AMSAT-UK

Proposal for a Geostationary Microwave Amateur Radio Payload

This paper is a response to the presentation by Frank Zeppenfeldt, PD0AP, at the October 2023 AMSAT-UK Colloquium.

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Content:

Overview.

The aim of this paper is to discuss the mission concepts and broad technical requirements for an amateur microwave payload to be placed in a geostationary Earth orbit. The approach taken describes, with justifications, a baseline communications transponder operating within the amateur satellite service. In addition, we look at the potential to augment the transponder functions by adding a low risk method of adding processing or coding gain to encourage software design and improve link budgets. We also examine how the higher microwave bands of 24-76GHz+ and some experimental systems can be added. An Earth facing camera is suggested for educational outreach, and we briefly examine the potential of other high altitude non geostationary orbits that may be suited for an amateur payload

Finally, “Beyond the Bent Pipe” by Martin Ling M0LNG,from the Dec 23 edition of OSCAR News. Martin discusses past and possible future transponder designs.

Coverage Area. – Geostationary equatorial position.

An ideal coverage area from geostationary orbit should include the member and cooperating states of the European Space Agency.

If we look at coverage of both Europe and Canada, from 36,000km, we can see there are a range of orbital slots between approximately 5 degrees and 47 degrees west that will cover both Europe and Canada. However, with Cyprus at 34 east and western Canada at 141 west, it is not possible to cover all of Europe and all of Canada from any single position in GEO. Therefore, the service area from a microwave amateur payload will, necessarily be a compromise between geographical limitations and population distribution

The maps below show coverage area from 3 example GEO positions of 5 degrees, 30 degrees and 47 degrees west. The contours show the elevation angle to the satellite from zero to 40 degrees in 10 degree increments. It can be seen that any location east of 5 degrees west will not provide meaningful coverage of Canada, while a satellite located any further than 47 degrees west will not provide a service to parts of Eastern Europe and Scandinavia.

