L/S_1 vs. U/V Transponders

J. B. Stephensen, AMSAT-NA

Since I'm likely to be the person designing the L-band receiver, at least for an analog transponder, I decided that I'd better look at its requirements. This is especially important if it is to become the primary transponder for class 0 (analog) and class 1 (low-speed digital) users in conjunction with an S_1-band transmitter. In this document, I compare the two uplink choices and what it would take to make an L uplink provide the same services as a U uplink. Each potential configuration is then examined with the spreadsheet provided by KA9Q. I also look at the downlink choices.

1. L and U Uplinks

We currently have 2 services using the U receiver – class 0 analog users with 2.5 kHz wide SSB signals and class 1 users with 30-50 bps BPSK signals. The class 0 users have a 1 kW EIRP uplink signal using a directional antenna and the class 1 users have minimal power into an omnidirectional antenna. If we want both services to work as designed, the receiver and antenna on the satellite should be designed to provide the same SNR with the same uplink EIRP. Table 1 shows the receiving system characteristics.

Band	U	L
Relative Propagation Loss	0 dB	+9.5 dB
Receiver Noise Figure	7 dB	3 dB
Total Relative Loss	0 dB	+5.5 dB

Table 1 – U and L Uplink Comparison

Propagation loss increases by about 9.5 dB due to the tripling of the uplink frequency, but that is offset to some extent by a lower receiver noise figure. The U receiver noise figure is high in order to tolerate PAVE PAWS interference. At L-band a 1.5-2 dB NF LNA IC with higher gain may be used to decrease the system noise figure. In order to maintain parity with the U uplink, an L uplink needs 5.5 dB more antenna gain. This can be achieved by using an array of 4 patch antennas or 4 crossed dipoles. The array would be square and about 250-mm sides and could fit in one corner of the satellite. Another option is a helical antenna, which trades area for length.

As the satellite moves through its orbit, the squint angle changes from 0° at apogee to 45° at MA32 and MA224 at the sub-satellite point or center of the footprint. At the earth's limb, the squint can reach 60°. The U receiver can operate over 75% of the orbit with a single crossed-dipole or patch antenna due to the lower propagation loss. This type of antenna can cover ±60° at the -3 dB points. The gain of the L antenna reduces coverage.

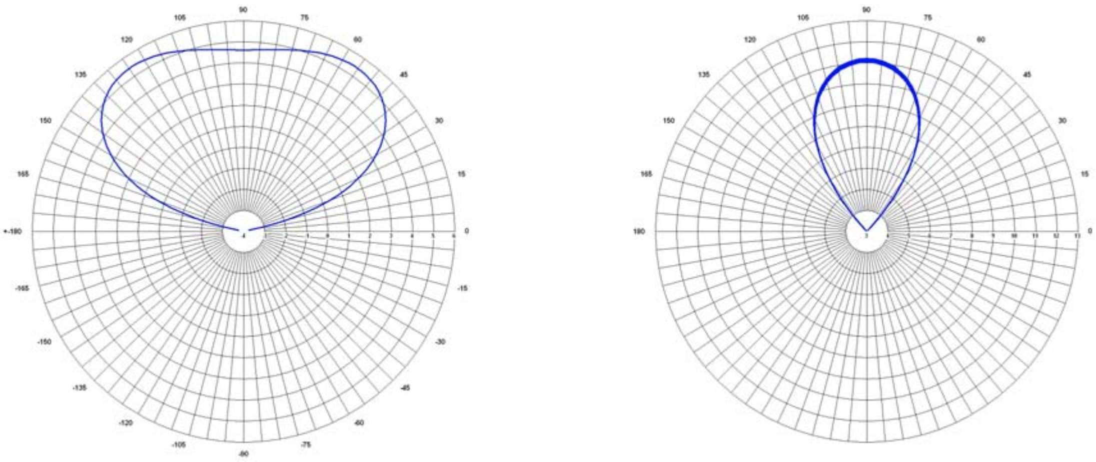


Figure 1 – Radiation patterns for fixed U (left) and L (right) Antennas.

