PART NAME	PART NUMBER
SENSOR & TRANSMITTER ASY – TIRE PRESSURE	**ES-9L2T-1A150-AF**

LET	F	F	F	F	F	F	F	F	F	F	B	F	F	A	F	D	F
FR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
LET	B	F	F	B	F	F	F	F	C	F	A	B	F	F	F	F	F
FR	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
LET	F	F	F	F	F	F	F	F	A	A	A	B	C	F	B	A	A
FR	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51
LET	F	B	D	B	F	A	A	A	A	F	F	F	F	B	F	F	A
FR	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68
LET	B	F	F	F	F	F	F	F									
FR	69	70	71	72	73	74	75	76									
LET																	
FR																	

DATE	LET	FR	REVISIONS	DR	CK
	A		Released ES-9L2T-1A150-AA		
			AE00-I-11907033-000		
			Removed ES-9L2T-1A150-AA		
	B	9	Update Note 5 in Section 1		
	B	11	Update Section 1.4.2		
	B	12	Update Section 1.4.4.1		
	B	13	Update Section 2		
	B	15	Update Table1		
	B	16 20	Update Tables 3 & 4		
	B	20	Update Figure 3		
	B	22	Update Section 3.1.3		
	B	26	Update Section 3.1.5 & Following Sub-Sections		
	B	29	Update Table 11		
	B	38	Add Section 3.1.6		
	B	41	Update Figure 5		
	B	47	Update Table 12		
	B	49	Update Table 13		
	B	53	Update Section 3.3.9.1		
	B	55	Update Figure 14		
	B	56	Update Section 3.3.12		
	B	69	Add Section 3.3.25		
	B	70	Update Figure 29		
	B	81	Add Section 4.5		
	B	82	Update Section 4.6 & Following Sub-Sections		
			Released ES-9L2T-1A150-AB		
			AE00-E-11945796-000		

REFERENCE	
PREPARED/APPROVED BY Arick Rushing	
CHECKED BY	DETAILED BY Arick Rushing
CONCURRENCE/APPROVAL SIGNATURES	
Design Engineering Supervisor Matt Swiss	
Design Engineering Management Robert Mince	
Manufacturing Engineering	
Reliability	
Purchasing	
Supplier Quality Assistance	

PART NAME
SENSOR & TRANSMITTER ASY – TIRE PRESSURE

PART NUMBER:
ES-9L2T-1A150-AF

DATE	LET	FR	REVISIONS	DR	CK
			Removed ES-9L2T-1A150-AB		
	C		The update included the addition of the BMT Counter Value as part of the transmission. Update to DSL.		
	C	22	Update Section 3.1		
	C	26	Update Section 3.1.4		
	C	27	Update Table 10		
	C	39	Update Section 3.1.6		
	C	54	Update Section 3.3.9.1		
			Released ES-9L2T-1A150-AC		
			AE00-E-12036405-000		
			Removed ES-9L2T-1A150-AC		
	D		The update is to add requirements		
			For FOE sensor at 433.92MHz.		
		16	Update Table 1		
			Released ES-9L2T-1A150-AD		
			AE00-E-12165028-000		
	E	13	Added anti-rotation requirements		
		24	Updated calibration values		
			From 14.50 to 14.70 psi		
		61-62	Update SLD Item #1 a. and b.		
		62	Update SLD item #3		
	F2/3	10	Updated Acronym List		
		12/13	Updated 1.4.1 & 1.4.2 &1.4.3		
		13	Added sections 1.4.5 and 1.4.6		
		15	Updated Section 2.4		
		17	Updated Survivability Pressure in table		
		19	Added 85/85 test to table 6		
		20	Updated Specification References		
		22	Added Group F to Figure 3		
		23	Updated Protocol for Frame 5		
		24	Updated Notes on Table 8		
		24	Update to 3.1.3 Auto Range is always on		
		25	Updated Notes on Tables 9A and 9B		
		30-35	Update of Table 11		
		32	Added row 18.5 Tool LF in Rotating Mode		
		36	Removal of DSL related function codes		
		37	Removal of DEA related function codes		
		38-42	Removal of DSL related function codes		
		48	Updated 3.3.4.1 for SLD		
		48	Added NOTES to 3.3.3.1		

REFERENCE

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Purchasing

Supplier Quality Assistance

		48	Added NOTE to 3.3.4.1		
		52	Complete update of Table 12		
		56	Added ERPC Info to Table 13		
		61	Clarification of SLD function 3.3.9.2		
		70	Added Section 3.3.14.2		
		67	Added NOTE to Section 3.3.12		
		70	3.3.12.4.1 Added ERPC		
		75	Updated Figure 23 - DSL bit now reserved		
		77-78	Updated 3.3.24 Information		
		78	Removal of DSL related information		
		87	Updated Test Equipment		
		88	Added 85/85 Test Procedure 4.3.3		
		95	Clarified Required Test Equipment		
		100	Updated Reference Documents		
	F4	74-75	Update to section 3.3.20		
		75	Updated Figure 23 adding diagnostic data		
		80	Rename Table 14 to Figure 14.1		
		81	Added Table 14.2 for extended diagnostics		
	F5	39	Added a Implementation note to 3.1.5.18		
		45	Updates to Figure 5		
		80	Update Table 14.1 - 111 case and priority		
		81	Added Table 14.2 Enhanced Diagnostics		
	F6	66	Update to Figure 14		
		66	Update to Figure 15		
	F7	31	Update to Table 11 to eliminate the Tool LF inhibit in rotating mode		
		79	Update to Figure 29		
		47	Added G_0_timer to section 3.3.2.2		
		57	Updated G_0_timer definition		
	F8	52	Removed invalid scenarios from Table 12		
		various	Change the use of the term Manufacturing Mode to Factory Mode for consistency		
		52	Update Max LF response time on first row of Table 12 to 1.0 to 10.5 seconds		
		52	Update Motion Measurement Period (Minimum) on line 4 back to 15 seconds		
		various	Removed table 9B and reference to Low, High pressure Auto Range sensors – except for title of Section 3.1.3.		
		80-82	Added tables 14.3 and 14.4 and reference to diagnostic Implementation #1 and #2		
		various	Removal to references to DSL functionality		
		72	Moved Figure 28 renaming it Figure 25 so it was with the test where it is referenced		
		various	Renamed all Figures from 25 and beyond		
		71	Updated Section 3.3.15 concerning forced transmissions. Now Section 3.3.21		
		71	Changed the name of Section 3.3.22 to LF Message Format		
		various	Removal of the BMT sensor type		
		52	Updated Table 12 to remove the SLD Sensor, BMT Sensor and BMT mode columns		
		52	Removed all rows out of Table 12 for BMT and NON-SLD sensor types.		
		75	Updates to Figure 23		
		various	Removed all references to DEA		
		various	Removed all references to SLD Sensor and all non-SLD Sensor functionality		
		27	Updated Table 11 to remove SLD Sensor, BMT Sensor and BMT mode columns		
		70	Created an Appendix Section 7		

		70-71	Moved the Extended Diagnostic Data into the Appendix as Tables 19 and 20.		
		71	Moved the definitions previous know as Table 14 to the Appendix as Table 21		
		52	Added the Retrieve Extended Diagnostic Data-LF Command and point to the Appendix for the RF message format.		
		71	Added the details of the Retrieve Extended Diagnostic message including the CRC calculation.		
		50	Updated Section 3.3.20 to include a link to the Data and Measurement Section 3.4.2		
		53	Updated Section 3.4.2 to include a note that clarifies sensor operation while a fault is present		
		50	Added a description how the checksums are calculated for Software LF Section 3.3.18		
		42	Added a comment for NON-SLD sensor configuration. This is only applicable for legacy implementations.		
		various	Updated reference to TS – 16949 to ISO/TS 16949 and included IATF 16949.		
		various	Updated the Reference Documents to the latest versions		
		55	Added diagnostic clarifications to table 14.3		
		20	Update the environmental compatibility reference in Figure one to the latest version		
		74	Updated errors in table 20 for diagnostic items 4, 5 and 7		
		35	Clarification in Section 3.3.5 to include SLD considerations for the first transmission from Stationary to Rotating mode.		
	F9	17	Updated the LF sensitivity requirements in Table 1		
		16-17	Updated: Time for the MARK/SPACE Frequency Transition, Transition from MARK to SPACE and SPACE to MARK and SPACE Frequency (ASK) in table one for clarification		
		46	Added a comment to 3.3.12.4.1 to indicate that the Last Measured Pressure entry condition takes precedence if both conditions occur at the same time.		

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LIST OF ACRONYMS

Acronym	Definition
AIAG	Automotive Industry Action Group
AQP	Advanced Quality Plan
CETP	Corporate Engineering Test Procedures
Cr(VI)	Hexavalent Chromium
CPA	Connector Positioning Assurance
DCR	Design Change Request
DV	Design Verification
ES	Engineering Specification
EESE	Electrical Electronics System Engineering
EMC	Electromagnetic Compatibility
EPRC	Enhanced Rapid Pressure Change
EPRC_LM	Delta pressure detection based on the Last Measured Pressure
EPRC_LT	Delta pressure detection based on the Last Transmitted Pressure
FNA	Ford North America
FOE	Ford of Europe
FMEA	Failure Modes and Effects Analysis
FIFO	First In – First Out
FCC	Federal Communication Commission
GCE	Global Core Engineering
ID	Identification
IC	Integrated Circuit
IP	In-Process
IRA	Initial Rotating Activation
MP&L	Material Planning and Logistics
N/A	Not Applicable
PV	Production Verification
PC	Printed Circuit
PPAP	Production Parts Approval Process
PSA	Preliminary Safety Assessment
RF	Radio Frequency
PDC	Pressure Decrease Confirmation
PIC	Pressure Increase Confirmation
RPC	Rapid Pressure Change
SAE	Society of Automotive Engineers
SLD	Supplier Localization Data
SREA	Suppliers Request for Engineering Approval
STA	Supplier Technical Assistance
TNF	Transmitter Nominal Frequency
TPM	Tire Pressure Monitoring
TPS	Tire Pressure Sensor
VO	Vehicle Operations
WDS	World Wide Design Specification

1. GENERAL

This specification describes the functional requirements, quality, reliability and test requirements for the tire pressure monitoring sensor.

The requirements herein must be met in addition to all other requirements applicable to electronic devices including but not limited to tire pressure sensor drawing, wheel assembly drawings, manufacturing requirements, and the tire mounting engineering specification.

The TPM sensor is a self-contained unit in which there are no electrical connections into or out of the device. The sensor shall be designed and packaged in a way in which it does not interfere with any tire mounting, dismounting, or matching procedures. The unit monitors and transmits tire cavity pressure and temperature using an RF signal to a receiver unit. Each of the TPM sensors will contain a unique ID code in its transmission data that a receiver can use to identify tire position or illuminate a warning lamp that identifies that one or more tires has a pressure out of range event.

The engineering tests, sample sizes, and test frequencies contained within this engineering specification reflect the typical minimum requirements established to provide a regular evaluation of conformance to design intent. The Engineering Specification is intended to evaluate specific characteristics as a supplement to normal material inspections, dimensional checking, and in-process controls, and should in no way adversely influence other inspection operations. Q1 suppliers may implement different test sample sizes and frequencies, providing these changes have been included in a Control Plan approved by the design responsible Program Engineer, GCE Engineer, and agreed to by the respective STA.

Preparation and submission of an acceptable Control Plan are the responsibility of the manufacturing source. The manufacturing source will retain the original Control Plan and any later revisions per TS-16949 and provide a copy to the design responsible Product Engineering activity. Control Plan approval by the GCE and by other activities is a prerequisite for initial sample review and approval.

Note:

1. Sensor/Transmitter's manufacture/supplier must comply with the "Restricted Substance Management Standard." It can be found at: http://www.mats.ford.com/mats/data/specs/pdf/99p9999a.pdf
2. The composition of the sensor/transmitter must be submitted to the Environmental Quality Office for signoff.
3. The Sensor/Transmitter must not contain Hexavalent Chromium "Cr(VI)".
4. The Sensor/Transmitter must not contain Poly-brominated diphenyl ethers (PBDE's)
5. The Sensor/Transmitter shall not contain Lead (Pb) and the supplier shall only use Lead-Free Solder unless a prior approval from Ford Engineering (EESE D&R) is acquired to use Lead Solder or components.

1.1 Component Sourcing

GCE reserves the right to disqualify any component and preclude its use by not giving approval to PV or DV. Re-qualification of that component supplier must have written approval of GCE.

1.2 Zero Defect Plan

The supplier shall establish a zero defect plan per STA Advanced Quality Planning (AQP) requirements. The plan must be approved by GCE. The plan shall include a control plan, in accordance with ISO/TS-16949 or IATF 16949, including a reaction plan for out of control conditions; a process Failure Mode Effects Analysis; and an overall Quality Plan, in response to ISO/TS-16949 or IATF 16949, Quality Systems Requirements for all products.

1.3 Traceability

Sensor assembly must conform to traceability requirements contained in Ford TS-16949 Documentation.

1.3.1 Date Codes

Date of assembly shall be identifiable by a record on the exterior of the housing for the life of the part. This shall take the form of two barcodes – one that provides traceability for the mechanical assembly, the other providing traceability for the electronic assembly. The mechanical label shall identify mechanical type and actual day of manufacture; the electronic label shall provide ID number for the device which is stored in the manufacturing information system against time of calibration and test. This data must be available within 24 hours to Ford Motor Company upon request. Both codes must be 3 of 9 bar code format (bar code ratio) and shall be linked together on the manufacturing information system.

1.3.2 Records

A record of date codes (or lot numbers) and supplier of all IC's and power devices with three or more leads assembled into the PC boards must be maintained on a daily basis. This data must be available within 24 hours to Ford Motor Company upon request.

1.3.3 First-in, First-out

For all parts, a first-in first-out (FIFO) usage shall apply through incoming inspection, storage/staging areas and production, including repair areas. Parts that are no longer of current usage shall not be permitted to accumulate in storage areas the bottoms of bins, repair areas, QC areas or any other place for more than 7 working days. As a result of the application of this principle, it shall be possible to estimate with reasonable accuracy when a given group of parts were used in the manufacturing of sensors, if it is subsequently discovered that these parts were no longer acceptable for use in sensors.

1.4 Design Objectives

1.4.1 Life requirement

The sensor must operate correctly for a minimum of 10 years / 150,000 vehicle miles whichever is first. Note: Assume the minimum number of journeys per day is 4, and the total time in normal rotating mode over the required life of the sensor to be 5.7%.
The battery shall function for the life of the transmitter. The battery manufacturer shall provide test data supporting battery life calculations with a three parameter Weibull distribution at 50% confidence. An analytical spreadsheet/model shall be provided to Ford GCE supporting the battery life calculations.

1.4.2 Weight

The sensor assembly shall satisfy the weight requirements as specified in the Engineering Specification.

1.4.3 Operating Conditions and Environment

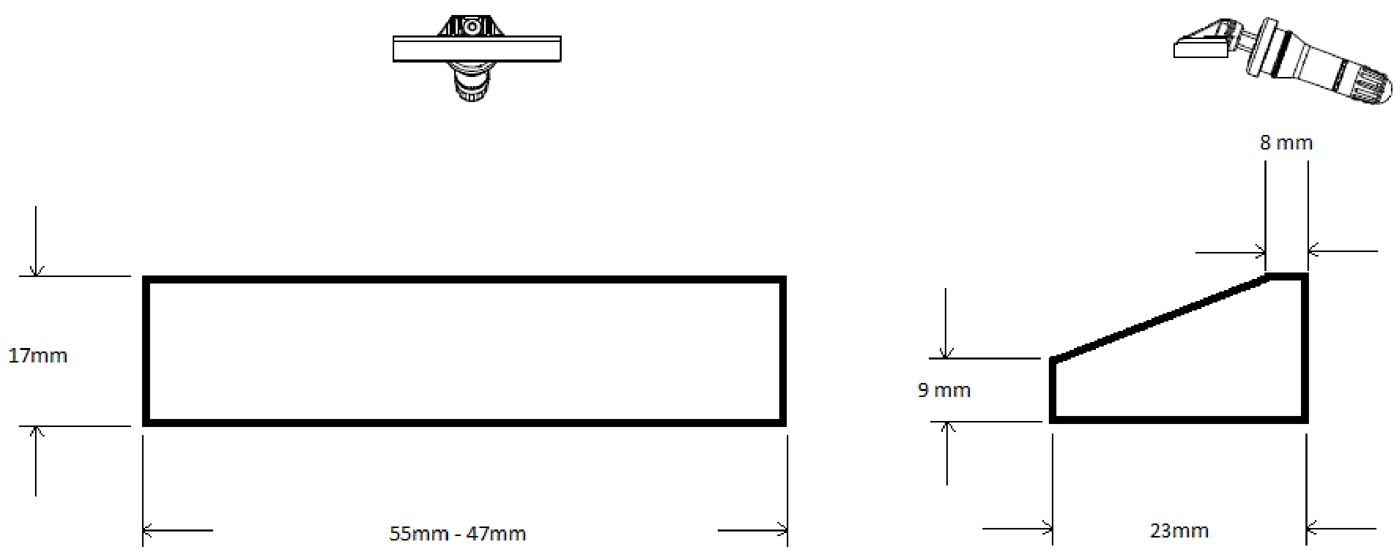
The TPM sensor is located within the tire-wheel assembly. The sensor/transmitter material must be compatible with steel and aluminum wheel materials which includes but not limited to: high strength low alloy (Steel), hot rolled low carbon (Steel), AA 356 (Aluminum), 6061 T6 (Aluminum), Chrome clad wheels, and AA 5454 (Aluminum). An installed sensor must be capable of withstanding 60 cycles of RQT-001101-002492/19 or equivalent with no loss of function, serviceability or significant degradation in appearance, including any galvanic contribution that would degrade wheel appearance.

1.4.4 Installation / Packaging

The wheel and sensor must be designed in parallel to ensure that the sensor is packaged in the drop well (Sensor must package within the minimum requirements of the Tire and Rim Association J-ISO and K-ISO drop well) of the wheel below the bead hump without any interference. The sensor shall maintain connection to the mechanism that attaches the sensor/transmitter to the wheel for 10 years / 150,000 miles. It also shall be capable of being detached (Without damaging the sensor or the attachment mechanism) for serviceability. The sensor shall also maintain 100% attachment to the mechanism that attaches the sensor to the wheel when exposed to various tire effluents /contamination in combination with temperatures and humidity.

1.4.5 Packaging Envelope & Shape

The sensor mechanical package must fit in the following envelope with
a tolerance of +/- 1mm (a typical sensor is shown to provide orientation). Variations to these requirements can be proposed, and will require approval from Ford GCE.



DRAWING NOT TO SCALE

1.4.6 Anti-Rotation / Damage Resistance

The sensor shall be designed in such a manner as to avoid and/or withstand damage throughout the life cycle of the product including but not limited to FoMoCo manufacturing processes, assembly in an external supplier process, dynamic vehicle operation and the service environment. In addition, if a specific sensor orientation with respect to the wheel needs to be maintained for any reason including antenna orientation, motion detection or sensor localization data (SLD), then the sensor must avoid and/or provide rotational resistance to forces that could be applied throughout the life cycle of the product as previously mentioned.
The overall performance of the sensor in the FoMoCo manufacturing environment will be evaluated in both off-line and pre-production testing with VOME and FORD GCE providing the final approval.

1) Summary of DV, PV, IP, and Life Test

Production Validation (PV) tests are used to obtain an initial estimate of the process potential to produce parts that conform to engineering requirements, and to identify causal or predictive relationships between significant design and process characteristics (to be used for process control). These tests must be completed satisfactorily using initial parts from production representative tooling and processes before (PPAP) approval and authorization of production parts can be issued. Sampling plans for PV testing must be included in the PV Control Plan.

In-Process (IP) tests are used to further understand the relationship between the significant design and process characteristics and to establish basis for continuing improvement. Tests must be completed with production parts on an ongoing basis. The General IP testing and Sampling plans for both IP-1 and IP-2 testing and evaluation of the significant process characteristics must be included in the control plan. When the process is found to be out of control or the test acceptance criteria are not met, the reaction plan approved in the Control Plan shall be invoked.

The supplier must satisfactorily demonstrate their test equipment and obtain the approval of STA prior to PPAP. This equipment must be recalibrated as required via the Control Plan. Plan to meet this intent must be approved by STA prior to PPAP.

NOTE 1: Any unit that undergoes DV, PV, durability or destructive testing shall be stored in appropriate conditions for a minimum of two years and a downstream recycler shall not reuse it by ordinary means.

NOTE 2: All requirements and tolerances shall have a minimum CpK of 1.67 with a target CpK of 2.0.

NOTE 3: The Supplier shall be responsible to test, develop tests, processes, execute design modifications and improvements with Ford GCE approval or direction in order to resolve all potential failures, field failures (test vehicles or warranty return) even if the sensor passed all DV, PV, and IP tests. Field failures are considered a sensor failure and all responsibility to resolve it lie on the supplier with Ford GCE approval.

a) Production Validation

All test results and data for production validation testing must be submitted in a written report to STA prior to PPAP. In addition, (48) forty-eight production TPM transmitters from the same production lot as the supplier's production validation PSA samples shall be submitted to GCE. These samples will be used to validate functional compliance to the requirements. GCE shall have final authority to approve PV testing.

2.2 Audit In-Process Tests Phase I (IP-1)

In –Process Tests – (IP-1): IP-1 tests are used to demonstrate process capability and must be completed using initial production parts from production tooling and processes, prior to first production shipment approval. IP-1 tests are to continue in effect until process capability is demonstrated.
The IP-1 test samples (10 pieces) shall be selected randomly on a daily basis from each production lot. The parts shall be subjected to tri-temperature (-40ºC, Ambient. and 100ºC) testing for the performance tests identified in Section 4.2. Process capability is demonstrated after successfully completing thirty (30) consecutive days of IP-1 testing. IP-2 may be implemented after successfully demonstrating process capability.

2.3 Audit In-Process Tests Phase 2 (IP-2)

In-Process Tests – (IP-2): IP-2 test program may be implemented only after process capability has been established. Tests must be completed with production parts on a continuing basis, according to the minimum sample size and test frequencies stipulated. The IP-2 test samples (10 pieces) shall be selected on a random basis from the weekly production lots. The parts shall be subjected to tri-temperature (-40 ºC, Ambient and 100ºC) testing for the performance tests identified in Section 4.2. Samples for these tests must be selected on a random basis to represent the entire production population as much as possible. Perform IP-2 test requirements as specified. In the event that any portion of these tests are not met, the reaction plan specified in the Ford ISO/TS-16949 or IATF–16949 Quality Control Specification shall be invoked except as noted.

2.4 Significant Parameters for Statistical Process Control

A method of statistical process control utilizing appropriate control charts, monitor points and sample sizes must be utilized in the manufacturing process. This program is to be jointly defined by the supplier and Ford STA as specified by an approved zero defects plan.
The tables that follow summarize the various DV, PV and IP tests with the acceptance parameters for each. They form the basis on which to develop a complete Control Plan for these and their related significant process characteristics. Refer to the Control Plan for the IP tests procedures. The Control Plan will classify frequencies, sample size and reaction plans; see the latest version of: Ford Quality System Requirements, ISO/TS-16949 or IATF 16949.

