Antenna Cable Attenuation at very high SWR

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Abstract

This article describes the additional losses that are incurred in antenna cables if the SWR at the antenna is very high. It shows that even though a tuning box at the Transceiver shows a good SWR, these additional losses might make the antenna ineffective. It derives a rule of thumb for these additional losses: $6\text{dB} - 10 \cdot \log_{10}(1 - 10^{(-ddb/10)}) - 10 \cdot \log_{10}(SWR) \quad dB$ This rule shows that if the SWR at the antenna is 100 or below at a simple cable loss of 0.5 dB, then the additional losses are relatively low and a tuner at the transceiver can be used. If the SWR is higher than 100, for instance 1000, then a matching circuit directly at the antenna is necessary to make the antenna effective.

1 Introduction

I have a home made vertical antenna, which consists of a 9m high fishing rod and a 10 m long wire winded around it, and with 2 radial wires, on top of my roof top terrace. It is connected with a 10m long RG58 coax cable to my Transceiver and antenna tuner. It works nicely on 40m.

1.1 Goal

I would like to get my 40m Antenna to also work on 80m and 160m. On 80m I had some problem getting the antenna tuned, but the tuning worked after inserting some more coax cable. But still, I was not received on 80m. It seemed like the transmit power was lost somewhere.

1.2 Problem to Solve

First I thought it was a lossy grounding, but that didn't bring any improvement. Then I looked at the 10m long RG58 coax cable connecting the antenna to the tuner. With the antenna simulation program xnec2c I found that my antenna on 80m has an SWR of about 2000! This first explained why it wasn't so easy to tune. But then I also found that this extremely high SWR also leads to very high additional cable losses, even though I could tune it! This is indicated and described for instance in [1] and [2].

1.3 Approach

I couldn't really find a calculation/formula/theory of the resulting additional cable loss in the public domain, so I derived it myself.

2 Consideration of Reflections in the Cable

The reflected power at the antenna shall be: r
Reflected voltage: $(SWR-1)/(SWR+1)$
Reflected power:

$$r = \left(\frac{SWR-1}{SWR+1}\right)^2$$

(see [3])
Linear single cable attenuation (linear attenuation according to the cable length): d
Magnitude of cable attenuation in dB: ddB (a positive number), yields

$$d = 10^{(-ddb/10)}.$$

The mismatch between the antenna cable and antenna causes a reflection of a certain part of the power. The tuner at the receiver causes the reflected power to be again reflected back to the antenna, such that the transceiver sees no reflected wave, and hence sees a good SWR. Since the tuner only has imaginary impedance's, it cannot 'burn' any energy, and the law of energy conservation then says that the energy needs to go back to the antenna. Each time in this back and forth game, a certain part of the power is coupled into the antenna. We assume that an antenna tuner at the transmitter is tuning the resulting impedance to a perfect match for the transceiver, specifically that it compensates and hence removes any imaginary impedance. At the antenna this then has the effect that the power that is reflected back to the antenna from the tuner is in phase, and the power adds up.

The power that is coupled into the antenna at the first reflection is: $d\cdot(1-r)$. The remaining power back to the transmitter is $d \cdot r$, which then goes through another attenuation back to the transceiver and from there back to the antenna, and hence sees another d^2 of attenuation. Then another fraction $1-r$ is coupled into the antenna, leading to the power of this reflected wave (3 cable lengths, 1 reflection):

$$d^3 \cdot r \cdot (1-r)$$

Then the next reflection, additional 2 cable length and coupling into the antenna:

$$d^5 \cdot r^2 \cdot (1-r)$$

and so on.

3 Derivation of an Attenuation Formula

If we continue these reflections, we obtain the sum of the coupled power into the antenna as:

$$p = \sum_{n=0}^{\infty} d^{2n+1} \cdot r^n \cdot (1-r) = (1-r) \cdot d \sum_{n=0}^{\infty} d^{2n} \cdot r^n =$$

$$= (1-r) \cdot d \cdot \sum_{n=0}^{\infty} (d^2 \cdot r)^n.$$

We know that

$$\sum_{n=0}^{\infty}(d^2 \cdot r)^n =$$

$$\frac{1-(d^2 \cdot r)^{\infty}}{1-d^2 \cdot r} = \frac{1}{1-d^2 \cdot r}.$$

(see [4]) since $abs(d \cdot r) < 1$.
Hence:

$$p = d \cdot \frac{1-r}{1-d^2 \cdot r}$$

This is also the total part of the power coupled into the antenna (we assumed transmit power =1).

