ECE 4094

Project A

(SDR for Sounding Rocket Telemetry)

Design Specification

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Table of Contents

Tables and Figures

Introduction

This design specification details the software and hardware architecture for a four-channel narrowband software-defined radio (SDR) receiver. It is the culmination of my FYP research in semester one so far, and it explains the rationale for changes that have been made to the initial proposal and updates the initial specifications to reflect what is realisable with the hardware that has been selected.

This specification also serves to allow verification of the soundness of the architecture, allow detailed design of a PCB and allow the development of software needed to tie this SDR into the existing ecosystem of open source SDR software. For a detailed breakdown of future tasks which need to be completed, and the timeline for doing so, including a Gantt chart, see the *Progress Report*.

For context, this project is primarily intended to be for use with Monash High Powered Rocketry's rockets, originally as both the rocket-mounted telemetry transmitter and as the ground station receiver. However, as this specification will explain, with the design moving to be a receiver only, it will find use only in the latter application. Other secondary applications for this project are also expected to be found, given its multi-channel capability.

System Specifications

At this stage of design, with the components selected, the system will meet the following specifications:

- Four independently tuneable receive channels
- 50Ω impedance inputs
- 3M 12-bit samples/second, which can be divided amongst the four channels, each channel having two outputs for I and Q
- Configurable receiver bandwidths of 200kHz and 300kHz
- 150kHz to 1.8GHz tuneable range

Parts List

Table 1: Parts List

Part	Description	Cost, approx., AUD	Qty	Total Cost	Supplier
NXP BGU7045	Low-noise amplifier (LNA) with bypass. Operates up to 1000 MHz and is used because it has a lower noise figure than the MSi001's internal LNAs over that range.	$1	4	$4	Element 14, Mouser, Digi-Key, LCSC
Mirics MSi001	Integrated multiband tuner chip. It is controlled over SPI and has baseband analogue I/Q outputs (two differential pairs, i.e. four lines).	$3	4	$12	AliExpress

Maxim MAX11131	12-bit ADC. 3Msps multiplexed between all input channels. The multiplexing scheme can be configured to automatically follow a schedule of which channels to sample from.	$15	1	$21	Element 14, Mouser, Digi-Key
Cypress FX2LP	USB 2.0 bridge. Used for reading samples from the ADC and transferring them over USB. Also takes commands from the PC and controls the tuners.	$20	1	$21	Element 14, Mouser, Digi-Key, LCSC, AliExpress
22 MHz TXCO, 2 ppm	Precision frequency reference. This will supply the tuners, with the ADC and the USB bridge chip supplied by another source.	$5	1	$5	Element 14, Mouser, Digi-Key, LCSC
Printed Circuit Board (PCB)	4-layer PCB, smaller than 100 x 100mm. Price includes registered shipping and minimum order quantity of five pieces.	$40	1	$40	JLCPCB
Total				$103	

Design Choices

Narrowband vs. Wideband

There are existing SDR radios which work on bandwidths in the range of tens of megahertz, however these are expensive systems, particularly due to cost in the area of digitisation (the ADC) and digital electronics required as data rates increase.

Each of the radiofrequency (RF) tuners proposed for this design can provide reception of almost 10MHz of bandwidth and provide convenient analogue baseband I/Q outputs, so it is unfortunate to be underutilising these tuners in this project. However, to fully utilise the MSi001 tuners would push this SDR up into the price range and capability of pre-existing SDR systems; see the SDRplay RSP1A [1] for an existing single-channel receiver which fully utilises the MSi001.

To avoid re-inventing the wheel, it has been decided to differentiate this project by providing narrowband reception only, and thus saving on cost. There are still many things possible with a narrowband SDR (especially an SDR with four channels), and reception of most of the telemetry systems Monash High Powered Rocketry uses would be covered.

Multi-channel functionality

When the project was conceived, it was specified that the SDR should have multiple receivers synchronised to the same frequency reference. This choice was made because there are few affordable multi-channel SDRs available, yet such an SDR would be useful for experiments with diversity, direction finding and potentially beam forming.

Moving to a Receive-Only SDR (Originally Intended to Have Receive and Transmit)

The design moved to be a receive-only radio system, making this radio suitable for the telemetry ground station, but not useful onboard a rocket, which has to transmit the data. This decision was made due to anticipating difficulties with licensing.

