Calculation of modem transformer transmit losses

The following method may be used to approximate the transmit signal loss caused by the transformer in a typical modem circuit. This simplified method is based on the assumption that a transformer can be characterized solely by resistive elements. This assumption will result in a small amount of error in most cases, and allows the modem designer to "budget" circuit gain and avoid burdensome calculations.

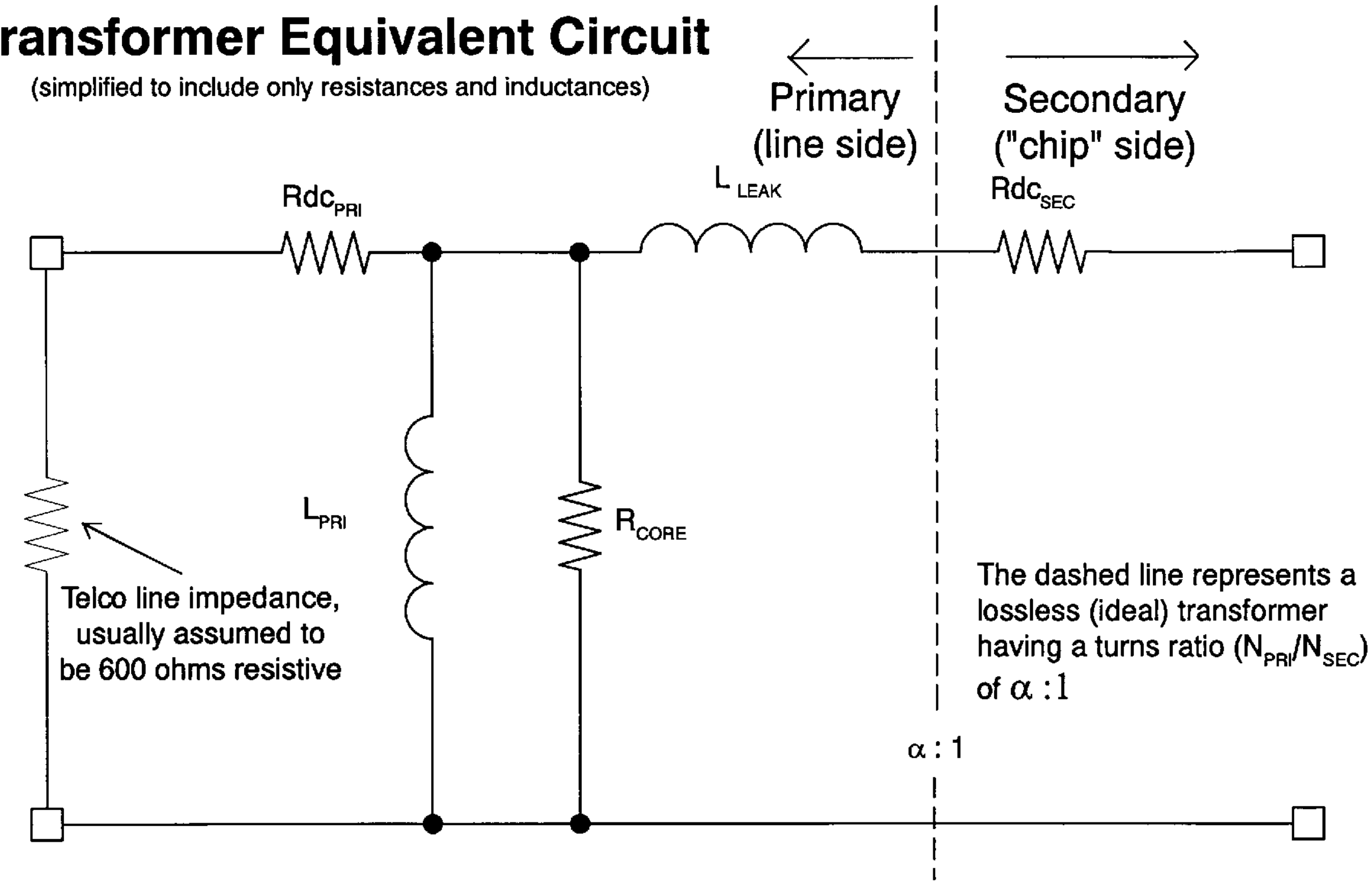
The most significant factor contributing to transformer loss is almost always the transformer's winding resistance. The next is core loss, which is small enough in most cases to be negligible. The last factor (that sometimes creates confusion) is the transformer's turns ratio. To avoid complicating the analysis, Midcom design engineers try to design modem transformers to have unity turns ratio. Doing so allows the use of a simple "T" equivalent circuit as the next few pages illustrate.

It is helpful to think of the transformer equivalent circuit as a lossless or "ideal" transformer surrounded by a set of parasitic circuit elements.

