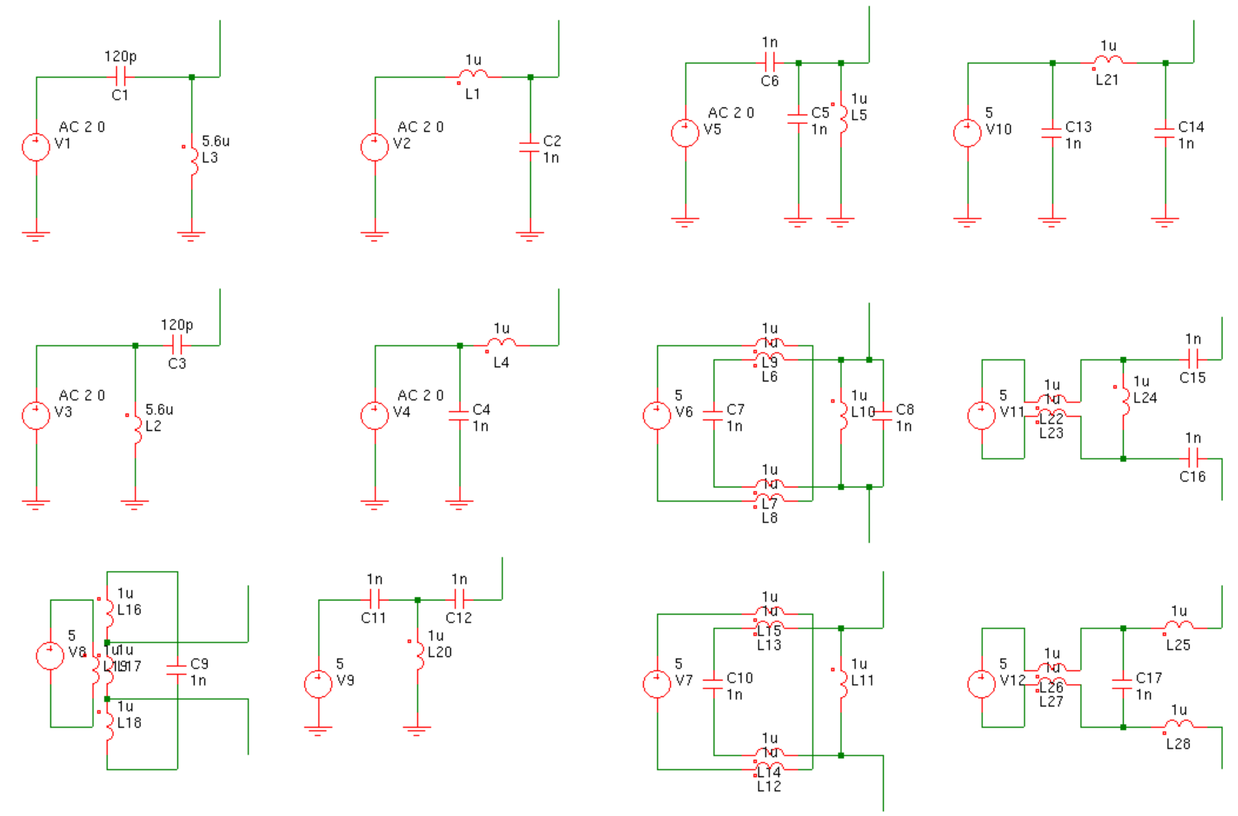
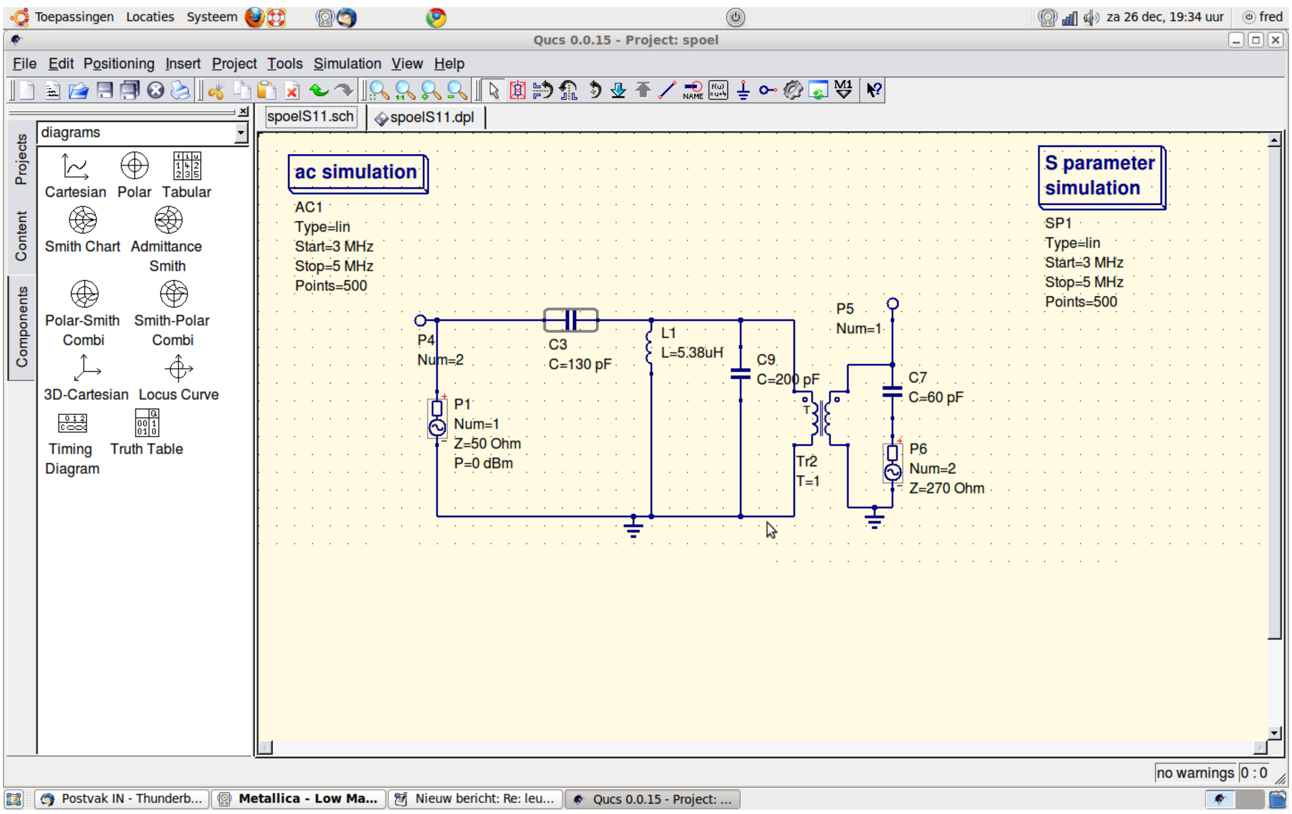
The truth about Antenna Tuners (I hope :-)).

