MASTR V: A Software Defined Base Station for Public Safety*

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ABSTRACT

This paper presents MASTR V – a new SDR base station for Land Mobile Radio (LMR) Systems, designed and developed by Harris Corporation. This base station uses an IP-based communication framework (including an IP backplane) to enable a completely modular software and hardware architecture. The modular design affords the station flexibility in redesign and development and allows the station to be easily adapted to different operating scenarios. The base station also incorporates several SDR design methodologies including the use of Direct Digital Synthesis (DDS), a FPGA designed using Simulink-based tools, digital demodulation, digital transmit power control, digital automatic gain control (AGC), a novel polar PA linearizer, and digital calibration. This allows the station to be software-reconfigurable for multiple, potentially arbitrary, modulations within the MASTR V's bandwidth capabilities including P25 Phase I and II, OpenSky®, High Speed Data EDACS, Analog-FM, WCQPSK linear simulcast and QAM.

1. INTRODUCTION TO MASTR V

The Harris MASTR V is the latest base station in the continual evolution of MASTR public safety and utilities base station products dating back to the early 1960s. The MASTR V supports the Project 25 (P25) Phase 1 and Phase 2 public safety standards and is capable of supporting other Harris public safety operating modes including EDACS®, OpenSky®, ProVoice®, and analog-FM. In addition, the MASTR V's linear transmitter can accommodate WCQPSK linear simulcast mode and enables QAM high-speed data and TETRA capabilities. Using state of the art SDR technologies, the MASTR V can in fact handle nearly any modulation, even with channel bandwidths exceeding those normally available for use in the public safety LMR bands. Also, it is the first known base station for public safety to use an IP backplane, with its associated advantages of flexibility, scalability, reliability, and testability. Other novel features of the MASTR V are discussed through the paper and specifically delineated in Section 4.

Figure 1: Harris 4-channel MASTR V

Figure 1 is a MASTR V rack configuration (for the 800 MHz public safety band) that has four programmable channel-pairs, using a 14-slot modular multi-channel T/R

* This item has been reviewed in accordance with the international traffic in arms regulation, 22CFR 120-130, and export administration regulations, 15 CFR 730-774, and determined by the export control department to be rated EAR99. General prohibitions still apply.

shelf assembly and four 2-slot High Power Amplifier/Power Supply (HPA/PS) shelf assemblies. Each channel-pair has transmitter and receiver frequencies separated by 45 MHz and all can operate simultaneously, each with 100 watt power output.

Table 1: MASTR V Transmitter Specifications

Frequency Range	851 - 869 MHz
Modes of Modulation	C4FM (P25 Phase 1), WCQPSK (Linear Simulcast), HDQPSK (P25 Phase 2)*
RMS RF Output Power	10 - 100 Watts -0/+0.79 dB
Modulation Emission Spectrum	Meets 47 CFR 90.210 (d), (g), (h) and NTIA Manual part 5.3.5.2
Frequency Stability	< 0.15 ppm
RF Output Impedance	50 ohms
Radiated and Conducted Spurious Emissions	< -70 dBc

Table 2: MASTR V Receiver Specifications

Frequency Range	799 – 816 MHz
Modes of Modulation	C4FM (P25 Phase 1 and Linear Simulcast), and HCPM (P25 Phase 2)†
Static 5% BER Sensitivity	Better than -118 dBm
Adjacent Channel Rejection	≥ 60 dB for C4FM
RF Input Impedance	50 ohms
Frequency Stability	< 0.15 ppm
Signal Displacement Bandwidth	> ± 1.0 kHz
Spurious and Image Rejection	≥ 90 dB

The MASTR V has an IP-based communication framework (including an IP backplane for communications between modules in the same station) that facilitates modular software and hardware architectures and supports IP-based remote code uploads and configuration. The IP backbone also offers the benefit of redundancy, one of the key requirements for public safety users. A Built-In Self Test (BIST) feature provides improved performance through remote diagnosis which is IP-addressable to every module, minimizing down time.

† Other waveforms can be accomplished with software changes

The modular design of the station gives it flexibility in redesign and development and allows it to be easily adapted to different operating scenarios. For example, the station can be easily reprogrammed for multiple operating modes, and by changing just a few modules, tailored to work in most public safety frequency bands including VHF, UHF, and 700/800 MHz.

