Application Report

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TLK110 Ethernet PHY Transformerless Operation

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ABSTRACT

The TLK110 is a single-port Ethernet PHY for 10BaseT and 100Base TX signaling.

This application report describes an application using Texas Instruments Ethernet PHY products without a transformer. This document also gives instructions for configuring the TLK110 in this mode, and the resulting behavior and performance of the PHY.

A transformerless operation mode has great benefit in the following scenarios:

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

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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.

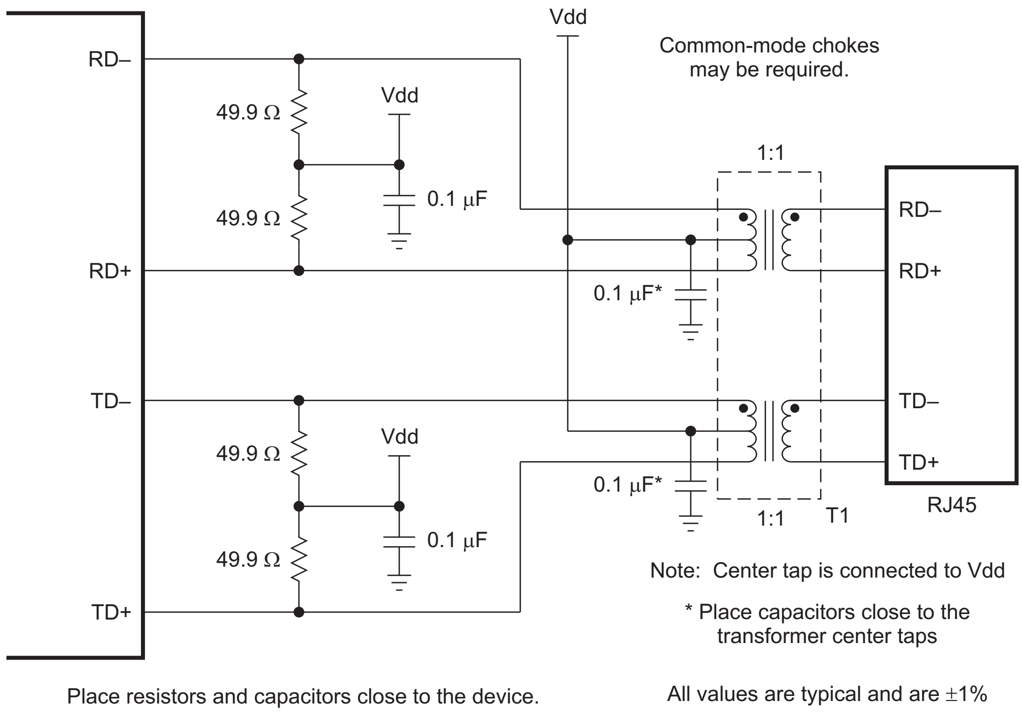


Figure 1. Typical 10/100 Mbps Twisted-Pair Interface

In default configuration, the chip wakes up when auto-negotiation is enabled with 10 Mbps and 100 Mbps. The auto-MDIX is also enabled in order to select 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-Mbps data appears as +1-V, 0-V, and –1-V differential signals, and 10-Mbps data appears as +2-5 V and –2-5 V differential signals across ideal loading. Figure 2, Figure 3, and Figure 4 shows an oscilloscope recording of the preceding signals.

