C/X Digital Transponder for Eagle

J. B. Stephensen – AMSAT-NA

The Eagle class 2 and class 3 downlink and class 2 uplinks require bandwidth that is only available in the bands above 1 GHz. Only the microwave bands are considered as the millimeter-wave bands suffer from excessive atmospheric attenuation at low elevations. There are 7 microwave bands allocated for the amateur satellite service on a worldwide basis as shown in table 1, below.

Band	Frequency	Direction	Other Uses
L	1,260-1,270 MHz	Up	Galileo
S_1	2,400-2,450 MHz	Up/Down	WiFi
S_2	3,400-3,410 MHz	Up/Down	(regions 2&3 only)
C	5,650-5,670 MHz 5,830-5,850 MHz	Up Down	WiFi -
X	10,450-10,500 MHz	Up/Down	-

Table 1 – Microwave Amateur Satellite Bands

Wide-band uplinks on L band may cause interference to Galileo receivers operating in the 1215-1300 MHz radionavigation band so it is desirable to avoid use of the L band for wide-band satellite uplinks. Narrow-band signals may fit in the null shown in figure 1 but wide-band signals will cause more interference. L is also not the best band for small antennas as a 2-foot dish is only 2.5λ wide and cannot be fed efficiently.

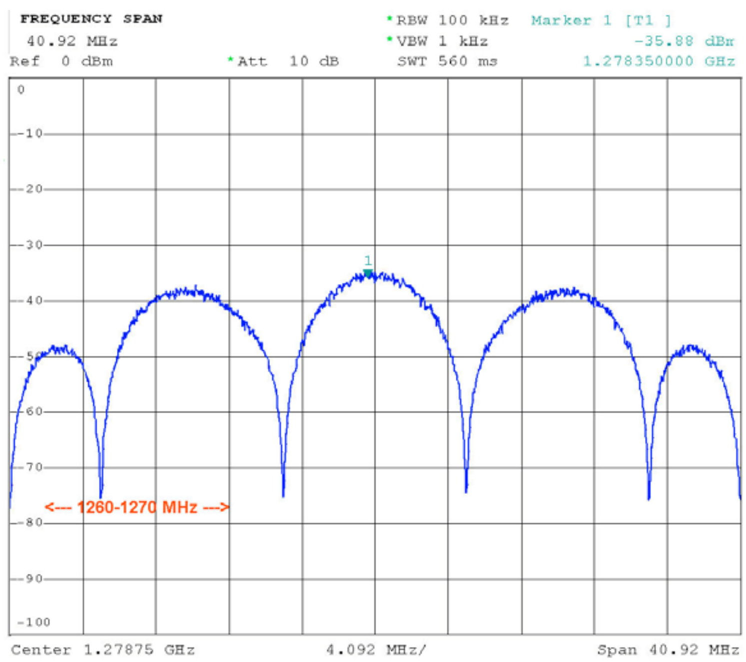

Figure 1 – Galileo Downlink Signal

The WiFi equipment operating in the 2400-2483 MHz ISM band is a source of interference, so it is useful to avoid the S_1 band for satellite downlinks. The S_2 band is not allocated for region 2 (Europe) so it is also undesirable. This results in two potential frequency pairs for digital transponders – S_1/C and C/X.

S_1/C has two problems – S_1 is unavailable in Argentina and some AMSAT members want S_1 used as a downlink for a L/S or U/S analog (SSB, CW, etc.) transponder. The digital transponder should be available throughout the orbit so sharing S for a digital uplink and analog downlink is not feasible.

The lower frequency pair, S_1/C, was deemed to be the most desirable as LNA noise figures are slightly lower, PA efficiencies may be slightly higher and the required antenna pointing accuracy is lower. However, the magnitude of these effects is much smaller today than in the past. C-band LNA ICs are now available with a 1.3 dB noise figure and X-band discrete-component LNA noise figures have been 0.9 dB or less for almost a decade. Power amplifier ICs are now available for both the C and X bands with ½ to 2 W RF outputs and X-band PA efficiencies are now 30%.