The U and L receivers require antennas with approximately 5 and 11 dBic of gain, respectively, to support uplinks using the same ground station EIRP. If the L uplink is only to be used near apogee, its antenna can be a fixed array of 4 patches or a single helical antenna. However, the pattern for this antenna is only 50° wide at the -2 dB points compared to 120° for the U antenna. Figure 1 shows the radiation patterns of U and L antennas with the required gain.

If the L uplink is to be used as the primary uplink for an analog transponder and/or the primary uplink for a digital transponder, it must be electrically steered. A phased array of 4 patches or 4 crossed-dipoles is then required. This is not the ideal size for a phased array, but the beam can be steered ±45° and is only 2 dB down at ±60°. The receiver must then have 4 inputs with a variable phase shift on each. The receiver LO could do the phase shifting or 4 outputs could be provided and the phase shifting done at baseband in the digital payload.

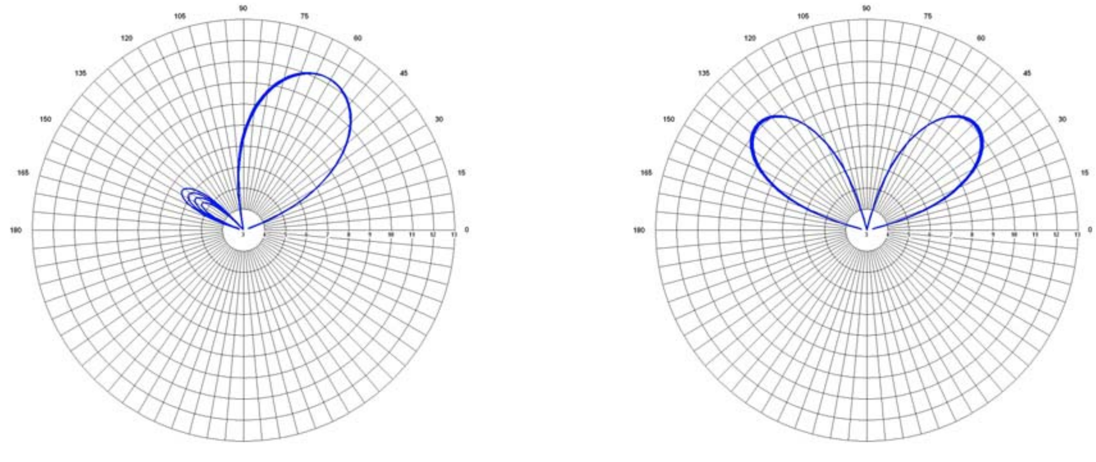
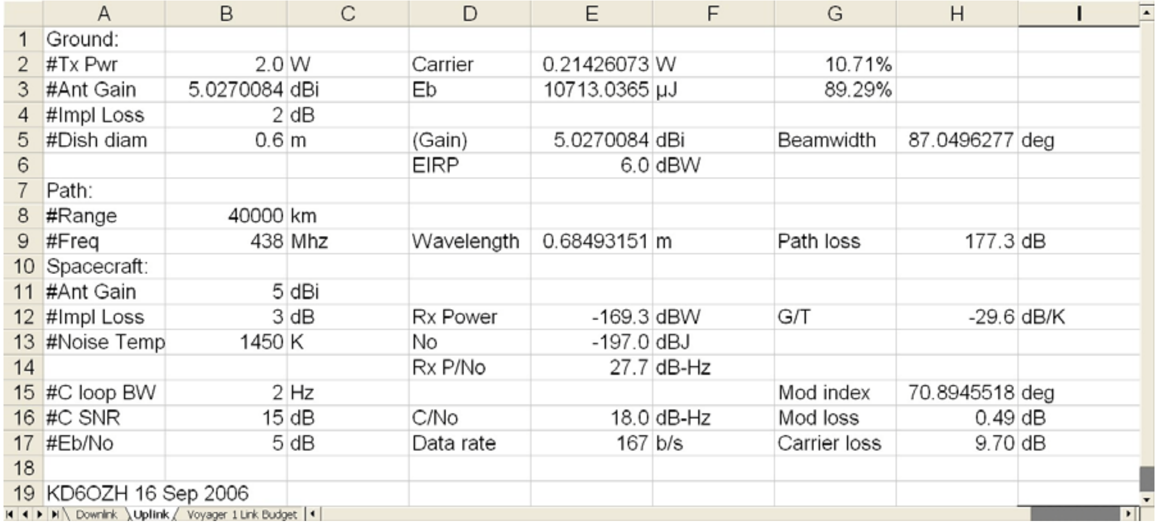


