PULSE TRANSFORMER DESIGN GUIDELINES

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ABSTRACT

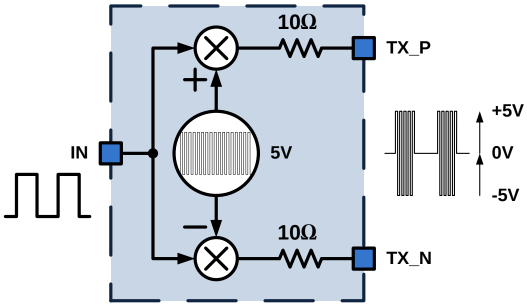
This application note gives the design guidelines of a pulse transformer that can be used for high-temperature isolated data transmission using the XTR40010 Isolated Two-Channel Transceiver.
Guidance is provided to XTR40010 users in order to specify the pulse transformer that fits their needs in terms of magnetic core characteristics, DC isolation, and dV/dt immunity.

INTRODUCTION

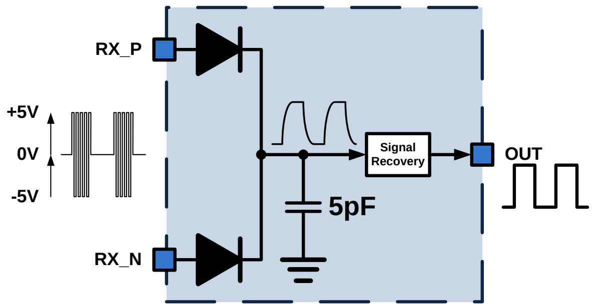
At high temperature, isolated data transmission cannot be realized using a classical opto-coupler since opto-couplers have bad temperature dependence and large drift of characteristics during aging. The best candidate to overcome the limitations of opto-couplers for high temperature applications is the pulse transformer. The next section of this application note gives design guidelines of a pulse transformer that can be used for high-temperature isolated data transmission using the XTR40010 Isolated Two-Channel Transceiver. The last section shows a design example using a commercially available ferrite core suitable for use with XTR40010.

DESIGN GUIDELINES

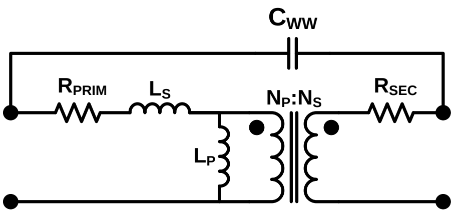
The signal delivered by the XTR40010 to the pulse transformer is a digital ±5V differential signal modulated with standard OOK modulation. The last stage of the XTR40010 transmitters implements a full bridge driver able to deliver at least 16mA DC current to the transformer with less than 10% drop of the output voltage. A typical equivalent circuit of the transmitter with the needed elements to model the transformer driver is as follows:



and to model the receiver side is as follows:



The transformer equivalent circuit can be defined as follows:



$\mathbf{R_{PRIM}}$ and $\mathbf{R_{SEC}}$ are the primary and secondary resistances due to the wires. $\mathbf{L_S}$ is the leakage inductance seen at the primary. $\mathbf{L_P}$ is the primary magnetization inductance. $\mathbf{N=N_S/N_P}$ is the transformation ratio. $\mathbf{C_{WW}}$ is the leakage capacitance between primary and secondary windings.

Magnetic core selection

Several parameters must be checked for the selection of a magnetic core suitable for the high temperature pulse transformer that can be driven by XTR40010:

- Curie temperature must be high enough to guarantee proper operation up to 230°C. A T_C>300°C is recommended.
- The frequency performances of the magnetic core must be good at the chosen carrier frequency (μ”<<μ’).
- The current*turn ratio of the primary winding must be checked to avoid saturation of the magnetic core. This parameter can be calculated using the following equation:

$$NI = \frac{B_{max} \cdot l_e}{\mu_0 \cdot \mu_r}$$

where **N** is the number of turns at the primary, **I** is the saturation current, $\mathbf{B_{max}}$ is the maximum magnetic induction of the magnetic material, $\mathbf{l_e}$ is the effective length of the magnetic core, and $\mathbf{\mu_r}$ is the relative permeability.

