Radio Frequency Design Equations

▶ useful functions and identities
▶ Units

▶ Constants
▶ Material Properties

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Introduction

Here is a collection of equations useful for RF circuit design. If you have any suggestions or questions, please send an email to **sage@circuitsage.com**.

Parameter Conversion

Y Parameter to S parameter conversion

$$Y2S(Y, Y_0) := \left| \begin{array}{l} I \leftarrow Y_0 \cdot \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \\ (I - Y)\cdot(I + Y)^{-1} \end{array} \right.$$

S Parameter to Y Parameter Conversion

$$S2Y(S, Y_0) := \left| \begin{array}{l} I \leftarrow Y_0 \cdot \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \\ (I + S)^{-1}\cdot(I - S) \end{array} \right.$$

Z Parameter to S Parameter Conversion

$$Z2S(Z, Z_0) := \left| \begin{array}{l} I \leftarrow Z_0 \cdot \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \\ (Z - I)\cdot(Z + I)^{-1} \end{array} \right.$$

S Parameter to Z Parameter Conversion

$$S2Z(S, Z_0) := \left| \begin{array}{l} I \leftarrow Z_0 \cdot \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \\ (I - S)^{-1}\cdot(I + S) \end{array} \right.$$

S to T Parameter Calculation

$$S2T(S) := \begin{pmatrix} \frac{S_{1,2}\cdot S_{2,1} - S_{1,1}\cdot S_{2,2}}{S_{1,2}} & \frac{S_{2,2}}{S_{1,2}} & \cdots \end{pmatrix}$$

T to S Parameter Calculation

$$T2S(T) := \begin{pmatrix} -\frac{T_{1,0}}{T_{1,1}} & \frac{1}{T_{1,1}} & \cdots \end{pmatrix}$$

$$\begin{pmatrix} \cdots & \cdots \\ -\frac{S_{1,1}}{S_{1,2}} & \frac{1}{S_{1,2}} \end{pmatrix} \qquad \begin{pmatrix} \cdots & \cdots \\ \frac{T_{0,0} \cdot T_{1,1} - T_{0,1} \cdot T_{1,0}}{T_{1,1}} & \frac{T_{0,1}}{T_{1,1}} \end{pmatrix}$$

S to ABCD Parameter Calculation

$$ABCD(S, Z_0) := \begin{bmatrix} \frac{(1 + S_{1,1}) \cdot (1 - S_{2,2}) + S_{1,2} \cdot S_{2,1}}{2 \cdot S_{2,1}} & Z_0 \cdot \frac{(1 + S_{1,1}) \cdot (1 + S_{2,2}) - S_{1,2} \cdot S_{2,1}}{2 \cdot S_{2,1}} \\ \frac{1}{Z_0} \cdot \frac{(1 - S_{1,1}) \cdot (1 - S_{2,2}) - S_{1,2} \cdot S_{2,1}}{2 \cdot S_{2,1}} & \frac{(1 - S_{1,1}) \cdot (1 + S_{2,2}) + S_{1,2} \cdot S_{2,1}}{2 \cdot S_{2,1}} \end{bmatrix}$$

ABCD to S Parameter Calculation

$$S(ABCD, Z_0) := \begin{array}{|l} A \leftarrow ABCD_{1,1} \\ B \leftarrow ABCD_{1,2} \\ C \leftarrow ABCD_{2,1} \\ D \leftarrow ABCD_{2,2} \\ \frac{1}{\left(A + \frac{B}{Z_0} + C \cdot Z_0 + D\right)} \cdot \begin{bmatrix} A + \frac{B}{Z_0} - C \cdot Z_0 - D & 2 \cdot (A \cdot D - B \cdot C) \\ 2 & -A + \frac{B}{Z_0} - C \cdot Z_0 + D \end{bmatrix} \end{array}$$

Y Parameter to ABCD Parameter Calculation

$$Y2ABCD(Y) := \begin{pmatrix} \frac{-Y_{2,2}}{Y_{2,1}} & \frac{-1}{Y_{2,1}} \\ \frac{-|Y|}{Y_{2,1}} & \frac{-Y_{1,1}}{Y_{2,1}} \end{pmatrix}$$