Table 1- Frequency Requirements

Test Characteristics	Test Use	Minimum	Target Value	Maximum	Unit
TPM Sensor / Transmitter maximum Field Strength[1] at 3 meters [2].	DV/PV/IP	Note 2	---	67[1]	dBuV/M
TPM Sensor / Transmitter maximum Field Strength[1] at 3 meters [2].	DV/PV/IP	Note 2	---	72.8[1]	dBuV/M
TPM Sensor / Transmitter Output Power Field Strength Piece to Piece Variation (From the Nominal Field Strength[3]) Across All Nominal & Extreme Temperatures.	DV/PV/IP	N/A	0	± 3.0	dBuV/M
TPM Sensor / Transmitter Nominal Frequency (TNF)	DV/PV/IP	314.935	315.00	315.065	MHz
TPM Sensor / Transmitter Nominal Frequency (TNF)	DV/PV/IP	433.855	433.920	433.985	MHz
Bit Rate (ASK & FSK)	DV/PV/IP	9120	9600	10080	Bits/second
Frequency Deviation (FSK Modulation Only)	DV/PV/IP	± 30	± 35	± 50	KHz
Time for the MARK/SPACE Frequency Transition – 5% of Bit width	DV/PV/IP	5	5.2	5.4	µS
MARK Frequency (ASK & FSK)	DV/PV/IP	TNF + 30 KHz	TNF + 35 KHz	TNF + 50 KHz	MHz
SPACE Frequency (FSK)	DV/PV/IP	TNF – 50 KHz	TNF – 35 KHz	TNF – 30 KHz	MHz

Table 1- Frequency Requirements - Continued

SPACE Frequency (ASK)	DV/PV/IP	No Transmission 0 MHz	No Transmission 0 MHz	No Transmission 0 MHz	MHz
Transition From MARK to SPACE and SPACE to MARK – 10% of each other	DV/PV/IP	.5	.52	.54	µS
Transponder Low Frequency Input Response Range	IP	118.75	125	131.25	KHz
Transponder Field Strength Sensitivity. The LF Coil in the sensor shall be perpendicular to the Wheel's Axes. **(No Continuous Wave Detection For Sensors in All Modes)**	N/A	N/A	N/A	N/A	N/A
Transponder Field Strength Sensitivity. The LF Coil in the sensor shall be perpendicular to the Wheel's Axes. **(LF Data Decoded)** (0°C to 50°C) Supplier shall provide the actual minimum and maximum LF Sensitivity of sensor as requested for in-plant tool validation.	DV/PV/IP	12	N/A	2.5	ηTp (Nano Tesla peak)
(LF Data Decoded) (-40°C to 0°C) and (50°C to 100°C)	DV/PV/IP	15	N/A	2.5	ηTp (Nano Tesla peak)
Transponder maximum allowable Field Strength. The Sensor shall be able to sustain and survive this LF field strength without any degradation in performance or damage to the LF interface/channel.	DV/PV/IP	50.0	N/A	N/A	µTp (Micro Tesla peak)
TPM Sensor / Transmitter Mark & Space Width (Half the Period)	DV/PV/IP	50	52	54	µS
TPM Sensor / Transmitter Bit Width (Full Period)	DV/PV/IP	100	104	108	µS

Notes:

1. Averaging factor must be a maximum allowance per Part 15 Sections 35 of FCC.
2. The Minimum Output power is defined by the acceptance criteria of the *Transmitter Output Power With Antenna Pattern* test specified in Section 4.9.
3. The Nominal Field strength shall be reported to Ford GCE by the supplier and recorded.

Table 2- Motion Indicator Activation/Deactivation Requirements

Test Characteristics	Test Use	Minimum	Target Value	Maximum	Unit
Motion Indicator Activation Centrifugal Force (G = 9.81 m/s^2 acceleration)	DV/PV/IP	2	N/A	9.5	G

Table 3- Pressure Requirements for Low Range Operation (0.0psig to 57.50psig)

Test Characteristics	Test Use	Minimum	Target Value	Maximum	Unit
Pressure Measurement Range	DV/PV/IP	0	N/A	57.50	psig
Survivability Pressure	DV/PV/IP	0	N/A	145 (15% margin)	psig
Pressure Measurement Resolution	DV/PV/IP	N/A	0.25	N/A	psi
Transmitted Pressure Tolerance (-40°C to 0°C)	DV/PV/IP	-2.875	0	+2.875	psi
Transmitted Pressure Tolerance (0°C to 50°C)	DV/PV/IP	-1.15	0	+1.15	psi
Transmitted Pressure Tolerance (50°C to 100°C)	DV/PV/IP	-2.875	0	+2.875	psi
Pressure Measurement to Measurement Variation	DV/PV/IP	N/A	0.0	0.25	psi

Table 4- Pressure Requirements for High Range Operation (57.50psig to 115.00psig)

Test Characteristics	Test Use	Minimum	Target Value	Maximum	Unit
Pressure Measurement Range	DV/PV/IP	57.50	N/A	115.00	psig
Survivability Pressure	DV/PV/IP	0	N/A	145 (15% margin)	psig
Pressure Measurement Resolution	DV/PV/IP	N/A	0.25	N/A	psi
Transmitted Pressure Tolerance (-40°C to 0°C)	DV/PV/IP	-5.75	0	+5.75	psi
Transmitted Pressure Tolerance (0°C to 50°C)	DV/PV/IP	-2.3	0	+2.3	psi
Transmitted Pressure Tolerance(50°C to 100°C)	DV/PV/IP	-5.75	0	+5.75	psi
Pressure Measurement to Measurement Variation	DV/PV/IP	N/A	0.0	0.25	psi

Table 5- Temperature Requirements

Test Characteristics	Test Use	Minimum	Target Value	Maximum	Unit
Temperature Measurement Tolerance (-40°C to –20°C)	DV/PV/IP	-5.0	0	+5.0	ºC
Temperature Measurement Tolerance (-20°C to 70°C)	DV/PV/IP	-4.0	0	+4.0	ºC
Temperature Measurement Tolerance (70°C to 125°C)	DV/PV/IP	-5.0	0	+5.0	ºC
Temperature Resolution	DV/PV/IP	N/A	1.0	N/A	ºC
Temperature Measurement to Measurement Variation	DV/PV/IP	N/A	0.0	1.0	ºC
Temperature Measurement Range	DV/PV/IP	-40	N/A	+125	ºC
Continuous Survivability Temperature (72 hr)	DV/PV/IP	N/A	+100	N/A	ºC

Note: All Tolerances are specified for a battery voltage of 2.1-3.6V.

Table 6 - Product Validation Test

Test Characteristics	Test Use	Acceptance Criterion	Specification Reference for Test
100% Functional Evaluation	DV/PV/IP	100% Pass performance test in SECT. 4	Section 4
Initial Performance Evaluation	DV/PV	100% Pass performance test in SECT. 4	Sections 4.1.1.1 and 4.1.1.4 of 00.00EA-D11
Low Temperature Exposure	DV/PV	100% Pass performance functional, and Visual Inspection tests in SECT. 4	Section 4.5.1 of 00.00EA-D11
Low Temperature Operation	DV/PV	100% Pass performance functional, and Visual Inspection tests in SECT. 4	Section 4.5.2 of 00.00EA-D11
High Temperature Exposure	DV/PV	100% Pass performance functional, and Visual Inspection tests in SECT. 4	Section 4.5.3 of 00.00EA-D11
High Temperature Operation	DV/PV	100% Pass performance functional, and Visual Inspection tests in SECT. 4	Section 4.5.4 of 00.00EA-D11
Powered Thermal Cycle	DV/PV	100% Pass performance functional, and Visual Inspection tests in SECT. 4	Section 4.5.5 of 00.00EA-D11
Thermal Shock Resistance	DV/PV	100% Pass performance test in SECT. 4	Section 4.5.6 of 00.00EA-D11
Powered Vibration	DV/PV	100% Pass performance and functional tests in SECT. 4	Section 4.6.1 of 00.00EA-D11
Mechanical Shock and Drop	DV/PV	100% Pass performance and functional tests in SECT. 4	Section 4.6.3 of 00.00EA-D11
Humidity/ Temperature Cycle	DV/PV	100% Pass performance test in SECT. 4	Section 4.5.8 of 00.00EA-D11
Water/ Fluids Ingress	DV/PV	100% Pass performance and functional tests in SECT. 4	Section 4.5.9 of 00.00EA-D11
Salt Mist Atmosphere	DV/PV	100% Pass performance and functional tests in SECT. 4	Section 4.7.1 of 00.00EA-D11
Chemical Resistance	DV/PV	100% Pass performance functional, and Visual Inspection tests in SECT. 4	Section 4.7.2 of 00.00EA-D11
Dust Test	DV/PV	100% Pass performance test in SECT. 4	Section 4.5.10 of 00.00EA-D11
Thermal Shock Endurance	DV/PV	100% Pass performance functional, and Visual Inspection tests in SECT. 4	Section 4.5.7 of 00.00EA-D11
High Temperature Endurance	DV/PV	100% Pass performance test in SECT. 4	Section 4.8.1 of 00.00EA-D11
85/85 High Temperature – High Humidity Endurance	DV/PV	100% Pass performance test in SECT. 4	Section 4.8.4 of 00.00EA-D11
Final Performance Evaluations	DV/PV	100% Pass performance test in SECT. 4	Sections 4.1.1.1 and 4.1.1.4 of 00.00EA-D11

FIGURE 1 – Sensor Product Validation Flow Chart

Note: Functional and visual checks will be performed between tests per RQT-001101-002492 or equivalent. Reference : CETP 00.00_e_412_7_2011 – Electrical and Electronic Component Environmental Compatibility Test or equivalent.

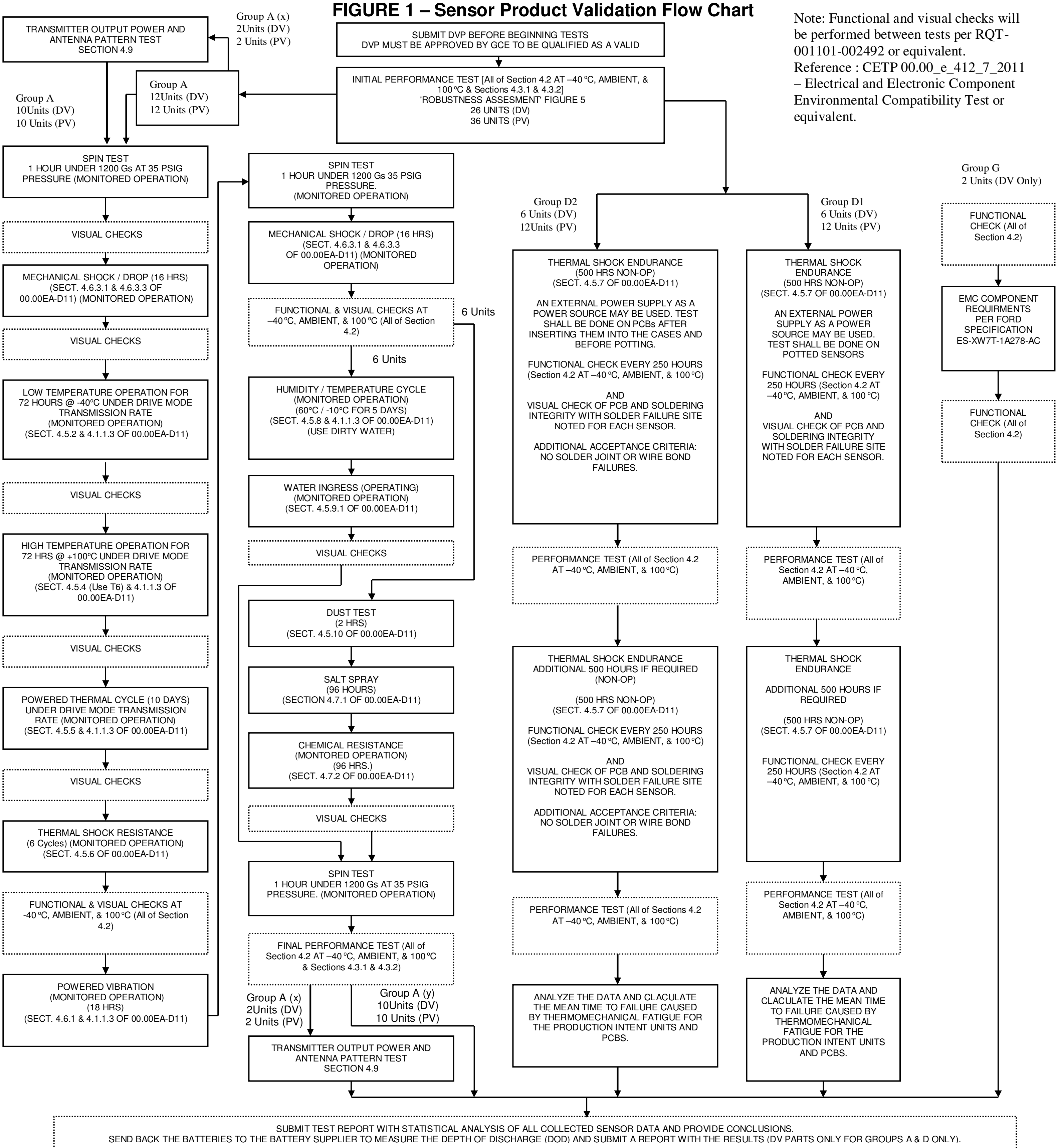


FIGURE 2 – Sensor Product Validation Flow Chart

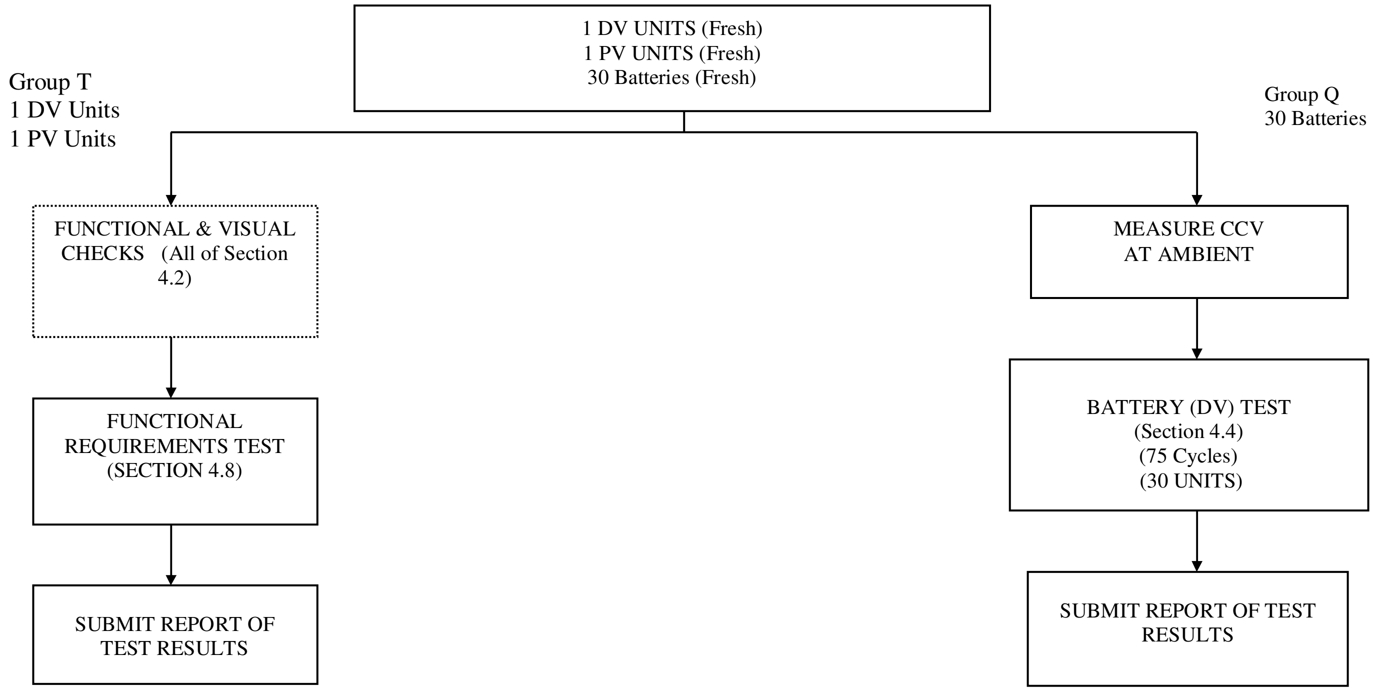
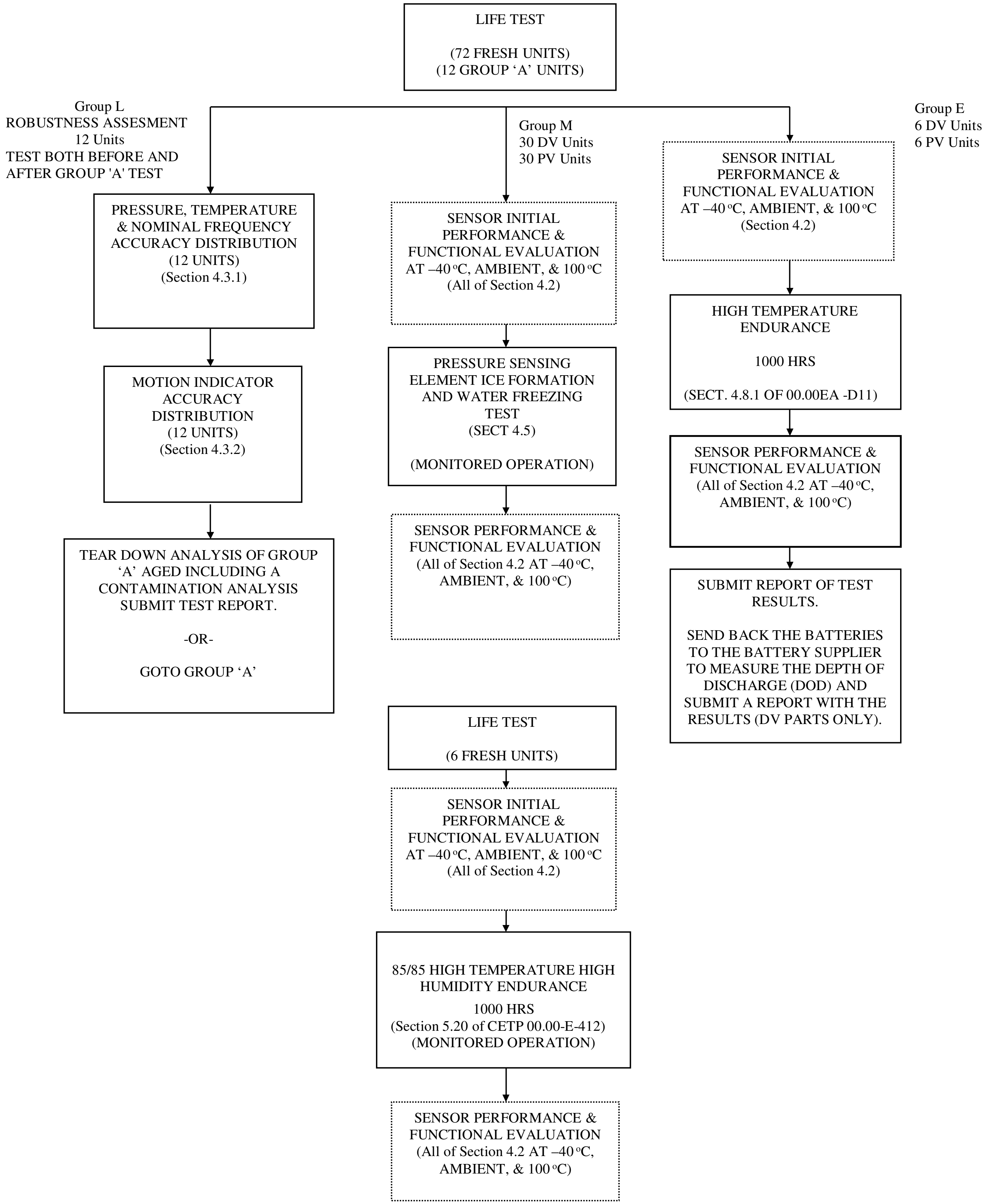


FIGURE 3 – Life Test



3. Functional Requirements

3.1 Protocol

The sensor protocol is specified in this section. Data is defined as the bit stream that includes: Pre-amble, ID, Pressure, Temperature, Status, and Check-sum.

Normal Mode: Data = Frame1 = Frame 2 = Frame 3 = Frame 4 SLD Mode: Date = Frame 1 ≠ Frame 2 ≠ Frame 3 ≠ Frame 4 ≠ Frame 5					
Pre-amble	**ID**	**Pressure**	**Temperature / BMT Counter Value/ SLD**	**Status**	**Check -Sum**
16 bits	32bits	8 bits	8 bits	8 bits	8 bits

3.1.1 Pre-amble:

Each message begins with 15 bits of zero followed with one bit of a one.

Pre-amble															
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

3.1.2 ID:

The message then includes 32 bits that represent the sensors identification number. The first four bits contained in the sensor ID are unique bits that represent the supplier's identification number as shown in Table 7.

Supplier ID	Sensor ID
4 bits (16 ID)	28 bits (268.4 million unique ID)

Table 7. Suppliers ID

Supplier ID Chart				
Invalid Data	0	0	0	0
Supplier # 1	0	0	0	1
Supplier # 2	0	0	1	0
Supplier # 3	0	0	1	1
Supplier # 4	0	1	0	0
Supplier # 5	0	1	0	1
Supplier # 6	0	1	1	0
Supplier # 7	0	1	1	1
Supplier # 8	1	0	0	0
Supplier # 9	1	0	0	1
Supplier # 10	1	0	1	0
Supplier # 11	1	0	1	1
Supplier # 12	1	1	0	0
Supplier # 13	1	1	0	1
Supplier # 14	1	1	1	0
Invalid Data	1	1	1	1

3.1.3 Pressure

Next is 1 byte that contains the pressure data. The sensor has two ranges for pressure measurement, a low range and a high range. The sensor measures pressure in the low range if the pressure is 57.50psig or less. The sensor measures in the high range if the pressure is above 57.50psig. The pressure accuracy requirements are stated in Tables 3 and 4.

3.1.3.1 Range from 0.0psig to 57.50psig

The transmitted pressure data must be linear between each incremental pressure measurement, with an increment of 0.25psi as shown in Table 8. The pressure sensor measurement must be referenced (Calibrated) to 14.70psi (e.g. 14.70psi absolute (0.0 psig) will be reported as 0x00.)

If the pressure value is measured with more than 8 bits resolution, the sensor can round up/down to the nearest incremental value to accommodate an 8 bits resolution pressure value prior to transmission (e.g. 4.60 shall be rounded down to 4.50; 4.90 shall be rounded up to 5.0.)

Table 8. Pressure Definition (Range from 0.0psig to 57.50psig)

Measured Pressure	Pressure data transmitted	Measured Pressure (Cont.)	Pressure Data Transmitted (Cont.)
0.00 psig	0x00	3.25 psig	0x0D
0.25 psig	0x01	::: ::: :::	::: ::: :::
0.50 psig	0x02	57.25 psig	0xE5
0.75 psig	0x03	57.50 psig	0xE6
1.00 psig	0x04	Invalid Data	0xE7
::: ::: :::	::: ::: :::	Invalid Data	0xE8
2.50 psig	0x0A	Invalid Data	0xE9
2.75 psig	0x0B	::: ::: :::	::: ::: :::
3.00 psig	0x0C	Invalid Data	0xFF

3.1.3.2 Range from 57.50psig to 115.0psig

The transmitted pressure data must be linear between each incremental pressure measurement, with an increment of 0.25psi as shown in Table 9A. The pressure sensor measurement must be referenced (Calibrated) to 14.70psi (e.g. 14.70psi absolute (0.0 psig) will be reported as 0x00.) The pressure data must be followed by the temperature data.

If the pressure value is measured with more than 8 bits resolution, the sensor shall round up/down the pressure value to the nearest incremental value to accommodate an 8 bits resolution pressure value prior to transmission (e.g. 4.60 shall be rounded down to 4.50; 4.90 shall be rounded up to 5.0.)