(reminder: p: final into the antenna coupled power, d: (linear) single cable attenuation, r: reflected part of the power at the antenna)

The additional cable loss is

$$p/d = \frac{1-r}{1-d^2 \cdot r}$$

3.1 Example

RG58 cable with ca. 5dB cable attenuation per 100m at 3.5 MHz, at 10m length hence ddb=0.5 dB, which doesn't look so bad. Assume we have an SWR of 1000 (e.g. a 40m vertical antenna on 80m), which we can still match with a tuner at the transceiver. Now we can compute our total cable losses.
single cable attenuation: $d = 10^{(-0.5/10)} = 0.89125$
Reflected voltage: $(SWR-1)/(SWR+1) = 999/1001 = 0.99800$
Reflected power: $r = ((SWR-1)/(SWR+1))^2 = 0.99800^2 = 0.99600$
Our total cable loss is:

$$p = d \cdot \frac{1-r}{1-d^2 \cdot r} = 0.01707$$

or in dB:

$$10 \cdot \log_{10}(0.01915243) = -17.68dB$$

That is a loss of almost 3 S-steps, which means our signal is probably lost in the noise floor or QRM. So even though the SWR looks good at the transceiver, most of the power is lost in the cable!

For a SWR=100 at the antenna we get:
p=0.14757, in dB: -8.31 dB, or an additional loss of -7.81 dB. This is is about 1 S-step attenuation in addition to our simple cable loss of -0.5 dB.

For a SWR=30 at the antenna we get:
p=0.36505, in dB: -4.3764 dB, or -3.8764 dB additional attenuation. This is is about half an S-step additional attenuation, which is workable.

For SWR=10 at the antenna: p=0.6292, in dB: -2.0121 dB total loss, additional loss: -1.5 dB. This is a hardly noticeable additional attenuation, so no problem.

Hence at an SWR of 10 the additional attenuation (additional to the simple cable losses) is negligible, but at SWR of 100 or more, an antenna tuning circuit should be used at the antenna, to bring the antenna SWR below about 30. The rest can then be tuned with an antenna tuner at the receiver.

3.2 Matlab/Octave Function

The follwoing is a Matlab or Octave function to compute the additional loss:

```
function L=loss(ddb,SWR);
%function to compute cable losses due to very high SWR
%usage: L=loss(ddb,SWR);
%L: additional cable loss in dB
%ddb: simple cable loss from transmitter to antenna (from cable loss tables)
%SWR: SWR from cable to the antenna

d=10^(-ddb/10);
r=((SWR-1)./(SWR+1)).^2;
%linear loss:
Ll=d*(1-r)./(1-(d^2*r));
%Loss in dB
L=10*log10(Ll);
```

3.3 Table of Total Attenuations

With this formula we can compute the following table, which shows the total attenuation in dependence of the SWR and the magnitude of the single cable loss in dB, ddB:

$SWR \vert ddB$	0.5	0.70711	1	1.4142	2	2.8284	4	5.6569
2	−0.61024	−0.85542	−1.1959	−1.6666	−2.315	−3.2068	−4.4344	−6.1326
4	−0.97544	−1.3379	−1.8192	−2.4496	−3.2664	−4.3194	−5.6831	−7.478
8	−1.689	−2.247	−2.9454	−3.8019	−4.8367	−6.0815	−7.5956	−9.4916
16	−2.863	−3.6674	−4.6124	−5.6998	−6.936	−8.3428	−9.9752	−11.947
32	−4.5554	−5.602	−6.7642	−8.0355	−9.4185	−10.935	−12.644	−14.662
64	−6.7208	−7.9572	−9.2747	−10.668	−12.142	−13.724	−15.476	−17.52
128	−9.2385	−10.6	−12.013	−13.476	−15.002	−16.619	−18.395	−20.453
256	−11.98	−13.414	−14.88	−16.382	−17.935	−19.571	−21.359	−23.424
512	−14.849	−16.322	−17.817	−19.34	−20.907	−22.552	−24.346	−26.415
1024	−17.788	−19.281	−20.79	−22.323	−23.897	−25.548	−27.345	−29.416

