AN-1519 DP83848 PHYTER Transformerless Ethernet Operation

ABSTRACT

This application report describes a method for using Texas Instruments PHYTER™ products without transformer magnetics. This includes a list of recommendations for configuring transformerless systems. A description of a typical network configuration is provided, followed by descriptions of non-typical transformerless configurations. Finally, this application note presents PHYTER product performance data recorded from a transformerless configuration.

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1 Introduction

PHYTER products are designed for robust operation to meet the needs of a variety of end user applications. Non-typical applications which are sensitive to cost, utilize short distance PCB connections, or even extreme environmental conditions may benefit from operation without the use of a transformer. Examples of such applications include extreme environment short distance cable applications, and backplane applications.

This application report is applicable to the following products:

DP83848C	DP83848Q-Q1
DP83848I	DP83849C
DP83848YB	DP83849I
DP83848M	DP83849ID
DP83848T	DP83849IF
DP83848H	DP83620
DP83848J	DP83630
DP83848K	DP83640
DP83848VYB	

2 Recommendations

In general, it is recommended that transformerless configurations utilize non-polarized blocking capacitors with DC voltage tolerance ratings that meet the needs of specific applications. See Figure 5. It is also recommended that blocking capacitors have a minimum capacitance of 33 nF to meet IEEE 802.3 impedance specifications, and a maximum capacitance constrained by application specific DC blocking specifications. It is also recommended that forced 100 Mb/s operation be utilized.

In general, network connections configured using non-typical topologies can raise application specific concerns, especially when node connection lengths exceed 1 meter. Therefore, it is recommended that network designs utilizing non-typical topologies be verified at the specific application level.

3 Typical Network Configuration Using Transformer Isolation

To understand non-typical transformerless application development constraints, it is first necessary to understand physical network services and signaling, and the functions that transformers provide in typical applications.

A typical network configuration consists of a point to point connection, through a cable, between two physical layer devices. Figure 1 shows a schematic for a typical transformer interface. The transmitter and the receiver of each node are DC isolated from the network cable by 1:1 transformers.

A typical network configuration provides the services of autonegotiation, Auto-MDIX, 10 Mb/s operation, and 100 Mb/s operation. Autonegotiation is a feature which automatically determines the optimal network operating speed. Auto-MDIX is a feature allowing either straight-through or cross-over cables to be used.

Autonegotiation uses link pulses to determine the operating mode. Link pulses appear as differential 2.5V signals when ideal 50 ohm balanced loading is provided. 100 Mb/s data appears as +1V, 0V, and -1V differential signals, and 10 Mb/s data appears as +2.5V and -2.5V differential signals across ideal loading. See Figure 2, Figure 3, and Figure 4.