The signal delivered to the telco line is therefore attenuated by these parasitic losses and accompanied by a voltage step-up or step-down depending on the turns ratio at the point in the equivalent circuit where the ideal transformer is located.

Transformer Equivalent Circuit

(simplified to include only resistances and inductances)



Telco line impedance, usually assumed to be 600 ohms resistive

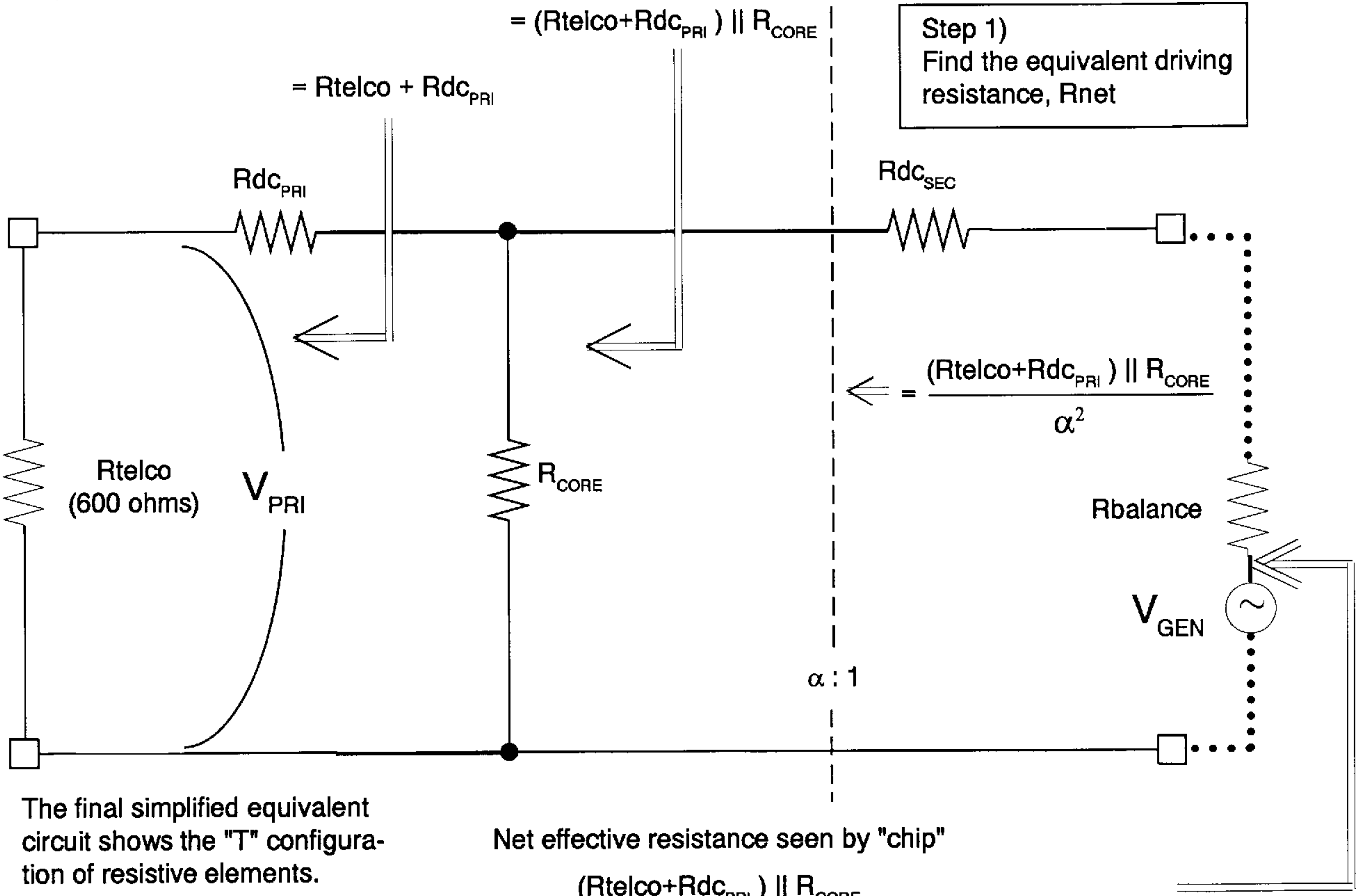
The dashed line represents a lossless (ideal) transformer having a turns ratio (N_{PRI}/N_{SEC}) of $\alpha : 1$

This is a somewhat simplified equivalent circuit showing most of the elements that contribute to total transformer loss. The elements internal to the transformer are located between the square blocks. Further simplification is possible by eliminating the inductive elements, which don't contribute significantly to overall mismatch losses in a well-designed transformer.

Transformer Equivalent Circuit

(further simplified to include only resistances)

Step 1)
Find the equivalent driving resistance, Rnet



The final simplified equivalent circuit shows the "T" configuration of resistive elements.

