Fundamentals of 100Base-T1 Ethernet

Application Note

July 21, 2020

Summary

This application note describes the topology and frame structure of the 100Base-T1 Automotive Ethernet protocol.

Introduction

Automotive Ethernet enables faster data communication to meet the demands of today's vehicles and the connected vehicles of the future. The term "Automotive Ethernet" can be used to refer to any Ethernet-based network for in-vehicle electrical systems. It encompasses 100Base-T1, as well as several other variants and speeds of Automotive Ethernet (e.g., 10Base-T1, 1000Base-T1).

100Base-T1 is 100 Mb/s Automotive Ethernet as defined by the IEEE in its 802.3bp specification. A variant of Automotive Ethernet known as BroadR-Reach was defined by BroadCom. The BroadR-Reach V3.2 specification is nearly identical to the 100Base-T1 specification, and the market will refer to both interchangeably.

The Benefits

100Base-T1 offers higher bandwidth than do most of the prevalent automotive serial-data standards. Being that it relies on a single, unshielded twisted pair, it also provides a low-cost cabling scheme. Cabling weight is about 30% less than shielded cabling with connectivity cost savings of about 80%.[1]

100Base-T1 also meets the stringent EMC and EMI requirements, as well as the temperature-grade requirements, of the automotive application space.

A final benefit is that all the software interfaces for the upper layers of the Ethernet stack are exactly the same as for standard Ethernet. If you've ever worked with Ethernet in the past, you'll probably already have all of the software and test tools covered.

The Challenges

The unshielded cables are susceptible to noise pollution. The inherently noisy auto environment requires a link negotiation between the Master and Slave to confirm that an error-free link is in place, but due to the bidirectional nature of the link, it can be challenging to decipher each side of the link to determine where problems occur.

How 100Base-T1 Works

Physical Topology

100Base-T1 utilizes a **point-to-point topology** directly connecting two nodes. The "-T1" signifies that the signal is carried over one, twisted pair of cables—in this case, unshielded cables. Unlike "normal Ethernet" (100Base-Tx), 100Base-T1 is a full duplex signal, so the same twisted pair will carry a bi-directional signal from a Master and Slave. If this signal were to be observed using an oscilloscope alone,

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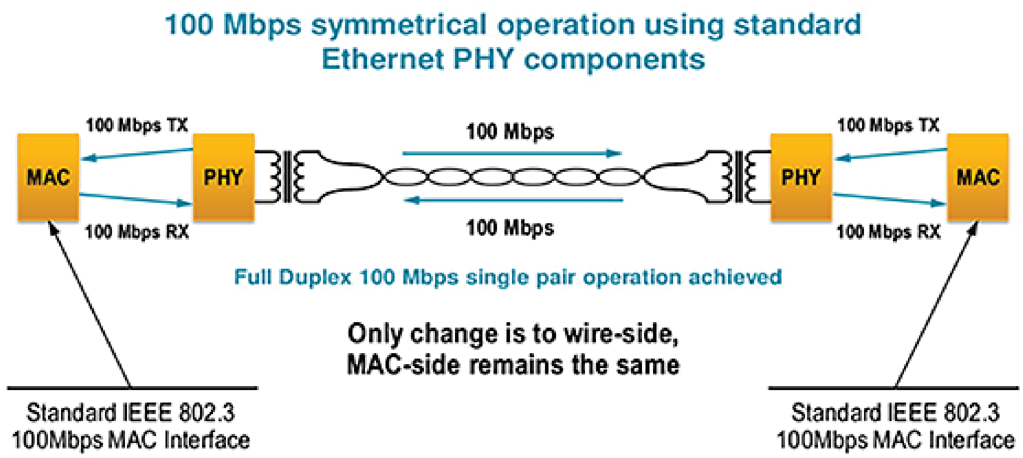
[1] According to the BroadCom BroadR-Reach press release, https://www.prnewswire.com/news-releases/broadcom-broadr-reach-portfolio-achieves-full-automotive-qualification-and-production-release-183042751.html

it would not be possible to discern which signal is from the Master and which is from the Slave, since signals are transmitted from both directions simultaneously. A directional coupler can solve this issue (e.g., TF-AUTO-ENET). The other approach would be to decode traffic from one DUT independent of the other (i.e, Master or Slave only), but this is not nearly as useful as being able to observe the full link.