Table 9A. Pressure Definition (from 57.50psig to 115.0psig)

Measured Pressure	Pressure data transmitted	Measured Pressure (Cont.)	Pressure Data Transmitted (Cont.)
57.50 psig	0x00	67.25 psig	0x27
57.75 psig	0x01	::: ::: :::	::: ::: :::
58.00 psig	0x02	95.00 psig	0x96
58.25 psig	0x03	95.25 psig	0x97
58.50 psig	0x04	::: ::: :::	::: ::: :::
::: ::: :::	::: ::: :::	115.00 psig	0xE6
66.50 psig	0x24	Invalid Data	0xE7
66.75 psig	0x25	::: ::: :::	::: ::: :::
67.00 psig	0x26	Invalid Data	0xFF

3.1.3.3 Maximum Survivability Pressure:

The sensor must be able to withstand exposure to the upper limit of the survivability pressure range as specified in Tables 3 & 4 for a minimum continuous period of 15.0 minutes regardless of the number of exposures the sensor experience during its lifetime.

3.1.4 Temperature / BMT Counter Value / Sensor Localization Data (SLD):

3.1.4.1 Normal Mode

The message then consists of 8 bits that contains the measured temperature of the inner gases of the tire and the BMT Counter value. The temperature data must be linear between each incremental temperature measurement, with an increment of 1.0ºC. The bits from 0x00 to 0x0F, 0xB6 to 0xBF and 0xE4 to 0xFF will not be used. The bits from 0xC0 to 0xE3 shall be used to transmit the BMT counter value. The temperature measurement must have a calibration point at –40ºC with 1ºC increments (e.g. –40ºC shall be referenced as 0x10) as shown in Table 10A.

Table 10A-Temperature/BMT Counter in Normal Mode

Measured Temp.	Temperature Data Transmitted	Measured Temp. (Cont.)	Temperature Data Transmitted (Cont.)
Invalid data	0x00	86.0ºC	0x8E
Invalid data	0x01	::: ::: :::	::: ::: :::
::: ::: :::	::: ::: :::	124.0ºC	0xB4
Invalid data	0x0F	125.0ºC	0xB5
-40.0ºC	0x10	Invalid data	0xB6
-39.0ºC	0x11	Invalid data	0xB7
-38.0ºC	0x12	::: ::: :::	::: ::: :::
-37.0ºC	0x13	BMT Counter = Zero	0xC0
::: ::: :::	::: ::: :::	BMT Counter = 1	0xC1
0.0ºC	0x38	::: ::: :::	::: ::: :::
1.0ºC	0x39	BMT Counter = 34	0xE2
2.0ºC	0x3A	BMT Counter = 35	0xE3
3.0ºC	0x3B	Invalid data	0xE4
::: ::: :::	::: ::: :::	::: ::: :::	::: ::: :::
84.0ºC	0x8C	Invalid data	0xFE
85.0ºC	0x8D	Invalid data	0xFF

3.1.4.2 SLD Mode per Sections 3.1.5.12 and 3.1.5.13

While in SLD mode, the 8 bits normally used for temperature reports the Sensor Localization Data (SLD), and the BMT Counter value. The bits from 0x00 to 0xD7 and 0xE0 to 0xFA shall be used to transmit the SLD and BMT counter value as described in section 3.3.9.1. The bits 0xD8 to 0xDF and 0xFB to 0xFF will not be used as shown in Table 10B.

Table 10B Sensor Localization Data in SLD Mode

Sequence	Frame Counter	BMT Counter	Data Transmitted		Sequence	Frame Counter	BMT Counter	Data Transmitted
0	0	N/A	0x00		2	3	6	0x3F
0	1	N/A	0x01		2	3	7	0x40
0	2	N/A	0x02		2	3	8	0x41
0	3	0	0x03		7	0	N/A	0xBD
0	3	1	0x04		7	1	N/A	0xBE
0	3	2	0x05		7	2	N/A	0xBF
0	3	3	0x06		7	3	0	0xC0
0	3	4	0x07		7	3	1	0xC1
0	3	5	0x08		7	3	2	0xC2
0	3	6	0x09		7	3	3	0xC3
….	….	….	….		….	….	….	….
0	3	11	0x0E		7	3	8	0xC8
0	3	12	0x0F		7	3	9	0xC9
0	3	13	0x10		7	3	10	0xCA
0	3	14	0x11		7	3	11	0xCB
0	3	15	0x12		7	3	12	0xCC
0	3	16	0x13		7	3	13	0xCD
0	3	17	0x14		7	3	14	0xCE
0	3	18	0x15		7	3	15	0xCF
0	3	19	0x16		7	3	16	0xD0
0	3	20	0x17		7	3	17	0xD1
0	3	21	0x18		7	3	18	0xD2
0	3	22	0x19		7	3	19	0xD3
0	3	23	0x1A		7	3	20	0xD4
1	0	N/A	0x1B		7	3	21	0xD5
1	1	N/A	0x1C		7	3	22	0xD6
1	2	N/A	0x1D		7	3	23	0xD7
1	3	0	0x1E		Invalid Data	Invalid Data	Invalid Data	0xD8
1	3	1	0x1F		::: ::: :::	::: ::: :::	::: ::: :::	::: ::: :::
1	3	2	0x20		Invalid Data	Invalid Data	Invalid Data	0xDF
1	3	3	0x21		Unknown SLD	0	N/A	0xE0
1	3	4	0x22		Unknown SLD	1	N/A	0xE1
1	3	5	0x23		Unknown SLD	2	N/A	0xE2
1	3	6	0x24		Unknown SLD	3	0	0xE3
1	3	7	0x25		Unknown SLD	3	1	0xE4
1	3	8	0x26		Unknown SLD	3	2	0xE5
1	3	9	0x27		Unknown SLD	3	3	0xE6
1	3	10	0x28		Unknown SLD	3	4	0xE7
1	3	11	0x29		Unknown SLD	3	5	0xE8
….	….	….	….		….	….	….	….
1	3	17	0x2F		Unknown SLD	3	11	0xEE
1	3	18	0x30		Unknown SLD	3	12	0xEF
1	3	19	0x31		Unknown SLD	3	13	0xF0
1	3	20	0x32		Unknown SLD	3	14	0xF1
1	3	21	0x33		Unknown SLD	3	15	0xF2
1	3	22	0x34		Unknown SLD	3	16	0xF3
1	3	23	0x35		Unknown SLD	3	17	0xF4
2	0	N/A	0x36		Unknown SLD	3	18	0xF5
2	1	N/A	0x37		Unknown SLD	3	19	0xF6
2	2	N/A	0x38		Unknown SLD	3	20	0xF7
2	3	0	0x39		Unknown SLD	3	21	0xF8
2	3	1	0x3A		Unknown SLD	3	22	0xF9
2	3	2	0x3B		Unknown SLD	3	23	0xFA
2	3	3	0x3C		Invalid Data	Invalid Data	Invalid Data	0xFB
2	3	4	0x3D		….	…..	…..	……
2	3	5	0x3E		Invalid Data	Invalid Data	Invalid Data	0xFF

3.1.5 Status:

The next part of the message consists of 8 bits representing the current sensor status.
The first 3 bits are assigned as Low Battery, Rotating/Stationary Mode, and Low Range/High Range Sensor. The last five bits are designated to report the function code. These are: De-Energize-LF, Factory-LF, Tool-LF, LF-Initiation, Normal-Factory False, Normal-Factory True, SLD Mode-Factory False, SLD Mode-Factory True, Exit-Factory-LF, and RPC Transmission.

Low Battery	Rotating / Stationary Mode	Low Range or High Range	**Function Codes:** De-Energize-LF, Factory-LF, Tool-LF, LF-Initiation, Normal-Factory False, Normal-Factory True, SLD Mode-Factory False, SLD Mode-Factory True, Exit-Factory-LF, RPC Transmission, RF Test Mode, and Detached (If Required).
1 bit	**1 bit**	**1 bit**	**5 bits**

3.1.5.1 Low Battery:

Low battery indicates that the battery is about to reach the minimum voltage level required to power the sensor at the maximum load.

Battery Normal
0

Battery Low
1

3.1.5.1.1 Minimum Voltage Level

The minimum voltage level for the sensor to operate sufficiently must be supplied in the DVP&R.

3.1.5.2 Rotating / Stationary Mode:

This reserved bit shall indicate which mode the sensor/transmitter is operating: The Rotating Mode or Stationary Mode (Sections 3.3.5 and 3.3.7 respectfully.) When the sensor enters the Rotating Mode, this bit shall change from "zero" to a "one" and shall stay "one" until the sensor enters the Interim Period. As long as the sensor is in the Interim Period or if it enters the Stationary Mode, this bit shall stay "zero".

Stationary Mode / Interim Period
0

Rotating Mode
1

3.1.5.3 Low Range or High Range

This indicates if the sensor is measuring in the low or high pressure range.
If measuring in the low pressure range the bit is zero, if in high range, the bit equals one.

"0 to 57.50psig" Range
0

"57.50 to 115psig" Range
1

Column	LF Initiation	Factory LF	De-Energize LF	Tool LF	Software LF	Exit-Factory LF	RF Test-Mode LF	RF-CW-Mode-LF	SLD Mode (Valid in Rotating mode only)	RPC Event	Mode: Rotating, Stationary, Interim, or Off	Factory Mode	Transmitted Function Code
1	False	False	False	False	False	False	False	False	False	False	Stationary/ Rotating/Interim	True	Normal-Factory True
2	False	False	False	False	False	False	False	False	False	False	Stationary/ Rotating/Interim	False	Normal-Factory False
3	False	False	False	False	False	False	False	False	True	False	Rotating	True	SLD Mode-Factory-True
4	False	False	False	False	False	False	False	False	True	False	Rotating	False	SLD Mode-Factory- False
5	False	False	False	False	False	False	False	False	True	True	Rotating	True/ False	RPC
6	False	False	False	False	False	False	False	False	False	True	Stationary/Interim	True/ False	RPC
7	True	False	False	False	False	False	False	False	True/ False	True	Rotating/Stationary/ Interim	False	RPC
8	False	False	False	True	False	False	False	False	False	True/ False	Stationary/Rotating/ Interim/Off	True/ False	Tool-LF
9	False	False	False	True	False	False	False	False	True	True/ False	Rotating	True/ False	Tool-LF
10	False	True	False	False	False	False	False	False	True/ False	True/ False	Stationary/Rotating/ Interim/Off	True/ False	Factory-LF
11	True	False	False	False	False	False	False	False	True/ False	False	Rotating /Stationary/Interim	True/ False	LF-Initiation
12	False	False	True	False	False	False	False	False	False	True/ False	Stationary / Interim	True/ False	De-Energize-LF
13	False	False	False	False	True	False	False	False	False	True/ False	Stationary / Interim / Off	True/ False	The response will be the RF Data defined in Figure 23 and Section 3.4
14	False	False	False	False	False	True	False	False	False	True/ False	Stationary / Interim / Off	True/ False	Exit-Factory-LF
15	False	False	False	False	False	False	True	False	True/ False	True/ False	Rotating / Stationary / Interim	True/ False	RF-Test-Mode
16	False	False	False	False	False	False	False	True	False	True/ False	Stationary / Interim	True/ False	The response will be based on the logic defined in Section 3.3.23

Table 11. Function Code Determination

3.1.5.4 De-Energize-LF:

This indicates the sensor is responding to a De-Energize-LF as described in Section 3.3.13.1.

Function Code: De-Energize-LF				
0	0	0	0	1

3.1.5.5 Factory LF

This indicates the sensor is responding to a Factory-LF as described in Section 3.3.16.

Function Code: Factory-LF				
0	0	0	1	0

3.1.5.6 LF- Initiation (Data LF)

This indicates the sensor is responding to an LF-Initiation as described in Section 3.3.14.

Function Code: LF-Initiation				
0	0	0	1	1

3.1.5.7 Normal: (Normal-Factory True & Normal-Factory False)

These indicate the sensor is measuring and transmitting within normal operational guidelines.

3.1.5.7.1 Normal-Factory True

This indicates the sensor is measuring and transmitting within normal operation guidelines with the sensor in Factory Mode.

Function Code: Normal-Factory True				
0	0	1	0	0

3.1.5.7.2 Normal-Factory False

This indicates the sensor is measuring and transmitting within normal operational guidelines with the sensor not in Factory Mode.

Function Code: Normal-Factory False				
0	0	1	1	0

3.1.5.8 RPC

This indicates that a Rapid Pressure Change (RPC) has occurred as specified in Section 3.3.12.
If such an event occurs, the sensor will transmit the following function code. If this was a decrease in pressure, the sensor will transmit the PDC (Pressure Decrease Confirmation) as specified in Sections 3.3.12.1.2, 3.3.12.2.1, 3.3.12.3.2. If it was an increase of pressure, the sensor will transmit the PIC (Pressure Increase Confirmation) as specified in Sections 3.3.12.1.1 and 3.3.12.3.1.

Function Code: RPC				
0	0	1	0	1

3.1.5.9 Tool-LF

This function code shall indicate that this sensor is responding to an LF Tool Command.

Function Code: Tool-LF				
1	0	1	0	0

3.1.5.10 Exit-Factory-LF

This function code indicates the sensor is responding to an Exit-Factory-LF command (Section 3.3.19) that forces the sensor to enter the normal mode from either Factory or OFF Mode.

Function Code: Exit-Factory-LF				
0	0	1	1	1

3.1.5.11 RF Test Mode

This function code indicates the sensor is in RF Test Mode. It was placed in this mode by an RF Test Command (Section 3.3.22).
Note: For the current implementation the response is not immediate.

Function Code: RF Test Mode				
0	1	0	0	1

3.1.5.12 SLD Mode-Factory False

This function code indicates the sensor is in Rotating Mode and out of Factory Mode.

Function Code: SLD Mode-Factory False				
0	1	0	1	1

3.1.5.13 SLD Mode-Factory True

This function code indicates the sensor is in Rotating Mode and in Factory Mode.

Function Code: SLD Mode-Factory True				
0	1	1	0	1

3.1.6 Check-sum

This part of the message consists of 8 bits, which represents a check sum that is based on the data transmitted in each frame.

Check-sum
8 bits represent the sum of all the bits

The check sum is calculated by splitting each frame into bytes, adding all the bytes and using the sum without the carry over as the check-sum as shown in the following example:

Pre-amble	ID	Pressure	Temperature	Status	Checksum
0000000000000001	10110001111100000110100110010111	10110011	01110101	00000001	-----

Without the pre-amble bits, this example produces a bit stream of 56 bits (7 Bytes). This stream is then split into bytes to produce the following:

B1= 10110001, B2= 11110000, B3= 01101001, B4= 10010111, B5= 10110011, B6= 01110101, B7= 00000001.

All bytes are then added as follows:

Bits Addition										
B1			1	0	1	1	0	0	0	1
B2			1	1	1	1	0	0	0	0
B3			0	1	1	0	1	0	0	1
B4			1	0	0	1	0	1	1	1
B5			1	0	1	1	0	0	1	1
B6			0	1	1	1	0	1	0	1
B7			0	0	0	0	0	0	0	1
Sum:	**1**	**1**	**1**	**1**	**0**	**0**	**1**	**0**	**1**	**0**
	Carry over		**Check-sum**							

The check-sum in this example is: **11001010**

3.1.7 Sensor Functional Requirements & Flow Diagrams

The sensor functional requirements re shown in Figures 4 & 5 Below:

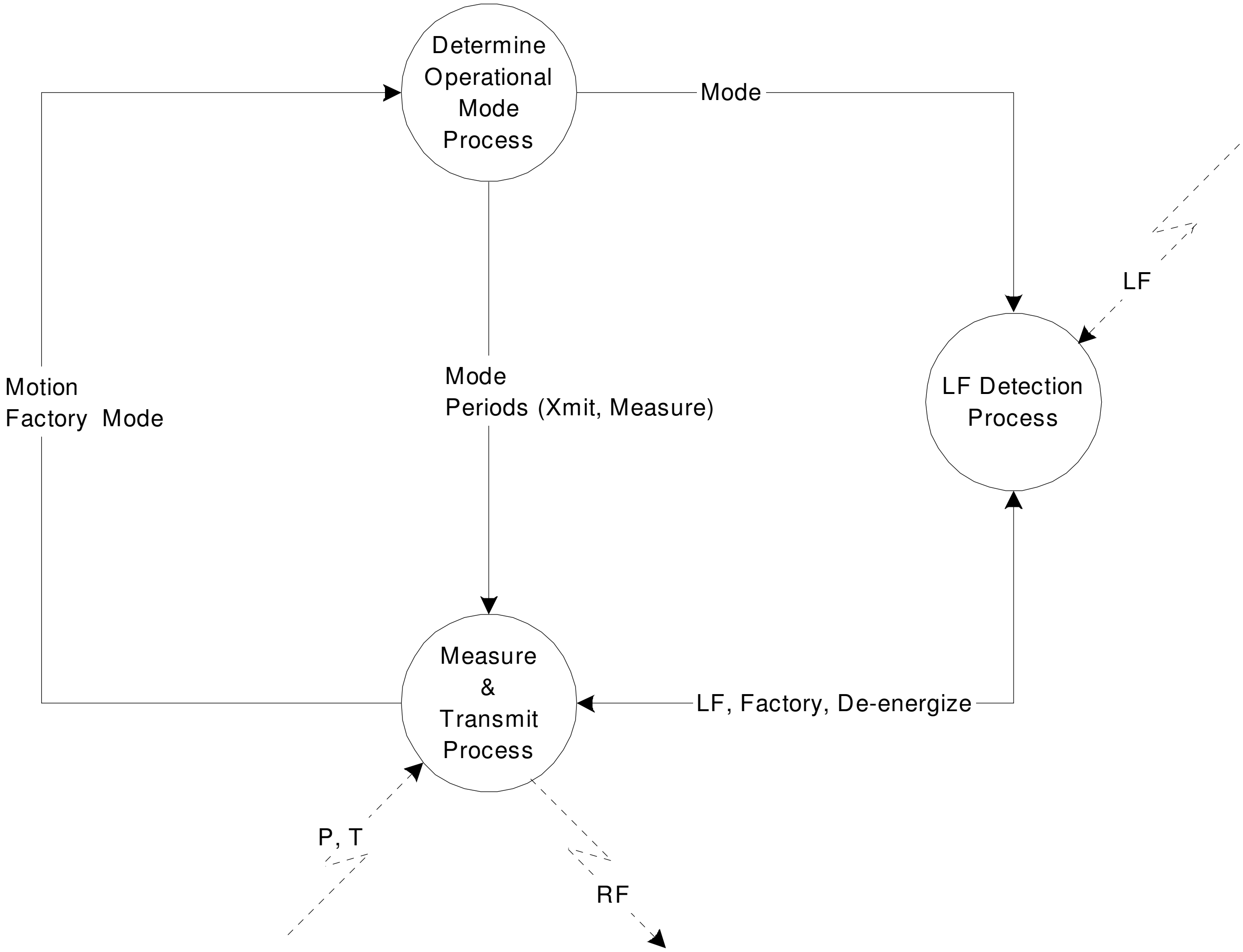


Figure 4. Sensor Data Flow Diagram

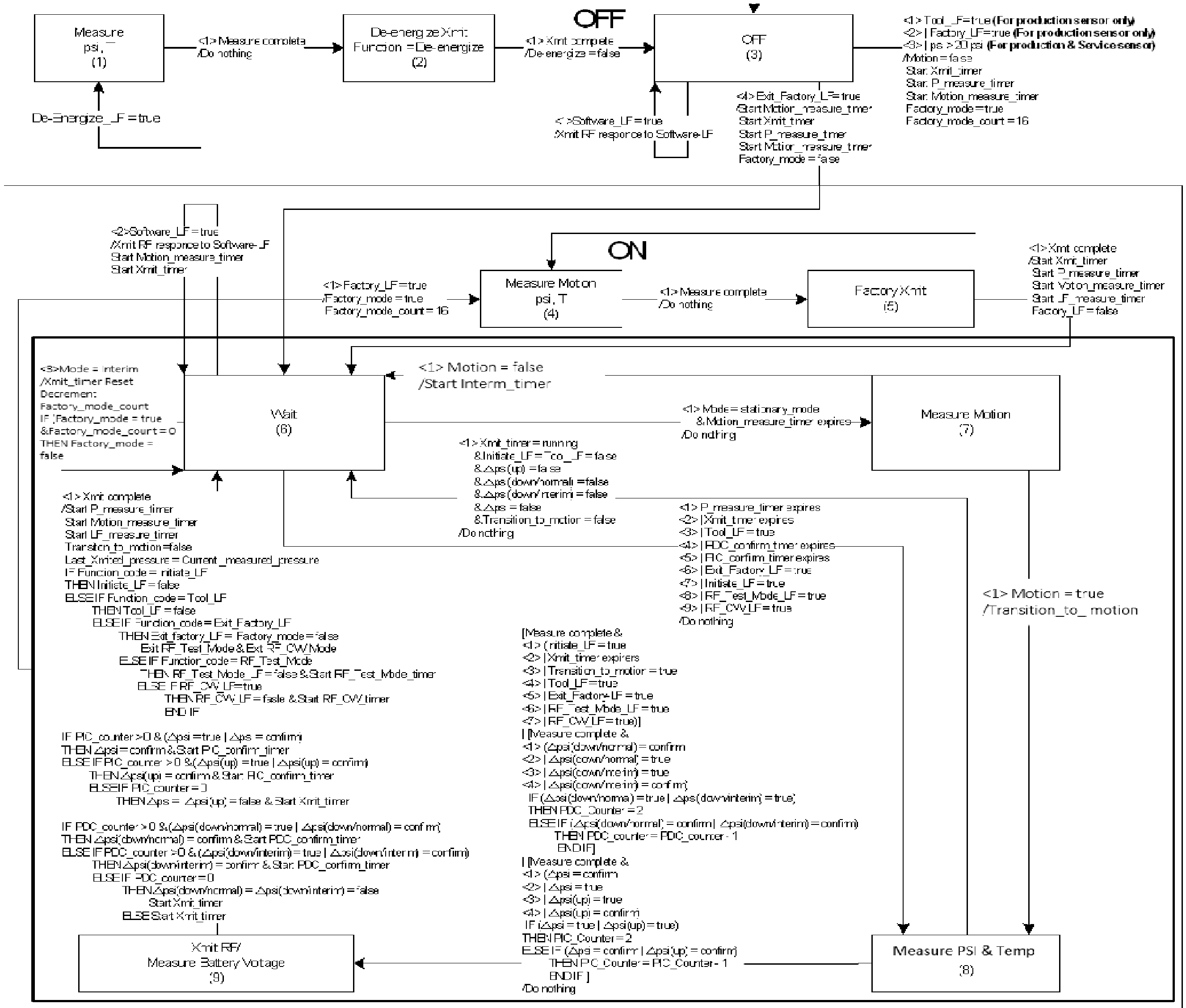


Figure 5. Sensor Functional Requirements (On/Off, Factory, Wait, Measure)

3.2 Bit Parameters

The sensor must fulfill all the parameters listed below:

3.2.1 Nominal Frequency

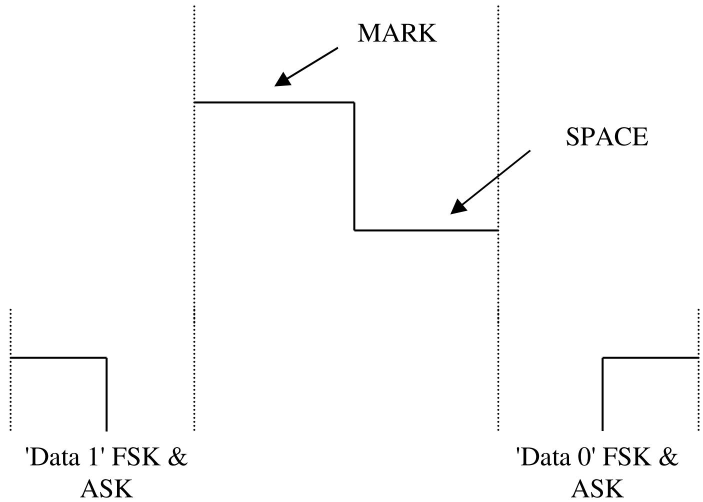
The Transmitter Nominal Frequency (TNF) must meet the requirements specified in Table 1 under all temperature conditions.

