METEORCOMM LLC

PP2 First Article Acceptance Test Plan and Results; Manufacturing Testing Approach

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PP2 First Article Acceptance Test Plan

Overview

- Three radio types:
  - Base station radio
  - Locomotive radio
  - Wayside radio
- PP2 Radios (Pre-production 2) – Final design iteration going into production.
- Manufactured by CalAmp.
- Meteorcomm (MCC) performed testing on sample units to verify the radios met specifications.
- Testing process – referred to as first article acceptance (FAI).

Test Conditions and Requirements

- Radio requirements and operating conditions are defined by:
  - ITC 220 MHz Radio Hardware Specifications, MCC DCN 00001040-E, August 29, 2011.
- The procedure for each test is defined by:
  - ITC 1.0 220 MHz Radio Hardware Performance Test Procedures, MCC DCN 00001434-A, August 29, 2011.
- Test plan document:
  - Field Radio 3 Joint Engineering Test Acceptance Plan, MCC DCN 00001530-A, September 16, 2011.
  - Same plan as applied to the F3 radios (predecessors to the PP2 radio design)

Test Process

- Testing is performed by the MCC product development test team.
- Results are recorded and stored on the MCC Engineering server.
- Defects and anomalies discovered during testing are tracked in Rally, a tool for managing product development and product testing activities.
- Approval process:
  - In-depth review of all test results, including representatives from product development, manufacturing, and product management.
  - Review of all open relevant defects.
  - Assess completeness of corrective actions.

Radio Overview

- Uses the 220 MHz band (217.6 – 222 MHz)
- Software defined radio (SDR)
  - Radio performance is defined by the hardware design, radio application software, and firmware.
- Half duplex operation:
  - Radios transmit and receive, but not at the same time.
  - Transmitter and receiver share frequencies.
- Two data rates available:
  - Full rate (32 kbps)
  - Half rate (16 kbps)

MCC Test Setups

- Automated test stations
- Separate test stations for TX and RX testing
  - Key test equipment:
    - Agilent N9030 PXA signal analyzer
    - Agilent E4438C vector signal generator
- Programmable power supplies
- Computer controlled environmental chamber

Test Summary

- Transmit (TX) and receive (RX) testing was performed on each radio type.
- Testing covered nominal conditions, temperature extremes, and voltage supply extremes.
- Transmitter testing included testing at maximum rated TX power as well as at lower TX levels.
- Some tests included testing at two different data rates.

Test Conditions

Radio firmware version: 1.0.29.02

Radio Type	Nominal Conditions	Temperature Extremes (°C)	DC Supply Voltage Extremes (VDC)	TX Power Levels (dBm)
24V Base	+25°C 24.0 VDC	-30 /+70	21 / 27	42.75 / 48.75
48V Base	+25°C 48.0 VDC	-30 /+70	27 / 54	
Locomotive	+25°C 74.0 VDC	-40 /+70	45 / 100	41 / 47
Wayside	+25°C 13.6 VDC	-40 /+70	10.9 / 15.5	38 / 44

RF Frequencies for Testing

- It is impractical to test all radio parameters at each possible operating frequency.
- Three frequency sets were tested:
  - Set 1 - Bottom, Middle, Top
    - Testing covers the upper end, lower end, and midpoint of the specified operating frequency range of the radios.
  - Set 2 – ITC frequencies (spectrum owned by PTC-220 LLC)
  - Set 3 – Four additional frequency points within the radio operating range

General Approach

- For the majority of the tests, perform each test on 5 units under nominal conditions.
- Perform tests at temperature extremes on 2-4 units as time permitted.
- Perform tests at supply voltage extremes on 2-4 units as time permitted.

Transmitter Tests

	# DUTs Normal Conditions	# TX Power Levels	# DUTs Temperature Extremes	# DUTs Voltage Extremes
Conducted Carrier Output Power	5	2	2	2
TX Error Vector Magnitude	5	2	2	2
Carrier Frequency Stability	5	2	2	2
Sideband Spectrum	5	2	2	2
Switching Spurious	5	2	2	2
Conducted Spurious Emissions	5	1	-	-
Adjacent Channel Power Ratio	5	2	2	2
Intermodulation Attenuation (Base Radio Only)	2	1	2	2
Transmitter Stability into VSWR	2	1	2	2
TX Power Versus Time (PVT)	3	1	1	1