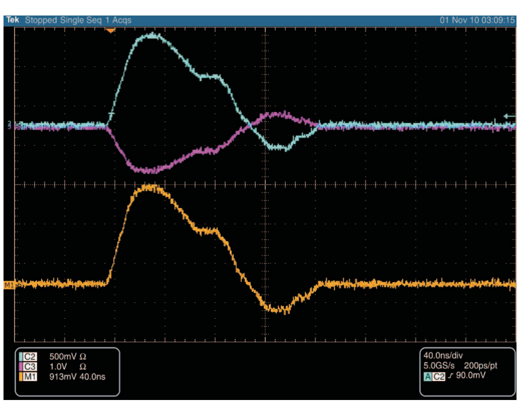


Figure 2. Link Pulse Waveform

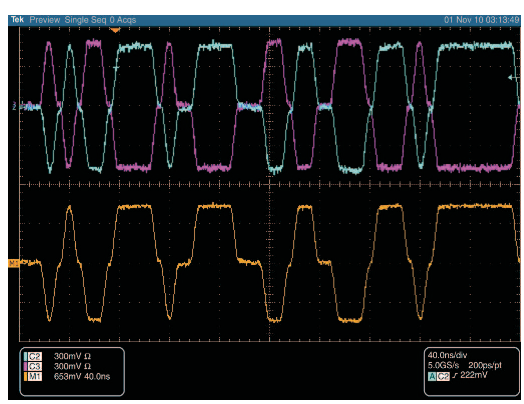


Figure 3. 100-BT (MLT3) Waveform

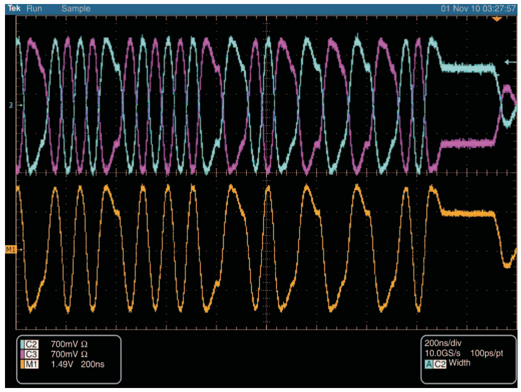


Figure 4. 10-Mbps Waveform

Transformers provide the functions of dc isolation from the cable. Because of 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 IEEE 802.3 specification, and include the ability to withstand cable faults to 1500-V, 50- or 60-Hz or 2250-V_{DC} voltage levels for 60 seconds.

The TLK110 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 non-typical applications, the isolation that the transformer provides in typical configurations can be implemented using non-polarized 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 non-typical transformerless network applications, several requirements must be met:

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

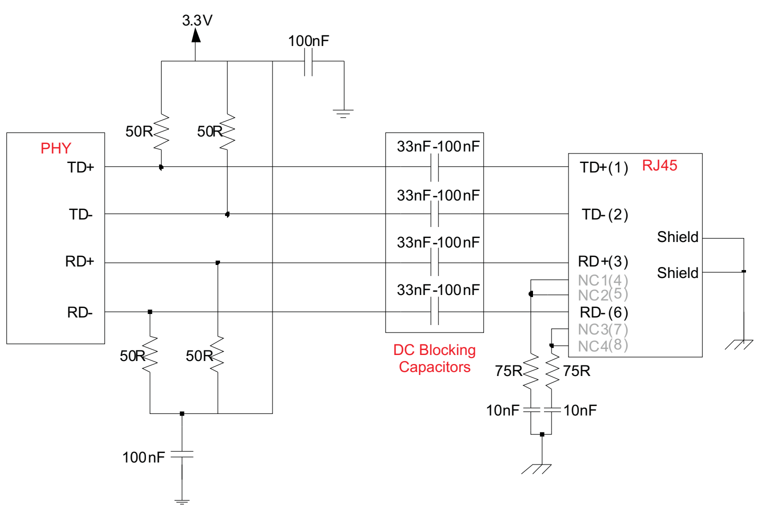


Figure 5. Transformerless Configuration

2.1 Transmitter Requirements

In 100-Mbps 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-Mbps 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-Mbps transmit drivers. Polarity reversing creates +1-V and –1-V signaling on the cable side of the capacitors (see Figure 6).

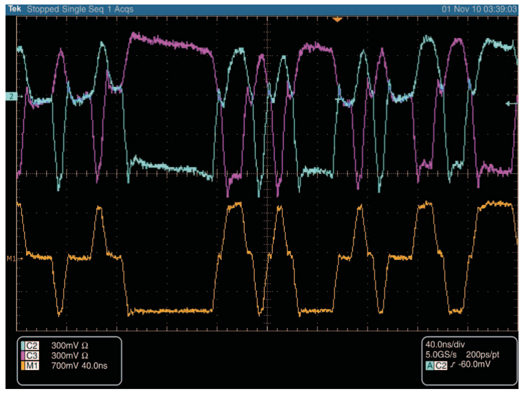


Figure 6. 100-Mbps Waveform Without Transformer

In 10-Mbps 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-Mbps 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 an oscilloscope recording of 10-Mb/t data signaling.

