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CIRCUIT TECHNOLOGY

APPLICATION NOTE #113

Transceiver Input Impedance

INTRODUCTION

This application note will outline a procedure to find the transceiver input impedance when it has power removed or when it has power on but is in a transmit inhibited state. If one looks at transceiver manufacturer's data sheets, this can be one of the most confusing specifications for an end user. Some manufacturers of transceivers call this specification "Transmitter Output Resistance", which it is not, while other manufacturers give a "Receiver Input Resistance" and a "Transmitter Output Resistance" with the condition that the transmitter is not transmitting (inhibited) and expect the end user to figure out if that means power on or off and at what frequency it is measured. Very few manufacturers state the measurement condition or even refer to the MIL-STD-1553B specification. This is one of the most under-specified parameters on any data sheet, and, is vague at best on how it relates to the MIL-STD-1553B specification.

The MIL-STD-1553 Specification

The specification refers not to the transceiver input impedance but rather to the terminal input impedance of which the transceiver is only one component. The other component is the "**Isolation Transformer**" that connects the transceiver to the bus, either directly or through a transformer coupled stub. The applicable paragraphs from MIL-STD-1553B are **4.5.2.1.2.3 "Input Impedance"** for terminals with transformer coupled stubs and **4.5.2.2.2.3 "Input Impedance"** for terminals with direct coupled stubs. Both specifications combined read, **"the magnitude of the terminal input impedance, when the RT is not transmitting, or has power removed, shall be a minimum of 1000 ohms (transformer coupled stub) or 2000 ohms (direct coupled stubs) within the frequency range of 75.0kHz to 1.0MHz. This impedance is that measured line-to-line at point A on Figure 9 (transformer coupled stub) or Figure 10 (direct coupled stubs).** Figure 9 and 10, from MIL-STD-1553B, are reproduced here as Figures 1 and 2 for convenience**.** In order to determine if the input impedance of the transceiver combined with the isolation transformer will make the terminal input impedance specification, as stated above, one must know the transceiver's input impedance as well as the transformer's self impedance at the specified frequencies. The transceivers input impedance is made up of two components;

1. The transmitter's input impedance when power is removed or when not transmitting (standby).
2. The receiver's input impedance when power is removed or in standby.

Since the MIL-STD-1553B specification is of the terminal input impedance, the transceiver's transmitter and receiver's input impedances represent a parallel impedance and are not mutually exclusive, as some manufacturer's data sheets would suggest. The input impedance specification of the **Isolation Transformer**, can be taken from the transformer manufacturer's data sheet. In almost all cases this impedance specification is **4000 ohms minimum, for frequencies between 75KHz and 1MHz**. Therefore a method for measuring the transceiver's input impedance needs to be determined.

Transceiver Input Impedance

One method, that will yield accurate results, is to use an impedance analyzer. The HP 4192A LF Impedance Analyzer will be used to determine the transceiver's input impedance over the frequency band of interest. One feature of this analyzer, the ability to "zero" out or reference null any circuit point, will be used to make this measurement. For the purposes of transceiver input impedance measurement, either Figure 1 or Figure 2 can be used.