Receiver Tests

	# DUTs Normal Conditions	# DUTs Temperature Extremes	# DUTs Voltage Extremes
Conducted Spurious Output Power	1	-	-
Maximum Usable Sensitivity	5	2	2
Error Behavior at High Input Levels	5	2	2
Co-channel Rejection (2 test regimens)	5	2	2
Adjacent Channel Selectivity (3 test regimens)	5	2	2
Blocking	5	2	2
Intermodulation Response Rejection	5	2	2
RX Spurious Response Rejection	1	-	-
RX Noise Floor Scan	2	1	1

Non-RF Tests

	# DUTs Normal Conditions	# DUTs Temperature Extremes	# DUTs Voltage Extremes
Power on Self Test (POST)	1	1	1
Ethernet Port Operation	5	2	2
CIM Functionality (SD memory card)	5	2	2
Power Cycle Reset Test	5	2	2

Example Test Coverage

Conducted Carrier Output Power - Measures the radio transmit power at the TX connector.

For each Radio Type:

- Number of units tested: 5
- Number of frequency points covered per unit: 7
- Number of power levels covered per unit: 2
- Temperature conditions: 3 (high, low, and nominal)
- Voltage conditions: 3 (high, low, and nominal)

PP2 First Article Test Results

Test Results Overview

- 437 separate tests covered all three radio types, tested across temperature, and voltage at nominal and extreme conditions.
  - 24V and 48V base stations were tested as separate radios.
- A total of 15 different issues or observations were noted.
- Most of the issues were marginal failures or failures at temperature or voltage extremes. For example:
  - DE1099 - FLT LED illuminated at +70 ºC
  - DE1553 - Rx Adjacent Channel Rejection degraded by 10dB at +70 ºC

Test Issues and Observations Outcomes

- Issues were resolved.
- Two manufacturing screens were added to the production line to catch specific failing behaviors:
  - RX Intermodulation distortion screen.
  - High noise TX/RX switch screen.
- After discussion with the RCT, the blocking specification was changed.

Test Issues and Observations Outcomes (continued)

- 3 issues were resolved with through firmware updates.
- 2 issues were identified as incorrect: the radios were operating as designed.
- 2 issues were seen on the same radio and found to be a bad component.
- The remaining issues were not reproducible or were marginal failures that were caught during radio level testing in production.

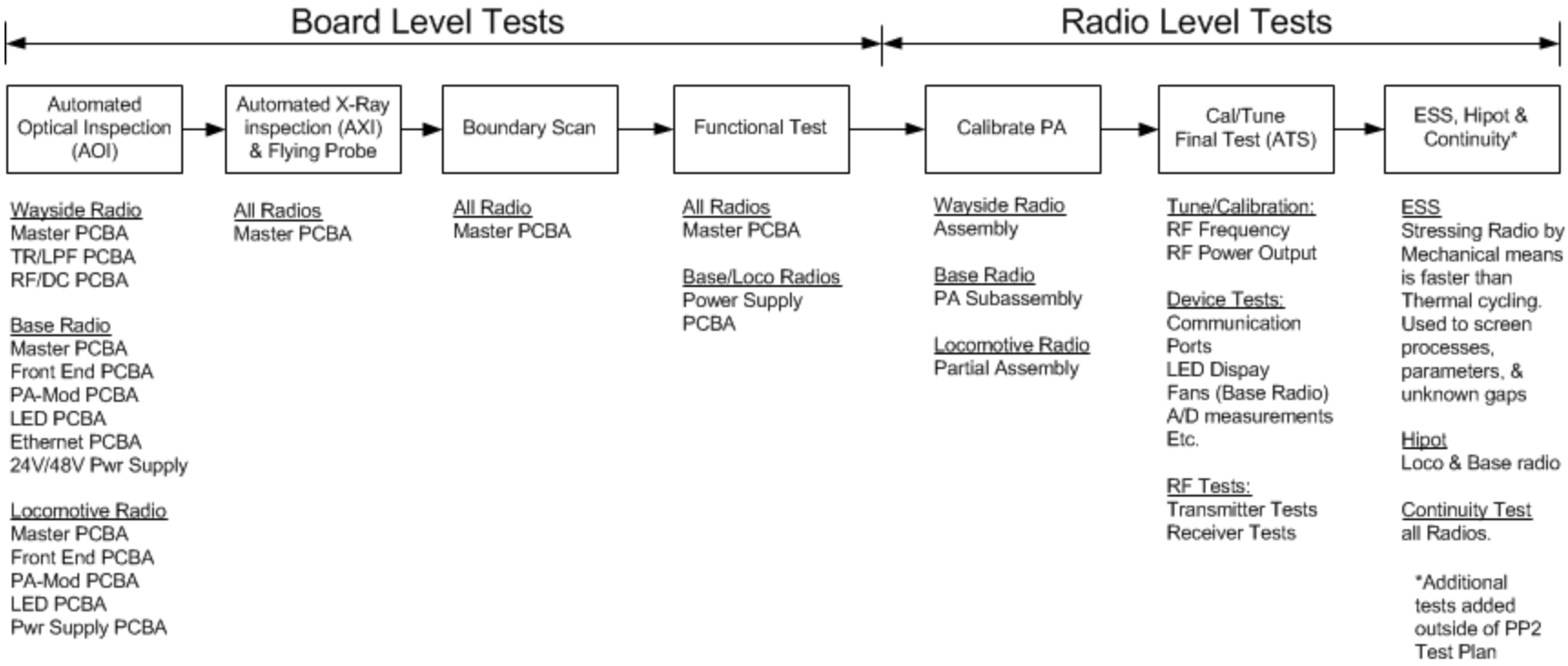
PP2 Radios Manufacturing Testing Approach