A non-assigned scientific licence [2] can be obtained from the Australian Communications and Media Authority (ACMA) which permits research, teaching, demonstrations and trials on a set of shared frequencies. In fact, low power experimentation with SDRs in a shielded lab environment is already done at Monash University, however the end goal is to use this SDR “in the wild” on an ongoing basis and not as a demonstration or trial. The most appropriate licence for this is the low interference potential devices (LIPD) class licence [3], which does not require operators to apply for a licence, and covers mobile phones, cordless handsets, Wi-Fi, alarm systems, as examples. An apparatus licence [4], of which the amateur apparatus licence (colloquially known as the “HAM licence”) is a type, can also allow operation on a few more bands and power levels, but requires an operator to apply for it.

However, in order for any radio transmitter device to be supplied and used in Australia under the LIPD class licence, the device needs to be certified for compliance [5]. Getting an SDR transmitter certified was found to be unlikely because it is such a general device, able to operate over a wide range of spectrum, with infinitely many different modulation schemes and different power levels, while the LIPD class licence is very explicit about what combinations of modulation schemes, bands and power levels may be used [6]. A few existing SDRs with transmit capability (at least ones made/distributed by US companies), attempt, in some cases, to circumvent similar legislation in their jurisdiction by classing SDRs as test equipment, however this is evidently a grey area if one does not hold a scientific or apparatus licence to operate such test equipment.

In any case, the complexity of dealing with licensing was felt to detract from the objectives of learning about radio design and producing a readily useable SDR.

Extending to Four Receive Channels (Originally Two)

While searching for discrete components for the RF front end (such as mixers, frequency synthesisers and filters), it was discovered that because only receive capability is required, a range of highly integrated tuners/front ends normally intended for cable and terrestrial TV applications would be suitable. Since these tuners are cheap and require few additional components, the cost to add additional receive channels is surprisingly small, so it was felt that the extra cost and design size were easily justified by the potential of having four phase-coherent, separately tuneable channels.

Inclusion of a Low-Noise Amplifier (LNA) as a Pre-Amplifier

The MSi001 tuner has integrated LNAs, however it was decided to include a discrete LNA to assist in three ways. Firstly, the noise figures of the integrated LNAs are approximately 6dB, whereas the external LNA which has been chosen (BGU7045), has a noise figure which is half this, and the noise introduced by amplifiers early in the chain is particularly crucial to performance. Secondly, the external LNAs have an IIP3 of 15dBm at max gain, which is greater than the IIP3 of approximately -10dBm which the MSi001 has at its max gain, indicating that the MSi001 will be more susceptible to intermodulation from powerful interferers if it is being run at max gain, so by not needing to run the MSi001 at max gain, its IIP3 is much improved. Thirdly, the MSi001 has a gap in its reception between approximately 240 – 470MHz, but luckily there is a ‘hack,’ or workaround, to allow operation in this band. The workaround involves routing the RF signal through a signal path within the tuner normally intended for reception between 150kHz to 30MHz. The integrated LNA and mixer used in this path are not expected to have much response to a signal that is so far outside their operating ranges, so the inclusion of an external LNA is intended to assist here.