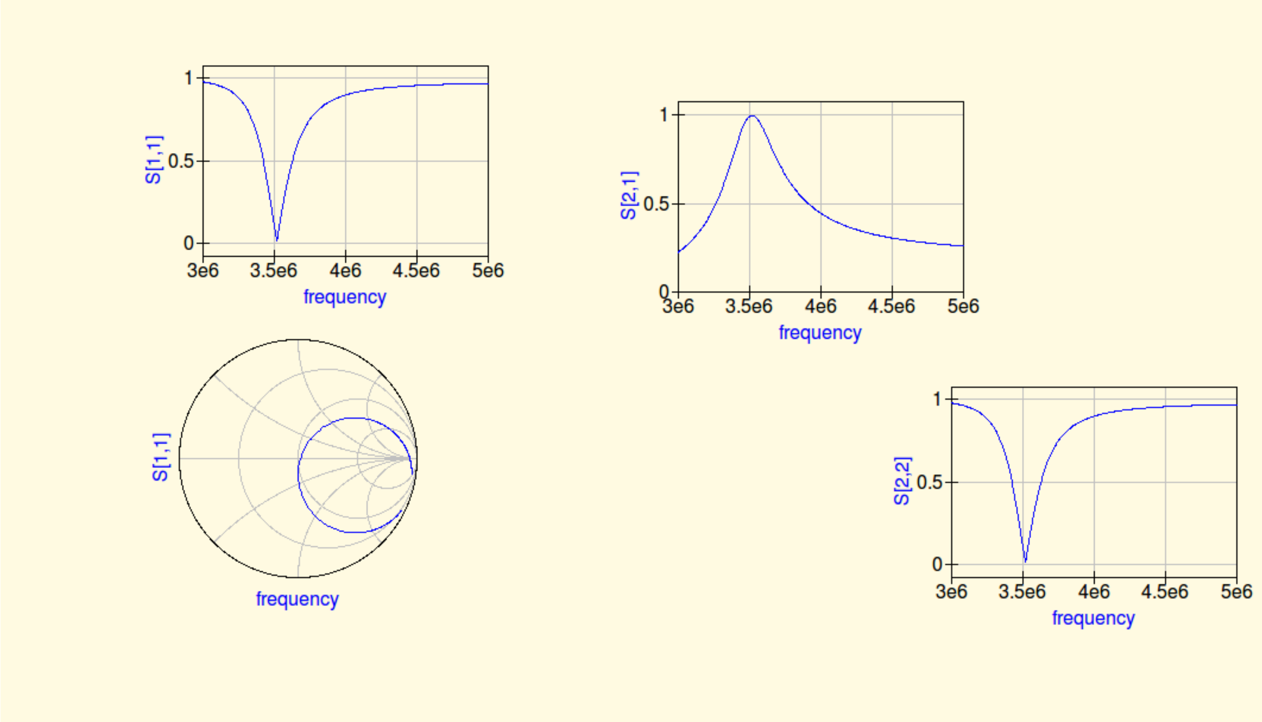
Another peace about tuners, why not. This is no receipt but just the things you must know to build a decent one. Here are some examples. Do not look at the values. You can use a program like Qucs, LTspice or Simetrix to simulate one. Use AC analysis.



