Application Report
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TLK100 Ethernet PHY Transformerless Operation

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ABSTRACT

The TLK100 is a single-port Ethernet PHY for 10BaseT and 100Base TX signaling.

This application report describes a method for using Texas Instruments Ethernet PHY products without a transformer.

A transformerless mode has great benefit in the following scenarios:

1. Nontypical applications which are sensitive to cost
2. Short-distance, printed-circuit board connections (compromises cable reach)
3. Industrial temperature operation

This application report describes how to use the TLK100 Ethernet PHY in a transformerless mode. Also described are the schemes for configuring the TLK100 in this mode and the resulting behavior and performance of the PHY.

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1 Typical Network Configuration

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.

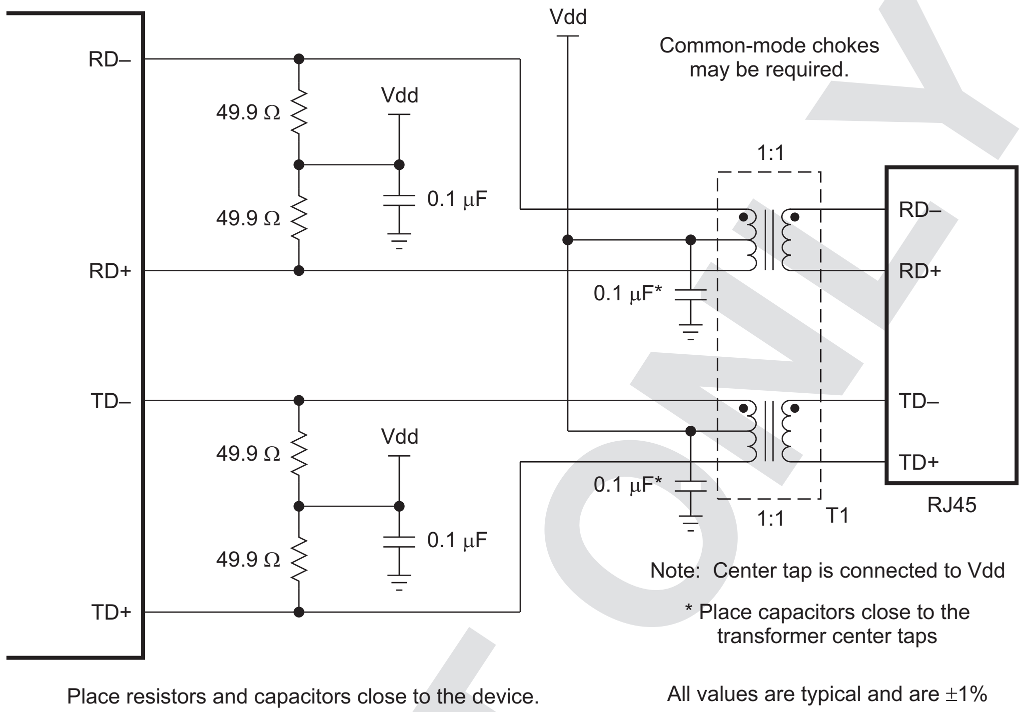

Figure 1. Typical 10/100 MB/s Twisted-Pair Interface

In default configuration, the chip wakes up when auto-negotiation is enabled with 10 Mb/s and 100 Mb/s. The auto-MDIX is also enabled in order to decide which pair to use for RX and which pair to use for TX, allowing either straight-through or crossover cables to be used. In auto-negotiation, the PHYs communicate with the link partner automatically in order to determine the optimal network operating speed.

Auto-negotiation uses link pulses to determine the operating mode. Link pulses appear as differential 2.5-V signals when ideal 50-Ω balanced loading is provided. 100-Mb/s data appears as +1-V, 0-V, and –1-V differential signals, and 10-Mb/s data appears as +2-5 V and –2-5 V differential signals across ideal loading. Figure 2, Figure 3, and Figure 4 shows scope recording of the preceding signals.