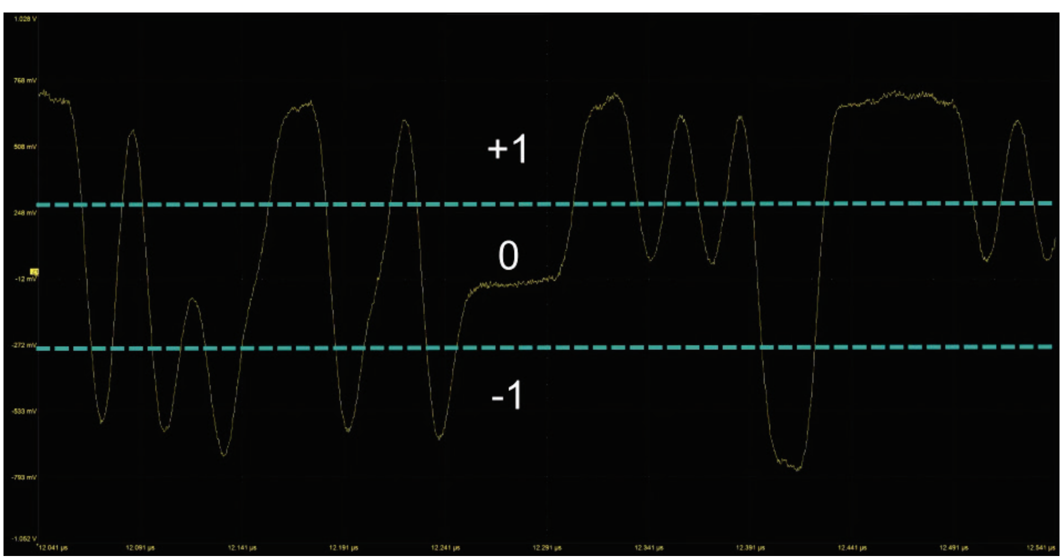


100Base-T1 topology.

Signaling

100Base-T1 utilizes **PAM3 signaling**. Pulse Amplitude Modulation, or PAM, uses the amplitude of the signal to encode the message information. PAM3, as the name implies, uses three distinct levels. The receiver sets a high and low threshold to determine the levels. Any samples above the high level is a +1, below the low level is a -1, and between the two levels is a 0.

Signaling with three discrete values is called a ternary signal or, in the case of Automotive Ethernet, a **ternary symbol**. In 100Base-T1, two ternary symbols are combined to form a **code group**. When a code group is representing data, it represents 3 bits of data. The 100Base-T1 specification defines how these code groups are mapped to the 3 bits.



PAM3 uses high and low thresholds to assign one of three ternary symbols to a signal.
In 100Base-T1, these ternary symbols are combined into code groups representing 3 bits of data.

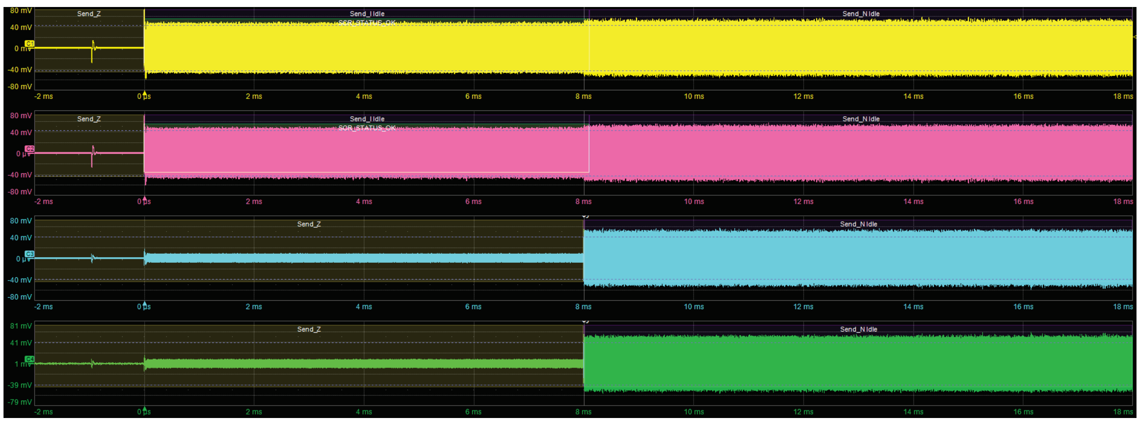
Link Startup/Handshaking

Upon power up, the Master and Slave initiate a handshaking process to establish the link, called the **link startup** or **link training** process. The link startup uses three different signals:

- SEND_Z, which is the transmission all zeros, called zero-codes
- SEND_I, which is the transmission of PAM3 idle signals
- SEND_N, which is the transmission of PAM3 data or idle signals

The handshake between the Master and Slave will progress through these three different signals.

The link startup begins with the Master transmitting PAM3 idle signals as it transitions from SEND_Z to SEND_I. During this time the slave continues to transmit SEND_Z. This allows the Master to train its echo canceller, while the Slave synchronizes to the Master’s clock, locks its scrambler and adjusts its signal conditioning.



100Base-T1 link startup showing Master (yellow, pink) and Slave (blue, green) switching from SEND_Z to SEND_I and SEND_N.

Next, the Slave switches from SEND_Z to SEND_I, while the Master stays in SEND_I. This allows the Slave to train its echo canceller, while the Master locks its scrambler and adjust its signal conditioning. The Master and Slave continue to send Idle Symbols (SEND_I) while they refine the timing, equalizer, and scrambler.

The last step is for the Master and Slave to validate that the link startup was successful by setting the scr_status, loc_rvcr_status, and rem_rcvr_status. If these statuses are all validated, both Master and Slave switch to SEND_N. If any of the statuses are negative (failed), the link startup restarts.

