Practical Considerations When Using GBI's Current Sense Transformers

There are basically two types of current sense transformers, ones designed and used to precisely measure current in accurate instrumentation applications and ones designed and used in switch-mode power converter type applications. In power conversion applications, current transformers are used to measure trends, peak values, and average values rather than absolute values. As a result, these devices do not need to have a very high degree of accuracy, but rather need to be efficient, dense, and exist in many shapes and styles capable of supporting all traditional types of manufacturing processes.

GBI has developed and supported the largest number of current sense transformers for power conversion applications in the magnetic industry. From larger ultra high current through hole versions to low profile pick-and-place surface mount versions, all of your design requirements should be able to be satisfied from the off the shelf offering of GBI current sense transformers. Because of the large offering of Current sense transformers, if your design has unique requirements, GBI has many styles to select from for modification.

A majority of the current transformer applications within power conversion are for either current limiting or control. These devices are used to sense current and limit the converters ability to provide excessive currents in fault conditions. While others apply them in current mode control schemes where an inner feedback loop is used to measure current and compare this information against an outer voltage loop error signal to form a PWM modulator. 75% of the existing high-density DC/DC converters being built and shipped today use this PWM topology and most applications use a current sense transformer to sense the switched current. These devices are used because they give good signal to noise ratio, provide voltage isolation from the sampled current to the output current, and improve the efficiency of the converter. In addition, these devices can be placed in the circuit improving the common mode rejection between the high dI/dT and high dV/dT circuitry and the small signal detect and control circuitry.

Below are design equations and considerations that may prove helpful when applying GBI Current sense transformers in switched converter applications. If a perfect fit is not found from the wide GBI offering, this design guideline can be used to better understand the design requirements and aid GBI in building the ideal device for your application. The circuit in Figure 1 will be studied because of its application versatility.

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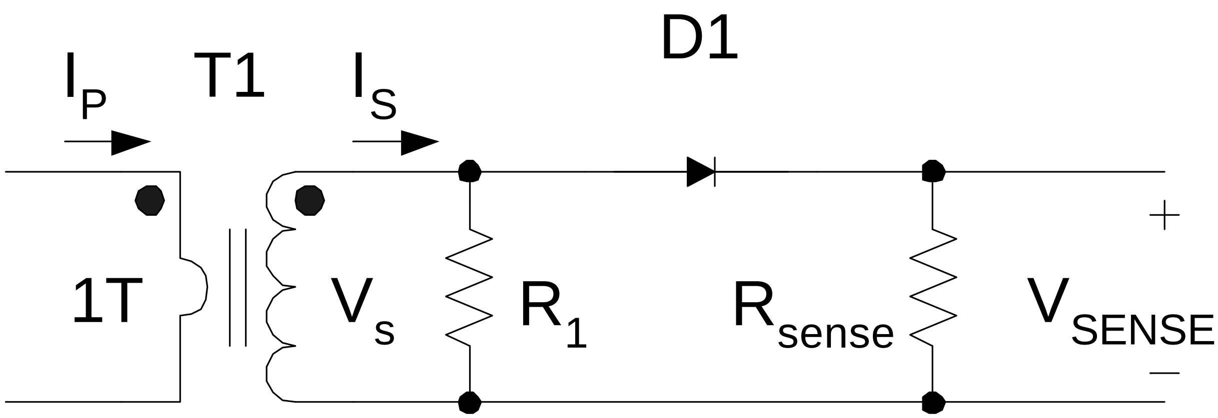

FIGURE 1

In the above circuit, T1 is the 1:N current sense transformer. Most current sense transformers have a single turn primary in an effort to minimize power loss and increase the signal to noise ratio. R1 is used to load the secondary of the transformer enabling rapid and consistent recovery of the device. D1 allows forward current to flow to the sense resistor R_{sense}, but blocks the secondary reverse recovery voltage, allowing R1 to properly reset the magnetizing energy set in the core during the PWM on-time of the converter. D1 also isolates the sense circuitry that follows R_{sense} by providing a uni-directional sense signal. Since Rsense is always much smaller in magnitude than R1, current in the secondary of the transformer during the on time flows through Rsense producing a voltage Vsense directly proportional to the primary current Ip.

Since no transformer is ideal, magnetizing inductance of the secondary should be designed to be as large as possible, keeping parasitic magnetizing current as small as possible. Typical values of N in the 1:N transformer range from 50 to 200. Magnetizing current effectively subtracts from the quantity being measured introducing an error into the measurement. Magnetizing currents that exceed 10% of the measured current quantity will introduce too much distortion for practical control and current limiting applications. Higher permeability cores are used in GBI current sense transformers giving the maximum magnetizing inductance for a given turns ratio.

The five step process for designing in a GBI current sense transformer is:

STEP 1: Calculate peak primary current being measured and maximum modulator on time.

STEP 2: Calculate secondary turns required to result in low signal distortion.

STEP 3: Select a transformer from GBI's wide offering that meets your mechanical and manufacturing requirements.

STEP 4: Calculate secondary reflected current and compare to secondary magnetizing current **and** make sure that
magnetizing current is 10% of the secondary current or less. If not, select device with a higher turns ratio.

STEP 5: Check operating flux density in core.