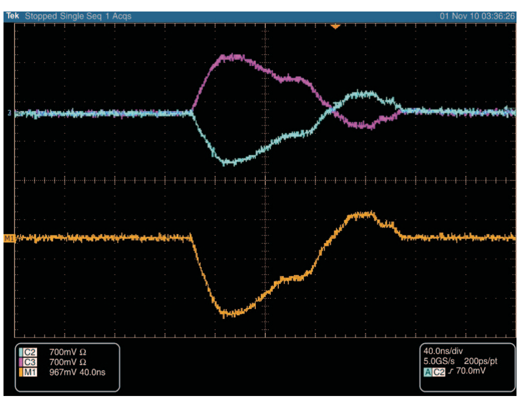


Figure 7. 10-Mbps Waveform Without Transformer

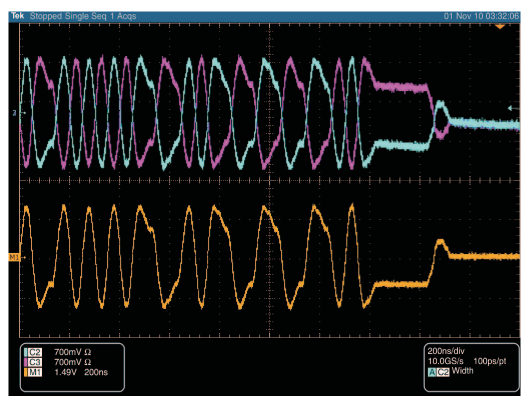


Figure 8. 10-Mbps Data Waveform

2.2 Receiver Requirements

In the TLK110 device, the receiver in both 100-Mbps and 10-Mbps modes is self-biased to V_{DD}, so the received signals at the transceiver side of the blocking capacitors are identical to the signals seen with 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:

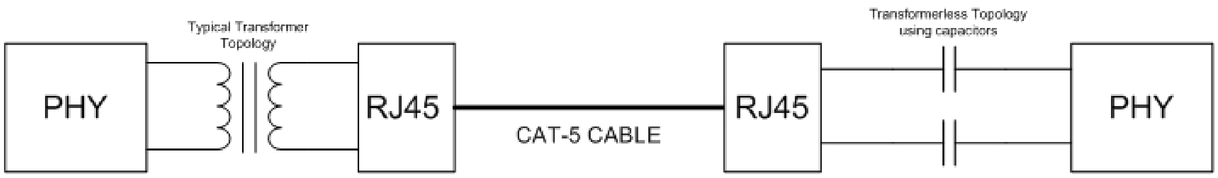
$$\left(\frac{2/\omega C}{100}\right) = \tan(+3) = 0.0524 \quad \Rightarrow \quad C = 30.4nF$$

The closest available capacitor is 33 nF.

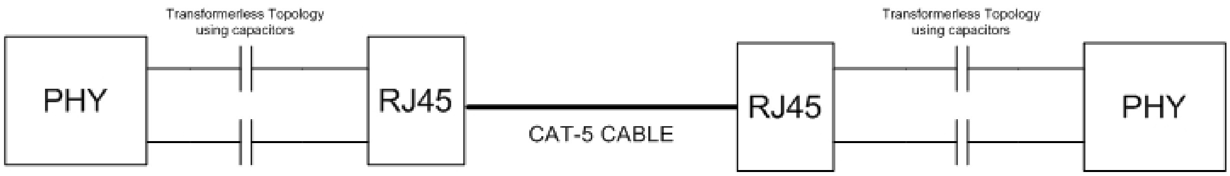
4 Network Connection Topologies

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.



Option 1: Capacitors to Transformer Topology



Option 2: Capacitors to Capacitors Topology

Figure 9. Network Connection Topologies

5 Test Results

To validate the performance of the transformerless operation, a TLK110 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 TLK110 device as a DUT
   System-level tests were performed in two different topologies represented in Figure 9 and two sets of capacitors, 0.1 µF and 33 nF.