ABCD Parameter to Y Parameter Calculation

$$ABCD2Y(ABCD) := \begin{array}{|l} A \leftarrow ABCD_{1,1} \\ B \leftarrow ABCD_{1,2} \\ C \leftarrow ABCD_{2,1} \\ D \leftarrow ABCD_{2,2} \\ \begin{pmatrix} \frac{D}{B} & \frac{B \cdot C - A \cdot D}{B} \\ \frac{-1}{B} & \frac{A}{B} \end{pmatrix} \end{array}$$

Z Parameter to ABCD Parameter Calculation

$$Z2ABCD(Z) := \begin{pmatrix} \frac{Z_{1,1}}{Z_{2,1}} & \frac{|Z|}{Z_{2,1}} \\ \frac{1}{Z_{2,1}} & \frac{Z_{2,2}}{Z_{2,1}} \end{pmatrix}$$

ABCD Parameter to Z Parameter Calculation

$$ABCD2Z(ABCD) := \begin{array}{|l} A \leftarrow ABCD_{1,1} \\ B \leftarrow ABCD_{1,2} \\ C \leftarrow ABCD_{2,1} \\ D \leftarrow ABCD_{2,2} \\ \begin{pmatrix} \frac{A}{C} & \frac{A \cdot D - B \cdot C}{C} \\ \frac{1}{C} & \frac{D}{C} \end{pmatrix} \end{array}$$

S Parameter to H Parameter Calculation

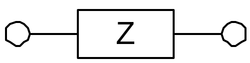
$$S2H(S) := \begin{array}{|l} \Delta \leftarrow (1 - S_{1,1}) \cdot (1 + S_{2,2}) + S_{1,2} \cdot S_{2,1} \\ \begin{bmatrix} \frac{(1 + S_{1,1}) \cdot (1 + S_{2,2}) - S_{1,2} \cdot S_{2,1}}{\Delta} & \frac{2 \cdot S_{1,2}}{\Delta} \\ \cdots & \cdots \end{bmatrix} \end{array}$$

$$\begin{bmatrix} \cdots & \cdots \\ \dfrac{-2 \cdot S_{2,1}}{\Delta} & \dfrac{(1 - S_{1,1}) \cdot (1 - S_{2,2}) - S_{1,2} \cdot S_{2,1}}{\Delta} \end{bmatrix}$$

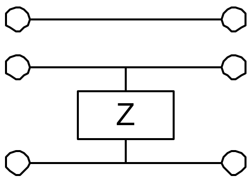
H Parameter to S Parameter Calculation

$$H2S(h) := \begin{array}{|l} \Delta \leftarrow (h_{1,1} + 1) \cdot (h_{2,2} + 1) - h_{1,2} \cdot h_{2,1} \\ \begin{bmatrix} \dfrac{(h_{1,1} - 1) \cdot (h_{2,2} + 1) - h_{1,2} \cdot h_{2,1}}{\Delta} & \dfrac{2 \cdot h_{1,2}}{\Delta} \\ \dfrac{-2 \cdot h_{2,1}}{\Delta} & \dfrac{(h_{1,1} + 1) \cdot (1 - h_{2,2}) + h_{1,2} \cdot h_{2,1}}{\Delta} \end{bmatrix} \end{array}$$

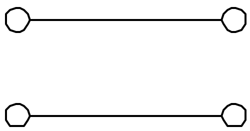
ABCD Parameters for Common Two-Port Circuits [1]



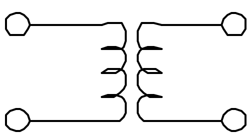
$$ABCD(Z) := \begin{pmatrix} 1 & Z \\ 0 & 1 \end{pmatrix}$$



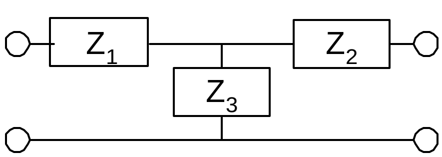
$$ABCD(Z) := \begin{pmatrix} 1 & 0 \\ \dfrac{1}{Z} & 1 \end{pmatrix}$$