Databus Interface Using Transformer Coupling – Figure 9, MIL-STD-1553B

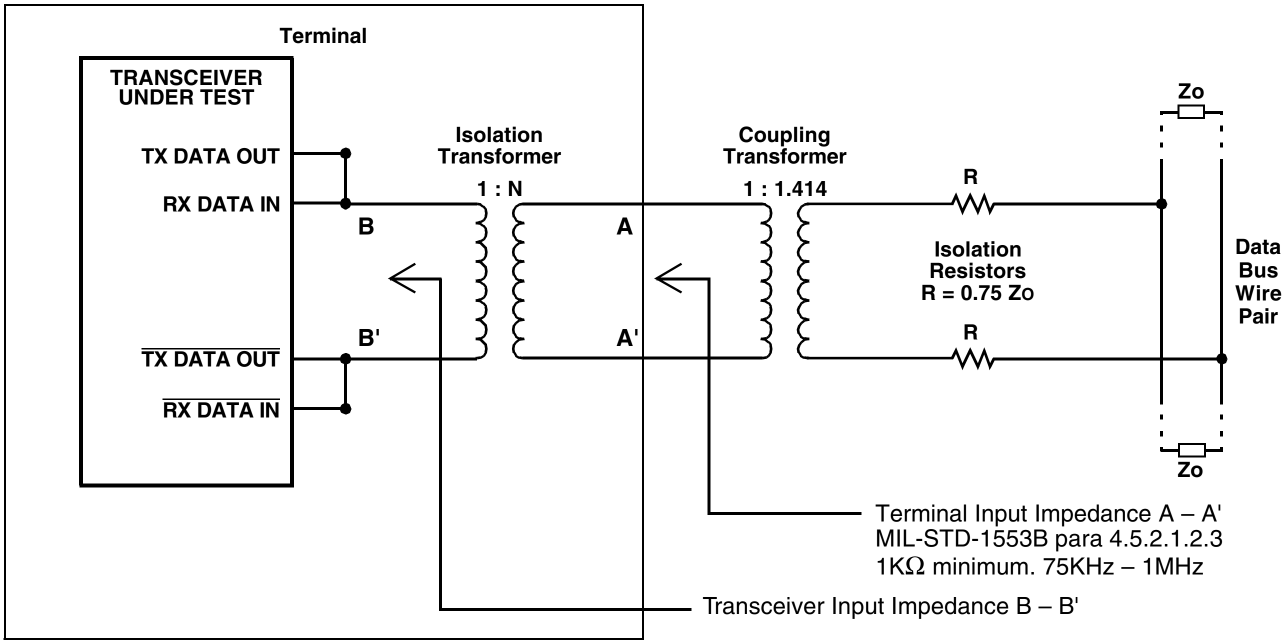

FIGURE 1

Databus Interface Using Direct Coupling – Figure 10, MIL-STD-1553B

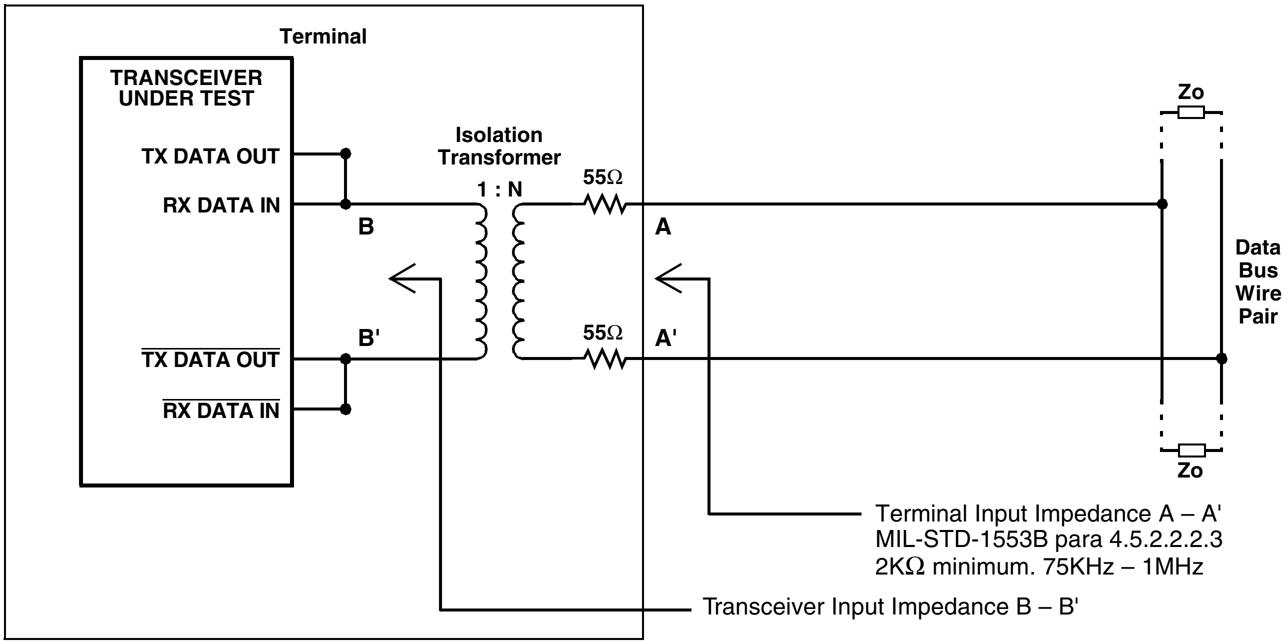

FIGURE 2

Transceiver Input Impedance (con't)

