

## Use of Ferrites in Broadband Transformers

### Introduction

Most of the magnetic information in this catalog is data obtained from cores wound with a single multi-turn-winding which forms an inductor. When a second winding is added on the core, the inductor becomes a transformer. Depending on the requirements, transformers can be designed to provide dc isolation, impedance matching and specific current or voltage ratios. Transformer designed for power, broadband, pulse, or impedance matching can often be used over a broad frequency spectrum.

In many transformer designs ferrites are used as the core material. This article will address the properties of the ferrite materials and core geometries which are of concern in the design of low power broadband transformers.

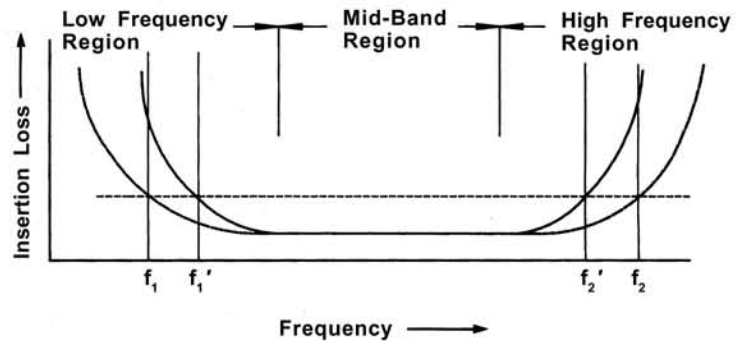
### Brief Theory

Broadband transformers are wound magnetic devices that are designed to transfer energy over a wide frequency range. Most applications for broadband transformers are in telecommunication equipment where they are extensively used at a low power levels.

Figure 1 shows a typical performance curve of insertion loss as a function of frequency for a broadband transformer. The bandwidth of a broadband transformer is the frequency difference between  $f_2$  and  $f_1$ , or between  $f_2'$  and  $f_1'$ , and is a function of the specified insertion loss and the transformer roll-off characteristics.

It can be seen that the bandwidth is narrower for transformers with a steep roll-off ( $f_2' - f_1'$ ) than those with a more gradual roll-off ( $f_2 - f_1$ ). Also in Figure 1, the three frequency regions are identified.

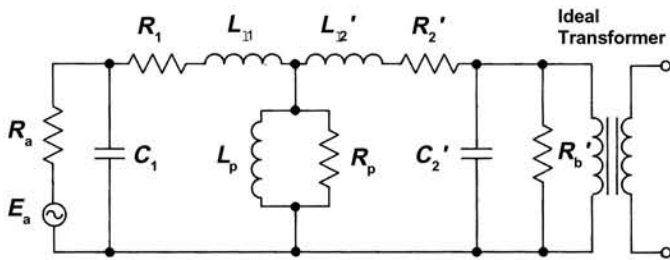
The cutoff frequencies are determined by the requirements of the individual broadband transformer design. Therefore,  $f_1$  can be greater than 10 MHz or less than 300 Hz. Bandwidths also can vary from a few hundred hertz to hundreds of MHz. A typical



**Figure 1** Typical Characteristic Curve of Insertion Loss vs. Frequency for a broadband transformer.

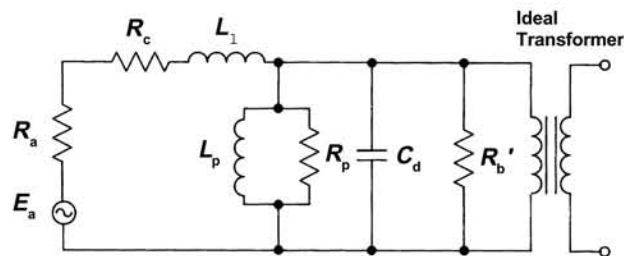
broadband transformer design will specify for the mid frequency range a maximum insertion loss and for the cutoff frequencies,  $f_1$  and  $f_2$  maximum allowable losses. Figure 2 is a schematic diagram of the lumped element equivalent circuit of a transformer, separating the circuit into an ideal transformer, its components and equivalent parasitic resistances and reactances. The secondary components, parasitics and the load resistance have been transferred to the primary side and are identified with a prime.