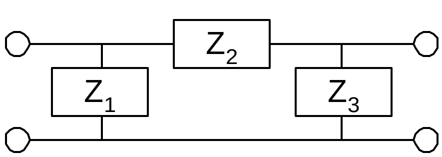
$$ABCD(Z_0, \beta, len) := \begin{pmatrix} \cos(\beta \cdot len) & j \cdot Z_0 \cdot \sin(\beta \cdot len) \\ j \cdot \dfrac{1}{Z_0} \cdot \sin(\beta \cdot len) & \cos(\beta \cdot len) \end{pmatrix}$$



$$ABCD(N) := \begin{pmatrix} N & 0 \\ 0 & \dfrac{1}{N} \end{pmatrix}$$



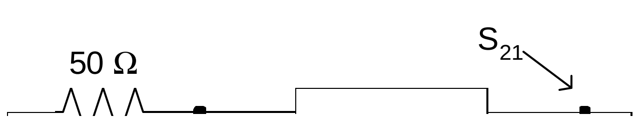
$$ABCD(Z_1, Z_2, Z_3) := \begin{pmatrix} 1 + \dfrac{Z_3}{Z_2} & Z_3 \\ \dfrac{Z_1 + Z_2 + Z_3}{Z_1 \cdot Z_2} & 1 + \dfrac{Z_3}{Z_1} \end{pmatrix}$$

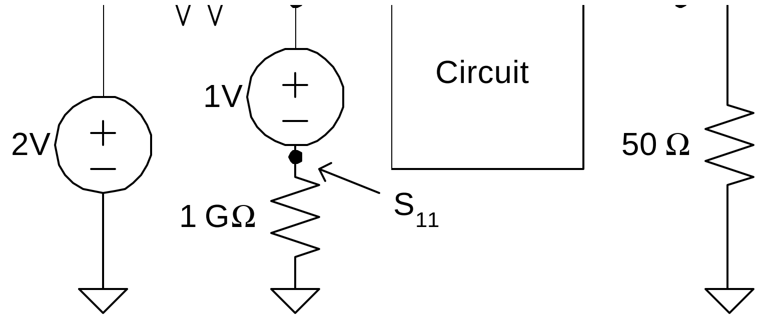


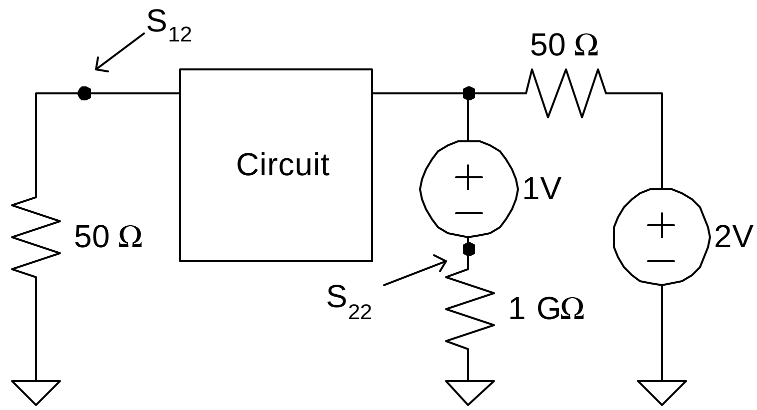
$$ABCD(Z_1, Z_2, Z_3) := \begin{pmatrix} 1 + \dfrac{Z_1}{Z_3} & Z_1 + Z_2 + \dfrac{Z_1 \cdot Z_2}{Z_3} \\ \dfrac{1}{Z_3} & 1 + \dfrac{Z_2}{Z_3} \end{pmatrix}$$

S Parameter Routines

Here is an easy method for measuring small-signal 50 ohm S-parameters with SPICE. The circuit is nice in that no extra post calculation is necessary.







Impedance Conversion from 50W S-Parameters [Gentili]