3.2.2 Bit Rate

The bit rate must meet the requirements specified in Table 1.

3.2.3 Modulation

During Rotating Mode, The modulation used for the sensor is FSK (Frequency-Shift Keying) with 50% Manchester bi-phase encoding. The FSK modulation must follow the FSK requirements as follows:



MARK (FSK) = Transmitter Nominal Frequency + Δ**f** (See Table 1)
SPACE (FSK) = Transmitter Nominal Frequency - Δ**f** (See Table 1)
Δ**f =** Frequency Deviation. (See Table 1)
Mark/Space Width = shall be as specified in Table 1.

'Data 1' in ASK = Peak Transmission power.
'Data 0' in ASK = No Transmission.

Time for MARK/SPACE frequency Transition = must be as specified in Table 1.
Transition from MARK to SPACE and SPACE to MARK must be as specified in Table 1.

During Stationary and Interim Modes the sensor shall transmit both FSK and ASK Modulation at the same frequency.

3.3 Sensor / Transmitter Structure

The sensor must fulfill the structure specified as shown below:

3.3.1 Bit Order

The overall message is transmitted in the following order: Pre-amble, ID, Pressure, Temperature, Status, and then Check-sum (refer to Section 3.1).

3.3.2 Transmission Randomization

3.3.2.1 Rotating Mode (Factory & Normal Mode (SLD Mode))

During one transmission, the message must contain frames such that each frame must contain data as defined in Sections 3.1 & 3.3.9.1. Within each transmission, a space must separate each frame (See Figure 7B below). The space shall satisfy the pseudo-random sequence number value and requirements of SLD transmissions per

Section 3.3.9.1. The total sum of all spaces and frames must not exceed the transmission time as specified in Section 3.3.3.1.

3.3.2.2 Stationary & Interim Mode (Factory & Normal Mode)
During one transmission, the message must contain identical data in each frame as defined in Section 3.1.
A random period of a minimum of 100msec and a maximum of 5.0 seconds must precede the first frame except in the event of a forced transmission. In this case, the first frame will be sent out immediately without a random period (See Section 3.3.20 and Figures 9, 10, and 11 below.) Between each transmission, a space must separate each frame (See Figures 10 & 11 below). The spaces for all transmissions shall be as specified in Figure 10 & 11. The total sum of all spaces and frames must not exceed the transmission time as specified in Section 3.3.3.2.

3.3.3 Transmission Time

3.3.3.1 Rotating Mode
Each sensor transmission during Rotating Mode must not exceed 0.500 second. This period includes the frames and random spaces within one transmission. The tolerance is specified in Table 12.
Note1: For current implementation: if an RPC is received in Rotating Mode, the worst case transmission can exceed 500ms.
(RPC transmission ASK + FSK ~ 975ms)
Note2: For current implementation: for an SLD mode 5 frame FSK transmission, the worst case duration is 587.4ms.

3.3.3.2 Stationary & Interim Mode
Each sensor transmission during Stationary & Interim Modes must not exceed 0.975 seconds. This period includes the frames and spaces within one transmission. The tolerance is specified in Table 12.

3.3.4 Packet Redundancy

3.3.4.1 Rotating & RF Test Mode (Normal, Burst Mode, SLD & Factory Mode)
All periodic transmissions sent by the sensor during Rotating Mode must contain four (4) identical frames (See Figures 6 & 7A below).
SLD transmissions contain 5 frames of data with the first four (4) containing a frame specific code and BMT counter per Table 10B.
Frame 5 contains temperature data (See Figure 7B below.). Each frame must contain one message that follows the bit order specified in Section 3.3.1.
NOTE: Frame 5 has a Normal Roll Function code rather than an SLD function code.

Random Period	**One Transmission = One packet = 4 Frames + 3 Random Spaces**						
100msec – 5.0 Second	Frame 1	Random Space	Frame 2	Random Space	Frame 3	Random Space	Frame 4

Figure 6. Normal Transmission during Rotating Mode and RF Test Mode.

One Transmission = One packet = 4 Frames + 3 Random Spaces						
Frame 1	Random Space	Frame 2	Random Space	Frame 3	Random Space	Frame 4

Figure 7A. Forced Transmission (Response to LF-Initiation, & RPC)

First Sequence Time	**One Transmission = One packet = 5 Frames + 4 Sequence Timing**								
Sequence Table (Per Section 3.3.9.1)	Frame 1	2nd Sequence Time – Frame 1 Time	Frame 2	3rd Sequence Time – Frame 2 Time	Frame 3	4th Sequence Time – Frame 3 Time	Frame 4	5th Sequence Time – Frame 4 Time	Frame 5

Figure 7B. SLD Transmission during Rotating Mode

3.3.4.2 Stationary & Interim Mode (Normal & Factory Mode)

All periodic transmissions sent by the sensor during Stationary or Interim mode contain nine frames of ASK modulation and four frames of FSK Modulation, see figure 8 through 11.

Random Period	**One Transmission = One packet = ASK Modulation + FSK Modulation**	
100msec – 5.0 Second	**ASK Modulation**	**FSK Modulation**

Figure 8. Normal Transmissions during Stationary & Interim Mode.

One Transmission = One packet = ASK Modulation + FSK Modulation	
ASK Modulation	**FSK Modulation**

Figure 9. Forced (Response to Tool-LF, De-Energize-LF, Factory-LF, Exit-Factory-LF, Software-LF, & RPC) Transmissions During Stationary & Interim Mode.

FSK Modulation = 4 FSK Frames + 4 Spaces, each space = 100msec ± 5%							
Space	FSK Frame 1	Space	FSK Frame 2	Space	FSK Frame 3	Space	FSK Frame 4

Figure 10. FSK Modulation within Each Transmission during Stationary & Interim Mode

ASK Modulation = 9 ASK Frames (F) + 8 Spaces (S), each space = 52.5msec ± 5%.																
ASK (F1)	S	ASK (F2)	S	ASK (F3)	S	ASK (F4)	S	ASK (F5)	S	ASK (F6)	S	ASK (F7)	S	ASK (F8)	S	ASK (F9)

Figure 11. ASK Modulation within Each Transmission during Stationary & Interim Mode

3.3.5 Rotating Mode

Rotating is one of the modes that can control the behavior of the sensor's sampling and transmission rates as described in Sections 3.3.8.1, 3.3.8.2, 3.3.9.1, and 3.3.9.3. The sensor shall enter Rotating Mode and transmit when the sensor's activation force is above the motion threshold as specified in Table 2. (See Section 3.3.10). When entering into Rotating Mode with PAL active, the sync frame must be calculated first, and then the sensor can transmit a sync or non-sync transmission. (See Section 3.3.10). The sensor must remain in Rotating Mode as long as the motion indicator is active. When the motion indicator is deactivated (See Section 3.3.10), the sensor must enter Interim Mode. The sensor must re-enter Rotating Mode any time the motion indicator is activated.

3.3.6 Interim Mode

When a vehicle stops moving (The activation force falls below the motion threshold as specified in Table 2), the sensor shall enter Interim Mode. The sensor must stay in this mode for a minimum of fifteen minutes (15.0 minutes). After this period expires, the sensor will enter Stationary Mode (See Section 3.3.7 and Figure 12).

3.3.7 Stationary Mode

The sensor must enter Stationary Mode after Interim Period has expired (See Section 3.3.6). If the motion indicator is reactivated, the sensor must exit this mode and enter Rotating Mode. (See Figure 12)

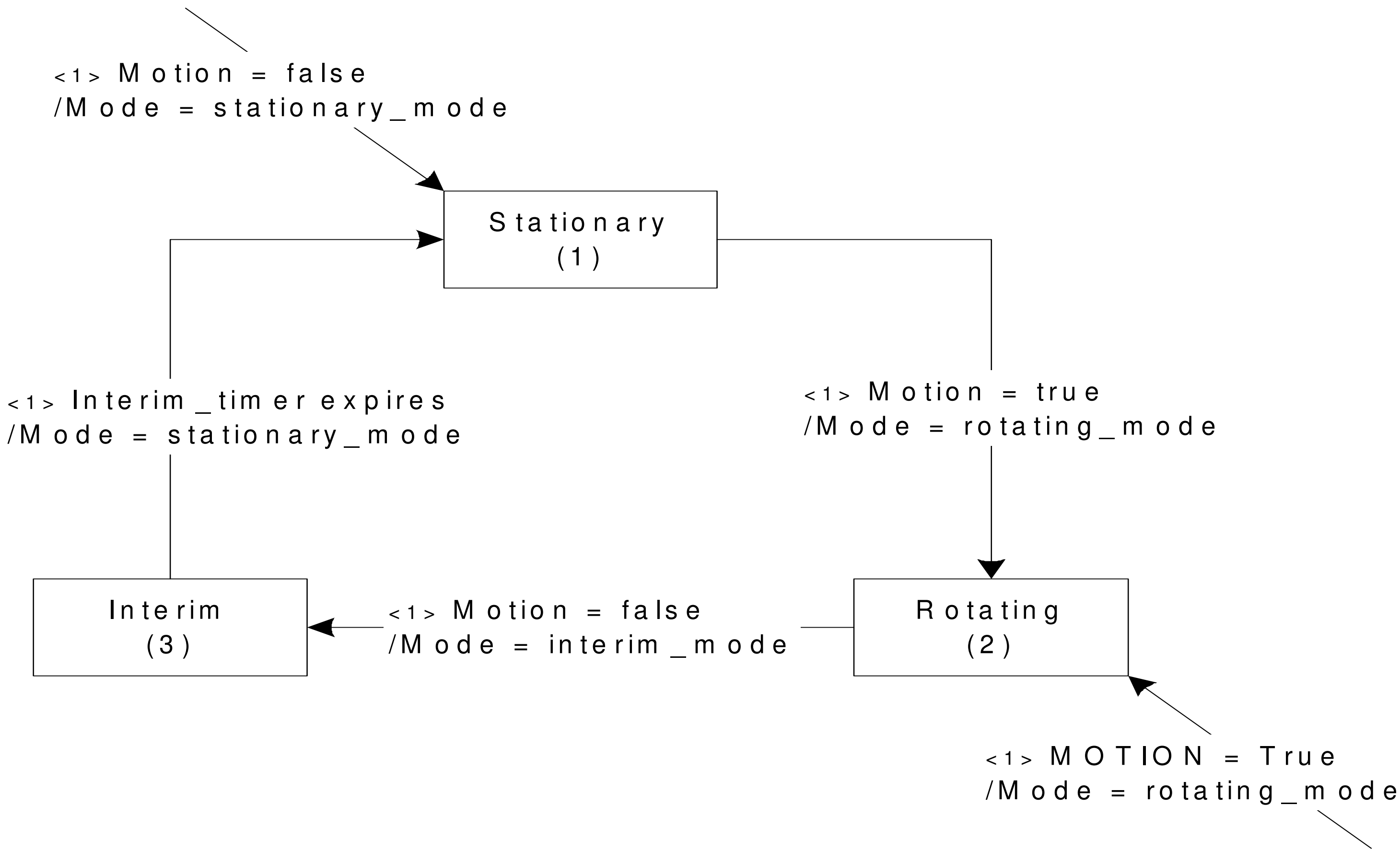


Figure 12. Sensor Rotating/Stationary Mode Functional Requirements

Table 12. Timer Periods (Tolerance is ± 20%)

Column	Mode	Production or Service Part	SLD Mode	Factory Mode	Pressure / Temperature Measurement Period (Minimum)	Motion Measurement Period (Minimum)	Xmit_timer / Transmission Rate	LF_measure_timer / LF Sampling Rate (Including the LF_polling_timer)	LF-polling_timer	Maximum response time to LF
1	Rotating	Production	True	True	15.0 Seconds	14.5 Seconds	8.0 Sec. Min 15.0 Sec. Max Avg = 12.5 Sec.	Comply with the sensor's maximum response time to LF	Comply with the sensor's maximum response time to LF	1.0 – 10.5 Seconds
2	Rotating	Production & Service	False	True	15.0 Seconds	15.0 Seconds	15.0 Seconds	Comply with the sensor's maximum response time to LF	Comply with the sensor's maximum response time to LF	1.0 Second
3	Rotating	Production & Service	True	False	15.0 Seconds	25.5 Seconds	15.0 Sec. Min 26.0 Sec. Max Avg = 21.5 Sec.	Comply with the sensor's maximum response time to LF	Comply with the sensor's maximum response time to LF	1.0 – 12.5 Seconds
4	Rotating	Production & Service	False	False	15.0 Seconds	15.0 Seconds	1.0 Minute	Comply with the sensor's maximum response time to LF	Comply with the sensor's maximum response time to LF	4.0 Second
5	Rotating	Service	True	True/ False	15.0 Seconds	25.5 Seconds	15.0 Sec. Min 26.0 Sec. Max Avg = 21.5 Sec.	Comply with the sensor's maximum response time to LF	Comply with the sensor's maximum response time to LF	1.0 – 12.5 Seconds
6	Stationary	Production & Service	False	True	1.0 Minute	10.0 Seconds	6.0 Hours	Comply with the sensor's maximum response time to LF	Comply with the sensor's maximum response time to LF	1.0 Second
7	Stationary	Production & Service	False	False	1.0 Minute	15.0 Seconds	6.0 Hours	Comply with the sensor's maximum response time to LF	Comply with the sensor's maximum response time to LF	4.0 Second
8	Interim	Production & Service	False	True	15.0 Seconds	15.0 Seconds	1.0 Minute	Comply with the sensor's maximum response time to LF	Comply with the sensor's maximum response time to LF	1.0 Second
9	Interim	Production & Service	False	False	15.0 Seconds	15.0 Seconds	6.0 Hours	Comply with the sensor's maximum response time to LF	Comply with the sensor's maximum response time to LF	4.0 Seconds
10	OFF	Production	False	N/A	1.0 Minute	N/A	N/A	Comply with the sensor's maximum response time to LF	Comply with the sensor's maximum response time to LF	1.0 Second
11	OFF	Service	False	N/A	1.0 Minute	N/A	N/A	(No measuring or sampling LF)	(No measuring or sampling LF)	(No measuring or sampling LF)
12	RF Test Mode (Rotating, Stationary, and Interim)	Production & Service	False	True / False	15.0 Seconds	15.0 Seconds	15.0 Seconds	Comply with the sensor's maximum response time to LF	Comply with the sensor's maximum response time to LF	1.0 Second

3.3.8 Pressure/Temperature Sampling Rate

The sensor shall be capable of sampling in both Rotating and Stationary modes. (See Table 12)

3.3.8.1 Sampling in Rotating Mode (Normal Only)

The maximum time between two consecutive pressure/temperature samples shall satisfy the requirements in Table 12. The maximum time between two consecutive motion samples shall satisfy the requirement in Table 12.

3.3.8.2 Sampling in Rotating Mode (Factory Mode Only)

The maximum time between two consecutive pressure/temperature samples shall satisfy the requirements in Table 12. The maximum time between two consecutive motion samples shall satisfy the requirement in Table 12.

3.3.8.3 Sampling in Stationary Mode (Normal Only)

The maximum time between two consecutive pressure/temperature samples shall satisfy the requirement in Table 12. The maximum time between two consecutive motion samples shall satisfy the requirement in Table 12.

3.3.8.4 Sampling in Stationary Mode (Factory Mode Only)

The maximum time between two consecutive pressure/temperature samples shall satisfy the requirement in Table 12. The maximum time between two consecutive motion samples shall satisfy the requirement in Table 12.

3.3.8.5 Sampling in Interim Period (Normal Only)

The maximum time between two consecutive pressure/temperature samples shall satisfy the requirement in Table 12. The maximum time between two consecutive Motion samples shall satisfy the requirement in Table 12.

3.3.8.6 Sampling in Interim Period (Factory Mode Only)

The maximum time between two consecutive pressure/temperature samples shall satisfy the requirement in Table 12. The maximum time between two consecutive Motion samples shall satisfy the requirement in Table 12.

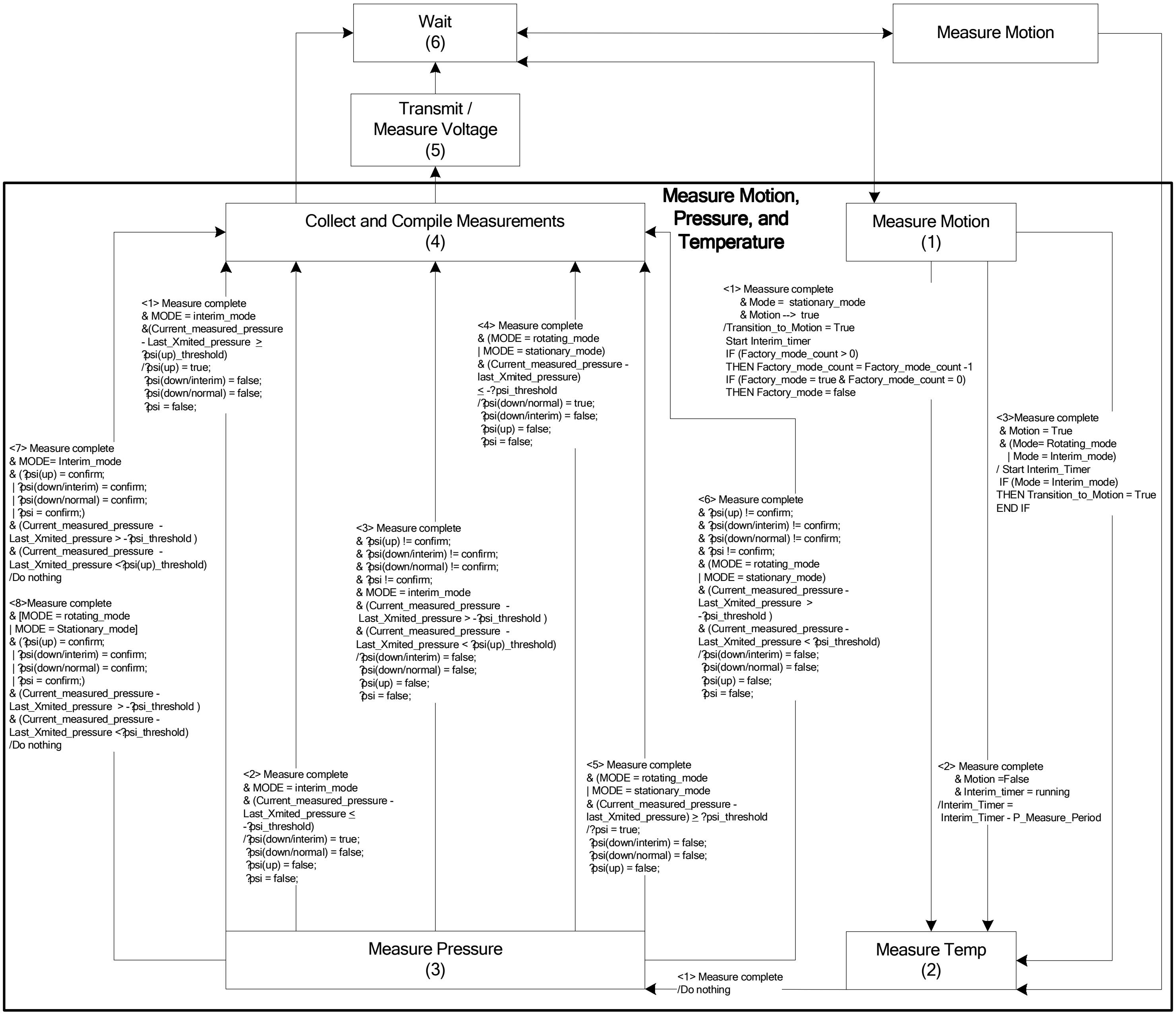


Figure 13. Normal & LF Initiate Function Code Measure Requirements

3.3.9 Transmission Rate

The sensor shall be capable of transmitting in either Rotating or Stationary Mode. (See Table 12 & Figures 14 & 15)

3.3.9.1 Transmitting Sensor Localization Data

The transmitter shall transmit data (The data defined in Section 3.1) at a rate that shall satisfy the requirements in Table 12. This data shall follow the following requirements:

The Sensor Localization Data (SLD) is a specific set of information that is transmitted instead of the temperature information. The SLD sends specific sequence values, the frame number all frames, and the transmission counter in the fourth frame in each single transmission (per Table 10B) for the first 24 transmissions after entering rotating mode from a stationary mode.

1. The sensor must be capable of detecting that it is passing a specific fixed angle point within the wheel during rotation.

    a. Note that a 250ms fixed delay shall be applied prior to the determination of the First Sequence Time as specified below. (Refer to Figure 7B SLD Mode Transmission).
    b. All timers related to SLD mode transmissions shall meet a +/- 1% timing tolerance.
    c. If the sensor was not able to detect it is passing a specified fixed angle point within the wheel while in rotating mode, the sensor shall transmit the respected “Unknown SLD” data (per Table 10B) instead of a sequence number described in step 2 below and then follow the frame & BMT counter value selection per steps 5 to 17 below.

2. If the sensor was not able to detect it is passing a specified fixed angle point within the wheel while in rotating mode and before transmitting the respected “Unknown SLD” frames per step 1(c) above, the sensor must confirm it is still rotating by taking a new motion sample before transmitting the “Unknown SLD” frames per step 1(c).

    a. If the sensor motion sample confirms that the sensor is rotating, then the sensor shall transmit the “Unknown SLD” frame per step 1(c) above.

    b. If the sensor motion sample indicates that the sensor is not rotating, the sensor shall not transmit, ignore the SLD data and not increment the BMT counter.

3. The sensor must pick the first pseudorandom sequence number (Any sequence number from "0" to "7") that represent a specific time measurement per the Sequence Number Values below.

Sequence Number Values:

Sequence Number	Value of Sequence (Time)
0	109.86 ms
1	189.94 ms
2	159.67 ms
3	119.63 ms
4	100.1 ms
5	109.86 ms
6	129.88 ms
7	109.86 ms

4. The sensor must start an internal timer (after the fixed 250ms delay) measuring the time from the instance it reached and passed the specific fixed angle point.

