Signal Transformer Application and Specification

A transformer in its simplest sense is two or more windings coupled by a common magnetic field (flux density). It is this magnetic field that provides the means to pass voltages and currents from one winding (primary) to the other winding (secondary). Magnetic flux is made when an alternating current flows through a winding (see Figure 1). This magnetic field (represented by magnetic flux lines) follows the path of least magnetic resistance (reluctance). The path that the flux follows then proceeds

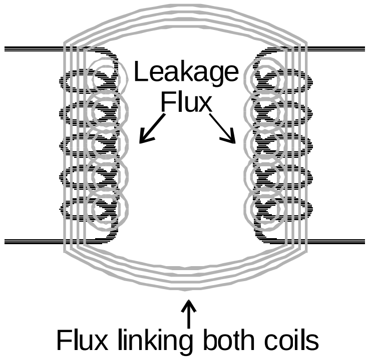

Figure 1

through to the other winding where a current is induced. However, not all of the flux created by the first winding flows through the second winding. The flux that does not connect the two windings is called leakage flux and is energy lost. There are other forms of energy losses such as core and winding losses which also reduce the efficiency of the transformer but will not be discussed in detail here. One way of reducing the amount of leakage flux is to shorten the path between the two windings or place the windings on top of each other. Properly configuring the winding allows more of the flux to link both windings and limit losses. Lowering leakage flux (leakage inductance) is a primary goal of the signal transformer designer since fewer losses means that a greater amount of the signal will be transferred in an undistorted manner.

There are many reasons for using a transformer including: isolation of DC currents, voltage and current transformations, and impedance matching. The type of signals to be transferred from the primary to secondary winding(s) relate directly to the type of transformer that should be used in an application. For instance, a transformer needed to provide DC isolation between two windings carrying large amounts of currents would be designed differently than a transformer that needs to provide an impedance match to a small signal communications network. In this article, the emphasis will be on two types of signal transformers that are designed specifically for the transmission of data at low power levels with DC isolation (the wide band transformer) and those designed to be non-isolating (the auto transformer). These types of transformers are not limited to low power capabilities, but the emphasis here is for use in communication and small signal applications.

The Wide Band Transformer

Many transformers are efficient in their ability to carry large amounts of voltage and current over a narrow range of frequencies. However, these transformers can become inefficient in terms of transferring energy that is free of distortion. A wide band transformer can transmit a clean, undistorted low power signal over a wide range of frequencies. This is important when transmitting a signal such as a square wave since each individual pulse is made up of a wide range of harmonics. These harmonics are what give the square wave its shape and are thus necessary to preserving the original wave shape.

A wide band transformer is used for many different applications including: impedance matching, phase shifting, isolation, coupling, balanced to unbalanced transitions, and current and voltage conversion, while still providing DC isolation between circuits. The major emphasis on a wide band transformer is usually placed on the ability to transmit small signal information over a wide range of frequencies. Wide bandwidths are possible through tight coupling between the primary and secondary winding(s). Due to tight coupling, the frequency range that can be achieved for efficient operation is much higher than a typical power transformer.

When speaking of the operable range of frequencies for a wide band transformer, one usually refers to the transformer's bandwidth. The bandwidth is the range of frequencies that are allowed to pass while still maintaining at least 1/2 of the signal power. The 1/2 power point is usually measured in dB and is specified as being 3 dB down from the insertion loss (see Figure 2).

Other parameters also need to be considered when evaluating a wide band transformer. Depending on the application, the maximum or minimum inductance on the primary or secondary winding, DC resistance of the

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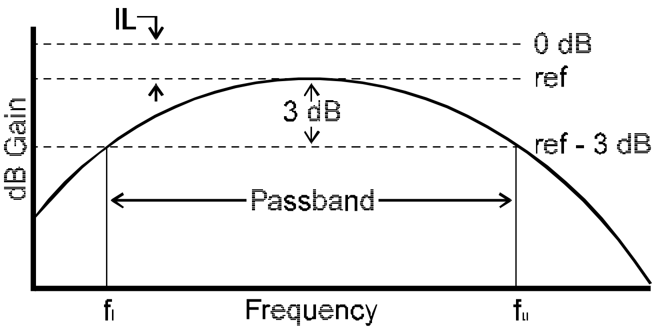

Figure 2

windings, rise time, or a number of other factors might be considered when designing or specifying a wide band transformer. One primary parameter that needs to be determined is the turns or inductance ratio. The ratio is used for matching the primary and secondary impedance of the transformer to the circuit into which it is inserted. This ratio is also crucial for “stepping up” or “stepping down” a voltage or current from one side of the transformer to the other.

Design Equations

As mentioned earlier, one of the main uses of the wide band transformer is to step-up or step-down voltages or currents. The same techniques can be applied to matching impedances between unbalanced circuits. For the purpose of design simplicity, a lossless transformer will

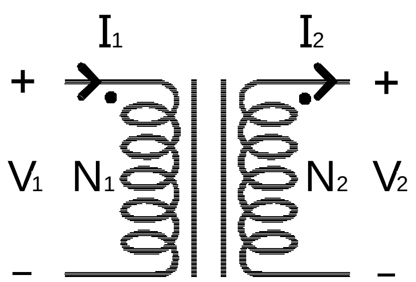

Figure 3

be used to derive the equations (see Figure 3). For a lossless transformer, the following equations are true:

$$\frac{N_1}{N_2} = \frac{V_1}{V_2} = \frac{I_2}{I_1} = a$$

Where:

N_1 = number of turns on primary
N_2 = number of turns on secondary
V_1 = voltage across primary
V_2 = voltage across secondary
I_1 = current through primary
I_2 = current through secondary
a = turns ratio

The inductance of a winding can be approximated by using the following relation:

$$L = N^2 A_L$$

where A_L is the equivalent inductance (per turns squared) of the core material. This is generally specified by the core manufacturer.