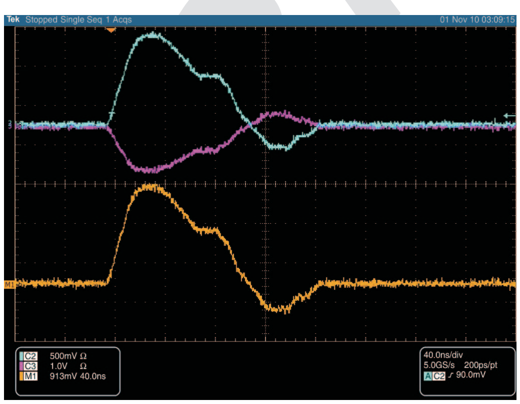

Figure 2. Link Pulse Waveform

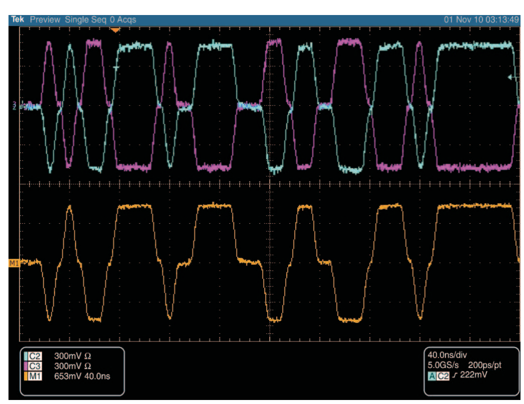

Figure 3. 100-BT (MLT3) Waveform

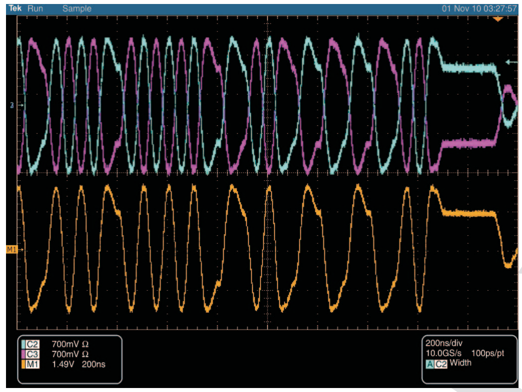

Figure 4. 10-MB/s Waveform

Transformers provide the functions of dc isolation from the cable. 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 1500-V, 50- or 60-Hz or 2250-V_{DC} voltage levels for 60 seconds.

The TLK100 transmitter and receiver are dc biased internally from the transformer center tap and through 50-Ω load resistors used in typical applications. Figure 1 describes a transform connection between a PHY and the RJ45 connector.

2 Transformerless Configuration

For nontypical applications, the isolation that the transformer provides in typical configurations can be realized using nonpolarized capacitors. Figure 5 describes such implementation, where the capacitors replace the transformers in a PHY to RJ45 connection.

In order to meet the operational requirements and the specific safety requirements of nontypical transformerless network applications, several requirements must be made:

1. Physical layer component transmit and receive separation
2. Biasing requirements.
3. High voltage dc isolation.

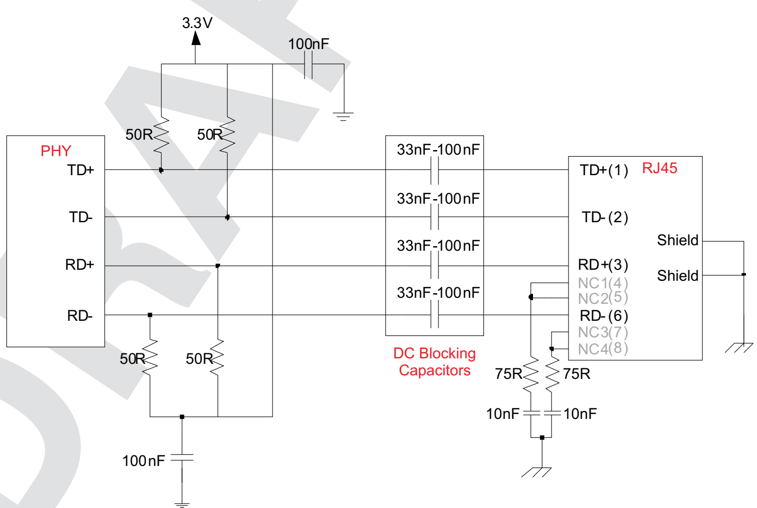

Figure 5. Transformerless Configuration

2.1 Transmitter Requirements

In 100-Mb/s mode, the differential driver is biased to V_{DD}. When configured with blocking capacitors, each side of the differential pair operates separately, and the transmit dc bias voltage shifts. A zero state in 100-Mb/s operation corresponds to a dc bias voltage near 3.3 V. Data signals appear as 3.8-V to 2.8-V signaling across the differential pair, which is within the operating range of the 100-Mb/s transmit drivers. Polarity reversing creates +1-V and –1-V signaling on the cable side of the capacitors (see Figure 6).

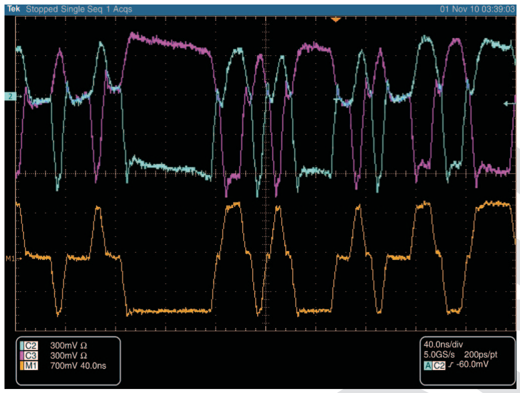

Figure 6. 100-MB/s Waveform Without Transformer

In 10-Mb/s mode, the differential driver is biased to V_{DD}. When configured with blocking capacitors, each side of the differential pair operates separately, each dropping 2.5 V across the differential load while the opposite signal remains fixed at V_{DD}. Thus, each signal switches between 3.3 V and 0.8 V, and 10-Mb/s signaling is asymmetrical (not balanced). On the cable side of the capacitors, the signal appears as +2.5-V and –2.5-V differential pulses. Link pulses appear as 2.5-V pulses which do not switch polarity (see Figure 7). Figure 8 shows scope recording of 10-Mb/t data signaling.

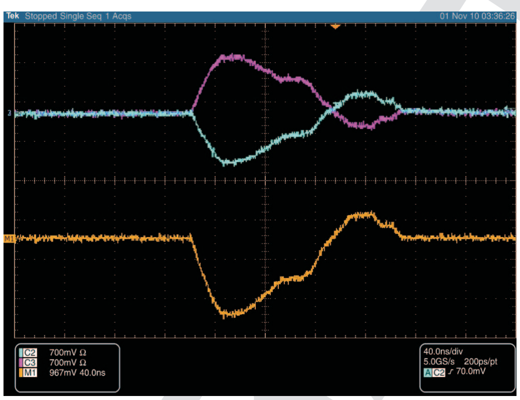

Figure 7. 10-MB/s Waveform Without Transformer

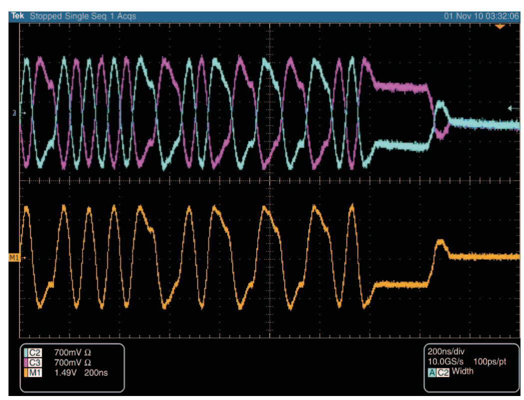

Figure 8. 10-MB/s Data Waveform

2.2 Receiver Requirements

In the TLK100 device, the receiver in both 100-Mb/s and 10-Mb/s modes is self-biased to V_{DD}, so, the received signals which appear at the transceiver side of the blocking capacitors are identical to the signals seen while using a transformer configuration.