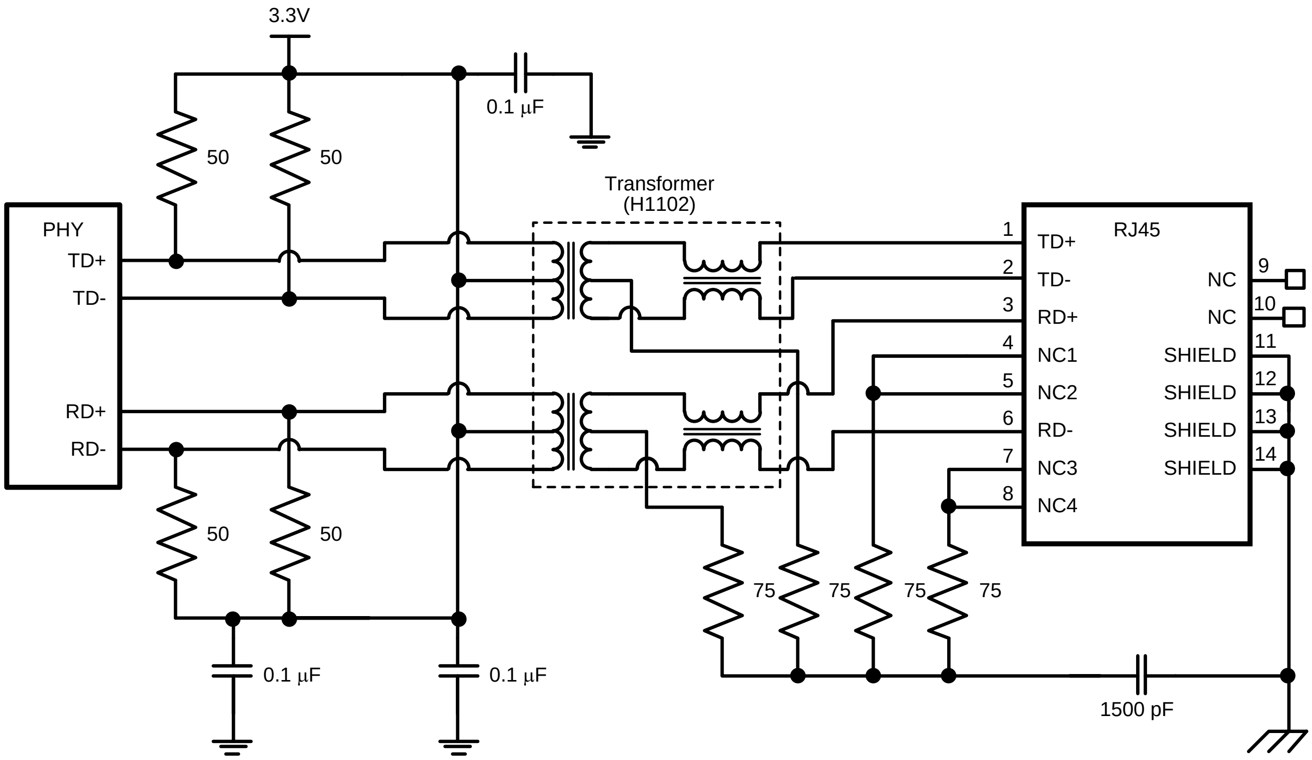

Figure 1. Typical 10/100 Mb/s Twisted Pair Interface

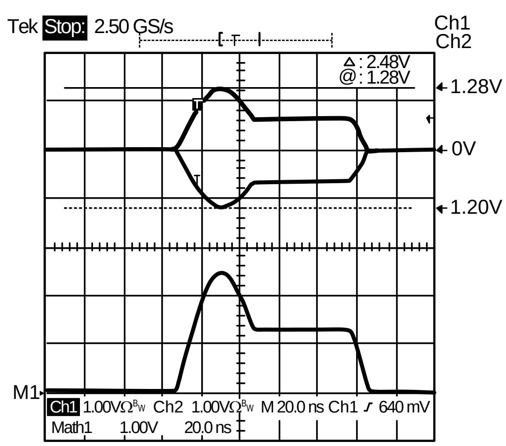

Figure 2. Sample Link Pulse waveform

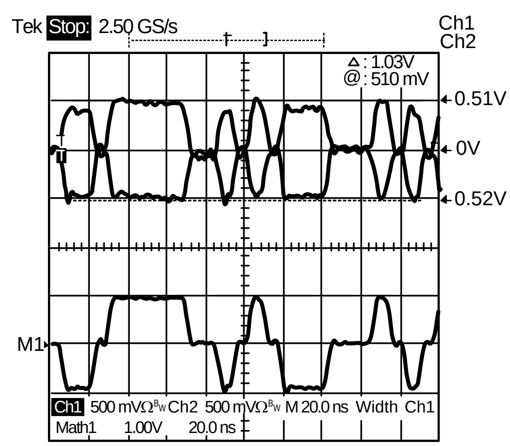

Figure 3. Sample 100 Mb/s Waveform (MLT-3)

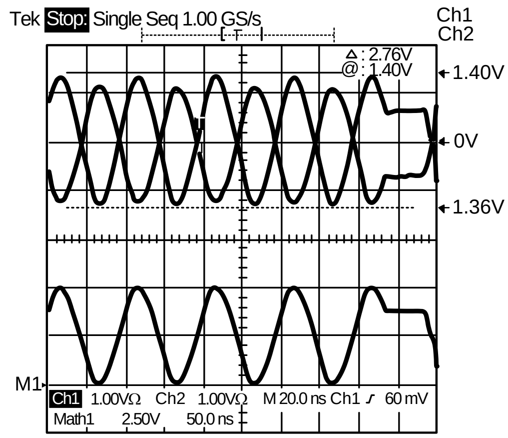

Figure 4. Sample 10 Mb/s Waveform

Transformers provide the functions of DC isolation from the cable, and DC biasing at the physical layer device.