To find the required turns ratio necessary to match two impedances Z_1 and Z_2, the following relations are used (note that the impedance is proportional to the *square* of the turns):

$$Z_1 = \frac{V_1}{I_1} = \frac{V_2}{I_2}(a^2) = Z_2(a^2) \quad \text{where} \quad \left[\frac{N_1}{N_2}\right]^2 = a^2$$

For example, if a 100 Ohm source Z_1 is to be connected to a 150 Ohm load Z_2, the resulting turns ratio necessary would be:

$$100 = 150a^2 \quad \sqrt{\frac{100}{150}} = a \quad a \cong 0.816 \quad \text{thus} \quad N_1 = 0.816 N_2$$

The Autotransformer

Another type of transformer that is applicable in communication systems is the autotransformer. The autotransformer has its own unique characteristics as well as having many of the benefits of the wide band transformer. It can be used in many of the same applications as the wide band transformer such as voltage dividers, impedance matching, phase shifting, and voltage and current transformations. It cannot, however, provide any DC isolation between the primary and secondary(s). What the autotransformer lacks in DC isolation, it gains in efficiency, lower leakage inductance, and better voltage regulation.

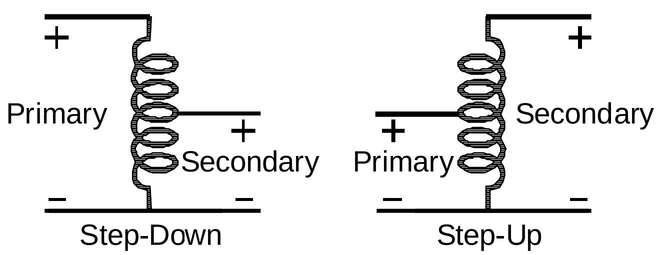

Figure 4: Autotransformer (Step-down, step-up)

The autotransformer is ideal when DC isolation is not necessary and optimum efficiency is needed. Additional efficiency is gained by way of greater coupling, which in turn leads to less leakage inductance. This is partially due to the autotransformer passing part of the energy from primary to secondary by voltage division. Whereas the DC isolating wide band transformer delivers all of its energy by transformer action, the autotransformer deliv-

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ers part of the energy directly through the winding and the other part through means of a magnetic medium. This allows for better coupling between the primary and secondary and thus less leakage inductance and increased bandwidth.

An autotransformer also requires less windings to achieve the same result as an isolation transformer. This is due to the secondary using part of the primary winding to achieve the necessary turn count for a step-up or step-down transformer (see Figure 4). Since fewer turns are needed to achieve the same primary to secondary impedance ratio, total copper loss will be reduced - thus it is more efficient than a comparable wide band transformer. Note that the autotransformer is not limited to a single secondary (or "tap"), but may have multiple taps off of the primary winding.

Design Equations

The techniques used in determining the appropriate number of turns to step-up or step-down a voltage, or match impedances is similar to that of the isolation wide

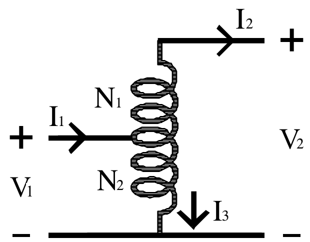

Figure 5

band transformer. For an autotransformer, the following equations should be used (see Figure 5):

$$\frac{V_1}{V_2} = \frac{N_1 + N_2}{N_2} = \frac{I_2}{I_1}$$

Where:

N_1 = number of turns common to secondary
N_2 = number of turns common to primary and secondary
V_1 = voltage across primary (common winding)
V_2 = voltage across secondary
I_1 = current in tap
I_2 = current in secondary
a = turns ratio

Again, the inductance of a winding can be approximated by using the following relation:

$$L = N^2 A_L$$

To use the autotransformer as a voltage divider network, use the following equation:

$$V_1 \left[\frac{N_1 + N_2}{N_2}\right] = V_2$$

To use the autotransformer as an impedance matching network, the following equations are used:

$$Z_1 = \frac{V_1}{I_1} = \frac{V_2}{I_2}\left[\frac{1}{(a+1)^2}\right] = \left[\frac{1}{(a+1)^2}\right] Z_2$$

$$100 = 150\left[\frac{1}{(a+1)^2}\right] \qquad \sqrt{\frac{100}{150}} = \left[\frac{1}{a+1}\right]$$

$$a \cong 0.225 \quad \text{thus} \quad N_1 = 0.225 N_2$$

Conclusion

An introduction to the basic design and application of the wide band transformer and autotransformer has been covered. It can be used as a guide to help in the development and specification of Coilcraft's line of wide band transformers and autotransformers which are available in PC and surface mount configurations. Please contact your local Coilcraft representative for information regarding standard and custom versions.

Bibliography

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