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SENT—Single Edge Nibble Transmission for Automotive Applications

RATIONALE

Not applicable.

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1. SCOPE

This document defines a level of standardization in the implementation of the digital pulse scheme for reporting sensor information via Single Edge Nibble Transmission (SENT) encoding. This standard will allow ECU and tool manufacturers to satisfy the needs of multiple end users with minimum modifications to the basic design. This standard will benefit vehicle Original Equipment Manufacturers (OEMs) by achieving lower ECU costs due to higher industry volumes of the basic design.

Requirements stated in this document provide a minimum standard level of performance to which all compatible ECUs and media shall be designed. This assures data communication among all connected devices regardless of supplier.

The intended audience includes, but is not limited to, ECU suppliers, sensor suppliers, component release engineers and vehicle system engineers.

1.1 Overview

The Single Edge Nibble Transmission encoding scheme (SENT) is intended for use in applications where high resolution sensor data needs to be communicated from a sensor to an Engine Control Unit (ECU). It is intended as a replacement for the lower resolution methods of 10 bit A/D's and PWM and as a simpler low cost alternative to CAN or LIN. The implementation assumes that the sensor is a smart sensor containing a microprocessor or dedicated logic device (ASIC) to create the signal.

SENT is a unidirectional communications scheme from sensor / transmitting device to controller /receiving device which does not include a coordination signal from the controller/receiving device. The sensor signal is transmitted as a series of pulses with data measured as falling to falling edge times. Details of the implementation may vary for specific sensor applications which are described in sub-documents of this specification.

2. REFERENCES

2.1 Applicable Publications

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest version of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

SAE J551 (All parts) Performance Levels and Methods of Measurement of Electromagnetic Compatibility for Vehicles and Devices

SAE J1113 (All parts) Electromagnetic Compatibility Measurement Procedures for Vehicle Components

SAE J1930 Electrical/Electronic Systems Diagnostic Terms, Definitions, Abbreviation and Acronyms

2.1.2 ISO Publications

Available from ANSI, 25 West 43rd Street, New York, NY 10036-8002, Tel: 212-642-4900, www.ansi.org.

None.

2.1.3 Supplier Publications

None.

2.1.4 Other Publications

CISPR 25 Limits and Methods of Measurement of Radio Disturbance Characteristics for the Protection of Receivers Used On Board Vehicles (available at webstore.iec.ch).

ES-XW7T-1A278-AC Ford Component and Subsystem Electromagnetic Compatibility Worldwide Requirements and Test Procedures (available at www.fordemc.com. This document shall be referred to as the Ford EMC Spec.)

GMW3097 General Specification for Electrical / Electronic Components and Subsystems, Electromagnetic Compatibility (this document will be referred to as the GM EMC Spec.)

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3. DEFINITION OF TERMS

3.1 Glossary

3.1.1 Media

The physical entity that conveys the electrical (or equivalent means of communication) signal transmission between electronic devices.

3.1.2 Protocol

The formal set of conventions or rules for the exchange of information between electronic devices. This includes the specification of the signal frame administration, frame transfer and physical layer.

3.1.3 Message

One sequence of calibration pulse and specified number of nibble pulses for that implementation. The number of nibbles is constant for each implementation but the individual message length can vary depending on the specific values of the nibbles.

3.1.4 Radiated Emissions

The energy that radiates from the physical layer.

3.1.5 Radiated Immunity

The level of susceptibility of physical layer components to communication errors in the presence of high energy electromagnetic fields.

3.1.6 Receiver Module

The processor that receives the encoded signal. Generally an ECU with falling-edge detection and timing measurement capabilities.

3.1.7 Transmitter Module

The device that generates the message to the receiver module. Generally a smart sensor.

3.1.8 Nominal

Time period assuming no transmitter clock error.

3.1.9 Pulse Period

Time between consecutive falling edges of the transmitting signal.