Isolation is necessary to meet IEEE 802.3 AC and DC isolation specifications for cabled configurations. IEEE 802.3 isolation requirements are described in section 14.3.1.1 of the specification, and include the ability to sustain cable faults to 1500V 50 or 60 Hz or 2250Vdc voltage levels for 60 seconds.

PHYTER product transmitters and receivers are DC biased internally, from the transformer centertap, and through 50 ohm load resistors used in typical applications.

4 Transformerless Configuration

In order to meet the operational requirements of non-typical transformerless network applications, several requirements must be met. Physical layer component transmit and receive separation and biasing requirements must be met, as well as high voltage DC isolation to meet the specific safety requirements of the application.

For non-typical applications, the isolation that the transformer provides in typical configurations can be realized using non-polarized capacitors. See Figure 5.

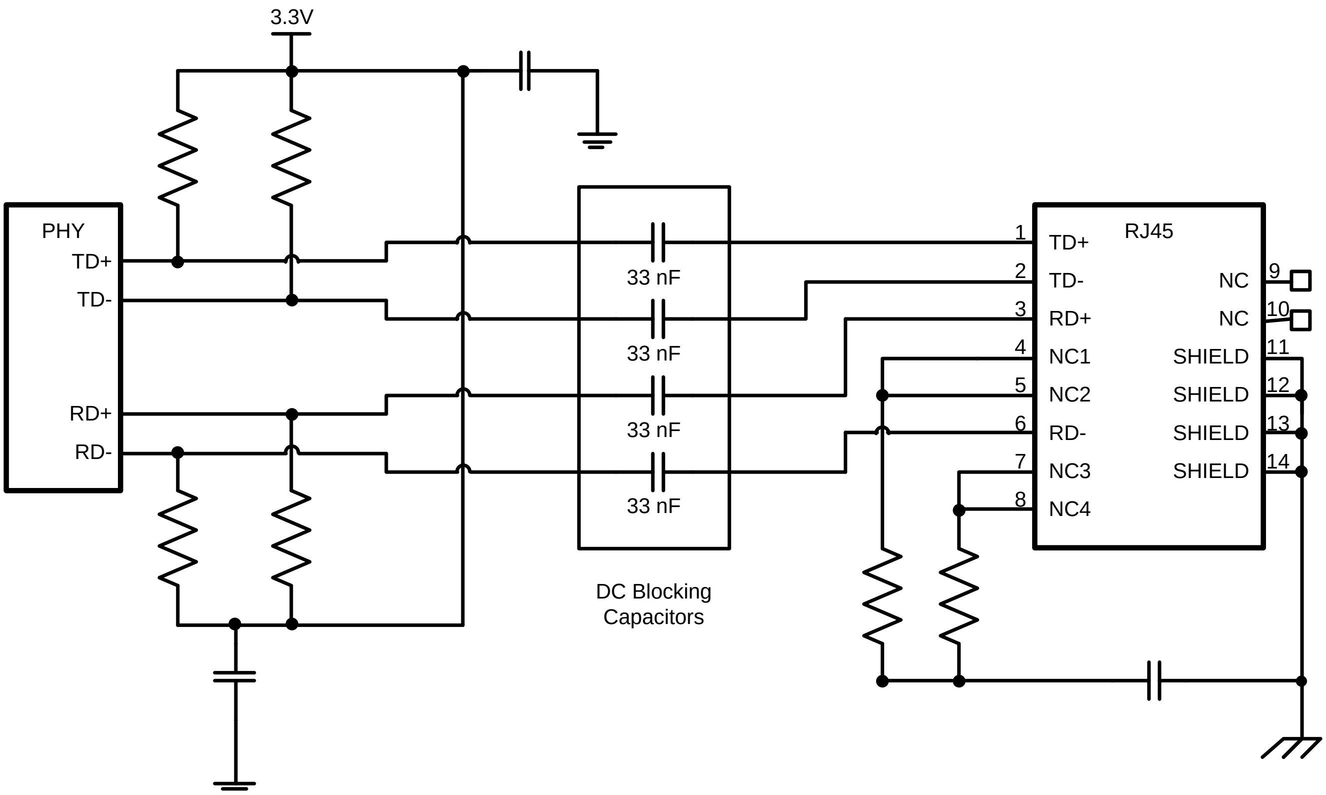

Figure 5. Transformerless Configuration

4.1 Transmit Requirements

A typical transformer based application includes a centertap connection to Vdd. 100 Mb/s signaling which is local to the component driver appears as 2.8V to 3.8V signaling across the transformer, with the polarity reversing to create +1V and -1V signaling at the transformer secondary. Refer to Figure 6. 10 Mb/s signaling appears as 2.05V to 4.55V signaling local to the component driver, with polarity reversing to create +2.5V and -2.5V signaling at the secondary of the transformer. Link pulses appear similar to 10 Mb/s signaling, without polarity switching. Refer to Figure 7.