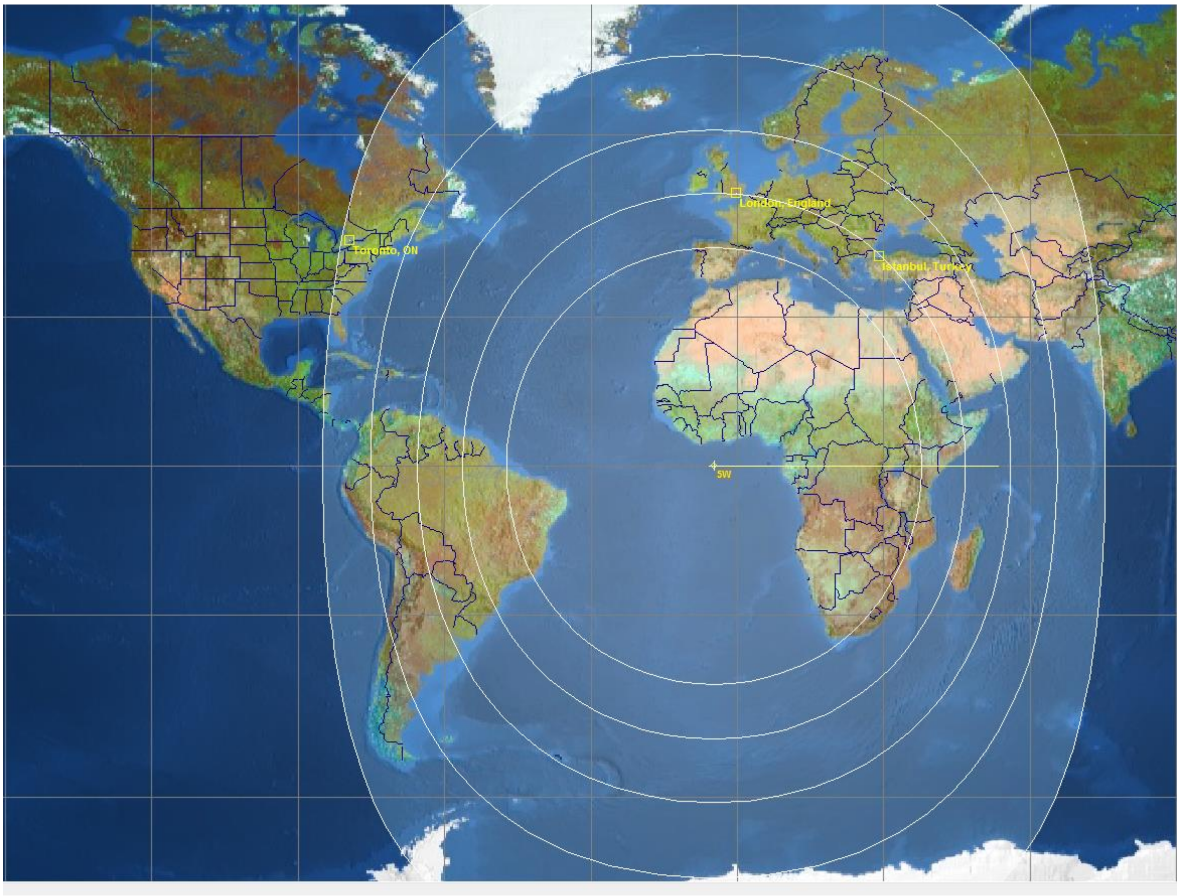


Figure 1 Coverage from a GEO satellite at 5 degrees west. Elevation contours 10deg increments

Figure 2 (above) Coverage from a GEO satellite located at 30 degrees west

Figure 1 Coverage from a GEO satellite located at 47 degrees west

Although the longitude selected for the mission will primarily depend on the availability of a suitable partner and launch, it is worth comparing the populations of Europe and Canada.
Europe, as a whole, has a population of 742 million while the table below shows Canada has 39 million inhabitants. It can be shown from population distribution, that **it is possible to provide a service to 67% of the Canadian population who live within 31% of the total land area.**

Canadian Provinces East of and Including Ontario

Canadian Population (2019) 39 million
Total Land Area (km2) 9.93 million

Province	Population	Percentage of total population	Percentage of land area
Ontario	15.110m	38.74	10.84
Quebec	8.695	22.29	15.53
New Brunswick	0.812	2.08	0.734
Nova Scotia	1.020	2.62	0.557
Prince Edward Island	0.171	0.44	0.057
Newfoundland / Labrador	0.526	1.35	4.080
Totals	26.334	67.52	31.75

Baseline Microwave Communication Transponder

For any new microwave payload to be successfully adopted by the amateur radio community, it is essential that access can be achieved without encountering excessive technical or financial barriers. If possible, use of a new transponder, designed to have wide appeal, should represent a modest technical challenge to an existing user base and be achievable within a reasonable financial outlay.

From the perspective of the satellite payload, it may be important to ensure that any hardware flown is compatible with the largest number of potential GEO platform operators. In particular, the antenna sizes should be contained within an acceptable volume, so the payload can be accommodated within a 'Small GEO platform'.

With these two requirements to consider, the majority view among the potential user groups surveyed is that the baseline transponder should operate with an X band, **10GHz downlink**, and with a C band **5.6GHz uplink.**

Since the launch of QO-100 there are now many users with high performance 10GHz receive systems, mainly based on commercial LNBs. By adopting a 10GHz downlink, this new GEO payload would immediately be accessible to existing users and offer an easy route for new operators owing to the widely available and low cost commercial satellite TV dishes / LNBs and other hardware.
Transmitting an uplink on 5.6GHz represents a modest technical challenge, but one that is considerably easier than generating signals on any of the higher microwave bands.

5.6GHz equipment for ground stations
Currently, there are several reasonably priced commercial products available which can generate a satellite uplink on 5.6GHz. Software defined radios, such as the Analog Devices ADALM Pluto or the MicroPhase ANT SDR (1), can both generate low level transmit signals from below 70MHz up to 6GHz. There are also several sources of amplifiers to amplify the low level signal up to a level suitable for a satellite uplink. Wi-Fi amplifiers around 2W are commonly available, while a high gain 12mW in and 10W output power amplifier module is available from SG Labs (2) in Bulgaria. By starting with a high user base, commercial companies will quickly see this GEO payload as an opportunity to develop and market new products for an emerging market. Details of dual band dish feeds and other valuable GEO / HEO resources are available at the Open Research Institute.(3)

Payload antenna considerations
At geostationary altitudes, the Earth subtends an angle of apx. 13 degrees. For the satellite to serve the whole of the visible Earth, then an antenna with a suitable beamwidth will have a gain of apx. 20dBi. At 5.6GHz, a single 20dB horn receive antenna, probably with right hand circular polarisation, will have an aperture considerably smaller than an equivalent on 2.4GHz. Such an antenna should be compatible with various sizes of GEO platforms.

On transmit, a 10GHz antenna of 20dB should be relatively easy to accommodate, although we believe that for compatibility between wideband and narrow band transmission modes, it may be necessary to have 2 separate transmit ports for individual vertical and horizontal polarisations.

Transponder configuration and added functionality

To achieve a high degree of reliability during the typical 15 year lifespan of a GEO satellite, a broadcast relay (TV) transponder has a very simple architecture. Usually, the transponder has minimal control circuitry, with functions such as input level control applied at the broadcast ground stations, rather than with AGC generated within the satellite.

