OPEN Alliance 10BASE-T1S Topology Discovery

TC14 – Topology Discovery

Author & Company	See Contributing Members on Page 2
Title	10BASE-T1S Topology Discovery
Version	1.0
Date	21 March 2023
Status	Final
Restriction Level	Public

Version Control of Document

Version	Author	Description	Date
0.1	Viliam Vozar	Initial version	2020-11-23
0.2	Viliam Vozar	Update of initial version	2021-01-15
0.3	Viliam Vozar	Added chapters Scrambler, Descrambler and Internal Delay Measurement. State diagrams and their descriptions updated.	2021-05-12
0.4	Viliam Vozar	Calibration of internal delay removed. State diagrams and their descriptions updated. Internal Delay Measurement description added.	2021-11-23
0.5	Viliam Vozar	State diagrams and their descriptions updated. INT_DELAY and TD_Pulse parameters updated. Delay / distance measurement result registers size increased (16 bit -> 2x 16 bit). Register map updated, addresses assigned to registers. MTX_DIS variable added. REC_ONLY bit removed, TD_EN bit added. TD_DM_TO changed to be optional.	2022-09-21
0.6	Viliam Vozar	Figure 11 and Figure 12 swapped Reference to INT_Delay measurement in Figure 11 and Figure 12 changed from Figure 5 to Figure 4 Internal Delay Measurement states renamed: Result++ -> DELAY_RESULT++ MEASUREMENT_DONE -> DELAY_MEASUREMENT_DONE	2022-11-07
1.0	Viliam Vozar	Changed Restriction Level to Public	2023-03-21

Restriction level history of Document

Version	Restriction Level	Description	Date
1.0	Public	Final	2023-03-21

Contributing Members

Piergiorgio Beruto (onsemi)
Viliam Vozar (onsemi)
Tim Baggett (Microchip)
Venkat Iyer (Microchip)
Seamus Ryan (Analog Devices)
Pablo Ventura (Analog Devices)

Contents

OPEN Alliance Specification Copyright Notice and Disclaimer

SUCH EXPRESS, IMPLIED, STATUTORY, AND ALL OTHER REPRESENTATIONS, WARRANTIES, AND GUARANTEES, INCLUDING WITHOUT LIMITATION ANY AND ALL WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR USE, TITLE, NON-INFRINGEMENT OF OR ABSENCE OF THIRD PARTY RIGHTS, AND/OR VALIDITY OF RIGHTS IN THIS OPEN SPECIFICATION; AND OPEN ALLIANCE AND THE CONTRIBUTING MEMBERS MAKE NO REPRESENTATIONS AS TO THE ACCURACY OR COMPLETENESS OF THIS OPEN SPECIFICATION OR ANY INFORMATION CONTAINED HEREIN. WITHOUT LIMITING THE FOREGOING, OPEN ALLIANCE AND/OR CONTRIBUTING MEMBERS HAS(VE) NO OBLIGATION WHATSOEVER TO INDEMNIFY OR DEFEND YOU AGAINST CLAIMS RELATED TO INFRINGEMENT OR MISAPPROPRIATION OF INTELLECTUAL PROPERTY RIGHTS.

OPEN ALLIANCE AND CONTRIBUTING MEMBERS ARE NOT, AND SHALL NOT BE, LIABLE FOR ANY LOSSES, COSTS, EXPENSES, OR DAMAGES OF ANY KIND WHATSOEVER (INCLUDING WITHOUT LIMITATION DIRECT, INDIRECT, SPECIAL, INCIDENTAL, CONSEQUENTIAL, PUNITIVE, AND/OR EXEMPLARY DAMAGES) ARISING IN ANY WAY OUT OF USE OR RELIANCE UPON THIS OPEN SPECIFICATION OR ANY INFORMATION HEREIN. NOTHING IN THIS DOCUMENT OPERATES TO LIMIT OR EXCLUDE ANY LIABILITY FOR FRAUD OR ANY OTHER LIABILITY WHICH IS NOT PERMITTED TO BE EXCLUDED OR LIMITED BY OPERATION OF LAW.

B.iii. Compliance with Laws and Regulations:

NOTHING IN THIS DOCUMENT OBLIGATES OPEN ALLIANCE OR CONTRIBUTING MEMBERS TO PROVIDE YOU WITH SUPPORT FOR, OR RELATED TO, THIS OPEN SPECIFICATION OR ANY IMPLEMENTED PRODUCTS OR SERVICES. NOTHING IN THIS OPEN SPECIFICATION CREATES ANY WARRANTIES OR GUARANTEES, EITHER EXPRESS OR IMPLIED, STATUTORY OR OTHERWISE, REGARDING ANY LAW OR REGULATION. OPEN ALLIANCE AND CONTRIBUTING MEMBERS EXPRESSLY DISCLAIM ALL LIABILITY, INCLUDING WITHOUT LIMITATION, LIABILITY FOR NONCOMPLIANCE WITH LAWS, RELATING TO USE OF THE OPEN SPECIFICATION OR INFORMATION CONTAINED HEREIN. YOU ARE SOLELY RESPONSIBLE FOR THE COMPLIANCE OF IMPLEMENTED PRODUCTS AND SERVICES WITH ANY SUCH LAWS AND REGULATIONS, AND FOR OBTAINING ANY AND ALL REQUIRED AUTHORIZATIONS, PERMITS, AND/OR LICENSES FOR IMPLEMENTED PRODUCTS AND SERVICES RELATED TO SUCH LAWS AND REGULATIONS WITHIN THE APPLICABLE JURISDICTIONS.

IF YOU INTEND TO USE THIS OPEN SPECIFICATION, YOU SHOULD CONSULT ALL APPLICABLE LAWS AND REGULATIONS. COMPLIANCE WITH THE PROVISIONS OF THIS OPEN SPECIFICATION DOES NOT CONSTITUTE COMPLIANCE TO ANY APPLICABLE LEGAL OR REGULATORY REQUIREMENTS. IMPLEMENTERS OF THIS OPEN SPECIFICATION ARE SOLELY RESPONSIBLE FOR OBSERVING AND COMPLYING WITH THE APPLICABLE LEGAL AND REGULATORY REQUIREMENTS. WITHOUT LIMITING THE FOREGOING, YOU SHALL NOT USE, RELEASE, TRANSFER, IMPORT, EXPORT, AND/OR RE-EXPORT THIS OPEN SPECIFICATION OR ANY INFORMATION CONTAINED HEREIN IN ANY MANNER PROHIBITED UNDER ANY APPLICABLE LAWS AND/OR REGULATIONS, INCLUDING WITHOUT LIMITATION U.S. EXPORT CONTROL LAWS.

B.iv. <u>Automotive Applications Only</u>: Without limiting the foregoing disclaimers or limitations of liability in any way, this OPEN Specification was developed for automotive applications only. This OPEN Specification has neither been developed, nor tested for, non-automotive applications.

B.v. <u>Right to Withdraw or Modify</u>:
OPEN Alliance reserves the right to (but is not obligated to) withdraw, modify, or replace this OPEN Specification at any time, without notice.

Introduction

The 10BASE-T1S is a 10 Mbit/s Ethernet PHY defined by the IEEE 802.3cg project (Clause 147). It is capable of operating in full/half duplex point-to-point or half-duplex multidrop mode over a single unshielded twisted pair (UTP) cable up to 25m long.

Furthermore, the IEEE 802.3cg project defines the Physical Layer Collision Avoidance (PLCA) Reconciliation Sublayer (Clause 148) meant to provide improved determinism to the CSMA/CD media access method. PLCA works in conjunction with the 10BASE-T1S PHY operating in multidrop mode.

Within a 10BASE-T1S multidrop network, there might be multiple identical devices which specific function depends on their physical location e.g. buttons, radars or lights. Topology Discovery allows 10BASE-T1S node to measure the distance between itself and another node. The node at the end of the line can measure the distance to each node one by one and the whole topology can be revealed. To find out which node is at the end of the line, any node on the line can measure distances to other nodes and find the farthest one.

Abbreviation/Symbols

+	May indicate either the arithmetical sum operation or the logical OR function, unless specified otherwise.
*****	May indicate either the arithmetical multiply operation or the logical AND function
BI_DA	Bi-directional Data Signal Pair A (BI_DA+, BI_DA-)
PLCA	Physical Layer Collision Avoidance

1 Scope

The purpose of this document is to specify a mechanism used to measure the distance between two 10BASE-T1S nodes, called Topology Discovery. The normative requirements for state machines, timing and voltage levels are provided in this document. The definition of actual implementation is beyond the scope of this document.

