

# II Components

## 3.2 Requirements for data and signal transformers

Transformers are used on data lines mainly for isolation and impedance matching. The signal should be largely unaffected in this case. From chapter I/1.9 we know that the magnetizing current is not transferred to the secondary side. For this reason, the transformer should have the highest possible main inductance.

The signal profiles are usually rectangular pulses, i.e. they include a large number of harmonics. For the transformer, this means that its transformation properties should be as constant as possible up to high frequencies.

Taking a look at the transformer equivalent circuit (chapter I/2.3, page 81 ff), it is apparent that the leakage inductances contribute to additional frequency-dependent signal attenuation. The leakage inductances should therefore be kept as low as possible.

Signal transformers therefore usually deploy ring cores with high permeability. The windings are at least bifilar; wound with twisted wires is better still. Because the power transfer is rather small, DCR is of minor importance.

The direct parameters, such as leakage inductance, interwinding capacitance etc. are usually not specified in the datasheets for signal transformers, but rather the associated parameters, such as insertion loss, return loss, etc.

The most important parameters are defined as follows:

- Insertion loss IL: Measure of the losses caused by the transformer

$$IL = 20 \cdot \log \frac{U_o}{U_i} \quad (2.42)$$

$U_o$  = output voltage

$U_i$  = input voltage

- Return loss RL: Measure of the energy reflected back from the transformer due to imperfect impedance matching

$$RL = 20 \cdot \log \frac{Z_s + Z_L}{Z_s - Z_L} \quad (2.43)$$

$Z_s$  = source impedance

$Z_L$  = load impedance

**Signal transformer  
bifilar**

**Insertion loss**

**Return loss**

- Common Mode Rejection: Measure of the suppression of DC interference
- Total harmonic distortion: The relationship between the total energy of the harmonics and the energy of the fundamental
- Bandwidth: Frequency range in which the insertion loss is lower than 3 dB

### 3.3 A transformer's effect on return loss

#### Return loss

Return loss is an expression in decibels (dB) of the power reflected on a transmission line from a mismatched load in relationship to the power of the transmitted incident signal. The reflected signal disrupts the desired signal and if severe enough will cause data transmission errors in data lines or degradation in sound quality on voice circuits.

The equation for calculating return loss in terms of characteristic complex line impedance,  $Z_0$ , and the actual complex load,  $Z_L$ , is shown below:

$$RL = 20 \text{ Log}_{10} \left| \frac{Z_0 + Z_L}{Z_0 - Z_L} \right| \text{ dB} \quad (2.44)$$

Expanding the return loss equation to terms of resistance and reactance we have this formula:

$$RL = 20 \text{ Log}_{10} \left| \frac{\sqrt{(R_0 + R_L)^2 + (X_0 + X_L)^2}}{\sqrt{(R_0 - R_L)^2 + (X_0 - X_L)^2}} \right| \text{ dB} \quad (2.45)$$

Since return loss is a function of line and load impedance, the characteristic impedance of a transformer, inductor or choke will affect the return loss. A simple impedance sweep of a magnetic component reveals that the impedance varies over frequency, hence the return loss varies over frequency. We will discuss further the effects of a transformer on return loss later. Now let's explore the relationship of return loss to other common reflection terms.

#### Reflection Coefficient

While return loss is generally used to denote line reflections in the magnetics industry; a more common term in the electronics industry for reflections is the complex reflection coefficient, gamma, which is symbolized either by the Roman character  $\Gamma$  or more commonly the equivalent Greek character  $\Gamma$  (gamma). The complex reflection coefficient  $\Gamma$  has a magnitude portion called  $\rho$  (rho) and a phase angle portion  $\Phi$  (Phi). Those of you familiar with the Smith Chart know that the radius of the circle encompassing the Smith Chart is rho equal to one.

**Common mode rejection**  
**Total harmonic distortion**  
**Bandwidth**

**Return loss**

**Reflection coefficient**

# II Components

The reflection coefficient, gamma, is defined as the ratio of the reflected voltage signal in relationship to the incident voltage signal. The equation for gamma is below:

$$\Gamma = \frac{V_{\text{reflected}}}{V_{\text{incident}}} = \frac{Z_L - Z_0}{Z_L + Z_0} \quad (2.46)$$

Keep in mind that just as impedance is a complex number, so is gamma and it may be expressed either in polar format with rho and Phi or in rectangular format:

$$\Gamma = \rho \angle \Phi = \Gamma_r + j\Gamma_i \quad (2.47)$$

Return loss expressed in terms of gamma is shown in the equation below:

$$RL = -20 \text{ Log}_{10} |\Gamma| \text{ dB} \quad (2.48)$$

## Standing wave ratio

## Standing wave ratio

The reflections on a transmission line caused by impedance mismatches reveal themselves in an envelope of the combined incident and reflected wave forms. The standing wave ratio, SWR, is the ratio of the maximum value of the resulting RF envelope  $E_{\text{MAX}}$  to the minimum value  $E_{\text{MIN}}$ .

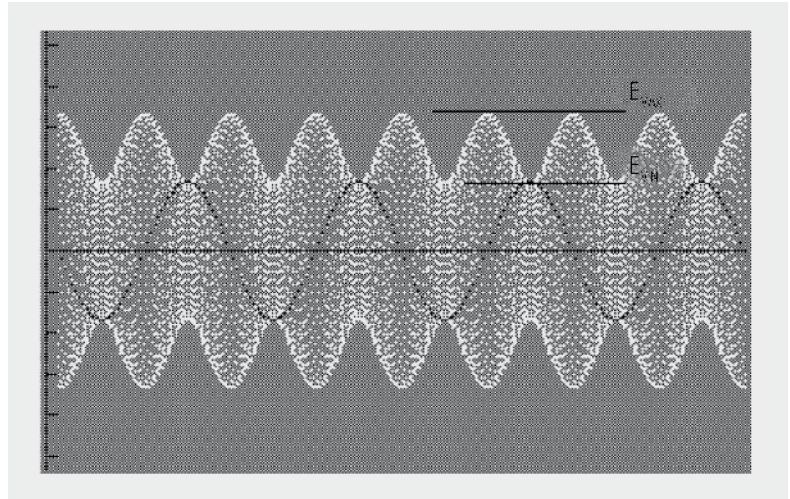


Fig. 2.63: Standing wave ratio

The standing wave ratio expressed in terms of the reflection coefficient is shown below:

$$VSWR = \frac{E_{MAX}}{E_{MIN}} = \frac{1 + |\Gamma|}{1 - |\Gamma|} \quad (2.49)$$

### Transmission loss

The last signal reflection expression that we will discuss is the transmission loss. Transmission loss is simply the ratio of power transmitted to the load relative to the incident signal power. Transmission loss in a lossless network expressed in terms of the reflection coefficient is shown below:

$$TL = -10 \text{ Log}_{10} (1 - |\Gamma|^2) \text{ dB} \quad (2.50)$$

Don't forget that the magnitude of gamma ( $|\Gamma|$ ) is rho ( $\rho$ ) and either form can be found in publications and documents regarding reflections.

### Related terms

Reviewing the complex reflection coefficient formula we can see that the closer matched the load impedance  $Z_L$  is to the characteristic line impedance  $Z_0$  the closer to zero the reflection coefficient is. As the mismatch between the two impedances increase the reflection coefficient increases to a maximum magnitude of one.

The table below shows how the varying complex reflection coefficient relates to SWR, return loss and transmitted loss. As can be seen a perfect match results in SWR equal to 1 and an infinite return loss. Similarly an open or short at the load will result in return an infinite SWR and 0 dB of return loss.

### Transmission loss