Primary inductance calculation

The primary magnetization inductance can be calculated using the classical equation of inductance charge:

$$v = L \cdot \frac{di}{dt}$$

as follows:

$$L = v \cdot \frac{dt}{di}$$

v is the actual voltage applied across the primary winding, **dt** is the maximum pulse width driving the transformer, **di** is the peak-to-peak ripple current through the primary winding.

dv/dt immunity

The **dv/dt** immunity is directly linked to the winding to winding capacitance C_{WW}. The **dv/dt** induces a constant current through the C_{WW} from one side of the transformer to the other side depending on the **dv/dt** polarity. This current can be calculated using the classical capacitor charge equation:

$$i = C_{WW} \cdot \frac{dv}{dt}$$

The induced current must be kept below 100mA to be absorbed by the power supply at the receiver side during the dv/dt event. It is recommended to put a 1µF decoupling capacitor on the receiver power supply for dv/dt>10kV/µs.

DESIGN EXAMPLE

Magnetic core selection

For the core material a good choice can be the 4C65[1] from Ferroxcube, which is a NiZn ferrite widely used in RF applications. Its magnetic losses are very low in the frequency range of operation of the XTR40010 (6-20MHz). The Curie temperature T_C is higher than 350°C. To be able to compute the saturation current, the core shape must be defined. The best choice for good DC isolation and high dV/dt immunity is the toroid shape. The toroid shape ensures a good magnetic coupling together with the possibility to have a significant physical distance between the primary and secondary windings to minimize the winding to winding capacitance C_{WW}. The smallest toroid shape available in the Ferroxcube catalog is the TN9/6/3[2] . Knowing the core shape and material, the current*turn ratio is obtained:

$$NI = \frac{B_{max} l_e}{\mu_0 \mu_r} = \frac{380mT \cdot 22.9mm}{4\pi 10^{-7} \cdot 125} \approx 55.4\ [A \cdot turn]$$

As described in the last section, the maximum current must be kept below 16mA which is the minimum guaranteed drive capability of the XTR40010 transmitter. With this limit for the current, the number of turns that will make the core enter into saturation is 3437.

Primary inductance calculation

Assuming the minimum carrier frequency to transmit through the transformer is 6MHz with 50% duty-cycle (t_{ON}=83.33ns) and that the current ripple is 32mA (transition from +16mA to -16mA), the primary inductance can be calculated as follows:

$$L_P \geq v \cdot \frac{dt}{di} = 5V \cdot \frac{83.33ns}{32mA} \approx 13\mu H$$

Once the core material and shape are known, the number of turns for making the 13µH primary inductance is:

$$N_P \geq \sqrt{\frac{L_P}{A_L}} = \sqrt{\frac{13\mu H}{30nH/turn^2}} \approx 21\ turns$$

where A_L is the nominal inductance of the core given in the datasheet of TN9/6/3-4C65.

As the drive level needed at the secondary side (on the receiver of the XTR40010) is the same as the drive level of the primary side, i.e. 5V, the transformation ratio must be kept at 1 to optimize the efficiency. Hence, the secondary windings number is:

$$N_S = N_P = 21\ turns$$

For a 20MHz carrier, transformer parameters are the following:

$$L_P \geq v \cdot \frac{dt}{di} = 5V \cdot \frac{25ns}{32mA} \approx 3.9\mu H$$
$$N_P \geq \sqrt{\frac{L_P}{A_L}} = \sqrt{\frac{3.9\mu H}{30nH/turn^2}} \approx 12\ turns$$
$$N_S = N_P = 12\ turns$$

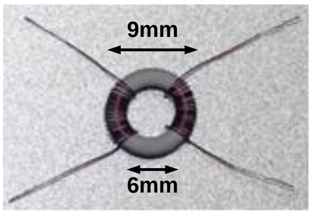
dV/dt immunity

The maximum winding to winding capacitance C_{WW} can be calculated for a dV/dt of 50kV/µs using the equation given in the last section:

$$C_{WW} = \frac{i \cdot dt}{dV} = \frac{100mA \cdot 1\mu s}{50kV} = 2pF$$

After realization using a 0.19mm high-temperature enameled copper wire and TN9/6/3-4C65 core, hereafter are the measured transformer equivalent circuit parameters:

- **R_{PRIM}=1.33Ω**
- **L_P=15.34µH**
- **L_S=5.87µH**
- **R_{SEC}=1.29Ω**
- **C_{WW}=0.34pF**



1 http://www.ferroxcube.com/prod/assets/4c65.pdf
2 http://www.ferroxcube.com/prod/assets/tn963.pdf

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