5. The instant the internal timer equals the specific time measurement represented by the first picked pseudorandom sequence number (Any sequence number from "0" to "7"), the sensor must transmit Frame "1"
6. The first sequence number, and Frame counter of "0" must be transmitted in Frame "1" per Table 10B.
7. The sensor must restart the timer the instant it starts the transmission of Frame "1"
8. The second sequence number must be the consecutive sequence number following the first sequence number used before the start of Frame "1" (e.g. if first sequence number was "3", then second sequence number must be "4")
9. The instant the internal timer equals the specific time measurement represented by the second sequence number, the sensor must transmit Frame "2"
10. The first sequence number, and Frame counter of "1" must be transmitted in Frame "2" per Table 10B.
11. The sensor must restart the timer the instant it starts the transmission of Frame "2"
12. The third sequence number must also be the consecutive sequence number following the second sequence number used before the start of Frame "2" (e.g. if second sequence number was "7", then third sequence number must be "0")
13. The instant that the internal timer equals the specific time measurement represented by the third sequence number, the sensor must transmit Frame "3"
14. The first sequence number, and Frame counter of "2" must be transmitted in Frame "3" per Table 10B.
15. The sensor must restart the timer the instant it starts the transmission of Frame "3"
16. The forth sequence number must also be the consecutive sequence number following the third sequence number used before the start of Frame "3" (e.g. if third sequence number was "0", then third sequence number must be "1")
17. The instant that the internal timer equals the specific time measurement represented by the fourth sequence number, the sensor must transmit Frame "4"
18. The first sequence number, Frame counter of "3" and the BMT counter value, representing the order of the transmission within the 24 transmissions required, must be transmitted in Frame "4"after the specific time measurement represented by the sequence number.
19. The sensor shall enter the SLD mode as soon as it enters Rotating Mode (Detects Motion) simultaneously.
20. This SLD Mode shall be configurable at the supplier’s End of Line.
21. The default configuration is SLD “on”.
22. If SLD Mode configured "on" in a sensor at EOL, it shall behave as described and shall become an SLD sensor.
23. If the SLD Mode is configured "off" at EOL, it shall not enter the SLD Mode during its life under any conditions. (This is only applicable for the legacy sensors)
24. The sensor shall stay in the SLD Mode unless the following occurs:

    If the sensor transmitted 24 transmissions in the SLD mode, the sensor shall exit the SLD Mode and proceed to the prospective mode depending on motion detection and other information available to the sensor.
25. An Internal Transmission Counter shall start from Zero to 23 to satisfy the 24 transmission requirement.
26. The BMT counter value must be used in Frame "4" within each transmission per Table 10B.
27. An Internal Frame Counter shall start from Zero to 3 to satisfy the 4 frame counter requirement.
28. The frame counter value must be used in all four frames within each transmission per the order of the transmission per Table 10B.
29. If the sensor has not completed the 24 transmissions in the SLD mode and the sensor stopped rotating, the sensor shall proceed to Interim Mode as described in Table 12 and suspend the internal transmission counter.
30. If the sensor enters Rotating Mode before Interim Period expires, it shall continue the SLD mode from the point it stopped until the Sensor transmits the total of 24 transmissions required by SLD.
31. The internal counter is suspended during the Interim Period and continues when sensor inters Rotating Mode again.

32. If the Interim Period expires before the sensors enters Rotating Mode again, the internal transmission counter shall be reset to 24.
33. After All 24 SLD transmissions are exhausted the sensor shall restart the SLD transmission only if the sensor enters the Rotating Mode from the Stationary Mode and not from Interim Mode.
34. The sensor shall transmit the SLD information with each transmission.
35. The SLD information shall be transmitted instead of the Temperature Data in Frames 1 thru 4 as shown below:

Data = Frame1 ≠ Frame 2 ≠ Frame 3 ≠ Frame 4 ≠ Frame 5					
Pre-amble	**ID**	**Pressure**	**Temperature / SLD**	**Status**	**Checksum**
16 bits	32 bits	8 bits	8 bits (Table 10B)	8 bits	8 bits

3.3.9.2 Transmitting in Rotating Mode (Normal Only)
The sensor shall transmit data (The data defined in Section 3.1) at a rate that shall satisfy the requirement in Table 12.

3.3.9.3 Transmitting in Rotating Mode (Factory Mode Only)
The sensor shall transmit data (The data defined in Section 3.1) at a rate that shall satisfy the requirement in Table 12.

3.3.9.4 Transmitting in Stationary Mode (Normal & Factory Mode)
The sensor shall transmit data (The data defined in Section 3.1) at a rate that shall satisfy the requirement in Table 12.

3.3.9.5 Transmitting in Interim Period (Normal Only)
The sensor shall transmit data (The data defined in Section 3.1) at a rate that shall satisfy the requirement in Table 12.

3.3.9.6 Transmitting in Interim Period (Factory Mode Only)
The sensor shall transmit data (The data defined in Section 3.1) at a rate that shall satisfy the requirement in Table 12.

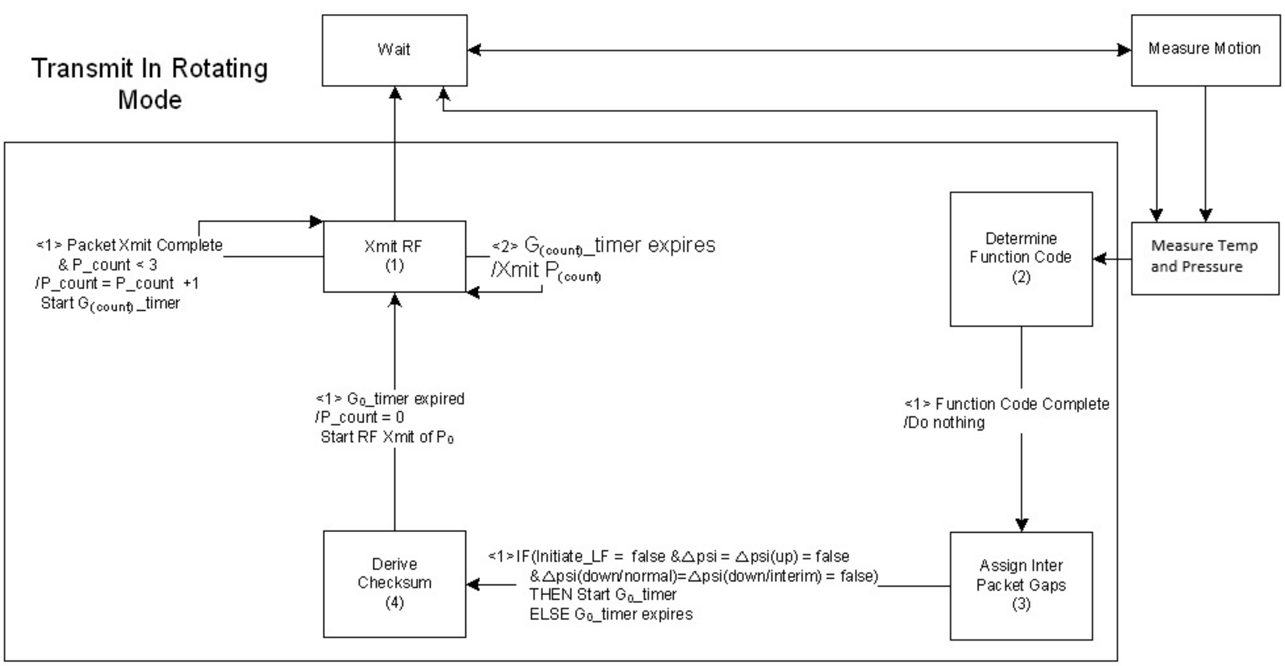


Figure 14. Sensor's Transmission Functional Requirements during Rotating Mode

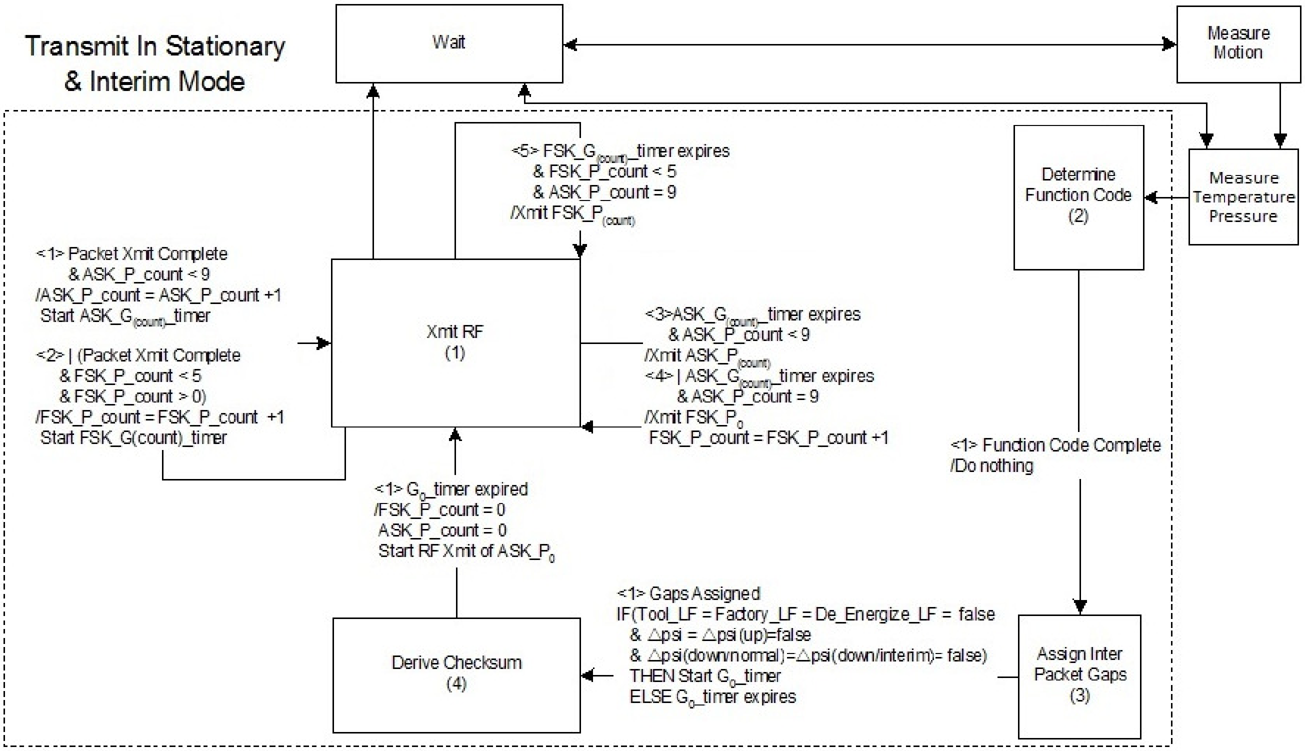


Figure 15. Sensor's Transmission Functional Requirements during Stationary and Interim Mode.

3.3.10 Motion Indicator Activation & Deactivation

The motion indicator shall be activated before the centrifugal force reaches the upper limit as specified in Table 2. The motion indictor shall not deactivate until the centrifugal force is below the limit at which it was activated. (See Figure 13).

3.3.11 Factory Mode

Factory mode requires the sensor to transmit more often to assure the programmability of the sensor during the manufacturing process. The transmitter shall send data as defined in Section 3.1. This mode shall be entered as soon as the sensor is re-energized as described in Section 3.3.13.2 or at the presence of a Factory LF command (See Section 3.3.16) In this mode, the sensor shall transmit at the rate described in sections 3.3.9.3, 3.3.9.4, and 3.3.9.6 for 16 motion activations (FCC Part 15.231, paragraph (e) states: "… devices operated under the provision of this paragraph shall be provided with a means for automatically limiting operation so that the duration of each transmission shall not be greater than one second and the silent period between transmissions shall be at least 30 times the duration of the transmission but in no case less than 10 seconds."). The sensor shall exit Factory Mode after 16 motion activations or after receiving an Exit-Factory LF command. (See Figures 5 & 13)

3.3.12 RPC Transmission

3.3.12.1 Stationary Mode

While the sensor in Stationary Mode, it shall satisfy the following requirements:
The sensor shall transmit an instantaneous measured data, as defined in Section 3.1, if a pressure change of 2.0 psi from the last transmission or greater has occurred with respect to the following conditions:

i. If the pressure change was a decrease in pressure, the sensor shall transmit immediately every time it detects the 2.0-psi or greater change from the last transmission.
ii. If the pressure change (of 2.0 psi or greater) was an increase of pressure, the silent period between the RPC transmission and the last transmission shall be 30.0 seconds, and the silent period between the RPC transmission and the next transmission (Normal scheduled transmission or another RPC transmission) shall also be 30.0 seconds, to be in compliance of FCC Part 15.231.

iii. The sensor shall then continue transmitting with respect to the transmission modes as described in Sections 3.3.5, 3.3.6, and 3.3.7. All transmissions that occur due to an RPC event shall have the RPC status code as specified in Section 3.1.5.8. (See Figure 13)

3.3.12.1.1 PIC Transmissions (Stationary Mode)

If the RPC transmission was triggered by a pressure increase, the sensor shall make two other independent pressure measurements and transmit them during the 62.0 seconds following the RPC transmission and each measurement/transmission shall have a silent period of 30.0 seconds between each transmission as shown in Figure 16. All PIC transmissions shall have the RPC status code as specified in Section 3.1.5.8. (See Figure 5)

3.3.12.1.2 PDC Transmissions (Stationary Mode)

If the RPC transmission was triggered by a pressure decrease, the sensor shall make two other independent pressure measurements and transmit them during the 6.0 seconds following the RPC transmission and each measurement/transmission shall have a silent period of 2.0 seconds between each transmission as shown in Figure 16. All PDC transmissions shall have the RPC status code as specified in Section 3.1.5.8. (See Figure 5)

3.3.12.2 Rotating Mode

While the sensor in Rotating Mode, it shall satisfy the following requirements:
The sensor shall transmit an instantaneous measured data, as defined in Section 3.1, if a pressure change of 2.0 psi from the last transmission or greater has occurred with respect to the following conditions:

i. If the pressure change was a decrease of pressure, the sensor shall transmit immediately every time it detects the 2.0-psi or greater pressure changes from the last transmission.
ii. If the pressure change (of 2.0 psi or greater) was an increase of pressure, the sensor shall not react to it. The sensor shall then continue transmitting with respect to the transmission modes as described in Sections 3.3.5, 3.3.6, and 3.3.7.
iii. All transmissions occurred due to a RPC event shall have the RPC status code as specified in Section 3.1.5.8. (See Figure 13)

NOTE: For the current implementation RPC enabled sensors have an option to enable the PIC response in rotating mode. For ERPC sensors, rotating mode pressure increase and decrease response is always enabled.

3.3.12.2.1 PDC Transmissions (Rotating Mode)

If the RPC transmission was triggered by a pressure decrease, the sensor/transmitter shall make two other independent pressure measurements and transmit them during the 5.0 seconds following the RPC transmission and each measurement/transmission shall have a silent period of 2.0 seconds between each transmission as shown in Figure 16. All PDC transmissions shall have the RPC status code as specified in Section3.1.5.8. (See Figure 5)

RPC / PDC / PIC Transmissions				
RPC Transmission	Silent Period	First PDC/PIC Measurement & Transmission	Silent Period	Second PDC/PIC Measurement & Transmission

Figure 16. RPC / PDC / PIC Transmissions

3.3.12.3 Interim Period

While the sensor is in Interim Period, it shall satisfy the following requirements:

i. The sensor shall transmit an instantaneous measured data (RPC Transmission), as defined in Section 3.1 if a pressure decrease of 2.0 psi from the last transmission or greater has occurred.

ii. The sensor shall also transmit an instantaneous measured data (RPC Transmission), as defined in Section 3.1, if a pressure increase of 1.0 psi from the last transmission or greater has occurred.

iii. The sensor shall then continue transmitting with respect to the transmission modes as described in Sections 3.3.5, 3.3.6, and 3.3.7.

iv. In the case of a pressure decrease, the sensor shall transmit immediately every time it detects a 2.0-psi or greater pressure changes from the last transmission

3.3.12.3.1 PIC Transmissions (Interim Mode)

If the RPC transmission was triggered by a pressure increase, the sensor shall make two other independent pressure measurements and transmit them during the 62.0 seconds following the RPC transmission and each measurement/transmission shall have a silent period of 30.0 seconds between each transmission as shown in Figure 16. All PIC transmissions shall have the RPC status code as specified in Section 3.1.5.8. (See Figure 5)

3.3.12.3.2 PDC Transmissions (Interim Mode)

If the RPC transmission was triggered by a pressure decrease, the sensor shall make two other independent pressure measurements and transmit them during the 6.0 seconds following the RPC transmission and each measurement/transmission shall have a silent period of 2.0 seconds between each transmission as shown in Figure 16. All PDC transmissions shall have the RPC status code as specified in Section 3.1.5.8. (See Figure 5)

3.3.12.4 Enhanced Rapid Pressure Change (ERPC)

When ERPC functionality is configured ON, the sample, transmit, and delta pressure detection requirements in this section replace those specified for RPC and in Table 12. ERPC shall be configurable (ON/OFF) at the supplier's EOL.

3.3.12.4.1 ERPC Pressure Sample and Transmit Time

When delta pressure is detected in any operational mode (Interim, Stationary, Rotating), the sensor shall enter ERPC Active mode and sample pressure and transmit every second for the duration specified in this section.
If |Sampled pressure-Last Measured Pressure| > ERPC_LM Threshold, then transmit for 10 seconds. This transmission duration shall be configurable.
If |Sampled pressure-Last Transmitted Pressure| > ERPC_LT Threshold, then transmit for 5 seconds. This transmission duration shall be configurable.
The sensor shall continue to sample and transmit for an additional 5 or 10 seconds (depending on entry criteria) if delta pressure is detected in ERPC mode. The decision to extend the transmit time shall be evaluated at every ERPC sample/transmission.
When these two conditions occur at the same time, the Last Measured Pressure entry condition takes precedence.

This transmission duration shall be configurable. Extend EPRC interim mode pressure sampling time (see below) for the first 15 minutes of Stationary Mode on transition from Interim mode. This provides a total of 30 minutes of Interim Mode pressure sampling time when vehicle exits Rotating Mode (15 minutes in Interim and 15 minutes in Stationary). The sensor shall have motion verification to avoid false entrance of Rotating Mode from Stationary or Interim.

Note: For current implementation – when a motion measurement is detected, a pressure delta check is performed to determine if a pressure delta was the cause. If a delta pressure is confirmed, the RPC transmission will be prioritized.

Pressure sampling time when ERPC is ON shall be set to following default values and shall be configurable:
Interim Mode, 3 seconds
Stationary Mode, 5 seconds
Rotating Mode, 5 seconds
ERPC Active Mode, 1 second
SLD Mode, 15 seconds

3.3.12.4.2 ERPC Threshold
For ERPC_LM , the delta pressure detection shall be set to 1 PSI for Stationary and Interim Modes, and 2 PSI for Rotating and SLD Mode.
For ERPC_LT, the delta pressure detection shall be set to 2 PSI.
These thresholds shall have a maximum allowable value of 10 PSI with a resolution of 0.25 PSI.
These Thresholds shall be configurable at the supplier's EOL.

3.3.12.4.3 ERPC Transmission
The sensor shall transmit 5 ASK and 3 FSK frames per transmission.
Alternative implementations for ERPC mode may be considered with approval from Ford GCE team.

3.3.13 Service Field

The sensor design shall include a feature that allows the sensor to be de-energized and re-energized using an LF transponder. Shipping shall not re-energize a de-energized sensor. Figure 17 below describes the de-energizing and re-energizing process.

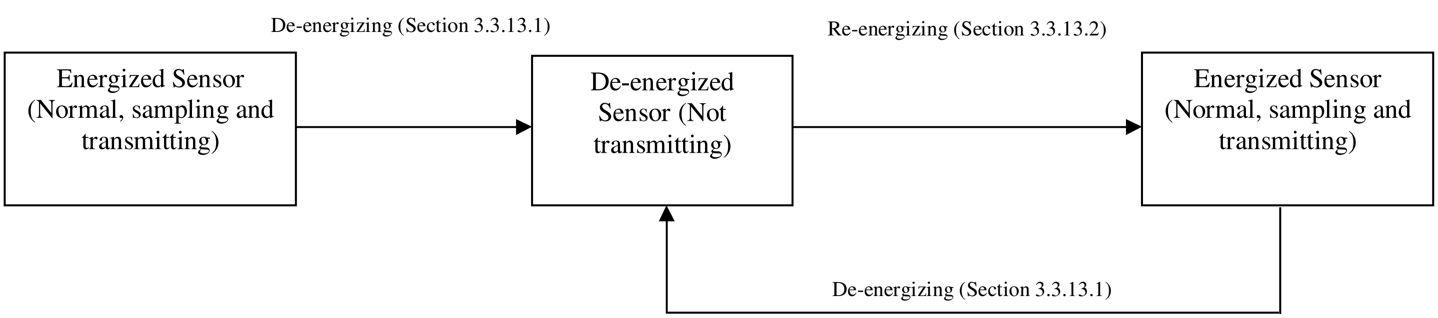


Figure 17. Sensor's Energizing and De-Energizing Process

3.3.13.1 De-energizing the sensor:

The sensor must de-energized (Not transmit) upon the presence of an LF signal with field strength as defined in Table 1. The sensor must de-energize if the LF message (see Section 3.3.21) contains the command data specified in Figure 18 below:

Command Data: De-energizing LF															
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Figure 18. Sensor De-Energizing Command Data

3.3.13.2 Re-energizing the sensor:

The sensor shall be capable of being re-energized in either of the methods defined in Sections 3.3.13.2.1, and 3.3.13.2.2.

3.3.13.2.1 LF Method (Production Sensor Only)

The sensor shall be re-energized after a Tool-LF, Exit-Factory-LF or Factory-LF is received (as described in Sections 3.3.16, 3.3.17, and 3.3.19).

3.3.13.2.2 Pressure Method (Production & Service sensors)

The sensor shall be re-energized if the air pressure measurement is 20.0 psig or more for two consecutive measurements.

3.3.14 LF Initiation

The sensor must provide data, as defined in Section 3.1, upon the receipt of an LF signal with field strength as defined in Table 1. The sensor must react (Transmit and provide data) no later than 300 ms after the LF data code has been detected. The sensor must be sensitive (As defined in Table 1) and able to detect the LF field. The sensor shall measure LF at the rate specified in Table 12 and shall have the LF polling window (LF_polling_timer) as described in Figure 29. The sensor shall transmit with LF-Initiation Function Code (as specified in Sections 3.1.5.6) if the LF message (see Section 3.3.21) contains the command data specified in Figure 19 below:

Note: Current Implementation – LF window is open for 55ms based on the current message timing.

Command Data: LF- Initiation															
0	0	0	1	1	0	0	1	0	1	1	1	0	1	1	1

Figure 19. LF-Initiation Command Data

3.3.15 Off Mode

3.3.15.1 Production Sensor

This mode is one of the modes that control the behavior of the sensor sampling and transmission rate. This Off Mode is only for production parts sensors that are used for the builds during the production process and not in the service environment. When the sensor/transmitter is de-energized (See Section 3.3.13.1), it shall transmit one last transmission with the De-Energize-LF function code (See Section 3.1.5.4) then enter the Off Mode immediately. When the sensor/transmitter is in this Off Mode, it shall continue sampling pressure and measuring LF at the rate specified in Table 12 but it shall not transmit any transmission until the sensor/transmitter is re-energized again (See Section 3.3.13.2)

3.3.15.2 Service Sensor

This mode is one of the modes that control the behavior of the sensor/ transmitter sampling and transmission rate. This Off Mode is only for service parts sensors that are used in service and not in production. When the sensor/transmitter is de-energized (See Section 3.3.13.1), it shall transmit one last transmission with the De-Energize-LF function code (See Section 3.1.5.4) then enter the Off Mode immediately. When the sensor/transmitter is in this Off Mode, it shall continue sampling pressure at the rate specified in Table 12 but it shall not transmit any transmission nor sample or measure LF until the sensor/transmitter is re-energized again (See Section 3.3.13.2)

3.3.16 Factory-LF

The sensor/transmitter must provide data, as defined in Section 3.1, upon the presence of an LF signal with field strength as defined in Table 1. The sensor must react (Transmit and provide data) no later than 150.0ms after the LF data code has been detected. The sensor shall transmit with Factory-LF function code (as specified in Section 3.1.5.5) if the LF message (see Section 3.3.21) contains the command data specified in Figure 20 below:

Command Data: Factory-LF															
0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1

Figure 20. Factory-LF Command Data

3.3.17 Tool-LF Data

The sensor/transmitter must provide data, as defined in Section 3.1, upon the presence of an LF signal with field strength as defined in Table 1. The sensor must react (Transmit and provide data) no later than 150.0ms after the LF data code has been detected. The sensor shall transmit with Tool-LF function code (as specified in Section 3.1.5.9) if the LF message (see Section 3.3.21) contains the command data specified in Figure 21 below:

Command Data: Tool-LF															
1	0	1	0	1	0	1	1	1	0	1	0	1	0	1	0

Figure 21. Tool-LF Command Data

3.3.18 Software Revision LF (Software-LF)

The sensor/transmitter must provide the software revision data upon the presence of an LF signal with field strength as defined in Table 1 with the LF data command specified in Figure 22 below. The sensor must react (Transmit and provide data) no later than 150.0 ms after the LF data code has been detected.