As an example, in a single ended Forward converter (see FIGURE 2), the primary current can be calculated and estimated using the following expression:

$$Ip = \frac{Vin * ton}{Lmag} + Io * \frac{Ns}{Np}$$

Where, L_{mag} = primary magnetizing inductance of the main power transformer (not current sense transformer)

N_s = secondary turns of main power transformer

N_p = primary turns of main power transformer

T_{on} = on time of PWM modulator

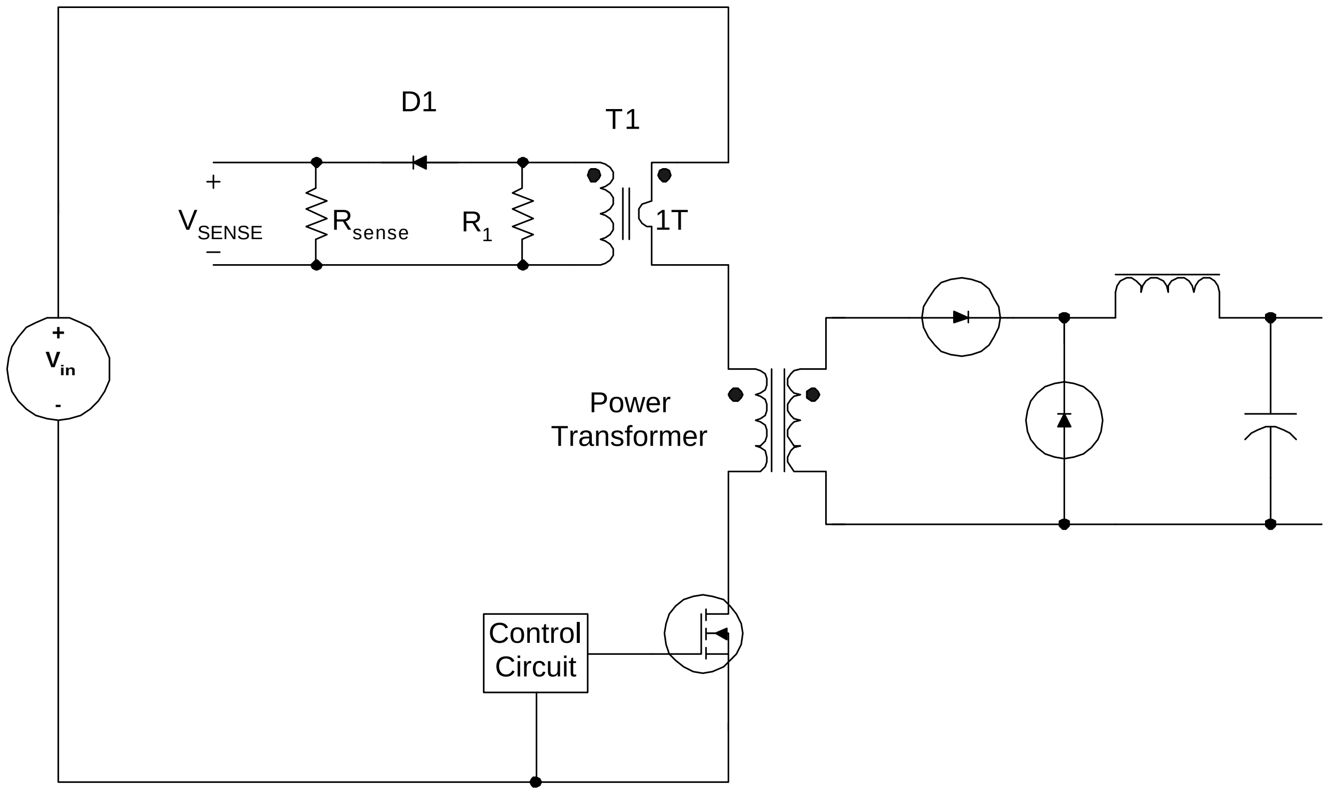

FIGURE 2

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The next Step is to calculate the secondary current components of the current sense transformer. First the signal component:

$$Is = Ip * \frac{Np1}{Ns1}$$

Where, Np1 = primary turns of current sense transformer, usually 1.
Ns1 = secondary turns of current sense transformer, usually a number between 50 and 100.

And now, the magnetizing (distortion) component:

$$Isd = \frac{Vin * ton}{Lmags}$$

Where, L_{mags} = secondary magnetizing inductance of the current sense transformer. This number can be calculated using GBI's data sheet information.

$I_{sd} < 0.1*I_s$ to ensure good signal to noise and low distortion.

The last step, STEP5, is to make sure that a proper Rsense has been selected and that the current sense transformer has margin from core saturation. Typical values of Vsense for current limiting applications range from 1 to 5 volts, while typical values of Vsense for control applications range from 1 to 2.5 volts. Rsense is calculated from the expression below.

$$Rsense = \frac{Vcontrol}{Is}$$

The voltage across the secondary of the current sense transformer is given by:

$$Vs = Is * Rsense + Vfwd$$

Where, V_{fwd} = forward voltage drop of rectifying diode D1. When possible, a low drop diode should be used for D1 which will minimize the volt second product across the secondary of the current sense transformer. The total flux swing in the device is given by:

$$\Delta B = \frac{Vs * ton}{Ae * Ns1} * 10^8 \quad \text{Gauss}$$

Where, A_e = effective core area of current sense transformer, available on GBI's datasheets.

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To reset the magnetizing energy built up in the transformer during the set interval, the voltage on both the primary and secondary must reverse (flyback) during the off time. This requirement must be accomplished each cycle to prevent flux walk and also must be accomplished with current flow in R1 only. D1 prevents reverse current to flow through Rsense; thus V_{sense} is always positive going. The reset time and reset voltage are determined by the value of R1. The reset voltage must be limited to practical values so that a schottky diode can be used for D1 and R1 must also be sized to ensure that the reset time is always shorter than the minimum off time of the PWM modulator. Increasing R1 reduces the reset time but increases the reset voltage.

The ΔB (total flux swing) for current sense transformer applications is typically small. This results in low core loss. Usually, winding considerations, such as current density in single turn and practical number of turns on the winding bobbin, determine the core size.