$$S_{conv}(S, Z_{Sbegin}, Z_{Send}, Z_{Lbegin}, Z_{Lend}) := \left| \begin{array}{l} \Gamma_S \leftarrow \dfrac{Z_{Send} - Z_{Sbegin}}{Z_{Send} + Z_{Sbegin}} \\ \Gamma_L \leftarrow \dfrac{Z_{Lend} - Z_{Lbegin}}{Z_{Lend} + Z_{Lbegin}} \\ D \leftarrow \left(1 - \Gamma_S \cdot S_{1,1}\right)\cdot\left(1 - \Gamma_L \cdot S_{2,2}\right) - \Gamma_S \cdot \Gamma_L \cdot S_{1,2} \cdot S_{2,1} \\ A_1 \leftarrow \dfrac{1 - \overline{\Gamma_S}}{\left|1 - \Gamma_S\right|} \cdot \sqrt{1 - \left(\left|\Gamma_S\right|\right)^2} \\ A_2 \leftarrow \dfrac{1 - \overline{\Gamma_L}}{\left|1 - \Gamma_L\right|} \cdot \sqrt{1 - \left(\left|\Gamma_L\right|\right)^2} \\ \left[\begin{array}{ll} \dfrac{\overline{A_1}}{A_1} \cdot \dfrac{\left(1 - \Gamma_L \cdot S_{2,2}\right)\cdot\left(S_{1,1} - \overline{\Gamma_S}\right) + \Gamma_L \cdot S_{1,2} \cdot S_{2,1}}{D} & \dfrac{\overline{A_2}}{A_1} \cdot \dfrac{S_{1,2} \cdot \left[1 - \cdots\right.}{\cdots} \\ \dfrac{\overline{A_1}}{A_2} \cdot S_{2,1} \cdot \dfrac{1 - \left(\left|\Gamma_L\right|\right)^2}{D} & \dfrac{\overline{A_2}}{A_2} \cdot \dfrac{\left(1 - \Gamma_S \cdot S_{1,1}\right)\cdot\left(S_{2,2} \cdots\right.}{\cdots} \end{array} \right. \end{array} \right.$$

Optimal Impedance Matching [Bowick]

$$Y_{popt}(Y) := \left| \begin{array}{l} G_S \leftarrow \dfrac{\sqrt{\left(2 \cdot \mathrm{Re}\left(Y_{1,1}\right) \cdot \mathrm{Re}\left(Y_{2,2}\right) - \mathrm{Re}\left(Y_{2,1} \cdot Y_{1,2}\right)\right)^2 + \left(\left|Y_{2,1} \cdot Y_{1,2}\right|\right)^2}}{2 \cdot \mathrm{Re}\left(Y_{2,2}\right)} \\ B_S \leftarrow -i \cdot \mathrm{Im}\left(Y_{\cdots}\right) + \dfrac{\mathrm{Im}\left(Y_{2,1} \cdot Y_{1,2}\right)}{\cdots} \end{array} \right.$$

$$B_S \leftarrow -j\cdot \mathrm{Im}\left(Y_{1,1}\right) + \frac{\cdots}{2\cdot \mathrm{Re}\left(Y_{2,2}\right)}$$

$$G_L \leftarrow G_S\cdot\frac{\mathrm{Re}\left(Y_{2,2}\right)}{\mathrm{Re}\left(Y_{1,1}\right)}$$

$$B_L \leftarrow -j\cdot \mathrm{Im}\left(Y_{2,2}\right) + \frac{\mathrm{Im}\left(Y_{2,1}\cdot Y_{1,2}\right)}{2\cdot \mathrm{Re}\left(Y_{1,1}\right)}$$

$$\begin{pmatrix} G_S + j\cdot B_S \\ G_L + j\cdot B_L \end{pmatrix}$$

Optimal Impedance Matching [Pozar]

$$Z_{popt}(S, Z_0) :=$$

$$\Delta \leftarrow S_{1,1}\cdot S_{2,2} - S_{1,2}\cdot S_{2,1}$$

$$B_1 \leftarrow 1 + \left(\left|S_{1,1}\right|\right)^2 - \left(\left|S_{2,2}\right|\right)^2 - \left(\left|\Delta\right|\right)^2$$

$$B_2 \leftarrow 1 + \left(\left|S_{2,2}\right|\right)^2 - \left(\left|S_{1,1}\right|\right)^2 - \left(\left|\Delta\right|\right)^2$$

$$C_1 \leftarrow S_{1,1} - \Delta\cdot\overline{S_{2,2}}$$

$$C_2 \leftarrow S_{2,2} - \Delta\cdot\overline{S_{1,1}}$$

$$\Gamma_{Spopt} \leftarrow \frac{B_1 + \sqrt{{B_1}^2 - 4\cdot\left(\left|C_1\right|\right)^2}}{2\cdot C_1}$$

$$\Gamma_{Spopt} \leftarrow \mathrm{if}\left[\left|\Gamma_{Spopt}\right| < 1, \Gamma_{Spopt}, \frac{B_1 - \sqrt{{B_1}^2 - 4\cdot\left(\left|C_1\right|\right)^2}}{2\cdot C_1}\right]$$