Manufacturing Testing Objectives

Have high confidence that the Base, Loco, and Wayside radios have been:

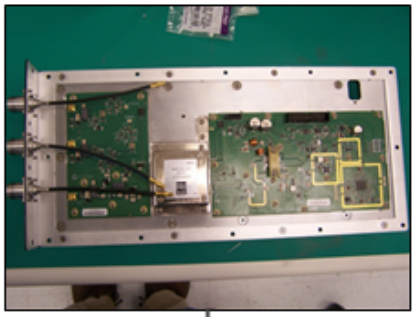
- Assembled correctly.
- Configured and calibrated properly.
- Meet product specifications.

Manufacturing Test Plan

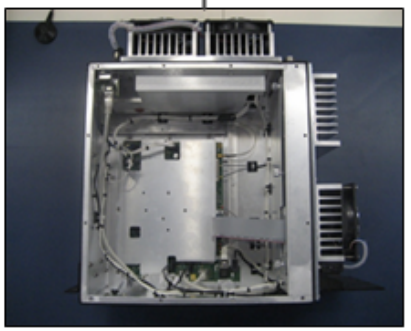


Manufacturing Process

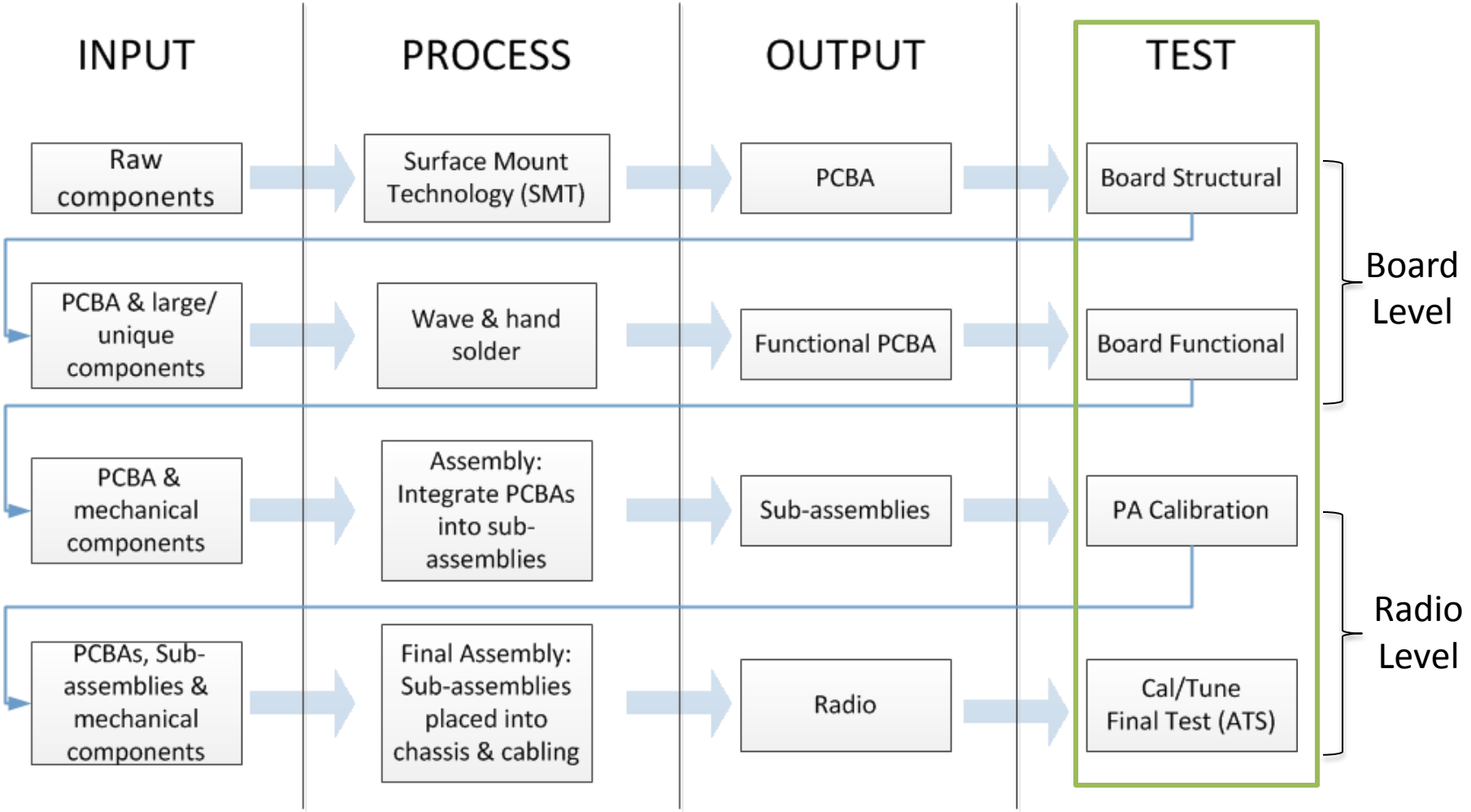
* Sample image for illustration only (Fuji SMT equipment)