Amateur use of a GEO payload is likely to comprise of two different groups, those using narrow band analogue and digital communication modes and another group who use wider bandwidth transmissions, including Digital Amateur Television.

To encourage development in both narrow and wideband modes and to avoid mutual interference, we suggest that the baseline transponder has two transmission paths linked by a common receiver.

Narrow band transponder

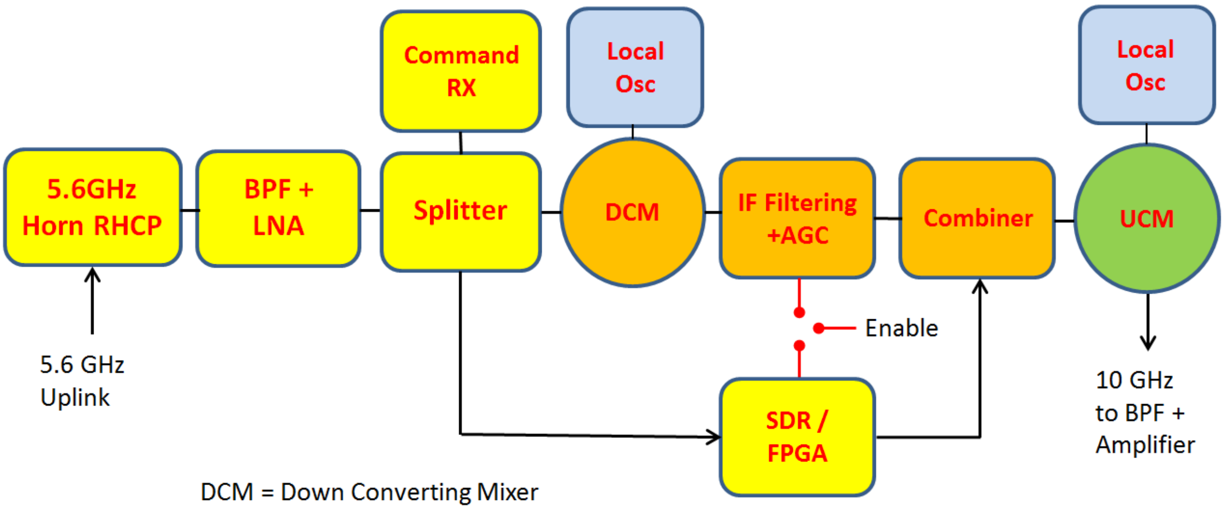
To accommodate the anticipated number of users, the narrowband transponder pathway should have a minimum bandwidth of 250kHz and a 10GHz output of 20 Watts. A more detailed link budget analysis will be necessary to confirm these estimates. Because of the different modes used simultaneously within this passband, automatic gain control is necessary to reduce any excessively high level signals, either individually or collectively. There are many ways in which this can be implemented: using analogue techniques for the entire passband, or digitally by limiting individual user signals. Ref: STELLA by Howard Long G6LVB, or LEILA by AMSAT-DL as examples.

Wideband Transponder

For the wideband transponder path, a bandwidth of 1MHz is suggested with an amplifier capable of 20 Watts. The input to this transponder can share a path through the 5.6GHz receiver, but using a different uplink frequency range.

Owing to the limited number of users who can access this transponder at the same time, AGC may not be necessary. A small portion of the spectrum allocated to this transponder could be used for a beacon, containing still images of the Earth. Finally, it might also be possible to include signal regeneration as an optional facility, rather than having a simple bent pipe function. However, given the 15yr lifetime and the rapid development of modulation techniques, any regeneration may have to be reprogrammable from a command station.

Possible Configuration for Narrowband Transponder



DCM = Down Converting Mixer
UCM = Up Converting Mixer

Signal regeneration and associated risk mitigation

In the diagram above, the transponder has been adapted to include signal regeneration. The basic transponder has a receiver connected to a downconverting mixer. The resulting intermediate frequency is used to generate the required transponder bandwidth with dedicated filters; it will also have AGC applied to level the users' signals and have telemetry beacons added before being mixed up to the required output frequency. All of these stages are typically analogue and are relatively low risk.

To take advantage of signal regeneration, which improves the link budget, three stages have been added. First, a passive splitter divides the input signal into an extra path. Second, a software defined radio, which processes the input signals and demodulates them, removing any added noise in the process. The now noise free signals are then re-modulated by the SDR and passed to the third stage, a passive combiner, which inserts the processed signals back into the transponder's upconverting mixer.

