Sensitivity and Dynamic Range: Sensitivity

- **The sensitivity is defined as the minimum signal level that a receiver can detect with "acceptable quality."**

$$NF = \frac{SNR_{in}}{SNR_{out}} = \frac{P_{sig}/P_{RS}}{SNR_{out}}$$

$$P_{sig} = P_{RS} \cdot NF \cdot SNR_{out}$$

$$P_{sig,tot} = P_{RS} \cdot NF \cdot SNR_{out} \cdot B$$

$$P_{sen}|_{dBm} = P_{RS}|_{dBm/Hz} + NF|_{dB} + SNR_{min}|_{dB} + 10\log B$$

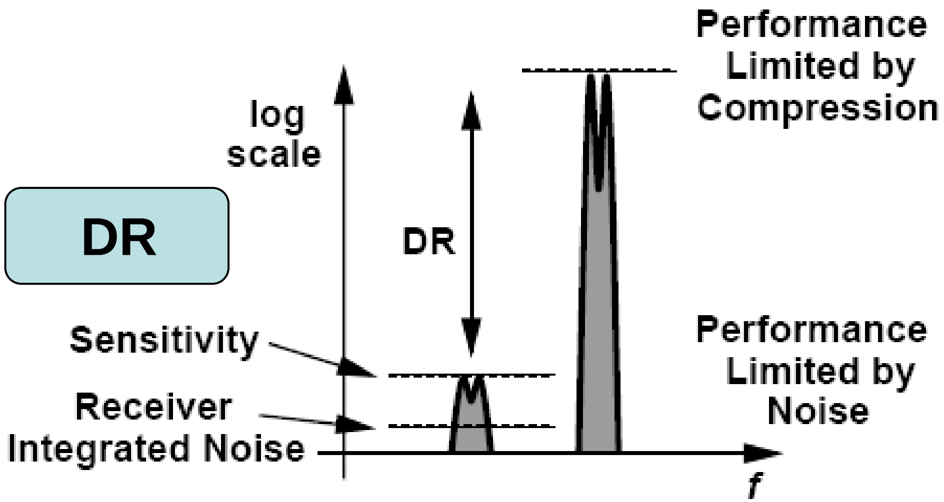
$$P_{sen} = \underbrace{-174\ \mathrm{dBm/Hz} + NF + 10\log B}_{\textbf{Noise Floor}} + SNR_{min}$$

Example of Sensitivity

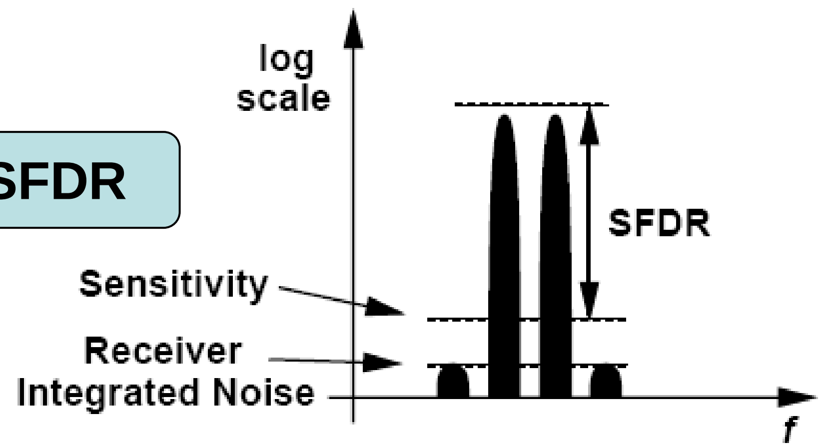
A GSM receiver requires a minimum *SNR* of 12 dB and has a channel bandwidth of 200 kHz. A wireless LAN receiver, on the other hand, specifies a minimum *SNR* of 23 dB and has a channel bandwidth of 20 MHz. Compare the sensitivities of these two systems if both have an *NF* of 7 dB.

Dynamic Range Compared with SFDR

DR



SFDR



- **Dynamic Range:**

  Maximum tolerable desired signal power divided by the minimum tolerable desired signal power

- **SFDR:**

  Lower end equal to sensitivity.