To simplify this circuit, the primary and secondary circuit elements have been combined and the equivalent reduced circuit is shown in Figure 3. The physical significance of the parameters are listed below the equivalent circuits. In the low frequency region the roll-off in transmission characteristics is due a lowering of the shunt impedance. The shunt impedance decreases when the frequency is reduced, which results in the increases level of attenuation. The impedance is mainly a function of the



**Figure 2** Lumped equivalent of a transformer.

- $E_a$  = source EMF
- $R_a$  = source resistance
- $C_1$  = primary winding capacitance
- $R_1$  = resistance of primary winding
- $L_{t1}$  = primary leakage inductance
- $L_p$  = open circuit inductance of primary winding
- $R_p$  = shunt resistance that represents loss in core
- Secondary parameters reflected to the primary side.
- $C_2'$  = secondary winding capacitance
- $R_2'$  = resistance of secondary winding
- $L_{t2}'$  = secondary leakage inductance
- $R_b'$  = load resistance



**Figure 3** Simplified equivalent transformer circuit

$$C_d = C_1 + C_2'$$

$$R_c = R_1 + R_2'$$

$$L_t = L_{t1} + L_{t2}'$$

For other circuit parameters see Figure 2.

primary reactance  $X_{LP}$  with a negligible contribution of the equivalent shunt loss resistance  $R_p$ . The insertion loss may therefore be expressed in terms of the shunt inductance:

$$A_i = 10 \log_{10} \left( 1 + \left( \frac{R}{\omega L_p} \right)^2 \right) \text{ dB}$$

$$\text{Where } R = R_a \times R_b' / R_a = R_b'$$

For most ferrite broadband transformer designs, the only elements that are likely to effect the transmission at the mid-band frequency range are the winding resistances. The insertion loss for the mid-band frequency region due to the winding resistance may be expressed as:

$$A_i = 20 \log_{10} \left( 1 + \frac{R_c}{R_a + R_b'} \right) \text{ dB}$$

$$\text{Where } R_c = R_1 + R_2'$$

In the higher frequency region the transmission characteristics are mainly a function of the leakage inductance or the shunt capacitance. It is often necessary to consider the effect of both of these reactances, depending upon the circuit impedance. In a low impedance circuit the high frequency droop due to leakage inductance is:

$$A_i = 10 \log_{10} \left( 1 + \left( \frac{\omega L_t}{R_a + R_b'} \right)^2 \right) \text{ dB}$$

This high frequency droop in a high impedance circuit, due to the shunt capacitance, is as follows:

$$A_i = 10 \log_{10} \left( 1 + (\omega CR)^2 \right) \text{ dB}$$

Reviewing the insertion loss characteristics for the three frequency regions, it can be concluded that the selection of ferrite material and core shape should result in a transformer design that yields the highest inductance per turn at the low frequency cutoff  $f_1$ . This will result in the required shunt inductance for the low frequency region with the least number of turns. The low number of turns are desirable for low insertion loss at the mid-band region and also for low winding parasitics needed for good response at the high frequency cutoff  $f_2$ .

## Low and Medium Frequency Broadband Transformers

For broadband transformer applications the optimum ferrite is the material that has the highest initial permeability at the lower cutoff frequency  $f_1$ . Manganese zinc ferrites, such as Fair-Rite 77 or 78 material, are very suitable for low and medium frequency broadband transformer designs. As stated before, the transformer parameter that is most critical is the shunt reactance ( $\omega L$ ), which will increase with frequency as long as the material permeability is constant or diminishing at a rate less than the increase in frequency. This holds true even if a transformer is designed using a manganese zinc ferrite where  $f_1$  is at the higher end of the flat portion of the permeability vs. frequency curve. Although the whole bandpass lies in the area where the initial permeability is decreasing, yet the bandpass characteristics will be virtually unaffected. For broadband transformers that use a manganese zinc ferrite material the core geometry should be such as to minimize the  $R_{dc}/L$  ratio. In other words, the ratio of dc resistance to the inductance for a single turn should be a minimum. The range of pot cores, standardized by the International Electrotechnical Commission in document IEC 60133, has been designed for this minimum  $R_{dc}/L$  ratio. Other core shapes can also be used in the design of these broadband transformers. Often the final core selection will also be influenced by such considerations as ease of winding, terminating and other mechanical design constraints of the transformer.

