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A Bistatic Multi Spacecraft Per Aperture UHF Ground Station

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Abstract

The 401–403 MHz ‘UHF’ radio band is a popular choice for experimental and commercial smallsat satellite telecommunications. Until now it has been impractical to support more than one such mission concurrently unless the ground stations are at least ten kilometres apart to prevent interference. To surmount this constraint, we developed a bistatic ground station where the transmitters are located distant to the receivers, with the stations linked by the Internet.

Our solution utilises software-defined radios at both the transmitting and receiving stations and the popular open-source *GNU Radio* platform to provide the back-end computation for the radios and to link the stations. Our prototype bistatic station was brought on-line in 2022.

The bistatic arrangement has some attractive operating features, including allowing both the receiver and transmitter to operate throughout the pass, minimising transmit-receive switching times, and an ability to confirm in real-time that the transmit and receive chains are performing nominally.

We developed our own scheduler to enable customers to securely book passes with APIs and web-based interfaces, and to subsequently retrieve payload data and pass logs.

The deliberate flexibility built into our scheduler software means that we will soon be able to control a series of bistatic ground stations the 1,200 kilometre length of New Zealand to act as a single virtual ground station. This will provide prolonged pass times for spacecraft in polar orbit and allow accurate tracking of such spacecraft early after launch to quickly determine their orbital state vectors and, for multiple payload launches, establish the health of all the spacecraft in a constellation.

Keywords: UHF, ground station, Awarua, antenna, bistatic, GNU Radio

Acronyms/Abbreviations

Python	Python programming language
SDR	Software Defined Radio
TLE	Two Line Element
TT&C	Telemetry, Tracking and Command
UHF	Ultra-High Frequency; in context 400 MHz–460 MHz
S-Band	In context, 2.0 GHz–2.3 GHz
X-Band	In context, 8.0 GHz–8.4 GHz

1. Introduction

The 401–403 MHz ‘UHF’ radio band is a popular choice for experimental and commercial smallsat satellite telecommunications. However, until now it has not been practical to support more than one such satellite mission concurrently unless the ground stations are at least ten kilometres apart to prevent interference. The high cost of establishing ground stations mean these spatial requirements are a significant barrier to providing UHF services. This paper describes a means to remove this constraint by using a bistatic ground station. The paper first explains the demands placed on the existing ground station and discusses practical considerations, and then describes the use of SDR hardware with an implementation of *GNU Radio* software (GR) to implement the bistatic station. A discussion on the hardware aspects of the receive and transmit RF chains follow. It concludes with an outline of future work.

Awarua Satellite Ground Station is situated at the very south of New Zealand and is owned and operated by Space Operations New Zealand Ltd. Our first commercial customers, subsequent to supporting ESA and CNES for the ATV launch campaigns between 2008 and 2013, operate their radio systems in the UHF as well as X- and S-Bands to support their own constellation missions [1]. Usefully the five UHF ground stations transmit in the 450 MHz band and receive in the 401 MHz band. This 49 MHz separation means that it ought to be straightforward for the receiver filters to reject transmissions from the adjacent 450 MHz transmitters. Furthermore, because each constellation operates on a single dedicated frequency pair, simple filters with low passband loss in the receive chain can be used, which should not degrade reception and are relatively inexpensive.

Difficulties subsequently arose when another customer requested us to host their 402 MHz UHF station. Their transmitted signals would therefore interfere with, and possibly damage, the existing UHF receivers. The only solution was to establish another ground station facility at Lochiel, some 36 km to the north of Awarua. Establishing a new permanent facility is not to be undertaken lightly. The arrangement worked until, at very short notice, yet another customer requested launch support using their own half-duplex 402 MHz equipment. Clearly, we couldn't install their antenna at either Awarua, or Lochiel. We rushed to install their ground station halfway between Awarua and Lochiel on our office roof in downtown Invercargill, which surprisingly worked very well and no impairment at the other stations was observed.

Aware of the continuing interest in the 402 MHz spectrum, we urgently began to investigate ways to support more than one 402 MHz mission from the same facility. We recalled that the same problem had been encountered and solved many years earlier when the New Zealand Post Office had operated the nearby Awarua ZLB Coast Radio Station operating in the HF bands from 1913 to 1991: its radio operators and their receivers were located at the Awarua station, and their microphones and morse code keys were connected by permanent land-lines to a radio transmitting station some 780 km away in the lower North Island of New Zealand. Up to a dozen operators co-existed under this arrangement. We decided to adopt the same bistatic solution, but with modern techniques and use the Internet instead of dedicated telecommunications links: we would establish a UHF transmitting facility in Invercargill and an associated receiving facility at Awarua, capable of supporting many simultaneous missions.