2 Normative References

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

[1] IEEE Computer Society, "IEEE Std 802.3cg™-2019, IEEE Standard for Ethernet, Amendment 5: Physical Layer Specifications and Management Parameters for 10 Mb/s Operation and Associated Power Delivery over a Single Balanced Pair of Conductors," IEEE Standards Association, New York, 2019.

[2] IEEE Computer Society, "IEEE Standard for Ethernet, IEEE Std 802.3," IEEE Standards Association, New York.

3 Terms and Definitions

For the purposes of this document, the terms and definitions given in the normative references in Section 2 apply.
ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp
— IEC Electropedia: available at http://www.electropedia.org/

Reference node	During Topology Discovery, the node which initializes and performs the distance measurement.
Measured node	During Topology Discovery, the node which responds to TD_pulses sent by the reference node during the distance measurement.
Remote node	During Topology Discovery, the node on the other side of measured line. From the reference node's point of view, it is the measured node and vice versa.
PLS_CARRIER.indication	See [1]
PLS_SIGNAL.indication	See [1]
PLS_DATA.request	See [1]

4 Overview

Topology Discovery is a procedure to measure the distance between two 10BASE-T1S nodes connected to the same line and is done in two steps. The first one is an internal delay measurement and the second one is a distance measurement. This procedure should be controlled via defined registers. Before the procedure is started, a reference node and a measured node should be selected and all other nodes connected to the same line should be prevented from any transmission. It is also recommended to disable the PLCA at all nodes to avoid periodic BEACON transmission.

The reference node starts the distance measurement by the transmission of a TD_Pulse (see 5). If the TD_Pulse was received by the measured node, it shall be transmitted back. When the reference node receives this response from the measured node, it shall transmit it back again and so on. This ping-pong goes on for a pre-set period and during this time, the number of received TD_Pulses is counted by both nodes.

The time between the reception of the TD_Pulse and its transmission back is called internal delay (TD_INT_DELAY) and may vary from implementation to implementation. For a precise calculation of the distance between two nodes, it is necessary to know their internal delays and therefore the internal delay measurement should be performed as well.

The result of the distance measurement is the number of TD_Pulses received within a known time interval. Using this number, the time needed for the TD_Pulse to travel between the nodes can be calculated. This time is influenced by the cable, MDI components and all parasitic elements of the line. The actual physical distance can be calculated from this time. Assuming a cable propagation delay of 5 ns/m, a measurement duration of 1 ms and a line length of 25 m, the achieved accuracy should not be worse than ±15 cm.

The polarity of the transmitted TD_Pulse is defined by the output of a scrambler and checked by a synchronized descrambler after reception by the remote node. If the polarity of the received pulse does not match with the expectation, the measurement is stopped and reported as unsuccessful. This approach ensures that the measurement is protected against faulty results, which could be caused by noise on the line.

To avoid a baseline wander on the line, (which can be caused by the transmission of pulses with same polarity) 1B/2B coding is applied at the output of the scrambler. Each bit is coded by two symbols with the opposite polarity, these are serialized and transmitted to the line (LSB first). Only one TD_Pulse is transmitted at a time and therefore it takes two cycles to transmit these two symbols and update the scrambler.

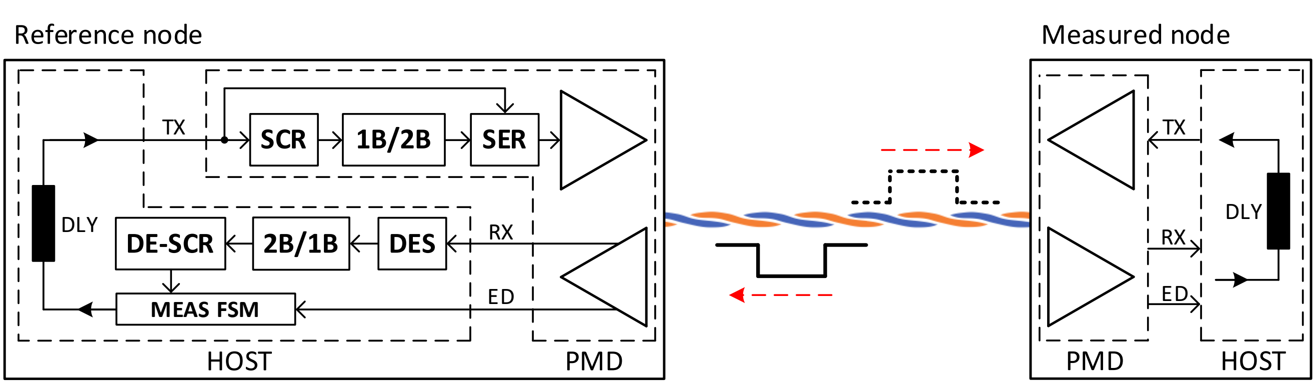

Figure 1: Overview

5 Topology Discovery pulse – TD_Pulse

The TD_Pulse is a differential voltage pulse between BI_DA+ and BI_DA- with defined voltage levels and time duration. It should be created by a 10BASE-T1S transmitter and it is used for the internal delay measurement and the distance measurement between two nodes connected to the same line. If a node is performing the distance/internal delay measurement and the TD_Pulse is received, it shall be transmitted back. The polarity of the transmitted pulse is defined by the scrambler and 1B/2B coding (See 8). Parameters of TD_Pulse are defined in Figure 2 and Table 1.

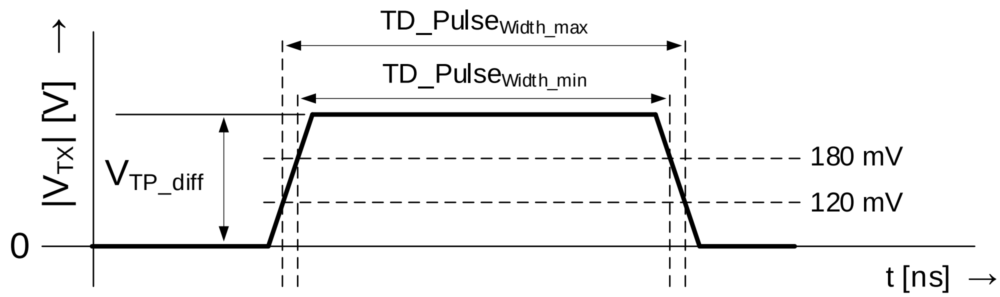

Figure 2: TD_Pulse

Table 1: Parameters of TD_Pulse

Parameters in the table shall be fulfilled over the full operating temperature and voltage range with load of 50 Ω and 15 pF connected to the transmitter output.

Symbol	Description	Min	Typ	Max	Units
V_{TP_diff}	Absolute value of differential voltage between BI_DA+ and BI_DA-. [1]	400	500	600	mV
$TD\_Pulse_{Width\_min}$	Minimum width of TD_Pulse	40			ns
$TD\_Pulse_{Width\_max}$	Maximum width of TD_Pulse			85	ns

6 Internal Delay Measurement

If the TD_Pulse is received by the reference or measured node during the distance measurement, it shall be transmitted back. The internal delay (TD_INT_DELAY) is the delay between the first edge of the received TD_Pulse and the first edge of the transmitted TD_Pulse. TD_INT_DELAY is a sum of internal delays (receiver, transmitter etc.) and shall be longer than 100 ns (see Table 2).

Table 2: Internal Delay Measurement – timing parameters

Symbol	Description	Min.	Units
TD_INT_DELAY	The duration of the internal delay	100	ns

The duration of the TD_INT_DELAY should be measured as it is necessary for a calculation of the distance between the nodes. The internal delay measurement function shall conform to the Internal Delay Measurement state diagram in Figure 4 and the associated state variables, functions and timers.
Before the measurement is started, all nodes on the shared line shall be prevented from any transmission which could affect the measurement (e.g. data, Beacon, Wake-up signaling etc.). This can be done using a Receive only mode. The internal delay measurement can be started via DLYM_START bit of TD Control Register if TD_EN bit of TD Control Register is set.

During the measurement, TD_Pulses are transmitted one after another for the time interval defined by the DM_DUR field of the TD Control register. The TD_Pulse shall be transmitted as soon as the first edge of the previous one is received. The number of received TD_Pulses (DLY_MR) shall be counted during the measurement and stored in the TD_DLY_RES_LOW and TD_DLY_RES_HIGH registers.