Radiofrequency (RF) Front-End

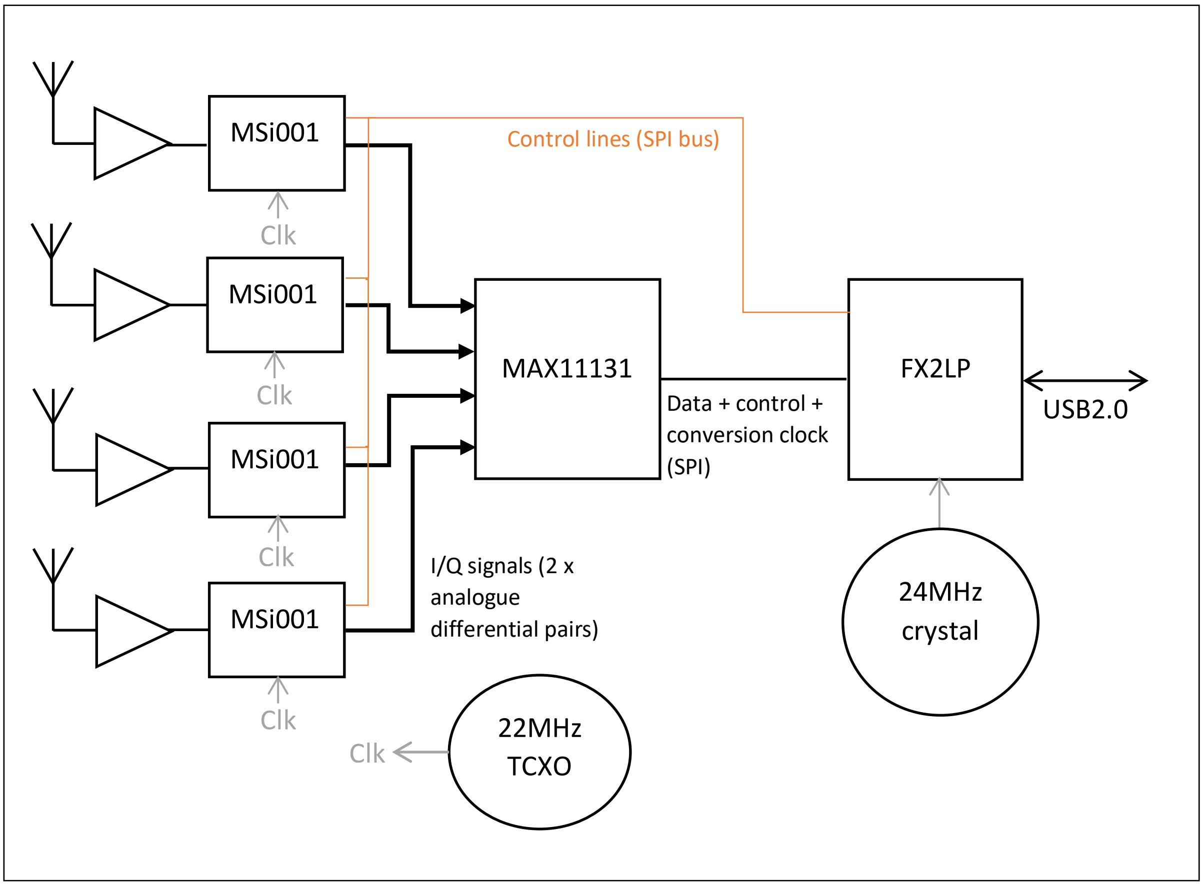

Figure 1: Electronics System Diagram

All MSi001 tuners will run from the same precision oscillator/reference, while the FX2LP, per its datasheet, needs a 24MHz crystal. It is unfortunate that the MSi001 cannot operate from a 24MHz reference, otherwise an extra part could be eliminated. The FX2LP will be able to output a 48MHz clock on the SPI bus, which the ADC can use for both making conversions and communication.

Not pictured in Figure 1 is that the LNAs have internal bypass capability if no amplification is desired. This is controlled by setting the voltage of the gain control pin on the external LNAs to zero, so these control pins will be connected to the (digital) GPIO of the FX2LP, to at least provide a choice max gain or bypass.

Note that each MSi001 outputs an in-phase analogue output as a pseudo-differential pair and also a quadrature analogue output as another differential pair. This means that all 16 analogue inputs of the MAX11131 ADC are used to sample from 8 pseudo-differential channels. Each analogue line ranges from 0V to V_{CC} (which will likely be chosen as 3.3V), centred around a common mode voltage of $V_{CC}/2$ (this is the pseudo-differential scheme), and output clipping occurs at 3V peak-to-peak, differential. This is well-matched to the analogue inputs of the MAX11131 in unipolar/pseudo-differential mode, which can cover a range from 0V to V_{DD} (which again will likely be chosen as 3.3V). However, not pictured in Figure 1 is that buffering may be required between the MSi001 and the MAX11131, because the analogue outputs of the MSi001 are fairly high impedance, being unable to drive a resistance smaller than 5kΩ and a capacitance greater than 20pF.

