P4XT Hardware Testbench

Introduction

Development of microwave hardware and software components eventually requires operation on physical hardware. While for complex SDR based designs the majority of development activities can take place in a pure software environment, eventually testing on real hardware is required.

In order to support global development, P4XT is planning two remotely accessible hardware test benches that will be used to provide the necessary hardware test capabilities. The test benches will be accessible to team members 24/7.

This document describes the various hardware development evaluation boards and related tools necessary for completing Phase I of the P4XT project. All of the equipment will continue to be used through Phase II and beyond. The tools will provide a hardware test and verification capability to support all stages of development.

The intent is for all of these tools to be accessible to authorized team member developers remotely. Generally, this will be accomplished through ssh and/or vpn access to the physical testbench locations. The tool connectivity and in most cases supporting software will be accessed through connections supporting windows or linux VMs running on one or more dedicated platforms. Remote access will also be provided to standard test equipment, primarily Spectrum Analyzers, signal generators, power meters, jtag programmers, noise generators and oscilloscopes. The intent is to allow global development to proceed 24/7 remotely with minimal manual intervention, sharing the test bench tools to the maximum extent.

Note that it is possible, if not outright easy, to connect test equipment in a manner that can result in equipment damage. Accordingly, it is generally necessary to “engineer” equipment configuration in a manner that is safe for both the test equipment and the devices under test.

Details from the Grant Proposal

The Phase 4 Digital Multiplexing Transponder grant proposal includes funds to establish and equip the two remotely accessible hardware test benches for open source amateur radio and amateur radio satellite service work. Lab equipment supports project research and development, verification and validation, and measurement and test.

California and Florida (United States) are the proposed locations for two labs. Population density, available volunteers to staff, supportive commercial and non-commercial sponsors, and density of test equipment vendors and re-sellers were all factors in proposing these two

locations. Other lab locations are possible, with outside the United States strongly preferred as a next step.

Proposed Budget

Here is the Funding Projection from the 2020 ARDC P4XT Grant. Lab Equipment Site 1 and Lab Equipment Site 2 are the two ORI Remote Labs under discussion.

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Achieving the milestones requires a funding grant of $500,000.
This will be allocated approximately to the following expense
categories:

Administrative Overhead $22,000
To mitigate unanticipated costs

Variable Overhead
Electricity $500
Test Equipment Repair and Calibration $2,000

Travel and Events
Participant Event and Souvenirs $4,000
Travel for Core Development Team (at least 10 individuals)
$20,000

Financial and Accounting
Accounting Services $1,000
Independent Financial Review 1 $4,000
Independent Financial Review 2 $4,000

Office
Shipping $4,000
GitHub "Teams" Fee for Five Years $540
Dreamhost web hosting share $320
Non-Profit Slack Pricing $100
Zoom Teams (or equivalent) for Five Years $750
Adobe Premiere Subscription for Five Years $1,260

Training
FPGA DSP Multiday Training (at least 10 individuals) $22,500

Mechanical
Metal and Machining Services Dual-Band Feed $10,000
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Metal and Machining Services Terrestrial Case $5,000
Plastics and Vacuum Forming Services $4,000
Cables $1,400
Mechanical Engineering Compliance Test $500

Certified Testing
Certified Range Testing for RF Performance $500
Certified Range Testing for Proof of Performance $900
Certified Range Testing for FCC Compliance $15,000
Certified Environmental and Safety Testing $600
Lab and Test Equipment

Lab Equipment Site 1 $50,000
Lab Equipment Site 2 $50,000

Computers and Computing Services
(10) FPGA Bitstream Creation Software Licenses $42,950
Simulation Software Equipment $2,000
Computing Services (AWS) for F1 Instance(s) $5,000

Engineering Article
Engineering Articles Bill of Materials $120,000
Engineering Articles Layout Costs $3,200
Engineering Articles Production $100,000
Engineering Articles Integration $9,000
Total $507,020

Amounts may be shifted somewhat between categories depending on need.

