Matching Networks, Q, Smith Charts

- Matching networks and Filters
- Definition of Q.
- Design of matching networks using Q.
- L, T, Pi (high Q) and low Q networks

Matching Networks and Filters

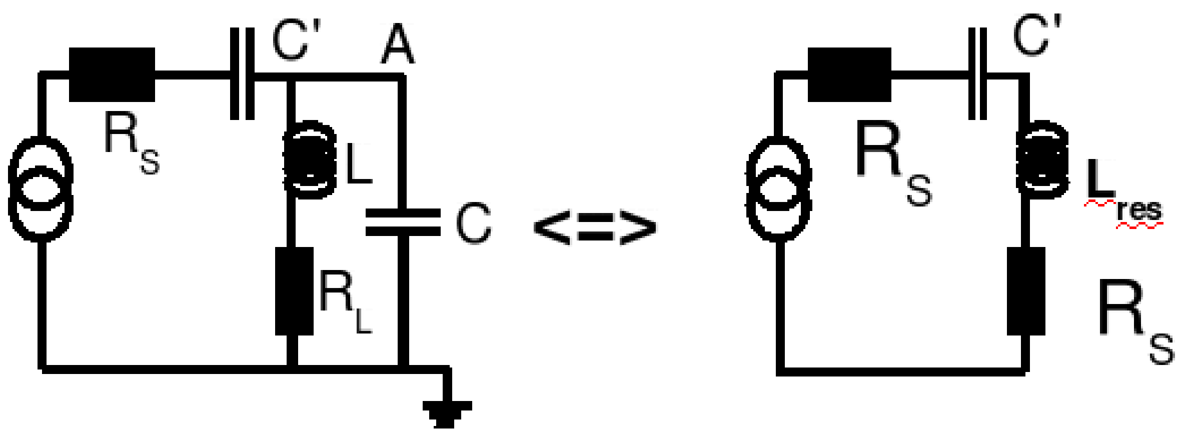
- For convenience we divide frequency dependent (**dispersive**) four port devices into either **matching** or **tuning networks** and **filters**.
- As we saw in the last lecture, we need to match a source to a load for **both** power transfer and take into account the characteristic impedance of any transmission line connecting them.
- To do this we use **matching networks**.
- Matching networks are basic building blocks in all RF circuits.
- Matching networks are required where the source and load impedances contain an appreciable reactance e.g. matching to antennas, transistor amplifiers and oscillators.
- Matching networks only work at one frequency, although they can be designed to be **slightly** broadband.
- Matching networks can be designed as filters.

Filters

- Filters are four port devices with a frequency response tailored for a particular purpose.
- Examples are low pass, high pass, stop band, bandpass.
- The main concern with filters is their frequency response.
- They may also match by absorbing stray reactances into the filter.
- Filter design is covered by examples in Bowick.

Matching Networks: Simple Example

- Simple visual picture of matching
- Match R_S to R_L.
- Choose the L and C so that the parallel resonance as seen at A produces an inductive impedance with a resistive part equal to R_S.
- Choose C' to cancel the inductive residual reactance.

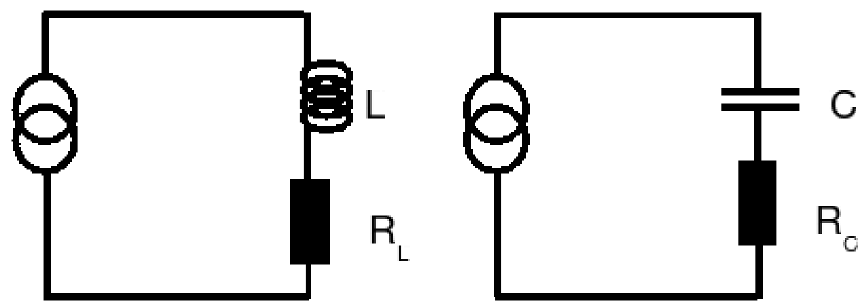


Definition of Q

- Q is the radian frequency multiplied by the ratio of electromagnetic energy stored to power dissipated in a reactance.
- Q is a measure of the energy stored in a reactance to that being dissipated.

$$Q = \frac{\omega \, Energy}{Power \, lost}$$

- For a lossless reactance $Q = \infty$.