Polarity of each transmitted TD_Pulse is defined by the scrambler output and 1B/2B coding. Polarity of each received TD_Pulse shall be checked. If this polarity does not match with the prediction, the measurement shall be stopped and reported as unsuccessful via the DLYM_ERR bit of the TD Status register.

A successful finish of the measurement shall be reported via DLYM_DONE bit of the TD Status register. Knowing the number of received TD_Pulses and the time duration of the measurement, the internal delay can be calculated using Equation 1.

$$TD\_INT\_DELAY = \frac{(DM\_DUR + 1) * 10^6}{DLY\_MR} \; [ns]$$

Equation 1

The measurement should be performed by one node at a time. The node, which performs the measurement, should be connected to the rest of the 10BASE-T1S line so all parasitic elements are present during the measurement. All other nodes connected to the same line shall stay in the Receive only mode.

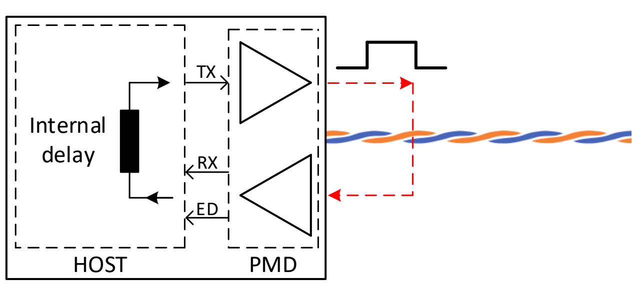

Figure 3: Internal Delay Measurement

6.1 Variables

The following variables are used in the state diagram.

DLYM_RUN	Allows the internal delay measurement. Set by: DLYM_START (Start of internal delay measurement) bit of the TD Control register. See 10.1.3. Values: 1 or 0
DLYM_ERR	DLYM_ERR (Internal delay measurement finished unsuccessfully) bit of the TD Status register. See 10.2.2 Values: 1 or 0
DLYM_DONE	DLYM_DONE (Internal delay measurement finished successfully) bit of the TD Status register. See 10.2.1. Values: 1 or 0
REFN	REFN (Reference node) bit of the TD Control register. See 10.1.2. Values: 1 or 0
AUTO_RUN	Allows the automatic mode. Set by: AUTO_START (Start of automatic mode) bit of the TD Control register. See 10.1.6. Values: 1 or 0
TD_EN	TD_EN (Topology Discovery enable) bit of the TD Control register. See 10.1.1. Values: 1 or 0
TD_P_REC	This variable is set TRUE if the TD_Pulse was received and is reset to FALSE at each state entry/reentry. Values: TRUE or FALSE
DLY_MR	DLY_MR (Delay measurement result) is the number of received TD_Pulses during the delay measurement. This number is stored in TD_DLY_RES_LOW and TD_DLY_RES_HIGH registers. See 10.5 and 10.6.
DM_DUR	DM_DUR (Duration of distance/delay measurement) bit field of the TD Control register. See 10.1.3. Values: 0 to 15
MTX_DIS	MAC transmission disabled. If True, the reconciliation sublayer (RS) shall assert the CARRIER_STATUS = CARRIER_ON via PLS_CARRIER.indication primitive to the MAC. Additionally, if the PLS_DATA.request is issued, the RS shall assert the SIGNAL_STATUS = SIGNAL_ERROR via PLS_SIGNAL.indication until the PLS_DATA.request primitive is de-asserted. Values: TRUE or FALSE

6.2 Functions

send_TD_Pulse() This function transmits one TD_Pulse (see 5) after TD_INT_DELAY. The polarity of this pulse is defined by the scrambler output and 1B/2B coding.

check_sequence() This function checks if the polarity of the received TD_Pulse matches with the prediction. If the polarities of received pulses match the prediction, the output of the function is 0, 1 otherwise.
Values: 1 or 0

6.3 Timers

All timers operate in the same fashion. A timer is reset and starts counting upon entering a state where "start x timer" is asserted, if it does not run already. If a timer is running already, entering a state where "start x timer" is asserted does not have any effect. A timer is reset and starts counting upon entering a state where "restart x timer" is asserted. Time "x" after the timer has been started, "x timer done" is asserted and remains asserted until the timer is reset.

Meas_timer This timer defines the duration of the internal delay measurement. During this time, the number of received TD_Pulses is counted.
Duration: DM_DUR +1 [ms]

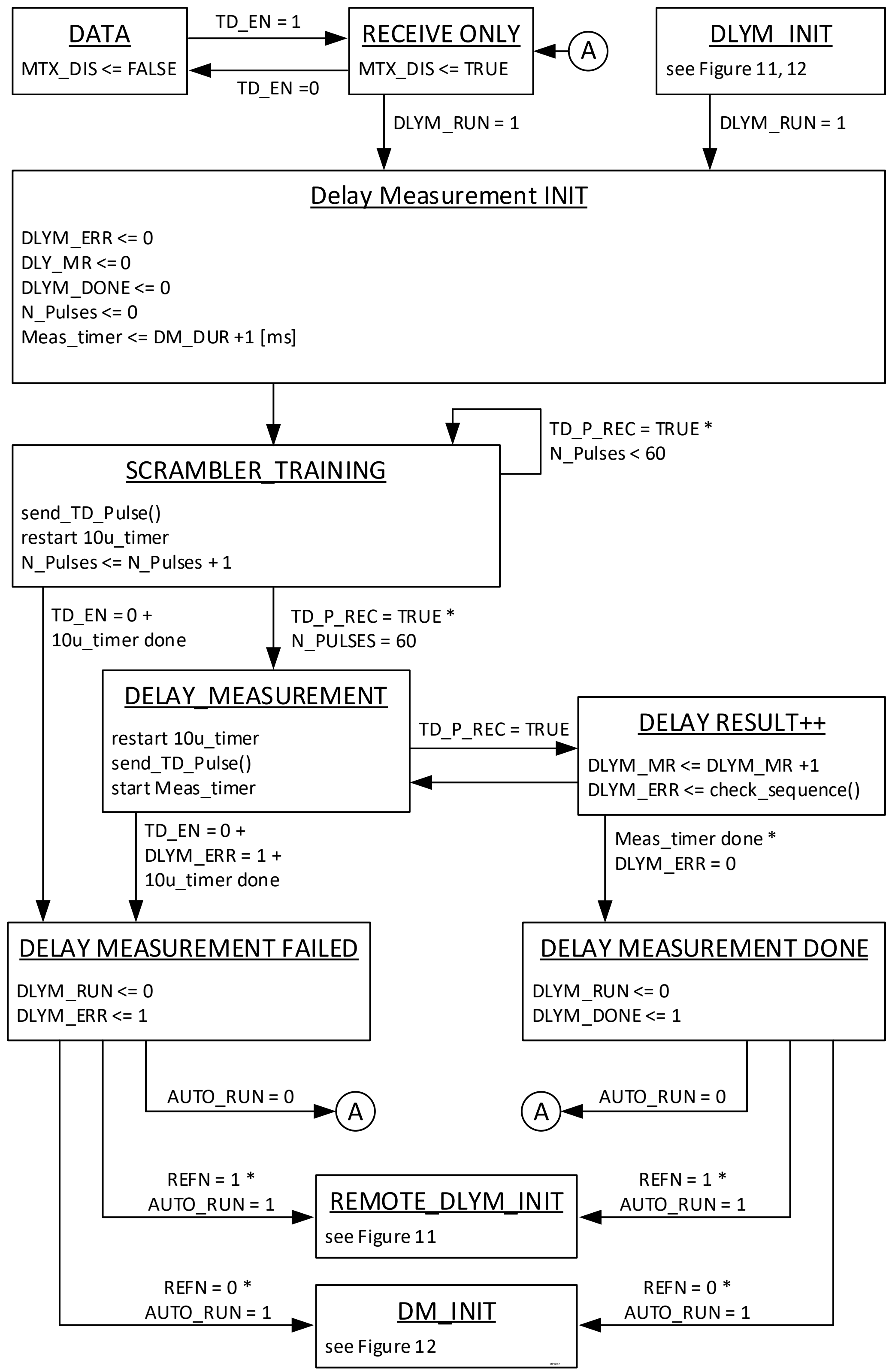

Figure 4: Internal Delay Measurement - state diagram

7 Distance Measurement

Two 10BASE-T1S nodes may perform the distance measurement by the transmission of the TD_Pulse TD_INT_DELAY after it was received from the remote node and by counting the number of received pulses within the defined time. The Distance Measurement function shall conform to the Distance Measurement state diagrams in Figure 5 and Figure 6 and the associated state variables, functions and timers.

