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AMSAT

RADIO AMATEUR SATELLITE CORPORATION

PROCEEDINGS OF THE
AMSAT-NA
27th Space Symposium and AMSAT-NA Annual Meeting

October 9 - 11
2009
Baltimore, Maryland

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First Edition

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October 2, 2009

Welcome!

It is with great pleasure that I personally welcome you to the 2009 AMSAT-NA Annual Meeting and Space Symposium. This meeting continues a tradition started in the early 1980s to provide an annual forum for amateur satellite enthusiasts to gather and share their ideas.

This year marks the 40th Anniversary of AMSAT. On March 3, 1969, the Radio Amateur Satellite Corporate was officially incorporated in the District of Columbia as a non-profit educational scientific organization. In 2009, we continue to pursue our mission of designing, building and operating experimental satellites and promote space education. With this in mind, we are completing ARISSat-1, an engineering test-bed for future satellites that we expect to be deployed from the International Space Station in 2010.

During the past year, the Engineering Task Force has met to develop a strategy for future AMSAT engineering projects. They will present a recommendation at this year's Board of Directors' Meeting. In addition, AMSAT is now cooperating with SUNY-Binghamton on a senior engineering 'Capstone Project' focusing on developing a 'NextGen Cubesat' design based upon work done by AMSAT on ARISSat-1. SUNY-Binghamton personnel will be presenting at this year's Symposium an outline of the work that they expect to complete and the critical role that AMSAT has in this process.

AMSAT worked on ITAR issues, by first submitting a Voluntary Disclosure in January 2009 and then filing four Commodity Jurisdiction requests with the Directorate of Defense Trade Controls, US State Department in July. These requests asked that the four commodity groups that AMSAT provided support for AMSAT-DL's Phase 3-E project (SDX, IHU-3, Can-Do! Bus and thermal design) be transferred from ITAR to Export Administration Regulations (EAR) managed by the Department of Commerce. We expect a ruling shortly.

Legal proceedings concerning the current lab situation In Maryland continue with both sides having agreed to a mediation process that will start later this month. Meanwhile, AMSAT is in discussions with a major university concerning the relocation of the AMSAT Lab and we expect to announce the name of that university shortly. Our discussions have included an onsite visit with AMSAT represented by Drew Glasbrenner, Bob Davis, and I.

We have accomplished much this year during difficult financial times. Forty years of amateur radio in space is certainly something to celebrate. Our future, with your support, can be just as bright.

73,

Barry A. Baines, WD4ASW
President

• • • — • — Silent Keys • • • — • —

Tom Clark, K3IO
k3io@amsat.org

It is with much sadness that we mourn the passing in 2009 of four of our friends, all of whom have been very important to AMSAT.

- **February: Dieter Schliemann, KX4Y** (by Frank Bauer, KA3HDO

"It is with great sadness that I announce the passing of Dieter Schliemann,KX4Y.

"Those that knew Dieter recognized that he was a "class act"---a great gentleman and colleague who will be sorely missed by all. Dieter was instrumental in leading and supporting many key activities in AMSAT and on the ARISS program.

"For ARISS, Dieter led the school contact IRLP/Echolink initiative. Through this amateur radio VOIP system, Dieter and his team substantially extended our reach of the school contacts. And through his efforts, tens of thousands of school students and ham radio operators, world-wide, could listen to other school contacts, enhancing education and giving all a better understanding of what it is like to live and work on ISS. Dieter's diplomacy, teambuilding skills and attention to the details were impeccable and were well respected within the team. He rose to the challenge when I asked him to lead the IRLP/Echolink team. At the time, there were strong, divergent opinions on the use of IRLP and Echolink on ARISS. He singlehandedly developed a cohesive team that is producing great results and are enjoying working together."

- **March: Mario Acuna, LU9HBG/W3** (by Tom Clark, K3IO)

"It is with great sadness that I learned today of the passing of a long-term friend of AMSAT, Mario Acuña, LU9HBG. Mario was a very senior scientist/engineer at NASA Goddard where he made his name by providing magnetometers for nearly every deep-space and planetary mission since the 1970's. His vitae can be viewed at http://ssed.gsfc.nasa.gov/vitae/acuna.html, and a nice writeup on him can be found at http://www.nasa.gov/home/hqnews/2005/jan/HQ_05022_acuna.html.

"Mario never bothered to get a US call, although he often had HF schedules with his relatives & friends in Argentina. In years past, Mario and I were contemporaries at Goddard, and we often commiserated about NASA's problems of "getting old"/"mature government bureaucracy" and about the dearth of young innovative scientists who enjoyed inventing new instruments. His loss hits me especially hard.

"When a young Martin Sweeting wanted to fly magnetometers for navigation on the earliest UoSAT's, Mario was the "go to" guy that put Martin on the right track. Since magnetometers are biased by metal and electrical currents in a spacecraft, Mario arranged for testing of the early UoSATs.

"When Jan, Karl and I were trying to minimize radiation damage in critical Phase-3 components (like the IHU and CMOS logic), Mario was our mentor in helping to figure out the best way to minimize damage and teaching us how to apply tantalum to the top and bottom of ICs."

• August: Art Goldman. N3OY (by Tom Clark, K3IO)

"It is with great sadness that I learned of the recent passing of Art Goldman, N3OY (formerly WA3CVG). Art was 67 and succumbed to melanoma.

"Art was very active in CARA (Columbia Amateur Radio Association) and was an AMSAT Life Member. Art often handled the satellite Field Day effort at W3AO (see http://www.arrl.org/contests/soapbox/?con_id=133&call=W3AO for 2006 pictures. W3AO is the 19 xmtr multi-multi joint effort of CARA & PVRC).

"Art lived in Columbia, MD which has severe antenna limits. Despite this, he managed to get on AO-40 using BBQ dish antennas. He showed up frequently in the AMSAT-BB archives. Art was also very active in the packet radio world in the 80's & 90's. Art (with NG6Q) developed the TCP/IP driver for the Eagle Computer card (Zilog 8530) for KA9Q's NOS.

"A personal remembrance: Rick Hambly (W2GPS), Bob McGwier (N4HY)& I remember fondly the 8-hour x 2-way "captive audience" trip to/from Dayton a few years ago. Despite Art's big city Jewish roots, he knew every country & western song every made. What with McGwier hailing from redneck Alabama, the trip was hilarious. I particularly remember the two singing to Toby Keith's hit C&W song "*I ain't as good as I once was, but I'm as good once as I ever was*"."

• September: Den Connors, KD2S (by Tom Clark, K3IO)

"It is with much sadness that I report the passing of Den Connors, KD2S at 2AM this morning. Den passed on after a year+ fight to conquer lymphoma. This morning, Ralph (KD1SM) sent me an Email reporting

> "Den checked-in to our weekly Club information net on 70cm Monday evening. As usual, he sounded pretty chipper."
> "Very shortly after that he developed a serious infection and his non-existent immune system could do nothing."

"Den was TAPR's first president, overseeing the transition from a local Tucson club into the multi-national TAPR. He was a major sponsor of the adoption of AX.25 as the amateur packet standard. Under his lead, TAPR introduced the TNC-1 and then later the TNC-2. Den worked with me to define an amateur store-and-forward packet radio satellite; this concept morphed into AMSAT's Microsats (AO16 thru 19, IO-26, AO-27 & MO-30)."

(from Don, WB5EKU), "Den brings back fond memories of the beginnings of packet and AX.25.Those were fun days. I enjoyed the TAPR meetings in Tucson and came away in awe of the knowledge and enthusiasm that he had. I lost contact with him when he moved east and am saddened at this news. My prayers and thoughts are for him and his family. He is one of those persons that are very hard to replace. We were better with him."

(from ARRL News), "The first president of Tucson Amateur Packet Radio (TAPR) Den Connors, KD2S, of Pepperell, Massachusetts, passed away September 3 from lymphoma. He was 58. Connors, an ARRL Life Member, conducted the first amateur packet radio contact with all-American hardware and software, using the Tucson Amateur Packet Radio Terminal Node Controller (TNC) with Lyle Johnson, WA7GXD (now KK7P), at 9:12 PM (PST) on June 25, 1982. The tests were conducted at 146.55MHz, with both stations sending plain-text ASCII messages. "Den was instrumental in the early PACSAT work, and as TAPR's first president, led that organization from a local club he co-founded into an international organization," Johnson said in an e-mail. "His was a very cheerful, positive, can-do influence."

ARISSat-1 Mechanical Design

SuitSat-2 as a box-shaped satellite without spacesuit.

By
Robert Davis, KF4KSS@amsat.org

Abstract

SuitSat-2, a Russian spacesuit fitted with amateur radio gear from AMSAT-NA and solar panels donated by NASA, was planned for release from the International Space Station. However, the early disposal of the spacesuit led AMSAT-NA and our partners to consider alternate packaging of the planned amateur radio gear. This paper describes the mechanical design and status of that new packaging of ARISSat-1 (renamed from SuitSat-2) as a squat 4-sided box.

Introduction

SuitSat-1, a Russian spacesuit fitted with an amateur radio transmitter, was released by hand from the International Space Station in 2006. Those spacesuits are discarded when their useful lifetime is reached. An improved and more capable follow-on project has been under development and named SuitSat-2. This time, it would have more capabilities, solar panels (instead of just the spacesuit battery), and a broader mission. Again, it would look like a spacesuit, but with solar panels strapped to the legs and an antenna jutting from the helmet.

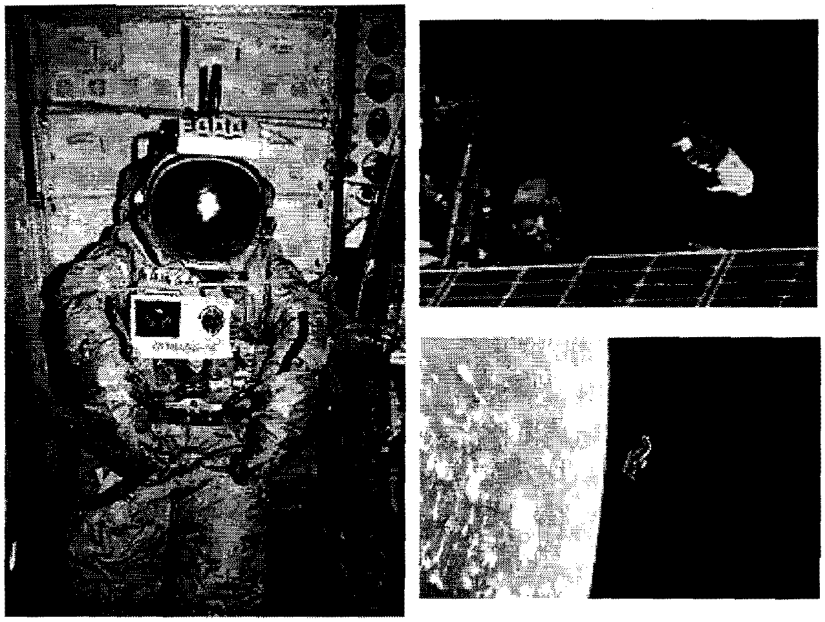


Figure 1 SuitSat-1 and its Release from ISS in 2006

However, when the spacesuit was demised earlier, Energia offered to release it as a satellite, if AMSAT-NA packaged it without using a spacesuit. This is when I joined the team to help design and build a structure as quickly as possible.

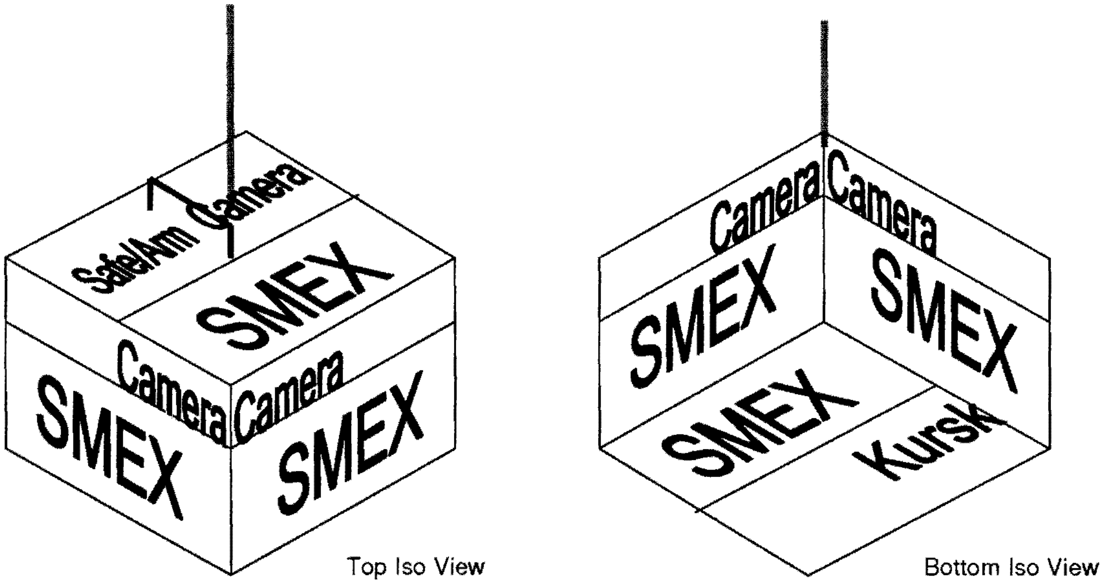
The block diagram is largely unchanged, but it's now called ARISSat-1 (ARISS is Amateur Radio on International Space Station) and looks like a satellite instead of a spacesuit.

SuitSat-2 As-Box Proposal

Sounds simple! Add some flanges to the boxes, and make a simple box-frame to hold them. What's the problem, right?

In July, I made a real simple line sketch of SuitSat-as-box then traveled to Orlando to discuss the concept with Lou McFadin W5DID, Gould Smith WA4SXM, Stan Wood W4NFY, and Dick Jansson KD1K. (And we got to see the Shuttle launch from Lou's backyard – that was especially arranged for us!)

My proposal was simple: Given the size of the SMEX solar panels donated by NASA, make the smallest box possible and assume everything fits inside. That placed the size of the box in the neighborhood of 19"x19"x10. To speed up the design and fabrication, the top and bottom would be made out of aluminum plate and the electronics would mount to them. This is not a typical satellite design starting point: normally we'd have the luxury of time to develop a sandwich (honeycomb) structure which is much lighter and stiffer. However, the compressed schedule before delivery to ISS couldn't accommodate anything more extravagant than a plate with holes.



Top Iso View

Bottom Iso View

Figure 2 SuitSat-2 As-Box Proposal

In Orlando, we made a very crude foam mockup of the walls of the satellite, and folded up cardboard boxes to go inside. This was sort of a reality check: does it really all fit?

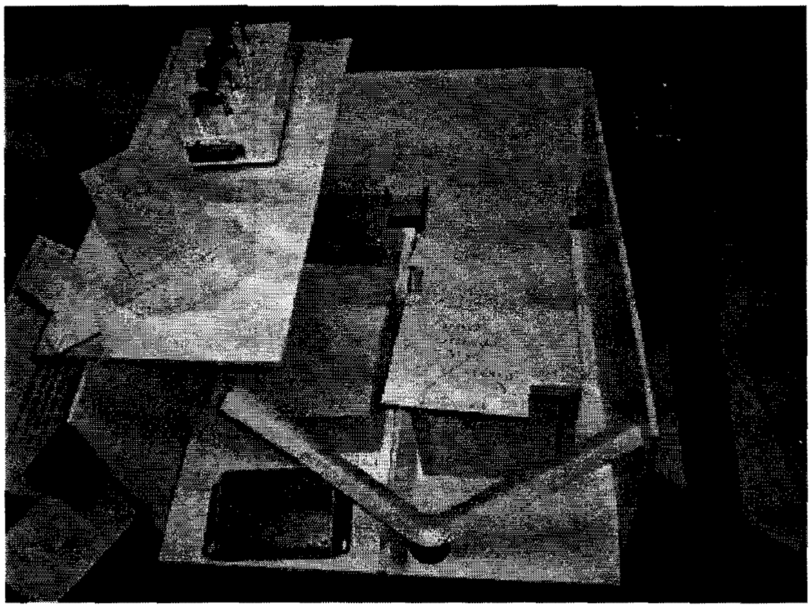


Figure 3 Original Foam Mockup

Upon my return, I made a better cardboard model, which I used primarily to help me visualize joints, gaps, access, tooling, etc.