In the block diagram above, the SDR has an input frequency of 5.6GHz, and an output at the chosen I.F. Different configurations are possible, with the SDR operating at the IF or having an output signal directly at 10GHz. The important consideration is that either the analogue or SDR path can be enabled separately by something as simple as a DC switch. This approach is low risk, because if the SDR malfunctions, perhaps to due radiation damage, normal operation of the analogue transponder can be restored by just switching the SDR off.

The SDR firmware, or gateware may be reprogrammable, but from a reliability perspective, there should be separate memory allocated for holding uploaded software rather than overwriting code used at launch.

24, 47 and 76GHz+ Microwave bands

At present, generating adequate RF output on frequencies on and above 24GHz is a significant problem for the average radio amateur. If these bands are to be included, then 24GHz is the only viable band where a significant number of operators could be expected to uplink to the satellite. For 24GHz, we would suggest an uplink receiver to act as a secondary input, providing a 24GHz to 10GHz narrowband transponder. The use of a 24GHz RX provides some redundancy in the event of a fault to the primary 5.6GHz receiver.
For 47GHz and above, receive systems on the ground could be developed at lower cost than a transmit capability. Therefore, 47GHz 76GHz and above are only used as transmitters on the satellite.
Access to both 47GHz and 76GHz is possible, as both are allocated to the amateur satellite service. However, you must consider that, while 47GHz is a primary allocation, 76GHz is only allocated on a secondary basis and that there is an increasing number of inter-satellite links being used between 60 and 80GHz.

Despite these limitations, 76GHz remains a band of considerable interest as component availability increases. There are opportunities to investigate propagation on a band that has significant atmospheric absorption challenges, especially at low elevation angles.
The proposed baseline use of either band is for a multimode beacon that is phase coherent with the 10GHz transmissions and is locked to real time. During a defined period, the transmission mode would cycle through several pre-programmed modes of transmission. The beacons could also carry telemetry or other data if desired.

Timing considerations

To maximise the potential for weak signal decoding, we believe that all the RF systems should be locked to a single master oscillator, thereby making all the oscillators phase coherent. In addition, locking beacons or telemetry to real time is an advantage for decoding weak signals, for example, those used in the WSJT suite of programs.
Locking the transmissions from the satellite to real time can be achieved by referencing the master oscillator to a GPS source, or by using a Chip Scale Atomic Clock (CSAC) driving a real time clock.

Both GPS and a CSAC have advantages and disadvantages:
A GPS system can provide both accuracy and real time, but requires additional antennas on the satellite.
A CSAC from MicroSemi, (4) is accurate within two microseconds per day or one millisecond per year. A CSAC is self-contained with no antenna needed, but needs a real time clock to be synchronised just before launch or to be set when the payload reaches orbit. A radiation tolerant option, intended for LEO applications, is available.

Educational Outreach / Imaging / Laser Experiment

Although this GEO opportunity has been discussed as an amateur microwave payload, it has always been important to use any amateur radio satellite or payload as an educational tool. Providing a service to inspire a wider audience, can encourage students to study science and engineering.
We suggest that a high definition camera is included both for educational outreach and general interest. A camera can be fixed to look back towards the Earth. With a field of view of around 20 degrees, it could image the visible disc of the Earth, while having enough margin for some pointing error.
The images would not be sent as video, since very little motion is observable from GEO. Instead, we propose that still images are sent at a modest data rate as a beacon signal at one end of the wideband transponder. A complete picture could be sent as multiple labelled blocks, perhaps 128 or 256 blocks of data for a complete image. The data would have forward error correction and take possibly five minutes to download. Importantly, the same data would then be transmitted a second time, allowing any frames missed in the first transmission to be filled in by software running at the ground station. We believe that such a system would be very popular with educators across the service area of the satellite.

Finally, we have seen, over the past few years, many examples of lasers being used for data transmission. In November 2000, AMSAT's AO-40 (5) was launched into high earth orbit with an experimental data transmitter, using a 500mW laser. The data rate was only 400bps but used an 850nm laser with a 1.2 degree beam divergence. We hope to investigate the possibility of including a laser data transmitter which can be fixed and nominally pointed at central western Europe. Although details of pointing accuracy of the platform would be required for analysis, it can be shown (6) that a 5W laser at GEO with a divergence of 8milli-radians would have a beam diameter of 600km and have a power density on the ground of apx 3.537e-12 mW/cm^2. Although there would inevitably be some pointing error on a fixed laser, a network of receivers placed around Europe could receive signals some of the time, compensating for fixed pointing errors and minor changes in attitude of the platform.

