Es'Hail-2: An Updated Look at Amateur Radio's 1st Geostationary Satellite

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Introduction

If all goes according to plan the Qatar Satellite Company's second satellite, Es'Hail-2, will be placed in a geostationary orbit by a Space-X Falcon-9 rocket within the next year. It will carry an AMSAT linear transponder as a secondary payload, giving amateurs for the first time access to a geostationary satellite.

The transponder uplink frequency will be 2.4 GHz, downlink frequency 10.489 GHz and the bandwidth 250 kHz.

The operational parameters of the transponder are analysed and possible technical solutions for the up- and downlink requirements are presented. Emphasis is placed on low cost equipment in the best Ham tradition.

A Brief History of Es'hailSat

Es'hailSat, the Qatar Satellite Company, was established in 2010. Es'hail-1, Qatar's first satellite, entered commercial service on 18 December 2013, Qatar's National Day. The soccer game between Paris St-Germaine and Real Madrid was broadcasted live in High Definition (HD) from Doha across the Middle East and North Africa. Current content include Al Jazeera and beIN Sport.

Es'hail-2 will provide additional capacity at the 25.5°East hotspot position for TV broadcasting. The cut-off date for proposals was 30 April 2014 with the expected launch during the second half of 2018 or even first half of 2019. It was originally planned for the second half of 2016.

Amateur Radio Payload

The Qatar Amateur Radio Society (QARS) managed to secure the privilege to have an Amateur Radio payload as part of Es'hail-2. Discussions regarding the payload were held with experts from AMSAT-DL, AMSAT-OH and AMSAT-UK. The flight model of the transponder is being built by AMSAT-DL.

Satellites in Geostationary Orbit

Geostationary orbit is a circular orbit above the equator with the orbital period equal to the Earth's rotational period. The satellite thus appears motionless at a fixed position in the sky to ground observers. This can only happen at an altitude of 35 786 km above mean sea level.

The previous high altitude amateur satellites were all in highly elliptical or eccentric orbits to increase the area covered and the time that the satellite is visible to the target area (on station). These satellites were referred to as Phase 3A (lost at launch), Phase 3B (AO 10), Phase 3C (AO 13) and Phase 3D (AO 40), that operated till 2004. Satellites in geostationary orbit are referred to as Phase 4 with Es'hail-2 being the first. It is referred to as Phase 4A. (There are currently other Phase 4 projects in development such as the one by AMSAT-NA but it will most probably no be visible from South Africa.)

The gain of an antenna on a geostationary satellite is limited by the area that needs to be covered (the satellite's footprint). With too much gain the beam width becomes very narrow leading to areas not being illuminated by the antenna on the satellite. This is the case for spot beams. In order to cover all the visible Earth from geostationary orbit the beam width may not be less than 17.4° leading to a maximum gain of ~20 dB as illustrated in Figure 1.