$$\Gamma_{Lpopt} \leftarrow \frac{B_2 + \sqrt{{B_2}^2 - 4\cdot\left(\left|C_2\right|\right)^2}}{2\cdot C_2}$$

$$\Gamma_{Lpopt} \leftarrow \mathrm{if}\left[\left|\Gamma_{Lpopt}\right| < 1, \Gamma_{Lpopt}, \frac{B_2 - \sqrt{{B_2}^2 - 4\cdot\left(\left|C_2\right|\right)^2}}{2\cdot C_2}\right]$$

$$Z_{Lpopt} \leftarrow Z_0\cdot\frac{1 + \Gamma_{Lpopt}}{1 - \Gamma_{Lpopt}}$$

$$Z_{Spopt} \leftarrow Z_0\cdot\frac{1 + \Gamma_{Spopt}}{1 - \Gamma_{Spopt}}$$

$$\begin{pmatrix} Z_{Spopt} \\ Z_{Lpopt} \end{pmatrix}$$

Input Reflection Ceofficient. Test for stability with given source and load impedances. The input and output reflection coefficients must be less than unity.

$$\Gamma_{in}(S, Z_L, Z_0) := \quad \Gamma_L \leftarrow \frac{Z_L - Z_0}{Z_L + Z_0} \qquad \left|S_{1,1} + \frac{S_{1,2}\cdot S_{2,1}\cdot\Gamma_L}{1 - S_{2,2}\cdot\Gamma_L}\right|$$

$$\Gamma_{out}(S, Z_S, Z_0) := \quad \Gamma_S \leftarrow \frac{Z_S - Z_0}{Z_S + Z_0} \qquad \left|S_{2,2} + \frac{S_{1,2}\cdot S_{2,1}\cdot\Gamma_S}{1 - S_{1,1}\cdot\Gamma_S}\right|$$

$$ML(\Gamma_S,\Gamma_L) := -10\cdot\log\left[\frac{\left[1-(|\Gamma_S|)^2\right]\cdot\left[1-(|\Gamma_L|)^2\right]}{(1-|\Gamma_S|\cdot|\Gamma_L|)^2}\right]$$

Mismatch Loss Equation

$$VSWR_S(\Gamma_S) := \frac{1+|\Gamma_S|}{1-|\Gamma_S|} \qquad VSWR_L(\Gamma_L) := \frac{1+|\Gamma_L|}{1-|\Gamma_L|}$$

Voltage Standing Wave Ratio Equations

$$RL_S(\Gamma_S) := -20\cdot\log(|\Gamma_S|) \qquad RL_L(\Gamma_L) := -20\cdot\log(|\Gamma_L|)$$

Return Loss Calculations

Stability

Stability parameter functions given S parameters for the device. Note these are a measure of conditional stability and not absolute stability. If K and u>1 then the device is stable independent of source and load impedance. Maximum power transfer can be used here. If K or u<1 then the device is conditionally stable and a simultaneous input and output match cannot be acheived, but a lossy match can be used for a usable amplifier. Absolute stability is then determined when the input and output reflection coefficients are less than one. The Rollet stability factor, K is

$$K(S) := \left|\begin{array}{l} \Delta \leftarrow S_{1,1}\cdot S_{2,2} - S_{1,2}\cdot S_{2,1} \\ \dfrac{1+(|\Delta|)^2-(|S_{1,1}|)^2-(|S_{2,2}|)^2}{2\cdot|S_{1,2}|\cdot|S_{2,1}|} \end{array}\right.$$

$$\mu(S) := \left|\begin{array}{l} \Delta \leftarrow S_{1,1}\cdot S_{2,2} - S_{1,2}\cdot S_{2,1} \\ \dfrac{1-(|S_{2,2}|)^2}{\left|S_{1,1}-\Delta\cdot\overline{S_{2,2}}\right| + |S_{2,1}\cdot S_{1,2}|} \end{array}\right.$$

The Linville Stability Factor, C, like the Rollet Stability factor, K, is useful for finding stable transistors, but not stable circuits, because it does not give you good indication of where the instability occurs. A C factor less than one indicates the transistor is unconditionally stable, while a C factor greater than one indicates the transistor may be unstable for certain load and source impedances. [Bowick]. The Linville stability factor is the best equation to use for hand calculations, because transistor parameters are best represented in Y parameter format for physical reasons.