The distance measurement shall be performed between two nodes on the same line from which one is configured as the reference node and the second one as the measured node. This configuration shall be done using REFN bit of TD Control Register. Before the measurement is started, all nodes on the shared line should be prevented from any transmission which could affect the measurement (e.g. data, Beacon, Wake-up signaling etc.). This can be done using Receive only mode. Then, the measured node and the reference node should start the measurement via TD_EN and DM_START bits of TD Control Register.

To initialize the measurement, the reference node transmits the TD_Pulse every ~10 µs for the time duration defined by TD_DM_TO (if implemented). Within this time, the measured node should be able to transmit a response. If the measured node is not able to send a proper response, the reference node shall report an unsuccessful measurement attempt via the DM_ERR bit of the TD Status register.

Once the reference node receives the response, synchronization of the scramblers must be achieved. This synchronization shall be finished within a reception of 60 pulses. Within this time, both nodes shall try both polarities and lock their descramblers. A node, with properly synchronized and locked descrambler, can predict the polarity of next TD_Pulse to be received. If this polarity does not match with the prediction after 60 pulses were received, the measurement shall be stopped and an unsuccessful measurement shall be reported via the DM_ERR bit of the TD Status register. This situation may be caused by reflections, an unexpected transmission of another node or by noise on the line.

After the synchronization of scramblers is achieved, exchange of the TD_Pulse shall start and the DIST_MR counter shall be incremented with each received TD_Pulse. The counting shall start at 0. The number of received pulses shall be counted for the time duration set by the DM_DUR bit field of the TD Control register. A successful finish of the measurement shall be reported via DM_DONE bit of the TD Status register.

The physical distance of the reference and measured nodes can be expressed as the time needed for the TD_Pulse to travel between these two nodes using Equation 2. If the propagation delay of the line is known, the physical distance can be calculated using this time.

$$t_{distance}[ns] = \frac{\frac{(DM\_DUR + 1) * 10^6}{DIST\_MR} - TD\_INT\_DELAY_R[ns] - TD\_INT\_DELAY_M[ns]}{2} \qquad \text{Equation 2}$$

Where DM_DUR+1 is the duration of the measurement in ms, DIST_MR is the number of received TD_Pulses and $TD\_INT\_DELAY_R$ / $TD\_INT\_DELAY_M$ is the internal delay of the reference / measured node.

Table 3: Topology Discovery Calibration – timing parameters

Symbol	Description	Min.	Units
TD_DM_TO	Topology Discovery Distance Measurement timeout	1	s

7.1 Variables

DM_RUN	Allows the distance measurement. Set by: DM_START (Start of internal delay measurement) bit of the Topology Discovery Control register. See 10.1.5. Values: 1 or 0
REFN	REFN (Reference node) bit of the Topology Discovery Control register. See 10.1.2. Values: 1 or 0
DLYM_RUN	Allows the internal delay measurement. Set by: Automatic mode procedure or DLYM_START (Start of internal delay measurement) bit of the TD Control register. See 10.1.3. Values: 1 or 0
DLYM_ERR	DLYM_ERR (Internal delay measurement finished unsuccessfully) bit of the TD Status register. See 10.2.2. Values: 1 or 0
DM_DONE	DM_DONE (Distance measurement finished successfully) bit of the TD Status register. See 10.2.3. Values: 1 or 0
DM_ERR	DM_ERR (Distance measurement finished unsuccessfully) bit of the TD Status register. See 10.2.4. Values: 1 or 0
DIST_MR	DIST_MR (Distance measurement result) is the number of received TD_Pulses during the distance measurement. This number is stored in TD_DIST_RES_LOW and TD_DIST_RES_HIGH registers. See 10.3 and 10.4.
TD_EN	TD_EN (Topology Discovery enable) bit of the TD Control register. See 10.1.1. Values: 1 or 0
TD_P_REC	This variable is set TRUE if the TD_Pulse was received from the line partner and is reset to FALSE at each state entry/reentry. Values: TRUE or FALSE
MEAS_ERR	This variable is set TRUE if an error occurs during the distance measurement. Methods for a recognition of errors are implementation specific. Values: TRUE or FALSE
N_PULSES	This variable is used to count the number of received TD_Pulses during the training of scramblers. Values: 0 to 60

SEQ_ERR — This variable is set to 1 in case of mismatch between the predicted polarity and the actual polarity of the received TD_Pulse, 0 otherwise.
Values: 1 or 0

DM_DUR — DM_DUR (Duration of distance/delay measurement) bit field of the TD Control register. See 10.1.3.
Values: 0 to 15

MTX_DIS — MAC transmission disabled. If True, the reconciliation sublayer (RS) shall assert the CARRIER_STATUS = CARRIER_ON via PLS_CARRIER.indication primitive to the MAC. Additionally, if the PLS_DATA.request is issued, the RS shall assert the SIGNAL_STATUS = SIGNAL_ERROR via PLS_SIGNAL.indication until the PLS_DATA.request primitive is de-asserted.
Values: TRUE or FALSE

7.2 Functions

send_TD_Pulse() — This function transmits one TD_Pulse (see 5) after TD_INT_DELAY. The polarity of this pulse is defined by scrambler output and 1B/2B coding.

check_sequence() — This function checks if the polarity of the received TD_Pulse matches with the prediction. If the polarities of received pulses match the prediction, the output of the function is 0, 1 otherwise.
Values: 1 or 0

7.3 Timers

All timers operate in the same fashion. A timer is reset and starts counting upon entering a state where “start x_timer” is asserted, if it does not run already. If a timer is running already, entering a state where “start x_timer” is asserted does not have any effect. A timer is reset and starts counting upon entering a state where “restart x_timer” is asserted. Time “x” after the timer has been started, “x_timer done” is asserted and remains asserted until the timer is reset.

TD_DM_TO — This timer is optional and defines the maximal allowed time to start the distance measuring. If the measurement was not started within this time, the attempt to do the measurement should be stopped and an error reported.
Duration: See Table 3.

10u_timer — This timer defines the maximal allowed time between the transmission of the TD_Pulse and the reception of the TD_Pulse as a response. If no response was received within this time, it is expected that the measured node was not ready to perform the measurement and therefore another TD_Pulse will be sent by the reference node.
Duration: 10 µs ± 10 %

Meas_timer — This timer defines the duration of TD_Pulse exchange between the reference node and the measured node. During this time, the number of received TD_Pulses is counted.
Duration: DM_DUR + 1 [ms]