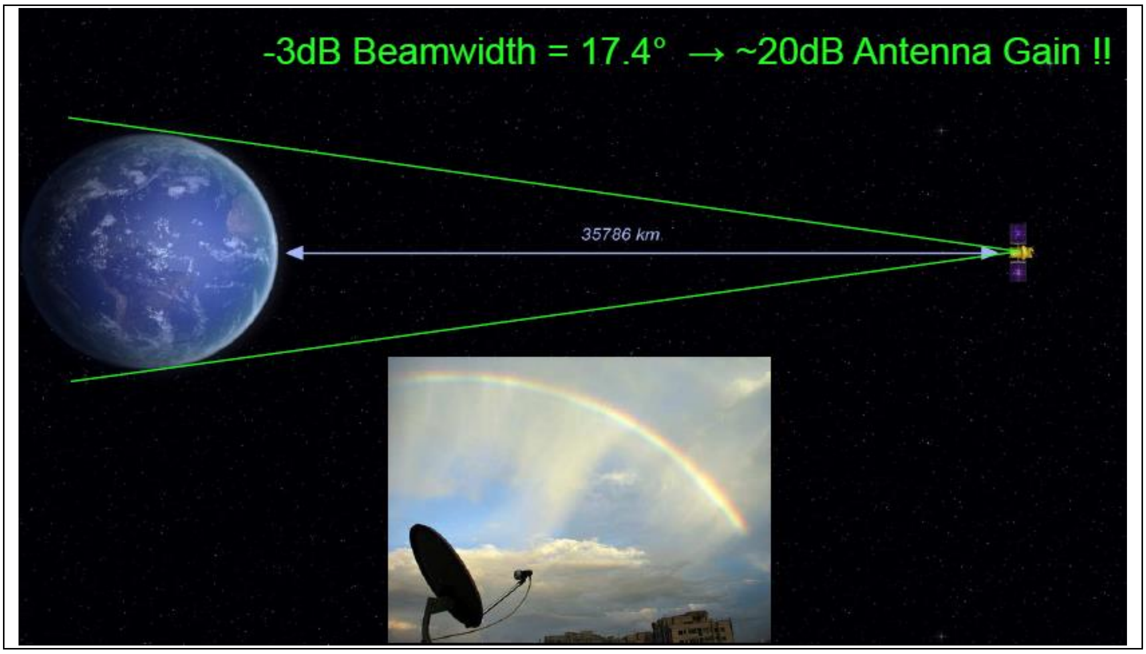

Figure 1: Angle of view from a geostationary satellite.

Es’hail-2 will be “parked” 35 786 km above the equator at 25.5°East, nearly due North from Pretoria and Johannesburg (which are at 28°E).

From Es’hail-2 the Earth will look as depicted in Figure 2.

Figure 2: Field of view from Es'hail-2.

Es'hail-2's footprint will cover a population of approximately 5.2 billion. This translates to more than 1.5 million Radio Amateurs in nearly 225 countries. This creates a golden opportunity for Hams wanting to achieve a DXCC via satellite.

A better idea of the countries that will be covered by Es'hail-2's footprint is given in Figure 3. Coverage includes the Eastern parts of Brasilia but not the mainland USA.

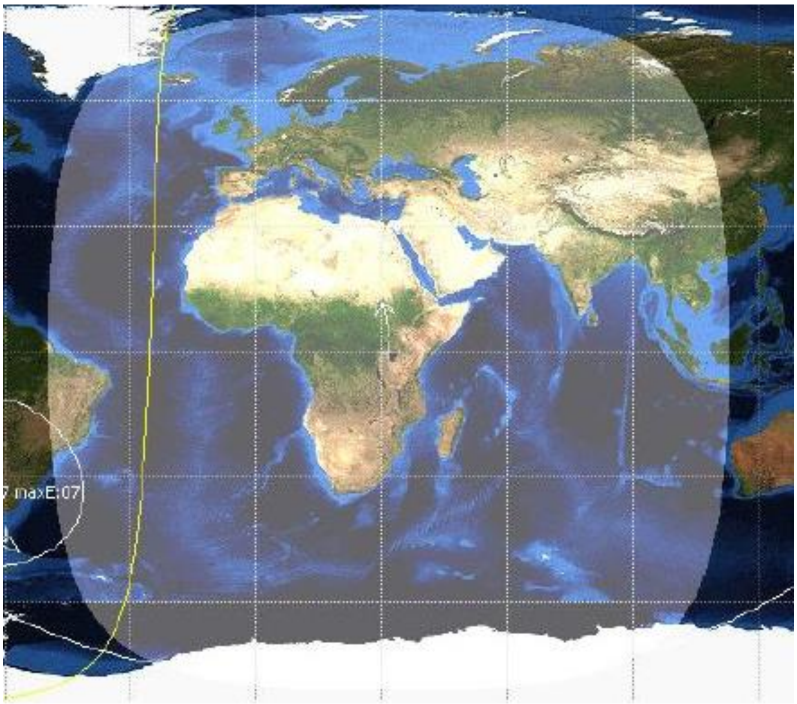

Figure 3: Es’hail-2’s footprint.