In 100 Mb/s mode configured with blocking capacitors, the transmit DC bias voltage shifts. A “zero” state in 100 Mb/s operation corresponds to a DC bias voltage near 2.3V. Data signals appear as 1.8V to 2.8V signaling across the differential pair, which is within the operating range of the 100 Mb/s transmit drivers. Polarity reversing creates +1V and -1V signaling on the cable side of the capacitors. Refer to Figure 8.

In 10 Mb/s mode, the differential driver is biased to Vdd. When configured with blocking capacitors, each side of the differential pair operates separately, each dropping 2.5V across the differential load while the opposite signal remains fixed at Vdd. Thus, each signal switches between 3.3V and 0.8V, and 10 Mb/s signaling is asymmetrical (not balanced). On the cable side of the capacitors, the signal appears as +2.5V and -2.5V differential pulses. Link pulses appear as 2.5V pulses which do not switch polarity. Refer to Figure 9.

While 10 Mb/s signaling is operational within these signal voltage ranges, it is not ensured. Specifically, the 0.8V operating point is not ensured to function normally under all conditions. Also, differential signaling in 10 Mb/s transformerless operation is not symmetrical as it is when a transformer is used, so there is added EMI radiation risk. Therefore, it is recommended that transformerless operation be restricted to forced 100 Mb/s modes, with autonegotiation disabled.

