Impedance measurements with the VNA

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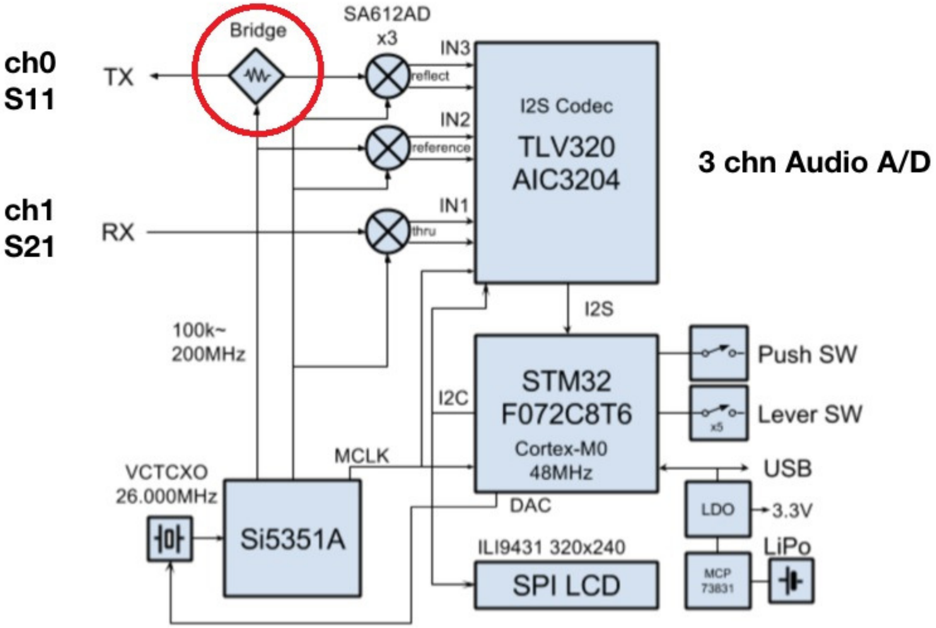
Architecture of a low-cost VNA

Low-cost VNAs are equipped with a reflectometric bridge to measure the reflection coefficient at port 1, whereas professional VNAs, which are more expensive, use a directional coupler.

The reflectometric bridge itself is highly accurate when measuring impedance (Z) close to its own impedance, typically 50 Ohms, and maintains good accuracy (< 5%) up to 10 times less or 10 times more than the nominal value, so from 5 to 500 Ohms.

As you move further away from this range, the instrument becomes progressively less accurate.

Next, we will look at the three main methods for performing impedance measurements as accurately as possible.



One port reflection measurement.

The first method, the simplest, to measure the impedance **Z** of a device is to measure the reflection coefficient **Γ**, also known as $\mathbf{S}_{11}$, when connected to port 1

$$\boldsymbol{Z} = \boldsymbol{Z}_0 \frac{1+\boldsymbol{S}_{11}}{1-\boldsymbol{S}_{11}}$$

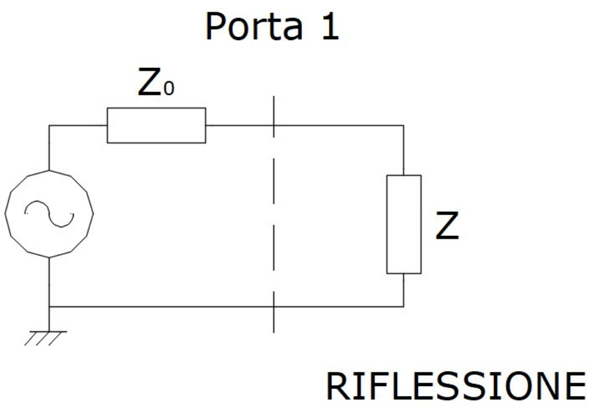
Where $\mathbf{Z}_0$ refers to the characteristic impedance of the VNA RF bridge; typically 50 Ohms.

This becomes in scalar terms:

$$R = 50\frac{1-(Re(S11)^2+Im(S11)^2)}{(1-Re(S11))^2+Im(S11)^2}$$

$$X = \frac{100\,Im(S11)}{(1-Re(S11))^2+Im(S11)^2}$$

The accuracy of the result is better than 4% between 5 and 400 Ohms.