7.4 State diagrams

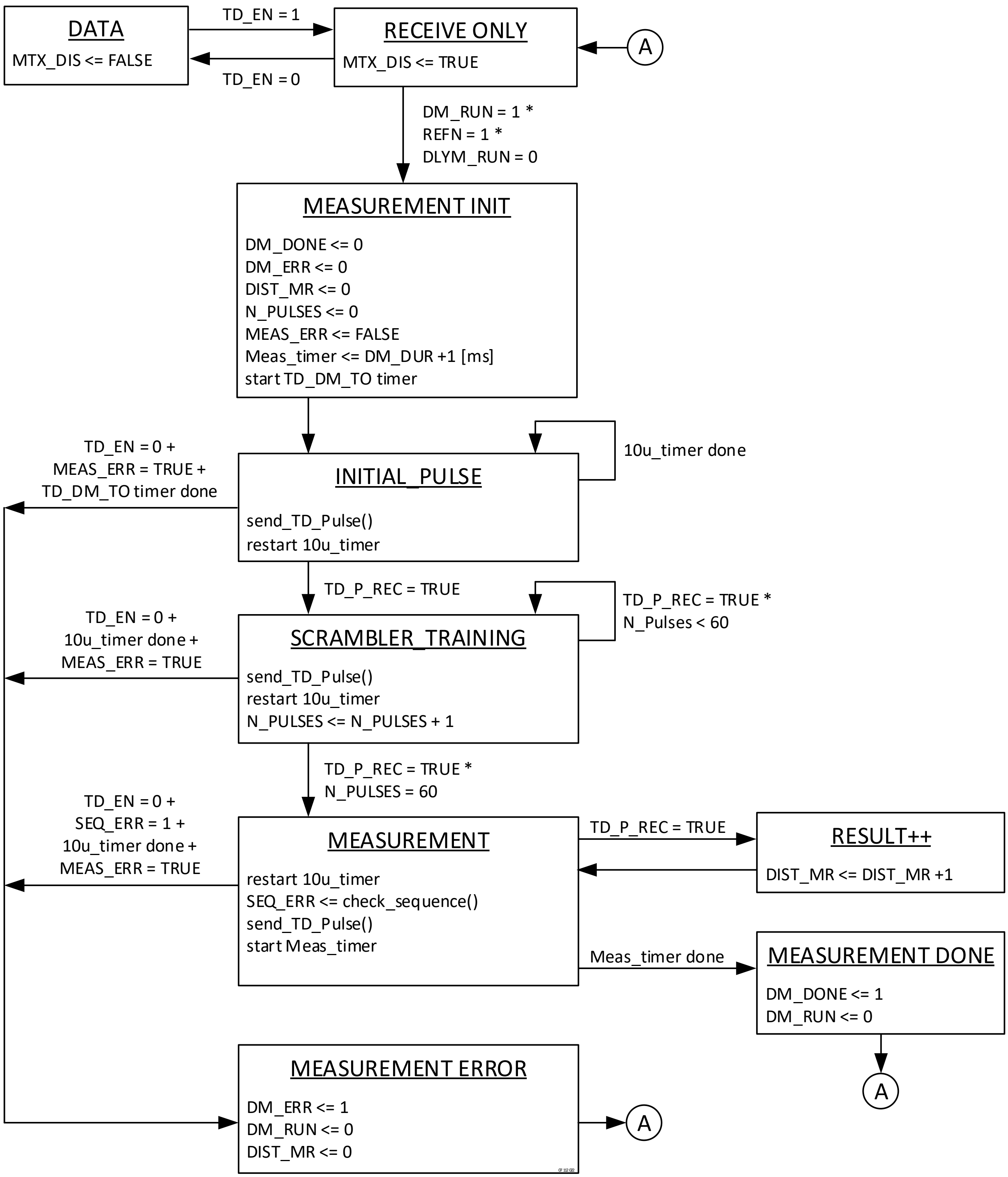

Figure 5: Distance Measurement - Reference node state diagram

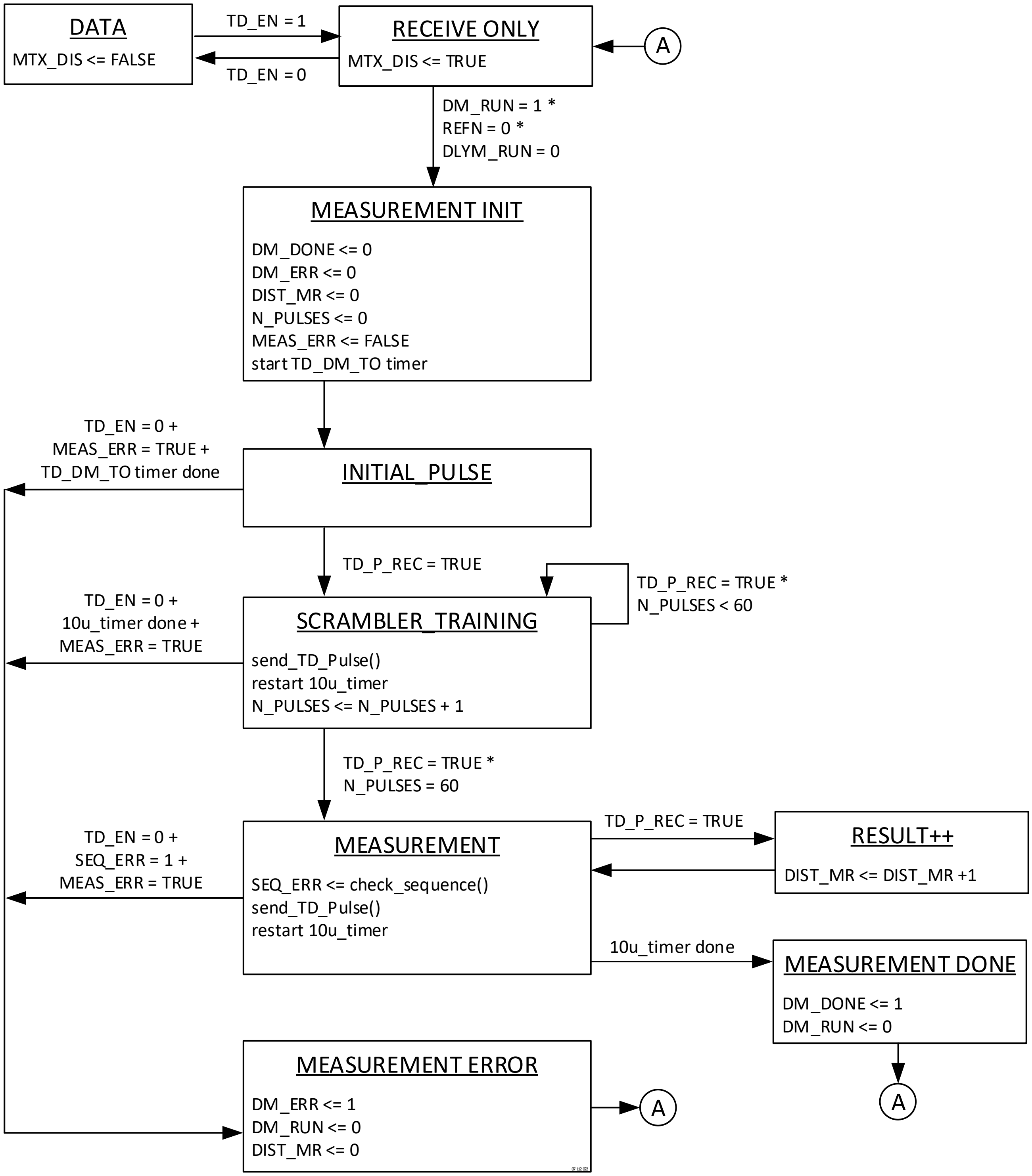

Figure 6: Distance Measurement - Measured node state diagram

8 Scrambler

Distance and internal delay measurement functions shall implement scramblers using a following polynomial function $g(x) = x^5 + x^4 + x^2 + x + 1$ for the reference node and $g(x) = x^5 + x^4 + x^3 + x^2 + 1$ for the measured node. These scramblers shall be updated once in two TD_Pulse transmissions. The output of these scramblers should be encoded by 1B/2B encoding as is shown in Table 4. This encoding defines the polarity of the TD_Pulse to be transmitted. LSB of the transceiver output shall be transmitted first.

Table 4: Scrambler 1B/2B encoding

Scrambler output [B]	Transceiver output [B]
1	{-1, +1}
0	{+1, -1}

The implementations of the additive scramblers using a linear-feedback shift registers are shown in Figure 7 and Figure 8. Bits stored in the shift register delay line at the time n are denoted $SR_n(4:0)$ and $SM_n(4:0)$. The '+' symbol denotes exclusive-OR logical operation.

If the initialization of the internal delay or distance measurement is executed, 5-bit vectors (SM and SR), representing the state or the scramblers, should be arbitrarily set. The initialization of scramblers is left to the implementer. Scramblers shall not be initialized to all zeros.

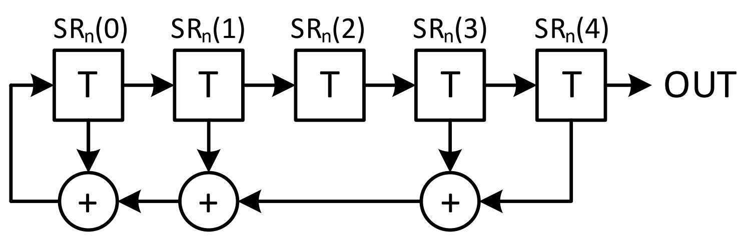

Figure 7: Additive scrambler - Reference node

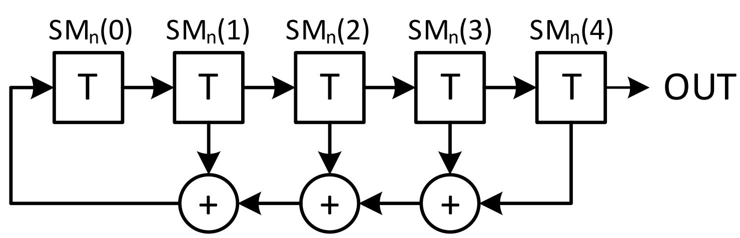

Figure 8: Additive scrambler - Measured node

8.1 Descrambler

The descrambler is used to check whether the measurement sequence was not interrupted by an unexpected pulse on the line. Once the scrambler and the descrambler are synchronized, polarities of received pulses can be predicted and checked.