4 Derivation of an Approximation Formula

For the additional cable loss we have

$$\frac{p}{d} = \frac{1-r}{1-d^2 \cdot r}$$

$$r = \left(\frac{SWR-1}{SWR+1}\right)^2 \approx 1$$

$$1-r = 1 - \frac{(SWR-1)^2}{(SWR+1)^2} =$$

$$\frac{(SWR+1)^2-(SWR-1)^2}{(SWR+1)^2} = \frac{(4 \cdot SWR)}{(SWR+1)^2} \approx \frac{4}{SWR}$$

$$1 - d^2 \cdot r = 1 - d^2 \cdot \left(\frac{SWR-1}{SWR+1}\right)^2 =$$

$$\frac{(SWR+1)^2 - d^2 \cdot (SWR-1)^2}{(SWR+1)^2} =$$

$$= \frac{((1-d^2) \cdot SWR^2 + (1-d^2) + (1+d^2) \cdot 2 \cdot SWR}{(SWR+1)^2} \approx (1-d^2)$$

Hence:

$$p/d = \frac{1-r}{1-d^2 \cdot r} \approx \frac{4}{SWR \cdot (1-d^2)}$$

In dB:

$$10 \cdot \log_{10}(4) - 10 \cdot \log_{10}(1-d^2) - 10 \cdot \log_{10}(SWR)$$

(1-d): power which the cable looses at a single length. Our final **approximation** or **rule of thumb** for the **additional** cable loss in dB is:

$$p/d \quad \text{in} \quad \text{dB} = 6\text{dB} - 10 \cdot \log_{10}(1 - 10^{(-ddb/5)}) - 10 \cdot \log_{10}(SWR) \quad dB$$

For an SWR=1024 and a single cable loss of ddB=0.5 dB, and using our approximation, we get an additional attenuation of -17.235 dB, which is a good approximation of the exact formula.
For SWR=128 and a single cable loss of ddB=0.5 dB, and using our approximation, we get an additional attenuation of -8.203 dB, only about 0.5 dB deviation from the exact value. Below about SWR=64 the approximation becomes increasingly inaccurate, so that in that case it is better to use the exact formula.

5 Measurement Comparison/ Verification

To verify and test the derived formula and table, we can use the open source circuit simulation program "Qucs" (for "Quite universal circuit simulator"). This is a versatile open-source circhuit simulator, available for many operating systems, eg. Linux and Windows [5]. It includes a coaxial cable model including losses. This has the advantage that quite different parameter settings can easily be tested and reproduced. I took the RG58 parameters for the model: din=0.81mm, dout=2.9mm, Er=2.25, Mur=1. This results approximately in the desired impedance of 50.9 Ohm. For the desired cable loss, the coefficient "tand", the loss tangent, and the conductivity "Sigma" can be used. I tried different values, and found Tand=0.003 and Sigma=5.9e7 result in losses which are quite similar to RG58 between 10 MHz und 1000 MHz, and lead to a loss of 4.7 dB for 100m cable length at 14 MHz, 3.9 dB at 10 MHZ, 15 dB at 100 MHz, 75 dB at 1000 MHz.

Figure (1) shows the simulated circuit for the test.

For 14 MHz and a cable length of 10.6 m we obtain a loss of 0.5 dB, as one column in the above table. The circuit simulates the antenna tuner. The antenna impedance is assumed to have a real valued resistance of 51200 Ohms, leading to an SWR of 1024 (since it is 1024*50). It has an inductor to compensate the imaginary part of the impedance at the source, and set the real part identical to the real part at the beginning of the cable, to simulate the antenna tuner at the transceiver. The simulation has a frequency range between 14 and 14.1 MHz. The simulation result is shown in Fig. (2).