$Q = \omega L / R_L$ $Q = 1/(\omega C R_C)$

Proof

- Consider the power dissipated in R_L and R_C

$$P_L = \frac{1}{2} I^2 R_L; \quad P_C = \frac{1}{2} I^2 R_C$$

- The energy in an inductor and a capacitor are given respectively by,

$$E_L = \frac{1}{2} L I^2; \quad E_C = \frac{1}{2} C V^2 = \frac{1}{2\omega^2 C} I^2$$

- Q = ω times ratios of energy to power dissipated are given by,
- For an inductive reactance,

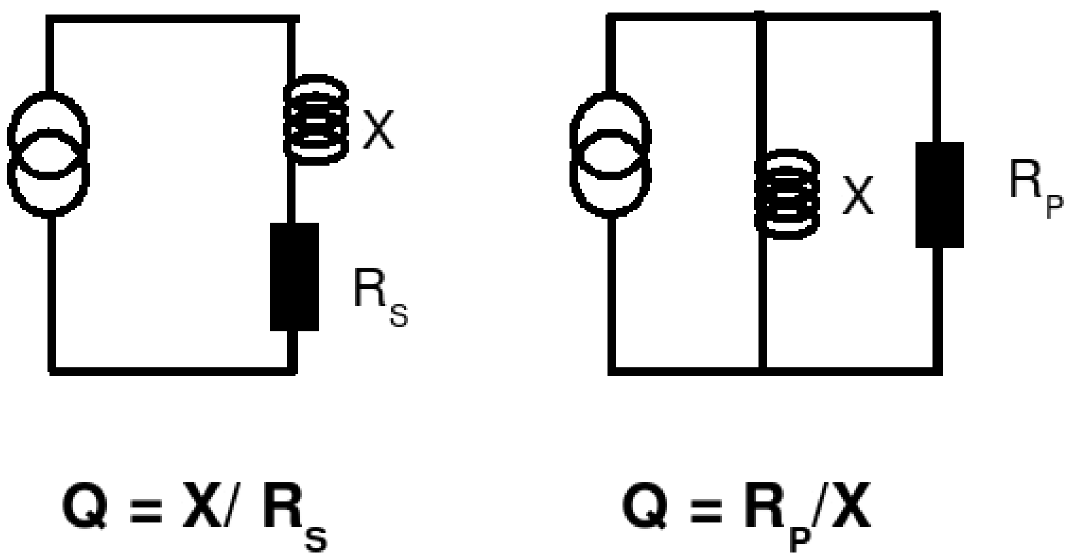
$$Q = \frac{\omega (L I^2 / 2)}{(R_L I^2 / 2)} = \frac{\omega L}{R_L}$$

- For an capacitive reactance,

$$Q = \frac{\omega (I^2 / (2\omega^2 C))}{(R_C I^2 / 2)} = \frac{1}{\omega C R_C}$$