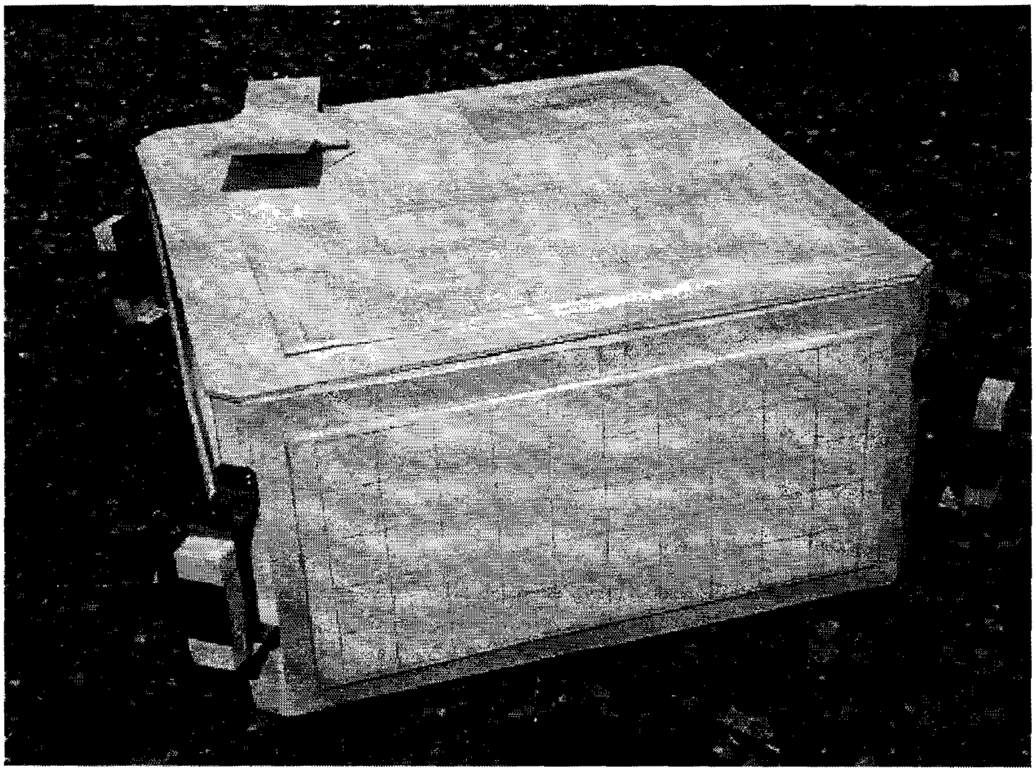


Figure 4 Final Foam Mockup (Exterior)

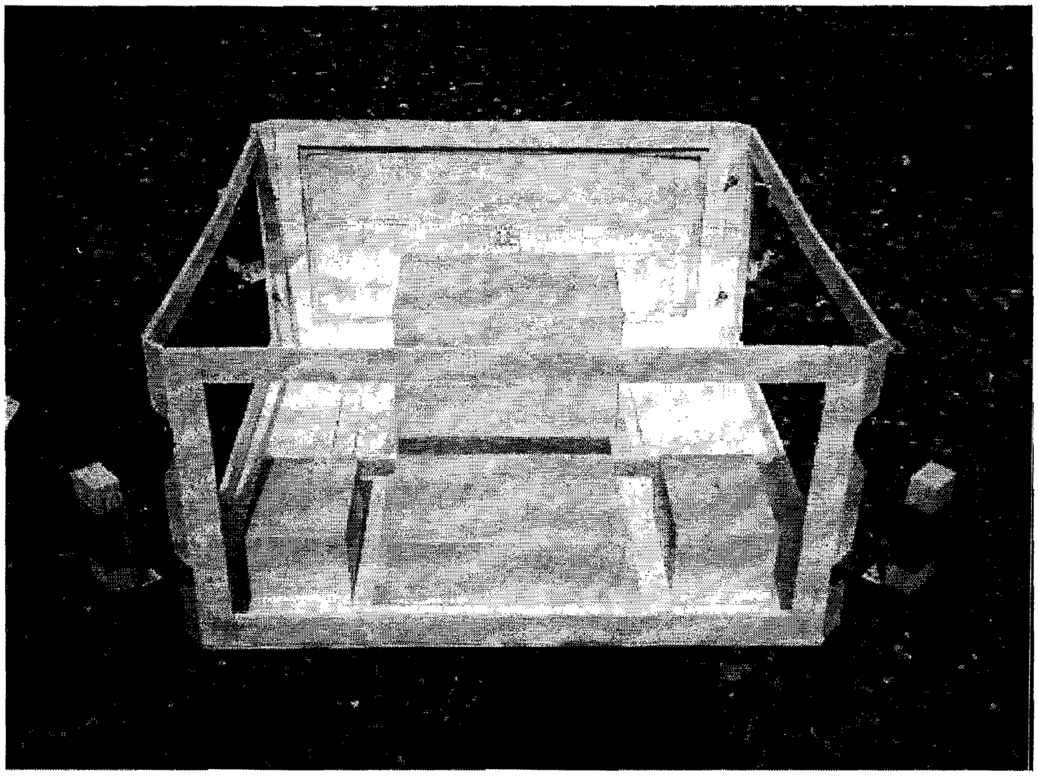


Figure 5 Final Foam Mockup (Interior)

Notice that the big box in the background of Figure 5 is the very large Orlan-M battery provided by Energia. This is the same battery that is used inside the Russian spacesuits.

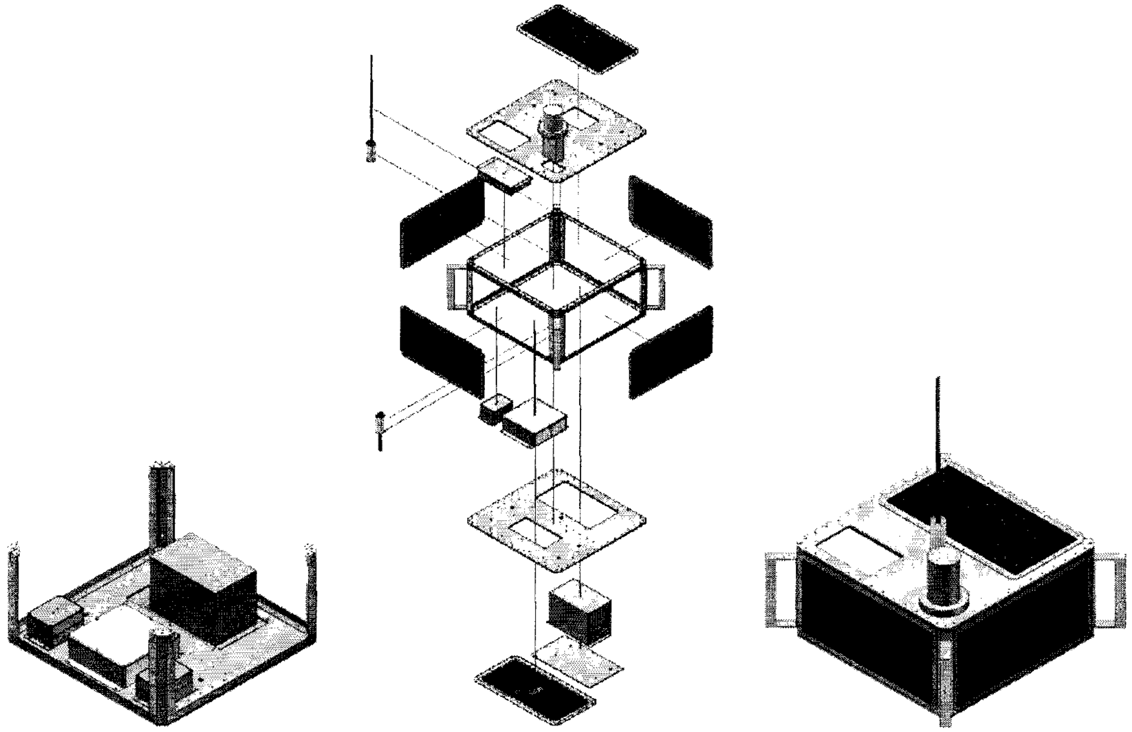


Figure 6 Early CAD Model

ARISSat-1 Design

The frame design settled down to a shape of 20.5"x20.5"10.5", with additional protrusions. The top and bottom ¼" thick aluminum plates were sized to provide enough thickness for threading the plate and to give the required stiffness to keep its natural frequency (drum mode) higher (greater than 50 Hz and preferably at least 100 Hz). The natural frequency is important, since the launch vibration loads contain much more energy at lower frequencies (so it's best not to resonate at low frequencies).

Separating the top and bottom plates are four robust machined angles at the four corners. These vertical angles are the main load path for items mounted to the top plate down to the launch vehicle. Electronics, inside commercial and custom boxes, are mounted to the interior faces of both the top and bottom plates. Each of the four sides, and the top and bottom plates, have a SMEX Solar Panel. These solar panels were donated by NASA.

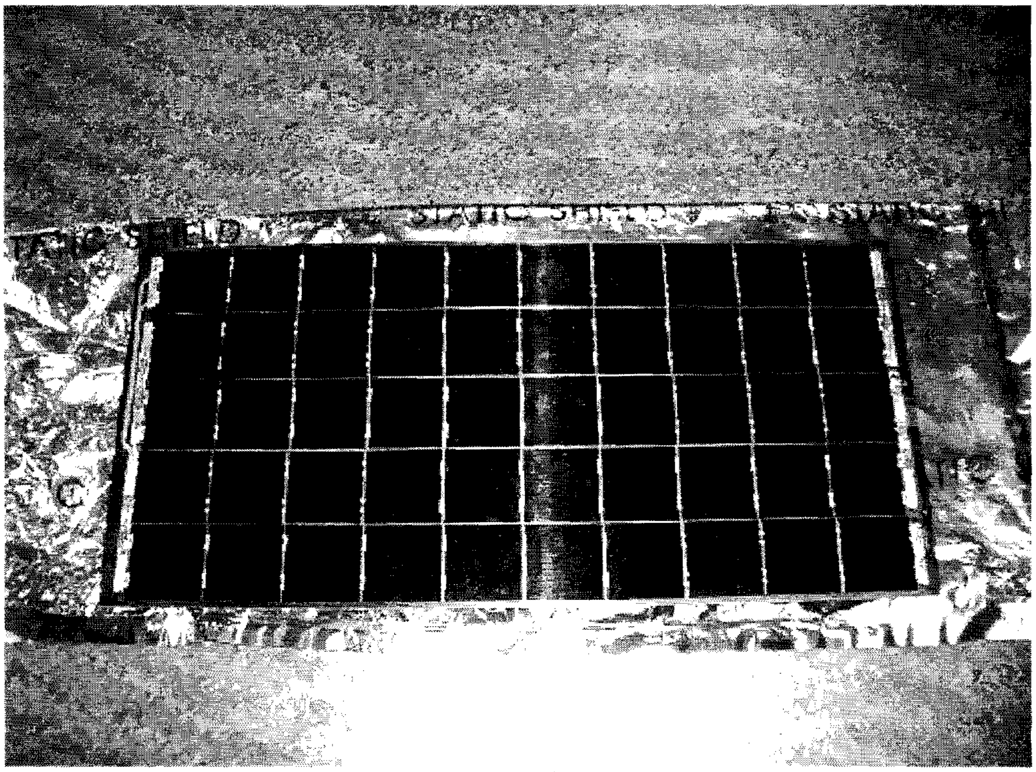


Figure 7 SMEX Solar Panel

At the vertical angles, there are handles for the cosmonaut to hold the spacecraft while removing covers and preparing for release by hand from ISS.