Proposal Summary

- 5.6GHz to 10GHz, mode C/X transponders for narrowband (250kHz 20W) and wideband, 1 MHz bandwidth + 20 Watts.
- Transponder design to include optional SDR block for signal regeneration in same or different mode. Fixed or programmable TBD.
- 5.6GHz uplink to be split between: two transponder chains and command channel
- 5.6GHz uplink antenna on satellite to be RHCP 20dBiC
- 10 GHz downlink antenna on satellite 20dBi. Narrowband and wideband transponders to have opposite polarisations V+H
- Separate 24 GHz receiver to function as transponder uplink.
- 47 GHz or 76 GHz multimode beacon / Downlink
- All downlink signals phase coherent. i.e. single reference clock.
  Timing by GPS reference or Chip Scale Atomic Clock.
- Camera: Still images sent as part of telemetry or beacon for Educational Outreach.
- Red or near Infra-Red laser experiment aimed towards western Europe.

References:

1 https://www.crowdsupply.com/microphase-technology/antsdr-e200
2 https://3fs.net.au/microwave/5-7-ghz-10w-pa-from-sg-lab/
3https://github.com/OpenResearchInstitute/documents/tree/master/Engineering/Antennas_and_Feeds/W1GHZ_5-10GHz_dual-band_feed

4 https://www.microsemi.com/document-portal/doc_download/1243238-space-csac-datasheet

5 https://nebula.esa.int/sites/default/files/neb_study/455/C14231ExS.pdf section 8.1
6 https://www.gentec-eo.com/laser-calculators/beam-divergence-and-diameter

Alternative Orbits

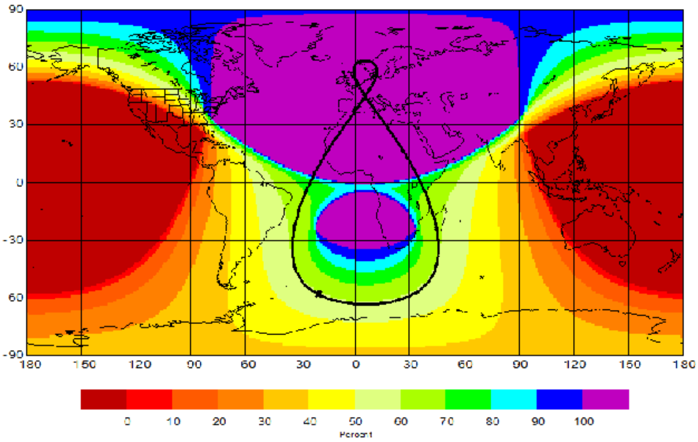
In addition to an amateur radio payload in Geostationary orbit, we can also examine two alternative high earth orbits.

1: A "TUNDRA" orbit

A "Tundra" orbit is high inclination (63.4 degrees), moderately eccentric orbit with a near 24 hour period. https://en.wikipedia.org/wiki/Tundra_orbit

It has been used for Some Sirius direct radio broadcasting in the US https://space.skyrocket.de/doc_sdat/sirius-cdr.htm and two spacecraft are currently under construction for communications purposes for the Nordic countries. https://investors.viasat.com/news-releases/news-release-details/arctic-set-high-speed-broadband-polar-mission-completes-key

It has also been proposed a possible disposal orbit: https://conference.sdo.esoc.esa.int/proceedings/sdc7/paper/328/SDC7-paper328.pdf



This image shows the nominal coverage period(up to 100%) that a constellation of two spacecraft could provide.

This orbit has some similarities to the more well known "Molniya" type orbit but, as the perigee is much higher, the spacecraft does not pass through the intense regions of the Van Allen belts.

The Sirius constellation was using 47 000km apogee with a 24000 km perigee

2: A HEO just below the Geostationary belt

In May 2023, a 16U CubeSat, called GS-1, was launched on a Falcon 9 to an initial orbit, just below the GEO belt (approx. 34000 km). It hosts several payloads for different customers including Earth observation, scientific experiments, and bring-into-use (BIU) services at Ku, Ka and V/Q frequency bands.
Gravity Space contracted with Space Inventor, Denmark, to build a multi-use spacecraft to be placed into geosynchronous orbit. The satellite features three electric Enpulsion Nano AR³ thrusters which were used to raise the orbit to GEO. https://www.enpulsion.com/

More info can be found here: https://www.nanosats.eu/sat/g-space-1 and a recent presentation about its orbit raising manoeuvers is available here. https://www.youtube.com/watch?v=1lrFTFLs4n4&list=PLTDI7lbh1cWrMoSV6ZknH1LZP7vEQSGGT&index=6&pp=iAQB

This demonstrates that it is possible to create a standalone platform of a reasonable size that could be carried to a sub-GEO orbit.

Advantages

In either orbit, our mission would not risk the commercially valuable GEO spacecraft, presently in orbit or planned. The mission would have more independence and could carry more experimental payloads and subsystems.