$$C(Y) := \frac{|Y_{1,2}\cdot Y_{2,1}|}{2\cdot Re(Y_{1,1})\cdot Re(Y_{2,2}) - Re(Y_{1,2}\cdot Y_{2,1})}$$

The Stern Stability Factor, K, predicts the absolute stability of a transistor for given source and load impedances. If K is greater than one, then the circuit is stable for that source and load impedance. If K is less than one, it may oscillate. [Bowick]

$$K(Z_S,Z_L,Y) := \frac{2\cdot\left(Re(Y_{1,1})+Re\left(\frac{1}{Z_S}\right)\right)\cdot\left(Re(Y_{2,2})+Re\left(\frac{1}{Z_L}\right)\right)}{|Y_{2,1}\cdot Y_{1,2}| + Re(Y_{1,2}\cdot Y_{2,1})}$$

Noise Figure of Passive Circuit

Noise Figure of a Passive Circuit given the Y-Parameters of the Circuit

$$Y2NF(Y,Z_S) := \left|\begin{array}{l} kT \leftarrow 1.66\cdot 10^{-20} \end{array}\right.$$

$$C_Y \leftarrow 2\cdot kT\cdot Re(Y)$$

$$Tr \leftarrow \begin{pmatrix} 0 & \frac{-1}{Y_{2,1}} \\ 1 & \frac{-Y_{1,1}}{Y_{2,1}} \end{pmatrix}$$

$$C_A \leftarrow Tr\cdot C_Y\cdot \overline{Tr^T}$$

$$\frac{\overline{\begin{pmatrix} 1 \\ Z_S \end{pmatrix}^T}\cdot C_A\cdot \begin{pmatrix} 1 \\ Z_S \end{pmatrix}}{2\cdot kT\cdot Re(Z_S)}$$

Power Gains

There are several different equations for the gain of amplifier. The transducer gain, G_T, is the foundation for all the gain equations given below. GT is the power gain of an amplifier with any source and load impedance.

$$G_T(\Gamma_G,\Gamma_L,S) := \frac{\left[1-(|\Gamma_L|)^2\right]\cdot(|S_{2,1}|)^2\cdot\left[1-(|\Gamma_G|)^2\right]}{\left[\left|(1-S_{2,2}\cdot\Gamma_L)\cdot(1-S_{1,1}\cdot\Gamma_G)-S_{1,2}\cdot S_{2,1}\cdot\Gamma_L\cdot\Gamma_G\right|\right]^2}$$

Transducer Gain (Available Power Gain)

If the assumption that $S_{12}=0$ (i.e. the power gain in the transistor is unilateral or flows in one direction), the the equation can be simplified to the unilateral power gain, G_{TU}.

$$G_{TU}(\Gamma_G,\Gamma_L,S) := \frac{\left[1-(|\Gamma_L|)^2\right]\cdot(|S_{2,1}|)^2\cdot\left[1-(|\Gamma_G|)^2\right]}{(|1-S_{2,2}\cdot\Gamma_L|)^2\cdot(|1-S_{1,1}\cdot\Gamma_G|)^2}$$

Unilateral Transducer Gain

For low noise amplifiers G_{ma}, maximum available gain (k>1)or maximum stable gain (k<1), is useful. The equation changes slightly depending on whether the device is conditionally or unconditionally stable. For k>1 (unconditionally stable) G_{ma} refers to a simultaneous conjugate match at the input and output of the amplifier. For k<1, there are a variety of impedances to provide maximum stable gain, but a simultaneous match is not possible without oscillation.

$$G_{ma}(S) := \begin{vmatrix} k \leftarrow K(S) \\ if\left[k>1, \left|\frac{S_{2,1}}{S_{1,2}}\right|\cdot\left(k-\sqrt{k^2-1}\right), \left|\frac{S_{2,1}}{S_{1,2}}\right|\right] \end{vmatrix}$$

Maximum Available Gain

To acheive minimum noise figure low noise amplifiers often comprimise a conjugate match the input, which reduces the gain. The gain with a conjugate match at the output and any impedance at the source is the available power gain, G_A.

$$G_A(\Gamma_G,S) := \begin{vmatrix} Sp_{2,2} \leftarrow S_{2,2} + \frac{S_{1,2}\cdot S_{2,1}\cdot\Gamma_G}{1-S_{1,1}\cdot\Gamma_G} \\ \frac{\left[1-(|\Gamma_G|)^2\right]\cdot(|S_{2,1}|)^2}{(|1-S_{1,1}\cdot\Gamma_G|)^2\cdot\left[1-(|Sp_{2,2}|)^2\right]} \end{vmatrix}$$

