Lecture 2

EC560 - Modern Electronics Circuits

Performance Evaluation

S-Parameters, Passive Elements in RF

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Outline
Transceiver Performance Evaluation

- **Signal-to-Noise Ratio (SNR)**
- **Noise Figure (NF)**
- **Sensitivity**
- **Reflection:**
  - **S-Parameters**
- **RF models of passive components**

Signal-to-Noise Ratio (SNR)

- **Indication of signal strength**

$$SNR_{Ratio} = \text{Signal Power} / \text{Noise Power}$$

$$= P_{Signal}/P_{Noise} = (A_{signal}/A_{Noise})^2$$

$$SNR_{dB} = 10 \log (\text{SNR ratio}) = 10 \log (P_{Signal}/P_{Noise})$$

$$= 20 \log (A_{signal}/A_{Noise})$$

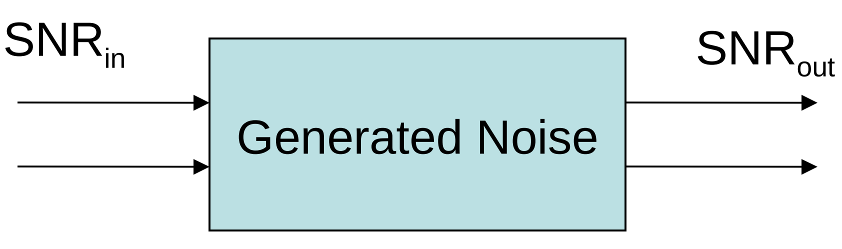
Noise Figure (NF)

- **Measure of SNR degradation by the circuit block, due to internally generated noise**

Noise Figure (NF_{dB}) = $SNR_{in(dB)} - SNR_{out(dB)}$ *all in dB*

Noise Factor (F) = SNR_{in}/SNR_{out} *all in ratios (not dB)*

NF = 10 log (F)



Sensitivity (in dBm)

- **Measurement Unit: dBm**

  1dBm = 1dBmWatt = Power referenced to 1mW

  = 10 log (Signal Power / 1 mWatt)

  Zero dBm = 1mW, 10dBm = 10mW, 1dBm change = 2x change

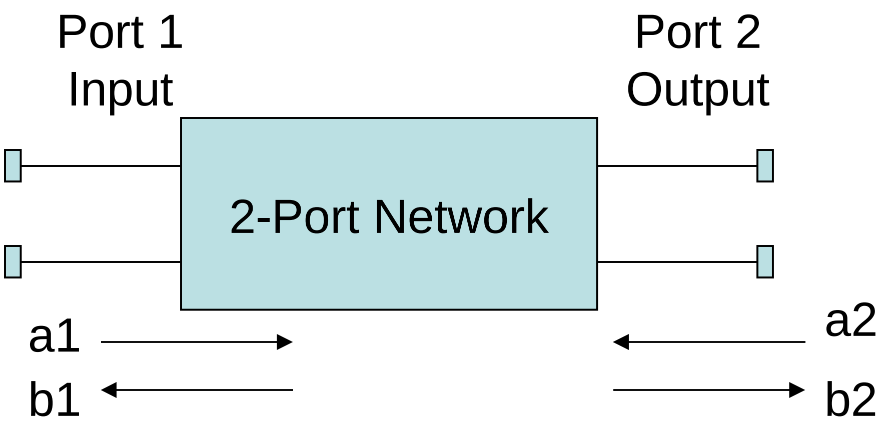
- **Sensitivity = Minimum Detectable Signal Power (P_{min}) referenced to 1mW Signal**

$$e = 10 \log (P_{min} / 1mW)$$

- **The smaller the better, usaully Pmin < 1mW, therefore e is negative (-60dBm, …)**
- **-98dBm is better than -95dBm, and it detects half the power of -95dBm**