4. ACRONYMS, ABBREVIATIONS, AND SYMBOLS

ASIC – Application Specific Integrated Circuit
CAN – Controller Area Network
ECU – Electronic Control Unit
EMC – Electromagnetic Compatibility
ESD – Electrostatic Discharge
ISO – International Organization for Standardization
kbits/sec – Thousands of data bits per second
LIN – Local Interconnect Network
LSN – least significant nibble

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MAF – Mass Air Flow
MidLSN – middle least significent nibble
MidMSN – middle most significent nibble
MidN – middle nibble
MSN – most significant nibble
OEM – Original Equipment Manufacturer
RE – Radiated Emissions
RI – Radiated Immunity
SAE – Society of Automotive Engineers
SENT – Single Edge Nibble Transmission
TPS – Throttle Position Sensor

5. SENT SYSTEM REQUIREMENTS

5.1 General Requirements

Transmission occurs independently of any action of the receiver module, i.e. the transmission shall not require a synchronization signal from the receiver module.

Assumptions used to design the encoding scheme:

- Actual Transmission time is dependent on the data values being sent and the transmitter clock variation.
- Message pulse order is fixed for all transmitters.
- Transmitter is allowed a maximum clock variation of ±20%.
- Transmission time for the longest data message and max transmitter clock variation is less than 1.0 millisecond at 3 microsecond bit time and 6 data nibbles.
- A transmitter specific nominal clock period (tick) between 3 microseconds and 10 microseconds.

5.2 Message Definitions

5.2.1 Transmission Sequence

The encoding scheme consists of a sequence of pulses which is repeatedly sent by the transmitting module. The transmission consists of the following sequence (all times nominal):

- Calibration/Synchronization pulse period 56 clock ticks.
- One 4 bit Status and Serial Communication nibble pulse (defined in 5.2.2) of 12 to 27 clock ticks.
- A sequence of one or more 4 bit Data nibble pulses (12 to 27 clock ticks each) representing the values of the signal(s) to be communicated. The number of nibbles will be fixed for each application of the encoding scheme (i.e. throttle position sensors, mass air flow, etc.) but can vary between applications. For example, if two 12 bit values are transmitted, 6 nibbles will be communicated.
- One 4 bit Checksum nibble pulse (defined in 5.2.5) of 12 to 27 clock ticks.

Figure 1 shows an example single message transmission for two 12 bit sensor values assuming a 3 microsecond clock tick.

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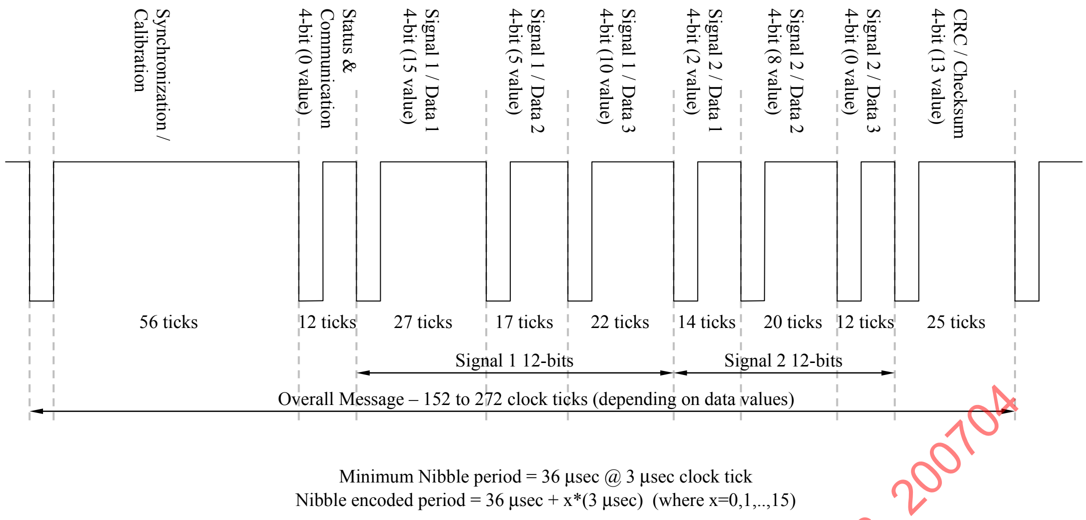

FIGURE 1 – EXAMPLE ENCODING SCHEME FOR TWO 12 BIT SIGNALS

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5.2.2 Transmission Properties of Calibration/Synchronization Pulse

- Nominal pulse period is 56 clock ticks.
- 5 clock ticks driven low time (all remaining clock ticks driven high).
- Actual period measured to correct for transmitter clock variation.