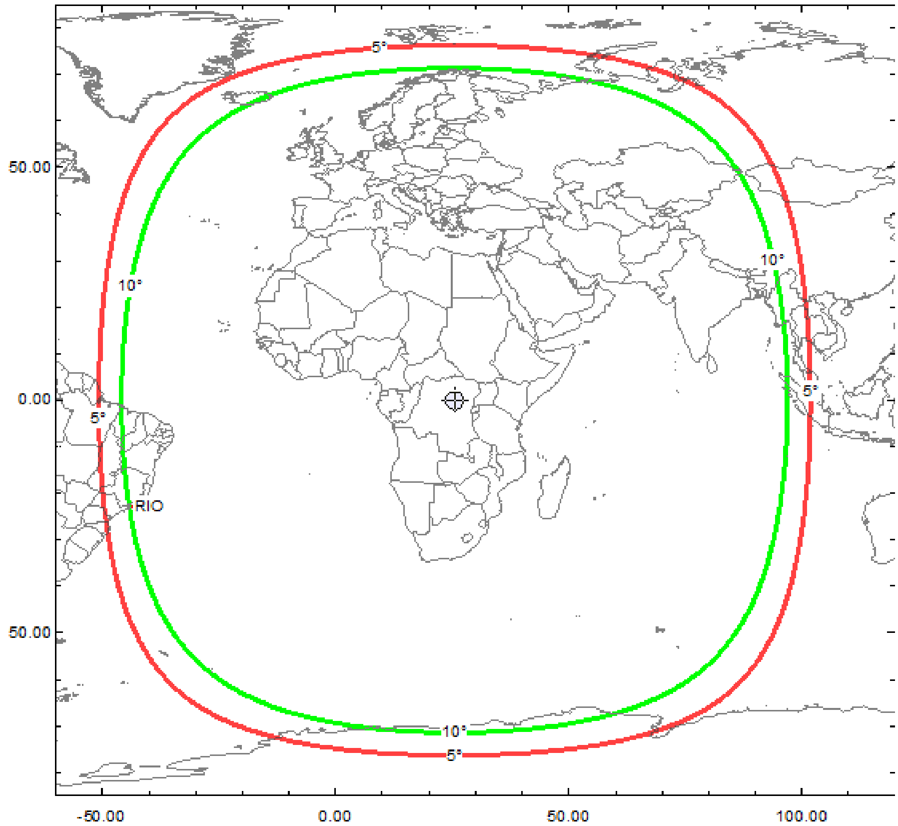

Figure 4: Another view of Es’hail-2’s footprint.

Es'hail-2 Linear Amateur Radio Transponder

The published uplink frequency is 2 400.050 to 2 400.300 MHz with the centre of the band being 2 400.175 MHz. Total bandwidth is thus 250 kHz and right hand circular polarization will be used.

The downlink frequency is 10 489.550 to 10 489.800 MHz with the centre of the band being 10 489.675 MHz. Vertical polarization will be used.

The preferred modes of operation will be SSB and CW. 5 Watt uplink power to a 60 to 75 cm offset dish should be more than sufficient for the uplink. The transponder will also be fitted with a "LEILA" (LEIstungs Limit Anzeige) input power limiter to ensure fair play and that the AGC of the transponder is not triggered (hogged) by a single, high power transmission, thus reducing the sensitivity of the satellite. In short, running higher uplink power than necessary will be counterproductive.

Possible Ground Station Solutions

A satellite transponder makes it possible to work full duplex. This simplifies the design of a ground station considerably as no transmit-receive switching, sequencers etc. are required. Things are even further simplified by using a separate transmit exciter and receiver.

2.4 GHz Uplink

Many satellite enthusiasts already possess an all mode 2m radio. This radio can be used to drive a linear up converter to generate the required 2 400 MHz signal. The linear up converter can be built according to the principles described by Paul, W1GHZ [1]. This modern approach making use of easily obtainable microwave components is considerably friendlier to the home brewer than previous approaches.