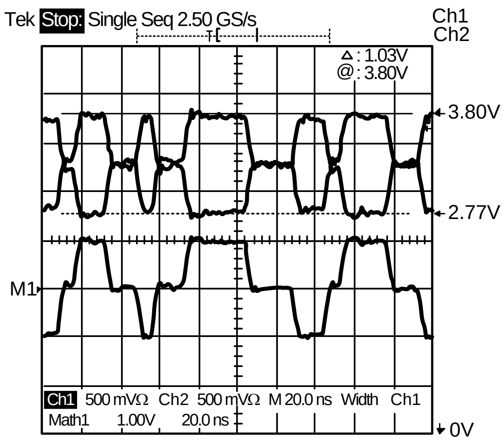

Figure 6. Sample 100 Mb/s Waveform

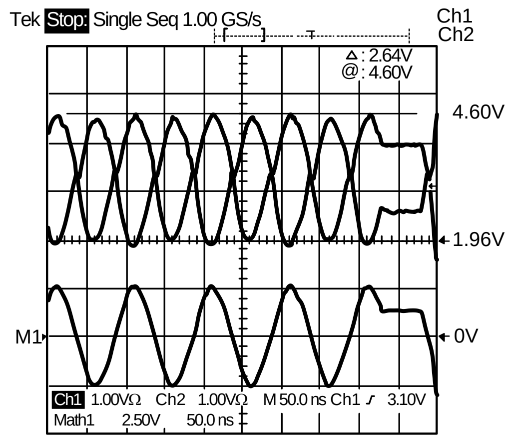

Figure 7. Sample 10 Mb/s Waveform

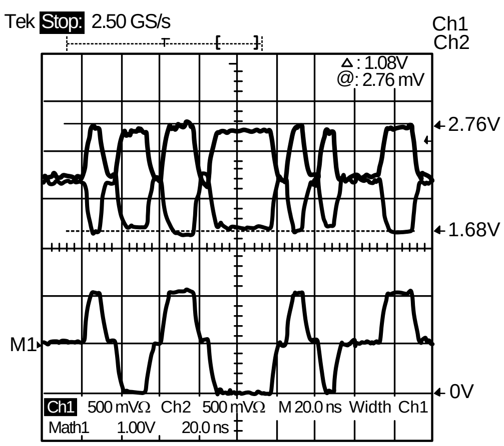

Figure 8. Sample 100 Mb/s Waveform With No Transformer

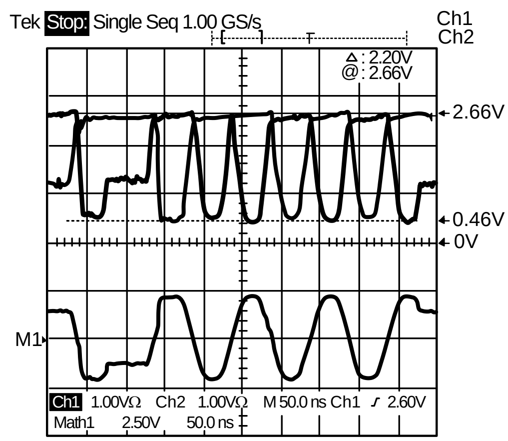

Figure 9. Sample 10 Mb/s Waveform With No Transformer

4.2 Receive Requirements

PHYTER component 100 Mb/s and 10 Mb/s receivers are self biased to Vdd, so the signals which appear at the receive side of the blocking caps are identical to the signals seen using a transformer.

Because the automatic MDIX switching feature is based on receive signal detection, MDIX functionality is not adversely affected by the use of blocking capacitors.

5 Capacitor Selection

Capacitors used for transformerless applications must be non-polarized, and meet application specific AC and DC isolation requirements. High voltage multi-layer ceramic capacitors are readily available for this purpose. With regard to choosing the value of the blocking capacitors, ANSI INCITS 263-1995 TP-PMD specifies that the physical layer must meet return loss standards for both magnitude and phase. For an unshielded twisted pair, the return loss must be greater than 16 dB, with an impedance range of 100 ± 15 ohms, nominally resistive with a phase angle less than 3° over the frequency range of 2 to 80 Mhz.

Since the impedance of a series capacitor is greatest at low frequencies, the 2 MHz operating point is of special interest. The minimum calculated capacitance value which meets this standard at 2 MHz is 30.42 nF. 33 nF is recommended because it represents the nearest standard value available, and is proven acceptable based on validation testing. The derivation for determining this value is attached as an appendix.

While there is no theoretical upper limit to the capacitance value, DC isolation specifications for non-polarized capacitors tend to decrease as capacitance increases.

6 Topology Considerations

Typical network configurations consist of two physical layer nodes connected through a cable with transformers at each node.

It is possible to connect a capacitive isolated node, to a capacitive coupled, transformer coupled node or a node with no isolation. The latter implies there will be only one set of blocking caps between two nodes. Refer to Figure 10. Connections can be made using 100 ohm twisted CAT5 cables or directly on PCB boards using 50 ohm traces (as in backplane applications).

While any of these possible topologies work well when connection distances are shorter than 1 meter, each topology may present application specific risks as connection distances increase.

Therefore, network connections configured using non-typical topologies need to be verified at the specific application level.