Figure 2 - 4-element Phased Array Radiation Patterns (90° & 180° Phasing)

Assuming a 2 dB feedline loss at the ground station, the additional satellite antenna gain allows class 0 users to operate with a single long Yagi antenna (20 dBi) and a 30 W power amplifier or two long Yagi antennas and a 15 W power amplifier. Class 1 low-speed digital users may continue to use an omnidirectional antenna, such as crossed dipoles above a ground plane or a single patch antenna. Tables 2 and 3 compare U and L uplinks for class 1 users.



	A	B	C	D	E	F	G	H	I
1	Ground:								
2	#Tx Pwr	2.0	W	Carrier	0.21426073	W	10.71%		
3	#Ant Gain	5.0270084	dBi	Eb	10713.0365	µJ	89.29%		
4	#Impl Loss	2	dB						
5	#Dish diam	0.6	m	(Gain)	5.0270084	dBi	Beamwidth	87.0496277	deg
6				EIRP	6.0	dBW			
7	Path:								
8	#Range	40000	km						
9	#Freq	438	Mhz	Wavelength	0.68493151	m	Path loss	177.3	dB
10	Spacecraft:								
11	#Ant Gain	5	dBi						
12	#Impl Loss	3	dB	Rx Power	-169.3	dBW	G/T	-29.6	dB/K
13	#Noise Temp	1450	K	No	-197.0	dBJ			
14				Rx P/No	27.7	dB-Hz			
15	#C loop BW	2	Hz				Mod index	70.8945518	deg
16	#C SNR	15	dB	C/No	18.0	dB-Hz	Mod loss	0.49	dB
17	#Eb/No	5	dB	Data rate	167	b/s	Carrier loss	9.70	dB
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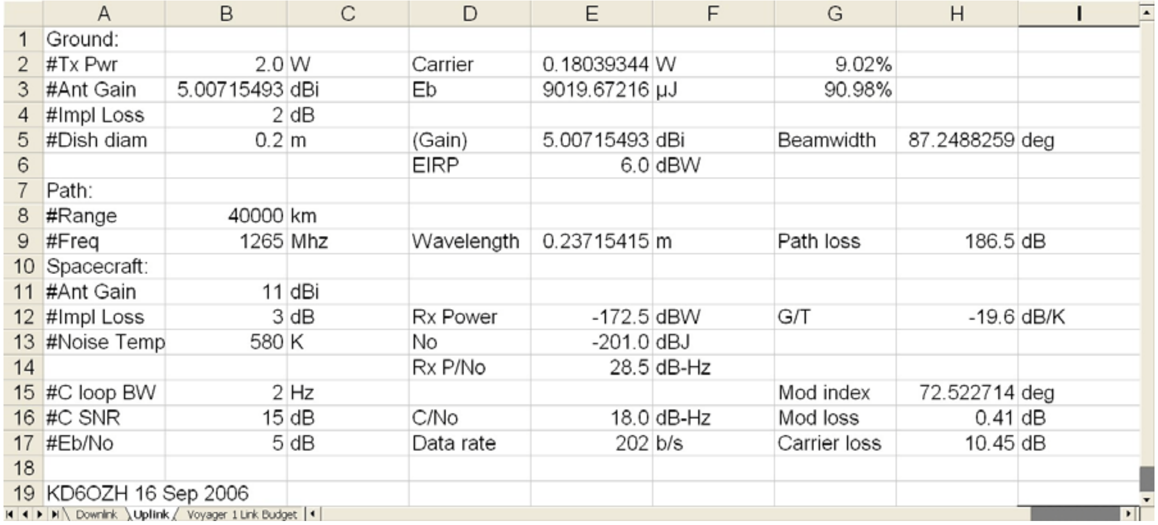
Table 2 – Class 1 U Uplink Characteristics