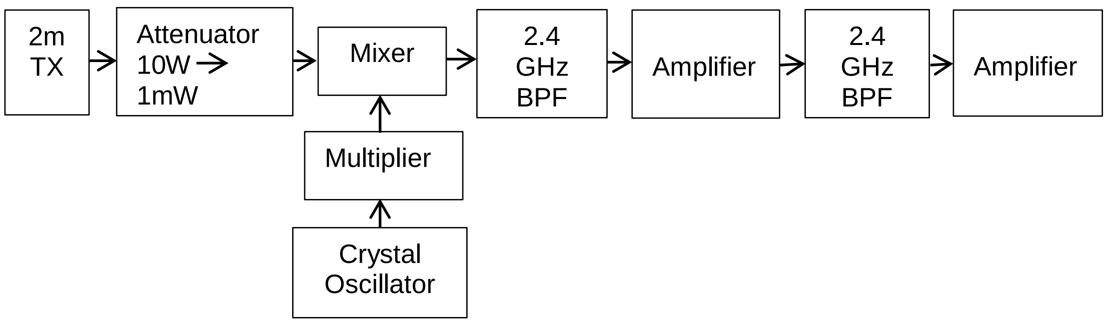

Figure 5: 2.4 GHz up converter block diagram.

10 Watt is a very common output power level for many all mode 2 m radios. This is way too much to drive a microwave mixer and an attenuator is required

to reduce the power level to the mixer to the 0 to 10 dBm level. A variable attenuator will help to optimally match the up converter to the 2 m radio used. Take note that some H/V/UHF radios such as the Icom IC706 may suffer from poor regulation of its output power. When the PTT is first pressed the radio may briefly transmit at full power before reducing its output to the required 10 Watt.

The low power 2 m signal is mixed with a +7 dBm, 2 256 MHz local oscillator signal. Passive diode ring mixers covering the 13 cm band are now available from manufacturers such as MiniCircuits. The mixer is used as an up converter, requiring that the 2m signal is fed to the IF port.

The output of the mixer is at the RF port and includes the sum of the LO and IF components at 2 400 MHz as well as the difference of the LO and the IF at 2 112 MHz. The wanted 2 400 MHz signal is selected by a bandpass filter with all the other frequency components being rejected by the filter.

The required bandpass filters, also referred to as cavity resonators [2] can be very cheaply constructed form copper pipe caps.

Figure 6: Copper pipe caps available from hardware and plumbing stores.

In South Africa the largest copper pipe cap easily available from hardware or plumbing stores has an internal diameter of 22 mm. This copper pipe cap should just be sufficient for the construction of a cavity filter covering the required 2.4 GHz frequency range.

The pass frequency is adjusted with the aid of a brass screw that changes the resonant frequency of the cavity.