We would not be dependent on a host for control and power etc.

Disadvantages

A standalone spacecraft is probably a more complicated mission.

As the spacecraft would not be "stationary", some form of tracking on the ground is needed. The required pointing accuracy, especially at higher frequencies, could be challenging for users. This requirement could/should lead to the development of electronically steerable, phased array antennas for amateur use.

Beyond the Bent Pipe

Lowering barriers and supporting innovation through a mixed-signal transponder architecture

Martin Ling M0LNG
Revision 4, 24th November 2023

Abstract

The majority of existing amateur satellite transponders, including QO-100, are of the “bent pipe” design. This approach is simple, reliable and provides great flexibility to users, but leaves many benefits on the table that would be available if the satellite took a more active role in communication. By demodulating and decoding uplink signals, then re-encoding and re-modulating them for downlink transmission, a satellite can contribute significant coding gain, reducing the link budgets required for round-trip communications. This regenerative approach could reduce ground station size and power requirements, and thereby reduce the cost and difficulty barriers to amateur participation, as well as benefiting the satellite power budget. Satellite assisted digital modes would be implemented via a software defined radio (SDR) platform in the payload, updated on-orbit with programs contributed by amateurs. Such a facility would greatly increase access to real-world testing in space, and thereby support innovation in satellite communication. It is not necessary for an SDR architecture to completely replace the bent pipe: these features can be integrated within an analog transponder in a flexible and fail-safe way, with minimal changes to proven designs.

Introduction

This article has been written in response to the presentation by Frank Zeppenfeldt PD0AP at the 2023 AMSAT-UK Colloquium, seeking input from amateurs towards an ESA proposal for a next-generation GEO amateur payload. One question in Frank’s presentation caught my eye in particular:

Analog, digital or complete on-board SDR/Linux/GPU-box with Docker containers in space?

The aim of this response is to explore and support the “SDR in space” idea, and to point out some of its key benefits. I also want to challenge any presumption that a choice must be made between analog, digital or SDR for a given payload. These options are not mutually exclusive.

Support for SDR-based digital capabilities does not need to exclude first-class support for simple analog modes. Nor should SDR be seen as a risky option which would have to discard tried-and-tested systems. I will illustrate how current transponder architectures can be adapted to support flexible and fail-safe integration of SDR capabilities into proven analog designs.

Coding Gain Lowers Barriers

Widespread adoption of new digital modes such as FT8 has transformed the amateur radio hobby over the past few years. By using high-performance coding methods such as low density parity-check codes (LDPC), these modes enable transmissions received at a very low signal-to-noise ratio to be recovered, often succeeding even when the signal appears to be lost in the noise floor. The coding scheme therefore effectively contributes gain, known as *coding gain*, to the link budget. This additional gain translates directly to reduced costs for users: contacts that once required large antennas and expensive transmitters can now be made with cheap, low-power, portable equipment.

The benefits of coding gain can be seen in the choices of modes used for amateur satellite communications today, e.g. FT8 and DVB-S2 are among the most popular modes used on QO-100. Although serving very different uses, both these modes use LDPC-based coding schemes. DVB-S2 has almost universally replaced the earlier DVB-S standard in amateur use, in large part because its higher coding gain means that smaller dishes and less power can be used. Similarly, FT8 has displaced earlier weak-signal modes like PSK31, over which it has a 14dB coding gain advantage.

Satellite Assisted Modes

So far, we are missing a key opportunity. With a conventional bent pipe satellite transponder, coding gain can only benefit a round trip link budget *once*. If the satellite were able to demodulate and decode an uplink signal, then re-encode and re-modulate the contained message for downlink transmission, coding gain could benefit the link budget *twice*. The gain involved can be quite significant, and the result could be that smaller antennas, lower power levels and thus cheaper and more portable equipment could be used on the ground. This regenerative approach can also benefit the satellite power budget, by allowing less TX power to be used on the downlink side.

These benefits could be achieved by implementing satellite based support for existing digital modes, but also by developing new modes designed specifically for satellite assisted use. Satellite assisted modes offer the opportunity to optimise separately for the different characteristics of the uplink and downlink bands, choosing different modulation and coding schemes for each link. There is considerable scope for amateur experimentation and innovation in this area.

The benefits to link budgets would be particularly relevant given the interest in using higher frequency bands (24, 47 or 77 GHz) for a future amateur GEO payload. The UK Microwave Group have noted that the maximum power levels that can be achieved with amateur equipment in these bands are quite limited. As a result, detecting and decoding signals at the satellite might be essential to successful round-trip communication.