The 2B/1B decoding shall first find the boundary of each pair of 2B pulses, to provide valid 1B data to the descrambler. This boundary can be detected by presence of consecutively equal polarity pulses, as they should belong to separate 2B/1B conversion pairs.

The Distance Measurement function shall descramble the 2B/1B decoded (according to Table 4) data stream and return the seed DR(4:0)/DM(4:0) for the descrambler during the training phase. Once the descrambler is filled with the seed, its output should match with the output of 2B/1B decoded data stream. The polarity can also be automatically detected: one assumption of the polarity is made first and the descrambler synchronization is monitored within a certain period to determine whether such an assumption is correct; if not, the same procedure is repeated with a different polarity assumption.

The descrambler shall be updated once in two TD_Pulse receptions. The implementations of additive descramblers by a linear-feedback shift registers are shown in Figure 9 and Figure 10.

During the internal delay measurement, descrambler which corresponds to node's own scrambler should be used. The intention is to check that all pulses transmitted to the line were received correctly and without any additional alien pulses.

During the distance measurement and REMOTE_DLYM state in Automatic mode, descrambler which corresponds to scrambler of the remote node should be used. The intention is to check that all pulses transmitted by the remote node were received correctly and without any additional alien pulses.

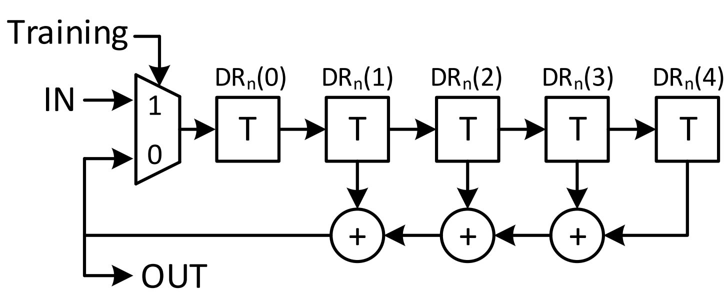

Figure 9: Additive descrambler - Reference node (Distance measurement), Measured node (Internal delay measurement)

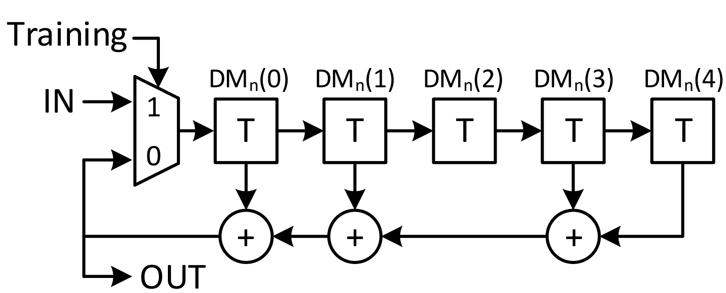

Figure 10: Additive descrambler - Measured node (Distance measurement), Reference node (Internal delay measurement)

9 Automatic mode

The automatic mode handles a switching between the internal delay measurement and the distance measurement. The implementation of the automatic mode shall conform to the Automatic mode state diagrams in Figure 11, Figure 12 and the associated state variables, functions and timers.

If the automatic mode is not used, a higher layer could first perform the internal delay measurement of the reference node and the measured node separately. Then, the measured node should enter the distance measurement mode and the reference node should enter the measurement mode afterwards. This switching between the internal delay measurement and the distance measurement can be handled by the node itself if the automatic mode feature is used.

Measurements shall be performed using two nodes connected the same line from which one is configured as the reference node and the second one as the measured node. This configuration shall be done using REFN bit of TD Control Register. Before the automatic mode is started, all other nodes on the shared line shall be prevented from any transmission which could affect measurements (e.g. data, Beacon, Wake-up signaling etc.). This can be done using Receive only mode. Then, the measured node shall start the automatic mode via TD_EN and AUTO_START bits of TD Control Register and the reference node shall do the same afterwards.

Once the automatic mode is started, the reference node performs the internal delay measurement. The measured node is observing the line and waits until the measurement is done. Then, the measured node starts the measurement of its internal delay. If any of these measurements fails, the automatic mode is stopped.

It can happen that the measured node enters the automatic mode after the reference node is done with its internal delay measurement. To prevent the measured node from getting stucked in this situation, the reference node shall send one TD_Pulse every 20 us.

Using the automatic mode, the reference node observes the internal delay measurement of the measured mode and saves its duration and the number of TD_Pulses. Using this approach, all the information necessary for a calculation of the distance are available at the reference node after the measurement is done.

After the successfully finished internal delay measurement, the measured node proceeds to the distance measurement and waits for the reference node to start the measurement. As soon as there is no activity on the line for a defined period, the reference node expects the delay measurement to be done and starts the distance measurement.

9.1 Variables

The following variables are used in the state diagram.

DLYM_RUN	Allows the internal delay measurement. Set by: Automatic mode procedure or DLYM_START (Start of internal delay measurement) bit of the TD Control register. See 10.1.3. Values: 1 or 0
DLYM_ERR	DLYM_ERR (Internal delay measurement finished unsuccessfully) bit of the TD Status register. See 10.2.2. Values: 1 or 0
DLYM_DONE	DLYM_DONE (Internal delay measurement finished successfully) bit of the TD Status register. See 10.2.1. Values: 1 or 0
REFN	REFN (Reference node) bit of the TD Control register. See 10.1.2. Values: 1 or 0
AUTO_RUN	Allows the automatic mode. Set by: AUTO_START (Start of automatic mode) bit of the TD Control register. See 10.1.6. Values: 1 or 0
TD_EN	TD_EN (Topology Discovery enable) bit of the TD Control register. See 10.1.1. Values: 1 or 0
TD_P_REC	This variable is set TRUE if the TD_Pulse was received and is reset to FALSE at each state entry/reentry. Values: TRUE or FALSE
AUTO_ERR	AUTO_ERR (Automatic mode finished unsuccessfully) bit of the TD Status register. See 10.2.5. Values: 1 or 0
DM_RUN	Allows the internal delay measurement. Set by: DM_START (Start of distance measurement) bit of the TD Control register. See 10.1.5. Values: 1 or 0
SEQ_ERR	This variable is set to 1 in case of a mismatch between the predicted polarity and the actual polarity of received TD_Pulse, 0 otherwise. Values: 1 or 0
MNDLY_MR	MNDLY_MR (Measured Node - Result of internal delay measurement) is the number of received TD_Pulses during the delay measurement of the measured node. This number is stored in TD_MNDLY_RES_LOW and TD_MNDLY_RES_HIGH registers. See 10.7 and 10.8.

MTX_DIS MAC transmission disabled. If True, the reconciliation sublayer (RS) shall assert the CARRIER_STATUS = CARRIER_ON via PLS_CARRIER.indication primitive to the MAC. Additionally, if the PLS_DATA.request is issued, the RS shall assert the SIGNAL_STATUS = SIGNAL_ERROR via PLS_SIGNAL.indication until the PLS_DATA.request primitive is de-asserted.
Values: TRUE or FALSE

9.2 Timers

All timers operate in the same fashion. A timer is reset and starts counting upon entering a state where “start x_timer” is asserted, if it does not run already. If a timer is running already, entering a state where “start x_timer” is asserted does not have any effect. A timer is reset and starts counting upon entering a state where “restart x_timer” is asserted. Time “x” after the timer has been started, “x_timer done” is asserted and remains asserted until the timer is reset.

TD_DM_TO This timer is optional and defines the maximal allowed time to perform the internal delay measurement of the link partner. If the link partner was not able to finish its measurement, the automatic mode should be stopped and an error reported via the AUTO_ERR bit.
Duration: See Table 3.