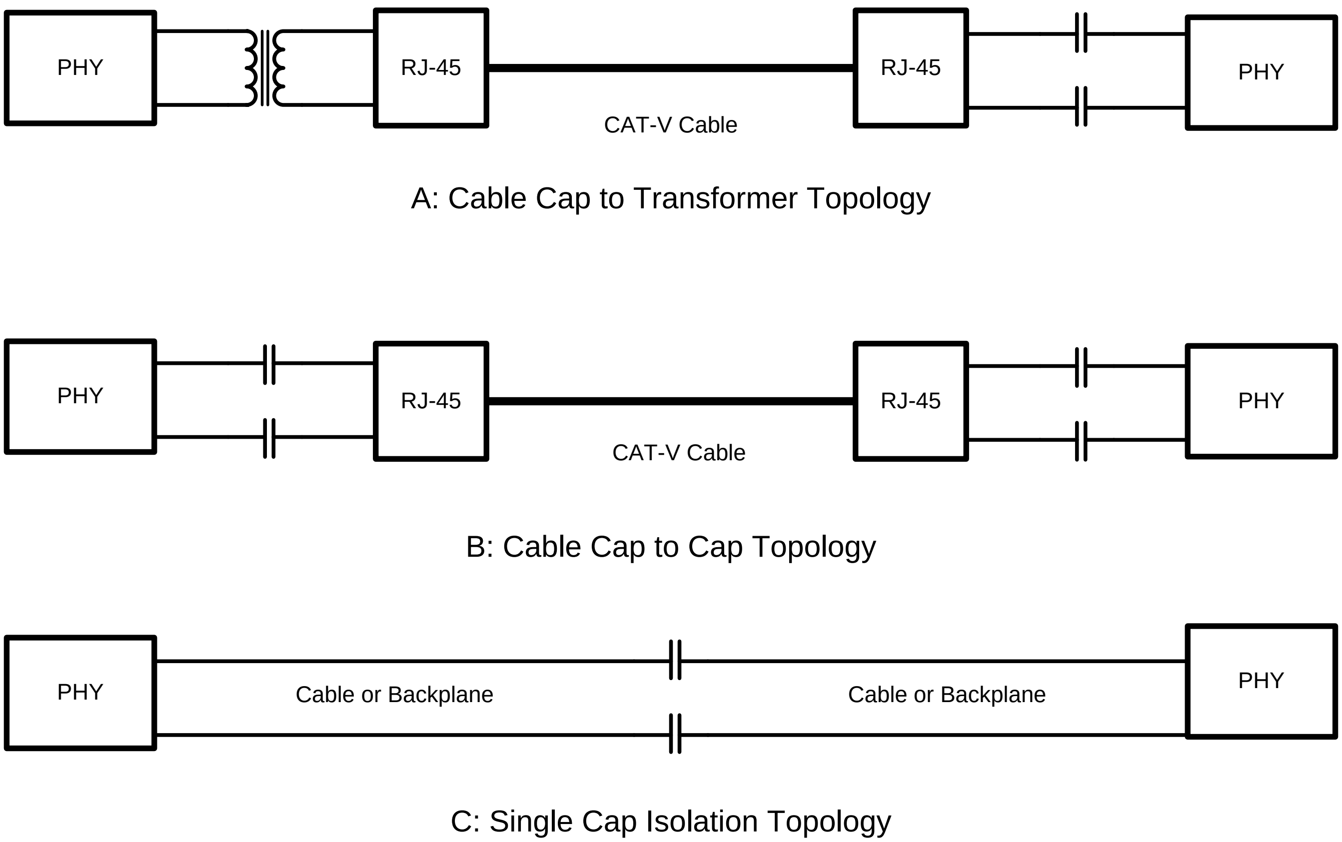

Figure 10. Non-typical Network Connection Topologies

7 Validation Results

To validate the performance of the transformerless implementation, a DP83848 device was configured as represented schematically in Figure 5 using both 0.1 uF and 33 nF capacitors. Standard IEEE compliance testing as well as bit error rate testing was performed. Bit error testing was performed with a traditional link partner, which utilized magnetics, and with a transformerless link partner.

IEEE compliance testing was performed on the transformerless interface with both straight and crossover cables. The results showed compliance for critical 100 Mb/s mode parameters (jitter, tx/rx return loss, Vod). Other IEEE tests, which are designed to simulate worst-case cable loading, did not pass, thus supporting the recommendation to use short distance configurations in non-typical transformerless applications.

In 10 Mb/s mode, as predicted, many of the tests resulted in non-compliance results. For the bit error rate tests conducted, error free operation of the transformerless circuit was obtained up to 100 meters in 10 Mb/s mode and in 100 Mb/s mode.

In each test, the link partners were configured to operate in both 10 Mb/s and 100 Mb/s modes, and the circuit under test was allowed to auto-negotiate with its link partner.

The following bit error rate test parameters were used:

- Packet lengths: 1514 bytes (+CRC)
- Minimum Interframe Gap (960 ns for 100 Mb/s, 9.6 us for 10 Mb/s)
- 10 million packets sent (100 Mb/s mode)
- 1 million packets sent (10 Mb/s mode)
- Full-duplex
- Auto-MDIX
- Cable lengths: up to 100 m
- Energy Detect Disabled (default state)

Results from tests performed with 0.1 uF capacitors and 33 nF capacitors were similar. Figure 11 through Figure 14 represent the 100 Mb/s passing results using 33 nF capacitors. In each diagram, the bold vertical lines represent passing limits.