At the same time, we recognised that it would serve our future customers better if we were to provide all future UHF ground station equipment. Our existing customers who provide their own equipment often suffer with UHF antennas and positioners that are somewhat unreliable, with coaxial cable to the antennas at risk of snagging, a propensity for water ingress and structural integrity not necessarily capable of surviving heavy commercial use. By us owning and operating the antennas, it becomes possible to reschedule a pass session to a redundant antenna should the prime antenna suffer a failure and so we could usefully improve customer reliability. Other benefits came to light, as is discussed below.

2. Practical UHF considerations

2.1 Attractions of the UHF band

Using the UHF bands for payload and TT&C is popular with experimental and commercial smallsat spacecraft in low Earth orbit because:

1. The radio systems can be very simple[*]
2. Licencing is relatively straightforward
3. Low-cost, omni-directional, easily deployed spacecraft antennas are often adequate
4. Ground segment hardware requirements are modest
5. Ground station antennas have half-power (-3 dB) beamwidths in the order of 30°, improving the opportunity to find a spacecraft early after launch separation when state vectors are still to be fully characterised
6. The low available bandwidth is often sufficient for TT&C and simple mission payloads.

There is an engineering trade-off to be made between ground station performance, and the spacecraft's transmitter power and antenna complexity. Power budgets and physical constraints on antenna size and deployment mean that, in our experience, the effective radiated power of most current smallsat spacecraft is between +27 dBm and +33 dBm. The ground station thus provides the only opportunity to close the transmission link budget.

Being able to resolve weak received signals is fundamentally dependent on the effective gain of the antenna and the noise temperature of the system. In practice, UHF ground station antenna gain is limited to around 19 dBi. Higher gains are possible, but at quickly escalating cost and complexity.

Low noise temperatures are directly related to the noise figure and gain of the Low Noise Amplifier (LNA), and the losses that precede it. Modern UHF LNAs have extremely good noise figures, in the range of 0.3–0.6 dB, which means that losses in the feed-line and bandpass filter limit performance. While it would be nice to omit the bandpass

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[*] A good example is the OpenLST radio board developed by Planet engineer Bryan Klofas, which successfully uses little more than a TI garage door opener radio chip to successfully provide a space qualified transceiver that can be used in both spacecraft and ground station applications [2].

filter, which introduces an in-band loss of 0.2–1 dB, without it the LNA would surely saturate, recalling that the instantaneous input power to the LNA is effectively the aggregate of all the radio signals reaching it over its entire operating bandwidth. This is likely to include high-powered FM broadcasting stations and cellular mobile telephone sites.

This highlights the importance of carefully choosing the LNA: it must have a low noise figure, sufficiently high gain that subsequent stages do not degrade the LNA's noise figure, and be able to operate linearly over the full range of input signals delivered to it, i.e., to operate within its 1 dB input power compression point (P1dB), so that intermodulation products are inconsequential.

Depending on the spacecraft orbit, the Friss Equation [3] predicts that the link budget has to contend with the arriving signals varying by some 14 dB as the range improves from around 2,000 km to, say, 400 km at nadir. In addition, signals will fluctuate should the spacecraft spin and block its antenna. Atmospheric conditions do not noticeably affect the path budget.

2.2 Detractions of the UHF band

Smallsat UHF radio links tend to fall into two categories: full- or half-duplex operation with uplink in the 450 MHz band and downlink in the 401 MHz band, and half-duplex with both uplink and downlink on a single frequency in the 402 MHz band. Technical and regulatory effort is minimised with the latter.

While establishing a single UHF ground station is straightforward, it is impossible to co-locate more than one 402 MHz station, or to co-locate a 402 MHz station with a 450 MHz/401 MHz station. This is because there is no practical way to prevent the 402 MHz transmitted signal from one antenna overloading the mast-head LNA in the front-ends of nearby 401 MHz and 402 MHz station receive-signal chains. The received power levels may be so high that even with filtering the LNAs would be destroyed, but at any rate non-linear operation of the LNA causes in-band intermodulation products that are difficult, or impossible to deal with and would cause the link to become unstable. This is the single-most important factor driving the adoption of a bistatic arrangement, where the receivers are co-located sufficiently distant to their associated co-located transmitters that the aggregated transmitted signals do not overload the LNAs under any circumstance.