Available Gain with Load Matched to 50 ohms (if using 50 ohm S parameters)

To prevent the output of a power amplifier or power amplifier driver stage from saturating the output impedance is often set lower than is desired from a simultaneous conjugate match, while the input is typically matched. The gain under this circumstance is simply called the power gain, G.

$$G(\Gamma_L, S) := \left| \begin{array}{l} Sp_{1,1} \leftarrow S_{1,1} + \dfrac{S_{1,2} \cdot S_{2,1} \cdot \Gamma_L}{1 - S_{2,2} \cdot \Gamma_L} \\ \dfrac{\left[1 - (|\Gamma_L|)^2\right] \cdot (|S_{2,1}|)^2}{(|1 - S_{2,2} \cdot \Gamma_L|)^2 \cdot \left[1 - (|Sp_{1,1}|)^2\right]} \end{array} \right.$$

Available Gain with Source Matched to 50 ohms (if using 50 ohm S parameters)

The unilateral gain, G_U, equation neglects the affects of S_{12}, but is useful for finding a simple equation for the maximum frequency of oscillation by setting G_U to one and solving for frequency.

$$G_u(Y) := \frac{(|Y_{2,1}|)^2}{4 \cdot Re(Y_{1,1}) \cdot Re(Y_{2,2})}$$

Unilateral Transducer Gain

Impedance Conversion Routines

Parallel impedance and series impedance Q finding and conversion routines.

$$Q_{LS}(R_S, L_S, \omega) := \frac{L_S \cdot \omega}{R_S}$$

Q of an L_S in series with R_S

$$Q_{LP}(R_P, L_P, \omega) := \frac{R_P}{L_P \cdot \omega}$$

Q of an L_P in parallel with R_P

$$LP2S(R_P, L_P, \omega) := \begin{pmatrix} \dfrac{Q_{LP}(R_P, L_P, \omega)^2}{1 + Q_{LP}(R_P, L_P, \omega)^2} \cdot L_P \\ \dfrac{1}{1 + Q_{LP}(R_P, L_P, \omega)^2} \cdot R_P \end{pmatrix}$$

Conversion from L_P and R_P to L_S and R_S

$$LS2P(R_S, L_S, \omega) := \begin{bmatrix} \dfrac{1 + Q_{LS}(R_S, L_S, \omega)^2}{Q_{LS}(R_S, L_S, \omega)^2} \cdot L_S \\ \left(1 + Q_{LS}(R_S, L_S, \omega)^2\right) \cdot R_S \end{bmatrix}$$

Conversion from L_S and R_S to L_P and R_P

$$Q_{CS}(R_S, C_S, \omega) := \frac{1}{R_S \cdot \omega \cdot C_S}$$

Q of an C_S in series with R_S

$$Q_{CP}(R_P, C_P, \omega) := R_P \cdot \omega \cdot C_P$$

Q of an C_P in parallel with R_P

$$CP2S(R_P, C_P, \omega) := \begin{bmatrix} \left(1 + \dfrac{1}{Q_{CP}(R_P, C_P, \omega)^2}\right) \cdot C_P \\ \dfrac{1}{1 + Q_{CP}(R_P, C_P, \omega)^2} \cdot R_P \end{bmatrix}$$

Conversion from C_P and R_P to C_S and R_S

$$CS2P(R_S, C_S, \omega) := \begin{bmatrix} \left(\dfrac{Q_{CS}(R_S, C_S, \omega)^2}{1 + Q_{CS}(R_S, C_S, \omega)^2}\right) \cdot C_S \\ \left(1 + Q_{CS}(R_S, C_S, \omega)^2\right) \cdot R_S \end{bmatrix}$$

Conversion from C_S and R_S to C_P and R_P

References

References

[Pozar] Microwave Engineering, 2nd edition, 1998, David M. Pozar, pg. 208.
[2] derived by Pucel, referenced in "Applied RF Techniques I," 5 day short course by Besser Associates.
[Gentili] "Microwave Amplifiers and Oscillators," by Christian Gentili.
[Bowick] "RF Circuit Design," Chris Bowick

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