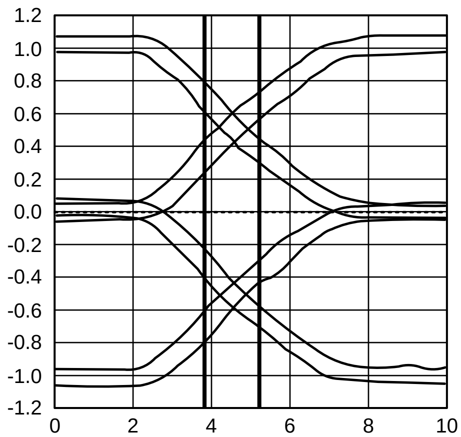

Figure 11. 100 Mb/s Jitter with 33 nf Blocking Capacitors

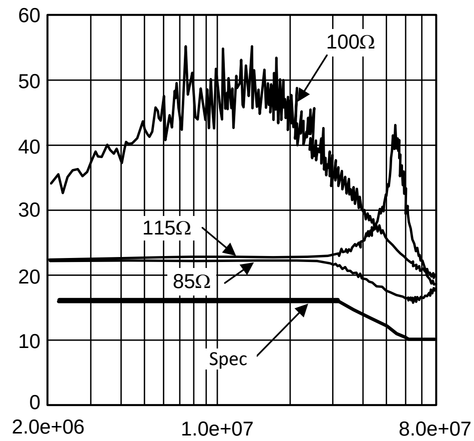

Figure 12. 100 Mb/s Receive Return Loss with 33 nf Blocking Capacitors

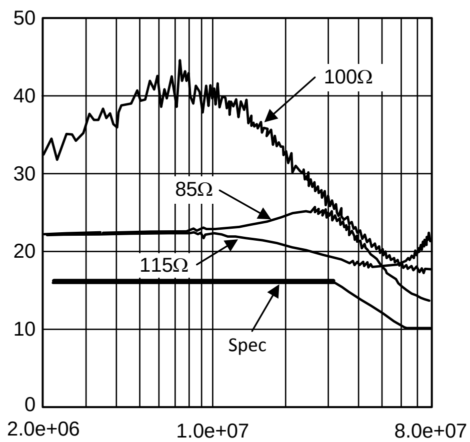

Figure 13. 100 Mb/s Transmit Return Loss with 33 nf Blocking Capacitors

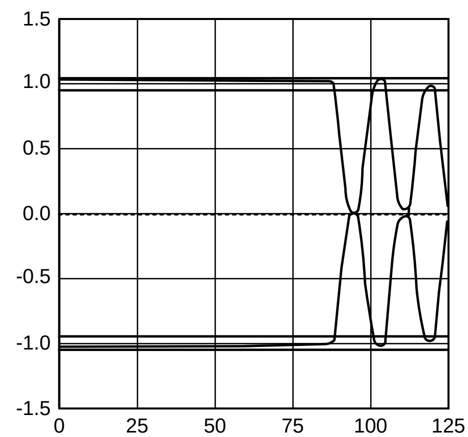

Figure 14. 100 Mb/s Vod with 33 nf Blocking Capacitors

8 Summary

In summary, this paper presents recommendations for configuring PHYTER products in non-typical transformerless network applications. Recommendations include the use of 33 nF or larger non-polarized capacitors for DC isolation from a network cable, with a minimum DC isolation rating which suits the individual application. Because transformerless configuration results in non-symmetrical 10 MB/s signaling which exceeds the recommended operating range of the 10 Mb/s transmission drivers, it is recommended that forced 100 Mb/s operation be utilized.

In support of these recommendations, operating conditions required by PHYTER product component transmit and receive functions, were presented. Test results were presented which validate PHYTER bit error and IEEE standard compliance performance.

Appendix A Calculating the Minimum Recommended Capacitance

The minimum series capacitance can be calculated using the following equation for return loss:

$$\text{Return Loss} = -20 \text{ Log } |(\text{Zload} - \text{Zo})| \,/\, |(\text{Zload} + \text{Zo})| \quad (1)$$

Where:

Return Loss = 16 dB

Zo = 100 ohms

Zload = 100 + 1/jωC + 1/jωC ohms (from circuit in Figure 5).

Substituting the above values into Equation 1 and solving, results in:

$$\omega C = 0.0622 \quad (2)$$

At 2 MHz, the minimum series blocking capacitor value, C, would be 4.95 nF based on the return loss requirement.

The ANSI standard also specifies a limitation on the phase angle of the load (+/-3° maximum). For the phase calculation, a 100 ohm load at -3° phase angle produces a worst case capacitance.

$$2 \times 1/\omega C = 100 \sin(-3°) = -5.233 \quad (3)$$

Solving Equation 3 for C at 2 MHz gives 30.42 nF, which represents minimum capacitor value required to meet the phase specification. The recommendation of 33 nF is the nearest standard value generally available, and proved acceptable based on validation testing.

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