	A	B	C	D	E	F	G	H	I
1	Ground:								
2	#Tx Pwr	2.0	W	Carrier	0.18039344	W	9.02%		
3	#Ant Gain	5.00715493	dBi	Eb	9019.67216	µJ	90.98%		
4	#Impl Loss	2	dB						
5	#Dish diam	0.2	m	(Gain)	5.00715493	dBi	Beamwidth	87.2488259	deg
6				EIRP	6.0	dBW			
7	Path:								
8	#Range	40000	km						
9	#Freq	1265	Mhz	Wavelength	0.23715415	m	Path loss	186.5	dB
10	Spacecraft:								
11	#Ant Gain	11	dBi						
12	#Impl Loss	3	dB	Rx Power	-172.5	dBW	G/T	-19.6	dB/K
13	#Noise Temp	580	K	No	-201.0	dBJ			
14				Rx P/No	28.5	dB-Hz			
15	#C loop BW	2	Hz				Mod index	72.522714	deg
16	#C SNR	15	dB	C/No	18.0	dB-Hz	Mod loss	0.41	dB
17	#Eb/No	5	dB	Data rate	202	b/s	Carrier loss	10.45	dB
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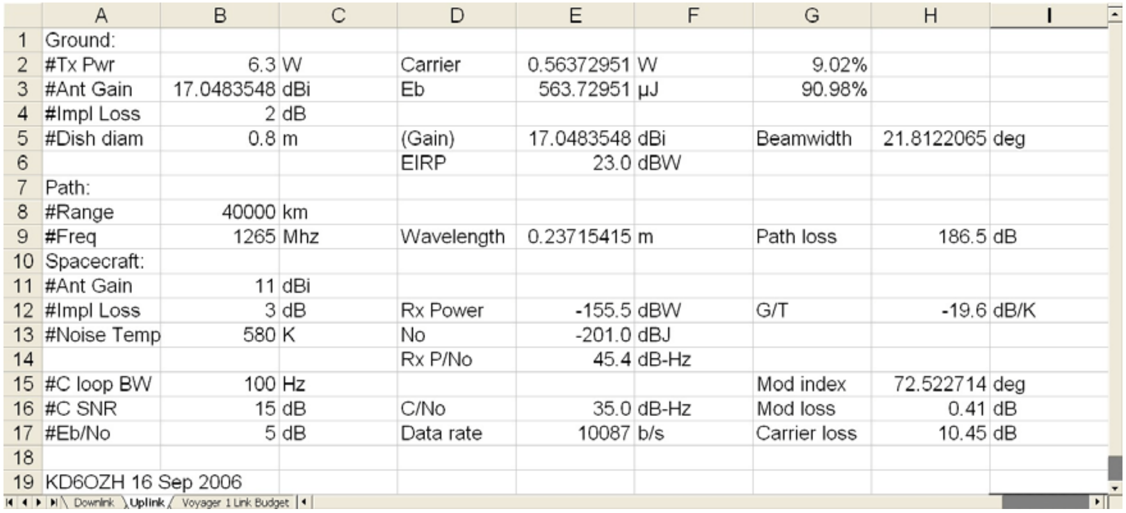
Table 3 – Class 1 L Uplink Characteristics

The power level for class 0 users for both U and L uplinks is 10 W EIRP. This is well below the level of most 23 cm mobile radios so is less likely to cause interference in the 1215-1300 MHz radionavigation band.

The L-band uplink can also be used for class 2 medium-speed digital (4800 bps) and class 3 high-speed digital (256 kbps) users as shown in tables 4 and 5.