5.2.3 Transmission Properties of Nibble Pulse

- Minimum pulse period is 12 clock ticks.
- 5 clock ticks driven low time (all remaining clock ticks driven high).
- Each nibble count is 1 clock tick (0 – 15 counts ⇒ 0 – 45 µs at a 3 µs clock tick).
- Minimum nibble pulse period (transmission value of 0) = 12 clock ticks (36 µs at a 3 µs clock tick).
- Maximum nibble pulse period (transmission value of 15) = 12 + 15 = 27 clock ticks (36 + 45 = 81 µs at a 3 µs clock tick).

5.2.4 Status and Communication Nibble

This nibble is reserved to enable the sensor to transmit miscellaneous information such as part numbers or fault code information. The nibble is defined in the following table:

TABLE 1 – STATUS AND COMMUNICATION NIBBLE DESCRIPTION

Bit Number	Bit Function
0	Reserved for specific application
1	Reserved for specific application
2	Serial Data message bits
3	Message start = 1, otherwise = 0

Serial data is transmitted (bit by bit) in bit 2 (of the Status and Communication nibble) of consecutive messages from the transmitter. Serial data will be communicated in a 16-bit sequence as shown in Table 2. The starting bit of a serial message is indicated by a “1” in bit 3 of the Status and Communication nibble. That SENT message and the next 15 must be successfully transmitted (no errors) for the serial value to be received.

The 16-bit message consists of a 4 bit Message ID nibble, 2 nibbles (1 byte) of data, and a CRC checksum nibble. The CRC checksum is derived for the Message ID and 2 data nibbles and is the same checksum algorithm as used to calculate the SENT CRC nibble (see 5.4). The Message ID is used to identify the type of data being communicated in the Data Byte. Actual Serial Data message IDs and data values are application specific.

TABLE 2 – SERIAL MESSAGE FORMAT

Serial Communication Nibble Receive No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Startbit (bit # 3)	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Serial Data (bit # 2)	Message ID				Data Byte								CRC			

5.2.5 Checksum Nibble

See 5.4.

5.3 Transmission and Reception of Message

5.3.1 Transmission of Message

Each specific implementation of the encoding scheme (e.g. throttle sensors, pedal sensors, mass air sensors, etc.) shall have a defined sequence, a calibration pulse followed by a constant number of nibbles. The transmitting module shall send the defined sequence repeatedly without pause.

5.3.2 Adjustment of Received Message Nibble Lengths

The ECU shall receive the encoded signal by monitoring the time between falling edges (the pulse period). The measurement of a pulse period equal to the calibration pulse ±20% shall signal the start of a new message. The actual period of the calibration pulse received shall be used to adjust the period of the succeeding nibble pulses within the message. This calibration pulse is required to correct for clock frequency variation in the sensor/transmitting device.

The ratio between the measured calibration pulse period and the nominal (56 clock tick) period is calculated. Each of the message's remaining measured pulse periods is then divided by this ratio to correct them back to the equivalent nominal period. These corrected periods then have the 12 clock tick minimum period subtracted and the resulting data length period divided by the nominal clock tick period and rounded to an integer value to obtain the data nibble value. The process is summarized by the following algorithm (assuming a 3 μs nominal clock tick):

Rcal = Measured Calibration pulse period/168 μs
Data Value N = Round[(Measure pulse period N/Rcal – 36 μs)/3 μs]

5.3.3 Received Message Diagnostics

The receiver module will monitor the message for the following conditions. If any of the below conditions are met, the receiver module shall declare that a message error has occurred and ignore the entire message.

- Calibration pulse length < 56 clock ticks – 25% or > 56 clock ticks + 25%.
- Too many or too few nibbles (falling edges) between calibration pulses.
- Checksum error.
- successive calibration pulses differ by > 1.5625% (1/64).
- any nibble data values measured as < 0 or > 15.