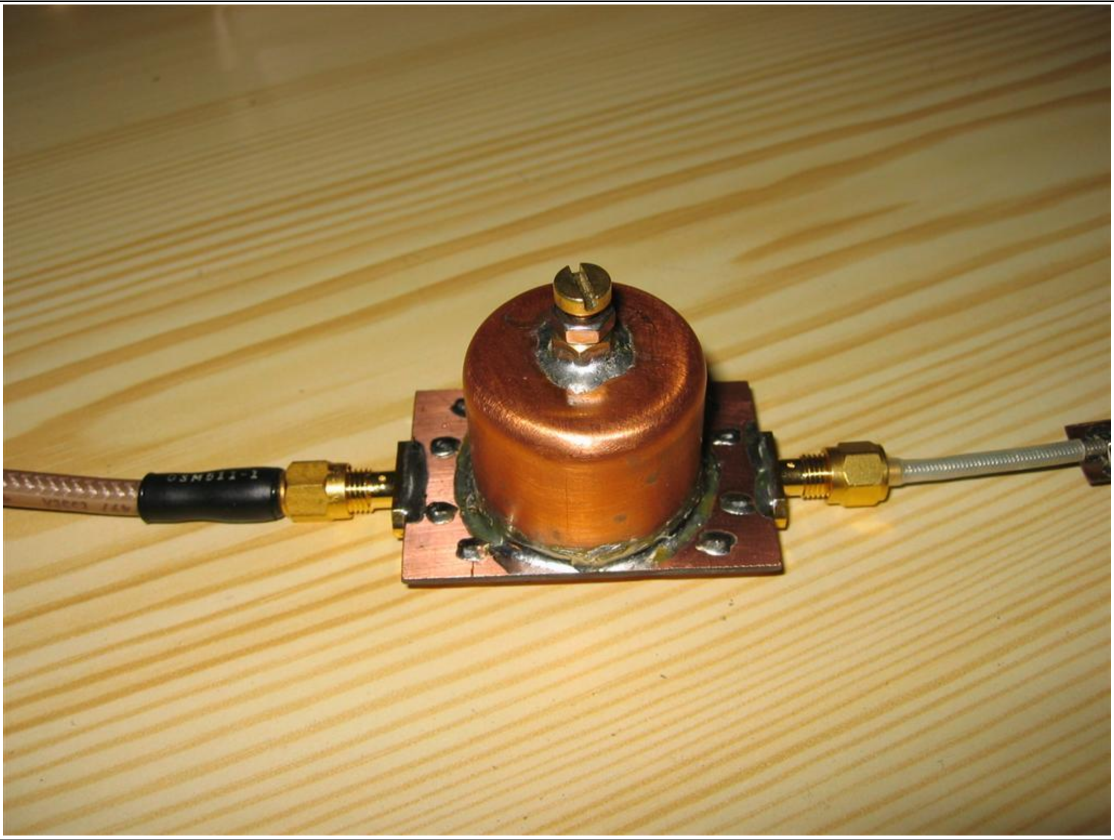

Figure 7: Example of a copper pipe cap bandpass filter.

The 2 400 MHz output of the bandpass filter is amplified by a low cost microwave monolithic integrated circuit (MMIC). The output of the MMIC is once again filtered by another bandpass filter to ensure spectral purity. The output of the bandpass filter is once again amplified.

The up converter should ideally be capable of delivering +20 dBm (100 mWatt) at 2.4 GHz. Low cost MMICs start to compress before the +20 dBm level. For that reason two of them are combined to ensure linear operation at the required 100 mWatt output level.

Many Chinese high power amplifiers are now available for the 2.4 GHz Wi-Fi band. In South Africa these amplifiers are illegal for Wi-Fi use but 100% legal for Amateur Radio applications. Specified frequency range is 2.3 to 2.5 GHz which suits us fine. Required drive power is typically +20 dBm with a gain of 17 dB. This translates to an output power level of 5 Watt or +37 dBm. Automatic T/R switching that senses the input port is also incorporated to further simplify matters. Suitable, unpackaged units can be procured overseas for as little as $30, including shipping to South Africa [3].