	A	B	C	D	E	F	G	H	I
1	Ground:								
2	#Tx Pwr	6.3	W	Carrier	0.56372951	W	9.02%		
3	#Ant Gain	17.0483548	dBi	Eb	563.72951	µJ	90.98%		
4	#Impl Loss	2	dB						
5	#Dish diam	0.8	m	(Gain)	17.0483548	dBi	Beamwidth	21.8122065	deg
6				EIRP	23.0	dBW			
7	Path:								
8	#Range	40000	km						
9	#Freq	1265	Mhz	Wavelength	0.23715415	m	Path loss	186.5	dB
10	Spacecraft:								
11	#Ant Gain	11	dBi						
12	#Impl Loss	3	dB	Rx Power	-155.5	dBW	G/T	-19.6	dB/K
13	#Noise Temp	580	K	No	-201.0	dBJ			
14				Rx P/No	45.4	dB-Hz			
15	#C loop BW	100	Hz				Mod index	72.522714	deg
16	#C SNR	15	dB	C/No	35.0	dB-Hz	Mod loss	0.41	dB
17	#Eb/No	5	dB	Data rate	10087	b/s	Carrier loss	10.45	dB
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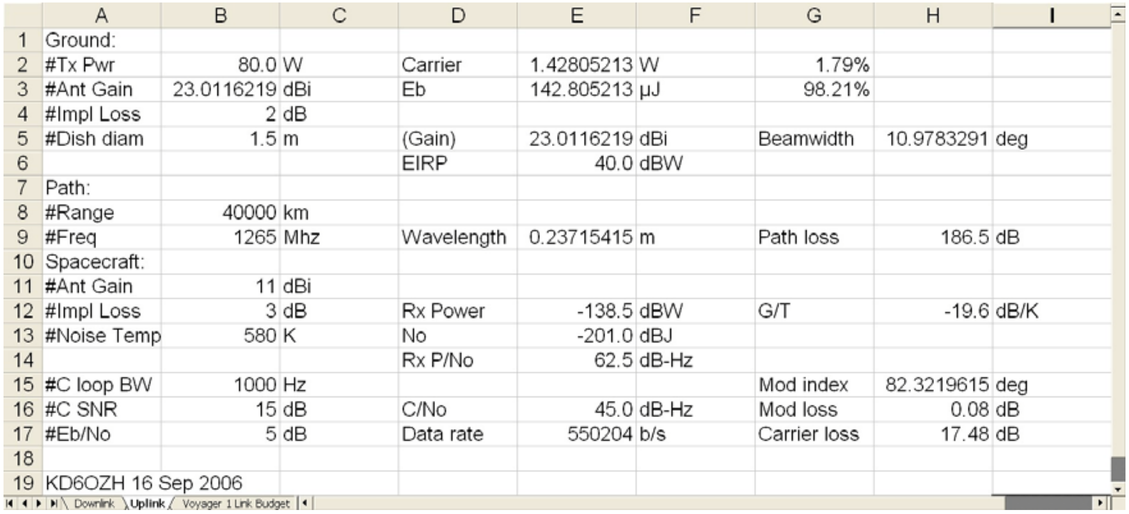
Table 4 – Class 2 L Uplink Characteristics

The class 2 earth station consists of a 10 W power amplifier, a feedline with 2 dB of loss and a single long Yagi antenna. The antenna has 20 dBi of gain, but there is a loss of 3 dB as it is linearly polarized. This would be a typical ATV antenna. The 315 W EIRP is somewhat higher than that of most mobile radios on 23 cm, so it is more likely to cause interference to the 1215-1300 MHz radionavigation service.



	A	B	C	D	E	F	G	H	I
1	Ground:								
2	#Tx Pwr	80.0	W	Carrier	1.42805213	W	1.79%		
3	#Ant Gain	23.0116219	dBi	Eb	142.805213	µJ	98.21%		
4	#Impl Loss	2	dB						
5	#Dish diam	1.5	m	(Gain)	23.0116219	dBi	Beamwidth	10.9783291	deg
6				EIRP	40.0	dBW			
7	Path:								
8	#Range	40000	km						
9	#Freq	1265	Mhz	Wavelength	0.23715415	m	Path loss	186.5	dB
10	Spacecraft:								
11	#Ant Gain	11	dBi						
12	#Impl Loss	3	dB	Rx Power	-138.5	dBW	G/T	-19.6	dB/K
13	#Noise Temp	580	K	No	-201.0	dBJ			
14				Rx P/No	62.5	dB-Hz			
15	#C loop BW	1000	Hz				Mod index	82.3219615	deg
16	#C SNR	15	dB	C/No	45.0	dB-Hz	Mod loss	0.08	dB
17	#Eb/No	5	dB	Data rate	550204	b/s	Carrier loss	17.48	dB
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Table 5 – Class 3 L Uplink Characteristics