Completion of link startup, showing the exchange of scrambler status messages.

100Base-T1 Frame Structure

The 100Base-T1 frame is similar to the traditional Ethernet frame but has some key differences to support the point-to-point topology. One unique aspect of the 100Base-T1 data frame is that it is marked by a Start-of-Stream Delimiter (**SSD)** and End-of-Stream Delimiter (**ESD**).

The SSD denotes the beginning of the frame. It is always represented by code groups 00, 00, 00. The code group 00 is reserved especially for the SSD and ESD and is not used anywhere else in data or idle mode.

The SSD is followed by the **Preamble**, which in 100Base-T1 is shortened due to the insertion of the SSD. While the preamble is included, it does not serve a function like it does in the traditional Ethernet packet. Normally in Ethernet, the Preamble provided a mechanism for synchronization at the beginning of the frame, useful for large networks with a bus connection so that devices could easily synchronize their receiver clocks. In 100Base-T1, it is only present for backwards compatibility but is not required because of the continuous connection of the point-to-point topology.

The Preamble is followed by the Start-of-Frame Delimiter, or **SFD**, which signifies the end of the Preamble and the beginning of the traditional Ethernet frame.

As with all Ethernet, the frame proper starts with the **Header**, including the Destination (**Dest-Address**) and Source (**Src-Addres**) MAC Addresses, which aren't so critical for 100Base-T1 given its point-to-point topology. The Header also includes the EtherType (**Type_Len**) field, which provides directions on how to interpret the forthcoming data payload.

Next comes the **DATA**.

The data payload is followed by a Frame Check Sequence (**FCS**), which is a 32-bit CRC used to detect any corruption of data.

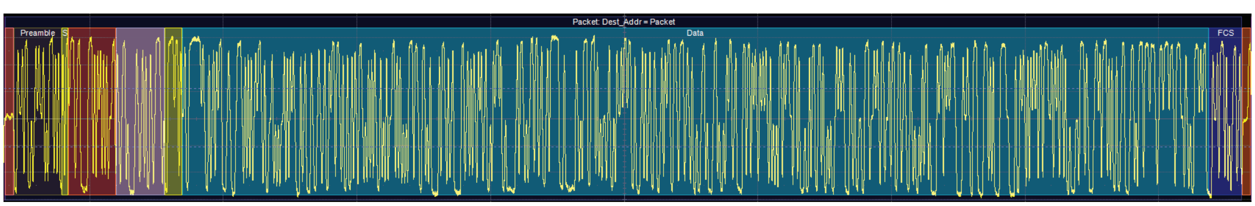
The 100Base-T1 frame ends with the **ESD**, which is not present in the traditional Ethernet frame. The ESD can be transmitted in two different manners, depending on whether the MII has indicated there was a tx_error during the data frame. An error-free ESD is represented by code group 00, 00, 11, while a frame containing an error will end with 00, 00, -1-1. Like the SSD, these specific sequences are reserved for this purpose, and you will not find them used anywhere else.

After the ESD, **Idle** symbols are again transmitted. The presence of the ESD in 100Base-T1 shortens the interframe gap (**IFG**).

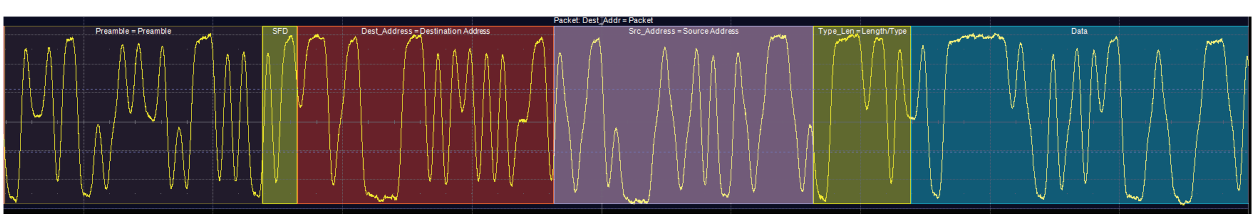
Field	Preamble		SFD	HEADER			DATA	FCS	IFG	
	SSD*			Dest_Address	Src_Address	Type_Len			ESD**	
Bytes	7		1	6	6	2	46-1500	4	N/A	

* SSD replaces first 9 bits of Preamble.

**ESD shortens IFG by 9 bits.



A 100Base-T1 packet consists of everything between the SSD and ESD (red bars at edges).



Following a Preamble and SFD, the frame begins with the Header with MAC Addresses as in legacy Ethernet. These are not required by the point-to-point topology, but are kept for backward compatibility.

Additional Resources

See our instructional videos on the *Fundamentals of the 100Base-T1 Frame*, *What is PAM3 Signaling?*, and *Understanding the 100Base-T1 Link Startup*.

Step-by-step procedures for using the Teledyne LeCroy 100Base-T1 serial trigger and decode option can be found in the *100Base-T1 Trigger, Decode, Measure/Graph and Eye Diagram Instruction Manual* on our website.