For a 2-foot dish, the C/X antenna is also more efficient than an S/C antenna. The reflector size at the lowest frequency increases from 4.5λ to 10λ so the feed is smaller. This reduces blockage and increases gain for both the uplink and downlink.

Antenna pointing accuracy is an issue as the -3 dB beamwidth decreases from 6.2° to 3.3°. However, since the pointing accuracy must be much greater than the ±4° of Yaesu rotators used for VHF/UHF antenna arrays, the difference between C and X bands should not significantly affect the cost. The position can be determined to less than 0.5° by counting shaft rotations on positioning motors or a combination of mechanical and electrical steering can be used. The narrower beamwidth has one advantage – the satellite can be lower on the horizon before thermal noise from the earth degrades the system noise figure.

Antenna size is not a problem. The downlink antenna gain cannot exceed 18 dBic, as it must illuminate the earth. 25 elements can provide this gain and 36 elements provide redundancy in case the electronics for some elements fails. Therefore, a 36-element X-band antenna is smaller than a C-band antenna, but the EIRP is the same. The earth-based downlink receiver will have the same aperture on either band, so the gain increases by 5 dB from C to X band, which compensates for the increase in path loss. The gain of the fixed-size earth-based uplink antenna also increases to compensate for increased path loss from S to C band, so moving from an S to C uplink does not require an increase in the number of elements. This frees up space on the satellite for other antennas or for more solar cells. Alternatively, the satellite may be smaller. Figure 2 shows the approximate size of the 36-element C and X arrays along with V and U antennas.

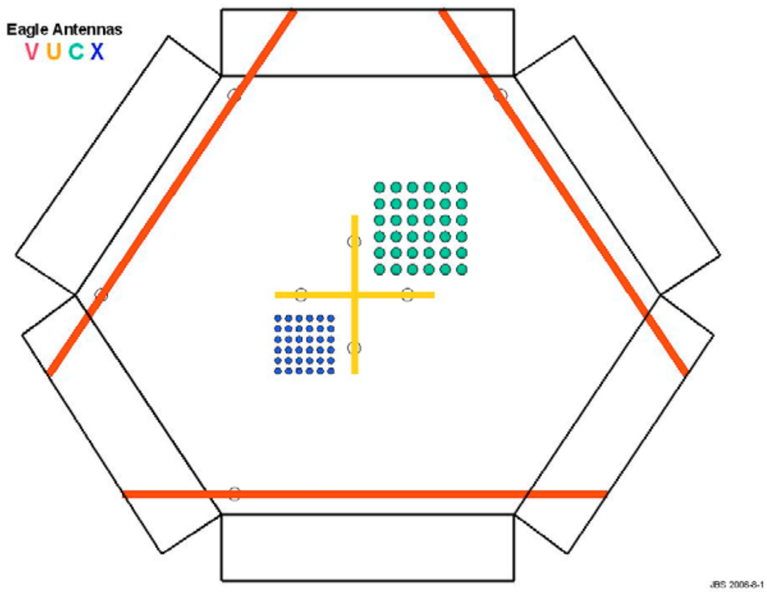

Figure 2 – Antenna Placement on 600 mm per side Hexagonal Spaceframe

The link analyses for the C uplink and X downlink are shown in tables 2 and 3, below. 5 dB of implementation loss is assumed – 2 dB is for antenna pointing errors and 3 dB for miscellaneous losses.