5.1 IEEE Test Results

IEEE compliance tests were performed on the transformerless interface for 10BT and 100BT in nominal conditions (nominal temperature and voltages). The results of both 10BT and 100BT tests satisfy most of the major IEEE requirements, approaching full compatibility, and maintaining all required system performance.

Minor test failures were observed mainly in tests that require the Transformer characteristics. For some pulse shaping IEEE tests, writing proprietary register field (reg 0x96(h), data = 3010(h)) might further improves IEEE compliance (no effect on performance).

5.2 System Test Results

Although IEEE requirements were not fully met, the tests showed that the TLK110 can operate using a transformerless configuration without problems over long cables.

The system-level tests included two different topologies, shown in Figure 9:

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

All tests were performed using the following parameters:

- Cable length: 120 meter CAT-5
- Capacitors-to-capacitors topology with TLK110 devices on both sides (DUT and link partner)
- Capacitors-to-transformer topology with TLK110 device on the DUT side and SmartBits® test equipment as the link partner

- Packet length of 1514 bytes (plus CRC) and minimum inter-packet gap as specified in the IEEE 802.3 specification (960 ns for 100 Mbs, 9.6 µs for 10 Mbs)
- 100e6 packets sent for 100BT and 10e6 packet sent for 10BT
- Auto-negotiation enabled
- Full duplex

Results:

- The transformerless circuit topology operated error-free with cable lengths of up to 120 meters of CAT-5 cable in both 10BT and 100BT modes.
- The results with the 33-nF capacitors and 100-nF capacitors were similar.

Figure 10 through Figure 11 represent the 100-Mbps passing results using 33-nF/100-nF capacitors:

