Design Study

Designing a Matrix Transformer from a Conventional Transformer

*Note: It may not be practical to design a one-for-one equivalent matrix transformer to replace a conventional transformer in an existing layout. For one, the footprint is very different. For another, one advantage of the matrix transformer is its very low leakage inductance. Much of the benefit may be lost if it is installed in a layout with significant inductance in the interconnections, a likely situation if it is installed in an existing layout with flying leads.*

There are a number of reasons for converting a conventional transformer to a matrix transformer design. It might be done to upgrade a circuit for higher frequency operation, or for lower profile, for lower temperature rise or for economy. If an existing design works well, it may be better to leave it alone due to the wide availability of conventional transformers and their components. However, if the flux must be de-rated significantly for thermal reasons, if proximity effects are troublesome, if it runs too hot or if the profile is too high, a matrix transformer will be a good choice.

Figure 1 shows a hypothetical E-I transformer design having a four turn push-pull winding (eight turns center tapped) with a one turn push pull secondary (two turns center tapped). Figure 1a shows the windings. An "equivalent" matrix transformer may have four "elements" comprising four cores and a single turn (two wire) push pull primary. There would be four secondaries in parallel, so each carries one fourth the current. Accordingly, the secondary conductors are the same size as the primary conductors, as shown in the cross section in figure 2.

A starting point is to "unwrap" the transformer winding to get an equal straight conductor. In Figure 1a, it can be seen that the length of a turn varies from the inside to the outside, but as a starting point, let us use the inside diameter to give a straight conductor as shown in figure 2a. Already, we are departing significantly from the conventional design, as many of the conductors are significantly shorter than their conventional transformer counterparts (because of the increasing circumference of the outer layers), so they will have lower resistance with the same copper cross section.

The next step is to design a core having the same area as the original transformer's center leg. The length of the conductor in figure 2a is a starting point, but make it shorter enough to allow for the secondary terminations. This will permit more trimming of the primary conductors, lowering the conductor resistance even more. A possible core is shown in figure 2. Using four such cores to make a matrix transformer will result in almost two times the core volume, doubling the core losses. However, the thermal conduction paths are much shorter and the losses are better distributed, so the current rating will almost certainly be very much higher if the original windings were designed for a specific temperature rise.
Fig. 1
\( A = 240 \)
\( V = 17,578 \)

Fig 2
\( A = 245 \)
\( V = 8,615 \)
\( 4V = 34,460 \)

Fig 1a

Fig 2a

Fig 3
\( A = 63 \)
\( V = 1,142 \)
\( 4V = 4,568 \)
Figure 4 shows the resulting "equivalent" matrix transformer, in "picture frame" configuration.

The results are not very attractive, thus the admonition to use caution in designing a one-for-one replacement.

It is likely, however, that some optimization can be incorporated in the design. For example, if the flux density of the original design was de-rated for thermal reasons, very likely that is no longer necessary. Also, an objective may be to increase the frequency. Figure 3 shows the resulting core if a 50% de-rating of the flux density is no longer needed, and if the frequency is doubled. In this circumstance, the core area can be reduced by 75%. Because the conductors are half the length, their cross section copper area can be reduced by half for the same resistance. Tightening everything up accordingly, the core volume is about 25% of the original transformer.

Operating at double frequency and double flux density will lead to much greater core losses per cubic centimeter or gram, but with one fourth the volume, the increased losses will be will be significantly offset. With the much better thermal characteristics, the temperature rise will almost certainly be much lower.

Figure 5 shows the resulting matrix transformer in picture frame configuration. Alternate layouts are possible as long as the cores are placed end to end, closely spaced. Figure 6 shows a row configuration, and figure 7 shows the cores stacked, for a smaller footprint.