The MASTR V also incorporates several SDR technologies and design methodologies including Direct Digital Synthesis (DDS), FPGAs developed using the latest model-based design tools, IF sampling with digital I/Q demodulation, digital transmit power control, digital automatic gain control (AGC) to facilitate mode-dependant characteristics (e.g., TDMA vs. FDMA), and a novel polar PA linearizer with digital control and calibration. MASTR V stations can also be configured in expandable receive diversity topologies (e.g., using spatial or polarization diversity receive antennas) using software-controlled combining algorithms such as Maximal Ratio or other techniques.

Specifications for the transmitter and receiver functions of the 700/800 MHz band version of the MASTR V are given in Table 1 and Table 2.

2. HARDWARE ARCHITECTURE

Figure 2 is a high level block diagram of the MASTR V hardware architecture and operation flow. The MASTR V consists of seven different modules: the transmitter (TX) module, the receiver (RX) module, the Power-Amplifier/LINearizer (PA/LIN) combination module, the BaseBand (BB) module, the Traffic Controller (TC) module, the Switch module, and the Power Supply module. The TX, RX, BB, TC and switch modules are directly plugged into the IP backplane through an Ethernet interface. The PA/LIN module is connected via Ethernet cable to the IP Backplane. Communications on the IP backplane are made possible by either one or two Ethernet switches (two are used if redundancy is desired for enhanced reliability). All digital data and control between modules is communicated via IP packets. The individual software-controlled modules are described below:

2.1. BB Module

Each BB module has a vital role in the operation of the station, controlling the operation of two channel-pairs, i.e., two TX, two RX, and two PA/LIN modules. Operation control includes initializing operational parameters, managing/coordinating control messaging, monitoring the health/status, and synchronizing the transmissions/receptions of its channels across the system (a system consists of multiple stations and hence channels). Each BB module has two processors: a Texas Instruments TMS3206455 (BBDSP) and a Freescale PowerPC MPC8321 (BBPPC).

The BB module also performs the modulation and demodulation of two RF channels. For the receive chain, the digital In-phase (I) and Quadrature (Q) representation of the received signal is routed, as IP packets, from the RX module to the BBDSP. The BBDSP provides the required narrowband channel filtering to optimize receive sensitivity and adjacent channel rejection as well as demodulation of the signal to the form which enables symbol values to be subsequently extracted in the TC module. In the scenario where receiver diversity is employed, the BBDSP is responsible for the synchronized demodulation of different receive data streams from the different RX modules. The demodulated data is sent to the respective TC modules for further processing (explained in Section 2.5).

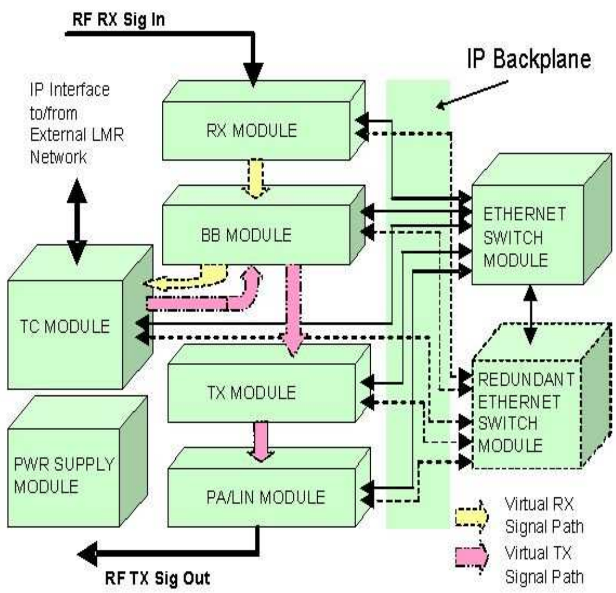

Figure 2: MASTR V Hardware Architecture

For the transmit chain, transmit data is routed, as IP packets, to the BB Module's BBDSP from the TC module. The BBDSP filters and modulates the data and sends the baseband modulated data samples to the TX modules, again as IP packets. The software implementation of narrowband filters in the BBDSP as well as the modularity and localization of the modulation/demodulation process offers flexibility and ease in reconfiguring the station for different current and future LMR waveforms.