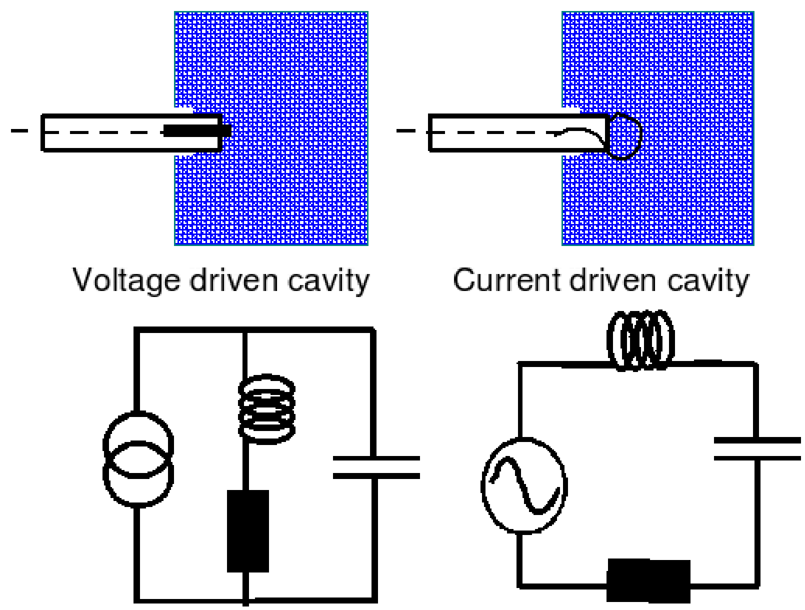
Properties

- The formula for Q depends on whether we imagine the R to be in series with or in parallel with the reactance. Just an issue of convenience.
- R in series with X, then $Q = X/R_s$
- R in parallel with X, then $Q = R_p/X$
- Notice that R_s is not the same as R_p but they are related (an exercise).



But What is Q and How to Measure it?

- Place a **high component** in parallel or series and measure the **resonance curve**
- Q determines how much oscillating radiofrequency energy per unit power consumption can be supported by a passive circuit in **isolation**.
- Careful not to load the circuit when you measure Q.

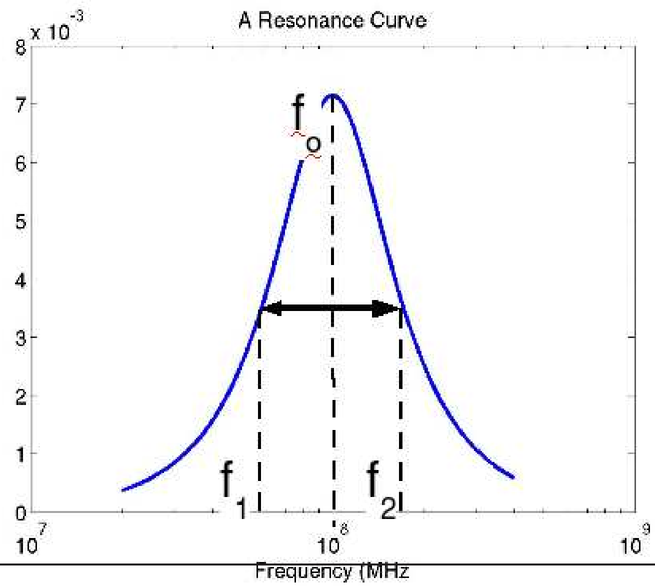


How to Measure Q?

- By using the typical **Resonance curve**.
- At the half power frequencies f_1 and f_2 of the cavity resonance.

$$Q = \frac{f_o}{f_2 - f_1}$$

- $f_2 - f_1$ gives the **3dB bandwidth** of the network.



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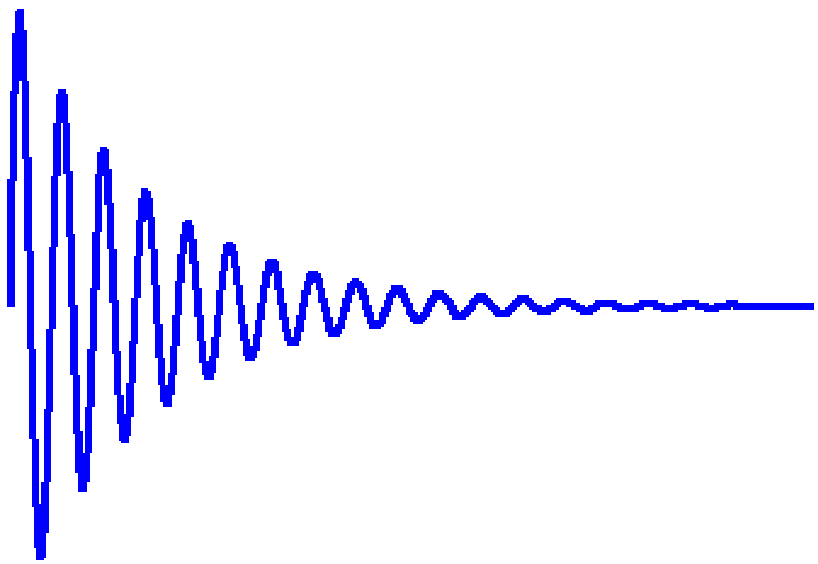
But What is Q and How to Measure it?