  Higher end defined as maximum input level in a *two-tone* test for which the third-order IM products do not exceed the integrated noise of the receiver

SFDR Calculation

Refer output IM magnitudes to input:

$$P_{IIP3} = P_{in} + \frac{P_{out} - P_{IM,out}}{2}$$

$$P_{IM,in} = P_{IM,out} - G. \qquad P_{in} = P_{out} - G.$$

$$P_{IIP3} = P_{in} + \frac{P_{in} - P_{IM,in}}{2}$$

$$= \frac{3P_{in} - P_{IM,in}}{2},$$

$$P_{in} = \frac{2P_{IIP3} + P_{IM,in}}{3}.$$

$$P_{in,max} = \frac{2P_{IIP3} + (-174\ \text{dBm} + NF + 10\log B)}{3}.$$

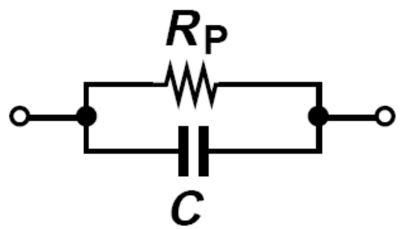
$$SFDR = P_{in,max} - (-174\ \text{dBm} + NF + 10\log B + SNR_{min})$$

$$= \frac{2(P_{IIP3} + 174\ \text{dBm} - NF - 10\log B)}{3} - SNR_{min}.$$

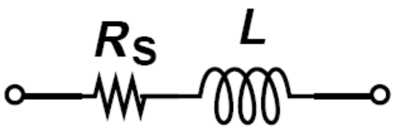
Passive Impedance Transformation: Quality Factor

- **Quality Factor, *Q*, indicates how close to ideal an energy-storing device is.**

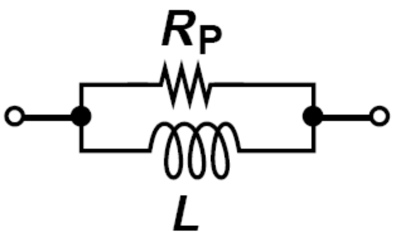
$$Q_S = \frac{\frac{1}{C\omega}}{R_S}$$



$$Q_P = \frac{R_P}{\frac{1}{C\omega}}$$

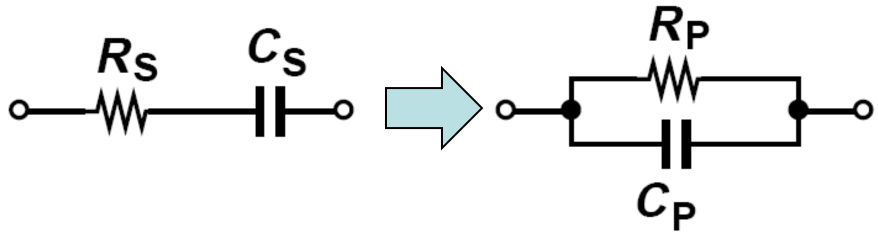


$$Q_S = \frac{L\omega}{R_S}$$



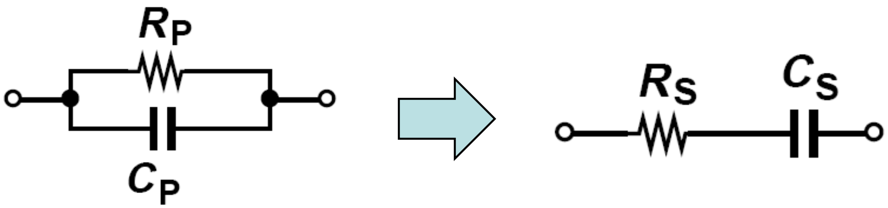
$$Q_P = \frac{R_P}{L\omega}$$

Series-to-Parallel Conversion



$$\frac{R_S C_S s + 1}{C_S s} = \frac{R_P}{R_P C_P s + 1}$$

Parallel-to-Series Conversion



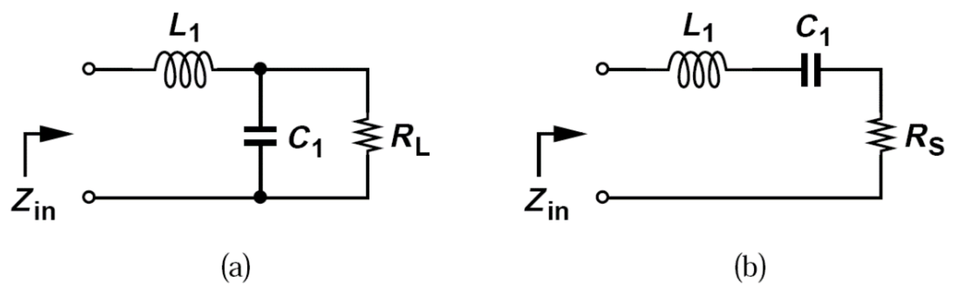
$$R_S = \frac{R_P}{Q_P^2}$$

$$C_s = C_P$$

- **Series-to-Parallel Conversion: will retain the value of the capacitor but raises the resistance by a factor of Q_s^2**
- **Parallel-to-Series Conversion: will reduce the resistance by a factor of Q_P^2**