Here is a sim-picture made in Qucs:



I see this tells also something about my music taste...

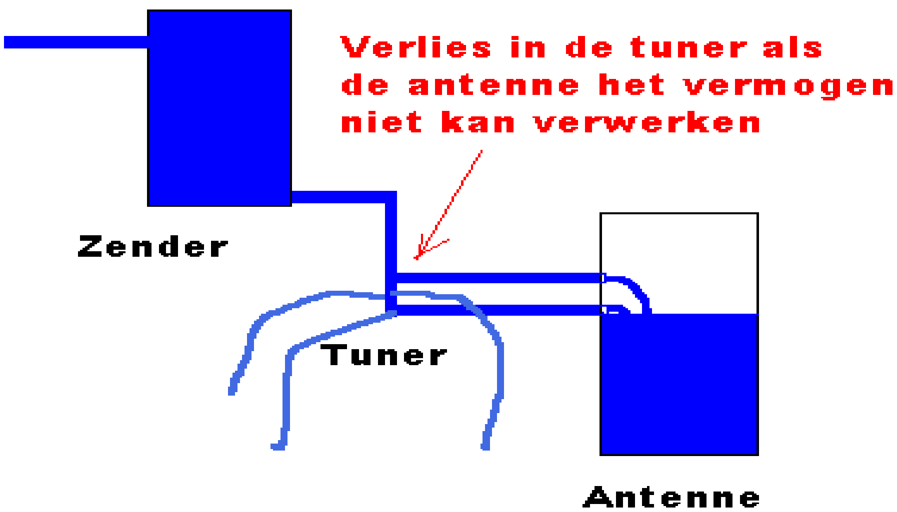


This are the results from the simulation.

Tuner fairytales:

Let's start with some lore. A tuner is a source of loss. No !! It just transforms the impedance of your antenna and feeder to (most times) 50 ohms. The value our transmitters like to see. Use good parts to get a high Q. BThe tuner itself must have a high unloaded Q. (Why ? you can read that in my tutorial about VNA's chapter about Q)
However, the tuner must be able to transduce it's energy so it must see a good load. If the antenna is not a good load the tuner must dissipate the power, it has no other option. So most times the tuner is the “victim” not the guilty one.

The way it works: The transmitter is a sort of water barrel that is connected to the water net.. There is a constant pressure. There is one hole the water is blown out. It has to go to a second barrel by means of a gutter. The problem is, our second barrel has two smaller holes. So we make a splitter/regulator in between. If the holes are very small the splitter (tuner) will not be able to deliver the amount of water it is receiving the gutter/regulator/splitter will spill the water. Is the splitter wrong ? No, the receiving barrel is the problem. We give it more water it can handle. (this was a Dutch text: zender=transmitter, the red text is telling there is loss if the antenna is not right)

