

Transducer Impedance Matching Using a Smith Chart

Matching the impedance of the source and load can improve overall efficiency by reducing the phase difference of the Voltage and Current.

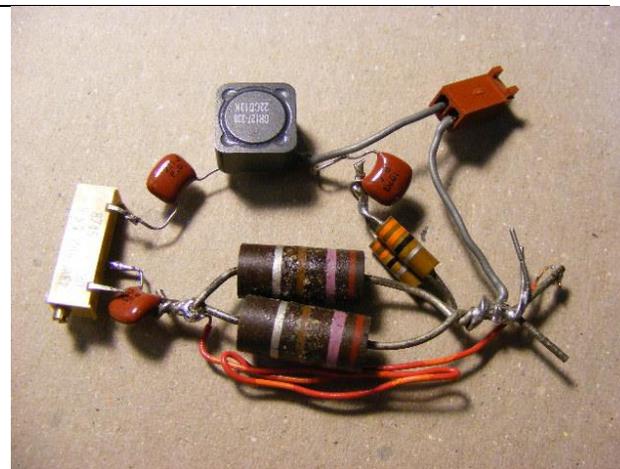
$$Power = Voltage * Current * \cos(\text{phase})$$

This is especially true in systems where the Voltage or Current is in some way constrained by the system.

An example of impedance matching using the Smith Chart and Vector Network Analyzer S11 measurements follows. An R-L-C discrete component circuit is used to demonstrate the matching process. Small surface mount chip inductors are used to implement simple matching circuits.

A simple R-L-C load is used to emulate the ceramic resonator used in ultrasound or sonar transducers. The equivalent circuit consists of two parallel branches. One branch models the components of the cable and mounting. For this example we use a series R+C (18 ohms + 1000pf). The other branch represents the resonant transducer elements as a series R+L+C (120 ohms + 33uH + 180pf) circuit. The L and C components model the resonant frequency, the series R is used to model the transducer losses or Q.

The circuit impedance is measured using the S11 reflection coefficient as measured using an HP 3577B vector network analyzer equipped with a 35677A S-Parameter test Set. It is displayed in Smith Chart format on the screen to the right. The load measurement is displayed on the lower half of the chart showing that it is “capacitive” over the range of 1 – 5 Mhz. The Smith Chart loop area depends on the Q of the inductor. The higher the Q, the larger the loop on the Smith Chart. The series RLC of the transducer resonates around 2.0 to 2.2 Mhz. At 2.2 Mhz the analyzer measures a load impedance of 72 ohms at -40 degrees. It would be desirable to match this load to something close to the 50 ohm resistive source impedance.



The Smith chart on the right contains a set of light green concentric lines. These are constant resistance lines. Inserting a standard value 3.9uH inductor in series with the modeled transducer load adds inductive reactance to the otherwise capacitive circuit without significantly changing the circuit's resistance.

The added inductance counteracts some of the capacitance and as a result moves the combined impedance up along one of the constant resistance lines, thus shifting the impedance from a capacitive 72 ohms at -40 degrees to a slightly inductive 58 ohms and 5 degrees at 2.2 Mhz. This is much closer to the desired 50 ohm resistive load.



Matching a load connected by cable

It is often the case that the source and load are separated by some distance. This requires the source to be connected to the load using some sort of cable. As an example we will use 10 feet of Cat-5E network cable to connect the source to the emulated transducer circuit. The impedance scan for the RLC transducer circuit by itself is shown at the right. At 2.2 Mhz the analyzer indicates the impedance is 72 ohms with a phase angle of -40 degrees.



When 10 ft. of Cat-5 cable is inserted between the load and the source, at 2.2 Mhz, the impedance drops from 72 ohms to 56 ohms and the phase is shifted from -40 degrees to -26 degrees. This is still a little short of the 50 ohm resistive goal we are trying to reach.