Surface Mount Technology (SMT) → Wave & hand solder → Assembly: Integrate PCBAs into sub-assemblies → Final Assembly: Sub-assemblies placed into chassis & cabling → Pack-out to inventory & Out of Box Audit



Manufacturing Flow



Board Level Tests

Board Structural Tests

- Purpose: Validate physical structure of the PCBAs
- Test type: AOI, AXI, Flying Probe, Boundary Scan
- Types of failures: shorts, opens, tomb stoning, reversed parts, missing parts, etc.

Board Functional Tests

- Purpose: Validates functional operation of certain circuitry/components on the PCBAs
- Test type: Board Functionality
- Test Areas: transmit, receive, power, GPS, Ethernet, memory, etc.

Board Structural Tests

- Automated Optical Inspection (AOI)
  - High definition camera system that compares images of a newly assembled PCBA (Device Under Test, “DUT”) to the design drawing of the PCBA
- Automated X-Ray Inspection (AXI)
  - Use of X-Ray to inspect connections (e.g. ball grid array) underneath chips that cannot be detected by AOI
- Flying Probe
  - Automated physical probe that compares values of components on DUT to correct PCBA
- Boundary Scan
  - Standardized protocol JTAG (IEEE Std 1149.x) allows manufacturer to test interconnects and Integrated Circuit (IC) logic that physical methods are unable to test due to increasingly smaller components and use of ICs.

Board Functional Tests

- Setup: With multiple PCBA systems, some level of ‘hot mock-up’ is put together to simulate radio functionality
- Applied to: Master PCBA (most complex PCBA for all three radio types)
- Types of functionality
  - Boot-up
  - Power On Self Test (POST)
  - ColdFire (Flash, DDR, GPS, Ethernet)
  - FPGA
  - CPLD
  - Clock Generation
  - RF interfaces
  - Power Reset

Radio Level Tests

Purpose

After integration PCBAs and sub-assemblies into the chassis, the radio level test verifies:

- Proper assembly of the radio and cable interconnects
- Radio has been properly calibrated
- Radio is working and meets product specifications

Tests

- RF features at frequencies within 220MHz band
  - Transmit (e.g. power output, frequency accuracy, adjacent channel power ratio)
  - Receive (e.g. bit error rate, current drain)
  - GPS (Wayside & Base radios)
- Device features

Radio Level Test System

Automated Test System (ATS)

Radio Level Tests (Transmitter)