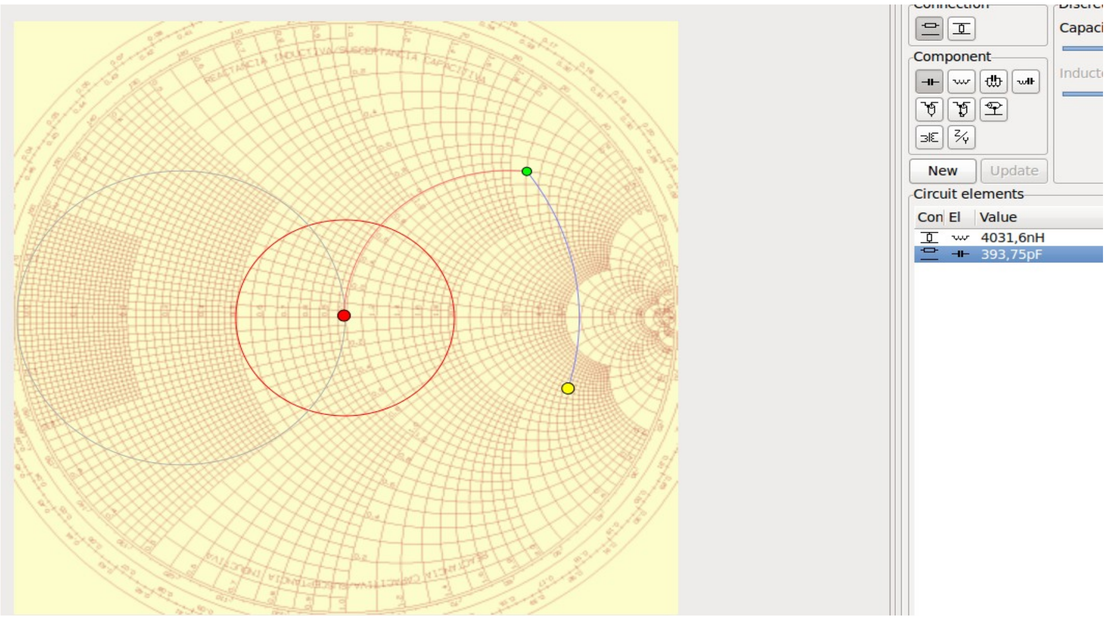


The antenna has a complex impedance. One part is ohms. The radiating resistance. This is the part that dissipates the power and like a lamp radiates light, this part radiates radio waves.

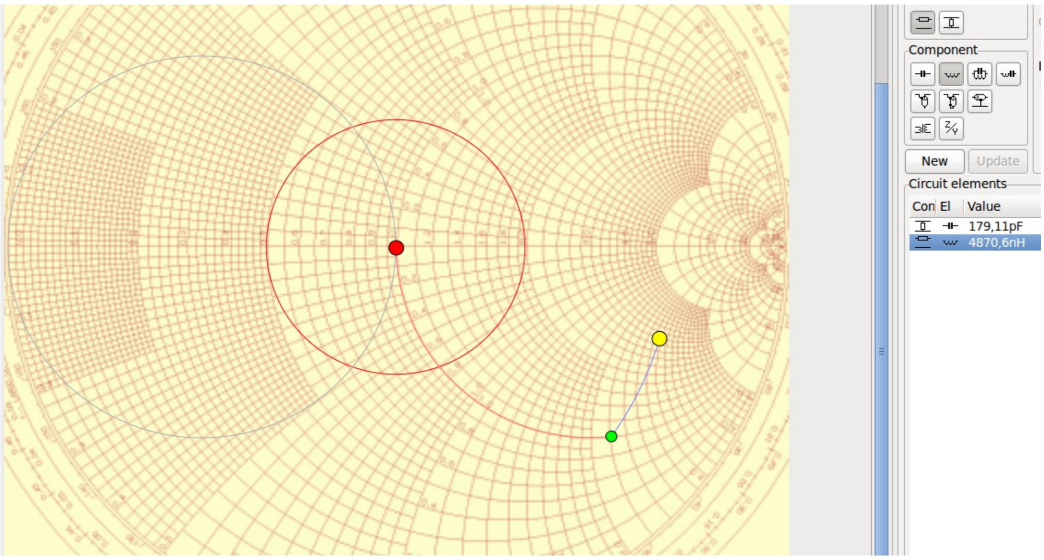
Beside the ohms part there is a capacitive or inductive part. Called reactance. A pure reactance can not dissipate power. So it won't radiate. If your antenna has a ohms part of 1 ohm and the rest a reactance, like a magnetic loop, EH antenna or very short antenna's, then a large part of your power can not be radiated. The tuner, your transmitters dearest friend offers itself and dissipates that power. It is not his fault he does this, we should use a real antenna behind a tuner.

