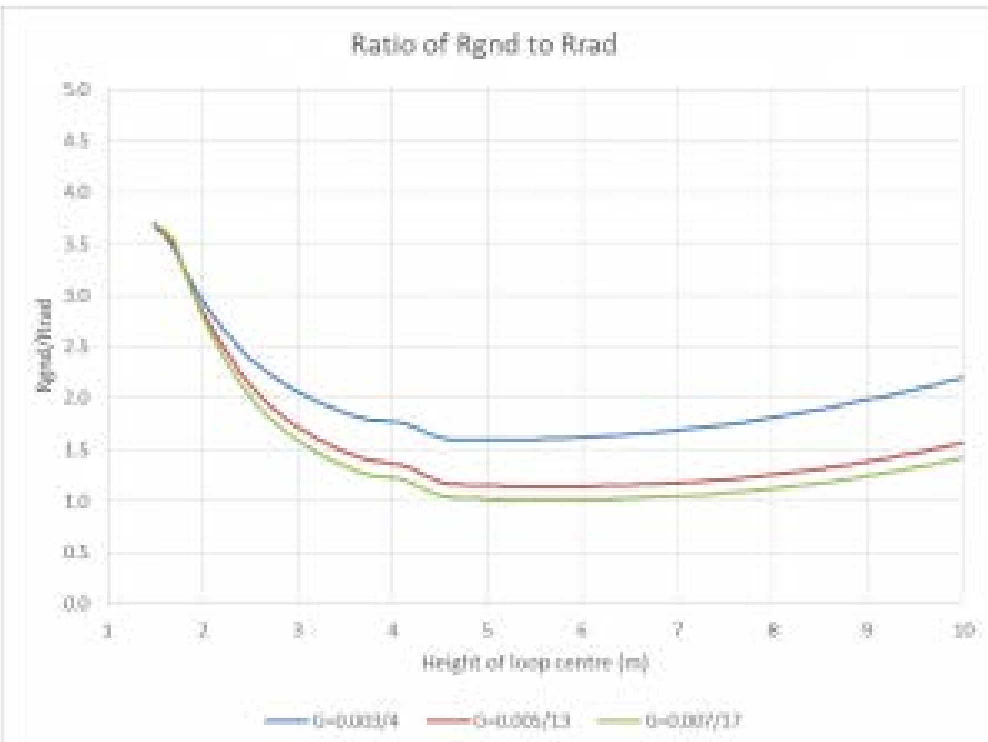
Rr is a component of feed point resistance Rt and radiation efficiency is calculated as PowerRadiated/PowerIn=Rr/Rt.

Equivalent ground loss resistance

Energy lost in heating the soil can be represented by an equivalent resistance component Rg of feed point resistance Rt. Since the loop structure in this model is lossless, Rg=Rt-Rr.

Models indicate that Rg/Rr is not very sensitive to loop diameter (within the limitations imposed by a small transmitting loop) which seems reasonable.

We might expect that Rg/Rr is sensitive to proximity to ground and the type of ground.



Above are the results of the NEC-2 models for three ground types which bracket the most common ground types that are encountered. Though Rg/Rr is sensitive to ground type, the sensitivity is relatively low, but Rg/Rr is quite sensitive to height, rising rapidly below about 4m.

The response shown is frequency sensitive, the shape of these curves is similar on 80 and 20m bands if the X axis is scaled in wavelengths, ie ground loss rises rapidly as height is reduced below about λ/10 on 20-80m bands. Rg/Rr is approximately inversely proportional to height below λ/10. Whilst λ/10 is easy to achieve on 20m, it is a lot more difficult on 80m and impractical for most users.