2.2. RX Module

The primary function of the RX module is the conversion of the received RF signal on a particular programmed frequency to baseband I and Q digital data samples that are then sent to the BB module. The RX module down converts the receive RF signal to a first IF signal that is further down-converted and sampled, at IF, within a high speed Analog Devices AD9864 A/D converter. Digitized I and Q samples from the AD9864 are sent to the BB module as IP packets over the Ethernet interface on the backplane. A Texas Instruments TMS3206421 processor implements this module's functions in software.

2.3. TX Module

The primary function of the TX module is the conversion of digital modulated baseband I and Q data received from the BB module as packets over the IP backplane to a modulated transmit RF signal on a programmed frequency. The baseband I and Q input data samples pass through several sample rate interpolation stages implemented in a Altera Stratix II FPGA and then input to a Analog Devices AD9879 chip which contains additional interpolation, high speed D/A converter, and a Direct Digital Synthesis (DDS) modulator that creates a modulated signal at an Intermediate Frequency (IF). The IF signal is then up-converted to RF and sent to the PA/LIN module for amplification with linearization. A Texas Instruments TMS320C6421 processor implements this module's functions in software.

2.4. PA/LIN Module

The purpose/function of the PA/ LIN module is to amplify the exciter output of the TX module to the base station output power level (adjustable from 10 to about 100 watts), which includes linearization of the output signal for linear waveforms (such as P25 Phase 2, TETRA, and WCQPSK linear simulcast) with time-varying envelope power. The PA/LIN module assembly is comprised of an RF High Power Amplifier (HPA) together with a linearizer board, which removes waveform distortion from the amplified signal based on a polar feedback technique.

2.5. TC Module

The purposes of the TC module are as follows:
- Code/format the data message for the transmit path.
- Interpret/decode the formatting of the data message for the receive path.
- Control all aspects of trunking (subscriber unit validation, assigned channels, queuing, key/unkey, etc.).
- Provide Voice-over Internet Protocol (VoIP) interfacing to the LMR network.

These functions are performed in software using a PowerPC MPC8360 processor.

2.6. Switch Module

The switch module provides Ethernet connectivity and routes data on the backplane among all of the other modules. Each station could have up to two switches: a primary and a secondary switch. The two switches actively ensure redundancy of the Ethernet connections on the station.

3. SOFTWARE ARCHITECTURE

The software on the MASTR V has a modular framework that allows it to be tractable, easily reconfigurable, and amenable to rapid development. The software is comprised of different functional components called computer software components (CSCs). Each CSC is in turn comprised of several distinct software functions called Computer Software Configuration Items (CSCIs) with individual inputs, outputs and data flows. The software structure with the different CSC/ CSCI relationships is illustrated in Figure 3. The CSCs are described below. Some of the most important CSCIs are also described.

3.1. Ethernet Interface CSC

This CSC is the most critical CSC for the station. It is responsible for setting up and controlling the LAN on the IP-backplane of the station across which the modules on the station communicate with each other. Note that interaction between modules is confined to IP messages and almost all messages are anchored to the BB module. This allows the messaging on the station to be streamlined.

3.2. Management CSC

This CSC is responsible for coordinating and enabling the operation of all the modules across the IP backplane. It is also responsible for all functions that access and monitor the health or state of the channel. The following are some of its CSCIs:

a. Discovery/ Hardware initialization CSCI

This component handles the initial communication and initialization for the modules across the backplane. The communication across the backplane is initiated and orchestrated by the BB module. The BB module polls all the slots allocated with the channels it controls. The RF and TC modules identify themselves to the BB module in response to the poll messages. The BB then sends each of the RF and TC modules its associated personality. The personality comprises of various specifications of the channel in which the modules participate. For example, the personality message includes transmit-receive frequency of the channel or the sampling rate. The modules then initialize different hardware and software components (e.g. D/A Converters, synthesizers, and buffering schemes) according to the parameters in the personality message.

b. Heartbeat monitor CSCI

The heartbeat monitor is enabled after the discovery phase is complete. The BB module periodically pings the other modules it is in charge of by sending a heartbeat (HB) message. The modules respond with a HB message. The BB thus monitors the health of the Ethernet on the backplane with this task. This task enables the automatic discovery of the absence of any modules in the station. A module shall indicate an Ethernet fault if it has not seen a HB from the BB module within the programmed time frame.

c. User interface CSCI

The user interface consists of two LEDs on the RF modules, four LEDs on the BB module and two LEDS and one display on the TC module. The LEDs are programmed to indicate any hardware/software fault statuses on the modules as well as the status of the Ethernet across the backplane of the station.