- Count the oscillations of a decaying signal in a resonator!
- How does this work????

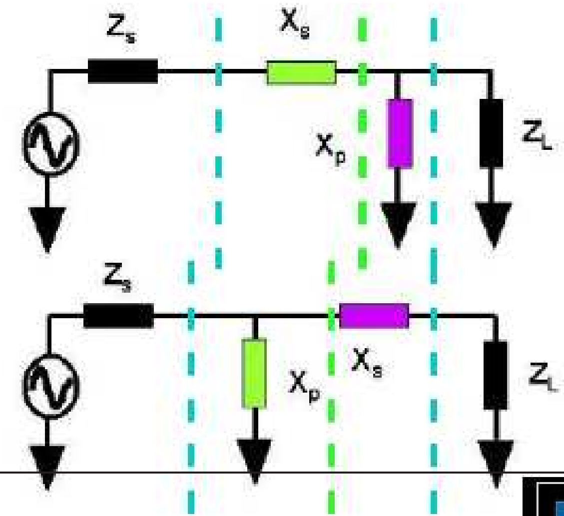


Matching Networks

- Use a matching network to match a source to a load for maximum transferred power.
- $Z_L = Z_S^*$
- Two different types we consider: L-networks and Pi/T networks
- Consist entirely of Ls and Cs.
- How to deal with reactive source and load impedances? Either treat by **absorption** or **resonance**
- Dont forget that if there is a transmission line in between the source and the load network then there are two matching networks: one to match the source impedance to Z_o and one to match Z_o to the load impedance.

L-Networks

- Consist of two matching elements.
- Choose shunt arrangement at Z_L (resp. Z_S) if $R_S < R_L$ (resp. $R_L < R_S$). Use series arrangement on the other side.
- Try to absorb source and load reactances into the matching impedance reactances.
- Since the impedances seen in either direction through the green line must be complex conjugates of each other, then the Q is the same for the circuits on either side of the green line.
- What about the blue lines?



L-Networks

- The relationships between the r_S, x_S and r_L, x_L are given by

$$\frac{r_L}{r_S} = 1 + Q^2, \ \frac{x_L}{x_S} = \frac{1+Q^2}{Q^2}. \ \ \mathbf{R_L\ shunt.\ R_S\ series.}$$

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- Q obtained from,

$$Q = \sqrt{\frac{r_L}{r_S} - 1}.$$

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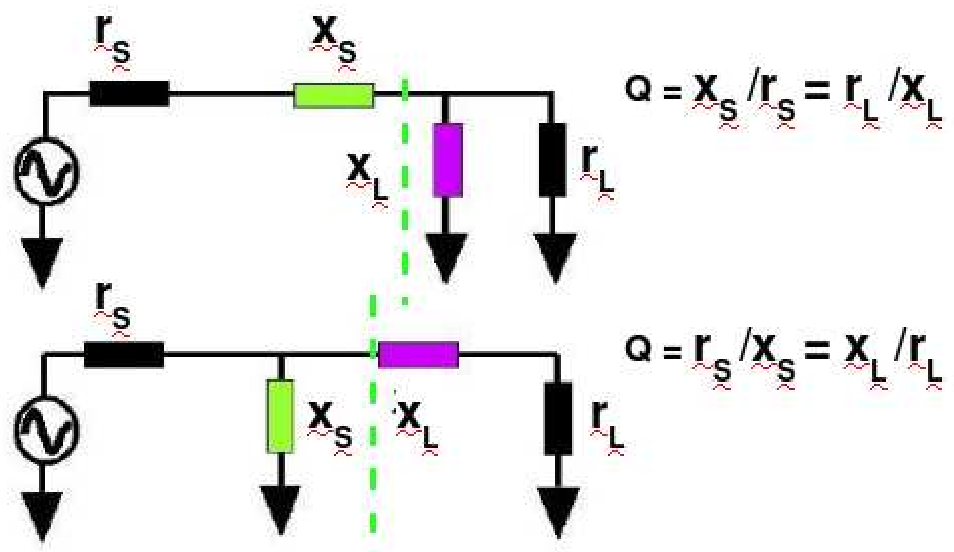