Some broad messages

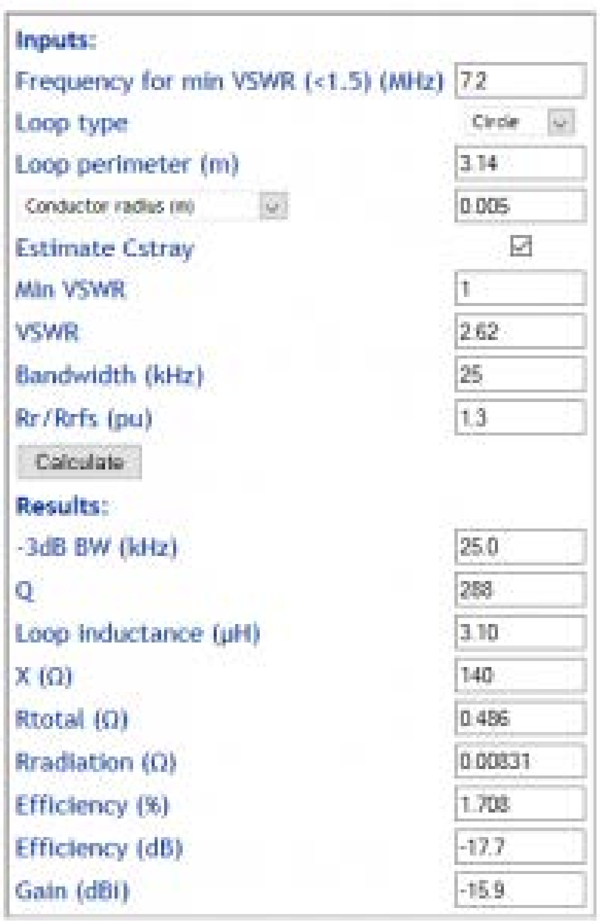
Some take home messages about the 1m diameter loop on 40m:

- small loops have very low radiation resistance;
- equivalent ground loss resistance increases rapidly as height is reduced below about λ/10 (~4m for the 40m band);
- radiation resistance increases slightly at very low height, but is likely to be more than offset by ground resistance increase in a reasonably efficient loop;
- performance is commonly dominated by structure losses (loop conductor, capacitor equivalent series resistance); and
- wide half power bandwidth is usually and simply the result of poor efficiency (typically high structure loss).

An example

We often see articles describing a loop of about 1m diameter for 40m at 1.5 – 2.0m height, made from RG213 coax and using some form of lossy tuning C (coax stub, FR4 PCB material, broadcast gang caps with high R contact springs etc), and the 'better' ones might brag half power bandwidth of 25kHz, the poorer ones 100-200kHz.

Lets look at a generic narrow example.