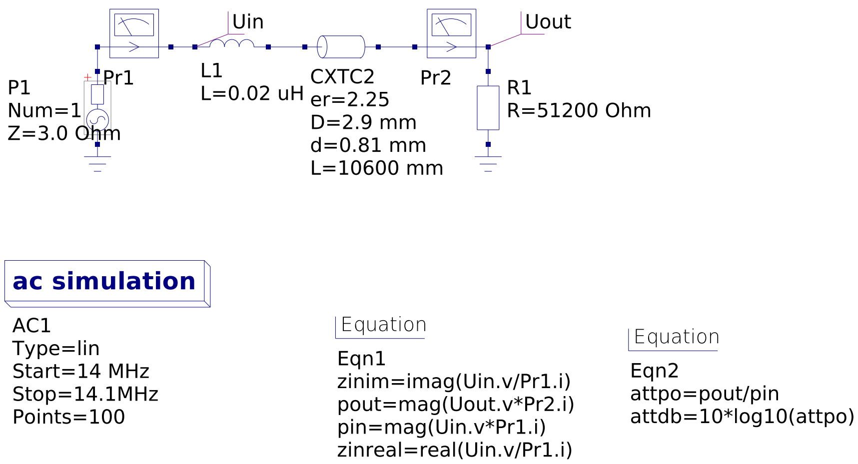

Figure 1: Circuit for measuring RG58 cable attenuation at high SWR

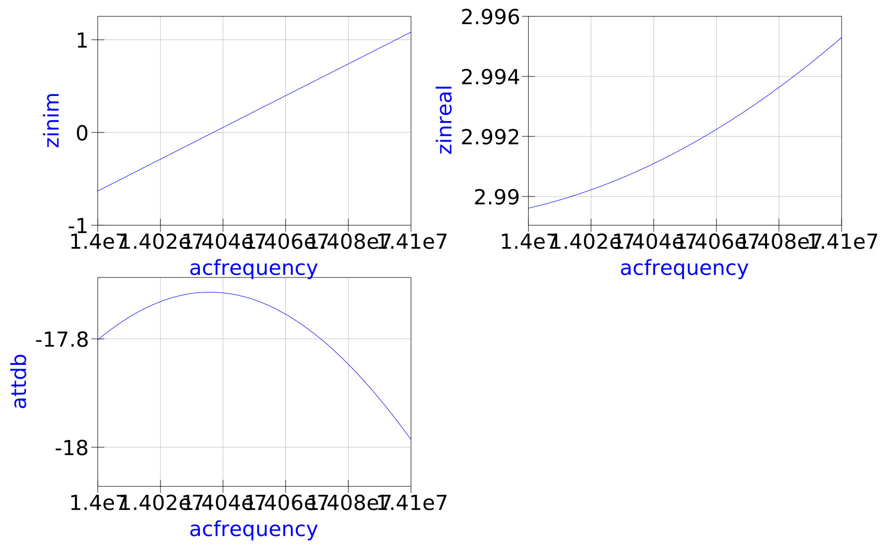

Figure 2: Results from the circuit for measuring RG58 cable attenuation at high SWR. Observe that the first plot shows the imaginary part of the impedance at the beginning of the cable, the next plot the real part of the impedance, and the 3rd plot shows the total attenuation of our coaxial cable (output power / input power in dB).

We see that the minimum attenuation is indeed obtained where the imaginary part of the impedance at the beginning of our coaxial cable is zero, the tuned frequency at the transceiver, and that the attenuation at that point is about -17.7 dB. It is indeed independent of the real part of the source (which is easily verified by trying it out in the simulation). A look at our table yields a result of -17.78 dB, so we have a nice correspondence between these values.

6 Conclusions

We derived an approximation of the additional cable attenuation at very high SWR at the antenna,

$$6\text{dB} - 10 \cdot \log_{10}(1 - 10^{(-ddb/5)}) - 10 \cdot \log_{10}(SWR) \quad dB$$

computed a table of total losses, and showed how to confirm these values with a test circuit in the simulation Program "Qucs". The exact and approximation formula show that an antenna with an SWR below about 30 and a single cable loss of 0.5 dB can be tuned at the transceiver, but at higher SWR's for instance SWR=1000, the antenna should be tuned such that its SWR becomes below about 30. The rest can then be tuned at the transceiver without too much loss.

References

[1] 'Was geschieht auf nicht angepassten HF-Leitungen?', Lorenz Borucki, DL8EAW, Funkamateur 12/2007, S. 1292

[2] http://www.wc7i.com/reflection%20section.htm

[3] http://en.wikipedia.org/wiki/Standing_wave_ratio

[4] http://en.wikipedia.org/wiki/Geometric_series

[5] http://qucs.sourceforge.net/