The load impedance seen by the source can be modified by adding an impedance matching circuit between the cable and the load. Inserting an L-pad matching network consisting of 2.2uH and 47uH, between the analyzer and the Cat-5 cable brings the 2.2 Mhz impedance measured at the source to 63 ohms and reduces the phase to 1 degree. This match, although not ideal, allows for some degradation of the transducer Q over the life of the device.



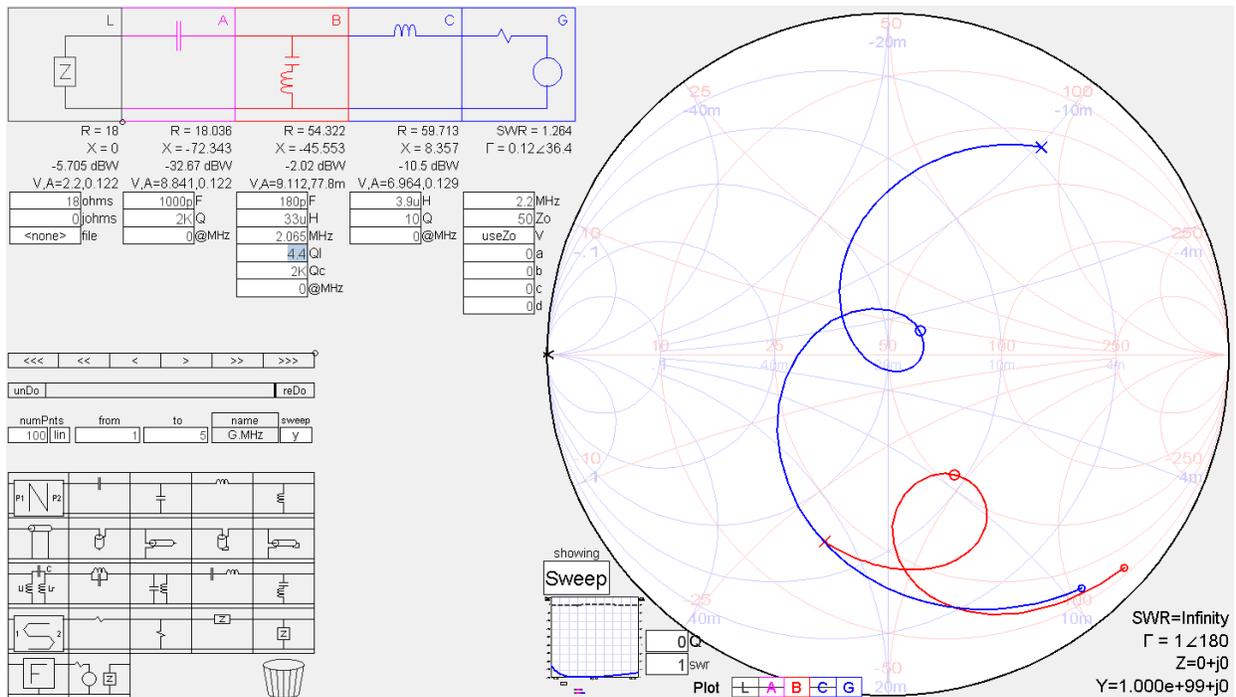
The matching circuits mentioned above were built using standard value chip inductors from TDK. They were assembled on a small piece of prototype board. The L-pad circuit on the left consists of two inductors wired as an L-pad (2.2uh in series, 47uH in parallel with the load).

The second circuit, located on the right side of the board, consists of a single series (3.9uH) inductor.