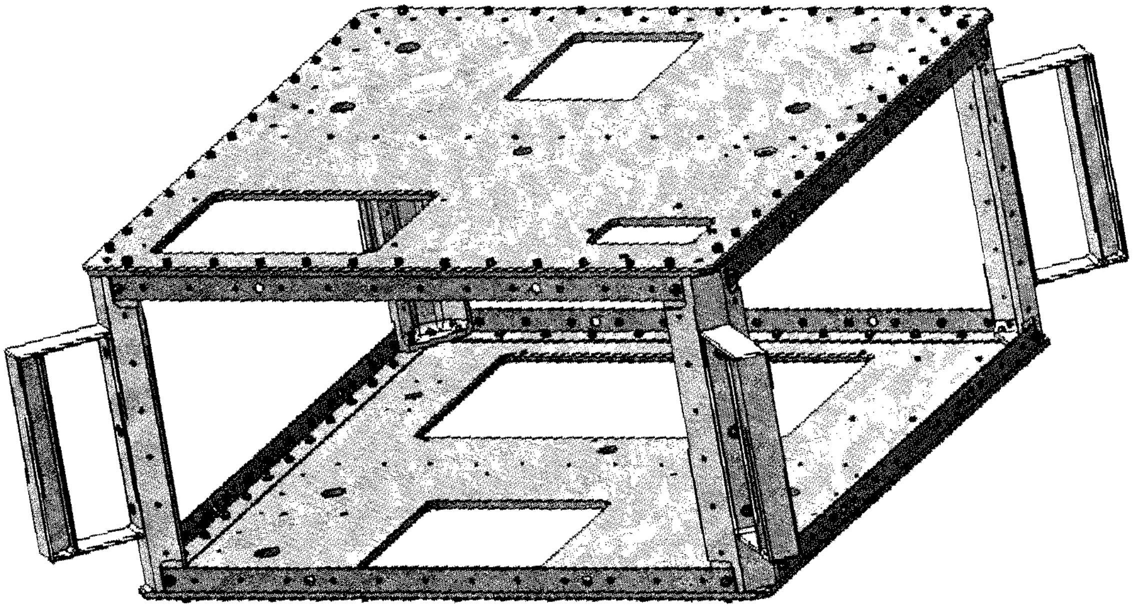


Figure 8 Structure Assembly Step One

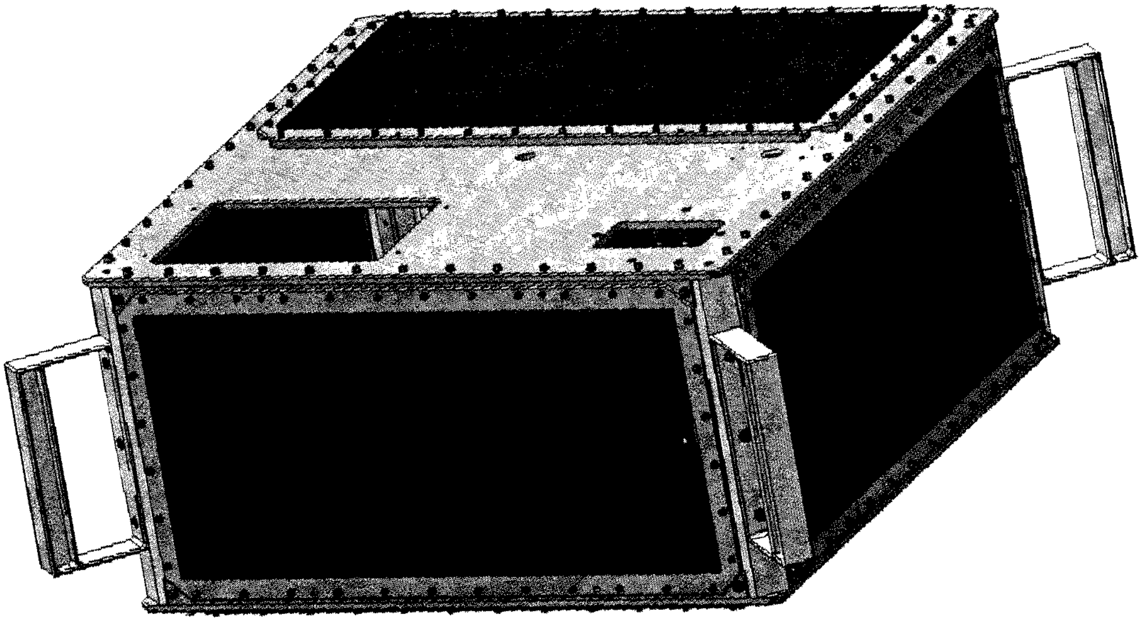


Figure 9 Structure Assembly Step Two

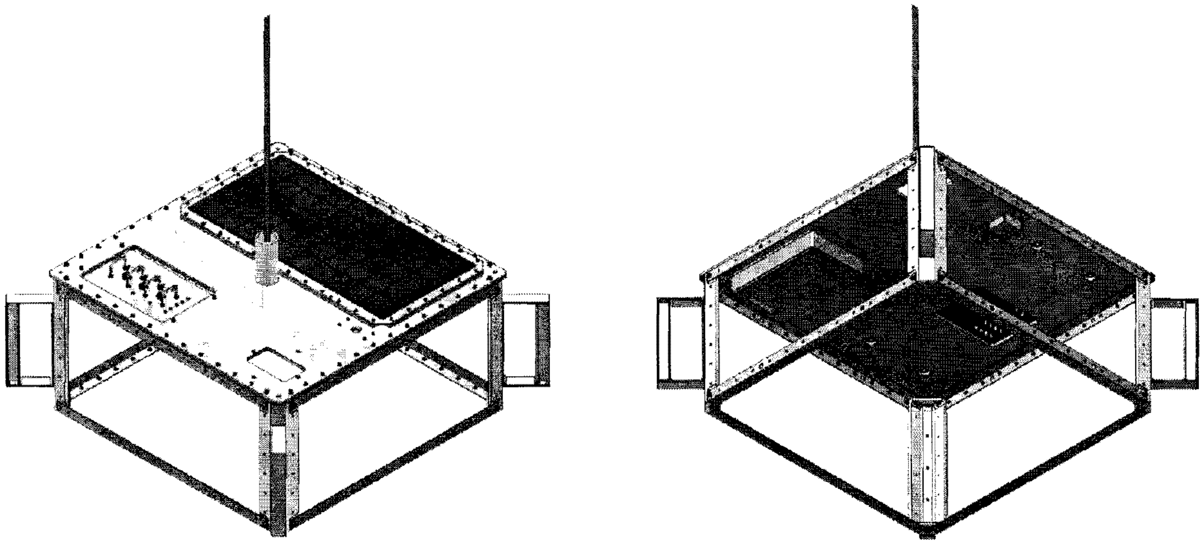


Figure 10 Installation of Electronics Boxes on Top Plate

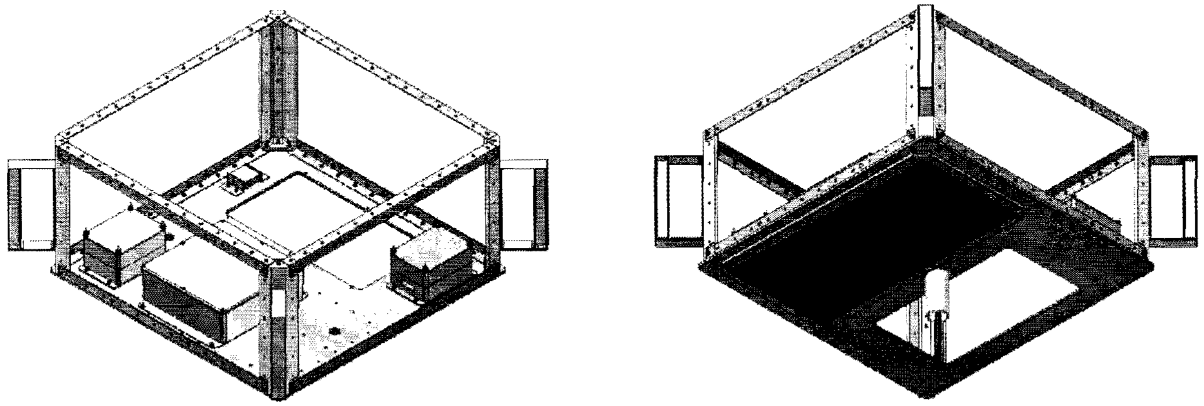


Figure 11 Installation of Electronics Boxes on Bottom Plate

The Kursk experiment is provided by one of our Russian partners (Kursk University) and will actually be installed in Russia prior to launch. The battery will be launched separately from the spacecraft, and will be installed by cosmonauts inside the International Space Station. This action is taken as a safety precaution.

The spacecraft is transported to the ISS in the Russian Progress launch vehicle. This is similar to how they launch people, but designed to carry only cargo.

The solar cells are thin glass and can crack and break easily. Therefore, covers are usually employed on spacecraft to protect those solar cells from accidental damage. Those covers are usually removed for flight since most spacecraft are launch into orbit and there's nobody there to remove the covers. This satellite is different than most! It will launch with the covers on! The covers will then be removed in orbit by the cosmonauts.

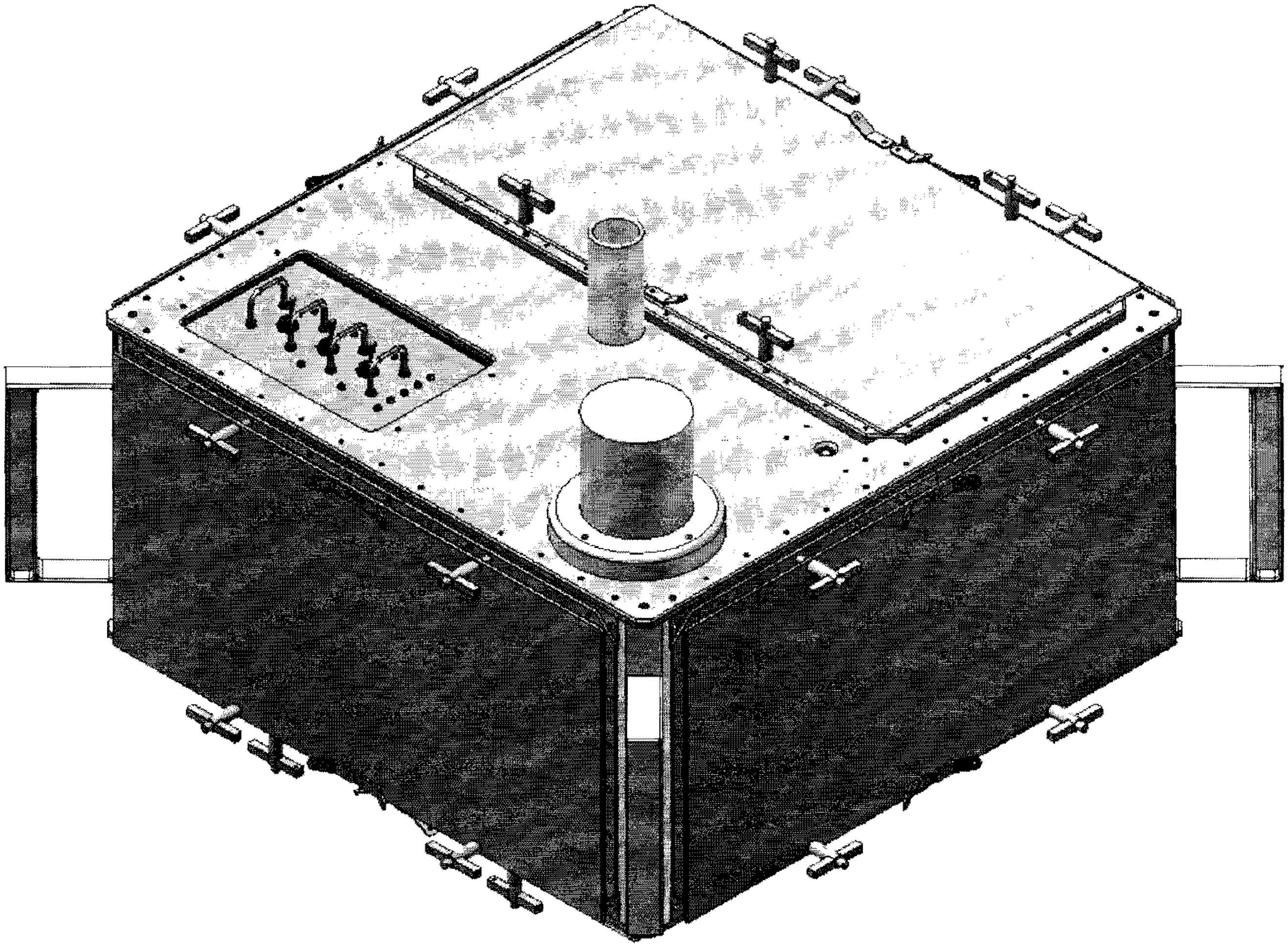


Figure 12 Covers over the Solar Panels

The design is documented in manufacturing and assembly drawings. The structure and assembly is CAD modeled with Autodesk Inventor. A couple of volunteers are helping with the mechanical design, including Bob Schwerdlin W2GL with electronics boxes, and Ken Blake with solar panel covers. Below is a sample manufacturing drawing.