Command Data: Software-LF															
1	0	0	0	1	1	0	0	1	1	1	0	1	1	1	1

Figure 22. Software-LF Command Data

RF Data in response to Software-LF					
Pre-amble	**ID**	**Software Revision**	**Check-sum**	**Extended Diagnostic Data**	**Check-Sum#2**
16 bits	32 bits	1 byte	1 byte	2 bytes	1 byte

Function Code Data MUX		
Spare	Sensor Diagnostics	Software Version
1 bit	3 bit	4 bits

Diagnostic Bits (With respect to Table 14.1)		
X	X	X

Figure 23. RF Data transmitted from sensor in response to Software-LF

The check sums are calculated by splitting each frame into bytes, adding all the bytes and using the sum without the carry over as the check-sum. Not including the pre-amble, the two checksums are calculated as follows:

SOFTWARE LF RF MESSAGE

32 bit ID				8 Software Revision	8 Checksum1 bits	16 Extended Diagnostic Bits		8 Checksum2 bits
4bit Supplier ID	MSB 28bit Unique ID LSB							
B1	B2	B3	B4	B5	B6 = B1+B2+B3+B4+B5	B7	B8	B9 = B6 +B7 +B8
40 bits included in checksum1								
64 bits included in checksum2								

3.3.19 Exit Factory LF

The sensor/transmitter shall energize and enter the normal mode immediately without entering the factory mode upon the presence of specific LF signal with Exit-Factory-LF message. Also the Exit-Factory-LF message shall force the sensor/transmitter to exit the factory mode immediately and enter the normal mode. The sensor shall react (Transmit and provide data) no later than 150.0 ms after the Exit-Factory-LF data code has been detected. The sensor shall transmit with Exit-Factory-LF function code (as specified in Section 3.1.5.10) if the LF message (see Section 3.3.21) contains the command data specified in Figure 24 below:

Command Data: Exit-Factory-LF															
1	1	1	1	1	0	0	0	1	1	1	0	0	0	0	0

Figure 24. Exit-Factory-LF Command Data

3.3.20 Forced Transmission

A forced transmission is defined as a non-periodic response either to an LF command or a rapid change in pressure. The details for this type of communication are defined in Sections 3.3.12 through 3.3.20. For all forced transmissions, the sensor shall transmit immediately without the initial random period as shown in Figure 9 except when a failure is present. Please refer to section 3.4.2 Data and Measurement Diagnostics for sensor behavior under these conditions.

3.3.21 LF Message Format

The sensor shall be able to decode LF data. The LF message data format is shown in Figure 25 below. The LF message includes a pre-amble, synchronization part, wake-up ID, and the command data. After the detection of the wake-up ID, the LF interface supports data employing ASK modulation of the LF carrier at 3.9Kbauds nominal with ± 0.06Kbauds tolerance. The data is reversed Manchester coded, which means that a 'zero' coded bit shall be a transition from high to low and 'one' coded bit shall be a transition from low to high. During the high state of the coded bit, the LF carrier is on, and during the low state of the coded bit, the LF carrier is off. The LF message shown in Figure 25 below shall be repeated for 5.0 seconds ± 20% by the LF transmitter (LF Tool or LF Equipment) in order for the sensor to receive the LF message and the period between each message shall be 10.0msec ± 20%.

3.3.21.1 Pre-amble

The pre-amble, is a sequence Manchester coded "zeros". The preamble shall be 5.0ms with a tolerance of +/- 20%.

3.3.21.2 Synchronization

In order to initialize the on-chip Manchester decoder and to detect the start of the wake up ID frame, a distinct synchronization pattern needs to be received by the sensor.

3.3.21.3 Wake Up ID

The wake up ID is the user programmed bit pattern used to filter specific tool LF message among all received LF messages. The LF interface continues data sampling if the wake up ID pre-programmed in the sensor matches the one in LF message. The rule is to take a number the representation of which in binary does not has periodic 0/1 scheme.
Wake Up ID is a 16 bits value equal to typically 0x5A5A.
The MSB (Most Significant Bit) of the wake up ID shall be transferred first i.e. from left to right 0101 1010 0101 1010.

0	1	0	1	1	0	1	0	0	1	0	1	1	0	1	0

3.3.21.4 Data

Data sent, 2 bytes, are decoded and buffered in the UART-like 2 bytes bit register of the sensor. The content of this register is stored in the output value LF_data and available to the rest of the application.

- The MSB of the data shall be transferred first

3.3.21.4.1 Data Transmitted by LF

The data transmitted by the LF data shall be: Tool-LF, Factory-LF, De-Energizing LF, Software LF, LF-Initiation, and Exit-Factory-LF as specified in Sections 3.3.17, 3.3.16, 3.3.13.1, 3.3.18, and 3.3.19 respectively.

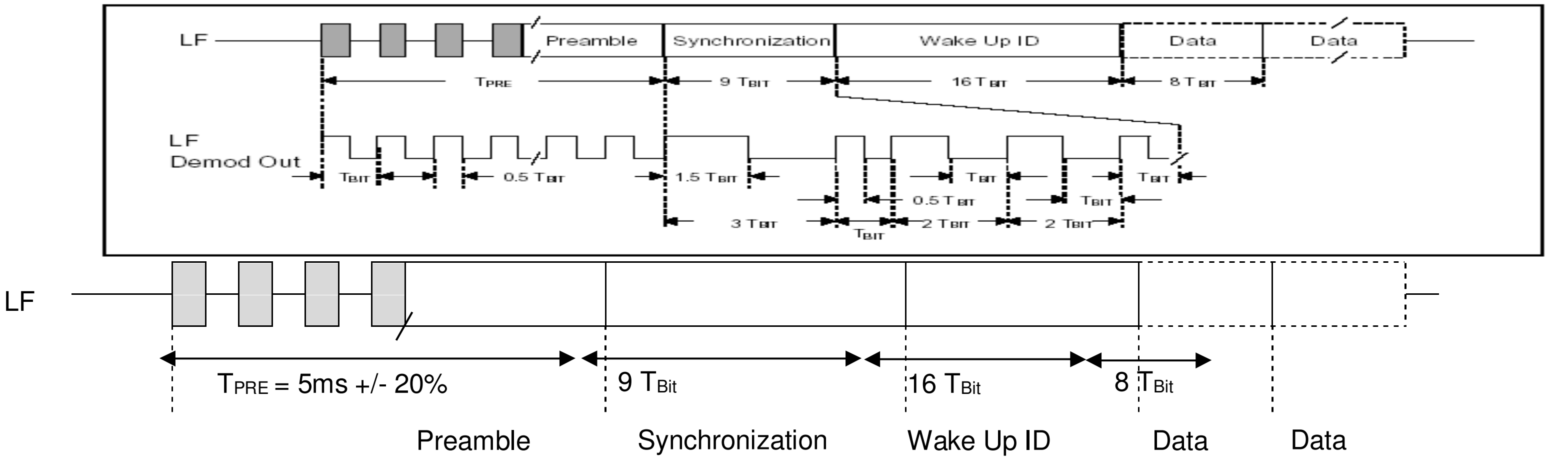


Figure 25. LF Message Data Format

3.3.22 RF Test Mode

The sensor must enter the RF Test Mode and provide the function code specified in Section 3.1.5.11 upon the presence of an LF signal with field strength as defined in Table 1 with the LF data command specified in Figure 25 below.

The sensor must react (Transmit and provide data) no later than 150ms after the LF data code has been detected. As soon as the sensor enters this mode it shall comply with all the sampling and transmission requirements specified in Table 12 with regarding this specific mode independent of rotating, stationary, or interim mode. The sensor shall transmit with packets redundancy as specified in section 3.3.4.1 and Figure 6.
The sensor shall count the number of frames (each transmission contains four frames as shown in Figure 6) it radiated since it enters this Mode, and this number shall be transmitted within the data radiated in each frame as shown in Figure 26 below.
The Data transmitted shall be in the format shown in Figure 26 below. When the counter for the number of frames reach the value 255 (All of the 8 bits are used), the counter shall reset and restart again until the sensor exit this mode.
When the sensor exits this mode it shall clear the number of frames counter. The sensor shall exit this mode upon the presence of an Exit Factory LF command as specified in Section 3.1.5.10.
The sensor shall start an eight hours timer from the moment it enters this mode and then shall exit this Mode immediately after the eight (8.0) hours' timer expires.

Command Data: RF Test Mode-LF															
0	0	0	1	1	0	0	1	1	0	0	0	0	1	0	0

Figure 26. RF Test Mode-LF Command Data

RF Test Mode Data Structure ≠ Frame1 ≠ Frame 2 ≠ Frame 3 ≠ Frame 4					
Pre-amble	**ID**	**Pressure**	**Number of Frames**	**Status**	**Check - Sum**
16 bits	32 bits	8 bits	8 bits	8 bits	8 bits

Figure 27. RF Data transmitted from sensor in response to RF Test Mode-LF

3.3.23 RF-CW- Mode

The sensor/transmitter must enter the RF-CW-Mode and upon the presence of an LF signal with field strength as defined in Table 1 with the LF data command specified in Figure 27 below.

The sensor must react (Transmit) no later than 150ms after the LF data code has been detected. As soon as the sensor enters this mode it shall start transmitting the CW frequency (Carrier Wave Frequency) of the sensor/transmitter as specified in Table 1 for High and Low Frequency.

The sensor shall start a ten minute timer from the moment it enters this mode and then shall exit this Mode immediately after the ten (10) minute timer expires.

Command Data: RF-CW-Mode-LF (High Frequency)															
0	0	0	1	1	0	0	1	0	0	1	1	0	1	1	0

Figure 28(A). RF-CW-Mode-LF Command Data (High Frequency)

Command Data: RF-CW-Mode-LF (ASK Frequency)															
0	0	0	0	0	0	1	0	0	0	0	0	1	0	1	0

Figure 28(B). RF-CW-Mode-LF Command Data (ASK Frequency)

Command Data: RF-CW-Mode-LF (Low Frequency)															
0	0	0	1	1	0	0	1	1	0	0	1	0	1	0	1

Figure 28(C). RF-CW-Mode-LF Command Data (Low Frequency)

3.3.24 Retrieving Extended Diagnostic Data

The additional data described in Tables 19 and 20 can be retrieved from the sensor using the following LF command:

Command Data: Retrieve Extended Diagnostic Data															
1	1	0	1	0	0	0	1	1	0	1	0	0	1	1	0

Upon receipt of this command, the sensor will send the entire data package in the format described in the Appendix.

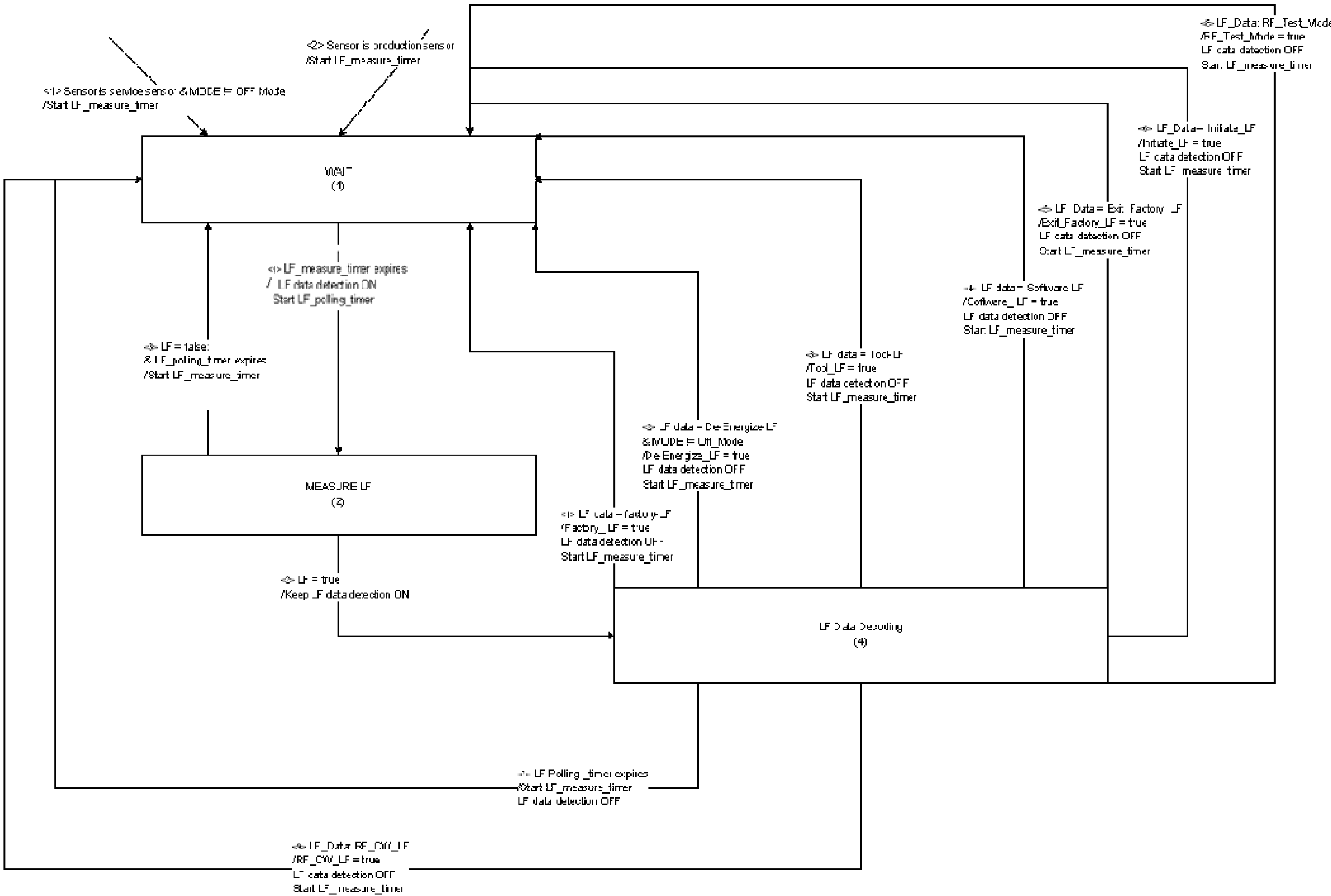


Figure 29. Sensor LF Detection Functional Requirements

3.4 Diagnostics

3.4.1 Battery Diagnostics

The sensor must be able to diagnose the internal battery and send out a low battery warning to the receiver as described in Section 3.1.5.1.

3.4.2 Data and Measurement Diagnostics

The sensor shall stop all transmissions if any of the failures specified in Tables 14.1 or 14.3 are present. When such a failure occurs, the sensor will respond only to the Software-LF command and the Retrieve Extended Diagnostic Data-LF commands (Including not responding to any RPC event) indicating that the sensor has failed by setting the applicable sensor diagnostic information specified in Table 14.1 or 14.3. If more than one failure is present, the sensor will respond with the highest priority failure.
The sensor can resume normal transmissions, measurements, and operations if all the failures are removed, and all data to be measured or transmitted is reliable and correct.

Table 14.1 – Sensor Failures and Diagnostic Bits (Implementation #1)

Item	Sensor Error/Failure	Sensor Diagnostic Bits			Priority
1	Sensor is Normal, No Failure Present	0	0	0	8
2	Mechanical Sensor Failure	0	0	1	1
3	EEPROM Error	0	1	0	2
4	Underflow of Pressure sensor	0	1	1	4
5	Underflow of Temperature sensor	1	0	0	6
6	Overflow of Temperature sensor	1	0	1	5
7	Underflow of Accelerometer	1	1	0	3
8	No Failure Present Extended Data Available	1	1	1	7

Table 14.2 – Extended Diagnostic Data (Implementation #1)

Extended Diagnostic Data	Description
15	Battery Low
14	Crystal Fault
13	Tx Error
12	Hardware Issue
11	Software Issue
10	Temperature under or overflow (history)
09	32KHz Oscillator cal failure
08	Tx Block/Frame skip
07	Long period in Rotating mode
06	Autolocation NoSync High
05	Pressure_sensor_fault (history)
04-00	Spare

Table 14.3 – Sensor Failures and Diagnostic Bits (Implementation #2)

Item	Sensor Error/Failure	Sensor Diagnostic Bits			Priority	Byte 9	Byte 10
0	Sensor is Normal, No Failure Present	0	0	0	6	0x00	0x00
1	Mechanical Sensor Failure (ADC and/or Clock)	0	0	1	1	Diagnostic 2 data byte 3 In Table 20	Reserved (set to 0x00)
2	EEPROM Error (Flash and/or RAM)	0	1	0	2	Diagnostic 4 data byte 7 In Table 20	Diagnostic 4 data byte 8 In Table 20
3	Pressure Sensor (Underflow/Overflow/Error/ Bondwire issue)	0	1	1	3	Diagnostic 7 data byte 13 In Table 20	Reserved (set to 0x00)
4	Underflow of Temperature sensor (Sensor in thermal shutdown)	1	0	0	N/A	N/A Note: In case of temperature sensor overflow the WFC is in low thermal shutdown, thus not responding to LF commands	
5	Overflow of Temperature sensor (Sensor in thermal shutdown)	1	0	1	N/A	N/A Note: In case of temperature sensor overflow the WFC is in low thermal shutdown, thus not responding to LF commands	
6	Accelerometer (Underflow/Error/ Bondwire issue)	1	1	0	4	Diagnostic 7 data byte 14 In Table 20	Reserved (set to 0x00)
7	No Failure Present Extended Data Available	1	1	1	5	0x00	0x00

Table 14.4 – Sensor Failures and Diagnostic Bits (Implementation #4)

Extended Diagnostic Data	Description
15-12	Spare
11	Spare
10	Spare
09	Spare
07	Spare
06	Accelerometer Underflow/Overflow/Error Bondwire issue
05	Spare
04	Spare
03	Pressure Sensor Underflow/Overflow/Error Bondwire issue
02	EEPROM Error (Flash, RAM)
01	Mechanical Sensor Failure (ADC, Clock)
00	Spare

4 Product Verification

Refer to Figures 1, 2 and 3 for a sequential list of required tests for PV, DV, and Life Test. Test unite is the sensor & attachment mechanism. Unless specified otherwise herein WDS 00.00EA-D11 shall apply (Table 6).

Note: ***Supplier shall submit a test procedure to GCE for each DV, PV, and IP test described in Figures 1, 2, and 3 prior testing. Any test procedure used for DV, PV or IP must be submitted to GCE and it must be approved by GCE to be qualified. Supplier shall identify failure modes in FMEA and demonstrate linkages with test methods in the DVP. Supplier shall submit additional test procedures to detect failure modes identified on a FMEA. Supplier shall submit The DVP & R to GCE.***

If the Low Battery reserved bit (Section 3.1.5.1) is "one" during or after any test through DV, and PV except if this test was performed at –40°C and was not part of the initial performance test, the sensor is considered failed the test.

If the Low Battery reserved bit (Section 3.1.5.1) is "one" during or after any test through IP, The sensor is considered failed the test.

4.1 Classifications

Refer to Table 15 below for a list of classifications via WDS 00.00EA-D11.

Table 15 – WDS Classifications

CLASSIFICATIONS	SENSOR / TRANSMITTER
Shock/Drop	III
Vibration	IV
Salt Mist	IV
Temperature	VII
Dust	I
Water / Fluids	VIII
Chemical Resistance	II
EMC	B

The Tire Pressure Sensor component temperature classification is VII per the WDS 00.00EA-D11. Refer to Table 16 below for the specific temperature limits defined for this classification:

Table 16- Temperature Classifications

Operation Test	T1 = -40°C
	T2 = 85°C
Exposure Test	T5 = -40°C
	T6 = 100°C
Performance Test	T3 = -40°C
	T4 = 100°C
Functional Test	T7 = 100°C
Ambient	20°C

4.1.1 FCC Part 15 Compliance

The manufacturing source shall be responsible for qualifying the TPM transmitter according to FCC Part 15 regulations, Industry Canada certifications, and the averaging factor must be calculated per FCC Part 15 Section 35 requirements.

Note: If vehicle platform is to be exported to non-FCC controlled area, the sensor/transmitter's manufacturing source must receive certification for every export country the product is shipped to, per the PDL for the vehicle's program.

4.1.2 Electromagnetic Compatibility

Test shall be performed as specified in the latest version of the FMC EMC test plan. The EMC test plan must be submitted and approved by core EMC. EMC testing must be conducted at an approved laboratory. The TPM transmitter must comply with EMC design and test requirements stated in the EMC ES as verified by a Ford EESE approved test plan.

4.1.3 Resonance Frequency

If any component within the TPM sensor/transmitter assembly is susceptible or have a resonance to a frequency between 0.0 Hz to 10.0 kHz at any magnitude, the supplier shall do the following:

- The supplier shall Report to Ford EESE D&R Engineer and Managements all susceptible and resonance frequencies.
- The supplier shall Report to Ford EESE D&R Engineer and Managements all components affected by these frequencies.
- The Supplier shall have the design robust and immune to any noises within these susceptible or resonance frequencies that may exist at any of the following:
    - Start of Production of Sensor/transmitter assembly.
    - During Production of Sensor/transmitter assembly.
    - All Shipping of sensor/transmitter, assembly, sensor/wheel assembly.
    - Assembly to the wheel.
    - Wheel manufacturing process.
    - Tire assembly process.
    - Vehicle assembly process.

4.2 SENSOR FUNCTIONAL CHECK TEST PROCEDURES

4.2.1 Transmitter Field Strength

This test shall be conducted as required and during all specified Functional Checks in Figures 1, 2, and 3.

Test Procedure
The sensor/transmitter supplier shall supply the test procedure and the procedure must be approved by GCE.

Test Requirement Acceptance Criteria
Transmitter field strength shall remain within the limits defined in Table 1. The Low Battery reserved bit (Section 3.1.5.1) shall be "zero" except if this test was performed at –40ºC and was not part of the initial performance test.

Retest Procedure
A retest may be permitted if the sampling time of the spectrum analyzer is not capable of catching the signal on the first pass.

4.2.2 Transmitter Frequency

Test Procedure
The sensor/transmitter supplier shall supply the test procedure and the procedure must be approved by GCE.

Test Requirement Acceptance Criteria
The nominal frequency recorded must remain within the limits defined in Table 1. The Low Battery reserved bit (Section 3.1.5.1) shall be "zero" except if this test was performed at –40ºC and was not part of the initial performance test.

Retest Procedure
No retest permitted.

4.2.3 Bit Width

Test Procedure
The sensor/transmitter supplier shall supply the test procedure and the procedure must be approved by GCE.

Test Requirement Acceptance Criteria
The recorded bit width must remain within the limits defined in Table 1. The Low Battery reserved bit (Section 3.1.5.1) shall be "zero" except if this test was performed at –40ºC and was not part of the initial performance test.

Retest Procedure
No retest permitted.

4.2.4 LF Sensitivity

Test Procedure
The sensor/transmitter supplier shall supply the test procedure and the procedure must be approved by GCE.