Note that there are no labor costs associated with the Phase 2 project because of the many qualified volunteers who are devoting resources to the project.

These ORI Remote Labs will also be available to collaborating organizations and individuals. The equipment will be selected with P4XT in mind as a priority. Acquisitions will focus on digital microwave wireless communications test equipment. Required protocol support will be DVB-S2, DVB-S2X, and DVB-T2. All modulation and coding combinations in these standards will be supported. This provides a real wealth of options for designs that implement subsets of functionality from the DVB protocols. In addition to the DVB-specific functions, arbitrary waveform generation will be provided. FPGA research and development will be enabled.

Target Hardware Configuration

The Target Hardware Configuration for the P4XT DMT consists of a stack of cube-sat form-factor boards, each approximately 90mm x 90mm. In most cases the board stacking is flexible and will not require the use of aligned stacking connectors. Board to Board, Board to bus, and RF connections will be made through connectors at the edge of the boards.

Redundancy

The baseline Target Hardware Configuration supports 1:1 redundancy at the board level. Configurations with redundant Baseband Processor Boards and/or redundant Digital Radio Boards will be supported. While hot standby will be supported, in most cases only the primary boards will be fully powered while the secondary boards are maintained in low power state.

Hot and Cold Redundancy of analog RF boards will also be supported.

Baseband Processor (BBP) Board

The BBP contains the Ultrascale+ MpSoC FPGA and its memory, low voltage supplies and master clock. The BBP is all digital. Inputs and outputs are IQ basebands transported over JESD204B/C links. In 1:1 redundant configuration there are two BBP boards and each can connect to either Digital Radio (DR) Board.

Digital Radio (DR) Board

The DR Board converts baseband digital to RF in both directions. The initial baseline DRB uses a single AD9371/5 device. The digital side is JESD204B. The RF analog inputs and outputs can be configured in the range from 300MHz to 6000MHz. RF from these boards is at a relatively low level on the order of 0dBm.

Analog RF (ARF) Boards

Analog RF Boards provide amplification and in some cases frequency conversion between the Digital Radio Boards and the antenna system. Unlike the BBP and DR boards which are normally identical across all applications, the ARF boards will normally be adapted to the specific system depending on the frequency ranges, input signal levels, and power output levels required. The reference design will provide inputs and outputs for the Amateur Radio Satellite services bands at UHF through 24 GHz.

Most analog RF Boards will provide for redundant RF inputs from two Analog RF Boards in order to maintain redundancy. In some cases, redundancy can be maintained all the way to redundant antenna systems.

Hardware Development Strategy

Hardware for the project will begin with off-the-shelf commercial carrier boards and evaluation boards and will evolve to the complete suite of fully custom cubesat formfactor designs over the course of the project. This will proceed through the following steps:

1. Off the Shelf Eval Boards configured for early development
2. Custom Cubesat Form factor Analog RF Boards for amateur UHF to 24GHz Satellite bands
3. Custom Interim Cubesat Form factor BBP PCBA that Accepts Off-the-shelf FPGA Trenz 76mm x 58mm FPGA/Memory modules
4. Custom Target Cubesat form factor Board for DR PCBA.
5. Custom Cubesat Formfactor BBP PCBA (FPGA + ECC Memory)

The off-the-shelf eval boards and the standard AD9371 evaluation board provide RF input and outputs similar to those provided by the target design. This allows development and testing of ARF boards to proceed at any time, overlapping development of the target DR Board Hardware. Prior to development of specific ARF boards, the input and outputs can operate with direct low-level L-Band inputs and output for initial testing and characterization. With suitable laboratory attenuators and bandpass filters, these will be directly compatible with test bench equipment including existing DVB-S2 transmitters and receivers.