	Radio Type	WAYSIDE		LOCO		BASE	
Supply Voltage (VDC)		10.9, 13.6, 15.5		45.0, 74.0, 100.0		21.0, 24.0, 27.0	
Transmitter Test	Transmit Frequency (MHz)	Modulation	TX Power Level (PEP, dBm)	Modulation	TX Power Level (PEP, dBm)	Modulation	TX Power Level (PEP, dBm)
TX power Out	221.9875 219.8125 217.6125	Half Rate	44	Half Rate, Full Rate	47	Half Rate, Full Rate	48.75
Peak to Average Power Ratio (PAR)	219.8125	Half Rate	44	Half Rate	47	Half Rate	45
TX frequency accuracy	221.9875 219.8125 217.6125	Half Rate	44	Half Rate, Full Rate	47	Half Rate	48.75
Modulation Accuracy/Error Vector Magnitude (EVM)	221.9875 219.8125 217.6125	Half Rate	44	Half Rate, Full Rate	47	Half Rate, Full Rate	48.75
Transmitter Current Drain	221.9875 219.8125 217.6125	Half Rate	44	Half Rate, Full Rate	47	Half Rate, Full Rate	48.75
TX power out	219.8125	Half Rate	38.75	Half Rate, Full Rate	41.74	Half Rate, Full Rate	40.0
TX frequency accuracy	219.8125	Half Rate	38.75	Half Rate, Full Rate	41.74	Half Rate, Full Rate	40.0
TX power control range - EVM	219.8125	Half Rate	36.5	Half Rate, Full Rate	41.74	Half Rate, Full Rate	40.0
Adjacent Channel Power Ratio	221.9875, 219.8125, 217.6125	Half Rate	44	Full Rate	47	Full Rate	48.75
Sideband Spectrum	219.8125	Half Rate	44	Full Rate	47	Full Rate	48.75

Radio Level Tests (Receiver)

	Radio Type	WAYSIDE		LOCO		BASE	
RX Port		Primary		Primary, Diversity		Primary, Diversity, Altermate	
Receiver Test	Frequency (MHz)	Modulation	RX Input Level (dBm)	Modulation	RX Input Level (dBm)	Modulation	RX Input Level (dBm)
Rx RSSI Calibration	219.9125	Full Rate	-50	Full Rate	-50	Full Rate	-50
Static Ref Sensitivity	221.8875 219.9125 217.7125	Half Rate	-111	Half Rate	-111	Half Rate	-111
Static Ref Sensitivity	221.8875 219.9125 217.7125	Full Rate	-108	Full Rate	-108	Full Rate	-108
Error Behavior at high input levels	221.8875 219.9125 217.7125	Full Rate	-7	Full Rate	-7	Full Rate	-7
Simultaneous Channel Test	219.9125	Half Rate	-50	Half Rate	-50	Half Rate	-50
Receiving Current Drain	221.8875 219.9125 217.7125	Half Rate	-111	Half Rate	-111	Half Rate	-111
Receiving Current Drain	221.8875 219.9125 217.7125	Full Rate	-108	Full Rate	-108	Full Rate	-108
Receiving Current Drain at high input levels	221.8875 219.9125 217.7125	Full Rate	-7	Full Rate	-7	Full Rate	-7
GPS Sensitivity	N/A	N/A	-130	N/A	N/A	N/A	-130
GPS DC Loading	N/A	N/A	-130	N/A	N/A	N/A	-130

Radio Level Tests (Device)

Device Feature Tests	WAYSIDE	LOCO	BASE
Radio Boot	X	X	X
Ethernet Ports (Maint & LAN)	X	X	X
IP Config	X	X	X
POST	X	X	X
TX power setting	X	X	X
Read temperature sensors	X	X	X
Radio info and version	X	X	X
Check board and radio type	X	X	X
SD Card (read/write)	X	X	X
Fans	N/A	N/A	X
LED Dispay	X	X	X

Power On Self Test (POST)

Purpose

Upon boot-up, the radio will runs a diagnostic to verify radio will operate properly.

	Locomotive	Base	Wayside
HOST: DDR	X	X	X
HOST: SDCARD	X	X	X
HOST: BOOT FLASH (C: & D:)	X	X	X
HOST: DATA FLASH (E:)	X	X	X
HOST: CALIBRATION PARAMETERS	X	X	X
HOST: CHANNEL TABLE	X	X	X
HOST: DHCP CONTROL	X	X	X
HOST: FAN CONTROLLER : PASS	N/A	X	N/A
HOST: MAC (0 & 1)	X	X	X
HOST: GPS	N/A	X	X
HOST: PA Temp	X	X	X
HOST: Driver Temp	X	X	N/A
HOST: PA Current	X	X	N/A
HOST: Driver Current	X	X	N/A
DSP: CLOCK	X	X	X
DSP: SPI	X	X	X
DSP: EXTERNAL CLOCK	X	X	X
DSP: RX ADC	X	X	N/A
DSP: TX NULL ADC	X	X	N/A
DSP: DDS	X	X	X
FPGA: MEMORY	X	X	X

Thank You