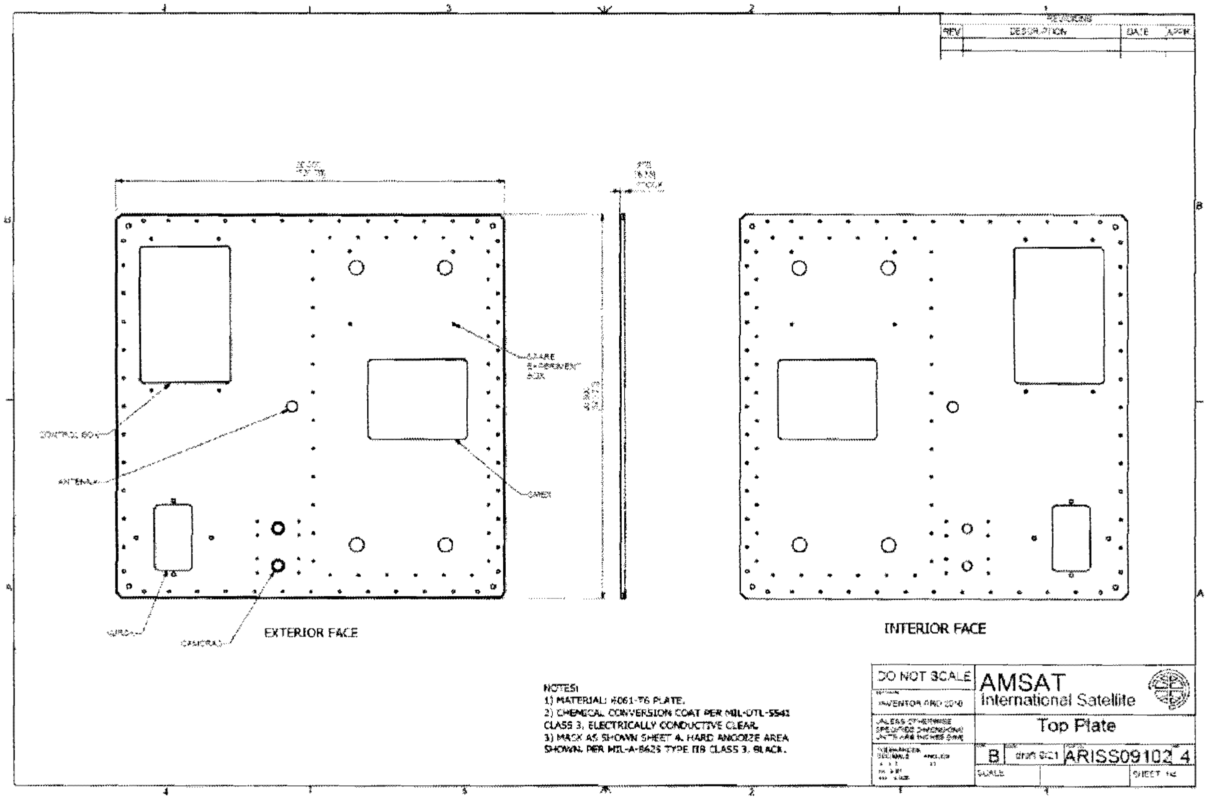


Figure 13 Top Plate drawing sheet 1

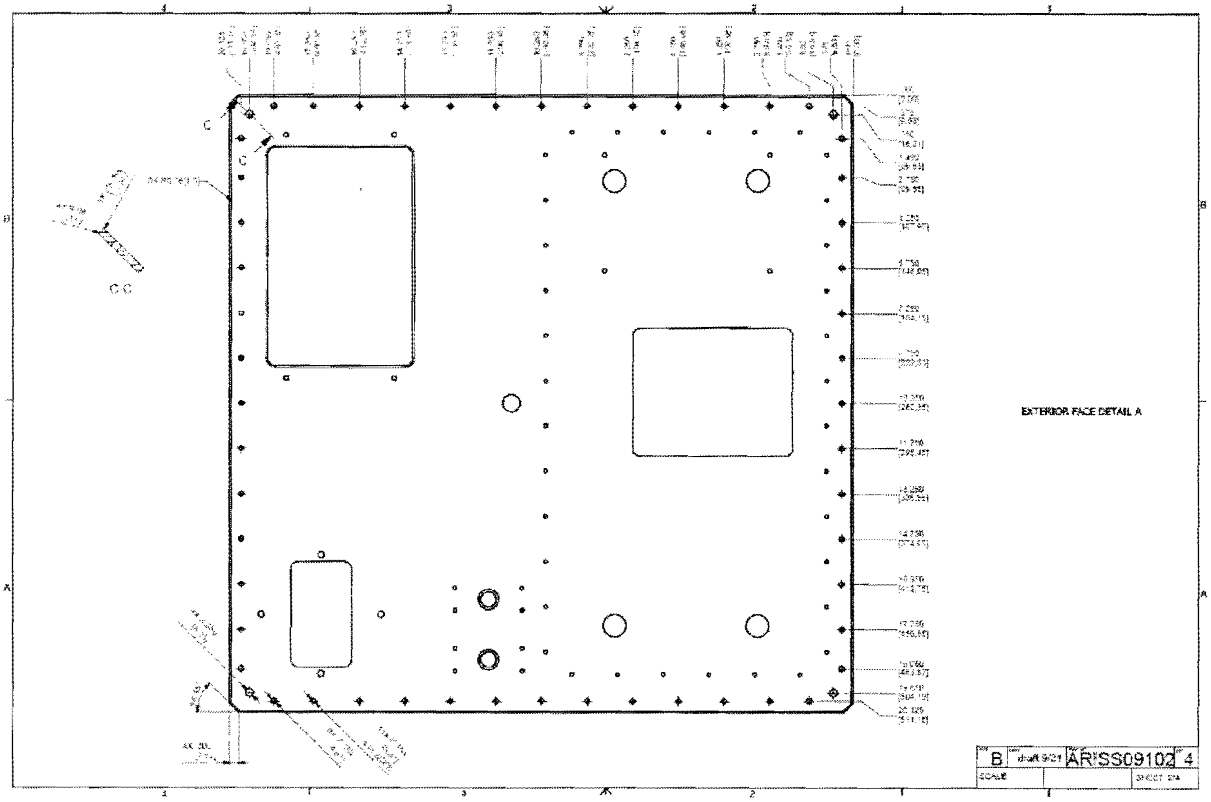


Figure 14 Top Plate drawing sheet 2

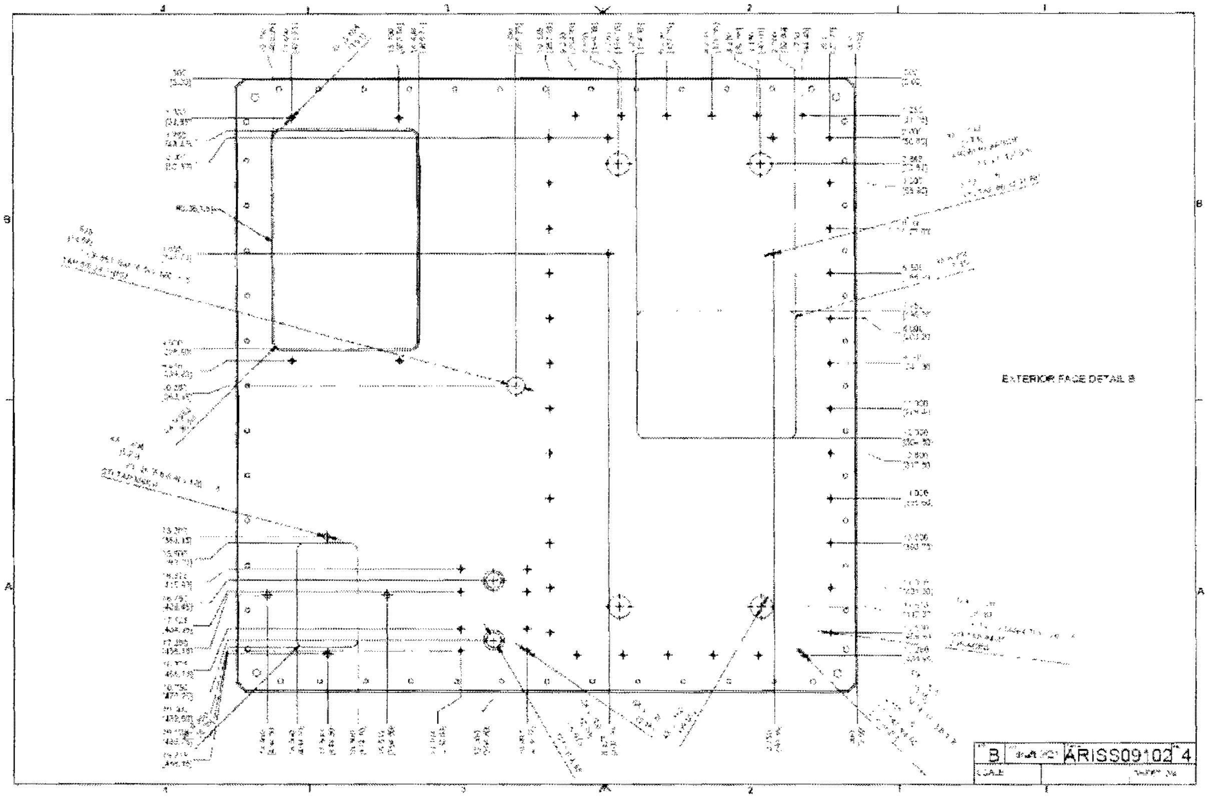


Figure 15 Top Plate drawing sheet 3

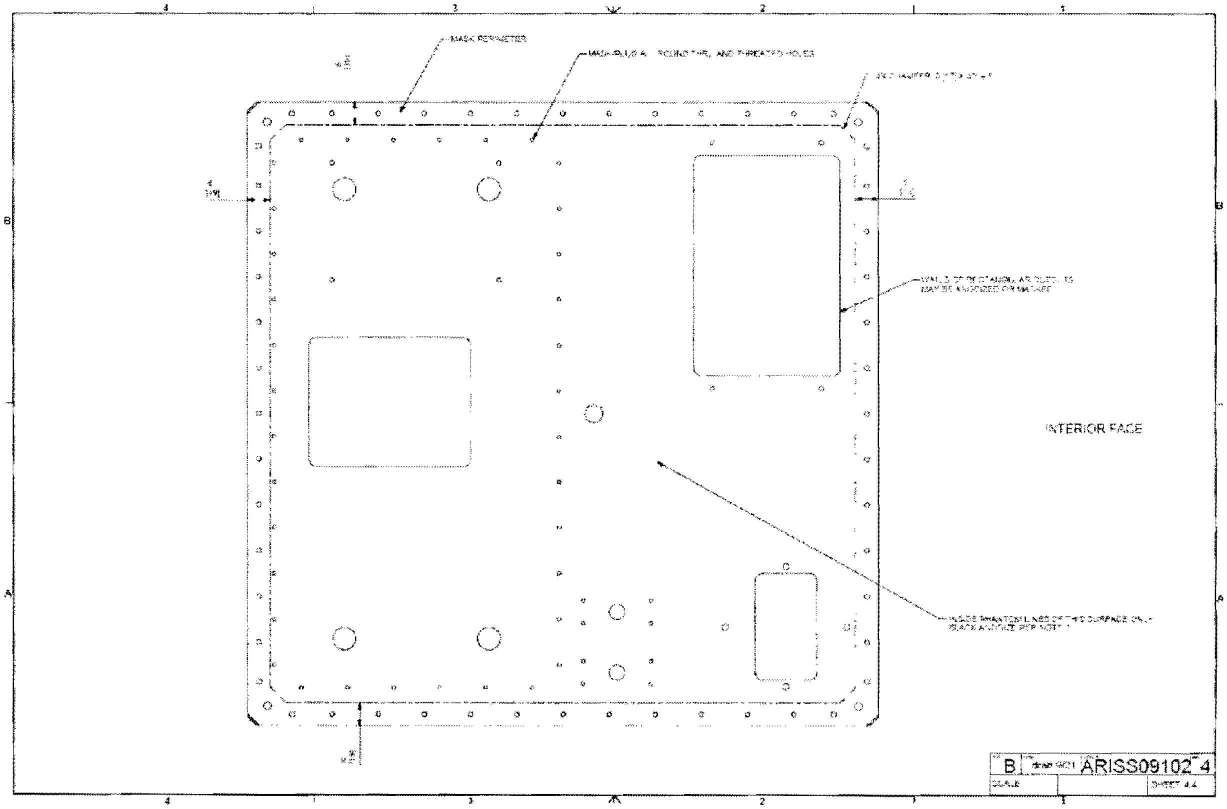
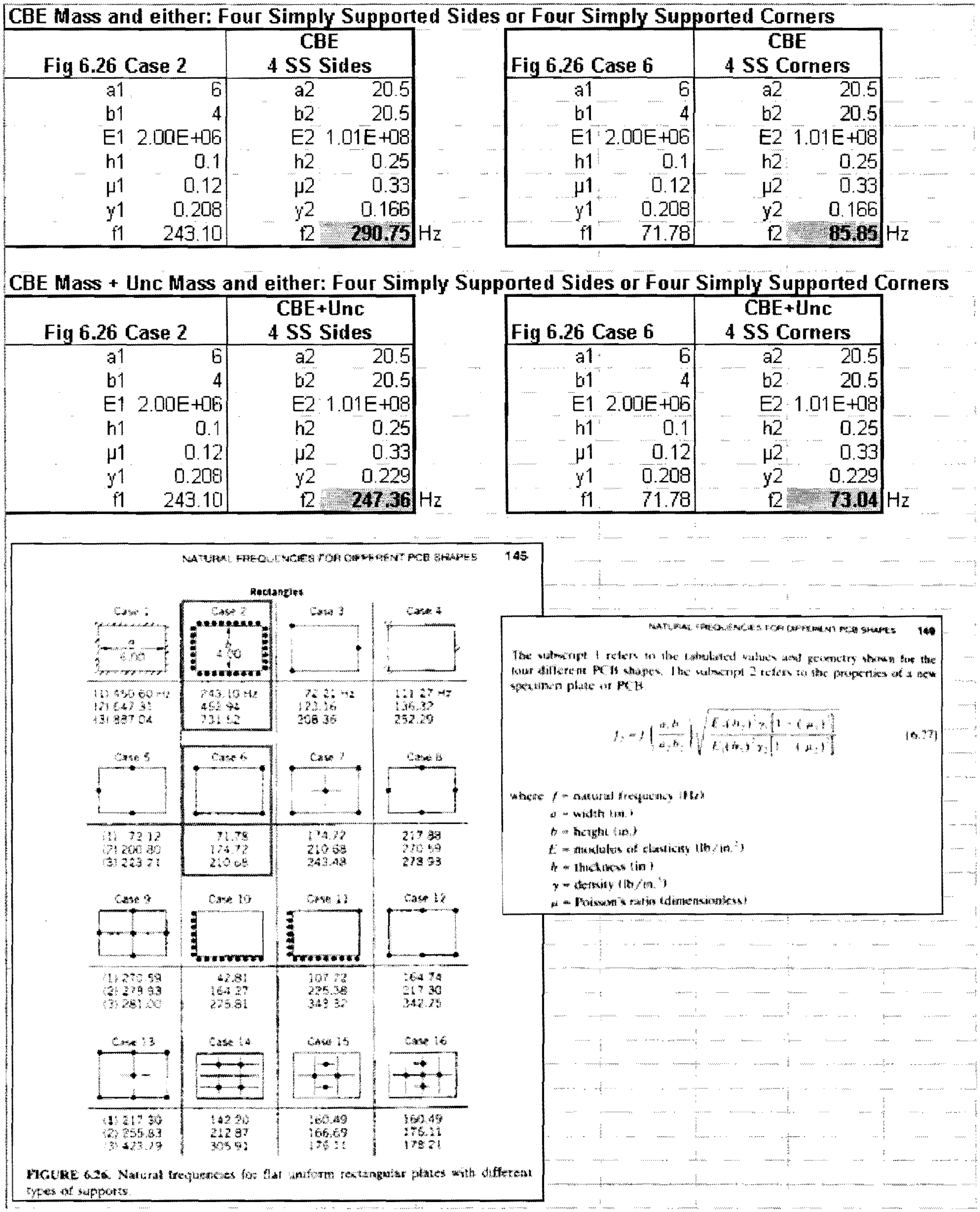


Figure 16 Top Plate drawing sheet 4

The design is also documented in analysis. The analysis verifies that we meet structural requirements. The requirements may include natural frequency, static load, vibration load, etc.



CBE Mass and either: Four Simply Supported Sides or Four Simply Supported Corners

Fig 6.26 Case 2		CBE 4 SS Sides		
a1	6	a2	20.5	
b1	4	b2	20.5	
E1	2.00E+06	E2	1.01E+08	
h1	0.1	h2	0.25	
µ1	0.12	µ2	0.33	
y1	0.208	y2	0.166	
f1	243.10	f2	290.75	Hz

Fig 6.26 Case 6		CBE 4 SS Corners		
a1	6	a2	20.5	
b1	4	b2	20.5	
E1	2.00E+06	E2	1.01E+08	
h1	0.1	h2	0.25	
µ1	0.12	µ2	0.33	
y1	0.208	y2	0.166	
f1	71.78	f2	85.85	Hz

CBE Mass + Unc Mass and either: Four Simply Supported Sides or Four Simply Supported Corners

Fig 6.26 Case 2		CBE+Unc 4 SS Sides		
a1	6	a2	20.5	
b1	4	b2	20.5	
E1	2.00E+06	E2	1.01E+08	
h1	0.1	h2	0.25	
µ1	0.12	µ2	0.33	
y1	0.208	y2	0.229	
f1	243.10	f2	247.36	Hz

Fig 6.26 Case 6		CBE+Unc 4 SS Corners		
a1	6	a2	20.5	
b1	4	b2	20.5	
E1	2.00E+06	E2	1.01E+08	
h1	0.1	h2	0.25	
µ1	0.12	µ2	0.33	
y1	0.208	y2	0.229	
f1	71.78	f2	73.04	Hz

NATURAL FREQUENCIES FOR DIFFERENT PCB SHAPES 145

Rectangles

FIGURE 6.26. Natural frequencies for flat uniform rectangular plates with different types of supports.

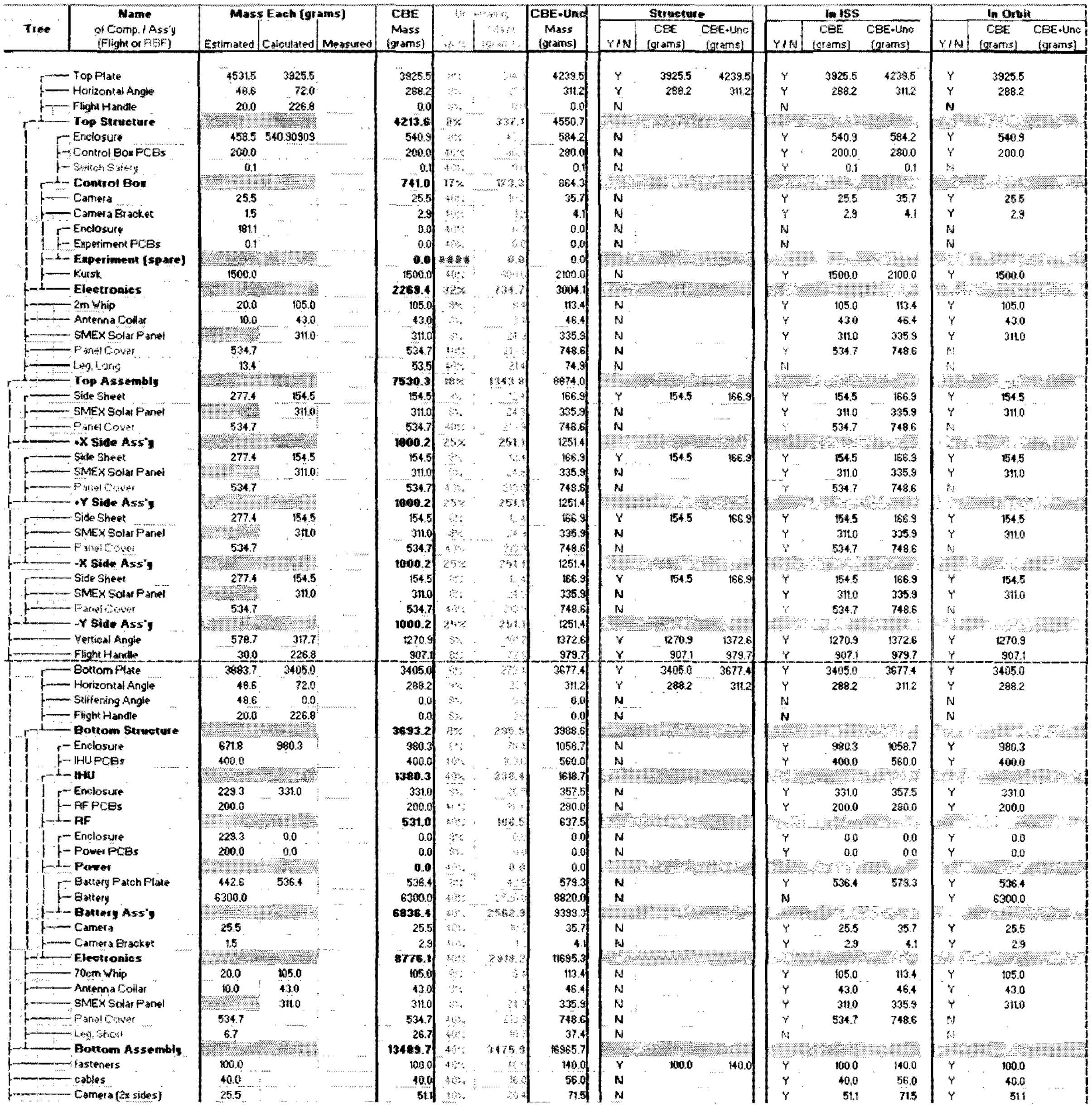
NATURAL FREQUENCIES FOR DIFFERENT PCB SHAPES 149

The subscript 1 refers to the tabulated values and geometry shown for the four different PCB shapes. The subscript 2 refers to the properties of a new specimen plate or PCB.

$$f_2 = f_1 \left(\frac{a_1 b_1}{a_2 b_2} \right) \sqrt{ \frac{E_2 (h_2)^2 \gamma_1 \left[1 - (\mu_1)^2 \right]}{E_1 (h_1)^2 \gamma_2 \left[1 - (\mu_2)^2 \right]} } \qquad (6.27)$$

where f = natural frequency (Hz)
a = width (in.)
b = height (in.)
E = modulus of elasticity (lb/in.^{2})
h = thickness (in.)
γ = density (lb/in.^{3})
μ = Poisson's ratio (dimensionless)

Figure 17 Sample Calculation (Natural Frequency of Top Plate)