L-Networks: Summary

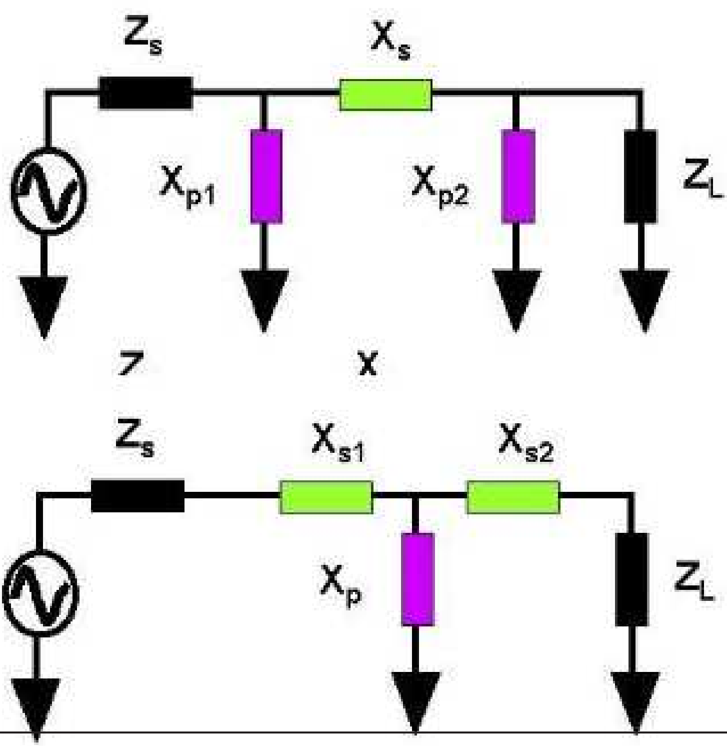
- Place the shunt of the L-network across the highest resistance and the series of the L-network in series with the lower resistance.
- Compute the Q required to match the source and load resistances.
- Use the Q to find x_S and x_L from r_S and r_L.
- Remember to place inductors in series with capacitors and vice versa in order to allow for complex conjugates.
- **Absorb** or **resonate** the source and load stray reactances X_S and X_L of the matching network with x_S and x_L.
- Whether we absorb or resonate depends on how large the strays are.

L-Networks: Limitations

- The value of Q arises from the calculation.
- In radiofrequency transmitter and receiver design, the simplest pre-antenna filter is going to be a matched filter like an L-network...
- But what if we need to specify Q?
- **Solution:** T and Pi networks.