Universal to any UHF ground station environment is that satellite operators launching experimental and prototype spacecraft often have limited space legacy to guide them and their focus may be restricted to the spacecraft itself; telecommunications is seldom at their front of mind, if at all, until launch. Further, UHF smallsat missions are often low-cost where the customers have severely constrained budgets. Supporting customers who need considerable assistance, but have small budgets is not economic unless flexible solutions that can be easily adapted for a range of missions are developed.

2.3 Bistatic station considerations and observations

Ideally, the receiving station should be sufficiently distant to the transmitting station that the terrestrial signal strengths are comparable with those from spacecraft. However, both stations need to have nearly identical views of the sky. Practically, distancing the stations to the extent that worst-case maximum signal levels are well within the dynamic range of the receive station LNAs is adequate. Depending on local terrain and vegetation, distances of more than 10 km are acceptable.

Bistatic stations offer some further useful advantages over standard stations. Most usefully, the transmit and receive chains' nominal performance can be measured in their entirety to confirm that all components of the system are functioning nominally merely by 'listening' to the transmitting station from the receiving station. Unlike conventional systems, this includes the aerial components and provides reassurance that the antenna positioners have not lost their calibration, which is their wont.

A second advantage is that the transmitter can be permanently keyed for the entirety of the spacecraft pass. This means that the time for the spacecraft to switch from transmit to receive is no longer critical in the station provisioning. This is helpful as it turns out that some smallsat designs call for very fast switching times that are not easily accommodated by conventional means.

3. Invercargill/Awarua bistatic station

3.1 Terrestrial radio path

Our implementation of a bistatic station is to use our Invercargill UHF ground station (INV-1) for transmitting purposes and Awarua (AWA-2) for receiving. The distance between the two is 13.6 km, presenting a free space path loss of 107 dB (see Figure 1). The path is obstructed by trees and so additional loss, in the order of 0.1 dB/m of trees [4], or 2 dB in aggregate, is introduced. Figure 1 also shows that Fresnel interference is likely, possibly introducing up to a further 6dB variability in received signal strength.

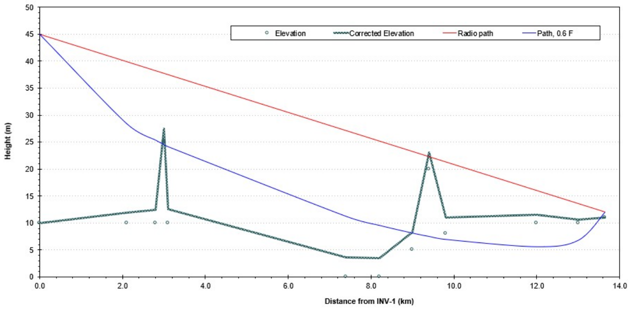


Figure 1. INV-1 to AWA-2 path. Earth rounding correction factor, K=3/2.

3.2 Software defined radio implementation

We use an Ettus 210N SDR for the core of our radio receiver and transmitter. The dynamic range of the Ettus is able to deal with all but the worst electromagnetic interference we encounter in the receive chain.

To interface with our SDRs, we utilise the open-source GR software platform [5]. This platform is now widely used and we have found the documentation to have greatly improved over the last two years, which we speculate is a consequence of Covid-19 lockdowns.

Radio data is streamed to and from customers—i.e., in both the receive and transmit directions—at baseband as an IQ data stream. These data streams are sent over Zero Message Queue (ZMQ) sockets in a publish-subscribe configuration. ZMQ sockets operate asynchronously, allowing one side of the connection to connect and disconnect arbitrarily without the other side having to handle the connection being made and broken respectively [6]. Furthermore, ZMQ is natively supported by GR. These aspects make ZMQ sockets perfect for handling multiple clients connecting to and disconnecting from our GR flowgraphs at the start and end of pass sessions.

In addition to using GR's native ZMQ interface, we have developed our own 'out-of-tree' (OOT) GR 'blocks' using GR's C++ API. These OOT blocks provide bespoke functionality in our GR flowgraphs that is not provided by the native GR environment. While GR's C++ API provides powerful customisability, it does pose a very significant learning curve over using the native GR blocks. However, once this learning curve has been overcome, developing bespoke GR blocks with good processing performance is relatively simple.