## Broadband Transformers with a Superimposed Static Field

In transformer designs that have a superimposed direct current, gapped cores can be employed to overcome the decrease in the shunt inductance. Hanna curves can be used to aid in the design of inductive devices that carry a direct current. For more information see section "The Effect of Direct Current on the Inductance of a Ferrite Core".

## High Frequency Broadband Transformers.

Although there is no clear division between the frequency regions, for this article it is assumed that the high frequency broadband transformer designs use nickel zinc ferrites as the preferred core material. This will typically occur for transformer

designs where the bandpass lies wholly above 500 kHz. At these higher operating frequencies it becomes more important to consider the complex magnetic parameters of the core material, rather than use the simple core constants, such as  $A_L$ , recommended for low frequency designs.

Another important consideration is that high frequency transformers are generally used in low impedance circuits, which means that these designs require low shunt impedances. This can often be accomplished with a few turns, hence winding resistances are no longer an issue, and the design concept of minimizing  $R_{dc}/L$  is no longer required. The design will instead become focused on core shape and material for the required shunt impedance at  $f_1$  along with reducing leakage inductance of the winding. Since the material characteristics permeability and losses affect the shunt impedance these parameters need to be considered in high frequency broadband transformer designs. Figures 4, 5 and 6 are typical curves of impedance  $Z$ , equivalent parallel reactance  $X_p$  and equivalent parallel loss resistance  $R_p$  as a function of frequency. They are measured on the same multi-aperture core 28—002302, in 73, 43, 61 & 67 material, wound with a single turn through both holes. For high frequency broadband transformers the toroidal core shape becomes an attractive core geometry. The few turns that are often required can easily be wound on the toroid. However, windings that require only a few turns may give rise to problems in obtaining the desired impedance ratios. To minimize leakage inductance it is suggested that the primary and secondary windings be tightly coupled and where possible a bifilar winding be used.

An improvement in core performance over toroids can be obtained by the use of multi-aperture cores, which can be considered as two toroidal cores side by side. This core shape has a lower single turn winding length than the equivalent toroidal core with the same core constant  $C_1$ , and will result in a wider bandwidth of the transformer design. Many broadband transformers have been designed utilizing nickel zinc ferrite toroids with good results. If bandwidth requirements cannot be met using toroids, multi-aperture nickel zinc cores should be considered.

The multi-aperture cores are available in the nickel zinc ferrite materials 67, 61 and 43 as well as the manganese zinc ferrite 73 material.

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## Summary

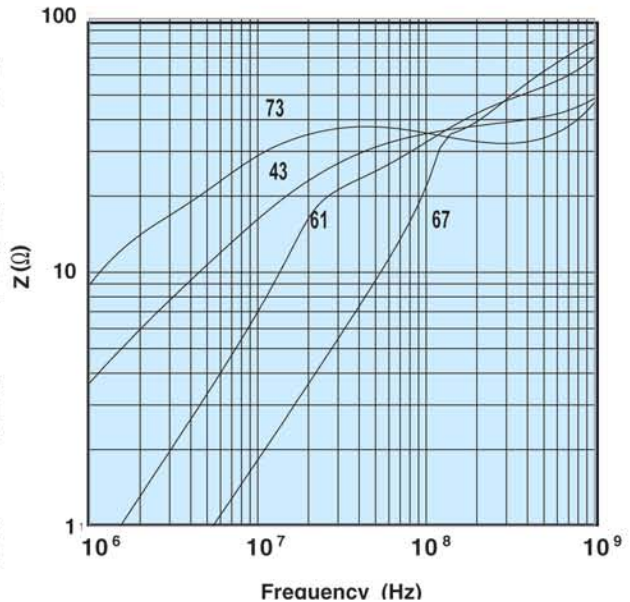
The low cutoff frequency  $f_1$  is the single most important factor in the ferrite material selection. The material with the highest initial permeability at  $f_1$  is the recommended choice.