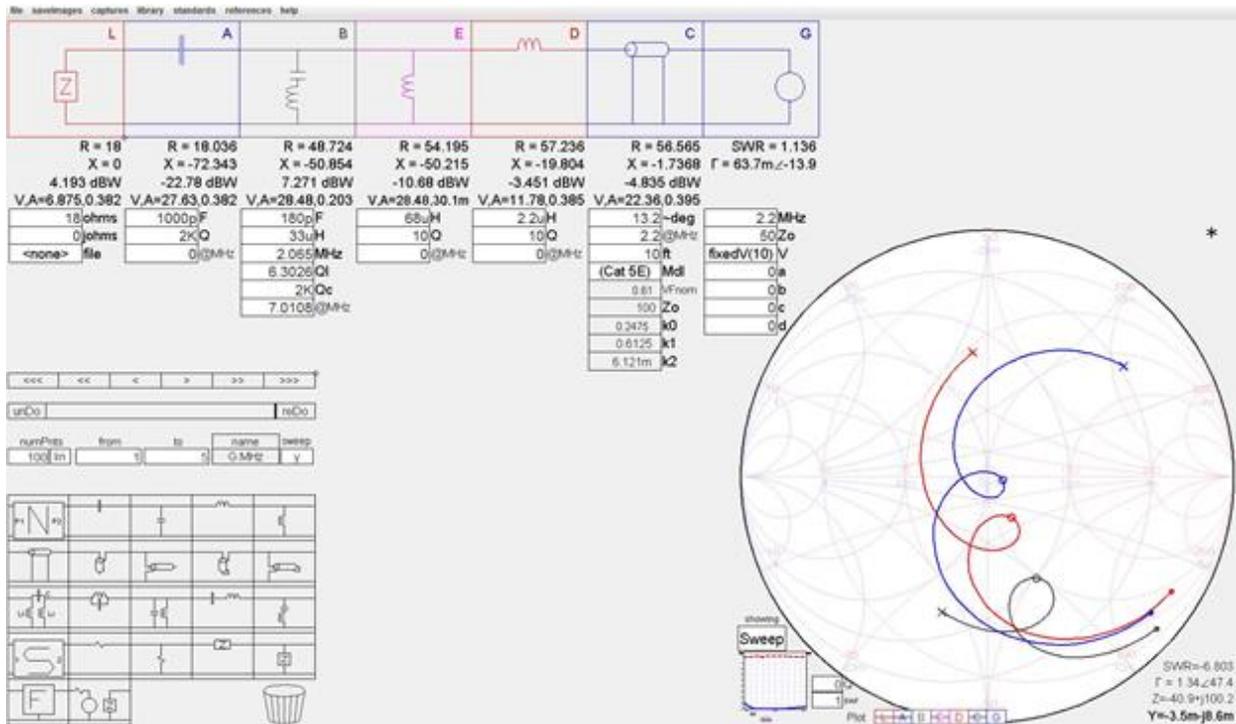


The Smith Chart is a good tool to design and analyze matching circuits, especially when the circuit includes a transmission line. AE6TY's SimSmith Smith Chart package is a handy tool with a convenient user interface. Circuit blocks are dragged and dropped to form the circuit model. Component values can be entered directly from the keyboard and easily adjusted with a few clicks of the mouse, providing immediate graphical feedback to the user.

On the Smith Chart representation below the red trace is the load impedance. This is modeled by SimSmith schematic blocks L, A, and B. A series matching inductor, block C, is all that is required to move the transducer impedance (blue trace) closer to the Smith Chart 50 ohm center point while also reducing the phase to near zero. By comparing the SimSmith graphs below with the network analyzer outputs above you can see that the SimSmith circuit model agrees nicely with the network analyzer measurements.



When the Cat-5 cable, block C, is inserted between the source and load, it reduces the need for series inductance from 3.9uH down to 2.2uH. The parallel leg of the L pad is used to adjust the impedance a little closer to 50 ohms. In the chart below the black trace is the load impedance, the red trace is the impedance at the input to the L-pad (blocks D, E) matching circuit, the blue trace is the impedance seen at the source, block G. With this matching circuit the SWR has been reduced to below 1.14 to 1.



Download and install AE6TY's SimSmith Smith Chart package. It is a great tool to use to develop or analyze impedance matching circuits. http://ae6ty.com/Smith_Charts.html

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