The class 3 earth station consists of a 120 W power amplifier, a feedline with 2 dB of loss and either an array of 4 long Yagi antennas or a 5 to 6 foot diameter dish. Note that the highest power amplifiers available for 23 cm at a cost below $1000 are a 120 W solid-state unit and a 150 W vacuum tube unit. The 16 kW EIRP used may cause interference to the 1215-1300 MHz radionavigation service.

2. S_1 and V Downlinks

Changing from a V downlink to an S_1 downlink is dramatic as shown in tables 6 and 7. I assume a simple J310 FET preamplifier for 2 meters and a 0.7 dB NF LNA for 13 cm. The antennas are the smallest M^2 Yagi for 2 m and a 2-foot dish with -10 dB total side-lobe levels for 13 cm. The V-band ambient noise level is the average galactic noise level for a rural location and comes from an NTIA survey for residential locations. The S-band ambient noise level is thermal noise for a rural location and +20 dB above thermal noise for a residential location (best case in SD meeting notes). In both cases, the ambient noise is attenuated 10 dB by the dish antenna feed.

Band	**Rural V**	**Residential V**	**Rural S_1**	**Residential S_1**
Relative Propagation Loss	0 dB	0 dB	+24 dB	+24 dB
Ambient Noise	+3 dB	+6 dB	-10 dB	+10 dB
Receiver Noise Figure	2 dB	2 dB	1 dB	1 dB
Receiver Noise Temp.	915 K	1830 K	104 K	3650 K
Relative Receiver MDS	0 dB	+3 dB	-9.5 dB	+6 dB
Antenna Gain	12 dBic	12 dBic	19.5 dBic	19.5 dBic
Relative Antenna Gain	0 dB	0 dB	+7.5 dB	+7.5 dB
Total Relative Loss	0 dB	+3 dB	+7 dB	+22.5 dB

Table 6 – Analog V and S_1 Downlink Comparison

Thus an S-band analog downlink in a rural location needs 7 dB of additional antenna gain to perform similarly to a V-band analog downlink. A fixed helical antenna or 4-element patch array on the satellite will compensate, but reduce orbital coverage. Electrically steering the antenna is a problem as there must be 4 HELAPS amplifiers – one for each antenna element.

In a residential area, 19.5 dB of additional antenna gain is needed. This much gain is impractical on the satellite, due to the space required. In addition to the additional gain on the satellite, the ground station antenna gain could be increased by 12.5 dB. This increases the diameter of the receiving dish from 2 feet to 8 feet.

An S-band digital downlink for class 1 users is at an extreme disadvantage as omnidirectional receiving antennas pick up ambient noise. In table 7, I assume that the antenna is mounted far enough above surrounding objects so that the 290 K thermal noise is attenuated by 3 dB.

Band	**V**	**S_1**
Relative Propagation Loss	0 dB	+24 dB
Transmitter Antenna Gain	3 dB	11 dB
Relative Received Signal Level	0 dB	-16 dB
Ambient Noise	6 dB	17 dB
Receiver Noise Figure	2 dB	1 dB
Receiver Noise Temperature	1830 K	18,300 K
Relative Receiver MDS	0 dB	+10 dB
Antenna Gain	5 dBic	5 dBic
Relative Antenna Gain	0 dB	0 dB
Total Relative Loss	0 dB	+26 dB

Table 7 – Digital V and S1 Downlink Comparison for Residential Area

Class 1 cannot work in residential areas with an S-band omnidirectional antenna and the required antenna gain would be impractical for this type of service.