Net effective resistance seen by "chip"

$$Rnet = \frac{(Rtelco+Rdc_{PRI}) \parallel R_{CORE}}{\alpha^2} + Rdc_{SEC} + Rbalance$$

Step 2) Calculate the voltage produced at the primary (V_{PRI}) as a funtion of V_{GEN} .

Define equations:

1) $I_{PRI} = \frac{I_g}{\alpha} \left(\frac{R_{CORE}}{R_{CORE} + R_{PRI} + Rtelco} \right)$

2) $VPRI = I_{PRI} \cdot Rtelco$

3) $V_g = I_g \; Rnet$

4) $Rnet = \left[\frac{[\,(Rtelco + R_{PRI}) \parallel R_{CORE}\,]}{\alpha^2} \right] + R_{SEC} + Rbal$

Step 2, continued:

The losses due to the transformer telco line and Rbal are defined as:

$$\text{Loss} = 20 \log_{10} \left(\frac{V_{PRI}}{V_{GEN}} \right) \text{dB}$$

using equations 1 through 4, we can re-write the loss equation as:

$$\text{Loss} = 20 \log_{10} \left(\frac{V_{PRI}}{V_{GEN}} \right) = 20 \log_{10} \left(\frac{I_{PRI} \cdot \text{Rtelco}}{I_g \cdot \text{Rnet}} \right)$$

$$= 20 \log_{10} \left[\frac{\frac{I_g}{\alpha} \left(\frac{R_{CORE}}{R_{CORE} + R_{PRI} + \text{Rtelco}} \right) \cdot \text{Rtelco}}{\frac{[(\text{Rtelco} + R_{PRI}) \parallel R_{CORE}]}{\alpha^2} + R_{SEC} + \text{Rbal}} \right]$$

$$= 20 \log_{10} \left[\frac{\frac{1}{\alpha} \quad \text{Rtelco} \; R_{CORE}}{(\text{Rtelco} + R_{PRI})(R_{CORE}) + (R_{CORE} + R_{PRI} + \text{Rtelco})(R_{SEC} + \text{Rbal}} \right]$$

Typical example using Midcom's V.32 pocket modem transformer, 671-8255 where

Rdc_{PRI} = 46.5 ohms Rdc_{SEC} = 67.6 ohms

R_{CORE} = 32k ohms   Rbalance= 600 ohms

Rtelco = 600 ohms $\alpha = 0.920$

$$Rnet = \frac{(600+46.5) \parallel (32k)}{(0.92)^2} + 67.6 + 600 = 1416.3 \text{ ohms}$$

(just for reference, we don't need this to calculated the acutal losses)

$$Loss = 20 \log_{10} \left[\frac{\frac{1}{\alpha} \quad Rtelco\ R_{CORE}}{(Rtelco + R_{PRI})(R_{CORE}) + (R_{CORE} + R_{PRI} + Rtelco)(R_{SEC} + Rbal)} \right]$$

$$= 20 \log_{10} \left[\frac{\left(\frac{1}{0.92}\right) (600)(32k)}{\frac{1}{(0.92)^2} (600 + 46.5)(32k) + (32K + 46.5 + 600)(67.6 + 600)} \right]$$

$$= 20 \log_{10} (0.4514) = \underline{\underline{6.91 \text{ dB loss}}}$$

This would mean that the driver circuit could supply up to -2.09 dBm to Rbalance with out exceeding the -9 dBm output limit.

Reality check for previous example (extra credit).

$$\text{Rnet} = \left(\frac{(600 + 46.5)\,(32k)}{600 + 46.5 + 32k}\right) \frac{1}{(0.92)^2} + 67.6 + 600 \;=\; 1416.3 \text{ ohms}$$

$$\text{Assume} = \quad V_g = 1V \angle 0^\circ \qquad I_g = \frac{V_g}{\text{Rnet}} = \frac{1}{1416.3} = 706.07$$

$$\frac{I_g}{a} = \frac{706.07}{0.92} = 767.5\,\mu A$$

$$I_{PRI} = \frac{I_g}{\alpha}\left(\frac{R_{CORE}}{R_{CORE} + R_{PRI} + \text{Rtelco}} = 767.5\right)\mu A \left(\frac{32k}{32k + 46.5 + 600}\right)$$

$$= 752.3$$

$$V_{PRI} = I_{PRI} \cdot \text{Rtelco} = (752.3\,\mu A)\,(600 \text{ ohms}) = \underline{\underline{0.45136V}}$$

$$\therefore \quad \text{Loss} = 20 \log\left(\frac{V_{PRI}}{V_g}\right) = 20 \log_{10}\left(0.45136\right) = \underline{\underline{6.91\text{dB}}}$$