Any of the errors above shall also cause the receiver to begin searching for a valid calibration pulse to re-synchronize reception to the transmitting device start of message. The diagnostics above will allow the receiption of message with ±25% timing range. However, only systems with a maximum ±20% timing range will be certified as meeting the SENT requirements.

5.3.4 Reset

Should the transmitting module reset for any reason, it shall start transmitting a new message immediately following its initialization procedure. The output signal shall be held in the high state until initialization is completed.

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5.4 Checksum Nibble Details

The Checksum nibble is a 4 bit CRC of the Data nibbles only. The Status and Communication Nibble is not included in the CRC calculation.

The CRC is calculated using polynomial x^4 + x^3 + x^2 + 1 with seed value of 0101.

5.4.1 Errors Detected and Not Detected by Checksum

The following bit flip errors are detectable using the polynomial:

1. All single bit errors.
2. All odd number of errors.
3. All single burst errors of length ≤ 4.
4. 87.5% of single burst errors of length = 5.
5. 93.75% of single burst errors of length > 5.

The fault mode of most concern for the signal encoding scheme is a shifted falling edge which would cause one nibble to appear to be a longer (shorter) period followed by a nibble with a shorter (longer) period than intended by the transmitting device. The CRC detects all cases of 1, 2, 4, 6, 8, 9, 10, 12, 13, 14 and 15 count shifts over two nibbles.

The CRC polynomial will not detect all cases of 3, 5, 7, 11 count shifts. These undetectable patterns are listed in Table 3. For example, row 3 of Table 3 has error pattern 101 followed by 11. If nibble 1 was 4 (100) and nibble 2 0 (000), after the bit flips nibble 1 becomes 1 (001) and nibble 2 becomes 3 (011). Nibble 1 has shifted by –3 and nibble 2 by +3. It is assumed that the risk associated with not detecting these types of faults is acceptable given the high update rate available to the encoding scheme.

TABLE 3 – BIT FLIP PATTERNS OVER TWO NIBBLES NOT DETECTABLE USING THE CRC POLYNOMIAL

Nibble 1 Error Pattern		Nibble 2 Error Pattern	
8	1000	1	1
13	1101	2	10
5	101	3	11
7	111	4	100
15	1111	5	101
10	1010	6	110
2	10	7	111
14	1110	8	1000
6	110	9	1001
3	11	10	1010
11	1011	11	1011
9	1001	12	1100
1	1	13	1101
4	100	14	1110
12	1100	15	1111

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5.4.2 CRC Implementation

The CRC checksum can be implemented as a series of shift left by 4 (multiply by 16) followed by a 256 array lookup. A MATLAB implementation is:

```
CheckSum= 5; % initialize checksum
for I=1:numNibbles
   tempCS = data(I)+CheckSum*16;
   CheckSum = CRC4Table(tempCS+1);
end
```

Where numNibbles is the number of nibbles to be checksummed, the data array contains the nibble to be checksummed and the 256 table is given below in MATLAB form:

```
% CRC 4 nibble lookup table
CRC4Table= [ ...
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 ...
13 12 15 14 9 8 11 10 5 4 7 6 1 0 3 2 ...
7 6 5 4 3 2 1 0 15 14 13 12 11 10 9 8 ...
10 11 8 9 14 15 12 13 2 3 0 1 6 7 4 5 ...
14 15 12 13 10 11 8 9 6 7 4 5 2 3 0 1 ...
3 2 1 0 7 6 5 4 11 10 9 8 15 14 13 12 ...
9 8 11 10 13 12 15 14 1 0 3 2 5 4 7 6 ...
4 5 6 7 0 1 2 3 12 13 14 15 8 9 10 11 ...
1 0 3 2 5 4 7 6 9 8 11 10 13 12 15 14 ...
12 13 14 15 8 9 10 11 4 5 6 7 0 1 2 3 ...
6 7 4 5 2 3 0 1 14 15 12 13 10 11 8 9 ...
11 10 9 8 15 14 13 12 3 2 1 0 7 6 5 4 ...
15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0 ...
2 3 0 1 6 7 4 5 10 11 8 9 14 15 12 13 ...
8 9 10 11 12 13 14 15 0 1 2 3 4 5 6 7 ...
5 4 7 6 1 0 3 2 13 12 15 14 9 8 11 10 ...
];
```

The CRC can also be implemented as a series of bit-wise XOR and shift operations.