The results will be the same for either circuit configuration; it is simply which method is more convenient for the user. We will use the circuit of Figure 2 for this measurement and set the analyzer to measure the magnitude of the impedance Z on Display A, the angle theta on Display B (set for radian readout), and the frequency set to 1MHz. This frequency is chosen, even thought the specification is any frequency between 75KHz and 1MHz, because it represents the worst case impedance. The HP 4192A analyzer leads are placed across circuit points A – A', which would be the Terminal's input/output. With the transceiver removed from the circuit, the analyzer's inputs are "zeroed" for the open circuit condition. Then a short circuit is placed across circuit points B – B' and the analyzer is again "zeroed" for the short circuit condition. The transceiver under test is inserted and the analyzer is set to measure the impedance of the transceiver directly. **The Isolation transformer' self-impedance has been zeroed out of the measurement** and the only transformer parameter that remains in the measurement is the transformer turns ratio. Once the transceiver impedance at 1MHz is known, then an equivalent Resistor/Capacitor parallel circuit can be found that represents the transceiver's input impedance (parallel combination of transmitter and receiver), at any frequency. Figure 3 represents the Transceiver equivalent circuit. The Terminal input impedance can now be found for the power off and power on-not transmitting (TX inhibit) cases.

Transceiver Input Impedance, Resistor / Capacitor Equivalent Circuits

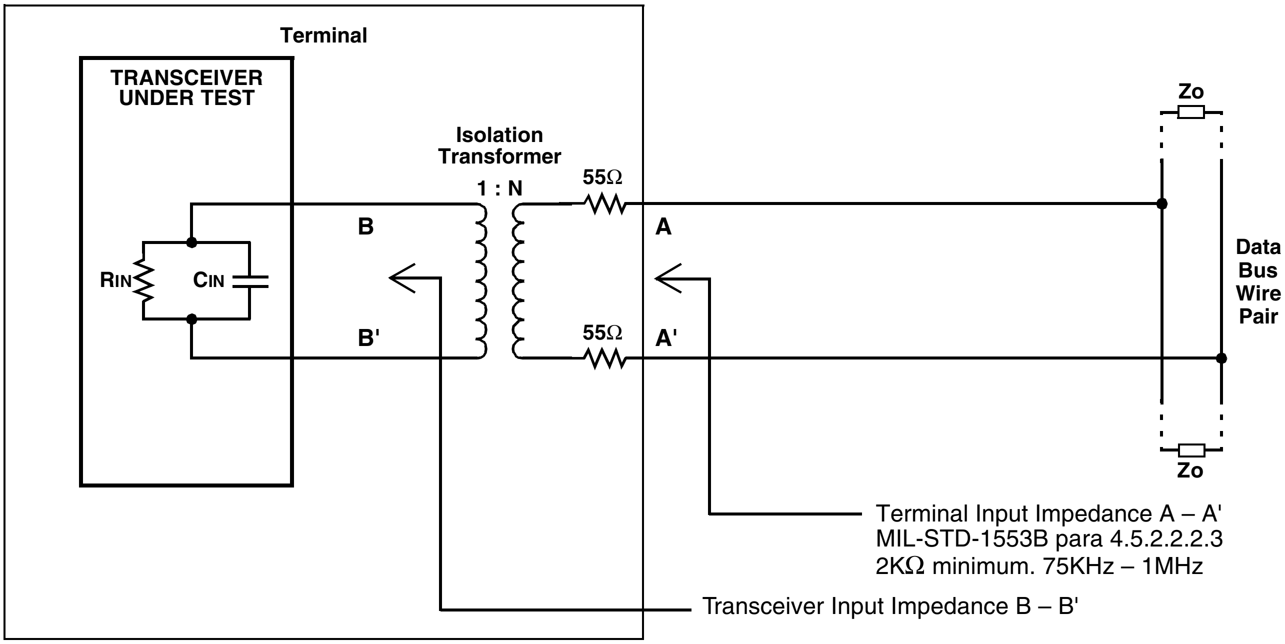

FIGURE 3

Measurement and Calculation

The following formulas apply to the circuit of Figure 3 with the following definitions:

ZSEC = Magnitude of the Impedance seen looking into points A - A.
ZPRI = Magnitude of the Impedance seen looking into points B - B'
TR = Transformer turns ratio = N (Secondary turns / Primary turns)
CIN = Equivalent Input Capacitance
RIN = Equivalent input resistance
ω = Radian frequency of interest - omega
θ = Angle of ZSEC in radians - theta

$$|Zpri| = \frac{Zsec}{TR^2}$$ **Equation 1**

$$Cin = \frac{1}{\sqrt{\omega^2 + \left[\frac{1}{\left(\frac{\tan(\theta)}{\omega}\right)}\right]^2} \cdot (Zpri)}$$ **Equation 2**

$$Rin = \frac{\tan\theta}{\omega \cdot Cin}$$ **Equation 3**

The magnitude of ZSEC and its angle, theta, are read directly from the HP4192A analyzer displays. Then ZPRI is calculated. With ZPRI known CIN and then RIN can be calculated. The analyzer measurements can be done for the power off condition and then for the power on-transmitter inhibited, condition. Each will yield a different parallel RC circuit. With the RC equivalent circuit and the minimum self-impedance of the Isolation Transformer, the minimum Terminal input impedance can be calculated for any frequency between 75KHz and 1MHz. Alternately one can measure the magnitude and angle with the analyzer for any frequency between 75KHz and 1MHz. But one must “zero out” the transformer self-impedance at any frequency measured to get Transceiver’s input impedance and then apply Equation 1.

To calculate the Transceiver’s input impedance at any frequency between 75KHz and 1MHz, once the parallel RC network is known, the following formula is used:

$$Zpri = \frac{\frac{1}{Cin}}{\sqrt{\omega^2 + \left(\frac{1}{Rin \cdot Cin}\right)^2}}$$ **Equation 4,** $$\theta = -\operatorname{atan}(\omega \cdot Rin \cdot Cin)$$ **Equation 5**

The minimum Terminal impedance can then be calculated for each frequency with the following formula:

Minimum Terminal input impedance = ZSEC (ZPRI * TR^2) || 4Kohms, angle = theta.

Where ZPRI is the Transceiver’s calculated impedance at any frequency and theta is the calculated angle and ZSEC is the transformed primary impedance.

Two sample calculations follow using the ACT 4487 and ACT 4454 hybrids. The ACT 4487 transceiver is a 3 input supply and utilizes a transformer with a 1.414:1 turns ratio for direct coupled stubs and a 2:1 turns ratio for transformer coupled stubs. The ARX 4454 transceiver is a single +5V supply and utilizes a transformer with a 1:2.5 turns ratio for direct coupled stubs and a 1:1.7675 turns ratio for transformer coupled stubs.

Sample Calculation 1 – Transceiver Input Impedance for the ACT4487, power off

Using the circuit of Figure 2, the following measurements were made after “zeroing out” the Isolation transformer’s self–impedance at 1MHz.

$$Zsec = 13.6\times10^{3}\Omega \qquad TR = 0.70$$

$$\theta = -0.349 \text{ radians} \qquad f = 1\times10^{6}$$

$$\omega = 2\cdot\Pi\cdot f$$

From the above equations:

$$|Zpri| = \frac{Zsec}{TR^{2}} \quad \textbf{Equation 1} \qquad Zpri = 2.721\times10^{4}$$

$$Cin = \frac{1}{\sqrt{\omega^{2}+\left[\frac{1}{\left(\frac{\tan(\theta)}{\omega}\right)}\right]^{2}}\cdot(Zpri)} \quad \textbf{Equation 2} \qquad Cin = 2\times10^{-12}$$

$$Rin = \frac{\tan(\omega)}{\omega\cdot Cin} \quad \textbf{Equation 3} \qquad Rin = 2.895\times10^{4}$$

For the power off condition the ACT 4487 Transceiver looks like a 28.95Kohm resistor in parallel with a 2 picofarad capacitor at 1MHz. The **minimum Terminal input impedance with the power off is:**

ZSEC || 4Kohms = 13.6Kohms || 4Kohms = 3.09Kohms > 2Kohm minimum

To calculate the Transceiver power off input impedance at 75KHz use equations 4 and 5 and change the frequency variable omega for 75KHz.