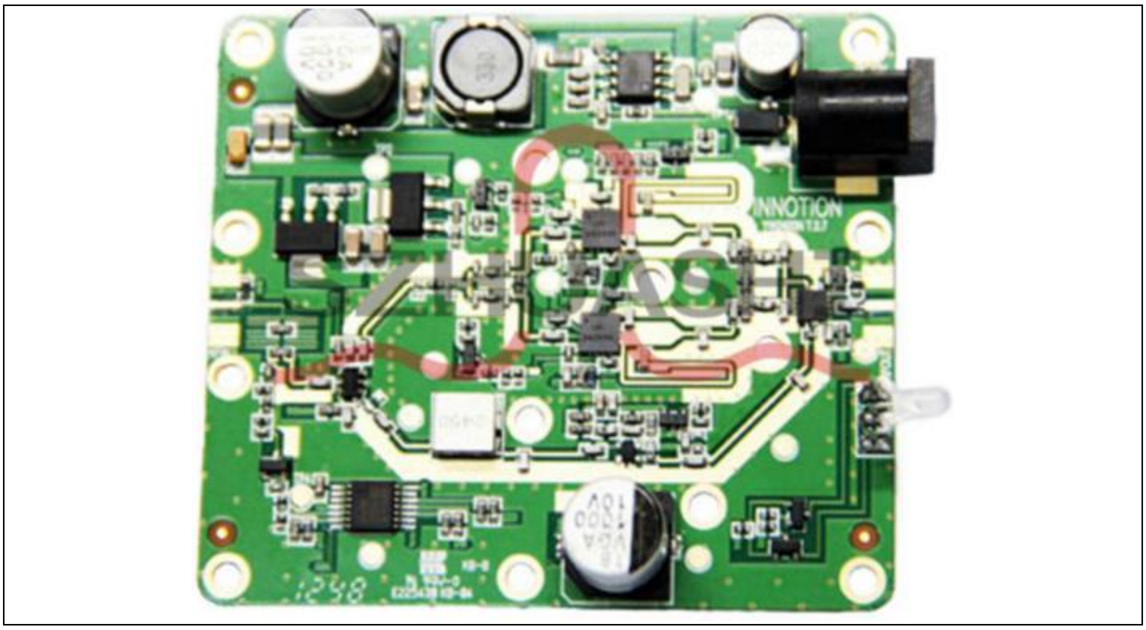

Figure 8: Unpackaged, low cost, 5 Watt, 2.4 GHz amplifier available from China.

This amplifier still requires suitable (SMA or N) connectors and must be built into an enclosure with the necessary heat sinking provided for the power transistors.

Properly packaged, “outdoor” amplifiers can be had for around $50 [4]. This includes a power supply and a few other accessories.

Ensure that the chosen amplifier has a gain of 17 dB. There are versions available with 13 dB gain, but this is too little to get to the 5 Watt level with a drive power of 100 mW.

Figure 9: Packaged, 5 Watt, 2.4 GHz amplifier available from China.

The up converter requires a 2 256 MHz LO signal at +7 dBm. This can be supplied by a crystal oscillator driving a MMIC into saturation and the required harmonic once again selected by a copper pipe cap filter [5].

Another option is the ADF4351 PLL evaluation board that is available from online Chinese suppliers at reasonable cost (~$30).