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6. SENT PHYSICAL LAYER OPERATION

The physical layer is responsible for providing a method of transferring digital data encoded as pulse lengths to the communication medium. The physical layer interface consists of a minimum of power, ground and signal wires.

6.1 Normal Communication Mode and Transmission Rate

Transmission bit rate is variable depending on the clock tick period, data values sent and the transmitter nominal clock variance and +20% clock tolerance. The longest transmission time for 6 Data nibbles is 272 clock ticks or 979 µs at a 3 µs clock tick period, this results in a worst case transmission rate of ~24.5 kBits/s. Transmitting one zero Status and Serial Communication nibble, 6 zero value Data nibbles and one zero checksum nibble at –20% clock tolerance results in a transmission rate of ~65.8 kBits/sec. These calculations ignore the contribution made by Serial data transmission (see 5.2.2).

6.2 Clock Tolerance

6.2.1 Transmitter–Receiver Communications

Table 4 lists the timing and resolution requirements for the transmitting and receiving modules. To avoid requiring a high cost oscillator in the transmitter, the transmitter clock frequency variation is allowed to be large.

TABLE 4 – COMMUNICATION CLOCK TOLERANCE

Device Type	Parameter	Clock Tolerance
Transmitter	Clock Accuracy	≤ ±20%
Transmitter	Clock Resolution	3 to 10 µs nominal
Receiver	Clock Accuracy	≤ 10 µs over a nibble period at a 3 µs clock tick ≤ 0.50 µs over a nibble period at a 10 µs clock tick

6.3 Electrical Interface Requirements

The SENT signal is a nominal 5 V square wave signal. The high state is defined by the receiver pull-up to the supply voltage and the low state by the transmitter driver voltage drop to ground. To minimize ground and supply offset effects, the receiving device shall provide a regulated 5 V supply and ground reference to the transmitting device as specified below. This signal is intended to operate in automotive under-hood control system applications. The driver and receiver shall be protected from shorts to ground or vehicle voltages and various transient pulses as required below and by the specific vehicle EMC requirements.

Figure 2 illustrates a possible equivalent circuit for a SENT transmitter and receiver. This circuit is an example only and should not be taken as a direct implementation requirement. All interface requirements in this document shall be met whether the implementation follows the example circuit topology or not.