To date, the primary GR functionality we have implemented is the capability to inject null samples (zeros) into a data stream when the source of that data stream is exhausted (stops producing data) in order to keep the data stream flowing at a constant sample-rate. For example, should a customer stop streaming data into our flowgraph— for example, when they disconnect at the end of a spacecraft pass—our custom block will begin injecting null data into the data stream in place of the customer's stream so, downstream of this block, it simply looks like the customer has begun streaming null data. This is illustrated in Figure 2.

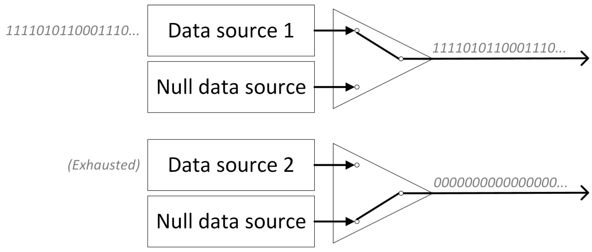


Figure 2: An example of a null stream being injected in place of Data source 2, which has been exhausted.

This functionality is required for providing advanced stream routing and multi-spacecraft-per-aperture capabilities. For example, when super-imposing multiple frequency-division multiplexed data streams together ready to be transmitted simultaneously from a single omni-directional antenna, if one data stream stops, GR will wait indefinitely for more data to be received on that stream before processing the remaining streams, preventing the remaining active streams from being transmitted. This is illustrated in Figure 3.

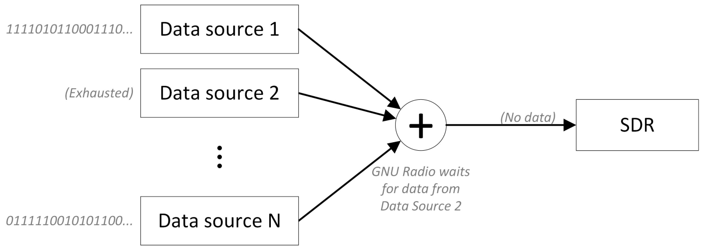


Figure 3: When Data source 2 stops streaming data, it holds up all other data streams too.

However, with our bespoke GR block, a null stream is injected in place of the exhausted data source which prevents GR from blocking the other incoming data streams and, since the null stream is all zeros it has no effect on the super-imposed output. This is shown in Figure 4.

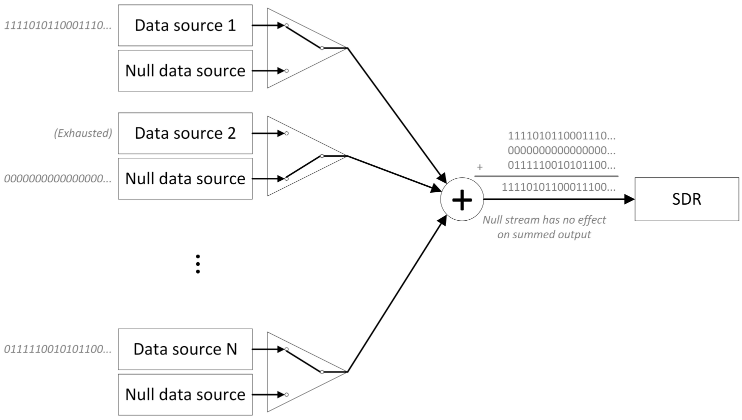


Figure 4: When Data source 2 stops streaming data, it is replaced by a null stream, which has no impact on the final super-imposed signal sent to the SDR.

We have also developed a powerful run-time control system, allowing stream routing, frequency tuning and other such variables within our primary GR flowgraphs to be controlled externally by a Python control script. This capability is necessary for the automated, real-time reconfiguration of the flowgraphs that makes seamless multi-mission operations possible.

This run-time control system is implemented using GR’s inbuilt message passing system, which allows some blocks to be controlled and configured using command messages in the form of polymorphic types (PMTs). GR includes native support for streaming these PMTs into and out of flowgraphs using ZMQ sockets—as with the radio data streams—so they are a logical choice for sending commands into the flowgraph.