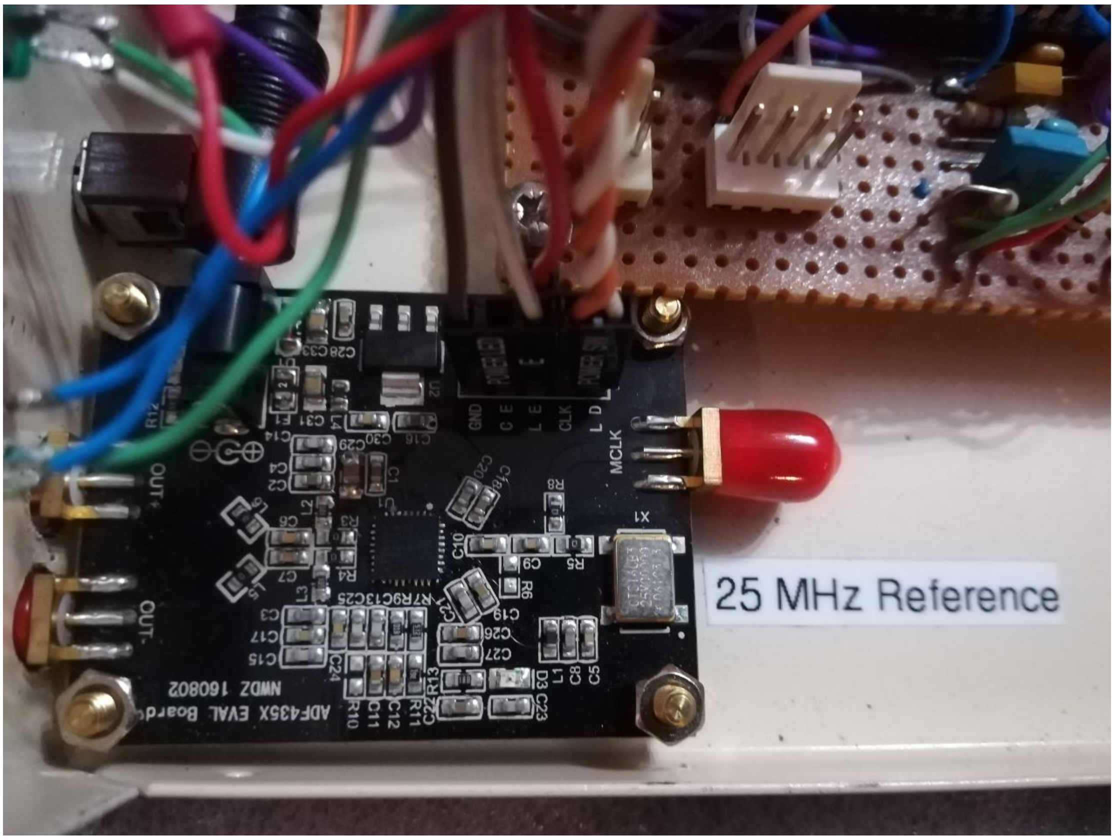

Figure 10: ADF4351 evaluation board.

The frequency coverage of the evaluation board is amazing and spans from 35 MHz to 4.4 GHz. The output power level is adjustable between -4 and +5 dBm. This evaluation board is also very useful as a LO for other microwave transverters for the 23 cm and even 70 cm bands. Information on how to control the ADF4351 with the aid of a PIC is available from PA0RWE's website [6].

Figure 11: ADF4351 VFO as built by ZS6BZP.

10 GHz Receiver

The 10.4898 GHz signal from Es'Hail-2 needs to be down converted to a much lower frequency for filtering and demodulation. It is possible to construct your own 10 GHz down converter but a much easier (and cheaper) option is to make use of a commercial Ku-band satellite Low Noise Block (LNB) down converter such as used for DSTV reception. The IF output of the LNB is fed to a suitable VHF receiver than can demodulate CW and SSB.

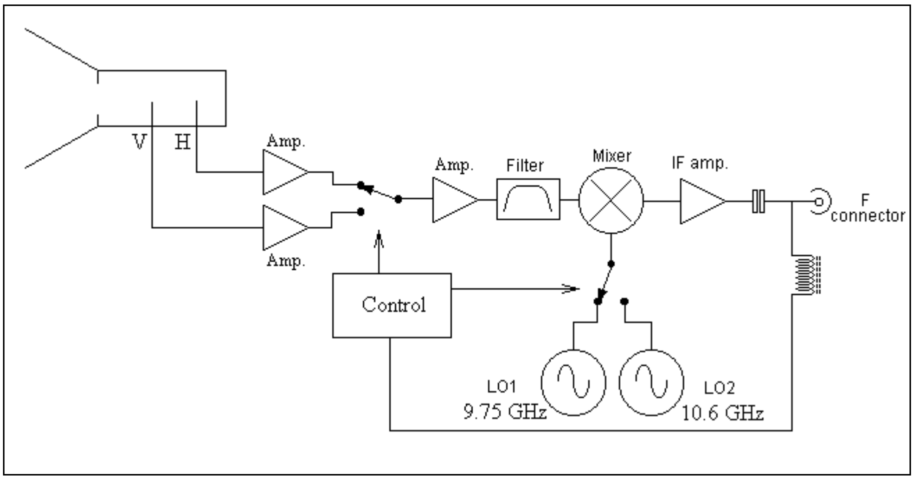

Figure 12: Universal Ku-band LNB block diagram [6].

The Universal LNB incorporates a circular waveguide to effectively illuminate the offset-feed parabolic dish antenna. Inside the waveguide are a vertical waveguide to coax and a horizontal waveguide to coax converter. These converters are simple waveguide probes directly connected to very low noise, GaAsfet amplifiers (LNAs). (Never touch these probes as the amplifiers will probably be destroyed by the static charges on your body.) The noise figures of these LNAs are typical <0.5 dB with values as low as 0.1 dB claimed by some (Chinese) manufacturers. Supplying the LNB with 12 V will select one of the polarizations and 18 V will select the other.

Although the LNB is designed for an input frequency range of 10.7 to 12.5 GHz, the filter preceding the mixer is usually wide enough to enable reception of signals as low as 10.250 GHz with minimal loss. This is very useful for operation on the 3 cm (10 to 10.5 GHz) amateur band.