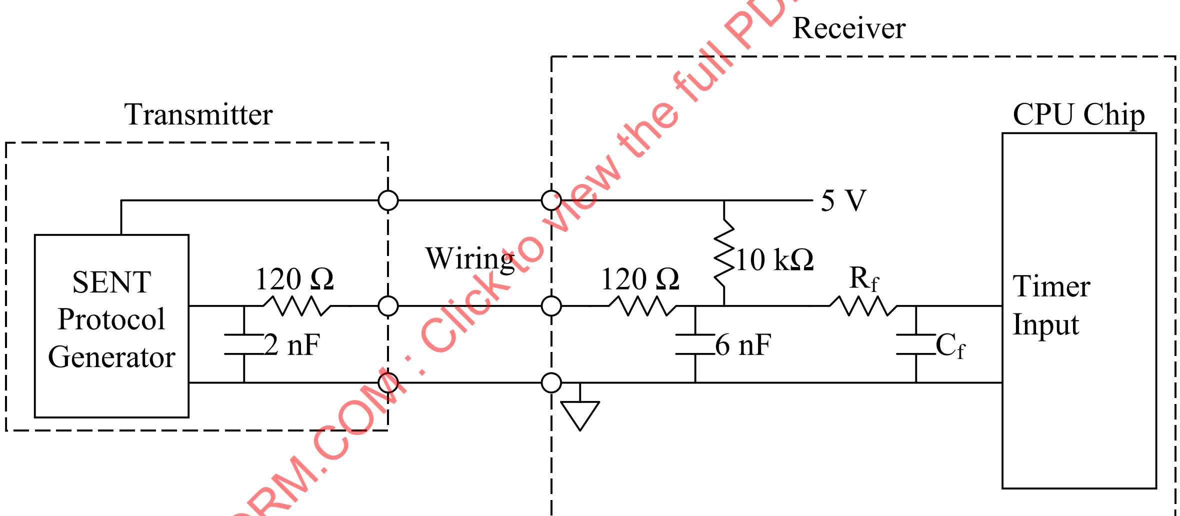

FIGURE 2 – EXAMPLE SENT SYSTEM INTERFACE CIRCUIT TOPOLOGY

6.3.1 Transmitter Driver Requirements

The transmitting device shall provide a driver with a configuration and technology suitable for the automotive environment. The driver shall ensure that the signal rise and fall time requirements are met when driving into the receiver passive load defined in the next section. The transmitter shall be protected from damage due to voltage or current conditions on the output signal outside those defined in Table 5 (e.g., shorts to power or ground). Any condition which could result in damage to the transmitter shall cause the transmitter to turn its driver Off to limit current flow and prevent damage. The requirements in Table 4 shall be met over the entire transmitter environmental requirement range.

In addition an EMC filter consisting of a 2 nF capacitor followed by a 120 Ohm resistor in series with the output pin is recommended to attenuate RF energy coupled on the external signal line. See Figure 2. In order to meet radiated emission EMC requirements, it is expected that a "shaped" waveform (controlled slope and corner rounding) will need to be driven by the transmitter. Figure 3 illustrates an example shaped waveform (falling and rising edge) that could meet emissions requirements.

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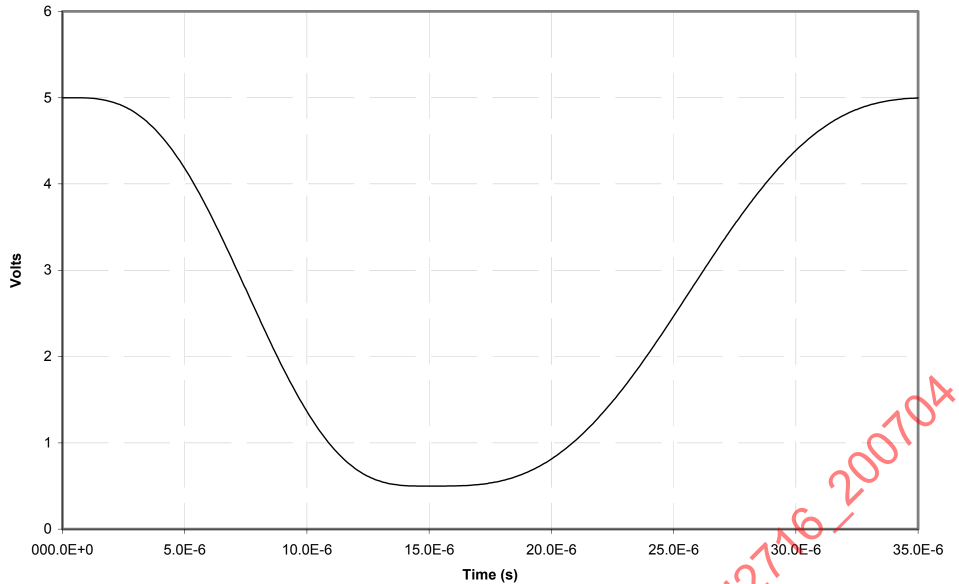

FIGURE 3 – EXAMPLE SENT SHAPED WAVEFORM TRANSMITTER OUTPUT

TABLE 5 – TRANSMITTER DRIVER REQUIREMENTS

Parameter			Limits Min	Limits Max	Units	Test Conditions / Definitions
a.	V_{OL}	=		0.5	V	Low state voltage @ 0.7 mA load current
b.	V_{OH}	=	4.5		V	High state voltage @ 0.1 mA load current
c.	I_{SUP}	=		20	mA	Current consumption from Receiver supply
d.	$I_{SUP-RIPPLE}$	=		1.0	mA	Variation in supply current consumption
e.	T_{FALL}	=		5.5	µSec	From 4.0 V to 1.0 V on wire
f.	T_{RISE}	=		16.2	µSec	From 2% of full scale above min V_{OL} value to 4.6 V on wire
g.	ΔT_{FALL}	=		0.1	µSec	Edge to edge jitter with static environment