S-Parameters Matrix

$$b1 = S_{11}\, a_1 + S_{12}\, a_2$$
$$b2 = S_{21}\, a_1 + S_{22}\, a_2$$

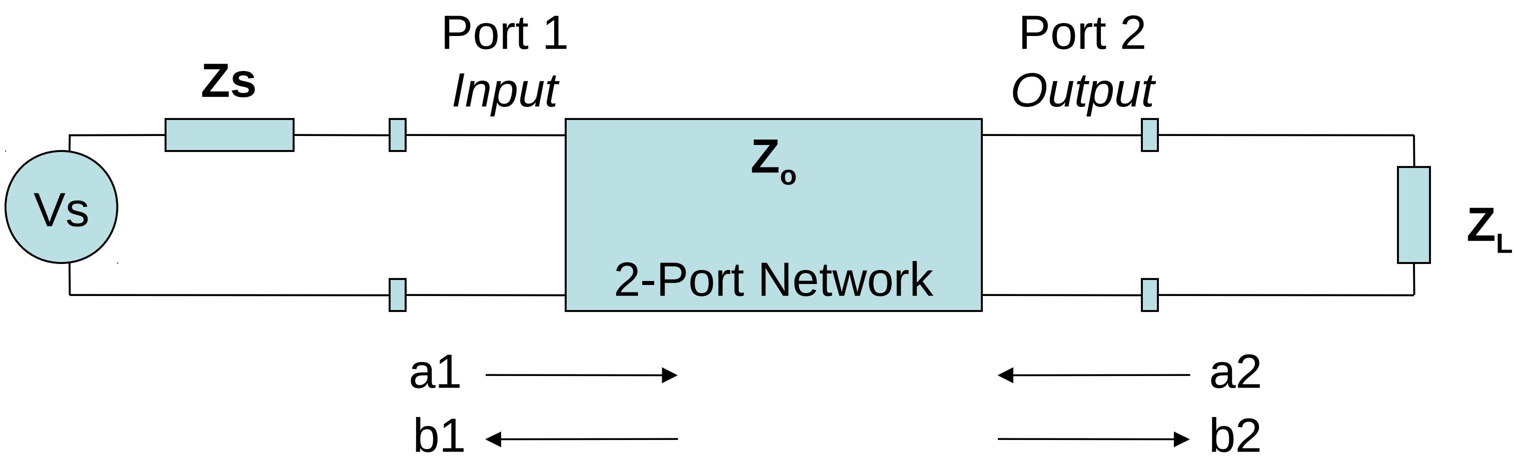


S-parameters are complex values

a_1 = Incident wave voltage at Port 1
a_2 = Incident wave voltage at Port 2
b_1 = Exiting wave voltage at Port 1
b_2 = Exiting wave voltage at Port 2

S_{11} = Input port voltage reflection coefficient
S_{12} = Reverse voltage gain
S_{21} = Forward voltage gain
S_{22} = Output port voltage reflection coefficient

Reflection Coefficient

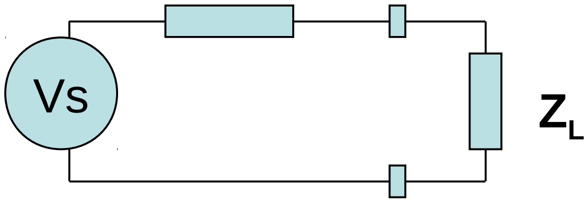


- **Reflection Coefficient "Γ_1"= b_1/a_1**

  $= Z_L - Z_0 \,/\, Z_L + Z_0$

@ $Z_L = Z_0 \Rightarrow \Gamma = 0$; @ $Z_L = 0 \Rightarrow \Gamma = -1$; @ Z_L = open $\Rightarrow \Gamma = 1$

S-Parameters: Max power Transfer



- **Antennas are example application**
- **Maximum power transfer to load at:**

Z_L = complex conjugate of Z_s

$$P = I^2_{rms} R_L = 0.5 * \{V_{max}/(Z_s+Z_L)\}^2 R_L$$
$$= 0.5 * V^2_{max} R_L / (R_s+X_s+R_L+X_L)^2$$

X_s, X_L are reactance (complex part of impedance)