Basic Matching Networks

$$Z_{in}(j\omega) = \frac{R_L(1 - L_1C_1\omega^2) + jL_1\omega}{1 + jR_LC_1\omega}$$



Thus,

$$Re\{Z_{in}\} = \frac{R_L}{1 + R_L^2C_1^2\omega^2}$$

$$= \frac{R_L}{1 + Q_P^2},$$

R_L **transformed down by a factor**

$$L_1 = \frac{R_L^2C_1}{1 + R_L^2C_1^2\omega^2}$$

$$= \frac{R_L^2C_1}{1 + Q_P^2}.$$

Setting imaginary part to zero

If $Q_P^2 \gg 1$

$$Re\{Z_{in}\} \approx \frac{1}{R_LC_1^2\omega^2}$$

$$L_1 = \frac{1}{C_1\omega^2}.$$

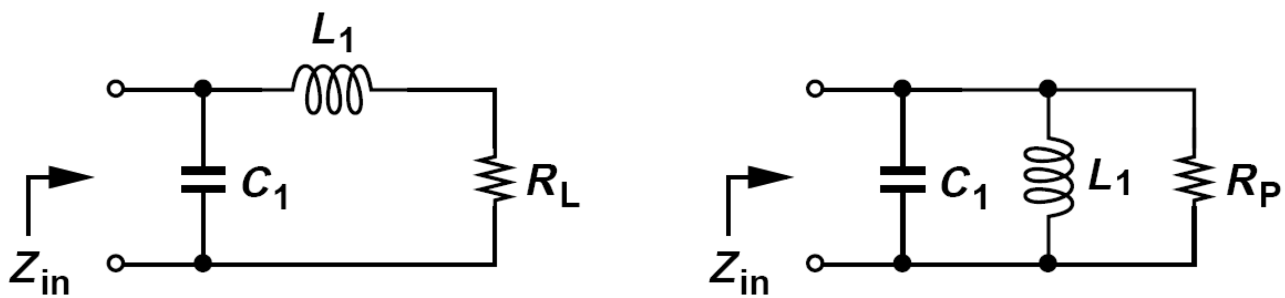
Example of Basic Matching Networks

Design the matching network of figure above so as to transform R_L = 50 Ω to 25 Ω at a center frequency of 5 GHz.

Another Example of Basic Matching Networks

Determine how the circuit shown below transforms R_L.

Solution:

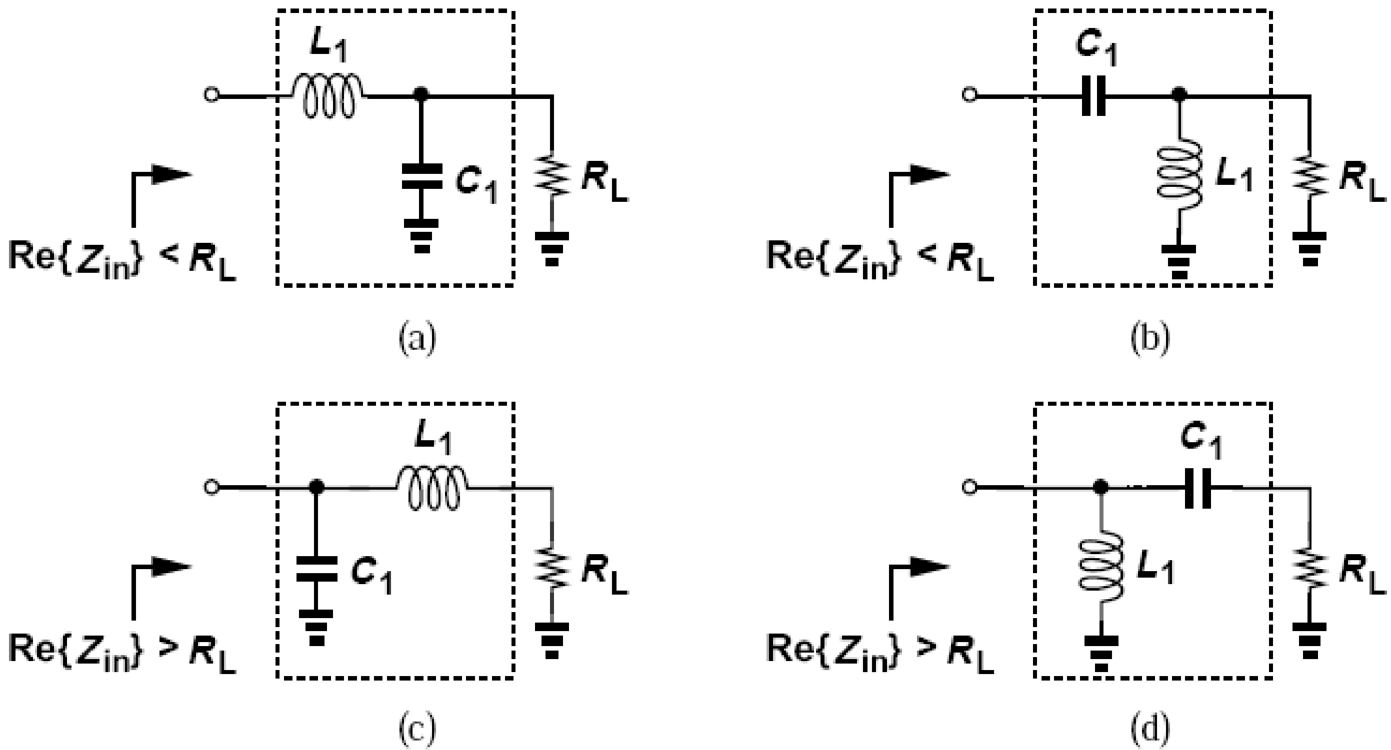


We postulate that conversion of the L_1-R_L branch to a parallel section produces a higher resistance. If $Q_S^2 = (L_1\omega/R_L)^2 \gg 1$, then the equivalent parallel resistance is

$$\begin{aligned} R_P &= Q_S^2 R_L \\ &= \frac{L_1^2\omega^2}{R_L}. \end{aligned}$$

The parallel equivalent inductance is approximately equal to L_1 and is cancelled by C_1

L-Sections

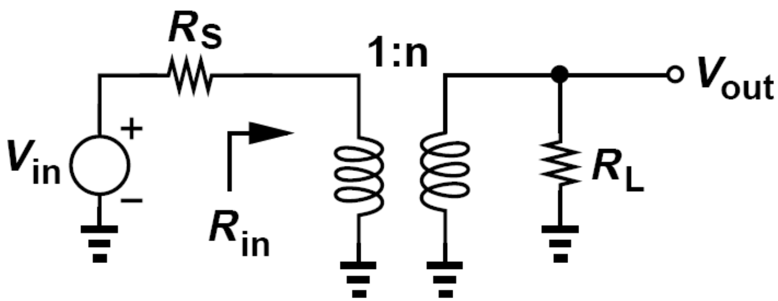


For example, in (a), we have:

$$\frac{V_{out}}{V_{in}} = \sqrt{\frac{R_L}{Re\{Z_{in}\}}}. \qquad \frac{I_{out}}{I_{in}} = \sqrt{\frac{Re\{Z_{in}\}}{R_L}}$$

a network transforming R_L to a lower value "amplifies" the voltage and attenuates the current by the above factor.