6.3.2 Receiver Input Requirements

The Receiving device shall provide a resistive pull-up to the supply voltage, a controlled threshold digital receiver, and a timing channel (to measure pulse periods). The receiver shall meet the requirements of Table 6 over the entire Receiving device environmental requirement range.

In addition to the filter in Table 5, an EMC low-pass filter consisting of a 120 Ohm resistor followed by a 6 nF capacitor is recommended to attenuate RF energy coupled on the external signal line. See Figure 2. This filter should be implemented as close to the signal input pin as possible.

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TABLE 6 – RECEIVER INPUT REQUIREMENTS

	Parameter		Limits Min	Max	Units	Test Conditions / Definitions
a.	$R_{PULL-UP}$	=	7000	13000	Ohms	Input pull-up resistance
b.	C_{INPUT}	=		0.1	nF	Parasitic input capacitance
c.	V_{IL}	=	1.39		V	Input low state threshold range
d.	$V_{IL-DELTA}$	=	-0.05	0.05	V_{IL}	Maximum input low state threshold variation over 1 millisecond interval with supply voltage constant
e.	V_{IH}	=		3.8	V	Input high state threshold range
f.	Tau	=	0.6	1.4	µs	Input filter time constant
g.	V_{HYST}	=	0.3		V	Input electrical hysteresis

The Receiving device shall also provide supply voltage and signal return outputs to power the Transmitting device. These outputs shall meet the requirements in Table 7 over the entire Receiving device environmental requirement range.

TABLE 7 – RECEIVER POWER SUPPLY REQUIREMENTS

	Parameter		Limits Min	Max	Units	Test Conditions / Definitions
a.	V_{OUT}	=	4.9	5.1	V	Supply voltage
b.	I_{OUT}	=	20		mA	Available current for Transmitting device
c.	C_{LOAD}	=		10	µF	Supply to return load capacitance in transmitter
d.	$V_{GND-OFFSET}$	=		0.02	V	Signal return ground offset in Receiving device
e.	$V_{3.3SUPPLY}$	=	3.234	3.366	V	Internal 3.3 V supply (if needed by Receiver)