Test Requirement Acceptance Criteria
The low frequency sensitivity shall remain within the limits defined in Table 1. The sensor/transmitter shall satisfy Sections 3.3.14, and 3.3.20. The Low Battery reserved bit (Section 3.1.5.1) shall be "zero" except if this test was performed at –40ºC and was not part of the initial performance test.

Retest Procedure
No retest permitted

4.2.5 Pressure & Temperature Tolerance and Performance

Test Procedure
This test shall be performed at ambient, maximum and minimum operating temperatures. Place the part into a pressure vessel and place the vessel into a thermal chamber. The pressure shall have the means to vary and control air pressure (i.e. external airline). Soak the vessel in the thermal chamber, until the pressure vessel's temperature is stabilized and is equal to the thermal chamber pre-set temperature, prior to the test. Following the soak period, activate the part in the vessel and use a data logger to store the pressure and temperature values transmitted from the device.

Test Requirement Acceptance Criteria
The test shall follow the Table 17 below. The pressure and temperature values transmitted must remain within the limits defined in Tables 3, 4 and 5. The Low Battery reserved bit (Section 3.1.5.1) shall be "zero" except if this test was performed at –40ºC and was not part of the initial performance test.

Table 17 – Temperature and Pressure Tolerance Test

Temperature	-40.0ºC	-40.0ºC	20ºC	20ºC	100.0ºC	100.0ºC
Applied pressure	30 psig	90 psig	30 psig	90 psig	30 psig	90 psig
Temperature	-40ºC min -35ºC max	-40ºC min -35ºC max	16.0ºC min 24.0ºC max	16.0ºC min 24.0ºC max	95ºC min 100ºC max	95ºC min 100ºC max
Pressure[1] (Low Range)	27.0 psig min 33.0 psig max	84.25 psig min 95.75 psig max	28.75 psig min 31.25 psig max	87.5 psig min 92.5 psig max	27.0 psig min 33.0 psig max	84.25 psig min 95.75 psig max
Pressure[1] (High Range)	24.25 psig min 35.75 psig max	84.25 psig min 95.75 psig max	27.5 psig min 32.5 psig max	87.5 psig min 92.5 psig max	24.25 psig min 35.75 psig max	84.25 psig min 95.75 psig max

1. Transmitted pressure readings are in reference to calibrated barometric pressure.

Retest Procedure
No retest permitted.

4.2.6 Motion indicator

Test Procedure
The sensor/transmitter supplier shall supply the test procedure and the procedure must be approved by GCE.

Test Requirement Acceptance Criteria
A transmission with the Rotating/Stationary Mode reserved bit is "one" must be received during 20-seconds logging period– this indicates that the motion indicator has detected the sensor is rolling. The Low Battery reserved bit (Section 3.1.5.1) shall be "zero" except if this test was performed at –40ºC and was not part of the initial performance test.

Retest Procedure
A retest is permitted only in the case where RF clashing results in a transmission being missed. This could happen if more than one transmitter is being tested at any time, or if there is inadequate shielding from other RF sources.

4.3 Life Test

4.3.1 Pressure, Temperature, and Frequency Accuracy Distribution

This procedures aim is to demonstrate the accuracy of actual applied pressure, temperature, and frequency vs. the transmitted pressure, temperature, and frequency of the TPM sensors, for both aged and non-aged parts.

Test Procedure
Place test sample sensors in pressure vessel. Then soak the vessel in the thermal chamber, until the pressure vessel's temperature is stabilized and is equal to the thermal chamber pre-set temperature, prior to the test. Induce 20 LF Initiation activation's with a transponder activation tool. Ramp pressure in vessel up then induce 20 LF Initiation activations again. Repeat this procedure as specified in Table 18 below for different temperature and pressure combinations. Record and log transmitted pressure and temperature reading for each separate LF Initiation transmission. Also record and log the Transmitter Nominal Frequency (TNF) at each transmission.

Table 18- Temperature and Pressure Accuracy Distribution Test

Thermal Chamber's pre-set Temperature	Number of LF Activations	Pressure Vessel's set Pressure							
-40ºC	20, at each pressure value	0 psig	20 psig	30 psig	50 psig	70 psig	80 psig	90 psig	100 psig
-15 ºC	20, at each pressure value	0 psig	20 psig	30 psig	50 psig	70 psig	80 psig	90 psig	100 psig
-5 ºC	20, at each pressure value	0 psig	20 psig	30 psig	50 psig	70 psig	80 psig	90 psig	100 psig
20 ºC	20, at each pressure value	0 psig	20 psig	30 psig	50 psig	70 psig	80 psig	90 psig	100 psig
85 ºC	20, at each pressure value	0 psig	20 psig	30 psig	50 psig	70 psig	80 psig	90 psig	100 psig
100 ºC	20, at each pressure value	0 psig	20 psig	30 psig	50 psig	70 psig	80 psig	90 psig	100 psig

Test Requirements/Acceptance Criteria
The pressure and temperature values transmitted must remain within the limits defined in Tables 3, 4 and 5, the pressure measurement-to-measurement variation for the same sensor shall remain within the limits defined in Tables 3, and 4, and the temperature measurement-to-measurement variation for the same sensor shall remain within the limits defined in Table 5. The transmitter nominal frequency (TNF) must remain within the limits defined in Table 1. The Low Battery reserved bit (Section 3.1.5.1) shall be "zero" except if this test was performed at –40ºC and was not part of the initial performance test.

4.3.2 Motion Indicator Accuracy Distribution

This procedures aim is to display that any drift in the Motion Indicator's activation point will remain within the limits defined in Table 2.

Test Procedure

Secure sensors in wheel spin fixture. Ramp up spin speed to simulate a centrifugal force at the sensor of 1g (9.81m/s2). Wait 5 minutes to see if any of the sensors perform Motion Indicator activation by providing a transmission with the Rotating/Stationary Mode reserved bit is "one". Then ramp up to 2g (19.62m/s2). Repeat steps until all sensors perform Motion Indicator activation. Log and record results.

Test Requirements/Acceptance Criteria

The activation point of the motion indicator shall be within the range of the motion indicator activation centrifugal force as described in Table 2. The Low Battery reserved bit (Section 3.1.5.1) shall be "zero" except if this test was performed at –40ºC and was not part of the initial performance test.

4.3.3 85/85 High Temperature – High Humidity Endurance

This procedure aims to demonstrate the component electronics are free from high temperature, high-humidity dependent failures during the intended useful life in extreme (but possible) vehicle conditions. To improve the ability of this test and accurately simulate the sensor in its vehicle level environment, we've added these updates to the procedure.

Test Procedure

A rotating fixture is to be housed within a temperature and humidity chamber to spin the parts at speeds that will guarantee the transition from Stationary to Rolling. Logging equipment is required to monitor the operation and functionality of each device under test for the entire duration of the 1000 hour test, collecting the details of each transition – beginning in stationary then to SLD mode, then to rolling (factory or non-factory), then to interim (factory or non-factory) to stationary (factory or non-factory) and then starting the cycle again. In each 24 hour period, the sensors will remain stationary for 23 hours, and rotate for one hour above the rolling threshold. Every 10 days the parts will be activated with an LF command, switching between Factory Mode and Normal Mode. At the end of the 1000 hour cycle, the parts will be run through a standard tri-temp test. The ambient testing should be completed within 15 minutes of the parts being removed from the test chamber.

Complete Test Flow (1000 hours)

24	48	72	96	120	144	168	192	216	240	264	288	312	336	360	384	408	432	456	480
Factory Mode										Normal Mode									
504	528	552	576	600	624	648	672	696	720	744	768	792	816	840	864	888	912	936	960
Factory Mode										Normal Mode									

984	1000
Factory Mode	

Variations to these test procedures can be proposed, and will require approval from the GCE team for approval.

4.4 BATTERY (DV) TEST

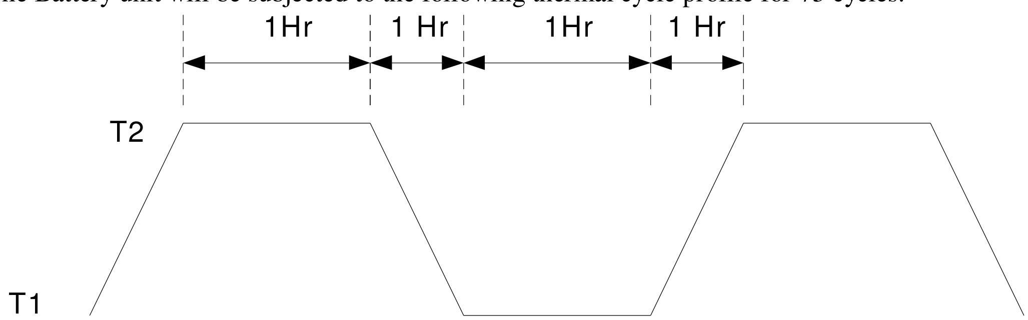
In order to determine capability of the Li Ion battery operating over the temperature range (T1 & T2 as specified in Table 16) and operating conditions of the TPS, the following battery testing shall be performed.

Test Groups

- 10 Batteries, which has a Depth of Discharge (DOD) that represent the total duration of the life requirements as described in Section 1.4.1. This DOD shall be calculated per the battery model and mission profile submitted and provided by the supplier and must be agreed on by GCE.
- 10 Batteries With 25% Depth of Discharge (DOD) shall be used.
- 10 Fresh Batteries shall be used.

Thermal Cycle Impact Test Procedure

- The Battery unit will be subjected to the following thermal cycle profile for 75 cycles:



- Battery shall be pulsed every 60 seconds
- Pulse Load shall be 10 mA for 35 msec
- Quiescent current shall be 2.5 uA
- Closed Circuit Voltage measurements shall be taken every 30 minutes.
- After the completion of the 75 cycles, each battery shall be installed in a sensor (Fresh DV sensor.) Each sensor shall be triggered by LF to force a transmission.

Test Requirements/Acceptance Criteria

- A transmission shall be received from each sensor and the subsequent transmission shall be logged.
- If any sensor did not transmit after the first LF trigger, it considered failed.

4.5 Pressure Sensing Element Ice and Water Freezing Test

The following tests shall be conducted to in order to verify the pressure sensing element robustness to ice formation. **Note:** Each test shall use 10 fresh parts.

Waters to be used in tests
First Test Phase 1: Tap Water (75 to 80 degree C)

Second Test Phase 1: Water with 2% Soap Concentration (75 to 80 degree C).

Third Test Phase 1: Water with 6% Soap Concentration (75 to 80 degree C).

Test Procedure

1. Place the Sensor in a pressure vessel.
2. Submerge as indicated in the table above.
3. Pressure to 35 psi gage.
4. Remove the water without removing the pressure from the chamber.
5. Move the sensor carefully into a cold chamber without vibration such that water inside the pressure hole is not removed or disturbed.
6. Make sure the pressure hole and the pressure sensing element is facing upward at all times and parallel to the surface inside the cold chamber.
7. Decrease the temperature inside the cold chamber to -40 degree C.
8. Keep the sensor in the -40 degree C environment for a minimum of 1.0 hour.
9. Spin sensor at 18G.
10. Trigger the sensor with LF and record data every 5 minutes.
11. Remove the sensor from chamber into a room temperature environment and trigger sensors with LF command immediately and every 15 minutes until it reaches room temperature.
12. Check that the pressure sensing element is functional and check for any mechanical or electrical damage.
13. Repeat for all 30 samples.

Test Requirements/Acceptance Criteria
The sensor shall pass all performance tests specified in section 4.2. The pressure sensing element shall function correctly and has no mechanical or electrical damages or errors. If any part fails any of the performance tests or at any LF trigger, stops transmitting, and after reviewing of all data collected in the test procedure, EESE D&R engineer shall review results to pass or fail the part.

4.6 IN-PROCESS (IP) TEST (100% OF ALL PRODUCED PARTS, NOT AN AUDIT TEST)

The following in process tests shall be performed on all produced parts (100% of all parts at the end of line) to ensure compliance with the key parameters as identified on the customer specification.

All performance test results shall be stored on the manufacturing information system against the ID for the part being tested. The exterior barcode labels on each part shall be scanned prior to the tests taking place and this data compared to the ID received as part of the transmitted signal. Mismatch in the two codes represents a test Failure.

4.6.1 Transponder sensitivity

Test Procedure
This test shall be performed at the Final test unit. Each part shall be activated by means of a Low Frequency (125 KHz) Transponder tool that has been calibrated to produce the minimum field defined in Table 1. The subsequent transmission shall be logged, the presence of which indicates that the transponder circuitry is within specification.

Test Requirements/Acceptance Criteria
A transmission with the ‘Tool-LF’ function code must be received and the subsequent transmission shall be logged, the presence of which indicates that the transponder circuitry is within specification. The Low Battery reserved bit (Section 3.1.5.1) shall be "zero".

Note: Supplier with only Ford approval can propose a substitute test to verify the integrity, robustness and functionality of the Transponder Sensitivity. If such a test is proposed, it shall be agreed on and approved by Ford Engineering in order to be a valid test.

4.6.2 RF Power, Frequency and Function Code

Test Procedure
This test shall be performed at the Final test unit. Each part shall be activated to produce an RF transmission. The RF signal field strength, nominal frequency, and frequency deviation shall be measured using a spectrum analyzer and recorded. The demodulated output from the analyzer shall also be decoded and checked for the status of the ‘Rotating/Stationary Mode’ reserved bit, "one" or "zero".

Test Requirements/Acceptance Criteria
All recorded values must meet the requirements defined in Table 1. The Low Battery reserved bit (Section 3.1.5.1) shall be "zero".

4.6.3 RF Bit Width

Test Procedure
This test shall be performed at the Final test unit. Each part shall be activated to produce an RF transmission. A spectrum analyzer shall be configured to produce a demodulated output, which shall be decoded, and the protocol bit widths measured and recorded.

Test Requirements/Acceptance Criteria
All recorded values must meet the limits defined in Table 1. The Low Battery reserved bit (Section 3.1.5.1) shall be "zero".

4.6.4 Spin Test

Test Procedure
This test shall be performed at the Final test unit. Each part shall be placed into the spin cell and the speed of rotation increased to a level, which represents a maximum centrifugal force defined in Table 2. This speed shall be maintained for a maximum of 20 seconds, during which time a spectrum analyzer shall be configured to produce a demodulated output for any transmission received. The data output from the analyzer shall be decoded and checked for the status of the ‘Rotating/Stationary Mode’ reserved bit, "one' or "zero".

Note: Supplier with only Ford approval can propose a substitute test to verify the integrity, robustness and functionality of the Motion Indicator. If such a test is proposed, it shall be agreed on and approved by Ford Engineering in order to be a valid test.

Test Requirements/Acceptance Criteria
A transmission with the ‘Rotating/Stationary Mode’ reserved bit is "one" must be received during 14-seconds logging period– this indicates that the motion indicator has detected the sensor is rolling. The Low Battery reserved bit (Section 3.1.5.1) shall be "zero".

Note: If Ford Engineering approved an alternative test, the acceptance criteria shall also be agreed on and approved by Ford Engineering.

4.6.5 Pressure and Temperature Tolerance

Test Procedure 'A'
During the IP RF test (Section 4.6.2) the pressure of the sealed chamber shall be set to 35 psig and the subsequent transmission received shall be decoded and the pressure and temperature data recorded. Then the pressure of the sealed chamber shall be set to 80 psig and the subsequent transmission received shall be decoded and the pressure and temperature data recorded.

Test Procedure 'B'
During the IP Spin test (Section 4.6.4) the pressure of the sealed spin cell shall be set to 50 psig and the subsequent transmission received shall be decoded and the pressure and temperature data recorded. Then the pressure of the sealed spin cell shall be set to 100 psig and the subsequent transmission received shall be decoded and the pressure and temperature data recorded.

Note: If an alternative test was approved for the IP spin test (Section 4.5.4), Supplier shall propose another test to verify the pressure and temperature tolerance during the rotating mode. If such a test is proposed, it shall be agreed on and approved by Ford Engineering in order to be a valid test.

Test Requirements/Acceptance Criteria
All recorded values must meet the requirements defined in Tables 3, 4, and 5.
All transmission shall have the 'Rotating/Stationary Mode' reserved bit as "one" and the Low Battery reserved bit (Section 3.1.5.1) shall be "zero" for both test procedures 'A' &'B'.

4.6.6 Battery Voltage Test

Test Procedure

Prior the installation of the battery into the sensor/transmitter, a 100% in-process battery voltage test must be performed

Test Requirements/Acceptance Criteria

The battery's voltage must be above the minimum voltage level, as described in Section 3.1.5.1.1, in order to pass this test.

4.7 Revalidation Requirements

The manufacturing supplier, STA, and GCE will jointly determine which potential changes to the design process, materials, or material sources would have significant impact on the product's function, performance, durability or appearance. The supplier will describe these conditions in the Control Plan, along with either

1) The revalidation plan that would be followed in each case, or
2) A provision to submit an amended Control Plan for approval if any of those process changes are planned.

The Control Plan must include a provision that, for any significant change in processing, GCE EESE, STA, and the manufacturing location (internal or supplier) shall jointly determine if PV re-testing is required, and if so, to what degree.

No change to processing may be allowed without prior engineering approval of the process changes and the attendant Control Plan changes.

4.8 Functional Requirements Test

This test is to be performed to verify and validate that the sensor/transmitter satisfy all the functional requirements of the TPM sensor/transmitter listed in Section 0 and the functional requirements as shown in Figures 4, 5, 6 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, and 29.

Test Procedure

The sensor/transmitter supplier shall supply the test procedure and the procedure must be approved by GCE.

Test Requirement Acceptance Criteria

The sensor/transmitter shall satisfy all the functional requirements of the TPM sensor/transmitter listed in Section 0 and the functional requirements as shown in Figures 4, 5, 6 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, and 29 to be considered as pass. IF the sensor does not satisfy any of the functional requirements, the failures must be recorded and the sensor is considered failed. The Low Battery reserved bit (Section 3.1.5.1) shall be "zero".

4.9 Transmitter Output Power With Antenna Pattern

This test shall be conducted only during the Initial and Final Performance Tests only. The samples used to run this test shall be the samples with the worst-case output power samples (Lowest measure output power in free air, Section 4.2.1).

Number of Samples To Be Tested:

2 samples of Group "A"

Instructions On Samples:

After measuring the output power of all sensors in the initial performance test, pick 2 samples sensors/transmitters with the worst-case and lowest measured output power as measured in Section 4.2.1. After the test, the samples serial number and sensor/transmitter Ids shall be recorded and the samples shall continue through group "A" testing in Figure 1 as part of the samples specified for that specific group.

After the Final performance test in conducted, re-run this test on the same samples that were previously went through this test after the Initial performance test (Samples with the same serial number and sensor/transmitter Ids recorded in the previous transmitter output power with antenna pattern test.)

Test Equipment

- Rim: Steel Size: 16 x 6.5
- Tire: 205/50ZR16 87. Size: 16
- Chamber
- Rotary Table
  - Capable of full 360 degree rotation
  - Rotational Surface is 1 meter off the ground.
- Vertical and Horizontal Polarized Antennas
  - A vertically polarized antenna is defined as sensitive to an electric field that is polarized perpendicular to the surface of the rotary table.
  - A horizontally polarized antenna is sensitive to an electric field that is parallel to the surface of the rotary table.
- Power Measurement Device

Notes:

1. This test requires the data to be reported in dBuV/m @ 3 meter. If the power is measured in watts it is required to convert the data appropriately. This is the responsibility of the supplier. Ford reserves the right to inspect the method used to convert the data.

2. This test procedure provides a measurement capability that does not necessarily represent a standard antenna pattern or EIRP measurement. However, it has been found that this measurement scheme is 'predictive' to the in-vehicle capability of the sensor.

Test Procedure

The sensor/transmitter supplier shall conduct the test as outlined below. If alternative test procedure is desired, the supplier shall supply the test procedure to Ford and the procedure must be approved by GCE.

1. Verify that all standard chamber calibration methods have been executed within the normal schedule.

2. Install sensor on rim/tire combination, henceforth called the 'Device under Test' or DUT for short, using either the production or the service methods.

3. Orient the DUT to the zero angle location as defined figures 30, 31, and 32.
   DUT shall be measured in all three orientations (i.e. flat, side, end) as defined in figures 30, 31, and 32.

4. Place the rim/tire/sensor on the one meter high rotary table three meters from the receive antenna.

5. Activate the sensor to force a RF transmission. (It is allowable to use the RFCW capability for those sensors so equipped.)

6. Measure the power received and record along with the angle of the DUT relative to step 3.

7. Rotate the DUT clockwise no more than 1 degree.

   Note: If the test setup allows the table to be rotating while measurements are occurring, then the rotational speed of the table must be less than 1 degree / measurement time of the power measurement device. If a spectrum analyzer is used that requires 50ms to make a measurement, then the rotational speed must less than 1 degree in 50 ms.)