Custom Boards

Interim BBP Carrier

Prior to final design and layout of the BBP, which is a complex 8 to 12 layer high-speed board, an interim 4 to 6 layer board will be produced to accept the Trenz TE080X modules. While the Trenz boards do not provide the low power ECC memory that will be in the target BBP board, this will be largely transparent during the early stages of development. The BBP carrier board will provide all of the IO that will be present in the target BBP. This will allow the board to be used across the full range of Trenz TE080X modules that cover the 900 Ball MPSoC devices from 2CG to 15EG. The BBP carrier board will provide interfaces to the DR board that will be nearly identical to the final target hardware. This will allow DR board design to proceed well-before design of the final BBP. This will also allow decisions regarding the specific FPGA, memory, and oscillator devices to be deferred until the DR boards have been fully tested and verified. Once tested and verified BBP Carrier Boards become available, the Trenz Carrier

platforms will no longer be required and the hardware will utilize only cubesat format mechanics (non-flight version).

DR Board

The baseline Digital Radio Board design will contain an AD9371/5 which converts between IQ baseband and RF. The AD9371/5 radio chips contain high speed ADC and DAC blocks, integrated signal processing for RF/Baseband conversion, and an ARM core that runs firmware that manages the various blocks and performs dynamic calibration functions.

Initially the DR Board will connect through the BBP Carrier Board to an onboard TE080X module. This will eventually be replaced by the production BBP Board with FPGA and 80 bit ECC LPDDR3/4 and flash on the board.

ARF Boards

ARF boards have analog IF on one side and RF to the antenna on the other side. In some cases the IF is at the same frequency as the RF and no frequency conversion is required. In some cases a frequency conversion is required, for example from IF to 10.5GHZ or 24GHZ.

The baseline GEO application for North America is 5GHZ uplink and 10.5GHZ downlink. For Ground based repeater operation through QO-100 the uplink is 2.4GHz and downlink is 10.5GHZ. However, as the transponder is on the ground in this application the transmit outputs are 2.4GHZ and the receiver inputs are L-BAND from the LNB's.

Testbench Locations

Two remote hardware testbench locations will eventually be provided. The RF and test equipment physical configurations will generally be manually reconfigurable during normal business hours at the locations, one on the US west coast and one on the US east coast. The configuration can involve remote operated RF-coaxial relays to route signal path connections. The coaxial relay connections will be characterized for each configuration with published vswr, insertion loss, and isolation. The configuration will specify interconnections and verification procedures.

The two locations will have nearly identical standard equipment although some less often used equipment may be unique to a location. The intent of the two locations is to provide a level of redundancy to help ensure that test results can be independently confirmed and issues related to particular hardware can be quickly identified. When unexpected results are found, tests can

be run on the other testbench to confirm that they are not due to subtle hardware or test setup failures.

Both locations will also contain an Ayecka TC1-BBF DVB-S2 receiver configured for remote control and the recovery of DVB-S2 BBFRAMES and an Ettus B200mini driven from a GNU Radio VM. These will serve initially as a reference DVB-S2(X) transmitter and reference DVB-S2 decoder.

During early development, most of the RF activities will take place at L-Band or lower frequencies, i.e. the lower portions of the 300MHz - 6000MHz nominal range of the AD9371, e.g. 432MHz, 932MHz, 1270MHz etc. These activities can take place in authorized amateur bands by licensed amateurs.

Hardware Configuration Items

Educational Support

A PLUTO SDR has been requested to support educational outreach and support.

Part Number	Description	Approx Cost
PLUTO	PLUTO SDR from Analog Devices	$ 150 donated

AD9371 Evaluation Reference Platform (1X).

This platform is the ADI standard reference platform for the AD9371. It consists of the following equipment:

Part Number	Description	Approx Cost
EK-U1-ZCU106-G	Ultrascale MPSoC Evaluation Kit	$ 2,500 avnet x2
ADRV9371-W/PCBZ	AD9371W Eval Board (Wideband)	$ 1,250 verical x2

The AD9371 reference platform will be used to run the various reference designs supplied by AD9371 in various configurations.