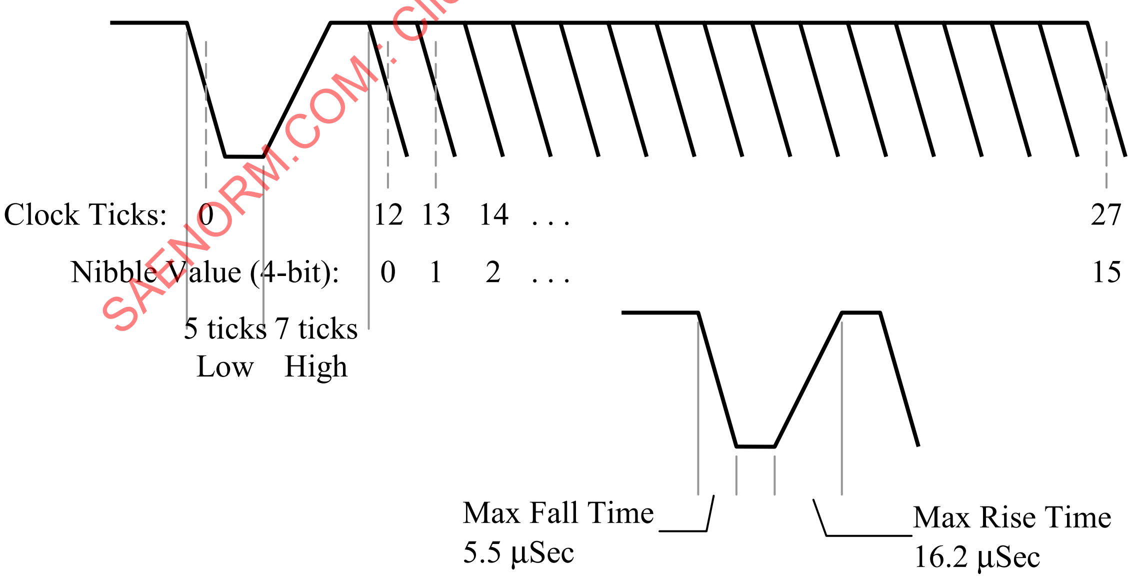

FIGURE 4 – EXAMPLE NOMINAL NIBBLE TIMES

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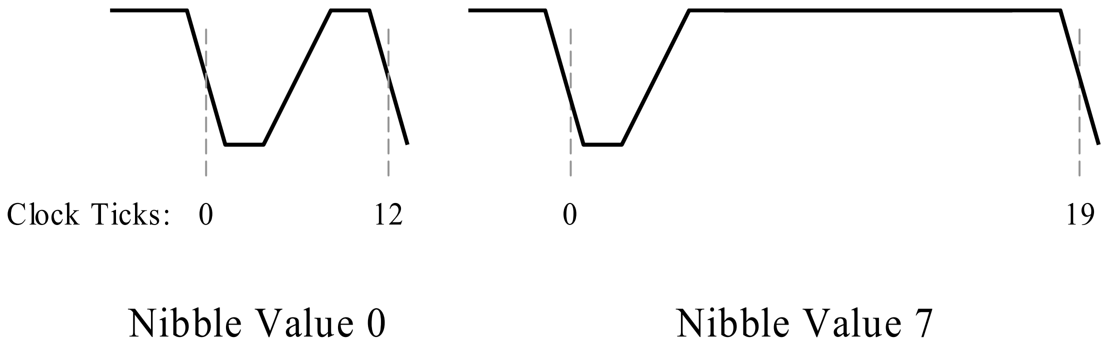

FIGURE 5 – CONTINUED EXAMPLE NIBBLE VALUES

6.3.2.1 ESD Transient Suppressor

If necessary, a circuit element such as a transorb (back-to-back zener) or a varistor device may be added in one or more places to provide ESD protection. However, when these devices are used they may add capacitance or introduce voltage and/or temperature variability to the signal time constant. When such devices are used the device load capacitor shall be reduced by an amount equivalent to the capacitance of the ESD transient suppressor.

6.3.3 Bus Wiring Harness and ECU Connectors

Connectors shall have less than 1 Ohms resistance over total vehicle life. The bus wiring shall utilize cables with less than 0.1 nF per meter of wire length. The maximum cable length shall be 5 meters.

6.4 ESD Immunity

The transmitting and receiving module I/O pins shall withstand the following electrostatic discharges without any damage to the transmitting or receiving module when subjected to testing per the vehicle manufacturer's component Electrostatic Discharge test. The particular vehicle manufacturer's component technical specification shall state the Criticality Level of the device. If the component technical specification does not specify the ESD level, use the requirements in Table 8.

TABLE 8 – ESD IMMUNITY REQUIREMENTS

ECU Condition	Contact	Air (Non-Contact)
Unpowered	± 6 KV	±8 KV

6.5 EMC Testing Requirements

The physical layer, when incorporated into an ECU or sensor design, shall function as specified in the device's intended electromagnetic environment. Additionally, the electromagnetic emissions produced during signal related operations shall not interfere with the normal operation of other ECU's or subsystems.

Testing using the below listed Ford EMC series of tests shall be used to assess the EMC performance of the physical layer design. Required testing methods include the following EMC test specifications.

1. Section 7.0 Radiated RF Emissions: RE310.
2. Section 10.3 RF Immunity Requirements 1 – 400 MHz: RI112, level 1 unless otherwise specified in the component spec.
3. Section 10.4 RF Immunity Requirements 400 – 3100 MHz: RI114, level 1 unless otherwise specified in the component spec.

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