RMT_DLY_DUR Measured Node - Duration of the internal delay measurement. This timer measures the duration of the internal delay measurement performed by the measured node.
Duration: 1 to 16 ms
Step: 1 ms

9.3 State diagrams

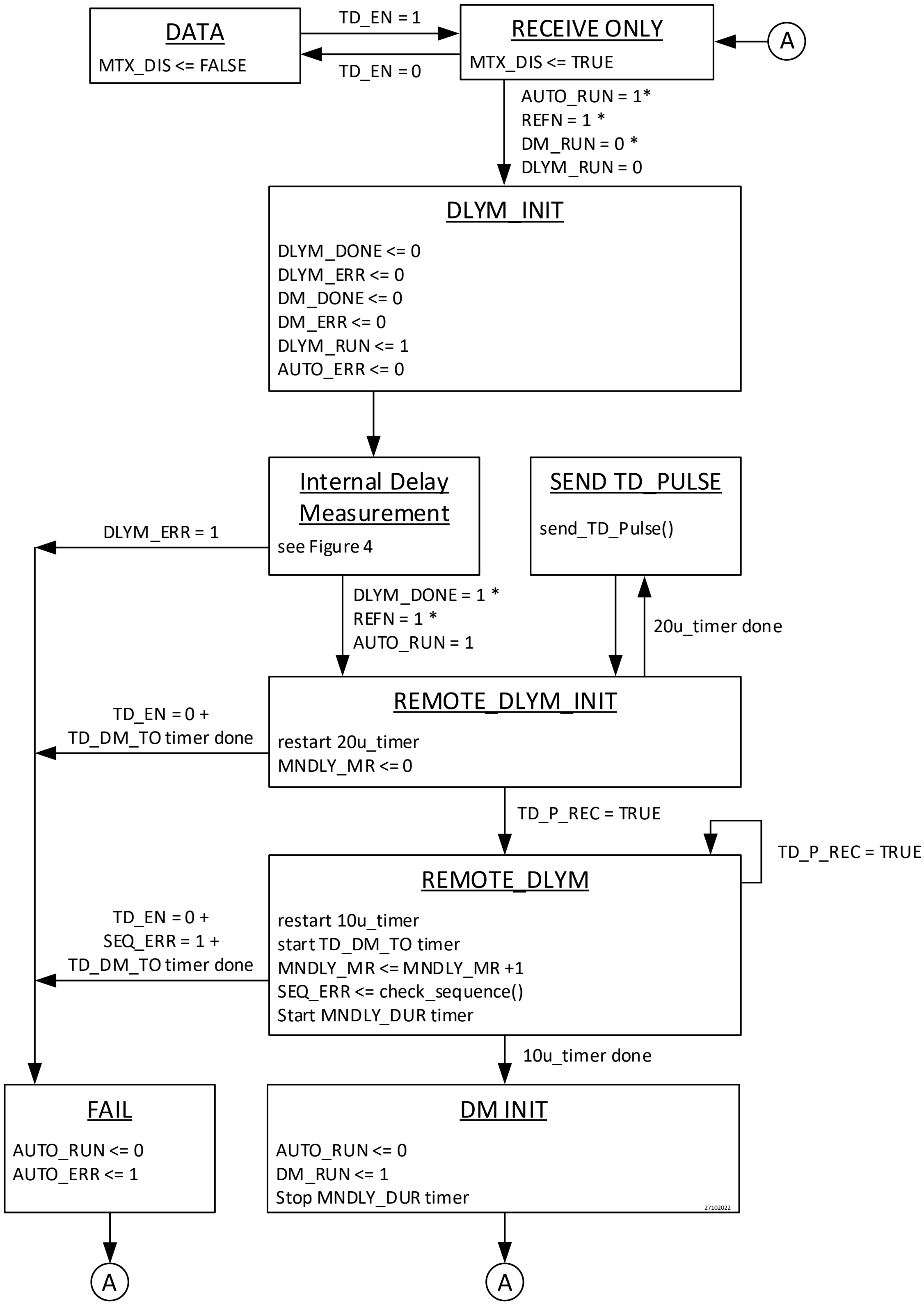

Figure 11: Automatic mode - Reference node

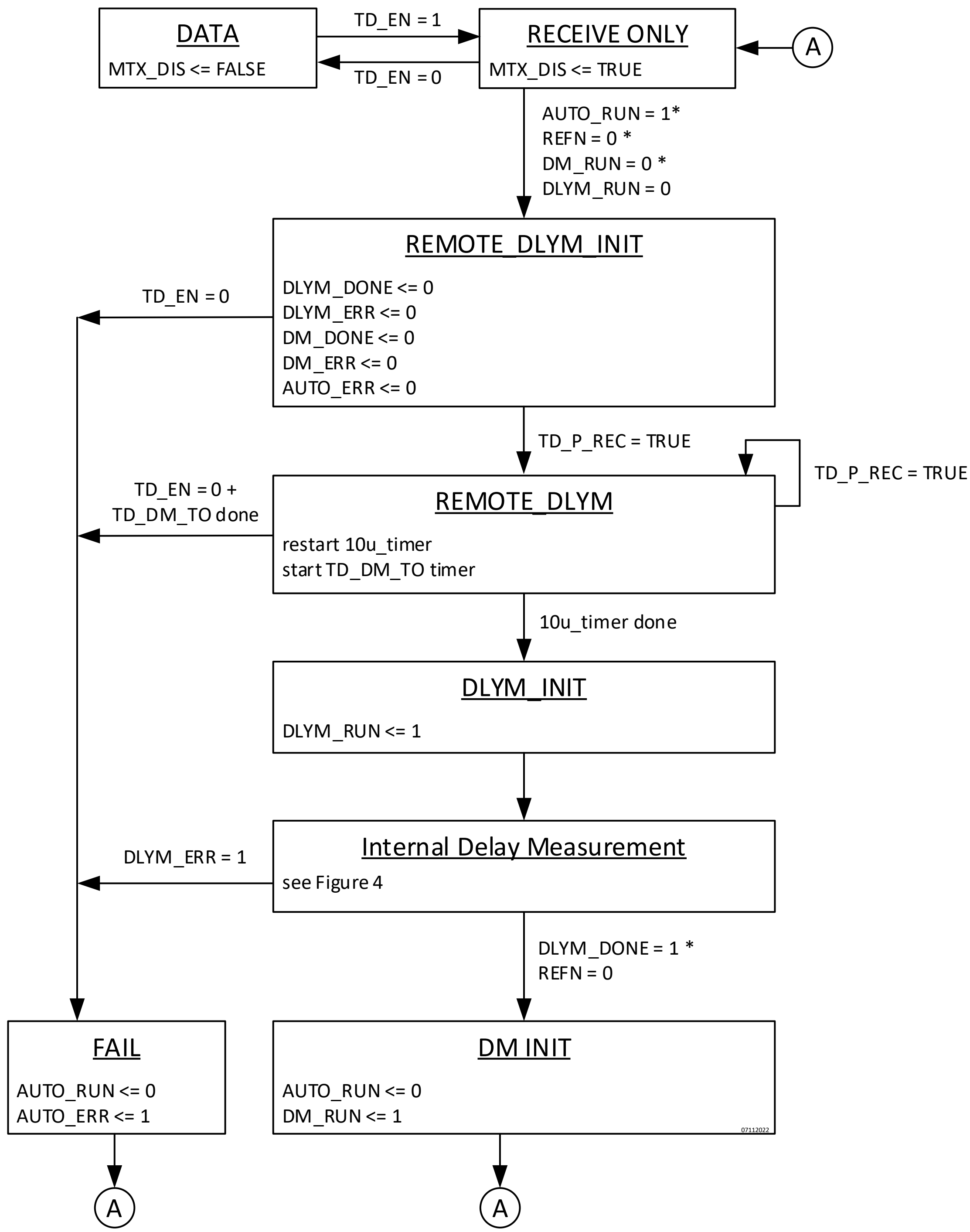

Figure 12: Automatic mode - Measured node

10 Register map

Topology Discovery registers are defined in MMD 31 (Vendor Specific 2) of the Clause 45 address space. This section provides a functional description of registers and bits used for Topology Discovery as well as their position within memory map.