Impedance Matching by Transformers

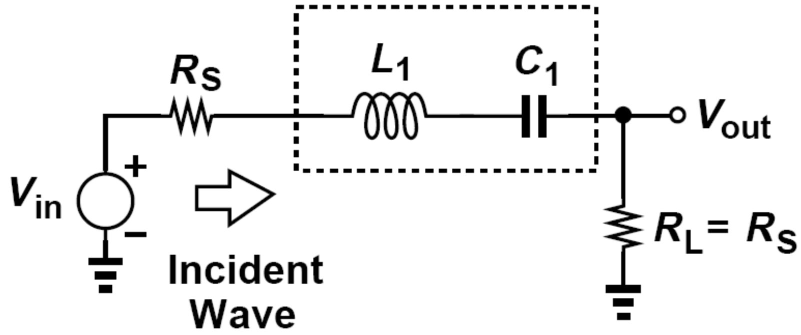


$$V_{in}^2/R_{in} = n^2V_{in}^2/R_L$$

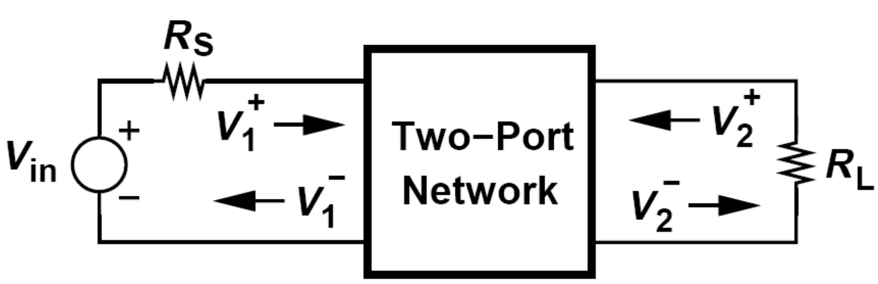
$$R_{in} = R_L/n^2$$

- **More on this in Chapter 8**

Scattering Parameters

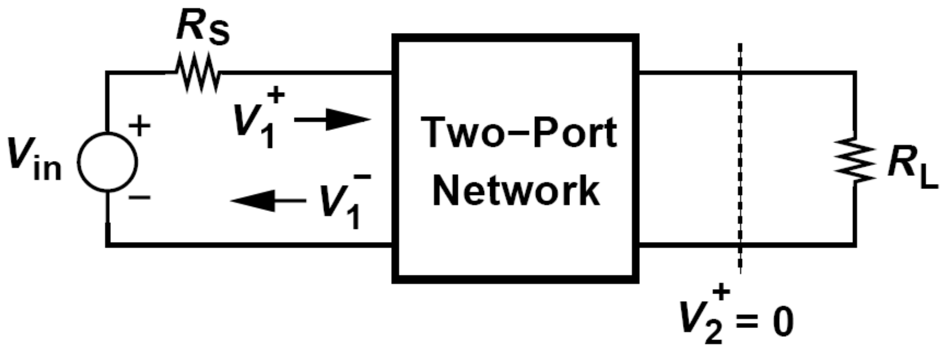


- S-Parameter: Use power quantities instead of voltage or current
- The difference between the incident power (the power that would be delivered to a matched load) and the reflected power represents the power delivered to the circuit.



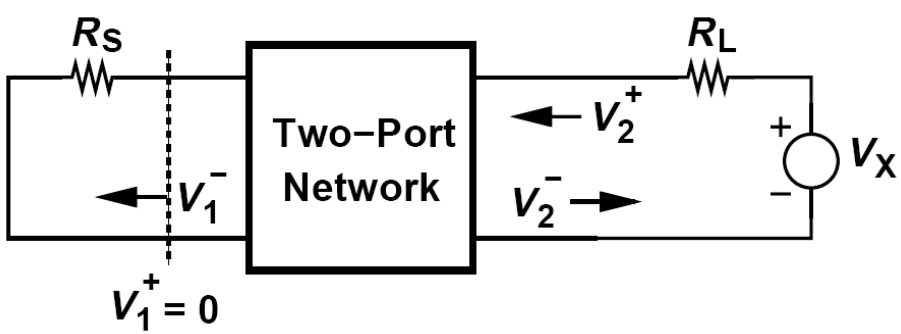
$$V_1^- = S_{11}V_1^+ + S_{12}V_2^+$$
$$V_2^- = S_{21}V_1^+ + S_{22}V_2^+.$$

S_{11} and S_{12}



$$S_{11} = \frac{V_1^-}{V_1^+}\Big|_{V_2^+=0}$$

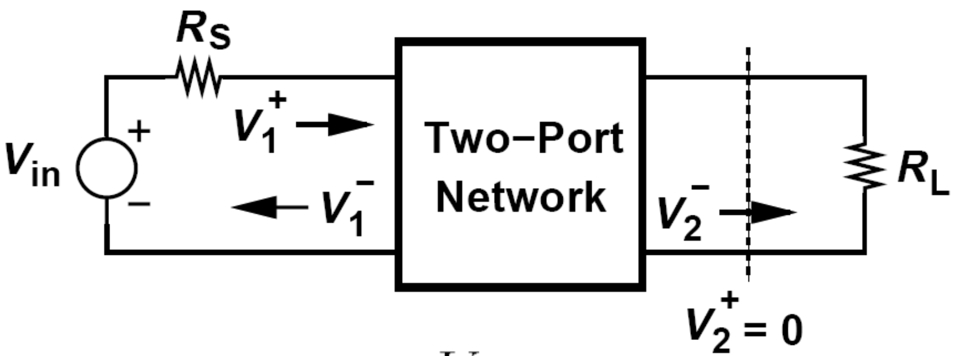
- **S_{11} is the ratio of the reflected and incident waves at the input port when the reflection from R_L is zero.**
- **Represents the accuracy of the input matching**