Ultrascale + Reference Platform (2X)

Early development will be facilitated by the use of commercial off-the-shelf modules for the various Xilinx Ultrascale+ MPSoc devices. The modules from Trenz have a small form-factor and are available with various 900 pin devices that cover the range of FPGA devices under consideration. The modules also provide onboard 64bit DDR4 RAM. FPGA IO's are brought out from the 8 layer board through 4 160-pin high speed connectors allowing the module to be plugged into another board.

Part Number	Description	Approx Cost
TEBF0808-04A	Carrier Board	$606 trenz x2
TEBT0808-02 (updated part number)	Test Board	$194 trenz x2
TE0790-03	XMOD FTDI JTAG ADAPTER	$42 trenz x2
TE0808-04-6BE21-L	ZU6EG-1FFVC900E Module 4 GB DDR4	$1076 trenz x2
KK0808-03	Heat Spread	$40 trenz x2
CBPROG-DONGLE	ClockBuilder Pro Field Programmer (SiLabs)	$99 digikey x2

DVB-S2 Reference Platform

This platform consists of off-the-shelf commercial equipment that provides DVB-S2(X) transmit and receive capability at the BBFRAME level (which allows Generic Streams as well as transport streams).

Part Number	Description	Approx Cost
DTA-2115B-SP	DVB-S2 PCIe Modulator	$ 3,788 proflixsales x2
DTC-383-S2X	DVB-S2X Option for DTA-2115B	$ 976 proflixsales x2
DTA-2132-SX	DVB-S2X Demodulator	$ 3,233 proflixsales x2

Generic RF Test Equipment

The generic RF test equipment can be remotely operated and controlled to generate RF inputs to and monitor RF outputs from the various devices under test. Inputs and outputs configurations for various test setups are controlled through remotely operating relays.

Part Number	Description	Approx Cost
Rigol DSG821A	Sig Gen w/IQ Modulation 2.1GHz	$ 3,700 testequip.net x2
Rigol RSA-5065N	Spectrum Analyzer/VNA 6.5 GHz	$ 10,500 testequip.net x2
FCPM-6000RC	Frequency Counter/Power Meter 6GHz	$1,500 minicircuits x2
Rigol DS1104Z-PLUS	100MHz 4CH DSO/16 CH DIG	$ 500 testequip.net x2
Rigol RPL1116	Logic Analyzer Probe for DS1000Z Plus	$ 200 testequip.net x2
Rigol DP832	Triple Output 195 Watt Power Supply w/remote control.	$ 473 testequip.net x2
Rigol OCXO-B08	High Stability Clock (software key)	$ 661 testequip.net x2

PCIe 4 PC Test Platform.

The PCIe 4 Test Platform is a high end PC based host system for multiple virtual machines that run the various software tools e.g. vivado, and provides access to the various hardware test capabilities. The machine is optimized to provide very high PCIe Lane bandwidth, Ethernet Connectivity, and very high speed recording and playback of IQ streams.

The 3970X Threadripper processor has 32 Cores/64 Threads and 88 PCIe 4.0 Lanes with Quad Channel DDR4 ECC Support

Part Number	Description	Approx Cost

	ASUS ROG Zenith II Extreme Alpha TRX40 Motherboard	$850
	Ryzen Threadripper 3970X MPU	$1980
F4-3200C16Q2-256GVK	32GB x 8 Memory	$1260
	Cooler	
	2X M2.2280 1TB SSD PCIe Gen 4 x 4 NVMe	$400
	3X Seagate SkyHawk AI Surveillance 16TB	$ 1150
	1500W Power Supply	
	Case	
	Windows 10 Pro	$150
	Netgear XS512EM 12-Port 10GigE/Multi-Gigabit Managed switch with 2 SPF+	$800
	2X SFP+ Twinax Direct attach Cable	$ 100