3.3 Networking

Our bistatic station network is split across two subnets, one at the Awarua site and one at the Invercargill site. These two subnets are bridged by an IPSec connection over the Internet. Furthermore, the customer connection to the receive site in Awarua is port-forwarded via the Invercargill site. Thus, the customer is only required to connect to the Invercargill site subnet, with all traffic bound for the Awarua site subnet routed through the Invercargill site connection.

Furthermore, the received radio data stream from the Awarua site is also routed through the Invercargill subnet via a GR redirection flowgraph. This allows the customer to connect over the Internet to the same IP address for streaming data in both the transmit and receive directions, with the only difference being the IP port number. This allows the same antenna routing system that controls the transmit data streams to also control the receive data streams, as illustrated in Figure 5.

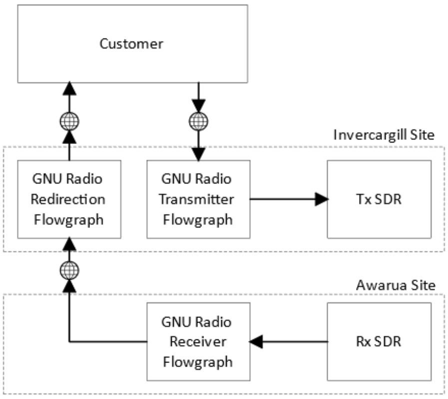


Figure 5: GR routing layout.

3.4 Scheduling

We developed our own scheduling and control software, optimised for simplicity and flexibility, and with support for multi-mission and LEOP operations. The software provides a flexible API for scheduling pass ‘sessions’, during which the customer has complete control of the antenna.

The flexible API design allows customers the ability to schedule sessions by either providing their own azimuth and elevation (pointing) vectors—which is especially useful for pointing at a fixed location when searching for a satellite during LEOP—or by providing a spacecraft TLE along with the start and end times of the pass the customer wishes to track, which is convenient for routine operations. This implementation provides simple and convenient scheduling of basic tracking sessions, whilst still supporting high configurability of sessions for customers with more specific requirements.

We have also developed a simple web application to complement the API and make scheduling sessions more human-friendly. This web application includes an orbital computation tool which, when provided with a spacecraft’s NORAD ID or TLE, computes the upcoming passes of the spacecraft over the Invercargill/Awarua bistatic station. It is then possible for a customer to simply select which of the upcoming passes they wish to track and the scheduling software will automatically schedule the corresponding sessions on the bistatic system.

3.5 Invercargill transmitting station

Our current Invercargill station comprises a stacked M2 400CP30A circular polarisation yagi antenna with nominal 19 dBi gain mounted on an M2 AE1000 positioner. We use an Ettus 210N software defined radio (SDR) to drive a Minicircuits ZHL-50W-52 50W high-power linear amplifier, which is good for 45.7 dBm output with 1 dB compression. Effective isotropic radiated power (EIRP) of up to 63 dBm is achievable, which we back off to meet present ITU rules that require 402 MHz stations to transmit with a maximum EIRP of 36 dBm.

Because it is a legacy station, the station is capable of reception and is equipped with a receive RF chain (see Figure 6). Under normal operation the receive chain is switched out of service.

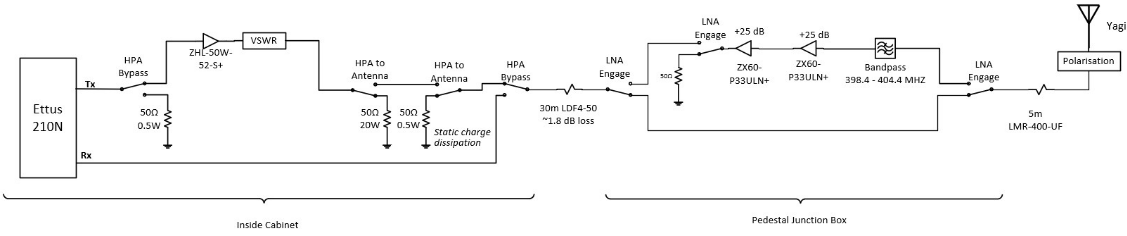


Figure 6. INV-1 RF chain.

3.6 Transmit antenna and power amplifier

For good reason, most UHF ground stations use circularly polarised yagi antennas, either singly, or stacked to obtain an additional 3 dB gain. Their high gain (typically 16–19 dBi) is difficult to achieve by other methods. However, the costs associated with steering them is not insignificant and all mechanical parts are subject to wear and tear.