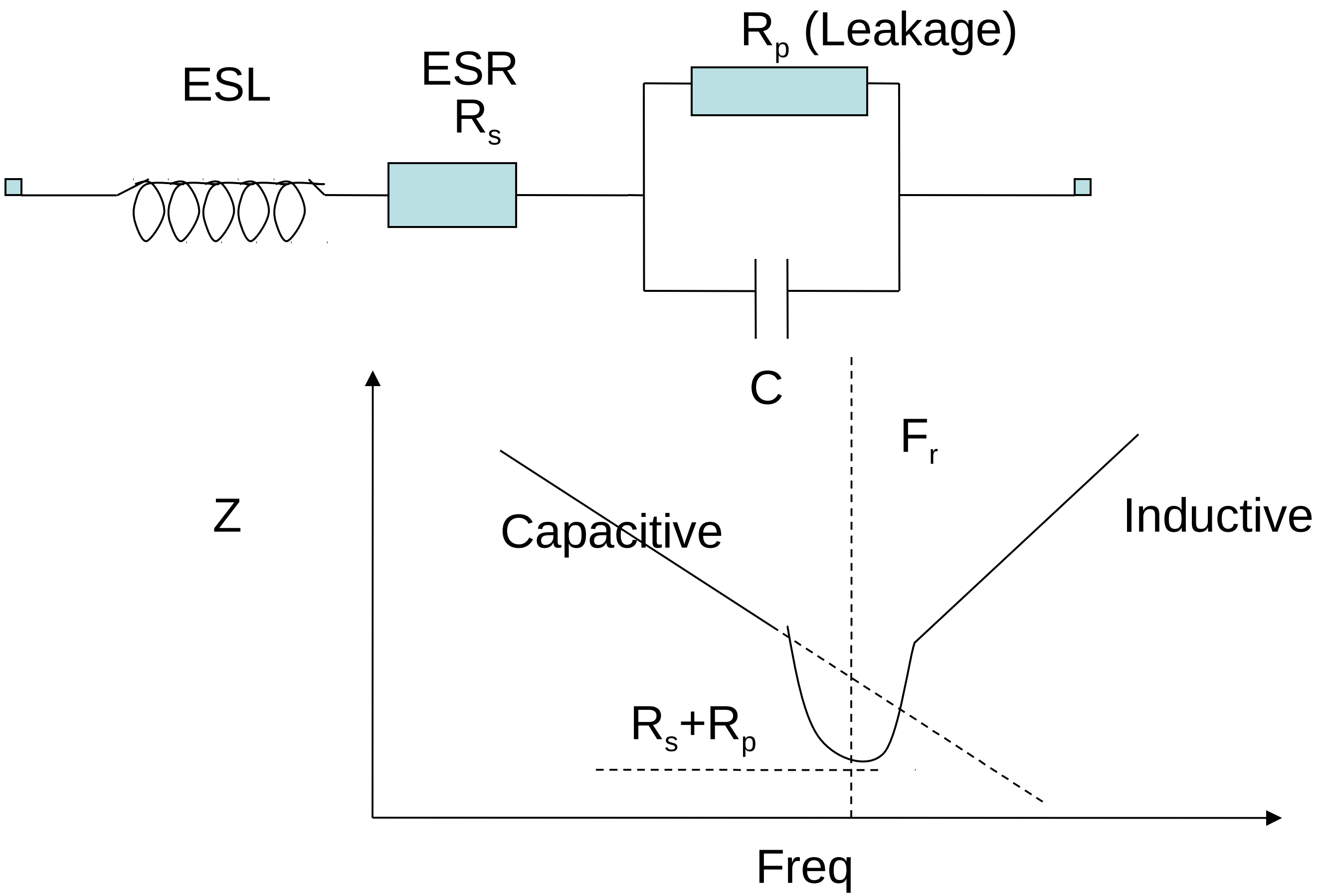
Minimize: $(R_s+X_s+R_L+X_L)^2 = (R_s+R_L)^2 + (X_s+X_L)^2$

P_L is max at $X_L = -X_s$ => $P = 0.5*V^2_{max} R_L/(R_s+R_L)^2$

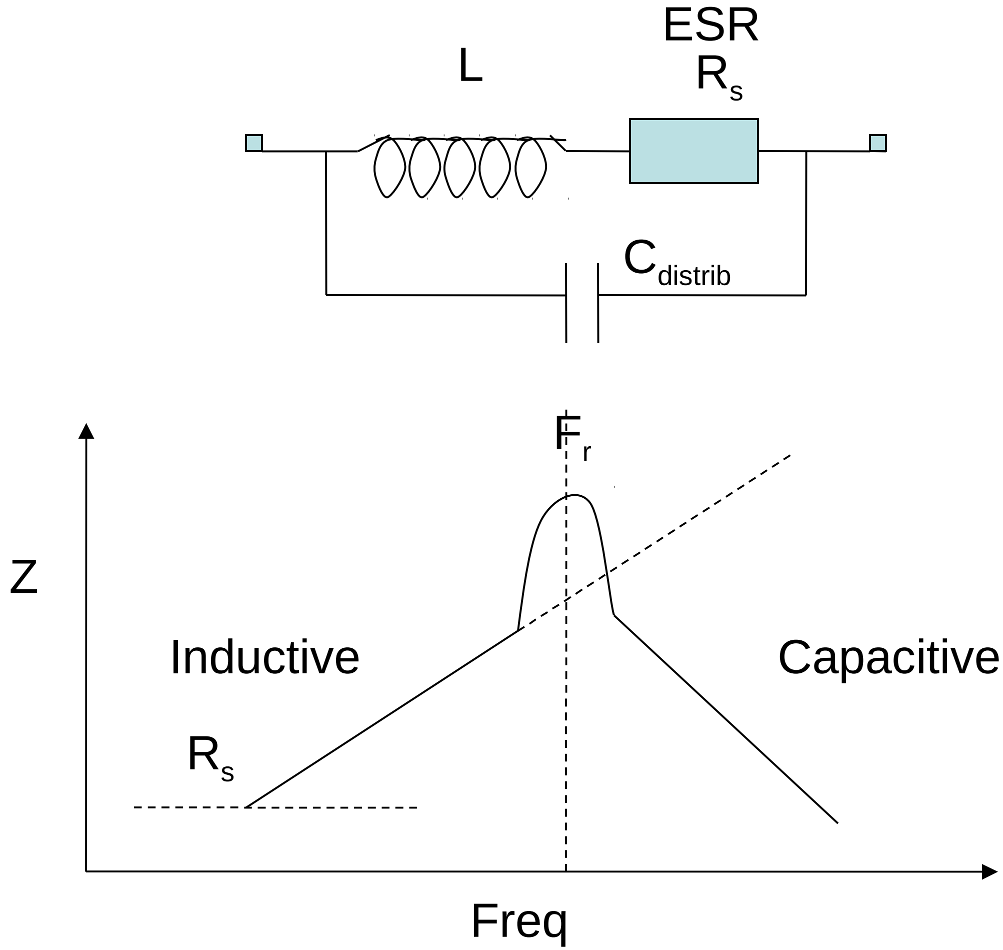
By taking 1st & 2nd deriv. w.r.t. R_L, P_{max} @ $R_L = R_s$