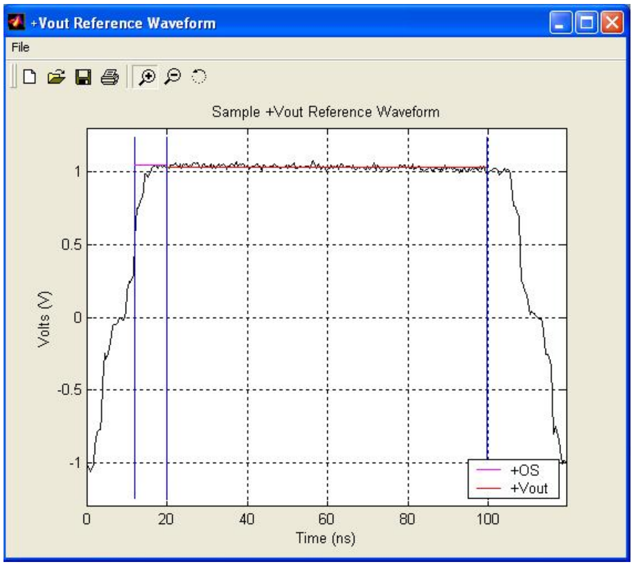


Figure 10. MLT3 Amplitude, 100BT With 33-nF Capacitors

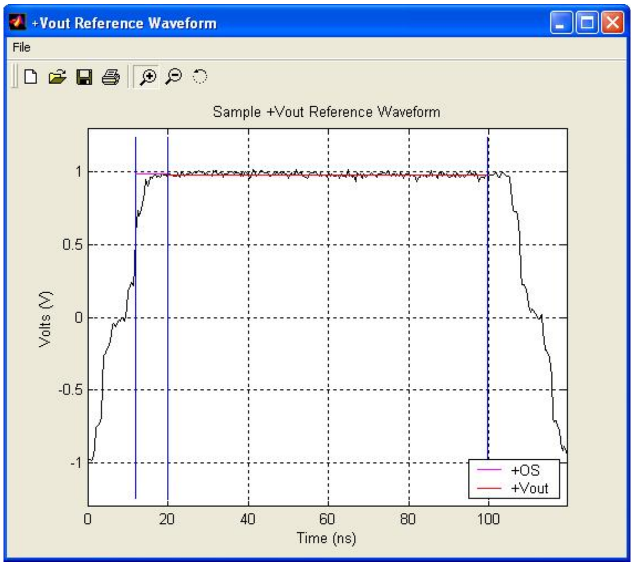


Figure 11. MLT3 Amplitude, 100BT With 100-nF Capacitors

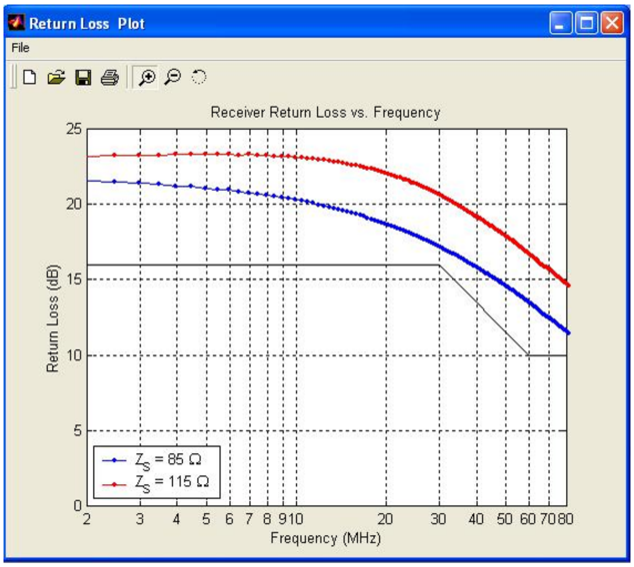


Figure 12. Receiver Return Loss, 100BT With 33-nF Capacitors

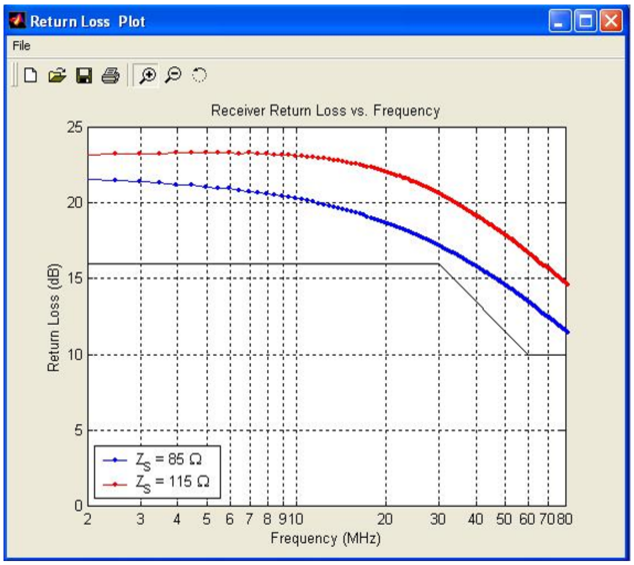


Figure 13. Receiver Return Loss, 100BT With 100-nF Capacitors

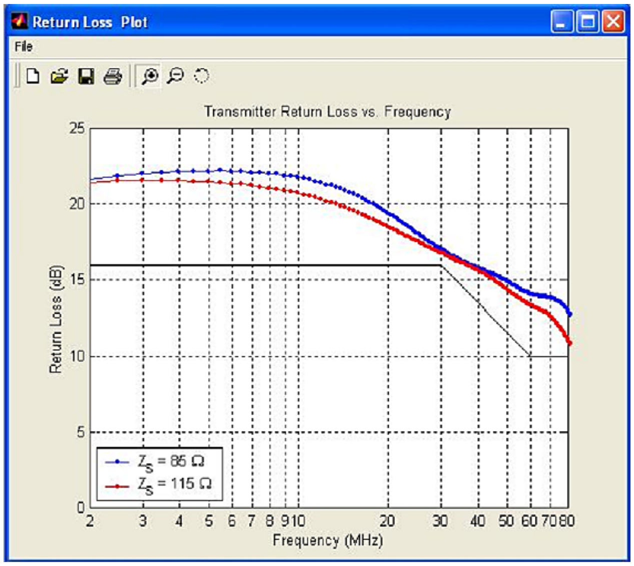


Figure 14. Transmitter Return Loss, 100BT With 33-nF Capacitors

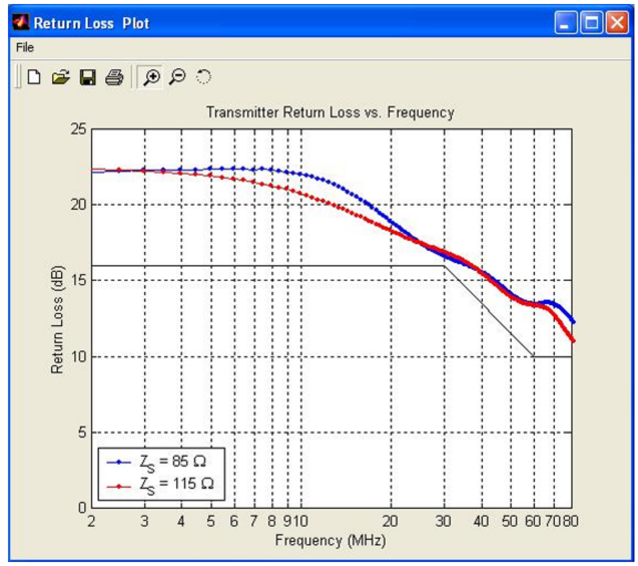


Figure 15. Transmitter Return Loss, 100BT With 100-nF Capacitors