3.3. Data CSC

This CSC is responsible for the data handling across the Ethernet backplane. The following are some of its CSCIs:

a. RX Application CSCI

This receiver application is responsible for acquiring modulated baseband I and Q data at the programmed sample rate. This data is sent via the Ethernet on the back plane to the BB module.

b. TX Application CSCI

This transmitter application is responsible for handling the modulated baseband I and Q data sent from the BB module. Data is passed on to the FPGA and AD9879 D/A Converter which modulates the data to the intermediate frequency for subsequent up-conversion to the transmit frequency of the channel. This application is also responsible for a power control loop between the TX module and the PA/LIN module. The power-loop is started when the transmit channel is keyed and is maintained thru the duration in which the channel remains active.

c. PA/LIN Application CSCI

This application also takes part in the power-loop operation between the TX and the PA/LIN module and also enables and disables the PA according to the activity on the channel.

d. BB Application CSCI

The BB application CSCI is responsible for handling the data received from the RX module or to be transmitted from the TX module. The modulated data received from the RX module is demodulated and valid messages are sent to the TC. On the transmit side, data to be transmitted is received by the BB module from the TC module. These data are then modulated to I and Q samples and sent, at the desired sampling rate, to the TX module.

3.4. Test CSC

This CSC is responsible for running built-in self tests (BIST), power-on self tests (POST) and monitoring faults on the module. The BIST and POST test all the peripherals on the module (e.g. EEPROM, LEDs, and CPLD) as well as many of the hardware components (e.g. synthesizer, A/D Converter). Various faults including operation faults, Ethernet connectivity faults on the backplane, software exceptions, messaging faults are continually monitored. Any state change is reported to the BB module. Thus the BB module is continually aware of the health of the channels associated with it. This CSC is also responsible for the creation of several test modes that allow off-the-air operational testing of the modules and the station as a whole.

3.5. Network CSC

This CSC is responsible for providing an interface to an external programming tool used to set up the operational parameters for the station (note that these parameters translate to personality parameters for the different modules). This CSC is also responsible for interfacing to networks outside the station.

3.6. Programmer CSC

This CSC is responsible for loading the personality of each channel into the BB module. It is also responsible for managing the code-loads to the modules. All the code-loads are first sent to the BB module. The BB module then takes care of distributing the code among all the modules associated with the channels it controls.

3.7. USB CSC

The USB CSC provides an easily accessible interface to the base station thru the BB module. It can be used to configure IP addresses, access fault logs and access the test mode for the station. It can also be used as an interface to provide code uploads to the station.

4. SUMMARY

The MASTR V incorporates leading-edge design concepts and SDR technologies to achieve significant advantages in reliability, scalability, testability, and growth potential for accommodating new waveforms and standards- all extremely important attributes for public safety customers. In summary, some of its more noteworthy design concepts and technologies are as follows:

- Truly a SDR multi-mode base station, designed to accommodate linear or constant-envelope modulations through simple software changes, and even modulations with bandwidths significantly greater than what is typically employed for public safety LMR frequency channels.
- The first known public safety base station to use an IP backplane, with its associated advantages of flexibility, scalability, reliability, and testability.
  - Its different modules can be plugged into any slot location.
  - Compatible with IP LMR networks.
  - New/future modules do not require backplane or controller module modifications. Can even place additional modules in another chassis if needed. Also provides easier back-to-back or band-to-band or modulation-to-modulation multi-station configuration capabilities.
  - Standardized code loading interface for all levels of code. Full system code upgrades may be automated.
  - Provides the capability to add remotely-located accessories to a site or channel (e.g. remotely located relay controls). Customers can provide wired or wireless Ethernet connection as needed.
  - Facilitates software controlled built-in test and alignment with remote addressing and diagnostics of individual modules and even devices within the modules.
- Uses a novel polar feedback TX linearizer and associated software-based auto-calibration system to achieve high transmit spectrum fidelity with minimal PA spectral re-growth, far surpassing public safety's requirements for transmitter Adjacent Channel Power and Regulatory mask requirements.
- Performs DDS I/Q transmit modulation using a state-of-the art high-speed, high dynamic range D/A converter. This avoids the often burdensome calibration issues associated with more traditional analog I/Q modulation.
- Performs IF sampling receive I/Q demodulation using a state-of-the-art backend chip that provides digital I and Q outputs from a single stage IF input signal. The associated advantages are avoidance of I/Q calibration and DC leakage associated with traditional I/Q demodulation.
- Uses digital control of the receive AGC function to enable optimization of its response characteristics to each operating mode (e.g., TDMA vs. FDMA configurations).
- Compatible with Cognitive Radio (CR) techniques that vary TX waveform parameters and/or receive filtering in real time, due to software control of these functions and processing capacity to accommodate CR engines and databases.