Z_L @ Max power transfer to load = R_s - X_s

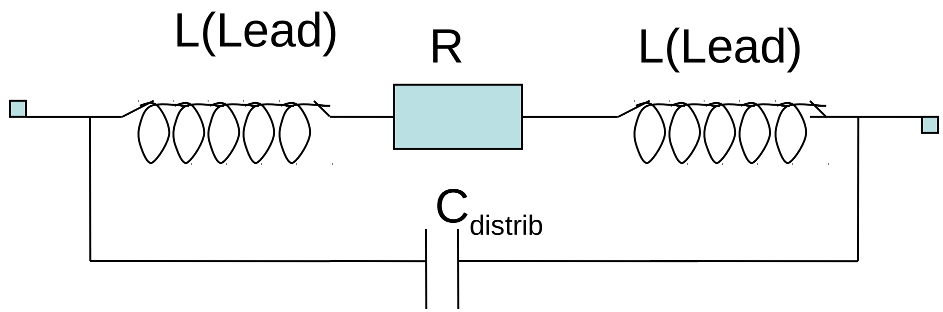
Capacitor RLC

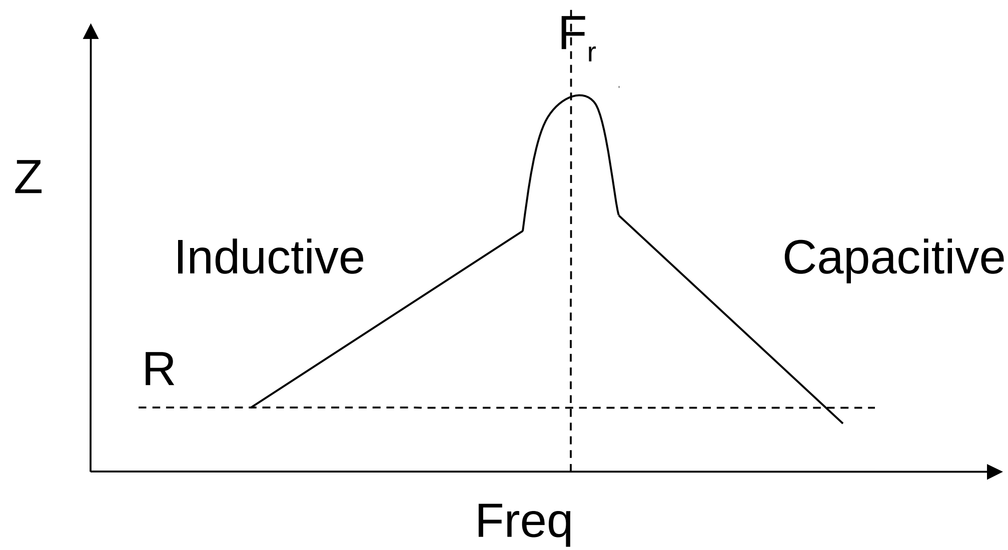


Coil RLC



Resistor RLC





MOSFET Parasitics

- **RLC for interconnects, not just C or R**
- **S/D substrate coupling**
- **Resistance of gate, channel Source/Drain**
- **S/D junction capacitance to gate, to substrate**
- **Substrate resistance to body contact**
- **MOSFET has input R&C, i.e. complex impedance => needs matching at RF!**