We have identified that a brute-force approach can be taken with the uplink chain: unlike a spacecraft, power is not a problem for terrestrial stations and the same EIRP can be achieved by using an antenna that is omni-directional in azimuth with a higher powered amplifier.

An ideal antenna needs to have around 14 dB more gain at 5° elevation than at 90° elevation to compensate for changing path loss through the pass. Our modelling has identified a modified parasitic Lindenblad antenna to be the most promising for this purpose (see Figure 7) and continuing work is underway to verify this [J. Topp, pers. comm.].

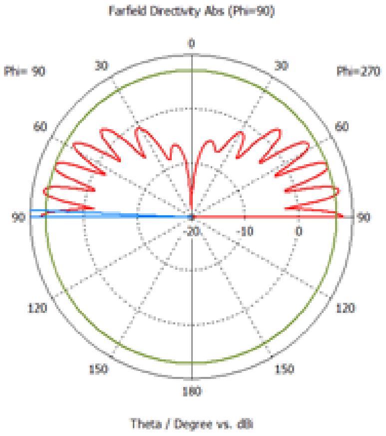


Figure 7. Modelled radiation pattern for elevation of a modified parasitic Lindenblad antenna.

3.7 Awarua receiving station

Our goal for the receiving station is to maximise G/T. Ideally, we would have the receive station well away from the 450 MHz transmitters to minimise filter stringency, but this is not practical.

Because the EIRP of the INV-1 station is currently 63 dBm, under worst case conditions when the receive aerial with a gain of 19 dBi is directed at the transmitter aerial, the received signal at AWA-3 is in the order of -46 dBm. Such a power level would be respectable for a reliable terrestrial point-to-point radio telecommunications link. While the received signal from the ground station could be some 70 dB stronger than a weak satellite signal, it lies well within the P1dB limit of a good quality LNA, with a safety margin exceeding 36 dB.

3.8 RF Filtering

We designed and fabricated a prototype three-section Chebyshev 10 MHz bandwidth interdigital bandpass filter to precede the LNA (Figure 8). Three sections provide sufficient attenuation of the nearby 450 MHz transmitter signals to prevent LNA saturation, with an acceptable insertion loss of less than 0.5 dB. Such a filter nominally has 0.15 dB ripple, but careful tuning can advantageously reduce insertion loss over the sub-band of interest through worsening the ripple over the nominal filter bandwidth. Satisfied that the prototype works, subsequent antennas are fitted with custom-designed commercial filters.

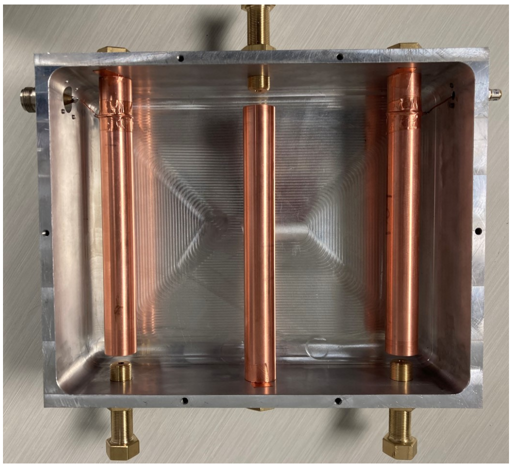
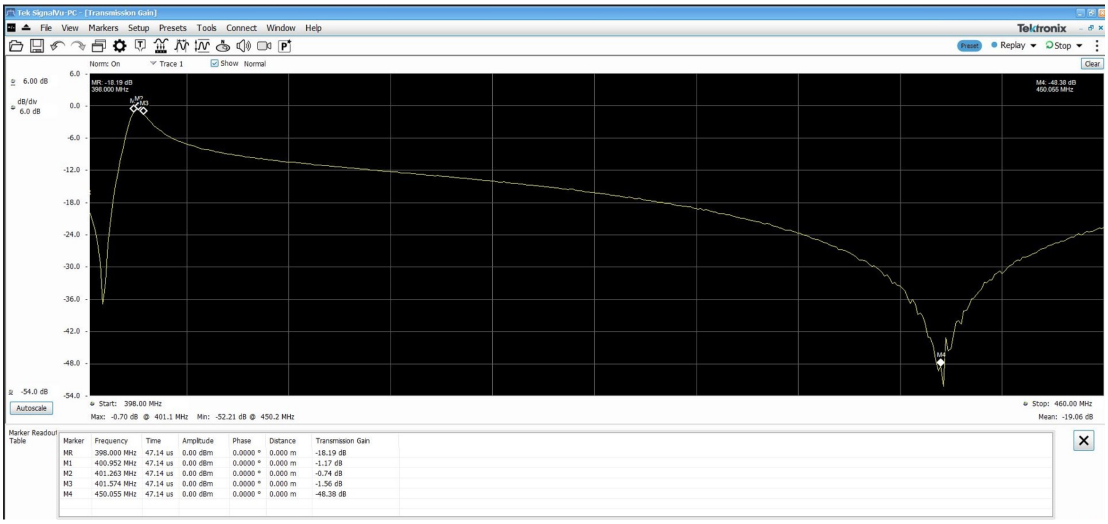