Tree	Name of Comp. / Ass'y (Flight or RBF)	Mass Each (grams)			CBE Mass (grams)	Uncertainty		CBE+Unc Mass (grams)	Structure			In ISS			In Orbit		
		Estimated	Calculated	Measured		%	Mass (grams)		Y / N	CBE (grams)	CBE+Unc (grams)	Y / N	CBE (grams)	CBE+Unc (grams)	Y / N	CBE (grams)	CBE+Unc (grams)
	Top Plate	4531.5	3925.5		3925.5	8%	[illegible]	4239.5	Y	3925.5	4239.5	Y	3925.5	4239.5	Y	3925.5	
	Horizontal Angle	48.6	72.0		288.2	8%	[illegible]	311.2	Y	288.2	311.2	Y	288.2	311.2	Y	288.2	
	Flight Handle	20.0	226.8		0.0	8%	[illegible]	0.0	N			N			N		
	Top Structure				**4213.6**	8%	337.1	4550.7									
	Enclosure	458.5	540.90909		540.9	[illegible]	[illegible]	584.2	N			Y	540.9	584.2	Y	540.9	
	Control Box PCBs	200.0			200.0	40%	[illegible]	280.0	N			Y	200.0	280.0	Y	200.0	
	Switch Safety	0.1			0.1	40%	[illegible]	0.1	N			Y	0.1	0.1	N		
	Control Box				**741.0**	17%	123.3	864.3									
	Camera	25.5			25.5	40%	[illegible]	35.7	N			Y	25.5	35.7	Y	25.5	
	Camera Bracket	1.5			2.9	40%	[illegible]	4.1	N			Y	2.9	4.1	Y	2.9	
	Enclosure	181.1			0.0	40%	[illegible]	0.0	N			N			N		
	Experiment PCBs	0.1			0.0	40%	[illegible]	0.0	N			N			N		
	Experiment (spare)				**0.0**	####	0.0	0.0									
	Kursk	1500.0			1500.0	40%	[illegible]	2100.0	N			Y	1500.0	2100.0	Y	1500.0	
	Electronics				**2269.4**	32%	734.7	3004.1									
	2m Whip	20.0	105.0		105.0	8%	[illegible]	113.4	N			Y	105.0	113.4	Y	105.0	
	Antenna Collar	10.0	43.0		43.0	8%	[illegible]	46.4	N			Y	43.0	46.4	Y	43.0	
	SMEX Solar Panel		311.0		311.0	8%	[illegible]	335.9	N			Y	311.0	335.9	Y	311.0	
	Panel Cover	534.7			534.7	40%	[illegible]	748.6	N			Y	534.7	748.6	N		
	Leg, Long	13.4			53.5	40%	21.4	74.9	N			N			N		
	Top Assembly				**7530.3**	18%	1343.8	8874.0									
	Side Sheet	277.4	154.5		154.5	8%	[illegible]	166.9	Y	154.5	166.9	Y	154.5	166.9	Y	154.5	
	SMEX Solar Panel		311.0		311.0	8%	24.9	335.9	N			Y	311.0	335.9	Y	311.0	
	Panel Cover	534.7			534.7	40%	[illegible]	748.6	N			Y	534.7	748.6	N		
	+X Side Ass'y				**1000.2**	25%	251.1	1251.4									
	Side Sheet	277.4	154.5		154.5	8%	[illegible]	166.9	Y	154.5	166.9	Y	154.5	166.9	Y	154.5	
	SMEX Solar Panel		311.0		311.0	8%	[illegible]	335.9	N			Y	311.0	335.9	Y	311.0	
	Panel Cover	534.7			534.7	40%	[illegible]	748.6	N			Y	534.7	748.6	N		
	+Y Side Ass'y				**1000.2**	25%	251.1	1251.4									
	Side Sheet	277.4	154.5		154.5	8%	[illegible]	166.9	Y	154.5	166.9	Y	154.5	166.9	Y	154.5	
	SMEX Solar Panel		311.0		311.0	8%	24.9	335.9	N			Y	311.0	335.9	Y	311.0	
	Panel Cover	534.7			534.7	40%	[illegible]	748.6	N			Y	534.7	748.6	N		
	-X Side Ass'y				**1000.2**	25%	251.1	1251.4									
	Side Sheet	277.4	154.5		154.5	8%	[illegible]	166.9	Y	154.5	166.9	Y	154.5	166.9	Y	154.5	
	SMEX Solar Panel		311.0		311.0	8%	[illegible]	335.9	N			Y	311.0	335.9	Y	311.0	
	Panel Cover	534.7			534.7	40%	[illegible]	748.6	N			Y	534.7	748.6	N		
	-Y Side Ass'y				**1000.2**	25%	251.1	1251.4									
	Vertical Angle	578.7	317.7		1270.9	8%	[illegible]	1372.6	Y	1270.9	1372.6	Y	1270.9	1372.6	Y	1270.9	
	Flight Handle	30.0	226.8		907.1	8%	[illegible]	979.7	Y	907.1	979.7	Y	907.1	979.7	Y	907.1	
	Bottom Plate	3883.7	3405.0		3405.0	8%	[illegible]	3677.4	Y	3405.0	3677.4	Y	3405.0	3677.4	Y	3405.0	
	Horizontal Angle	48.6	72.0		288.2	8%	[illegible]	311.2	Y	288.2	311.2	Y	288.2	311.2	Y	288.2	
	Stiffening Angle	48.6	0.0		0.0	8%	[illegible]	0.0	N			N			N		
	Flight Handle	20.0	226.8		0.0	8%	[illegible]	0.0	N			N			N		
	Bottom Structure				**3693.2**	8%	295.5	3988.6									
	Enclosure	671.8	980.3		980.3	8%	[illegible]	1058.7	N			Y	980.3	1058.7	Y	980.3	
	IHU PCBs	400.0			400.0	40%	[illegible]	560.0	N			Y	400.0	560.0	Y	400.0	
	IHU				**1380.3**	[illegible]	238.4	1618.7									
	Enclosure	229.3	331.0		331.0	8%	[illegible]	357.5	N			Y	331.0	357.5	Y	331.0	
	RF PCBs	200.0			200.0	40%	[illegible]	280.0	N			Y	200.0	280.0	Y	200.0	
	RF				**531.0**	[illegible]	106.5	637.5									
	Enclosure	229.3	0.0		0.0	8%	[illegible]	0.0	N			Y	0.0	0.0	Y	0.0	
	Power PCBs	200.0	0.0		0.0	8%	[illegible]	0.0	N			Y	0.0	0.0	Y	0.0	
	Power				**0.0**	40%	0.0	0.0									
	Battery Patch Plate	442.6	536.4		536.4	8%	[illegible]	579.3	N			Y	536.4	579.3	Y	536.4	
	Battery	6300.0			6300.0	40%	[illegible]	8820.0	N			N			Y	6300.0	
	Battery Ass'y				**6836.4**	[illegible]	2562.9	9399.3									
	Camera	25.5			25.5	40%	[illegible]	35.7	N			Y	25.5	35.7	Y	25.5	
	Camera Bracket	1.5			2.9	40%	[illegible]	4.1	N			Y	2.9	4.1	Y	2.9	
	Electronics				**8776.1**	[illegible]	2919.2	11695.3									
	70cm Whip	20.0	105.0		105.0	8%	[illegible]	113.4	N			Y	105.0	113.4	Y	105.0	
	Antenna Collar	10.0	43.0		43.0	8%	[illegible]	46.4	N			Y	43.0	46.4	Y	43.0	
	SMEX Solar Panel		311.0		311.0	8%	[illegible]	335.9	N			Y	311.0	335.9	Y	311.0	
	Panel Cover	534.7			534.7	40%	[illegible]	748.6	N			Y	534.7	748.6	N		
	Leg, Short	6.7			26.7	40%	[illegible]	37.4	N			N			N		
	Bottom Assembly				**13489.7**	[illegible]	3475.9	16965.7									
	fasteners	100.0			100.0	40%	[illegible]	140.0	Y	100.0	140.0	Y	100.0	140.0	Y	100.0	
	cables	40.0			40.0	40%	16.0	56.0	N			Y	40.0	56.0	Y	40.0	
	Camera (2x sides)	25.5			51.1	40%	20.4	71.5	N			Y	51.1	71.5	Y	51.1	

Figure 18 Sample Accounting of Mass

What are we doing now that we wouldn't normally do?

The rapid development schedule is driving some details that would not be typical of a spacecraft project. The top and bottom plates of the spacecraft are fast to develop and even faster to build as ¼" thick aluminum, than a more typical sandwich (honeycomb) panel with thin facesheets and a core. Sandwich panels use two facesheets (typically thin sheetmetal or carbon fiber) that are spaced apart by a core (in this case expanded foil). The same principle is at work in poster board (2 pieces of thick paper glued to a foam sheet). The resulting sandwich panel is stiffer and sometimes stronger than the sum of its parts. Therefore it can be made lighter. For example, a sandwich panel made of two 0.040" aluminum sheets and a .375" thick expanded foil core is 3 times stiffer but 1/3 the weight as a ¼" thick aluminum plate. Unfortunately, there's a considerable time penalty in using sandwich panels, and on ARISSat-1 that time is just not available.

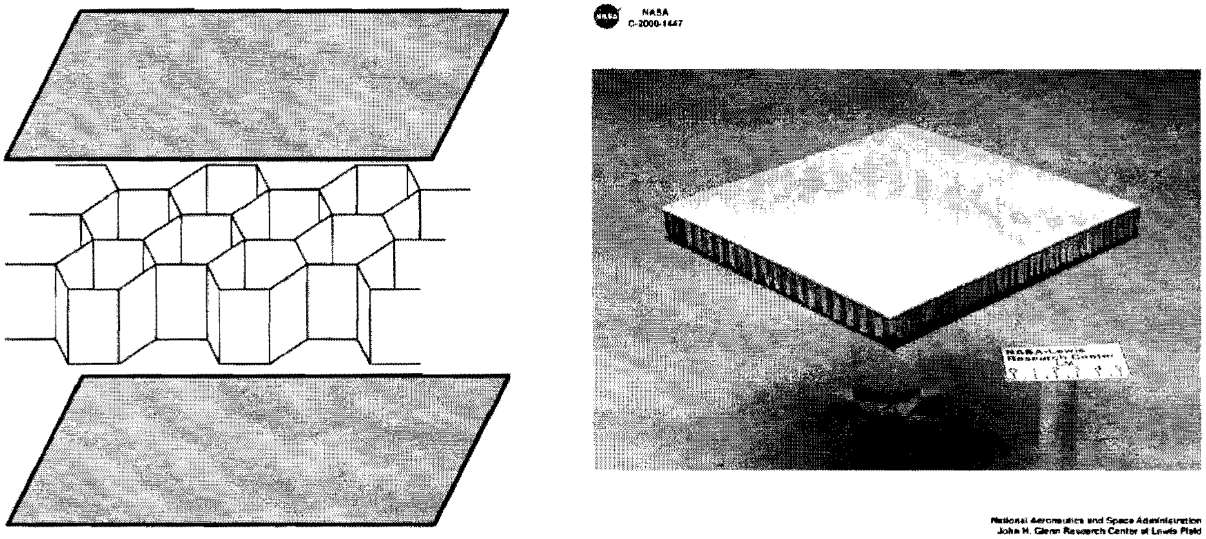


Figure 19 Construction of Sandwich Panel (source: wikipedia.org)

The design of ARISSat-1 is still being documented and still under review, yet we are proceeding with fabrication. This is due to the compressed schedule and it does introduce risk. On a typical spacecraft program, there would be distinct design then fabrication phases, which are separated by a design review milestone. The ARISSat-1 team is doing their best to design, document and implement within the schedule, while maintaining communication within our team and to NASA and Russian partners (including management, safety, experiments, launch vehicle interface, crew training, etc).

Status

Design and analysis is nearly complete. The spacecraft structural components are heading to the machine shop soon. Our documents are under internal review and by NASA, Energia, and Kursk University. The mechanical design appears to meet all requirements. The material and fastener stresses have positive Margins of Safety. The Natural frequencies of the Top and Bottom Plates and of the individual circuit boards are high. Our preliminary safety documentation has been submitted for review. We have provided information about Covers, Handles and cosmonaut procedures.

Plans for the Final Months

Although the mechanical design of ARISSat-1 was only born in July 2009, fabrication is beginning imminently. After that, the entire structure will be assembled once without the electronics to verify the fit of all pieces. Then, the structure will be handed over to integration of electronics. From there, the spacecraft undergoes testing, shipping to Russia, integration of the Kursk experiment, more testing, launch, and finally release by hand from the International Space Station. Stay tuned and new volunteers for this and other AMSAT projects are welcome!

The ARISSat-1 Linear U/V Transponder

Bill Ress – N6GHZ
ARISSat-1 Team Member

Introduction

ARISSat-1 will be flying a linear transponder having an uplink at 435.750 MHz (COMMRX) and a downlink at 145.938 MHz (COMMTX). The uplink passband will be 16 KHz wide and will support one FM channel and up to four SSB signals. The downlink signal will be 40 KHz wide and will not only include the 16 KHz linear segment, but a FM signal used for SSTV and voice announcements, a BPSK telemetry channel and the CW beacon signal, all generated in the SDX. The downlink transmitter will provide 0.5 watts RF output shared between the four information channels.

Overall Design Objectives

As with any satellite application, efficient use of the available power is the essential first consideration when designing system functions. DC to RF conversion efficiency must be the highest possible in both the COMMRX and the COMMTX. Size and weight are the next important design considerations.

An added design consideration for ARISSat-1 was that all the system functions were to be designed with "modularity" considerations. At the October 2008 AMSAT-NA Board meeting, it was decided to develop all new systems so that they could be configured to build a satellite which would meet "any" launch opportunity. This meant designing for a satellite as small as a CubeSat.

The 145 MHz COMMTX Power Amplifier

The start of the transponder design focused on the 145 MHz COMMTX RF output stage since it would be the dominate circuit, which would determine overall efficiency. The most stringent design constraints are; a) 0.5 watts of linear RF output, b) high DC to RF conversion efficiency, c) small size, and d) low spurious and harmonic output.

Device Selection

While a wide selection of broadband VHF/UHF RFIC's is available from a number of semiconductor manufacturers, they are almost all operating in the Class A mode. This means that, while they are very linear and have very desirable gain and power output characteristics, they operate in the most inefficient class of operation, since it draws current at all times regardless of the input signal level.. Class AB device operation, on the other hand, is a linear mode where a small amount of DC current is draw during no signal input, and the current drawn depends on the signal input level. This class of operation seemed to be a much better choice for efficiency, but very few RFICs use this mode. The ones I found were not usable at this frequency and power level.

Using discrete silicon MOSFET RF transistors seem to be the answer to designing a high efficiency, high gain Class AB power stage. After building and testing many prototypes using a variety of devices, the Mitsubishi RD01MUS1 was selected. At 175 MHz, it is rated at 0.8W Pout with a gain of over 16 dB with efficiencies greater than 70% possible. The idle current can be adjusted easily by applying a positive DC voltage to the grid, and it does this all this while operating with a Vdd of 8 DC, which is readily available from the satellite power supply unit (PSU).

Another nice benefit of using a discrete device is the requirement that the input and output be matched. This circuitry used for matching also provides additional signal filtering not provided by the broadband RFIC's. In this application, a PI network is used to do the output impedance matching. This not only did the impedance matching, but the PI network, being a low pass filter, also helps attenuate the second and third harmonics present in the output.

When running 0.5 watt Pout, the DC input current is 140 mA at 8Vdc, or a DC power input of 1.12 watts, for an efficiency of 45%. The COMMTX output stage circuitry is shown in Figure 1 and the gain, Pout versus Pin, is shown in Figure 2.