Parallel attenuation measurement

The second method to measure the impedance **Z** of a device is to measure the scattering parameter $\mathbf{S}_{21}$ between ports 1 and 2 with the impedance under test connected in parallel between the ports and ground.

The impedance **Z** is calculated using the formula:

$$\boldsymbol{Z} = \frac{\boldsymbol{Z}_0}{2} \frac{\boldsymbol{S}_{21}}{1-\boldsymbol{S}_{21}}$$

Here, $\mathbf{Z}_0$ refers to the characteristic impedance of the VNA RF bridge, typically 50 Ohms.

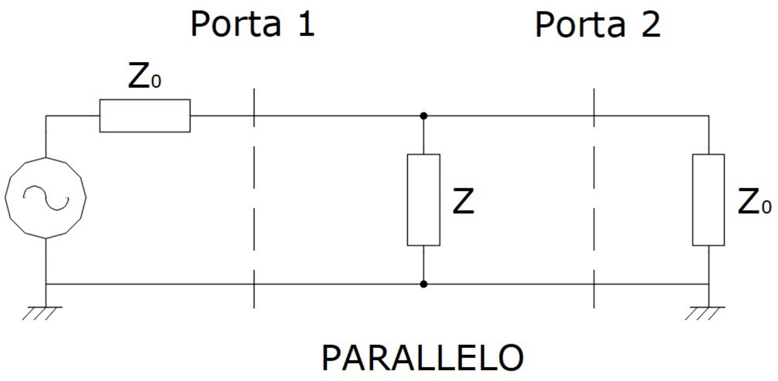
In scalar terms, this becomes:

$$R = 25\frac{Re(S21) - Re(S21)^2 - Im(S21)^2}{(1 - Re(S21))^2 + Im(S21)^2}$$

$$X = 25\frac{Im(S21)}{(1 - Re(S21))^2 + Im(S21)^2}$$

The accuracy of the result is better than 4% between a few milliwatts and 30 Ohms.

Therefore, it is well-suited for low impedance measurements.



Series attenuation measurement

The third method to measure the impedance **Z** of a device involves measuring the scattering parameter $\mathbf{S}_{21}$ between ports 1 and 2 with the impedance under test connected in series between the two ports.

The impedance **Z** is obtained using the formula:

$$\boldsymbol{Z} = 2\boldsymbol{Z}_0 \frac{1-\boldsymbol{S}_{21}}{\boldsymbol{S}_{21}}$$

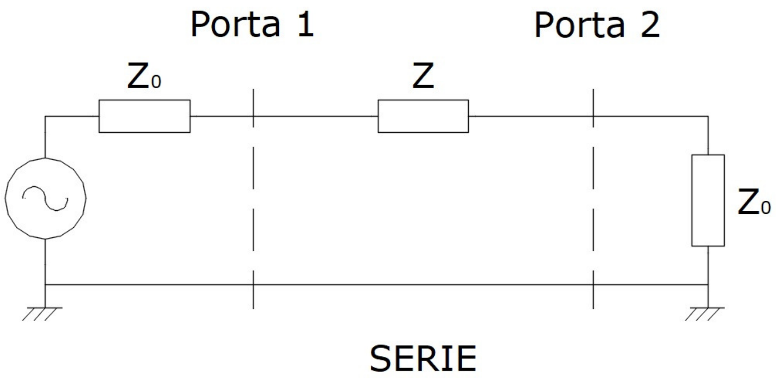
Here, $\mathbf{Z}_0$ refers to the characteristic impedance of the VNA RF bridge, typically 50 Ohms.

In scalar terms, this becomes:

$$\boxed{\begin{gathered} R = \frac{100[Re(S21) - (Re(S21)^2 + Im(S21)^2]}{Re(S21)^2 + Im(S21)^2} \\ X = \frac{-100\; Im(S21)}{Re(S21)^2 + Im(S21)^2} \end{gathered}}$$

The accuracy of the result is better than 1% between 200 Ohms and over 100 kOhms.

Therefore, it is well-suited for high impedance measurements.



Accuracy of the three methods

Grafico dell’accuratezza in funzione del metodo scelto. (Immagine presa Copper Mountain Technologies)