Figure 8. Prototype three section interdigital filter.

While the interdigital filter was adequate to prevent the LNA saturating, we found that the dynamic range of our SDRs struggled to deal with the 50 dB difference between local transmitter signals and weak spacecraft. Two cavity filters with notch filtering (repurposed from the terrestrial land mobile radio service) after the LNA provided the solution (Figure 9). Because this filter comes after the LNA, its higher 2.5 dB insertion loss is of no consequence to overall receiver performance.



Max: -0.70 dB @ 401.1 MHz Min: -52.21 dB @ 450.2 MHz

Mean: -19.06 dB

Marker	Frequency	Time	Amplitude	Phase	Distance	Transmission Gain
MR	398.000 MHz	47.14 us	0.00 dBm	0.0000 °	0.000 m	-18.19 dB
M1	400.952 MHz	47.14 us	0.00 dBm	0.0000 °	0.000 m	-1.17 dB
M2	401.263 MHz	47.14 us	0.00 dBm	0.0000 °	0.000 m	-0.74 dB
M3	401.574 MHz	47.14 us	0.00 dBm	0.0000 °	0.000 m	-1.56 dB
M4	450.055 MHz	47.14 us	0.00 dBm	0.0000 °	0.000 m	-48.38 dB

Figure 9. Characteristic of the cavity bandpass and rejection filter.

4. Results

Despite—or perhaps because of—the extensive effort required to develop our UHF bistatic system, the system has been ultimately successful, both as a prototype and as an operational antenna system. In the past 12 months we have supported three customers on the system with a total of 12 spacecraft and have received numerous further expressions of interest. Over this time, the system has been continually upgraded and has become a reliable workhorse of our operations.

Equally valuable, through operating the bistatic antenna system, we have learnt and gained valuable lessons and experience which have enabled us to improve the current system and plan for future systems. We now have a better understanding of what our customers' needs and wants are. This will enable us to develop future antenna systems providing further benefits.

5. Future work

The developmental and operational work we have performed thus far have suggested many ideas for future work. We are actively developing these opportunities for commercialisation, which are now briefly discussed.

5.1 Next-generation Scheduler

From the lessons learnt developing and operating the current scheduling and control system for the bistatic antenna array, we have begun design of a next-generation higher performance scheduling and control system, which will be more scalable, modular and configurable than the current system. This new system will also tie multiple stations together through the concept of ‘super-sessions’ (see below) and provide a more convenient and configurable user interface for customers.

5.2 Super-sessions

We posit that it should be possible to gain up to 50% more contact time with a spacecraft in polar orbit per pass by beginning to track the spacecraft from a ground station at the south of the South Island and then handing over to another station at the north of the North Island, 1,200 km away to the north, to finish the track and vice-versa. With good clock synchronisation between the two stations and careful network routing of the radio data streams, this handover between stations can theoretically be made seamless from the point of view of the customer, with the contact period appearing to be executed by a single ‘virtual’ ground station.

We call this concept of synchronising two (or more) ground station sessions a ‘super-session’. Having overcome the difficulties of scheduling and determining passes for nearby bistatic stations, we are now adapting these techniques to the purpose of implementing this super-session concept.

5.3 Digital antenna polarisation

For smallsats, both linear and circular polarisations are in general use, while most commercial ground stations are set up for circular polarisation only. Although it is straightforward to swap between right- and left-hand circular polarisations, it is much more complicated to swap between circular and linear polarisations. This means that a 3 dB penalty is usually incurred whenever communicating with linearly polarised spacecraft.