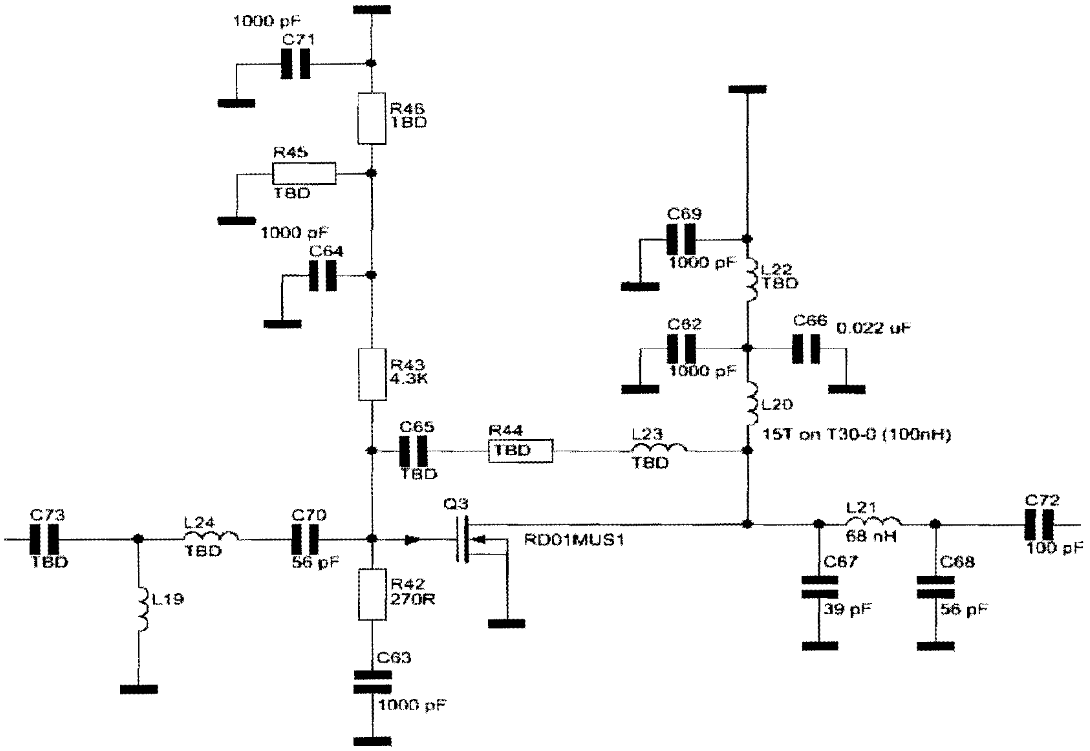


Figure 1 – 145 MHz COMMTX Class AB Output Stage

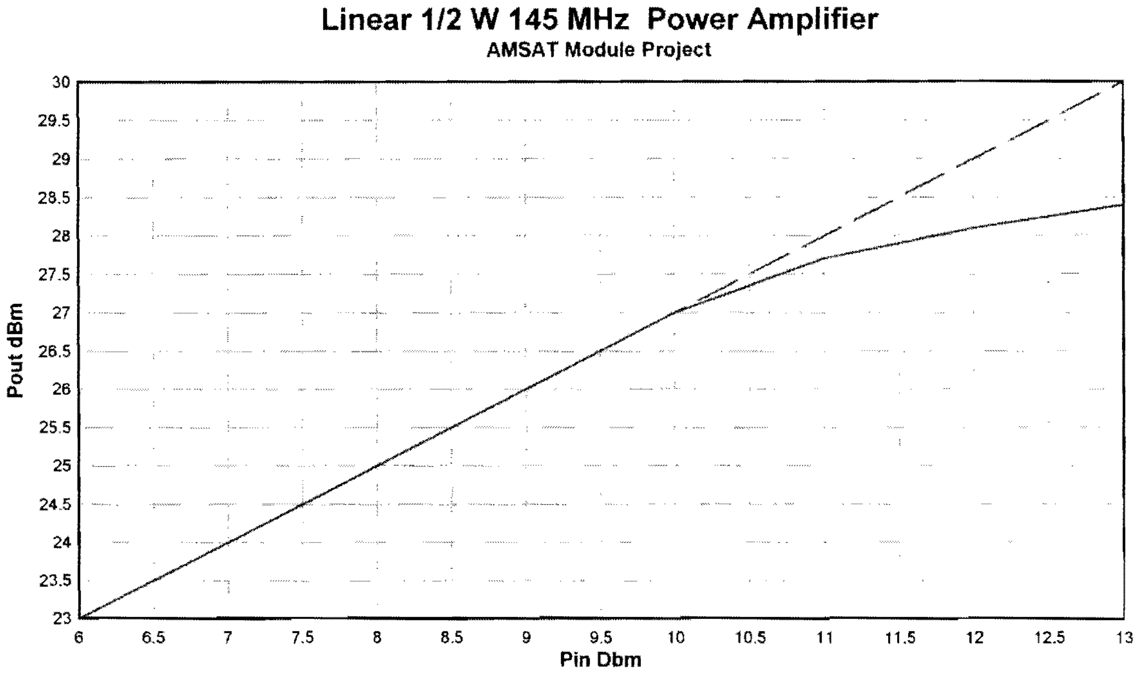


Figure 2 – Power Amplifier Gain and Pout versus Pin

The Overall 145 MHz COMMTX Design

The COMMTX function as an up converter. It takes the 10.7 MHz output from the SDX, at approximately -13 dBm, and up converts it to 145.938 MHz using a local oscillator at 135.238 MHz.

The 10.7 MHz input signal is first filtered and then amplified before going to the passive double balanced mixer. The local oscillator signal is a phase locked loop (PLL), the Si5338, with its reference coming from a 19.2 MHz temperature compensated crystal oscillator having better than +/- 2.5 PPM frequency stability over -30 to +70 degrees C.

The 145 MHz filter in the output of the mixer is a departure from the convention use of the large and bulky helical filters. These helical filters are becoming scarce so it was decided to significantly reduce the filter size and PCB footprint by designing a discrete 4 pole BPF.

Following the BPF, two linear driver stages, the MBC13916 and the MCL ERA-5SM, provide the gain and power level to drive the RD01MUS1. To insure that all harmonics are below -60 dBc, a seven pole LPF follows the output stage PI network.

The COMMTX schematic is shown in Figures 3 and 4. Figure 5 shows the PCB which measures 60 cm (2.35") by 71 cm (2.8"). The PCB assembly is just 6.9 cm (0.27") high.

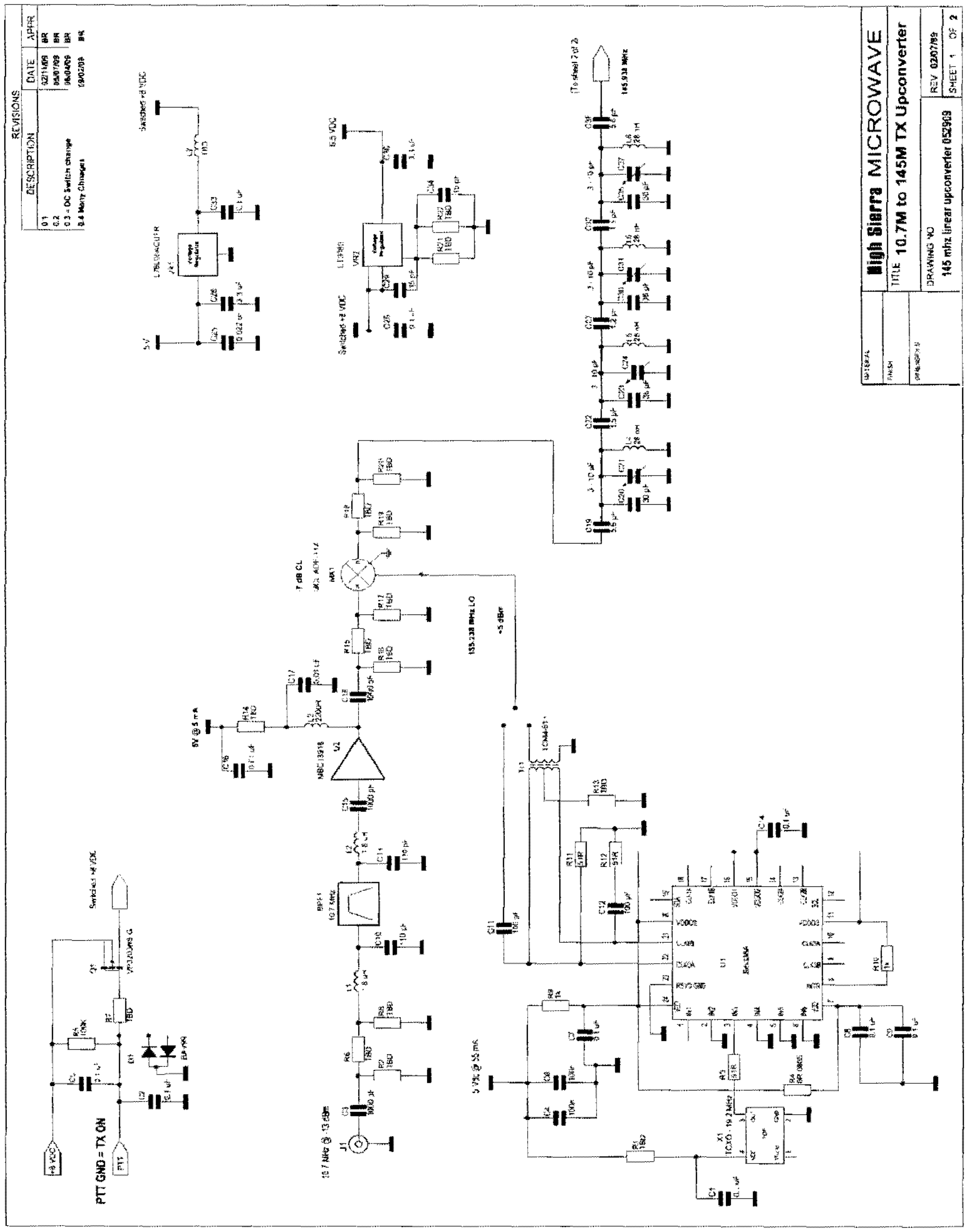


Figure 3 – COMMTX Schematic – Sheet 1 of 2

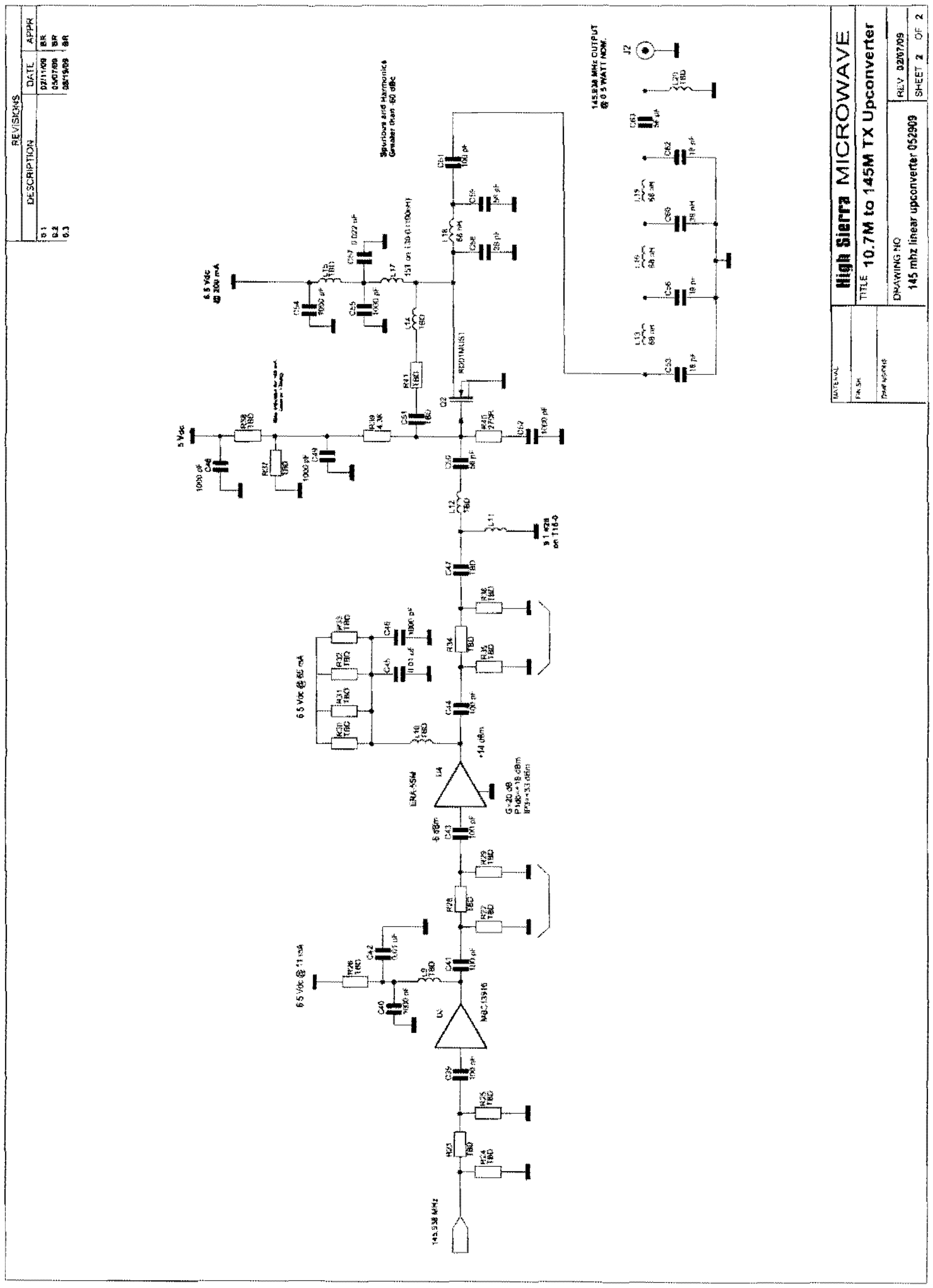


Figure 3 – COMMTX Schematic – Sheet 2 of 2

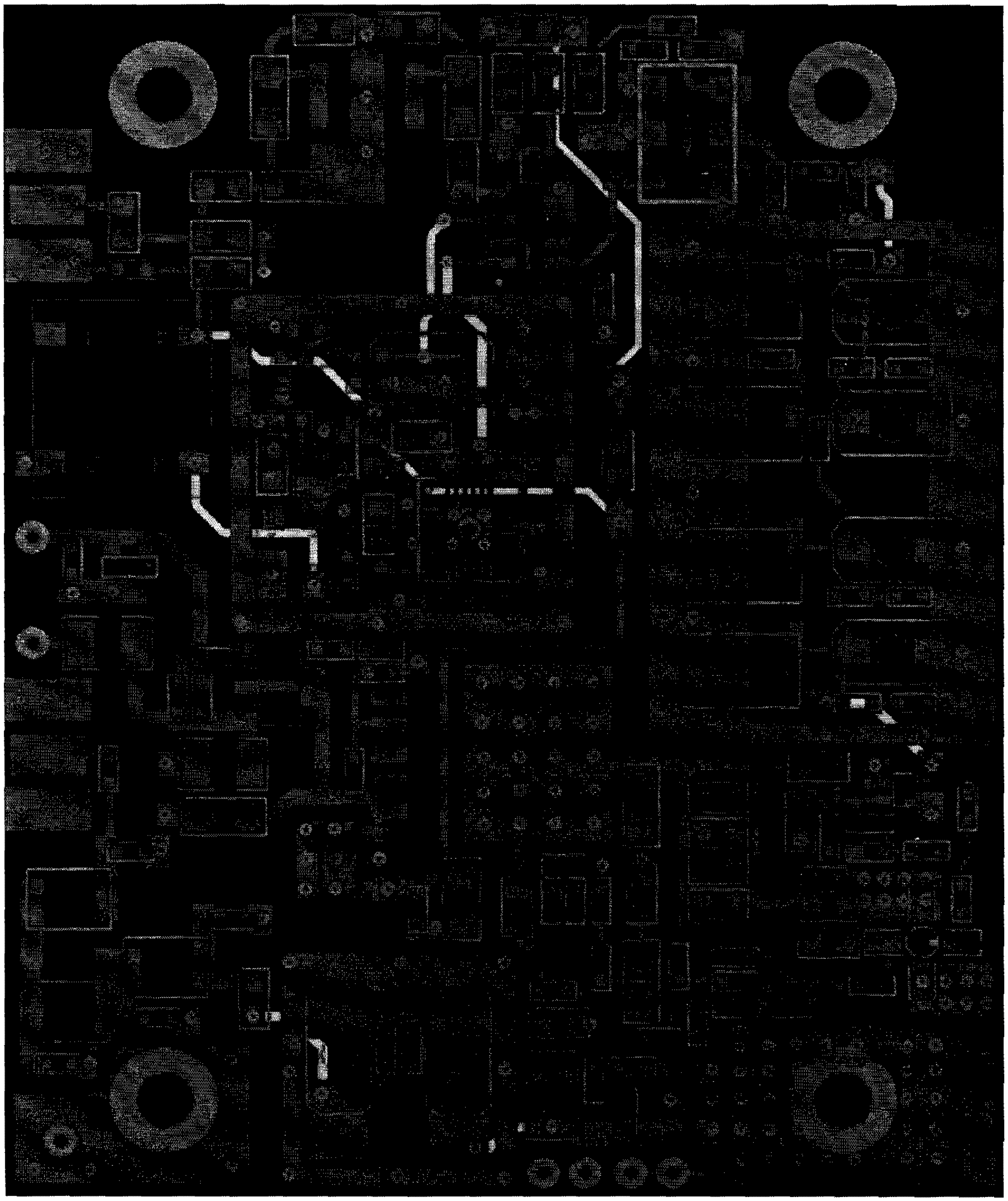


Figure 5 – 145 MHz COMMTX PCB Layout

145 MHz COMMTX Performance Data Summary:

Input: 10.7 MHz at -13 dBm

Output: 145.938 MHz at +27 dBm

Harmonics: more that 60 db below the output signal

Spurious: more than 60 dB below the output signal

DC Input: 8 Vdc at 265 mA maximum (2.12 watts)

Overall eff% 23.5%

The 435 MHz COMMRX

Overall Design

The 435 MHz COMMRX is a linear, low noise, single conversion down converter with an IF output at 10.7 MHz. The 10.7 MHz output has an adjustable output level of -15 to 0 dBm. This 10.7 MHz signal feeds the SDX. The down converter also incorporates AGC which keeps the 10.7 MHZ IF output constant with RF input levels of -120 dBm and higher. The noise figure is nominally 4.5 dB.

The local oscillator at 446.442 MHz is provided by a phase locked loop (PLL) oscillator (also the Si5338), with its reference also being a 19.2 MHz temperature compensated oscillator, which provides +/-2.5 PPM frequency stability over -30 to +70 degrees C.