Because the automatic MDIX switching feature is based on receive signal detection, the use of a blocking capacitor does not adversely affecting MDIX functionality.

3 Capacitor Selection

The specification requirements of the return loss for both magnitude and phase for an unshielded twisted pair must be greater than 16 dB at 2 MHz, with an impedance range of 100 ±15 Ω, nominally resistive with a phase angle less than 3° over the frequency range of 2-to-80 MHz (ANSI INCITS 263-1995) .

To meet the specification requirements, the capacitors used for transformerless applications must be selected with special consideration of the following parameters:

- The capacitors must be nonpolarized.
- The capacitors must meet the ac and dc isolation requirements.

Multilayer ceramic capacitors that withstand high voltages are the best option for transformerless operation.

The nearest standard value available which represents the standard requirements at 2 MHz is 33 nF (see Section 3.1).

Because the impedance of a series capacitor is greatest at low frequencies, the 2-MHz operating point is of special interest. Because dc isolation specifications for nonpolarized capacitors tend to decrease as capacitance increases, it is not recommended to use high-value capacitors.

3.1 Capacitors Calculation

The IEEE RL specification at 2 MHz is –16 dB. The following equation calculates ωC.

$$RL = 20 \cdot \log_{10}\left(\frac{Z_{Load} - Z_0}{Z_{Load} + Z_0}\right) = -16 \quad , \quad Z_0 = 100\ \Omega \quad , \quad Z_{Load} = Z_0 + 2 \cdot X_C$$

$$Z_{Load} = 137.66\ \Omega$$

Remembering that the frequency of interest is 2 MHz (worst-case impedance), the minimum series blocking capacitor value, C, is 4.23 nF based on the return loss requirement.

$$Z_{Load} = 100 + 2 \cdot X_C = 137.66\ \Omega$$

$$X_C = \frac{1}{\omega C} = 18.83\ \Omega \quad \Rightarrow \quad C = 4.23\, nF$$

The ANSI standard also specifies a limitation on the magnitude of phase angle of the load (±3° maximum). For the phase calculation, a 100 Ω gives:

$$\left(\frac{2/\omega C}{100}\right) = \tan(+3) = 0.0524 \quad \Rightarrow \quad C = 30.4nF$$

The closest available capacitor is 33 nF.

4 Network Connection Topologies

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 transformer-coupled node or connecting capacitive isolated node to capacitive isolated node as shown in Figure 9.