When the ground station uses linearly polarised antennas, linearly polarised radio links are prone to deep fading as the spacecraft passes overhead, or spins. Nulls of 20 dB, or more are possible. To improve performance, it is desirable to swap between horizontal and vertical polarisations rapidly and seamlessly. Using conventional relay switching, it is not possible to switch polarisations while the transmitter is keyed as it takes in the order of 10–30 mS to sequence and switch relays. This can be problematic for some spacecraft communication protocols.

We realised that we could replace the coaxial cable phasing harnesses used to produce circular polarisation on conventional orthogonal yagi antenna arrangements with feeds of arbitrary length to a dual-input SDR and carry out the phasing in the digital domain. Such an approach not only opens the way to swapping polarity digitally, but also would enable us to seamlessly swap between polarisations. Regardless, it should be possible to implement a system that vector-adds the signals from both the vertical and horizontal antennas to avoid fading and improve signal quality, E_b/N_0. Fully implemented, it should be unnecessary to even identify which polarisation is being used.

The low form factor and falling prices of SDRs along with faster Ethernet interfaces mean that the radio RF chain and digitiser can now all be mounted at the antenna pedestal cabinet. When combined with an Ethernet controlled positioner (see below) only a single Ethernet cable and one power cable need to be extended from the equipment building to the antenna. This simplification is useful as coaxial cable is expensive and care needs to be taken when designing ground stations to ensure that cable losses are acceptable; where there are long cable runs, ‘hard-line’ coaxial cable is necessary, which is very expensive to purchase, install and terminate.

While digital antenna phasing could be used to swap between linear and circular polarisation in the transmit chain, it is more economic to take a brute-force approach and instead use a high power amplifer with twice the output power and transmit only with circular polarisation.

5.4 LEOP ranging and orbit determination

Located at the antipodes, New Zealand is ideally located to support spacecraft shortly after launch separation for launches from Europe and also Rocket Lab’s Launch Complex 1 at Mahia, New Zealand. New Zealand is also well positioned to support the subsequent launch and early operations phase (LEOP) of such missions.

The ability to communicate with more than one station at a time becomes particularly advantageous for customers with more than one spacecraft on the same launch who need fast confirmation that all their spacecraft are nominal, and the ability to prioritise any spacecraft that are off-nominal. Depending on the orbit injection, it is possible to communicate with more than one spacecraft with one receive antenna should the spacecraft be located closely in the sky, or from separate antennas. During at least part of the spacecraft phasing, having more than one antenna would be advantageous. We are working on this.

The techniques involved for our proposed super-session may also be adapted for ranging spacecraft through contemporaneous signal measurements from suitable geographically separated stations. This is an area where we are collaborating closely with the University of Canterbury. Modelling to date is very promising and we believe that we should be able to extract good state vectors from a single super-session immediately after separation.

5.5 Controller board

We are presently testing our own antenna positioner and peripheral device controller board for antenna pedestal deployment. It is capable of supporting all popular commercial UHF positioners. Because it can monitor motor, LNA and other currents, and SWR it is possible to monitor the performance of all system components in real time. Monitoring positioner motor current over time would identify any degradation in the positioner, or even if a cable to the antenna is catching.

As the controller is Ethernet controlled, only a single power supply and one Ethernet cable is required to be extended to the antenna pedestal, see Figure 10. The resultant cost savings in cabling is expected to be significant.

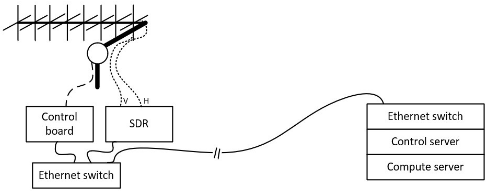


Figure 10. Schematic of a full Ethernet operated station (Single cable power supply omitted for clarity).

6. Conclusion

It is not possible to operate more than one UHF satellite ground station at the same facility unless the transmitters all operate with 40 MHz or so separation from their receivers to allow sufficient filtering to protect the receivers. We have developed a prototype bistatic UHF ground station, where the receivers are 13.3 km distant from any transmitters operating on similar frequencies that overcomes this difficulty. This allows for many simultaneous missions to be supported.

The technology and software used for the bistatic arrangement could be adapted to provide ‘super-sessions’, giving longer contact times than would otherwise be possible, and to provide multi-spacecraft LEOP services, including orbit determination. These features are in development.

Acknowledgements

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