The COMMRX shares its input filtering at 435 MHz and its low noise amplifier (LNA) with the Command receiver (CMDRX). The 435 MHz signal is split after the first LNA in a lumped 435 MHz power divider and cabled to the CMDRX which sits "piggy back" on top of the COMMRX, sharing its same hole mounting pattern.

During the design process, care was taken to maximize amplifier stage efficiencies while maintaining adequate "headroom" to insure linear operation. This design tradeoff resulted in a COMMRX module which requires 135 mA at 8 Vdc, or 1.08 watts. Since the 8 Vdc is down regulated in a linear voltage regulator (linear because it is low noise) to 5 Vdc, if the COMMRX was run from a 5 Vdc supply, the input power would then only be 675 mW.

Filtering

Instead of using the helical filters for the 435 MHz input, a very small SAW filters are used. Two of these filters are used prior to the active mixer and they provide over 90 dB of image rejection. The 10.7 MHz filters are small ceramic filters, each having a 1 dB bandwidth of 50 KHz. Using these small filters significantly reduce the size and height of the PCB assembly.

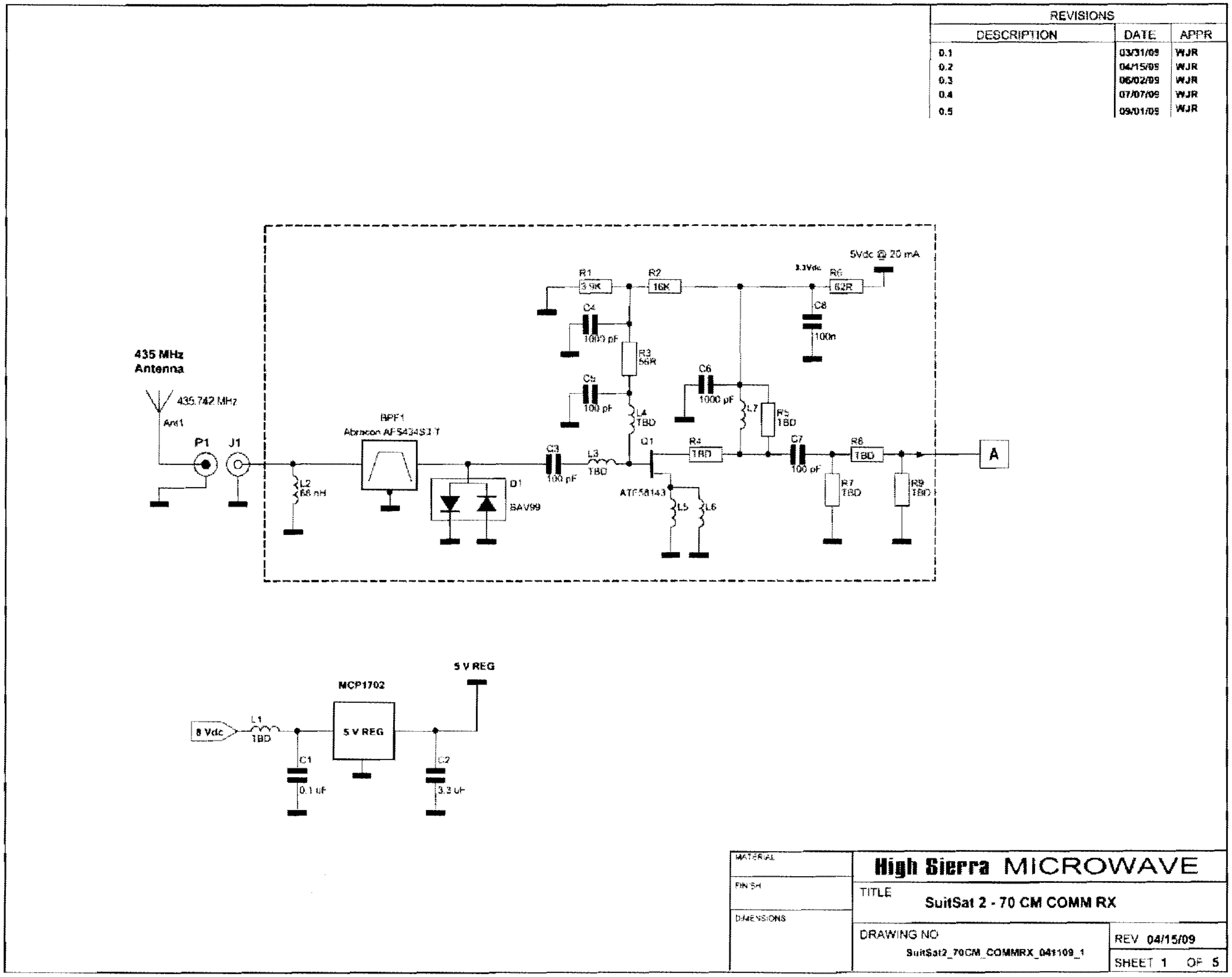
Size

The size of the PCB is the same as the COMMTX, which is 60 cm (2.35") by 71 cm (2.8"). The height of the COMMRX assembly is just 6.9 cm (0.27"). It uses the same mounting hole pattern as the COMMTX permitting the two to be stacked. When stacked using a metal shielding plate between them, their combined overall height can be less than 19 cm (0.75").

The 435 MHz COMMRX Performance Data Summary:

RF Input:	435 MHz
Noise Figure:	4.5 dB
Image Rejection:	> 90 dB
AGC Threshold:	-120 dBm
IF Output:	10.7 MHz
IF Output Level:	-15 to 0 dBm
DC Input:	8Vdc @ 135 mA
Size:	60 cm (2.35") by 71 cm (2.8") by 6.9 cm (o.27") high