Table 5: Topology Discovery registers

MMD	Address	Name	Description
31	0xCE00	TD_CTRL	TD Control register
31	0xCE01	TD_STAT	TD Status register
31	0xCE02	TD_DIST_RES_LOW	TD Distance Measurement Result [15:0]
31	0xCE03	TD_DIST_RES_HIGH	TD Distance Measurement Result [31:16]
31	0xCE04	TD_DLY_RES_LOW	TD Delay Measurement Result [15:0]
31	0xCE05	TD_DLY_RES_HIGH	TD Delay Measurement Result [31:16]
31	0xCE06	TD_MNDLY_RES_LOW	Measured Node Delay Measurement Result [15:0]
31	0xCE07	TD_MNDLY_RES_HIGH	Measured Node Delay Measurement Result [31:16]
31	0xCE08	TD_MNDLY_DUR	Measured Node Delay Measurement Duration

10.1 TD_CTRL - TD Control register (31.CE00)

Table 6: TD_CTRL – TD Control register

Bit(s)	Name	Description	R/W [a]	Default
15	TD_EN	Topology Discovery enable	RW	0
14	REFN	Reference node / Measured node selection	RW	0
13	DLYM_START	Start of internal delay measurement	RW-SC	0
12:9	DM_DUR [3:0]	Duration of distance measurement	RW	0
8	DM_START	Start of distance measurement	RW-SC	0
7	AUTO_START	Start of automatic mode	RW-SC	0
6:0	-	Reserved	RO	0
NOTE [a] RO = read-only, RW = read-write, SC = self-clearing				

10.1.1 TD_EN

Topology Discovery enable. When set, the node shall enter Receive only mode, data and BEACON transmission is disabled but the receiver still works as in DATA mode. Clearing of this bit causes termination of any Topology Discovery procedure and return to Data mode.

10.1.2 REFN

Reference node. When set, the node should behave like the reference node during the measurement and should use the scrambler polynomial associated with the reference node. Otherwise, the node should behave like the measured node and should use the scrambler polynomial associated with the measured node.

10.1.3 DLYM_START

Start of internal delay measurement. If TD_EN bit is set, DLYM_START bit starts the internal delay measurement by setting DLYM_RUN = 1. This bit is cleared automatically. The result of the measurement is reported in the TD_DLY_RES register.

10.1.4 DM_DUR

Duration of distance/delay measurement. It configures the duration of the distance/delay measurement to N+1 ms, where N is the value of this bit field. A longer measurement time means better precision of the measurement, using shorter time, the measurement will be done faster.

10.1.5 DM_START

Start of distance measurement. If TD_EN bit is set, DM_START bit starts the distance measurement by setting DM_RUN = 1. This bit is cleared automatically. The result of the measurement is reported in the TD_DIST_RES register.

10.1.6 AUTO_START

Start of automatic mode. If TD_EN bit is set, AUTO_START bit starts the automatic mode by setting AUTO_RUN = 1. This bit is cleared automatically.

10.2 TD_STAT - TD Status register (31.CE01)

Table 7: TD_STAT – TD Status register

Bit(s)	Name	Description	R/W [a]	Default
15	DLYM_DONE	Internal delay measurement finished successfully	RO	0
14	DLYM_ERR	Internal delay measurement finished unsuccessfully	RO	0
13	DM_DONE	Distance measurement finished successfully	RO	0
12	DM_ERR	Distance measurement finished unsuccessfully	RO	0
11	AUTO_ERR	Automatic mode finished unsuccessfully	RO	0
10:0	-	Reserved	RO	0

NOTE
[a] RO = read-only, RW = read-write, SC = self-clearing

10.2.1 DLYM_DONE

Internal delay measurement finished successfully. When set, this bit indicates that the internal delay measurement was done and the result is available at the TD Delay Measurement Result register. This bit is cleared at the beginning of the internal delay measurement and at the beginning of the automatic mode.

10.2.2 DLYM_ERR
Internal delay measurement finished unsuccessfully. There was an error detected during the measurement or the measurement was stopped manually before it was done. This bit is cleared at the beginning of the internal delay measurement and at the beginning of the automatic mode.

10.2.3 DM_DONE
Distance measurement finished successfully. Result of the measurement is available at the TD Distance Measurement Result register. This bit is cleared at the beginning of the distance measurement and at the beginning of the automatic mode.

10.2.4 DM_ERR
Distance measurement finished unsuccessfully. The measurement was manually stopped, there was no response from the measured node within TD_DM_TO (if implemented) or there was an unexpected activity on the line. This bit is cleared at the beginning of the distance measurement and at the beginning of the automatic mode.

10.2.5 AUTO_ERR
Automatic mode finished unsuccessfully. This bit is cleared at the beginning of the automatic mode.

10.3 TD_DIST_RES_LOW - TD Distance Measurement Result register - Low (31.CE02)

Table 8: TD_DIST_RES_LOW – TD Distance Measurement Result register - Low

Bit(s)	Name	Description	R/W [a]	Default
15:0	DIST_MR_LOW	Result of distance measurement [15:0]	RO	0
NOTE [a] RO = read-only, RW = read-write, SC = self-clearing				

10.3.1 DIST_MR_LOW

Lower 16 bits of the distance measurement result, which contain the number of TD_Pulses received during the last distance measurement.

10.4 TD_DIST_RES_HIGH - TD Distance Measurement Result register - High (31.CE03)

Table 9: TD_DIST_RES_HIGH – TD Distance Measurement Result register - High

Bit(s)	Name	Description	R/W [a]	Default
15:0	DIST_MR_HIGH	Result of distance measurement [31:16]	RO	0
NOTE [a] RO = read-only, RW = read-write, SC = self-clearing				

10.4.1 DIST_MR_HIGH

Upper 16 bits of the distance measurement result, which contain the number of TD_Pulses received during the last distance measurement.

10.5 TD_DLY_RES_LOW - TD Delay Measurement Result register - Low (31.CE04)

Table 10: TD_DLY_RES_LOW – TD Delay Measurement Result register - Low

Bit(s)	Name	Description	R/W [a]	Default
15:0	DLY_MR_LOW	Result of delay measurement [15:0]	RO	0
NOTE [a] RO = read-only, RW = read-write, SC = self-clearing				

10.5.1 DLY_MR_LOW

Lower 16 bits of the delay measurement result, which contains the number of TD_Pulses received during the last internal delay measurement.

10.6 TD_DLY_RES_HIGH - TD Delay Measurement Result register - High (31.CE05)

Table 11: TD_DLY_RES_HIGH – TD Delay Measurement Result register - High

Bit(s)	Name	Description	R/W [a]	Default
15:0	DLY_MR_HIGH	Result of delay measurement [31:16]	RO	0
NOTE [a] RO = read-only, RW = read-write, SC = self-clearing				

10.6.1 DLY_MR_HIGH

Upper 16 bits of the delay measurement result, which contains the number of TD_Pulses received during the last internal delay measurement.

10.7 TD_MNDLY_RES_LOW -TD Measured Node Delay Measurement Result register - Low (31.CE06)

Table 12: TD_MNDLY_RES_LOW – TD Measured Node Delay Measurement Result register - Low

Bit(s)	Name	Description	R/W [a]	Default
15:0	MNDLY_MR_LOW	Measured Node - delay measurement result [15:0]	RO	0
NOTE [a] RO = read-only, RW = read-write, SC = self-clearing				

10.7.1 MNDLY_MR_LOW

Lower 16 bits of the Measured node – delay measurement result, which contains the number of TD_Pulses received from the measured node during its last internal delay measurement in the automatic mode.

10.8 TD_MNDLY_RES_HIGH -TD Measured Node Delay Measurement Result register - High (31.CE07)

Table 13: TD_MNDLY_RES_HIGH – TD Measured Node Delay Measurement Result register - High

Bit(s)	Name	Description	R/W [a]	Default
15:0	MNDLY_MR_HIGH	Measured Node - delay measurement result [31:16]	RO	0
NOTE [a] RO = read-only, RW = read-write, SC = self-clearing				

10.8.1 MNDLY_MR_HIGH

Upper 16 bits of the Measured node – delay measurement result, which contains the number of TD_Pulses received from the measured node during its last internal delay measurement in the automatic mode.

10.9 TD_MNDLY_DUR -TD Measured Node Delay Measurement Duration register (31.CE08)

Table 14: TD_MNDLY_DUR – TD Measured Node Delay Measurement Duration register

Bit(s)	Name	Description	R/W [a]	Default
15:12	MNDLY_DUR	Measured Node - Duration of internal delay measurement [ms]	RO	0
11:0	-	Reserved	RO	0

NOTE

[a] RO = read-only, RW = read-write, SC = self-clearing

10.9.1 MNDLY_DUR

Measured node – duration of internal delay measurement. The duration of the last internal delay measurement of the measured node in the automatic mode (4bit wide).