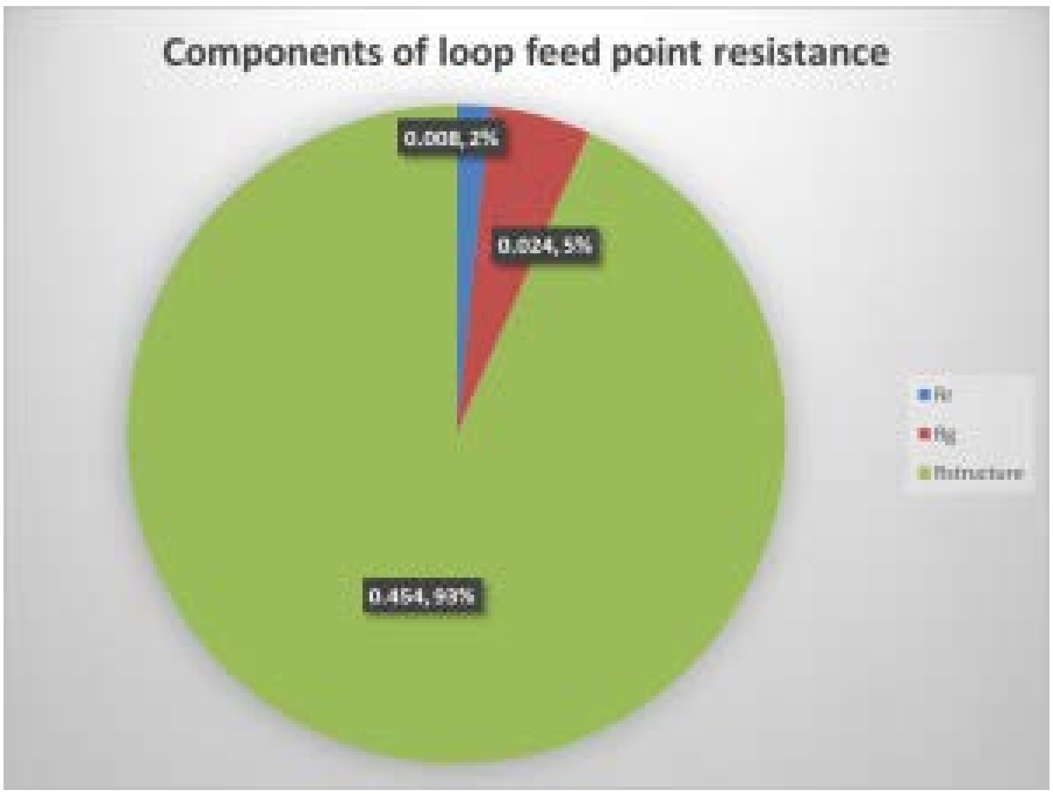


Inputs:	
Frequency for min VSWR (<1.5) (MHz)	7.2
Loop type	Circle
Loop perimeter (m)	3.14
Conductor radius (m)	0.005
Estimate Cstray	☑
Min VSWR	1
VSWR	2.62
Bandwidth (kHz)	25
Rr/Rrfs (pu)	1.3
Calculate	
Results:	
-3dB BW (kHz)	25.0
Q	288
Loop inductance (µH)	3.10
X (Ω)	140
Rtotal (Ω)	0.486
Rradiation (Ω)	0.00831
Efficiency (%)	1.708
Efficiency (dB)	-17.7
Gain (dBi)	-15.9

Above is a solution to the scenario using [Calculate small transmitting loop gain from bandwidth measurement](#).

At 2m height to centre of the loop, the graph above suggests that Rr should be perhaps 30% higher than free space Rrfs, so about 8mΩ. Using the graph above, Rg is around three times Rr, so about 24mΩ.

The inductance of the loop has been calculated and the measured half power bandwidth gives a pretty good fix on the total loop input resistance Rt=486mΩ. Deducting Rr and Rg, we are left with 454mΩ total structure resistance which is a lot more than the resistance of a 10mm diameter copper conductor (~70mΩ) as a braided conductor has higher resistance than a smooth copper tube and the capacitor loss must be brought to book. In fact 95% of the loss resistance is due to the loop conductor and capacitor, and they could be reduced by 70% or more with more suitable components and materials.

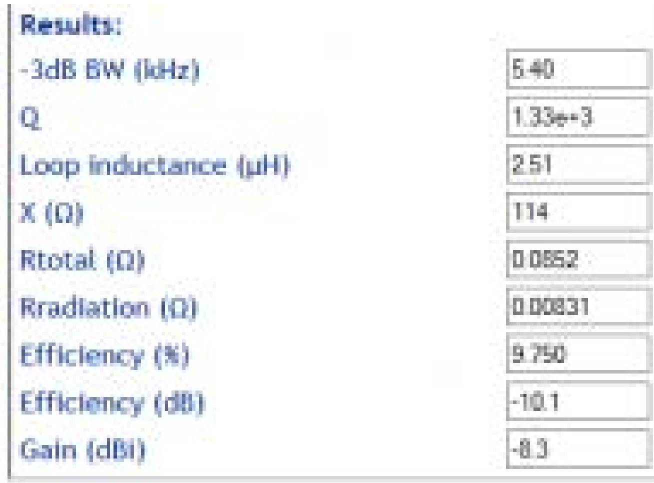


The pie chart above shows that Rr, the only component that gives rise to radiation is just 2% of Rt, meaning radiation efficiency is just 2%.