8. Repeat steps 5-7 for one complete 360 degree revolution of the table.

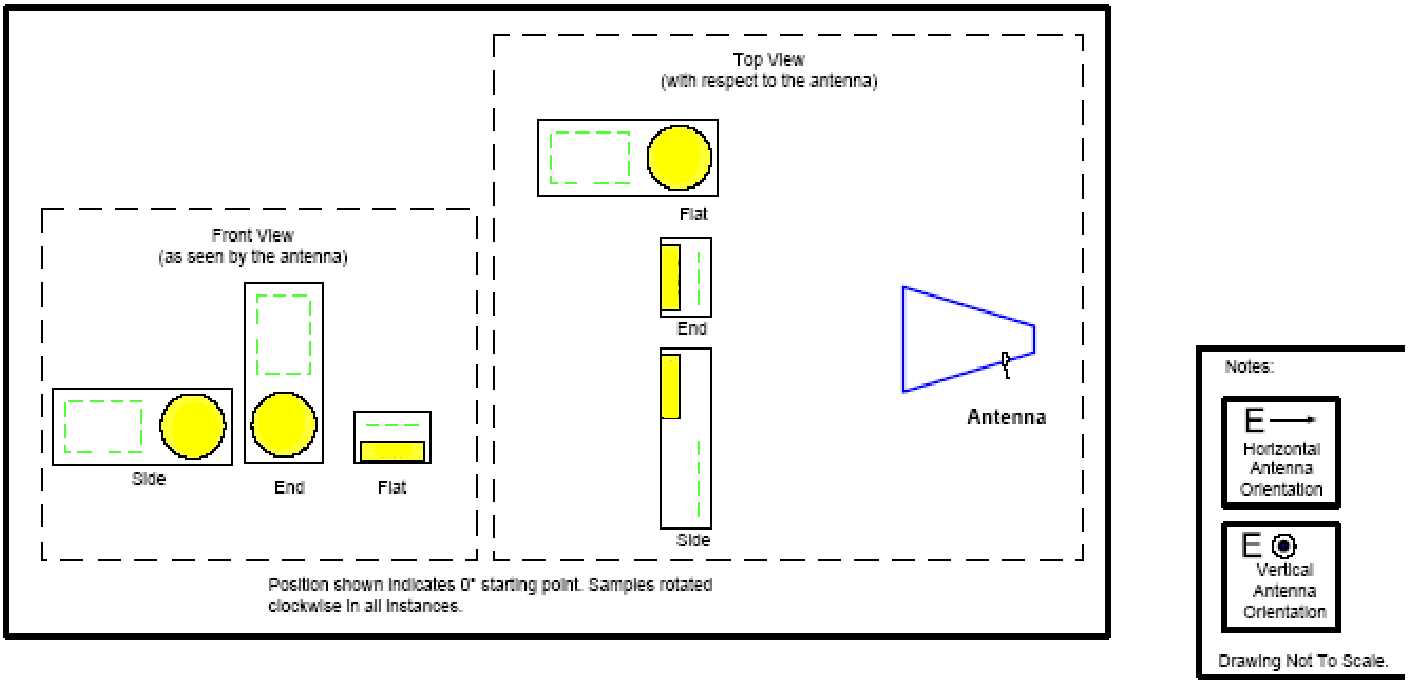


Figure 30. TPM Sensor/Transmitter Radiation Pattern Measurement Setup

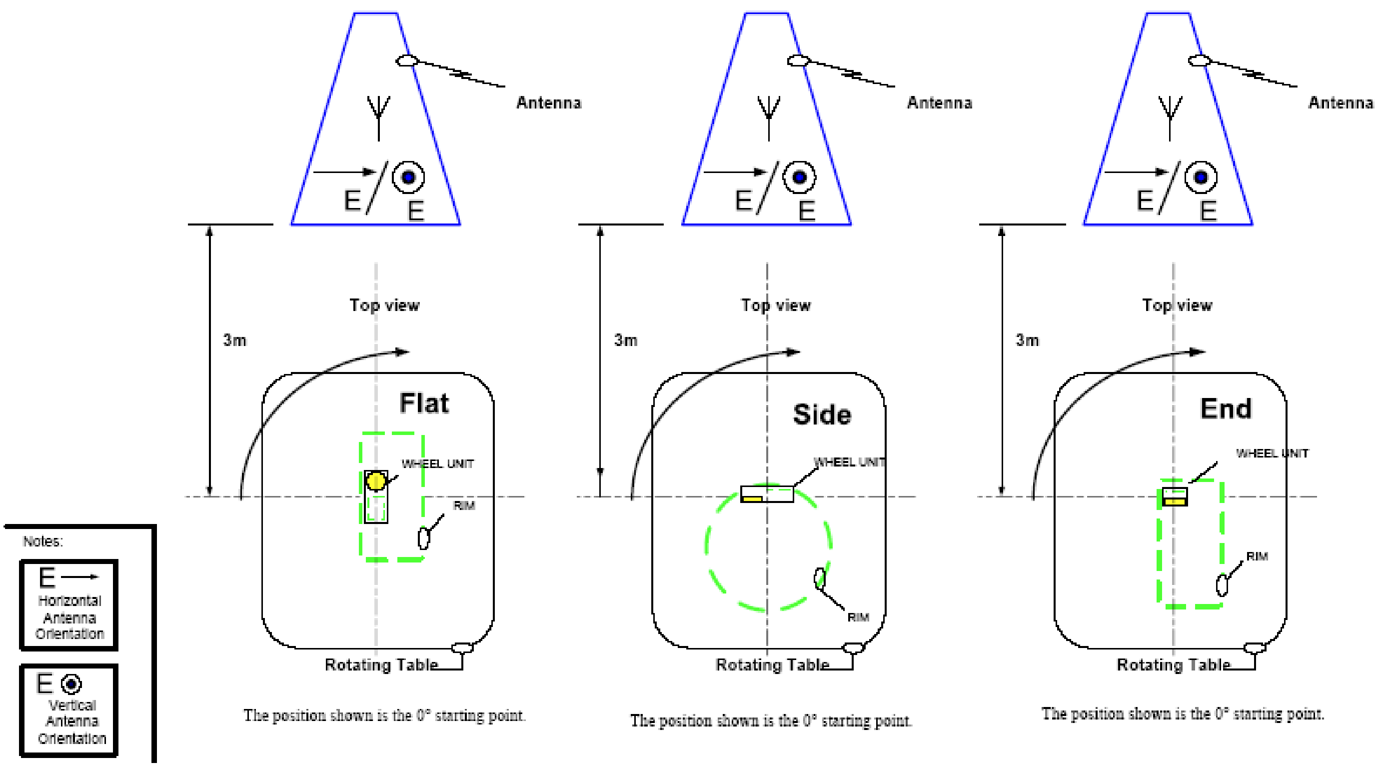


Figure 31. Sensor/Transmitter And Rim Orientation For Radiation Pattern Measurements, Top View. Drawing is not to scale.

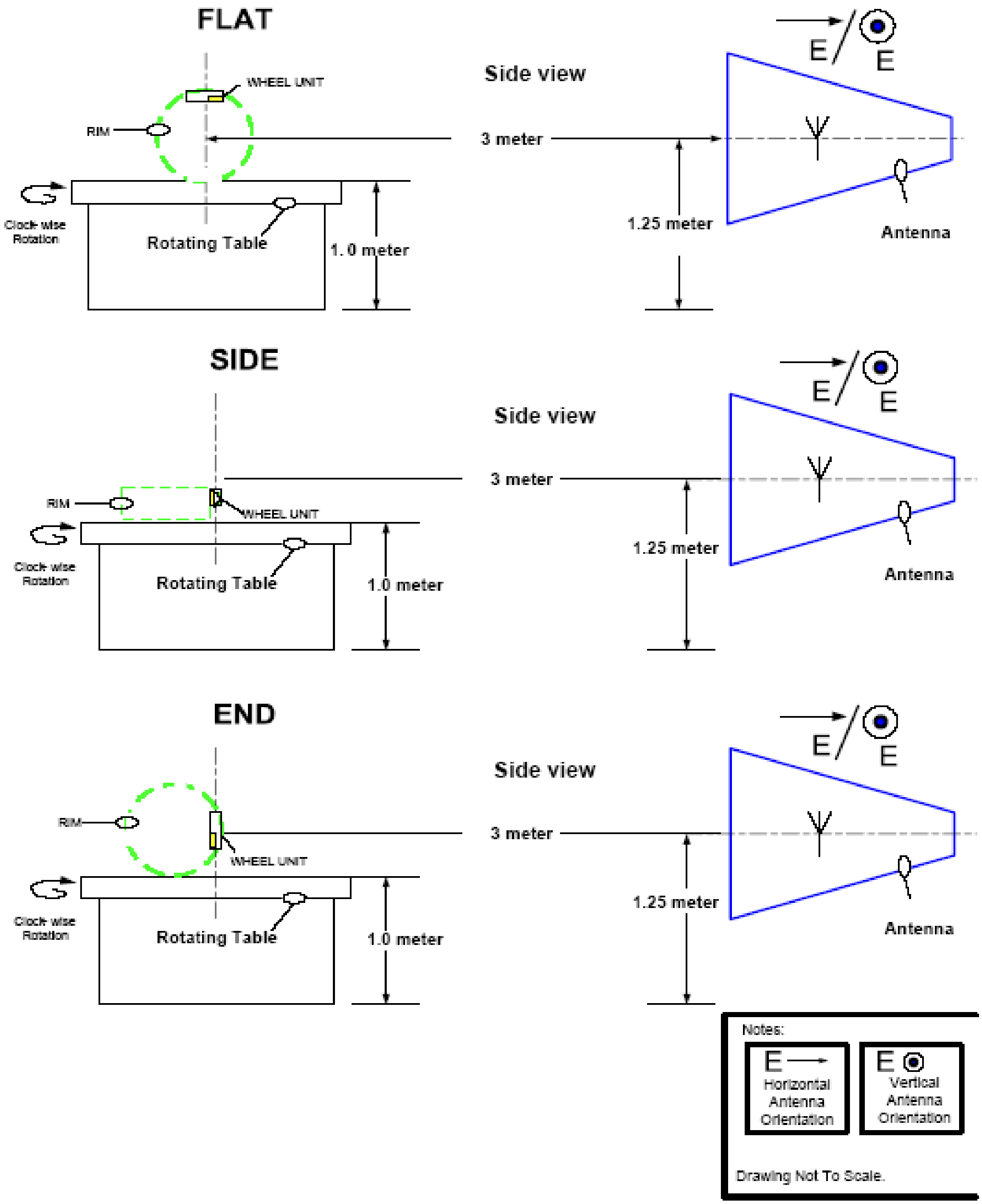


Figure 32. Sensor/Transmitter And Rim Orientation For Radiation Pattern Measurements, Side View.

Test Requirement Acceptance Criteria
Both of the following criteria must pass for the sensor to pass

1. 80% of the angles must be above 65 dBuV/m (Peak power measurements) for every test configuration.
2. 50% of the angles must be above 72dBuV/m (Peak power measurements) for at least 4 of the 6 test configurations.

5 Instruction and Notes

5.1 Control Plans

Control Plans address all significant design and process characteristics, which include all ES tests and Control Plan Item characteristics. They describe the process potential studies that will be performed for production validation (including PV tests) and the ongoing product and process evaluation for continuing improvement (including IP tests). They include acceptance criteria, sample sizes, frequencies, data analysis methods and reaction plans. It is desirable that the Control Plan also includes or refers to a maintenance plan for the equipment used in the manufacturing process.

The Control Plan is developed, and updated as necessary, by the manufacturing supplier in conjunction with STA and GCE EESE. The Control Plan defines the management of the upstream production process and part variables (significant process characteristics) that affect the outcome of the ES tests or other significant design characteristics. The Control Plan also identifies the specific ES tests, with their sample sizes and frequencies that will be performed in order to:

- Confirm whether the process is being managed effectively.
- Further identify significant process characteristics
- Evaluate performance of marginal processes.
- Better anticipate the customer effect of proposed process improvements

For any part on which the ES tests have been specified, the manufacturing source must present the control Plan and any revisions to STA for approval.
Suppliers are required to adopt the framework outlined in Ford ISO/TS-16949 or IATF 16949 and in Planning for Quality in order to achieve the type of process controls necessary for continuous improvement. Additionally, Continuing Process Control and Process Capability Improvement will provide further information on control charting.

5.2 Lot Definition

Refer to the Control Plan.

5.3 Record Retention

Supplier shall maintain all pertinent books and records relating to a Purchase Order for a period of two years minimum after completion of services or delivery of supplies pursuant to that Purchase Order (Referencing the latest version of the Production Purchasing Global Terms & Conditions).

The IP test variable data produced as a result of performing the sample lot test requirements outlined in Section II must be collected and stored for STA review. The records must be stored such that all parametric data for any one-sample piece may be recalled, with traceability to the lot in which the sample was taken.
A periodically prepared Pareto Chart will be supplied to Ford, indicating frequency of component failures.

5.4 Packaging and Handling

All components shall be packed in a manner such that both physical and electrical damage will be prevented during shipment. The pressure hole on the TPM transmitters must be free from any foreign objects. The shelf life of the sensor must be at least 10 years. If the components are shipped to any Ford assembly plant, MP&L and VO personnel must approve this package. If the components are shipped PIA to the wheel suppliers, the wheel supplier personal must approve this package.

The sensor design shall include a feature that allows the sensor to be de-energized & re-energized as described in Section 3.3.13. All production & service sensors/transmitter shall be in the OFF Mode (As described in Section 3.3.15) when leaving the sensor supplier plant & during shipping. Shipments shall not damage, re-energize or de-energize the sensor. The sensor shall remain in the OFF Mode until intentionally re-energized by any of the methods described in Section 3.3.13.2.

The use of halogenated hydrocarbon solvents, silicone greases, silicone mold release compounds, and mercury may not be used in any form of the process per WSS-M99P9999-A1.

All printed circuit boards must be de-fluxed after the final solder operation unless a no-clean flux is used. All boards must be protected from water, salt water, dirt, grease, solvents and any other liquid or solid.

5.5 Component Identification Requirements

All TPM transmitters must be permanently and legibly marked, in a convenient location (as space permits), with the following minimum information:

- The Ford Logo oval
- FCC ID #
- CAN ID #
- The Ford part number in full
- Recyclability symbol
- Indelible Record related to date of assembly (electronic ID)
- 5 Digit Manufacturing Code

6 Compilation of Reference Documents

Ford Quality System Requirements, ISO/TS-16949 or IATF 16949.
WDS 00.00EA-D11
RQT-001101-002492 or equivalent
FMC Electromagnetic Compatibility Specification
The FMEA Handbook
Ford Production Parts Packaging & Shipping Guide
Production Purchasing Global Terms & Conditions, latest version
Dates shown in this section are to be superseded by the most recently released edition.

7. Appendix

The definitions for Extended Diagnostic Data are shown below in Tables 19 and 20.

This data can be retrieved by using the LF command defined in Section 3.2.24 The message format is defined as:

Pre-amble	ID	Data Mux/ Function	Frame Counter	Word 1	Word 2	Word 3	Word 4	Word 5
16 bits	32 bits	8 bits	8 bits	16 bits	16 bits	16 bits	16 bits	16 bits

Continued:

Word 6	Word 7	Word 8	Word 9	Word 10	Word 11	Check-sum (MSW)	Check-sum (LSW)	Termination bits
16 bits	16 bits	16 bits	16 bits	16 bits	16 bits	8 bits	8 bits	3 bits

Checksum calculated as below:

16 Bit CRC (C3; CRC-16F/5) **x^16 +x^14 +x^12 +x^11 +x^8 +x^5 +x^4 +x^2 +1**	**16-bit CRC; Poly 0xAC9A (0x15935) = 10101100100110101** **Preload = 0x0000** **Provides HD=5 up to 241 bit payload.** **Payload = 224 bits (WUID1-4 + Data_mux + Spare + Data Bytes 1-22)**

The values are to be initialized to zero from the manufacturer. For those diagnostic elements that count the number of events that have occurred, once a maximum has been reached the value stored can remain at that value – See tables 19 and 20.

Table 19 – Extended Diagnostic Data (Implementation #1)

Byte	Data Bytes	Function	Description
9-10	Data bytes 1-2	Diagnostic 1	Provide snapshot of battery status over a period of time
11-12	Data bytes 3-4	Diagnostic 2	Log of software determined crystal start-up failure
13-14	Data bytes 5-6	Diagnostic 3	Transmission fail indicator
15-16	Data bytes 7-8	Diagnostic 4	The number of Power on reset conditions detected (hardware fault indicator)
17-18	Data bytes 9-10	Diagnostic 5	The number of Watchdog reset conditions detected (software fault indicator)
19-20	Data bytes 11-12	Diagnostic 6	High Byte Maximum measured temperature
			Low Byte Minimum measured temperature
21-22	Data bytes 13-14	Diagnostic 7	A count of Skipped transmission packets
23-24	Data bytes 15-16	Diagnostic 8	A count of Skipped transmission frames
25-26	Data bytes 17-18	Diagnostic 9	A count of the number of continuous 24hr roll mode events
27-28	Data bytes 19-20	Diagnostic 10	A count of the number of SLD mode No-Sync events
29-30	Data bytes 21-22	Diagnostic 11	Count the number of journeys made (expiration of interim/ service to stationary mode)

Table 20 – Extended Diagnostic Data (Implementation #2)

Byte	Data Bytes	Function	Description
9-10	Data byte 1	Diagnostic 1	Bits 0-6 count the number of low battery flags in the RF frame (transitions from 0 to 1) Bit 7 indicates the extended data is corrupt Counter stops counting at 0xF
	Data byte 2	Reserved	Set to 0x00
11-12	Data byte 3	Diagnostic 2	Log of software determined XTAL crystal start-up failures ADC (HB) Crystal (LB) Once 3 are detected the part transitions to Safe mode Counter stops counting at 0xFF
	Data byte 4	Reserved	Set to 0x00
13-14	Data byte 5	Diagnostic 3	Count of the number failed RF transmission frames Counter stops counting at 0xFF
	Data byte 6	Reserved	Set to 0x00
15-16	Data bytes 7-8	Diagnostic 4	Count of the number of HW generated resets Data byte 7 low nibble: Flash error reset (ECC) Data byte 7 high nibble: Thermal shutdown resets Data byte 8 low nibble: POR resets Data byte 8 high nibble: Memory errors resets (NVRAM/stack) If the extended diagnostics is corrupted bit 7 from Diagnostic 1 will be set to indicate data corruption Counter stops counting at 0xF
17-18	Data byte 9	Diagnostic 5	Count of the number of SW generated resets Data byte 8 high nibble: WDG resets Data byte 9 low nibble: SW Scheduler error resets Data byte 9 high nibble: Memory errors resets (NVRAM/stack) Counters stop at 0xF
	Data byte 10	Reserved	Set to 0x00
19-20	Data bytes 11-12	Diagnostic 6	High Byte Maximum measured temperature
			Low Byte Minimum measured temperature
21-22	Data bytes 13-14	Diagnostic 7	Data byte 13: Number of pressure sensor errors (underflow, overflow, error, bondwire)
			Data byte 14: Number of acceleration sensor errors (underflow, overflow, error, bondwire)
23-24	Data bytes 15-16	Diagnostic 8	N/A (refer to Diagnostic 3) set to 0x00
25-26	Data byte 17	Diagnostic 9	Count of the number of times the sensor has been in continuous motion detection for 24 hours. The counter stops at 0xFF
	Data byte 18	Reserved	Set to 0x00
27-28	Data bytes 19-20	Diagnostic 10	The count of SLD mode No-Sync events The counter stops at 0xFFFF
29-30	Data bytes 21-22	Diagnostic 11	A count of the number of journeys made Expiration of Interim/service mode to stationary mode The counter stops at 0xFFFF

Table 21 – Definitions

<table>
<tr><th>Terms</th><th>Description</th><th colspan="2">Value for sensor</th></tr>
<tr><td>□psi(down)_threshold</td><td>Pressure change threshold</td><td colspan="2">2.0 psi</td></tr>
<tr><td>□psi(up)_threshold</td><td>Increase of pressure in an interim period threshold</td><td colspan="2">1.0 psi</td></tr>
<tr><td>□psi</td><td>Pressure increase in the rotating or stationary mode.</td><td colspan="2">True/False/confirm</td></tr>
<tr><td>ERPC_LM</td><td>Delta pressure detection based on the last measured pressure</td><td colspan="2">1 PSI for Stationary and Interim modes, 2 Psi for Rotating mode.</td></tr>
<tr><td>ERPC_LT</td><td>Delta pressure detection based on the last transmitted pressure</td><td colspan="2">2 PSI</td></tr>
<tr><td>□psi(up)</td><td>An increase of pressure in an interim period</td><td colspan="2">True/False/confirm</td></tr>
<tr><td>□psi(down/interim)</td><td>A decrease of pressure in an interim period</td><td colspan="2">True/False/confirm</td></tr>
<tr><td>□psi(down/normal)</td><td>A decrease of pressure in rotating or stationary mode</td><td colspan="2">True/False/confirm</td></tr>
<tr><td>Current_measured_pressure</td><td>The periodic measured pressure value</td><td colspan="2">(As measured) Psi</td></tr>
<tr><td>Last_Xmited_pressure</td><td>The last pressure value transmitted</td><td colspan="2">(As transmitted) Psi</td></tr>
<tr><td>Transition_to_motion</td><td>The detection of motion</td><td colspan="2">True/False</td></tr>
<tr><td>Xmit_timer</td><td>The periodic transmission timer</td><td colspan="2">Table 12</td></tr>
<tr><td>P_measure_timer</td><td>The periodic pressure measurement timer</td><td colspan="2">Table 12</td></tr>
<tr><td>PDC_confirm_timer</td><td>The pressure decrease confirmation (PDC) transmission timer</td><td colspan="2">2.0 Seconds</td></tr>
<tr><td rowspan="2">PIC_confirm_timer</td><td rowspan="2">The pressure increase confirmation (PIC) transmission timer</td><td>Rotating</td><td>Stationary/ Interim</td></tr>
<tr><td>N/A</td><td>30.0 Seconds</td></tr>
<tr><td>Interim_timer</td><td>The period in which the sensor is in the Interim Period.</td><td colspan="2">Section 3.3.6</td></tr>
<tr><td>Motion_measure_timer</td><td>The periodic motion measurement timer</td><td colspan="2">Table 12</td></tr>
<tr><td>LF_measure_timer</td><td>The periodic LF sampling timer</td><td colspan="2">Table 12</td></tr>
<tr><td>G_0_timer</td><td>The random gap delay before the beginning of a non-forced transmission</td><td colspan="2">Figure 14 & 15</td></tr>
<tr><td>$G_{(count)}$_timer</td><td>The timer for the gaps between each packet within a transmission. During rotating mode.</td><td colspan="2">Figure 14 & 15</td></tr>
<tr><td>FSK_$G_{(count)}$_timer</td><td>The timer for the gaps after each FSK packet within a transmission during the stationary & interim modes.</td><td colspan="2">100.0 msec. Minimum</td></tr>
<tr><td>ASK_$G_{(count)}$_timer</td><td>The timer for the gaps after each ASK packet within a transmission during the stationary & interim modes.</td><td colspan="2">50.0 msec Minimum</td></tr>
<tr><td>PDC_counter</td><td>The counter that counts the PDC repeated transmission after a decrease RPC event.</td><td colspan="2">Figure 5</td></tr>
</table>

Terms	Description	Value for sensor
PIC_counter	The counter that counts the PIC repeated transmission after an increase RPC event.	Figure 5
LF_polling_timer	The timer that that starts when the LF channel is open to measure the presence of LF field.	Figure 29
Factory_mode_count	The counter that counts the motion activation in factory mode.	Figure 5
$P_{(count)}$	The packet transmitted within one transmission. During rotating mode.	Figure 14 & 15
$FSK\_P_{(count)}$	The FSK packet transmitted within one transmission during stationary & interim modes.	Figure 15
$ASK\_P_{(count)}$	The ASK packet transmitted within one transmission during stationary & interim modes.	Figure 15
P_count	The counter that counts the packets within one transmission. During rotating mode.	Figure 14
FSK_P_count	The counter that counts the FSK packets within one transmission during stationary & interim modes.	Figure 15
ASK_P_count	The counter that counts the ASK packets within one transmission during stationary & interim modes.	Figure 15
P_0	The first packet transmitted within one transmission. Same as $P_{(count)}$ as count = 0. During rotating mode.	Figure 14
FSK_P_0	The first FSK packet transmitted within one transmission. Same as $P_{(count)}$ as count = 0. During stationary & interim modes.	Figure 15
ASK_P_0	The first ASK packet transmitted within one transmission. Same as $P_{(count)}$ as count = 0. During stationary & interim modes.	Figure 15
Initiate_LF	The detection of LF initiation protocol	True/False Figure 5
Factory_LF	The detection of the Factory LF protocol	True/False Figure 5
Tool_LF	The detection of the Tool LF protocol	True/False Figure 5
Exit_Factory_LF	The detection of the Exit-Factory-LF protocol.	True/False Figure 5 & Section 3.3.19
Software_LF	The detection of the Software-LF protocol	True/False Figure 5 & Section 3.3.18
De-Energize_LF	The detection of the De-Energize LF protocol	True/False Figure 5
RF_Test_Mode_LF	The detection of the RF-Test-Mode LF protocol	True/False Figure 5
RF_CW_LF	The detection of the RF-CW-Mode LF protocol	True/False Figure 5
RF_Test_Mode	A Mode the sensor enters after the detection of the RF-Test-Mode LF protocol.	Section 3.3.24
RF_CW_Mode	A Mode the sensor enters after the detection of the RF-CW-Mode LF protocol.	Section 3.3.25

Historical Usage of Supplier IDs:

Supplier ID Chart				
Invalid Data	0	0	0	0
Supplier # 1 – Continental banded variants	0	0	0	1
Supplier # 2 – Lear banded variants – high & low pressure	0	0	1	0
Supplier # 3 – Sensata Edison variants	0	0	1	1
Supplier # 4 – Sensata Faraday Non-Pal variants	0	1	0	0
Supplier # 5	0	1	0	1
Supplier # 6 – Sensata Faraday PAL variants	0	1	1	0
Supplier # 7	0	1	1	1
Supplier # 8	1	0	0	0
Supplier # 9	1	0	0	1
Supplier # 10	1	0	1	0
Supplier # 11	1	0	1	1
Supplier # 12	1	1	0	0
Supplier # 13	1	1	0	1
Supplier # 14	1	1	1	0
Invalid Data	1	1	1	1