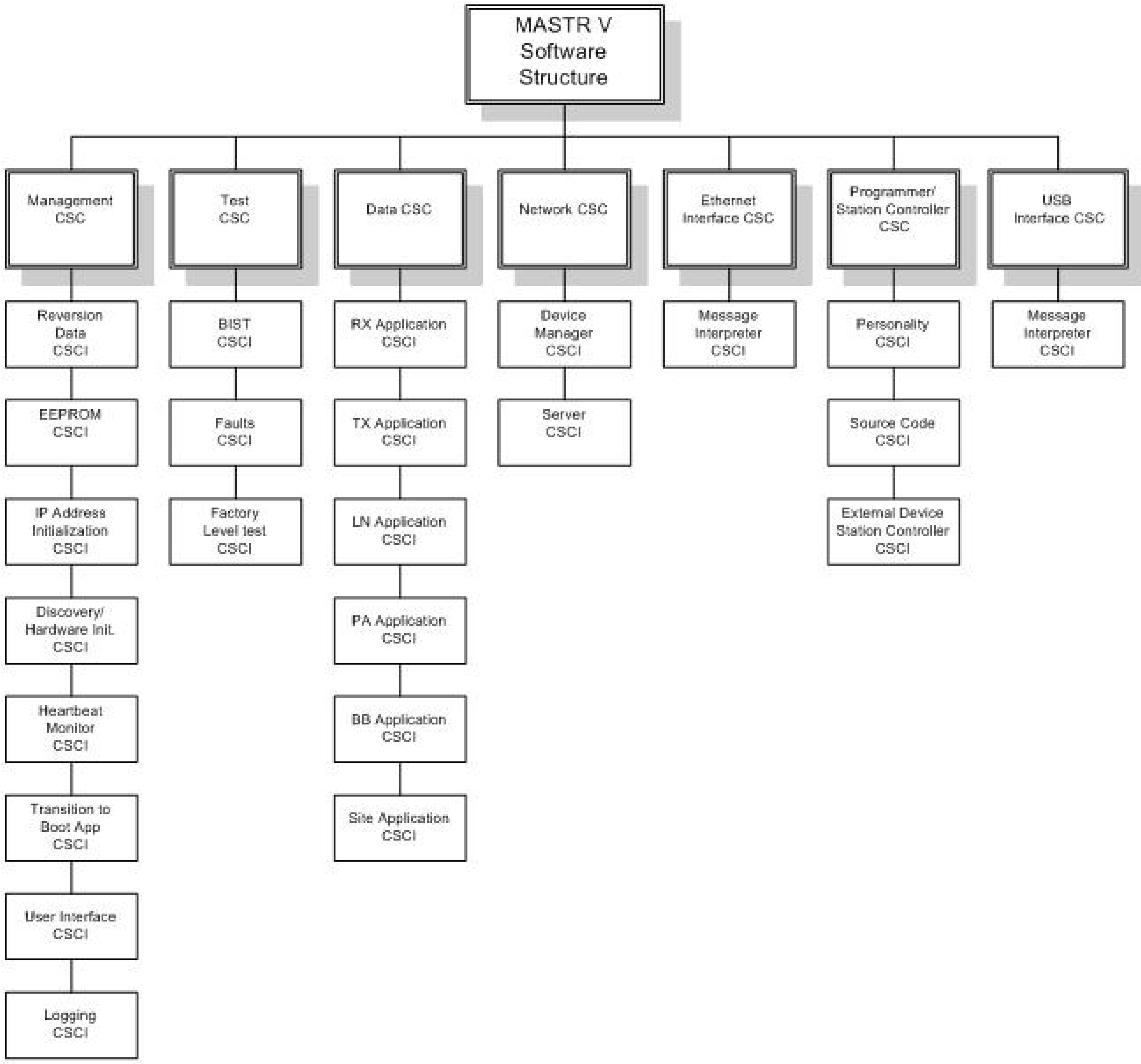

Figure 3: MASTR V Software Architecture

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