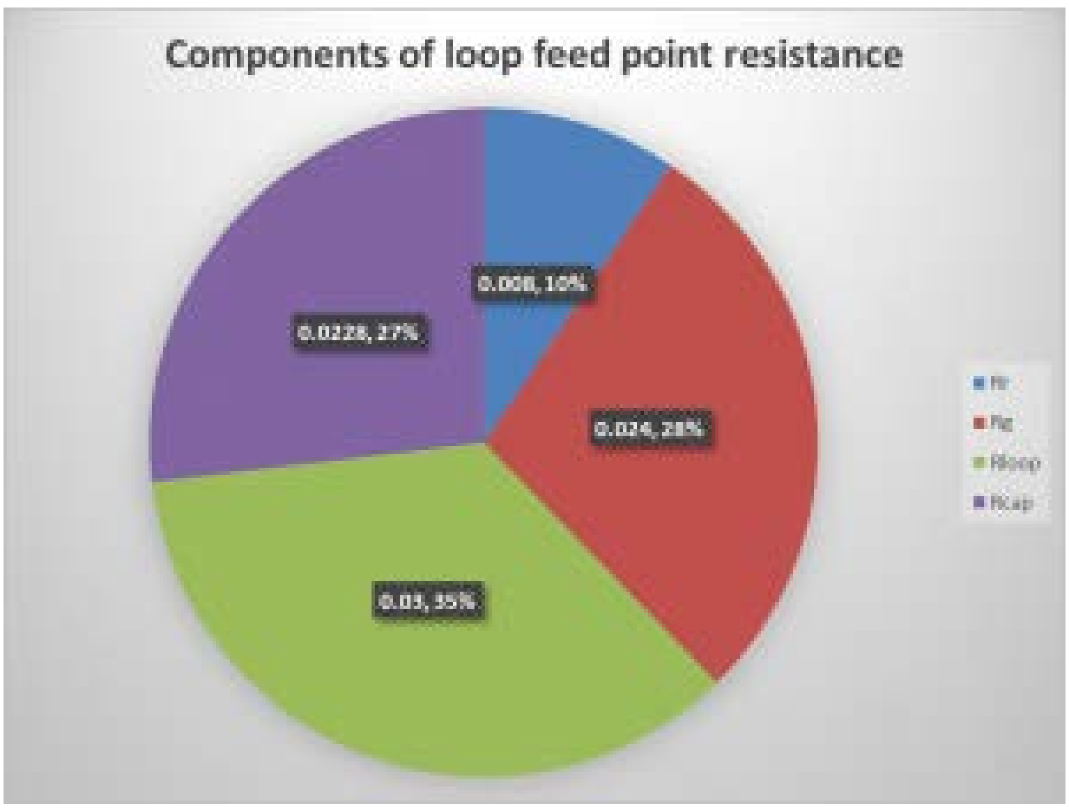
Improved

Staying with the same loop diameter and height above ground (same Rr and Rg components), but reducing loop structure loss, we can improve efficiency.

https://owenduffy.net/blog/?p=4888



Changing the loop conductor to 25mm diameter copper tube reduces conductor resistance to about 30mΩ and reduces inductance (the latter will tend to increase bandwidth). Using a low loss capacitor (eg vac cap) of Q=5000 gives capacitor resistance of 23mΩ.



Above, the components of Rt. As a result of reduction of the structure resistances (loop conductor, capacitor), Rr is now 10% of Rt, and radiation efficiency is 10% against 2% for the previous case… a 7dB increase in radiated power.

Note that bandwidth is quite a deal narrower, it is a characteristic of small efficient loops, but the increased conductor diameter helps not only in reducing resistance but also in reducing inductance which helps bandwidth.

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80m

Rr is proportional to the fourth power of electrical diameter, so physically practical loops have extremely low Rr on 80m and require expensive loop components to offset such low Rr and to win usable bandwidth with reasonable efficiency.

Above is a design using a 2m diameter loop of 50mm diameter copper with a vac cap (Q taken as 5000), 2m centre height above average ground. Half power bandwidth is just 8kHz and efficiency below 3% despite a fairly extravagant structure.