Software System

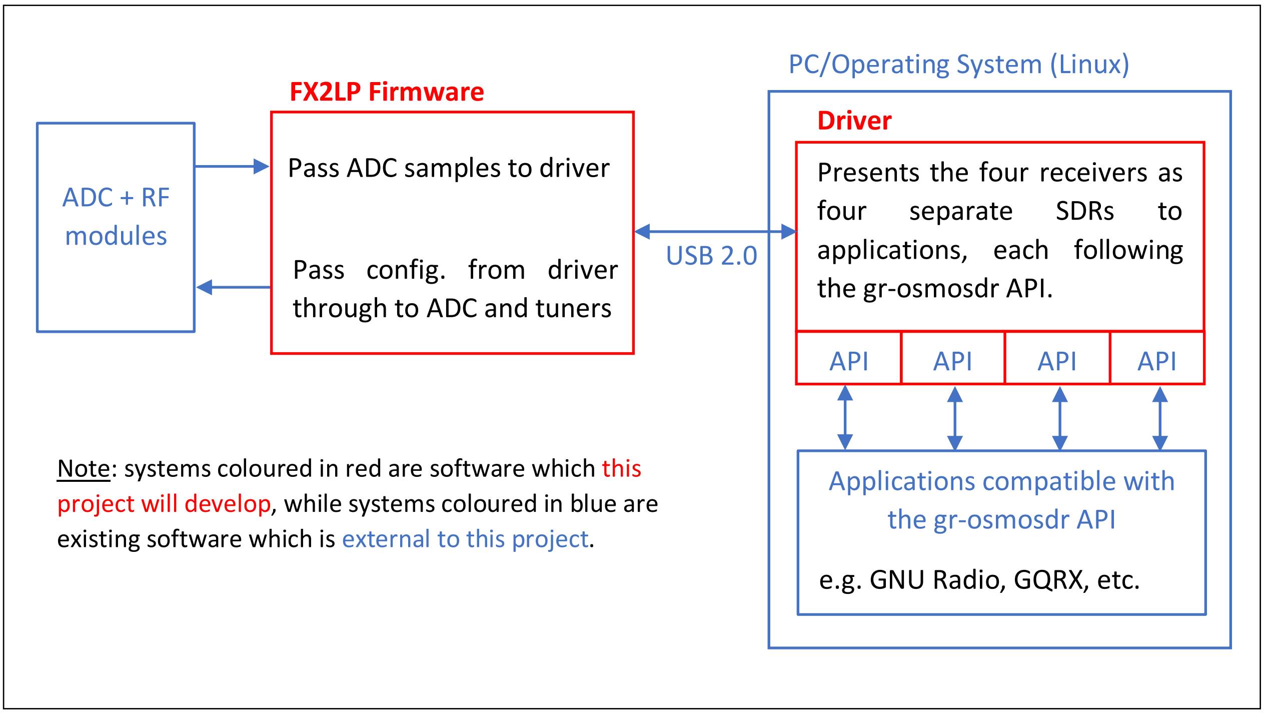

Figure 2: Software System Diagram

The driver will be developed initially for Linux, and will be derived from the existing open source libmirisdr drivers [7], [8]. These existing drivers present a single receiver (made up of an MSi001 tuner and an MSi2500 ADC + USB bridge) to applications following the gr-osmosdr API. The libmirisdr drivers will act as an excellent starting point but are expected to require extensive modification and testing, as the SDR of this design specification contains multiple MSi001 tuners and uses a very different ADC and USB bridge. Further, by having the driver expose a standard API which has been widely used in the open source SDR ecosystem (the API used by gr-osmosdr devices) it will be more straightforward to leverage that ecosystem.

The firmware that needs to be written for the Cypress FX2LP will control the tuners via a shared SPI bus, passing register configurations received from the driver via USB. The second SPI bus on the FX2LP will need to run at 48MHz and will be dedicated entirely to retrieving samples from the ADC (and, in the reverse direction, for configuring the ADC). The driver will then be responsible for the bulk transfer of 12-bit samples over USB, back to the driver. The FX2LP also has a multitude of GPIO ports, some of which will be exposed to the driver and used for slow signalling, including enabling and disabling the external LNAs, turning on and off indicator LEDs, etc.

References

[1] SDRplay, “RSP1A - SDRplay,” [Online]. Available: https://www.sdrplay.com/rsp1a/. [Accessed 9 June 2020].

[2] Australian Communications and Media Authority, "Scientific licence," 18 May 2020. [Online]. Available: https://www.acma.gov.au/licences/scientific-licence. [Accessed 9 June 2020].

[3] Australian Communications and Media Authority, "Low interference potential devices (LIPD) class licence," 30 January 2020. [Online]. Available: https://www.acma.gov.au/licences/low-interference-potential-devices-lipd-class-licence. [Accessed 9 June 2020].

[4] Australian Communications and Media Authority, "Apparatus licences," 14 February 2020. [Online]. Available: https://www.acma.gov.au/apparatus-licences. [Accessed 9 June 2020].

[5] Compliance Engineering, "Short Range RF Devices and Australian Compliance Requirements," [Online]. Available: https://www.compeng.com.au/document-library/short-range-rf-devices-and-australian-compliance-requirements/. [Accessed 9 June 2020].

[6] Australian Government, *Radiocommunications (Low Interference Potential Devices) Class Licence,* 2015.

[7] osmocom and various contributors, "libmirisdr - GitHub," [Online]. Available: https://github.com/osmocom/libmirisdr.

[8] f4exb and various contributors, "libmirisdr-4 - GitHub," [Online]. Available: https://github.com/f4exb/libmirisdr-4.