Manganese zinc ferrites, 77 and 78, can be used to a cutoff frequency  $f_1$  of 500 kHz. Above this frequency use a nickel zinc ferrite, again depending upon the frequency  $f_1$ , select 43, 61 or 67 material.

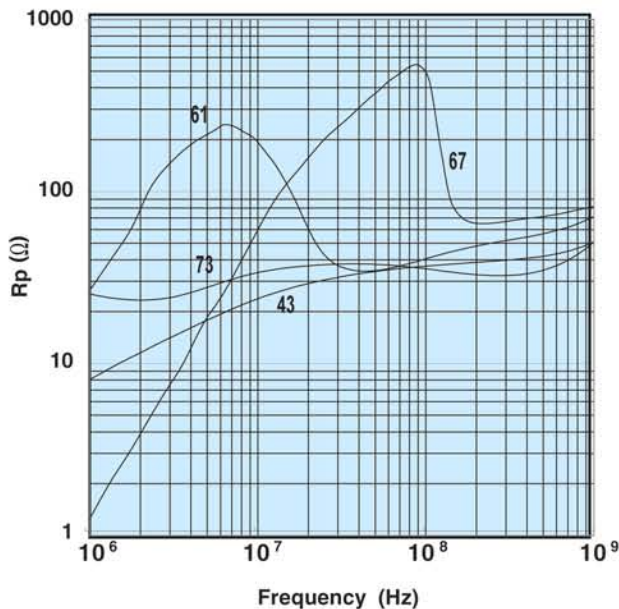
For low and medium frequency transformers the optimum core shape should provide the lowest DC resistance per unit of inductance. If there is a superimposed dc present the use of gapped cores and Hanna curves is suggested. For high frequency designs, use nickel zinc ferrite. The toroidal and multi-aperture cores are the recommended core configurations.

The number of turns should be kept to a minimum to reduce leakage inductance and self-capacitance of the windings. Wind primary and secondary windings tightly coupled or as bifilar windings to lower leakage inductance.

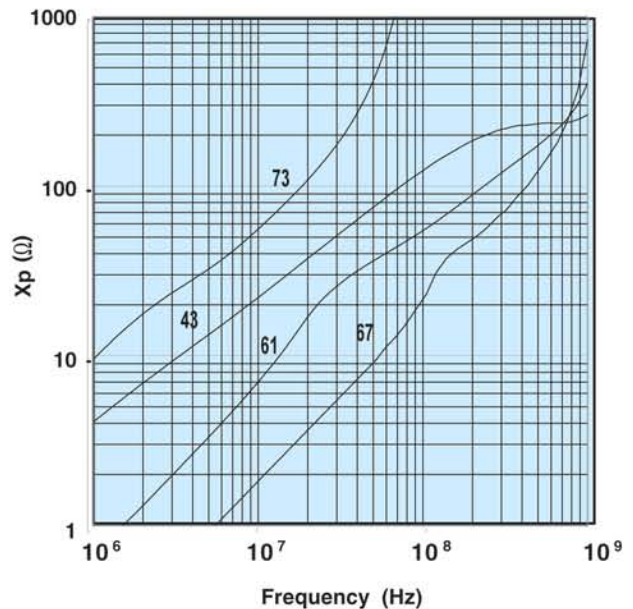
The "Multi-Aperature Core Kit", (part number 0199000036), contains a variety of components suited for broadband transformer design evaluations.



**Figure 4** Impedance vs. frequency for part number 28—002302 in 73, 43, 61 & 67 material.



**Figure 5** Parallel resistance vs. frequency for part number 28—002302 in 73, 43, 61 & 67 material.



**Figure 6** Parallel reactance vs. frequency for part number 28—002302 in 73, 43, 61 & 67 material.

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