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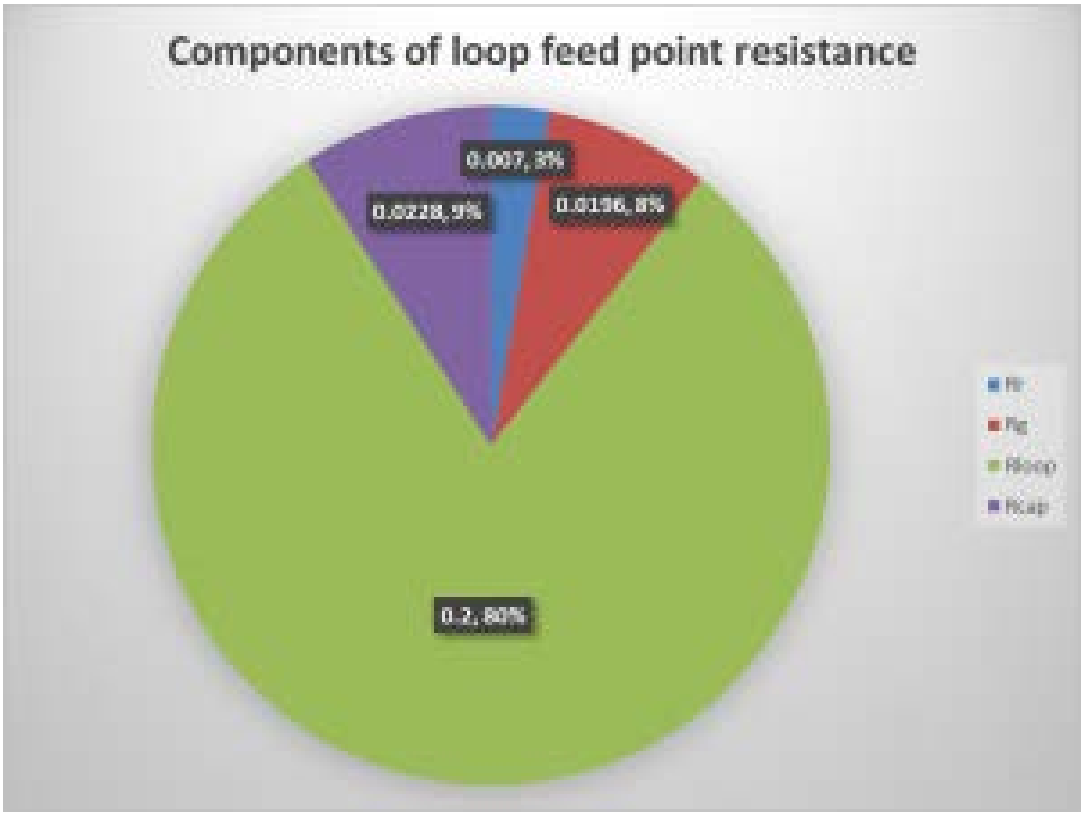

Above, the components of feed point resistance. Even though the loop conductor is 50mm diameter copper, it consumes 80% of the RF input power.

Sure, you will get contacts with this antenna… but you will get more with a lower cost half wave dipole if you can accommodate it.

Conclusions

- small loops have very low radiation resistance;
- equivalent ground loss resistance increases rapidly as height is reduced below about λ/10 (~4m for the 40m band);
- radiation resistance increases slightly at very low height, but is likely to be more than offset by ground resistance increase in a reasonably efficient loop;
- Rg/Rr is approximately inversely proportional to height below about λ/10 (~4m for the 40m band);
- performance is commonly dominated by structure losses (loop conductor resistance, capacitor equivalent series resistance exacerbated by poor component choice) but where structure losses are low, Rg may be significant;
- wide half power bandwidth is usually and simply the result of poor efficiency (typically high structure loss); and
- whilst small transmitting loops seem to have the greatest appeal for the lower bands, performance degrades very quickly as frequency is reduced and it becomes impractical to achieve good performance.

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