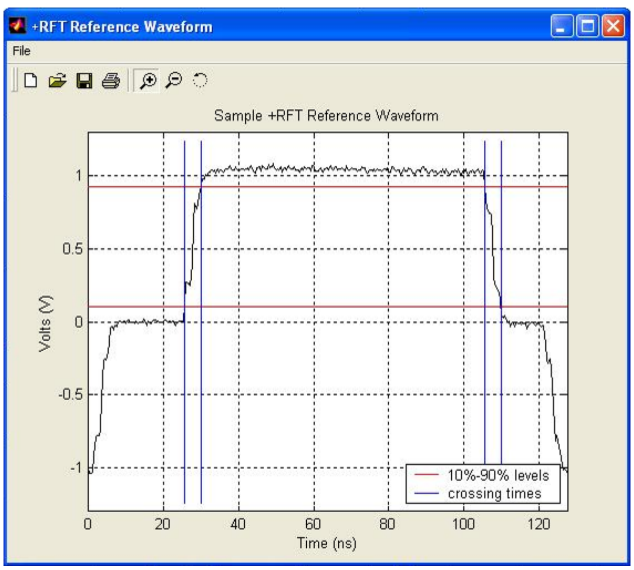


Figure 16. MLT3 RFT, 100BT With 33-nF Capacitors

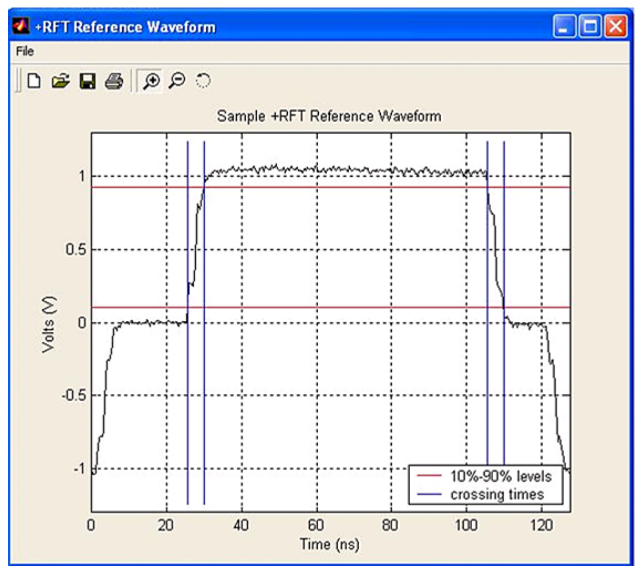


Figure 17. MLT3 RFT, 100BT With 100-nF Capacitors

6 Summary

In summary, this application report presents recommendations for configuring the TLK110 Ethernet PHY in non-typical 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 TLK110 is able to work in a transformerless configuration in 10BT and 100BT with error-free operation up to a 120-meter CAT-5 cable (under the conditions specified herein. IEEE standard is not fully compliant).