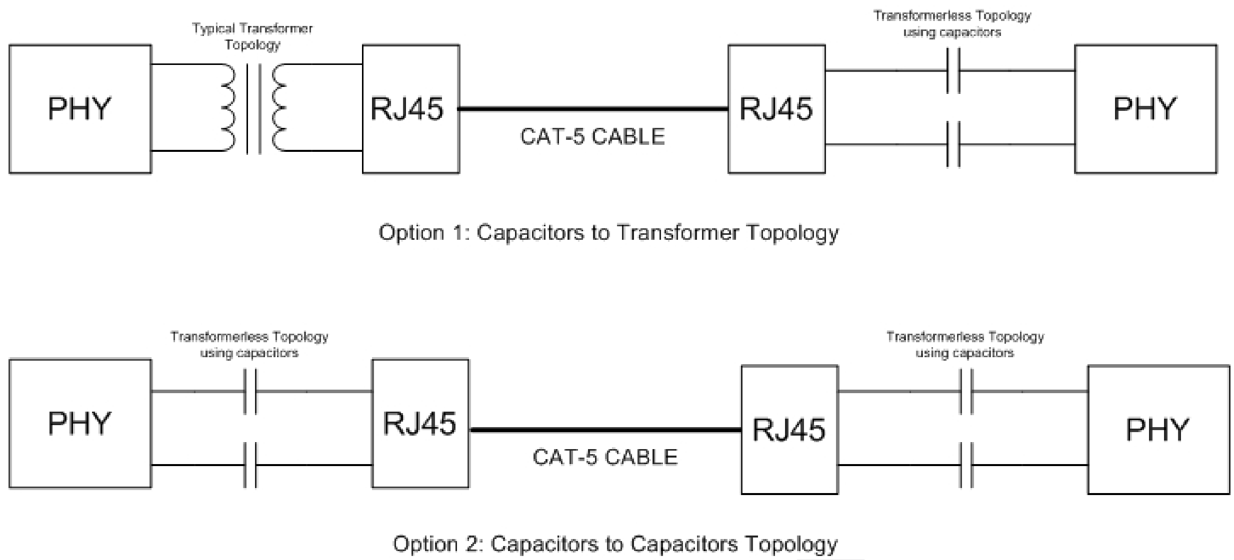

Figure 9. Network Connection Topologies

5 Testing Results

To validate the performance of the transformerless operation, a TLK100 device was configured as represented schematically in Figure 5, using both 100-nF and 33-nF capacitors.

The validation tests are divided into two parts:

1. Standard IEEE compliance testing for 100BT and 10BT according to UNH tests suite (tests performed using 0.1-µF and 33-nF capacitors).
2. System-level tests (BER tests) using a TLK100 device as a DUT and link partner.
   System-level tests were performed in two different topologies represented in Figure 9 and two sets of capacitors, 0.1 µF and 33 nF.

IEEE compliance testing were performed on the transformerless interface for 10BT and 100BT.

The results of the 100BT were compatible with IEEE requirements, and in most of the tests the margins were very good.

These tests performed only in nominal conditions and not validated over extreme temperature and voltages.

The results of the 10BT came close to being fully compatible with IEEE requirements. Most of the tests passed; the minor failures occurred on nominal conditions.

Although IEEE requirements were not fully met, the tests showed that the TLK100 can operate at 10BT mode, using a transformerless configuration without any problems over long-distance cables.

System-level tests performed in two different topologies as represented in Figure 9:

1. Capacitors to transformer topology.
2. Capacitors to capacitors topology.

All tests were performed using the following parameters:

- Cable length: 150 meter CAT-5
- TLK100 device is on both sides (DUT and link partner).
- Packet length of 1514 bytes (+CRC) and minimum inter packet gap as specified in the IEEE 802.3 specification (960 ns for 100 Mb/s, 9.6 µs for 10 Mb/s).
- 100e6 packets sent for 100BT and 10e6 packet sent for 10BT
- Auto-negotiation enabled.
- Full duplex.

- Auto crossover enabled.
- Nominal condition only (room temperature and nominal voltages)

Results:

- Error-free operation of the transformerless circuit was obtained in up to 150 meters CAT-5 cable topology in both 10BT and 100BT modes.
- The results with the 33-nF capacitors and 100-nF capacitors were similar.

Figure 10 through Figure 17 represent the 100-Mb/s passing results using 33-nF/100-nF capacitors:

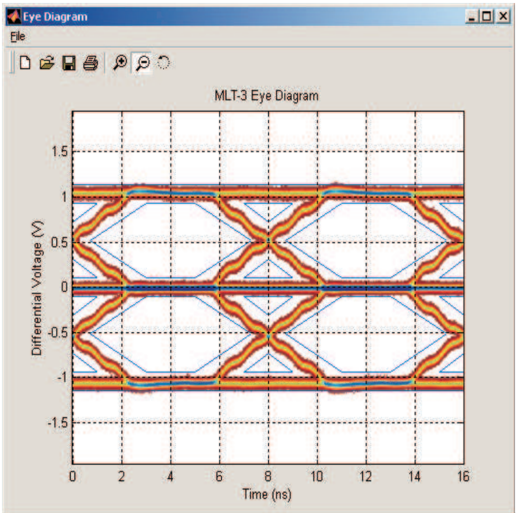

Figure 10. 100BT Jitter With 33-nF Capacitors

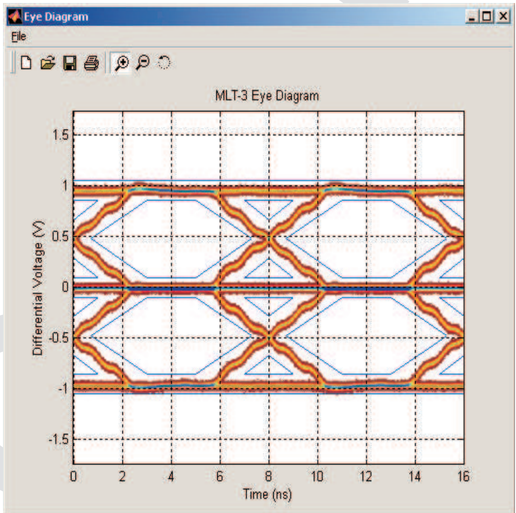

Figure 11. 100BT Jitter With 100-nF Capacitors

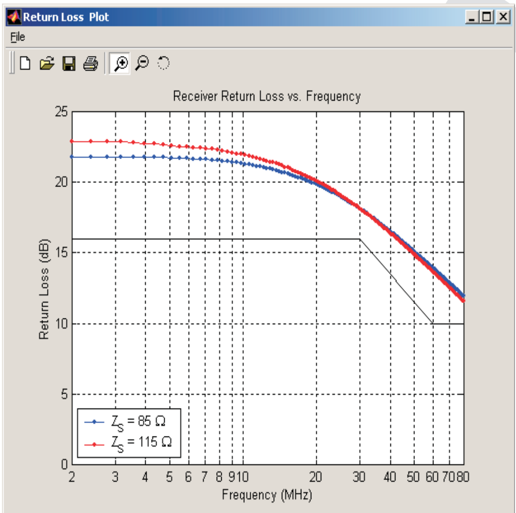

Figure 12. 100BT Receiver Return-Loss With 33-nF Capacitors

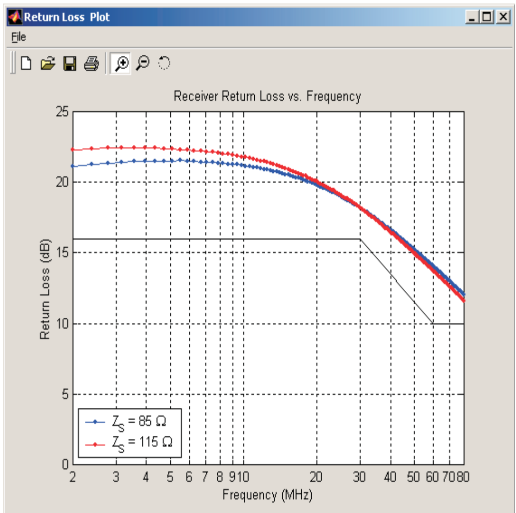

Figure 13. 100BT Receiver Return-Loss With 100-nF Capacitors

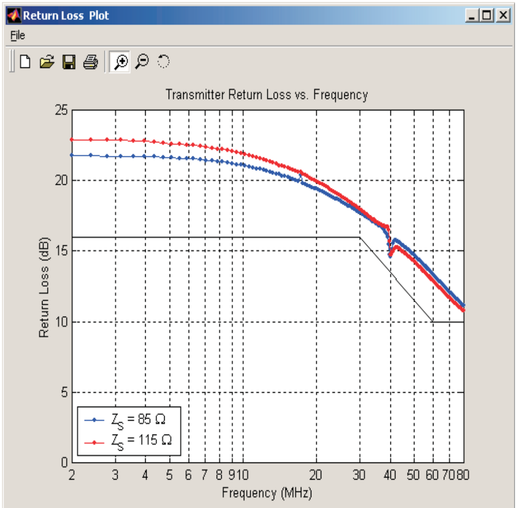

Figure 14. Transmitter Return-Loss With 33-nF Capacitors

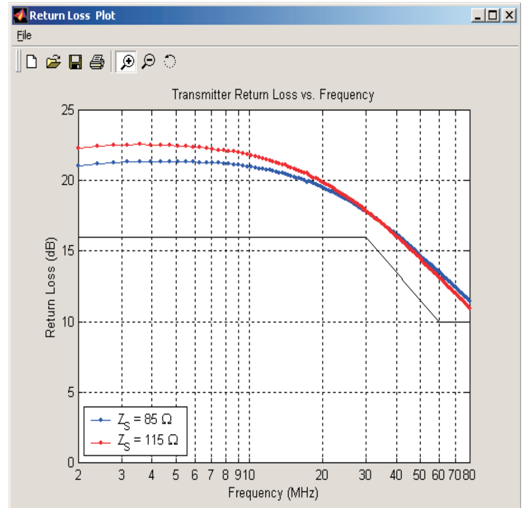

Figure 15. Transmitter Return-Loss With 100-nF Capacitors

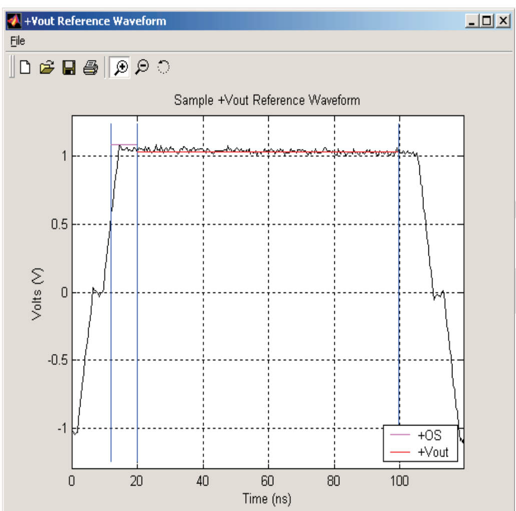

Figure 16. 100BT MLT3 Amplitude With 33-nF Capacitors

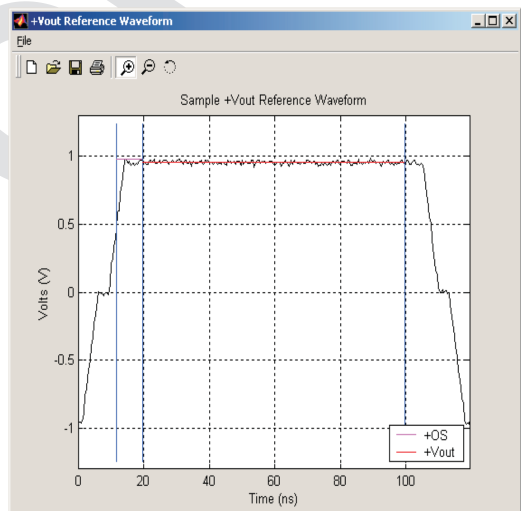

Figure 17. 100BT MLT3 Amplitude With 100-nF Capacitors

6 Summary

In summary, this application report presents recommendations for configuring the TLK100 Ethernet PHY in nontypical transformerless network applications. Recommendations include the use of 33-nF or larger nonpolarized capacitors for dc isolation from a network cable, with a minimum dc isolation rating which suits the individual application.

The validation results presented in this application shows that the TLK100 is able to work in a transformerless configuration in 10BT and 100BT with error-free operation up to a 150-meter CAT-5 cable (under the conditions specified herein) and IEEE standard compliance performance in 100BT.

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