	A	B	C	D	E	F	G	H	I
1	Ground:								
2	#Tx Pwr	5.0	W	Carrier	0.19913492	W	3.98%		
3	#Ant Gain	28.009626	dBi	Eb	199.134925	µJ	96.02%		
4	#Impl Loss	2	dB						
5	#Dish diam	0.6	m	(Gain)	28.009626	dBi	Beamwidth	6.17498684	deg
6				EIRP	33.0	dBW			
7	Path:								
8	#Range	40000	km						
9	#Freq	5660	Mhz	Wavelength	0.05300353	m	Path loss	199.5	dB
10	Spacecraft:								
11	#Ant Gain	18	dBi						
12	#Impl Loss	3	dB	Rx Power	-151.5	dBW	G/T	-13.1	dB/K
13	#Noise Temp	640	K	No	-200.5	dBJ			
14				Rx P/No	49.0	dB-Hz			
15	#C loop BW	100	Hz				Mod index	78.4883609	deg
16	#C SNR	15	dB	C/No	35.0	dB-Hz	Mod loss	0.18	dB
17	#Eb/No	5	dB	Data rate	24109	b/s	Carrier loss	14.00	dB
18									
19	KD6OZH 16 Sep 2006								

Table 2 – Uplink Characteristics

The uplink assumes the use of four Hittite HMC408 power amplifier ICs in the ground station. Each produces 1.6 W RF output and after combining and transmission line losses, 5 W is assumed to arrive at the 2-foot dish antenna to create 3.2 kW EIRP. The satellite receiver is assumed to use Avantek MGA-665P8 LNA ICs and have a noise figure of 3 dB. The typical noise figure of each IC is 1.5 dB with a 1.9 dB absolute maximum. 1.1 dB of PCB and transmission line loss and 60 K of noise from earth-based 802.11 devices are assumed.

	A	B	C	D	E	F	G	H	I
1	Spacecraft:								
2	#Tx Pwr	18	W	Carrier	0.04667225	W	0.26%		
3	#Ant Gain	18	dBi	Eb	46.672248	µJ	99.74%		
4	#Impl Loss	2	dB	EIRP	28.6	dBW			
5	Path:								
6	#Range	40000	km						
7	#Freq	10460	Mhz	Path loss	204.9	dB			
8				Wavelength	0.02868069	m			
9	Ground:								
10	#Dish diam	0.6	m	Gain	33.3439311	dBi	Beamwidth	3.34134087	deg
11	#Ant Gain	33.3439311	dBi						
12	#Impl Loss	3	dB	Rx Power	-146.0	dBW	G/T	8.6	dB/K
13	#Noise Temp	150	K	No	-206.8	dBJ			
14	#Rx P/No				60.9	dB-Hz			
15	#C loop BW	100	Hz				Mod index	87.081205	deg
16	#C SNR	15	dB	C/No	35.0	dB-Hz	Mod loss	0.01	dB
17	#Eb/No	5	dB	Data rate	384668	b/s	Carrier loss	25.86	dB
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Downlink / Uplink / Voyager 1 Link Budget

Table 3 – Downlink Characteristics

The satellite downlink uses 36 M/A-COM MAAPGM0034 power amplifier ICs. They provide 500 mW saturated output with a 30% power-added efficiency, so an array of 36 provides 18 W RF power output and 1.1 kW EIRP with 60 W DC power input. The ground-station receiving system has a 1 dB NF LNA, transmission line losses are 0.5 dB and antenna side-lobe levels are -10 dBc.

The receivers and transmitters must have local oscillators with low enough phase noise so as not to significantly affect the carrier tracking and demodulation of the data links. Requirements have not yet been provided by the digital payload designers, but the requirements of class 2 and 3 links at C/X should not be harder to meet than class 1 links at U/V. Since class 1 and 2 downlinks operate at 20 times the data rate of uplinks, the uplink requires the lowest phase noise. The class 1 service is 30-50 bps with an uplink at 435 MHz. The class 2 service is 4800 bps with an uplink at 5660 MHz. Thus the data rate for class 2 is at least 96 times higher than class 1, but the uplink frequency only increases by a factor of 10.7 when going from 436 to 5660 MHz. This should allow the use of relatively simple LOs for C band.

A digital C/X transponder looks feasible for Eagle and frees up S_1 for a L/S_1 analog transponder. This document can be updated once phase noise requirements are available.