An SDR Testbed In Orbit

In the past, supporting digital retransmission capabilities on a satellite transponder would have required the selection and implementation of a specific supported mode to be used throughout the lifetime of the mission. Any viable choice would have had to be quite simple and conservative, and so would in practice offer little benefit for amateur experimentation compared to the infinite flexibility of a simple bent pipe transponder.

However, times have changed and SDR is now the primary route for implementing digital radio systems. Most new digital communications equipment, even if purpose-built for specific standards, is now based on an SDR architecture, and there is an extensive range of well-proven hardware and software components available for developing SDR designs. Adopting this approach has the key benefit that the function of the system can be updated or changed simply by loading new software.

A reprogrammable SDR transponder in orbit, to which new programs could be submitted by users, would provide extensive opportunities for experimentation and innovation – and the results could have wide benefits. Currently, both amateur and commercial satellite designers must be quite conservative about their choices when it comes to communication system design. With a platform already in orbit and available for testing, new ideas could be prototyped and proven in space before being launched on other missions, accelerating the uptake of new techniques.

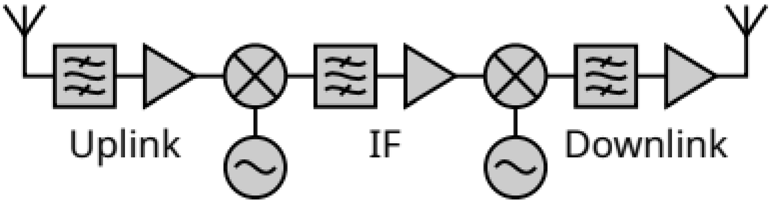
Given the relatively large size, power budget and bandwidth likely to be available on a GEO payload, a very capable and accessible SDR platform could be included. If the platform used were a Linux-based computer capable of running the GNU Radio framework and other standard open-source tools, then there would be a huge number of users able to contribute to developing and testing new software on the ground to be tried out in space. A much wider audience would be able to participate in satellite communication development.

Such an idea may sound risky if one imagines the payload including a typical SDR transceiver such as a HackRF, Pluto or LimeSDR, which can operate at any programmed frequency. In practice though the SDR implementation would need to be purpose-built for the payload, and with appropriate design it is straightforward to ensure that the hardware would be physically unable to transmit outside a specified frequency range and power level.

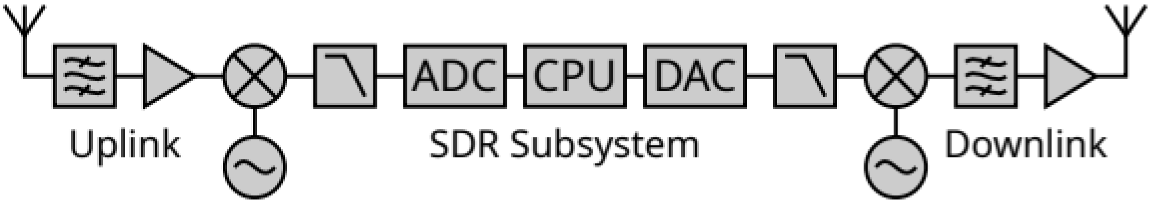
Projects would still need to be selected, reviewed, tested and approved by the operating team before being uploaded for operation. However with the most critical constraints being enforced by hardware, the software approval process could be streamlined. It is likely that such a testbed would be extremely popular, and its use could result in very rapid innovation in satellite communications.

Fail-safe SDR Integration with an Analog Transponder

Now I will look at how existing transponder architectures can be adapted to support these features. The simplest possible bent pipe analog transponder consists only of an input BPF, LNA, mixer, LO, output BPF and PA. In practice multiple conversions are often used, with additional filtering at each IF stage. For the purposes of discussion, we can consider an architecture with a single IF stage:

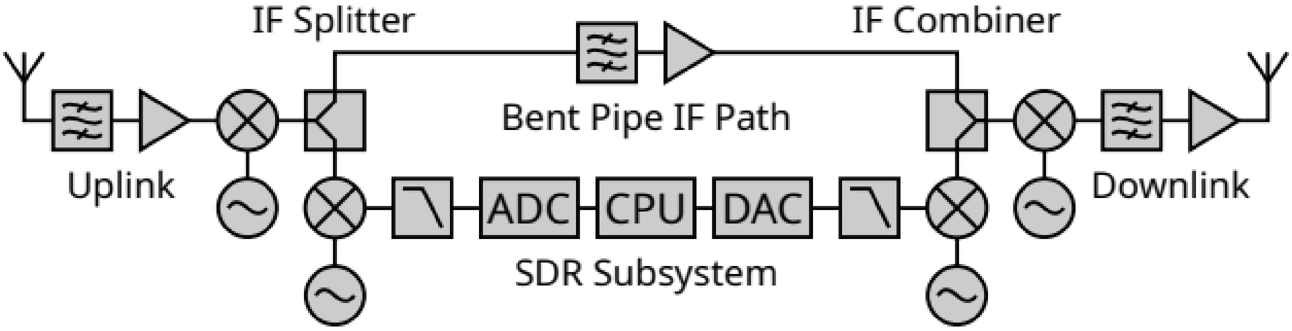


To support software-defined capabilities, the obvious approach is a fully SDR-based transponder. Such a design would downconvert the uplink frequency to baseband; low-pass filter it to avoid aliasing; digitise with an ADC; process in software; output analog baseband with a DAC; low-pass filter again; and then finally upconvert to the downlink frequency. The basic idea is shown below. Note that I am omitting some things from this diagram for simplicity, such as the use of quadrature conversion and sampling, which do not really impact the overall structure.



The key problem with this approach is that it is completely dependent on the software running on the CPU in the middle. That software would be critical to operation, and thus risky to modify. Software development, testing and approval would inevitably be an onerous process. And while the SDR could be configured to retransmit part of its input bandwidth unmodified, to function like a conventional bent pipe, there would inevitably be some degradation of retransmitted signals. This design would therefore represent a step backwards in support for simple analog modes.

However, it is possible to combine these approaches in a way that offers the best of both worlds. An SDR subsystem can operate alongside a conventional bent pipe within the same transponder, by using a passive splitter and combiner at the IF stage to share the uplink and downlink paths:



This architecture offers a lot of flexibility. With appropriate selection of LO frequencies and filter bandwidths, the transponder's uplink and downlink ranges can be divided up between the bent pipe and the SDR in any combination. Unlike a bent pipe, the SDR can have differing input and output bandwidths, so the uplink and downlink allocations need not be symmetric. The input sub-ranges may also overlap, allowing the SDR to "listen in" on transmissions within the bent pipe range.

The architecture is inherently fail-safe against an SDR fault. The original bent pipe path is unchanged, except that a little more gain must be used by the satellite to overcome splitter and combiner losses. No software error could prevent bent pipe operation. The worst-case failure mode is that the SDR would transmit erroneously within its own limited downlink sub-range until reconfigured, which would be done via the satellite's separate command and control receiver. If necessary, the SDR could be disabled completely, leaving a purely analog transponder.

A proven analog transponder design can be used, modified only with passive elements. In practice, splitters and combiners are often already present in the IF section to support additional subsystems alongside the linear transponder, e.g. a beacon source or command receiver. Adding an SDR subsystem only requires adding further branches to these existing elements.

In fact, multiple SDRs could be added in parallel, each with its own uplink and downlink sub-ranges. This would enable the provision of a "stable" SDR supporting satellite assisted modes for general use, and an "experimental" SDR on which new software could be tested, with minimal risk and without disrupting operation for users, allowing software development to be much less onerous.

A Minimal SDR for FUNcube+

I am currently working on a simple version of this concept for the AMSAT-UK FUNcube+ mission, aiming to use a low-power FPGA with ADCs and DACs at kHz-range sample rates to provide a basic SDR capability within the power and bandwidth constraints of a 2U cubesat.

We are particularly interested in the potential for FUNcube+ to receive multiple simultaneous uplink signals, across a bandwidth wide enough to avoid the need for Doppler corrections from the ground, whilst retransmitting messages on the downlink in a narrowband, coded form that minimises PA power requirements on the satellite and aids reception at ground stations.

As illustrated above, the SDR subsystem would be integrated alongside the existing linear transponder. This would use additional branches on the splitter and combiner that are already present in the 10.7MHz IF section of the FUNcube design.

Because of the constraints of the satellite, this SDR would be capable only of relatively simple narrowband modes, and developing software for it would be a fairly specialised process. However, it could still provide significant benefits as outlined above.

A larger GEO payload as envisaged by ESA could support a far more capable SDR platform, which would be accessible to a much wider audience of amateur developers, and support wideband modes.

Conclusion

Returning to Frank’s question for a GEO payload: *Analog, digital or complete on-board SDR?*

I argue that there is no need to choose: all of the above, please! These capabilities can be combined in a way that is flexible, fail-safe and which builds on proven transponder designs.

Putting a programmable SDR platform in orbit would provide an accessible and exciting testbed to support innovation in satellite communications. Such a platform would also enable the implementation of new satellite assisted digital modes, that could reduce link budget requirements and lower the barriers to participation for users.

Although it is possible to implement limited versions of these ideas on a cubesat scale, a new GEO payload offers a unique chance to deploy a much more capable and accessible platform. We should make the most of this rare opportunity.

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