A 22 kHz tone imposed on the supply voltage selects the 10.6 GHz local oscillator (LO2 in Figure 12). With no tone present the 9.75 GHz local oscillator (LO1 in Figure 12) is selected. A Dielectric Resonator (DR) is used for the local oscillator. Measurements have shown that although the DRO is stable enough for wideband TV or FM signals, it will not be suitable for the reception of narrowband CW and SSB signals. Freely available DSTV LNB's will not be the answer for receiving the 10.4848 GHz Es'hail-2 downlink.

Various techniques are available to suitably stabilise the LNB DRO. Injection locking is probably the easiest but lots of experimenting and advanced test equipment will be required to develop a suitable solution. Fortunately, technology is advancing at a rapid rate and high stability LNBs are now available at a very reasonable price. The Avenger Universal Single High Stability PLL2 LNB uses advanced phase locked loop (PLL) techniques to lock the LO's to a stable, crystal controlled reference oscillator. Tests have shown that the stability of the Avenger PLL2 is adequate for our requirements. It has also been confirmed that the input bandwidth of the Avenger PLL2 extends down to at least 10.250 GHz. For DSTV applications the exact LO frequency is not critical, with the result that the accuracy (precision) of the LO signal is not that good. This is not a problem as it is an easy matter to compensate for this fixed IF offset.

Figure 13: Avenger PLL321S-2 Single High Stability LNB.

Another possible option is the European Octagon Single LNB OPTIMA. This LNB also features a high stability PLL local oscillator and seems to be the weapon of choice for German Radio Amateurs.

Figure 14: OCTAGON OSLO Single High Stability LNB [7].

To ease the ground station's power supply requirements a single 12 V supply can be utilised. The 9.75 GHz LO is then selected. When Es'hail-2's 10.489.7 GHz signal is mixed with the 9.75 GHz LO signal, an IF of 739.7 MHz is obtained. The LNB is designed for an IF output of 950 to 2 150 MHz but once again the losses associated with working outside the official frequency range are acceptable. 739.7 MHz is not near any of the amateur radio bands but fortunately modern, low cost USB SDR dongles cover this frequency range. Using a SDR solution brings all the benefits of spectrum and waterfall displays as well as "click and tune" operation. The spectrum and waterfall displays also make finding your own transmission infinitely easier. The higher performance FunCube+ dongle is also an excellent choice.

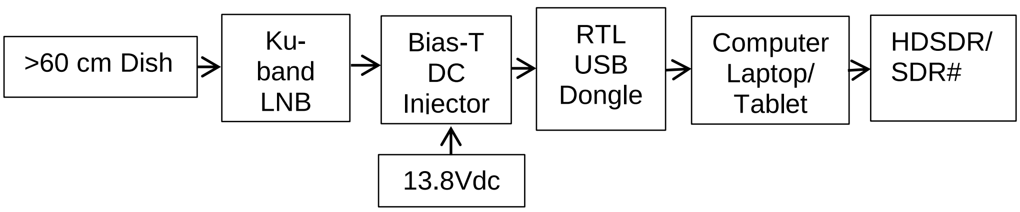

Figure 15: Possible Es'hail-2 receiver chain block diagram.

Conclusion

Not long ago operating CW or SSB on the 2.4 and 10 GHz amateur bands presented formidable technical challenges. Fortunately there are now commercial products available that can be "repurposed" to operate Amateur Radio's first geostationary satellite, Es'hail-2 on the cheap.

DSTV dishes with a diameter as small as 60 cm will suffice for both the 2.4 GHz uplink as well as the 10.4898 GHz downlink, although diameters of 75 cm will ensure some margins. On the receive side a high stability Ku-band LNB in the form of the Avenger PLL2 or the OCTAGON OSLO that feeds a RTL or FunCube dongle based SDR is all that is required. Activity on the 250 kHz wide transponder downlink can be monitored with the aid of a spectrum or waterfall display on a laptop or even a tablet.

A multimode 2m radio forms the basis of the 2.4 GHz uplink. A crystal controlled up converter with an output power level of 100 mW (+20 dBm) is all that is required to drive a 2.4 GHz, 5 Watt Wi-Fi "signal booster".

With a footprint that covers 225 countries, a new area in working DX via satellite will be heralded once Es'hail-2 is "parked" above the equator at 25.5°East.

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