$$S_{12} = \frac{V_1^-}{V_2^+}\Big|_{V_1^+=0}$$

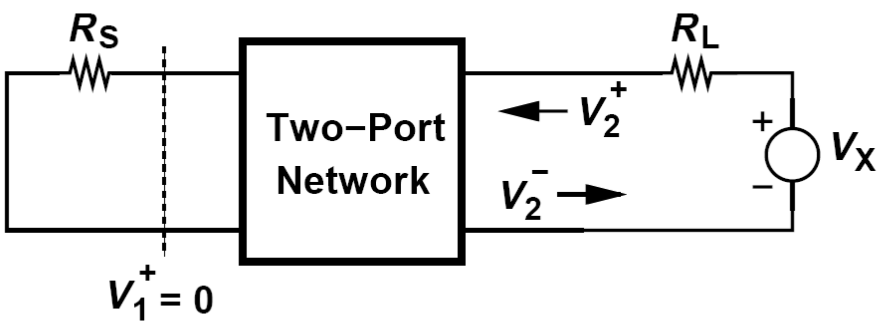
- **S_{12} is the ratio of the reflected wave at the input port to the incident wave into the output port when the input is matched**
- **Characterizes the *reverse isolation***

S_{21} and S_{22}



$$S_{21} = \frac{V_2^-}{V_1^+}|_{V_2^+=0}$$

- S_{21} is the ratio of the wave incident on the load to that going to the input when the reflection from R_L is zero
- Represents the gain of the circuit



$$S_{22} = \frac{V_2^-}{V_2^+}|_{V_1^+=0}$$

- S_{22} is the ratio of reflected and incident waves at the output when the reflection from R_s is zero
- Represents the accuracy of the output matching

Scattering Parameters: A few remarks

$$V_1^- = S_{11}V_1^+ + S_{12}V_2^+$$
$$V_2^- = S_{21}V_1^+ + S_{22}V_2^+$$

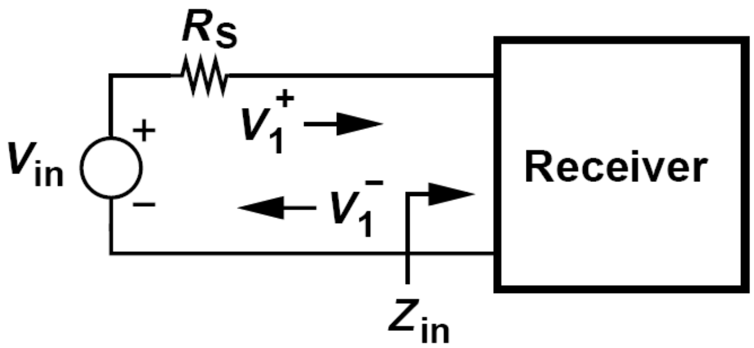
- **S-parameters generally have frequency-dependent complex values**
- **We often express S-parameters in units of dB**

$$S_{mn}\big|_{dB} = 20\log|S_{mn}|$$

- **The condition $V_2^+=0$ does not mean output port of the circuit must be conjugate-matched to R_L.**

Input Reflection Coefficient

In modern RF design, S_{11} is the most commonly-used S parameter as it quantifies the accuracy of impedance matching at the input of receivers.



$$\begin{aligned} V_1^- &= V_{in}\frac{Z_{in}}{Z_{in}+R_S} - \frac{V_{in}}{2} \\ &= \frac{Z_{in}-R_S}{2(Z_{in}+R_S)}V_{in}. \end{aligned}$$

$$\frac{V_1^-}{V_1^+} = \frac{Z_{in}-R_S}{Z_{in}+R_S}.$$

- **Called the "input reflection coefficient" and denoted by G_{in}, this quantity can also be considered to be S_{11} if we remove the condition $V_2^+ = 0$**