But if an antenna has radiating resistance and we feed it with open line we can make a very good multiband antenna. An open line has almost no loss, so a high swr is not an extra loss. The tuner needs to transform the impedance towards 50 ohms. To do that he needs two parts . An inductor and a capacitor. If we load the tuner enough it can transduce the energy. The Q is about stored energy. A high Q in a component means it can store a lot of energy without spilling. A tuner with a low loaded Q will tell you it is loaded right so the energy transfers on. For an oscillator you want a high loaded Q. The energy has to cycle in that oscillator. In a tuner you don't want that.

This has to do with math but to keep it simple. An impedance can be transformed by resonating it with a series element or absorb it by a shunt. Besides getting the reactance out of the way, it looks like the ohms part changes. It is still the same load but the transmitter now thinks it's 50 ohm. You see here some smithcharts. The yellow dot is the antenna. It is capacitive so we use a shunt to walk along an admitance circle (not in this picture but most times they are) towards the 50 ohm impedance circle. A coil goes against the clock. A capacitor the other way round. So now it is 50 ohms but the transmitter wants the real stuff, so after that we use a series element, a capacitor to move over an impedance circle towards 50 ohms real.



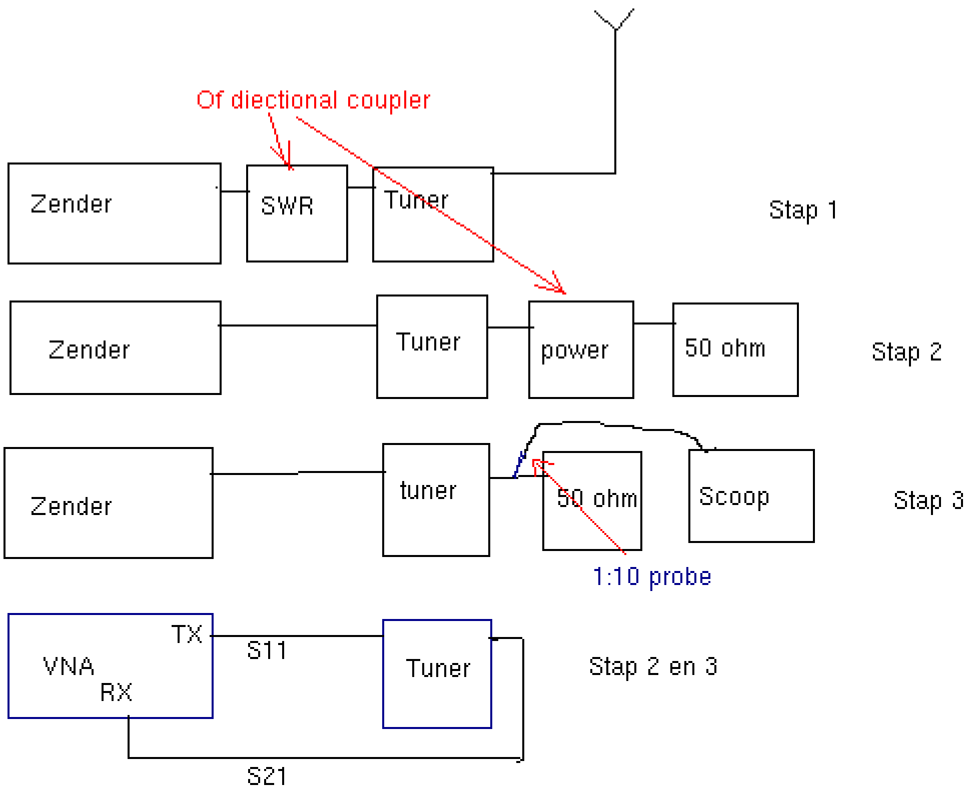
We were in the inductive quadrant so we had to use a capacitor to resonate. That 50 ohm is the center. The series capacitor goes against the clock a coil the other way round. So you can combine elements to get you towards 50 ohms. The pictures are made with LINsmith, an open source program. There are several free others to find.