$$\omega = 4.712\times10^{5}$$

$$Cin = 2\times10^{-12}$$

$$Rin = 2.895\times10^{4}$$

$$|Zpri| = \frac{\frac{1}{Cin}}{\sqrt{\omega^{2}+\left(\frac{1}{Rin\cdot Cin}\right)^{2}}} \quad \textbf{Equation 4} \qquad Zpri = 2.894\times10^{4}\Omega$$

$$\theta = -\operatorname{atan}(\omega\cdot Rin\cdot Cin) \quad \textbf{Equation 5} \qquad \theta = -0.027 \textbf{ radians}$$

Therefore the Transceiver’s power off input impedance, at 75KHz, is 28.94Kohms at an angle of -0.027 radians or -1.547 degrees. The **minimum Terminal input impedance, at 75KHz, with power off is:**

28.94Kohms * (0.707)^{2} || 4Kohms = 14.47Kohms || 4Kohms = 3.13Kohms

Sample Calculation 2 – Transceiver Input Impedance for the ACT4454, power off

Again using the circuit of Figure 2, the following measurements were made after “zeroing out” the Isolation transformer’s self-impedance at 1MHz.

$$Zsec = 16\times10^{3}\Omega \qquad TR = 2.5$$

$$\theta = -1.36 \text{ radians} \qquad f = 1\times10^{6}$$

$$\omega = 2\cdot\Pi\cdot f$$

From the above equations:

$$|Zpri| = \frac{Zsec}{TR^{2}} \quad \textbf{Equation 1} \qquad Zpri = 2.56\times10^{3}$$

$$Cin = \frac{1}{\sqrt{\omega^{2}+\left[\frac{1}{\left(\frac{\tan(\theta)}{\omega}\right)}\right]^{2}}\cdot(Zpri)} \quad \textbf{Equation 2} \qquad Cin = 6.079\times10^{-11}$$

$$Rin = \frac{\tan(\theta)}{\omega\cdot Cin} \quad \textbf{Equation 3} \qquad Rin = 1.223\times10^{4}$$

For the power off condition the ACT 4454 Transceiver looks like a 2.56Kohm resistor in parallel with a 60.8 picofarad capacitor at 1MHz. The **minimum Terminal input impedance with the power off is:**

ZSEC || 4Kohms = 16Kohms || 4Kohms = 3.2Kohms > 2Kohm minimum

To calculate the Transceiver power off input impedance at 75KHz use equations 4 and 5 and change the frequency variable omega to 75KHz.

$$\omega = 4.712\times10^{5}$$

$$Cin = 60.79\times10^{-12}$$

$$Rin = 1.223\times10^{4}$$

$$|Zpri| = \frac{\frac{1}{Cin}}{\sqrt{\omega^{2}+\left(\frac{1}{Rin\cdot Cin}\right)^{2}}} \quad \textbf{Equation 4} \qquad Zpri = 1.155\times10^{4}\Omega$$

$$\theta = -\operatorname{atan}(\omega\cdot Rin\cdot Cin) \quad \textbf{Equation 5} \qquad \theta = -0.337 \text{ radians}$$

Therefore the Transceiver’s power off input impedance, at 75KHz, is 11.55Kohms at an angle of -0.337 radians or -19.3 degrees. The minimum Terminal input impedance, at 75KHz, with power off is:

11.55Kohms * $(2.5)^{2}$ || 4Kohms = 72.2Kohms || 4Kohms = 3.79Kohms

Conclusion

All of the above measurements can be made with the power on and with the transmitter in the inhibited mode. An equivalent parallel RC circuit can be found, for the Transceiver input impedance, under this condition. The equations are valid for either the transformer coupled or the direct coupled databus connection circuits. The only parameter that changes from one circuit connection to the next is the turns ratio of the Isolation transformer.

In general the MIL-STD-1553B specification is hard to violate since the Isolation transformer is usually much better than it's minimum specification of 4Kohms from 75KHz to 1MHz. In most cases manufacturers measure this parameter for only the 1MHz case since it represents the worst case frequency for input impedance. For any Transceiver, with an Isolation transformer of any turns-ratio, the minimum Transceiver input impedance reflected to the Isolation transformer secondary, "ZSEC", must be equal to or greater than 4Kohms to make the minimum Terminal input impedance specification as stated in paragraph **4.5.2.2.2.3 (2Kohm)** for the direct coupled case, and must be equal to or greater than 2Kohms to make the minimum Terminal input impedance specification as stated in paragraph **4.5.2.1.2.3 (1Kohm)** for the transformer coupled case.

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