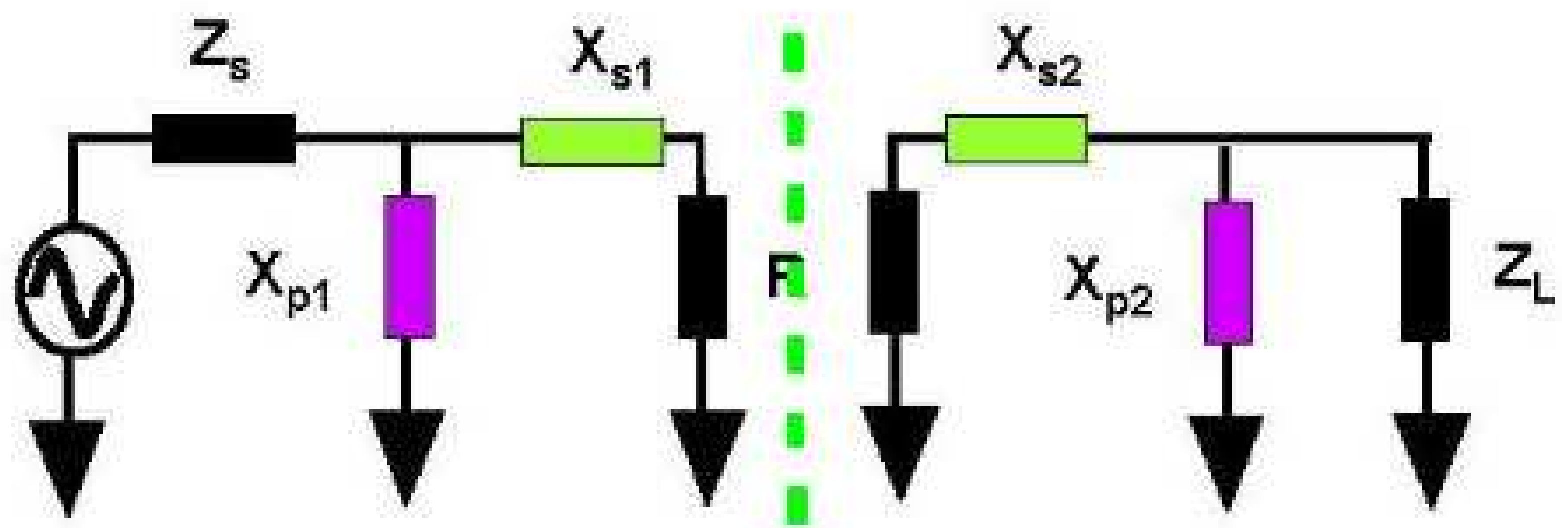
T and Pi: High Q Networks

- Can allow us to choose Q.
- Q however is always **higher** than for an L-network. Why?



Analysis of T and Pi Networks

- Choose Q.
- Consider the T or Pi network to be a pair of back to back L networks.
- The virtual resistance in a Pi network must be smaller that those on the source and load.



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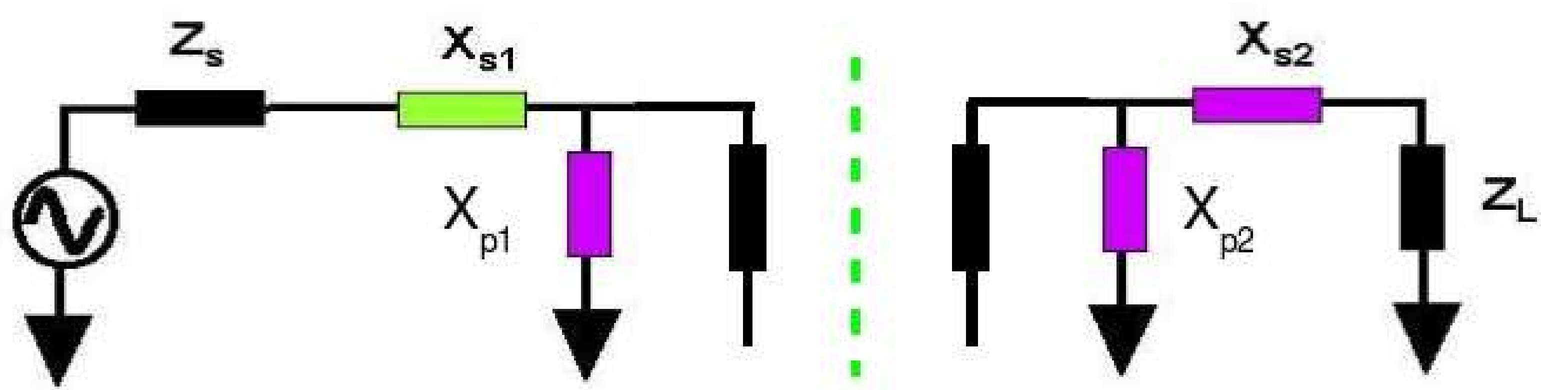
T Networks

- The virtual resistance in a T network must be larger that those on the source and load.



Low Q Networks

- Q however is always **lower** than for an L-network.
- OK for broadband match.