There are many tuners but basically they are based on L, T or PI configurations,
There are very good building instructions on the international site of PA0FRI. (google on his call, you will find it)
I just tell you how it really works. There are some rules:

Rule 1:
More parts=less efficiency
Rule 2:
Use quality parts, the better they are, the smaller the losses. So big massive air or roller inductors.
Rule 3:
Be sure the unloaded Q is high, the loaded Q must be low
Rule 4:
A commercial tuner is made to adapt to almost every antenna, or excuse for an antenna. Otherwise customers complain. This is the T-tuner. This does not mean it is the best tuner, It has the highest loss.
Rule 5:
For a good tuner you have to measure the specs of the antenna and design the tuner that does its job. So not a broad, all adapting tuner, but a specialized one for your needs. My F-match can tune my antenna from 80 to 6 meters without switches but it can only do high impedances because that is what my antenna represents. So it can not tune 10+J100 or 75-J20 but 270-J720 or 150+J500 it does without problems.
Rule 6:
A balun (when goining from open line to coax) needs to be at the TX side. There the impedance is always 50 ohms so you do not need a hefty one. I used a 1" ferrite without problems at 100W. The thing important is not power but voltage. That will be seldom to high with our legal 400W. But a bigger one is save, I use 4C65 for this. A T200 is not a good toroid for current chokes

How you measure the efficiency of a tuner. It is hard to do but possible. The worst part it all dependents on the load (loaded Q, remember) So you have to measure it with the load your antenna represents on the band of choice. You can use a High Z probe to measure the in and output. You know the input Z but not the output Z. However you can use a resistor and capacitor in series to imitate a load. Tune on your antenna and after that use a potentio meter and variable capacitor and try to find the swr=1 point again. Then you can measure the voltage over your load (you need a differential probe for it but sometimes two probes and A-B on scopes work to at low frequency). You can also measure the current but that is also not easy. You need good current probes for that. The antenna wire is the primary turn of the probe transformer so that does things with the impedance of your antenna. Measuring the radiation with a sniffer is also not a good method. Most times your in the near field. The best way is with a VNA but it is still hard on big Z values. You need to measure Rho (or the return loss and phasor angle and calculate Rho) Then you measure S21, the insertion loss as a result of the missmatch towards 50 ohms. Then you calculate 10xlog(1-|Rho|²) and the difference between the two is your loss. My VWNA can do a more easy way. See the VNA tutorial chapter about tuners. You can also use a SWR/power meter. SWR can be calculated back to Rho (on the configuration of you tuner you can see if your load is above or below 50 ohm. You connect TX-swr meter-tuner-antenna. Tune for swr=1 and measure power. Then disconnect antenna and place dummy. Measure SWR again and note it. Remove SWR meter (and best connect a 50 ohm pass-through terminator) and fit it between dummy and tuner. Measure power. 10xlog(Puit/pin) gives you the S21 value. This gives problems with high Z loads. The error factor becomes to big and SWR meters are a bit deaf..



One end mismatched

When either generator or load impedance is mismatched to the Z_0 of the line and the other is matched,

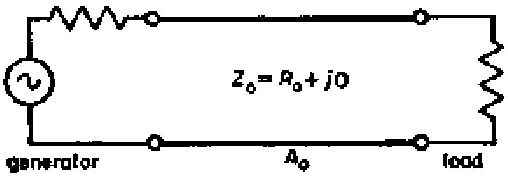
$$\text{(mismatch loss)} = \frac{P_m}{P} = \frac{1}{1 - |\rho|^2} = \frac{(S+1)^2}{4S} \qquad (1)$$

where

P = power delivered to load

P_m = power that would be delivered were system matched

S = standing-wave ratio of mismatched impedance referred to Z_0



Compared to an ideal transducer (ideal matching network between generator and load):

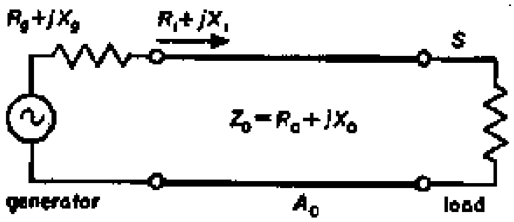
$$\text{(transducer loss)} = A_0 + 10 \log_{10} (P_m/P) \text{ decibels} \qquad (2)$$

where A_0 = normal attenuation of line.

Generator and load mismatched

$|X_0/R_0| \ll 1$

When mismatches exist at both ends of the system:



$$\text{(mismatch loss at input)} = \frac{P_m}{P} = \frac{(R_g + R_1)^2 + (X_g + X_1)^2}{4 R_g R_1} \qquad (3)$$

$$\text{(transducer loss)} = (A - A_0) + A_0 + 10 \log_{10} (P_m/P) \text{ decibels} \qquad (4)$$

Have fun,

Fred PA4TIM
5 juli 2010