435 MHz COMMRX Schematics



REVISIONS		
DESCRIPTION	DATE	APPR
0.1	03/31/09	WJR
0.2	04/15/09	WJR
0.3	06/02/09	WJR
0.4	07/07/09	WJR
0.5	09/01/09	WJR

Figure 6 – 435 MHz COMMRX – Sheet 1 of 5

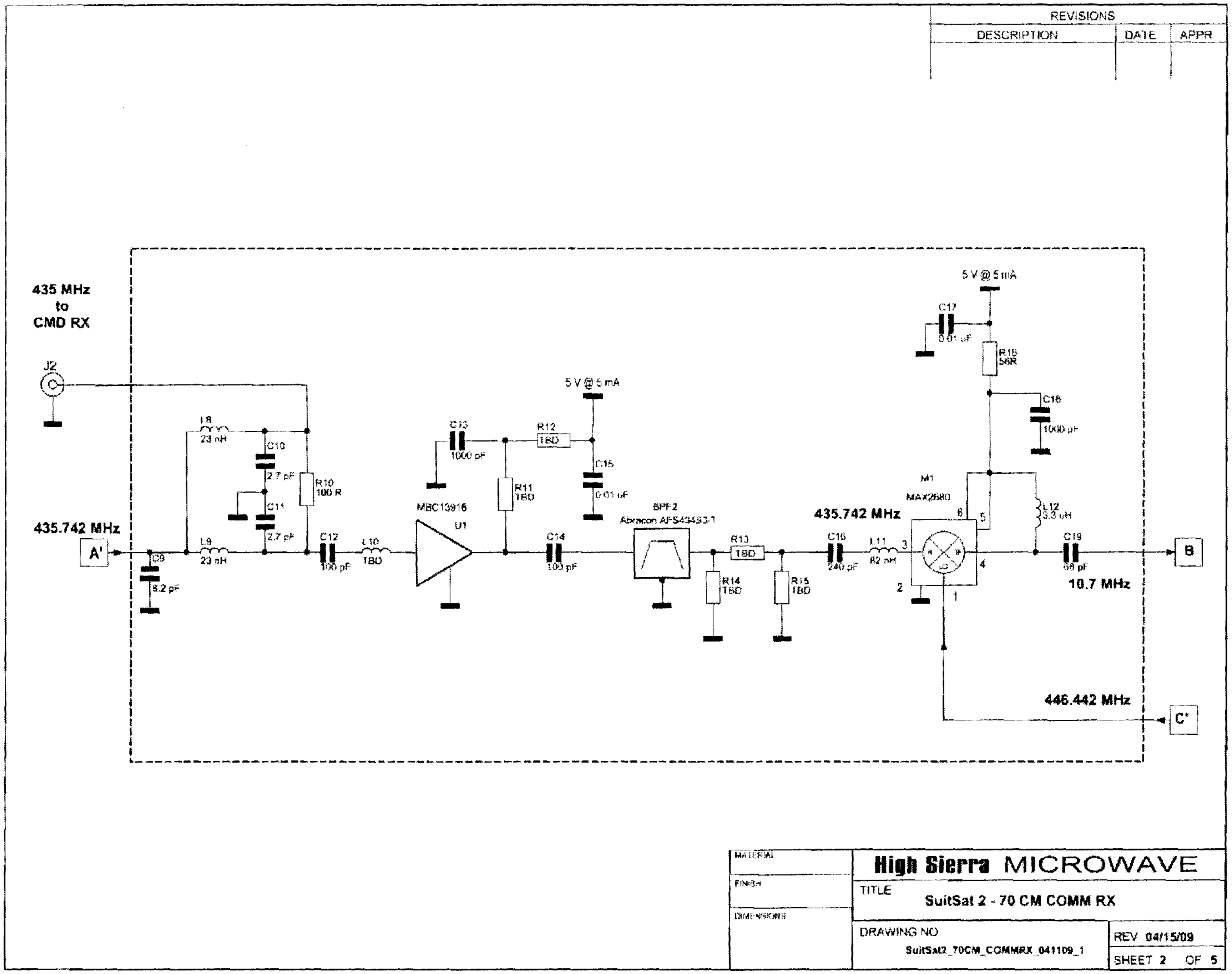


Figure 7 – 435 MHz COMMRX – Sheet 2 of 5

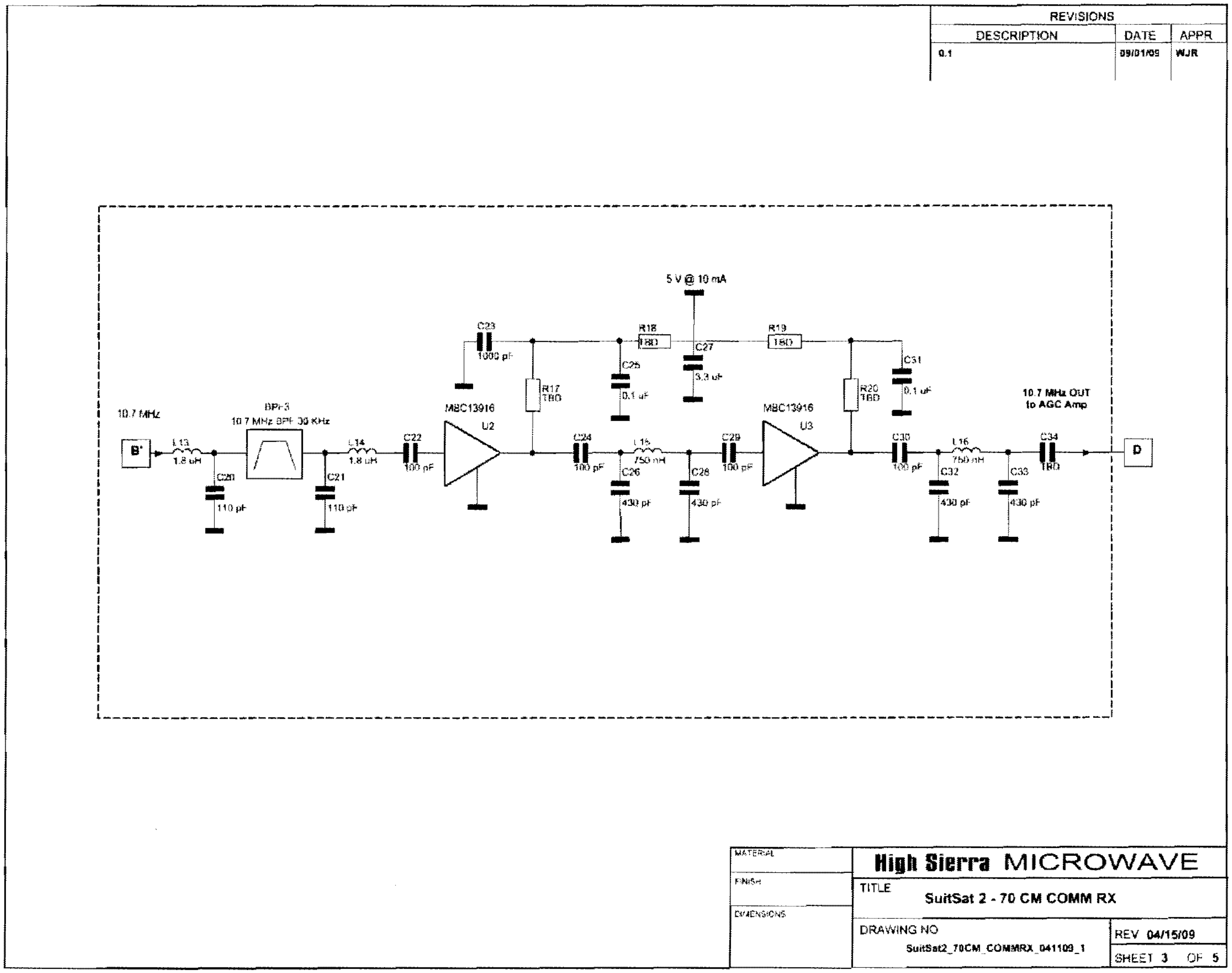


Figure 8 – 435 MHz COMMRX – Sheet 3 of 5

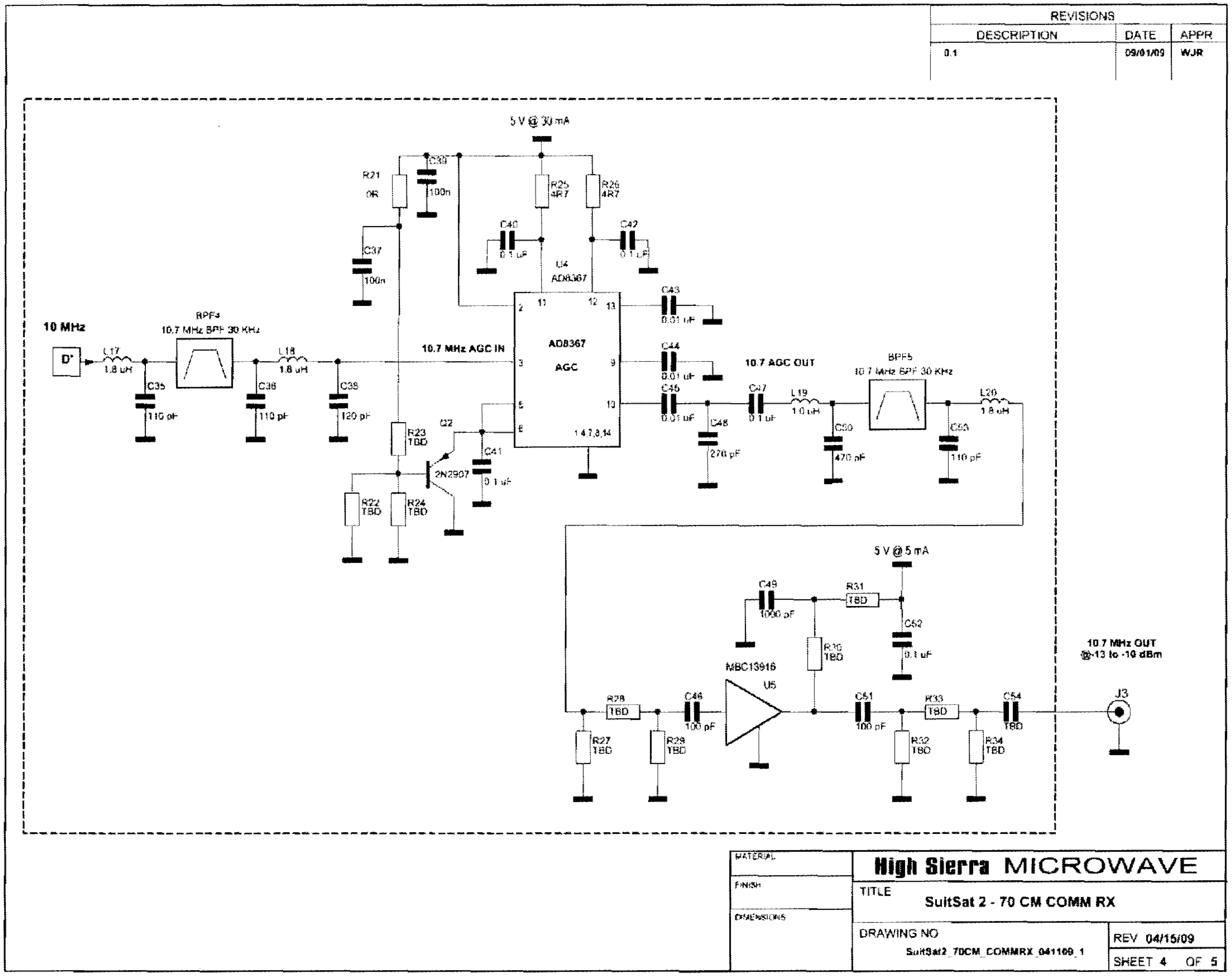
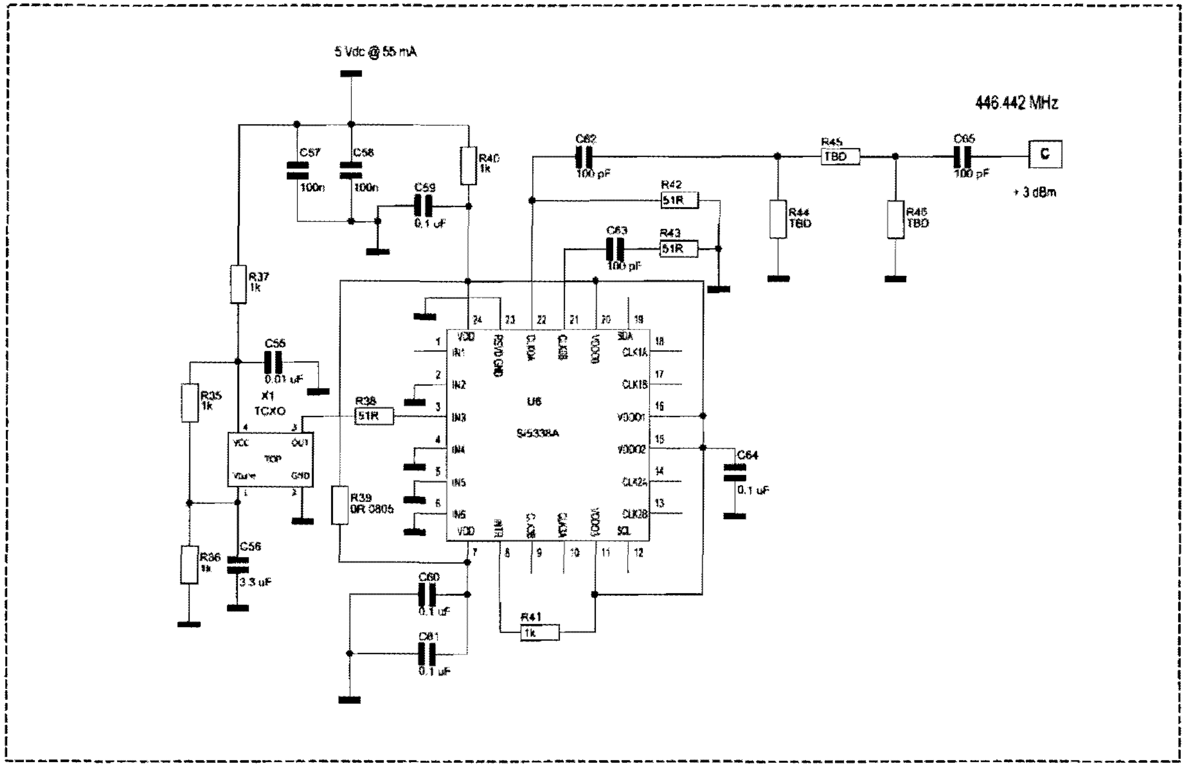


Figure 9 – 435 MHz COMMRX – Sheet 4 of 5

REVISIONS		
DESCRIPTION	DATE	APPR
0.1	09/01/09	WJR



MATERIAL

FINISH

DIMENSIONS

High Sierra MICROWAVE

TITLE
SuitSat 2 - 70 CM COMM RX

DRAWING NO
SuitSat2_70CM_COMMRX_041109_1

REV **04/15/09**

SHEET **5** OF **5**

Figure 10 – 435 MHz COMMRX – Sheet 5 of 5

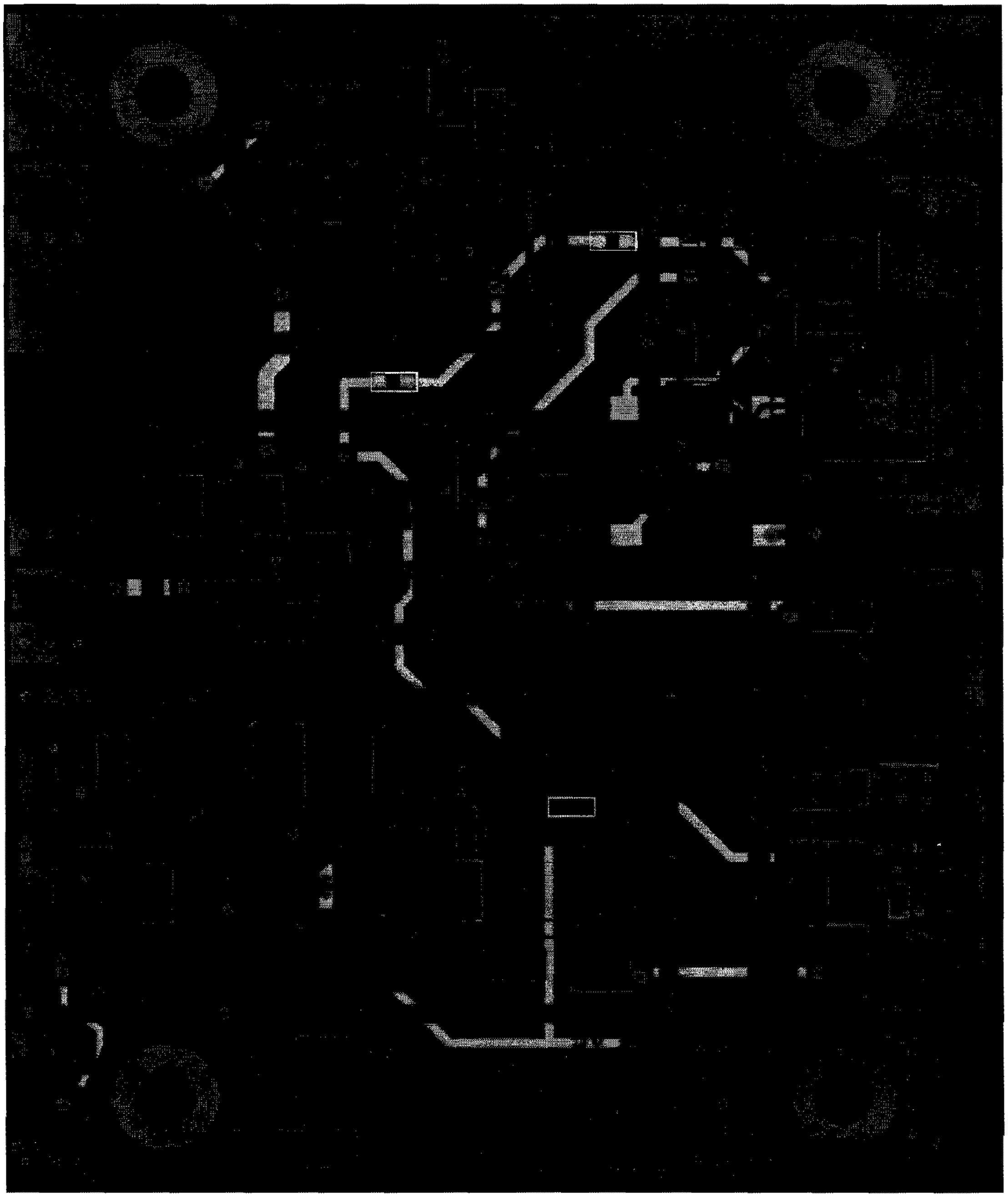


Figure 11 – 435 MHz COMMRX PCB Layout

Summary

In designing the linear U/V transponder for the ARISSat-1 satellite requirement, we have also provided an efficient "modular" design that can be modified to fit most all future satellite configurations that AMSAT-NA will build, requiring a mode U/V capability.

Software Radio Technology

On ARISSat-1

Anthony Monteiro, AA2TX

AMSAT Space Symposium, 2009

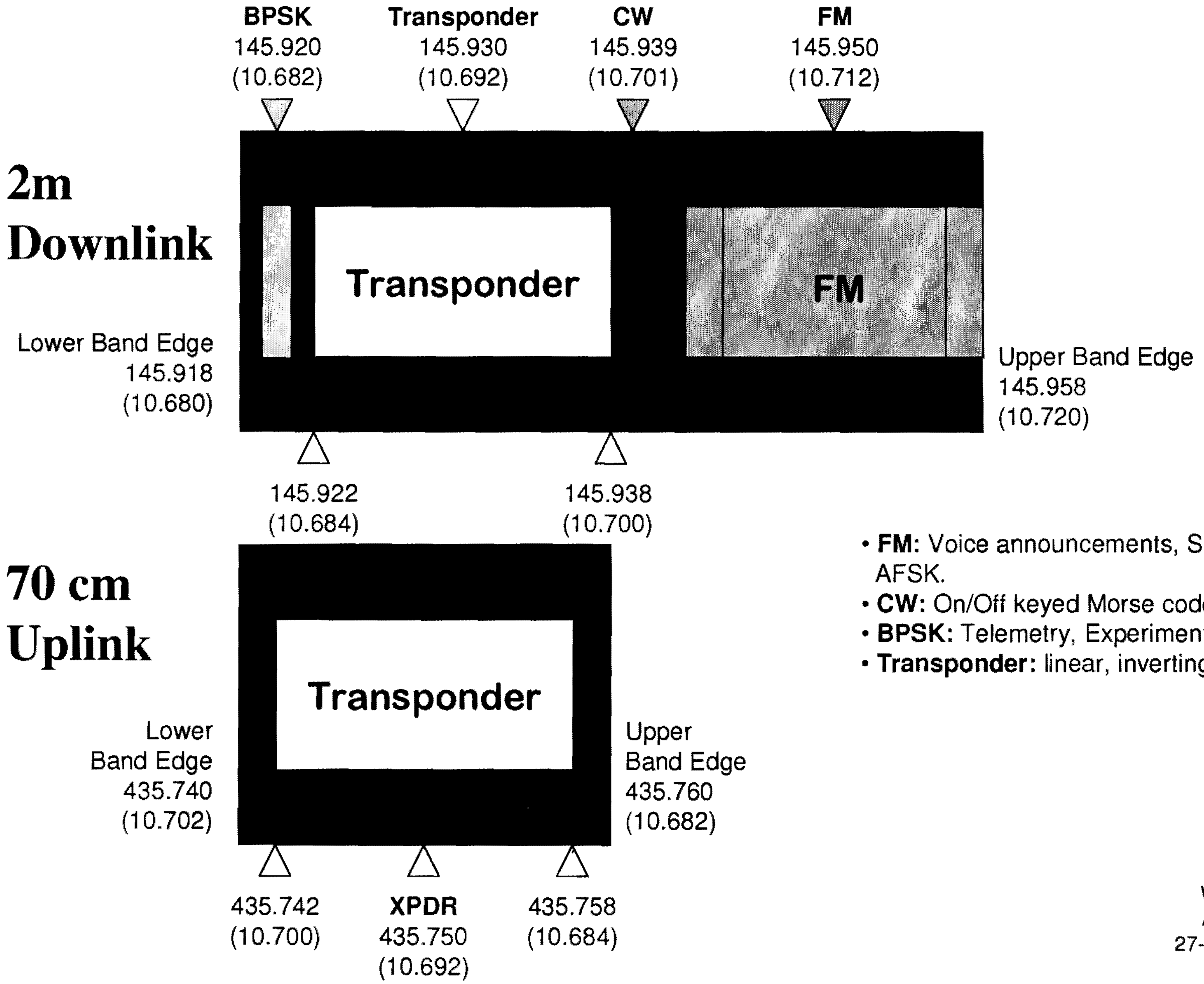
Overview

- Functionality
- Hardware Architecture
- Software Architecture
- Digital Signal Processing

Radio Signals Created in Software

- CW Beacon
- FM Audio
- BPSK Telemetry
- Linear Transponder

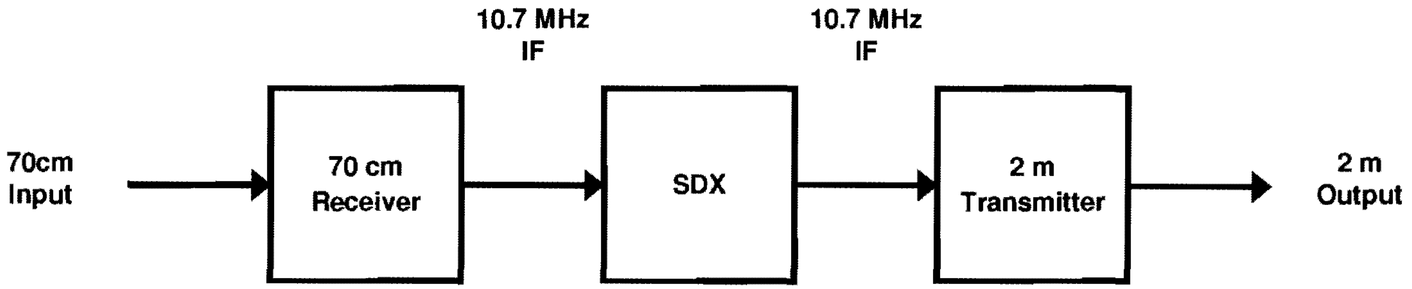
ARISSat-1 Band Plan



- **FM:** Voice announcements, SSTV, AFSK.
- **CW:** On/Off keyed Morse code
- **BPSK:** Telemetry, Experiment data
- **Transponder:** linear, inverting

W5DID
AA2TX
27-Feb-2009

ARISSat-1 Radio Architecture



70cm Input

70 cm Receiver

10.7 MHz IF

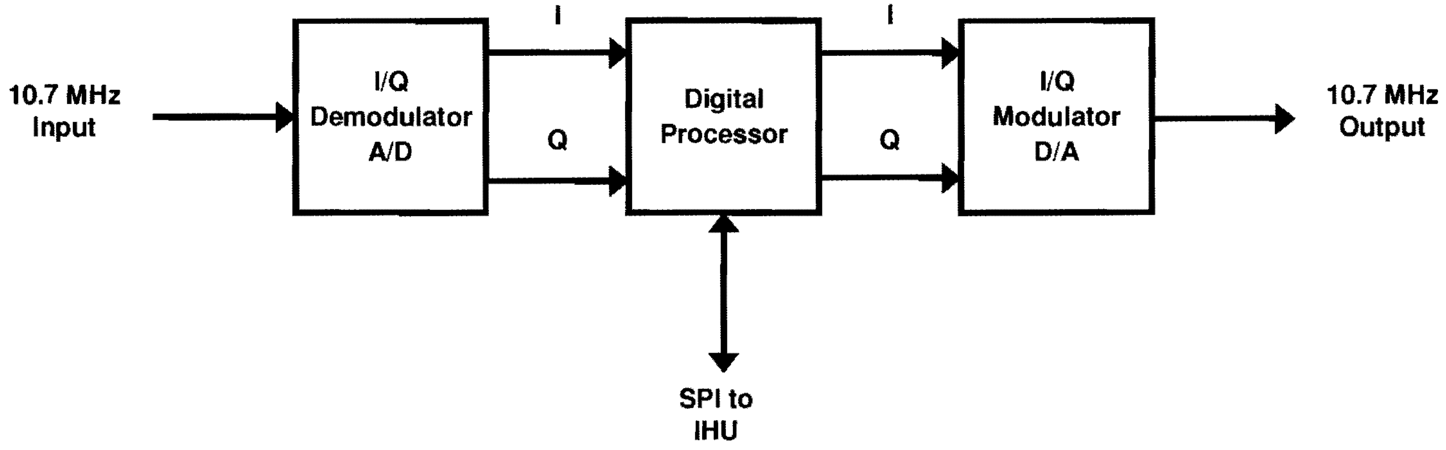
SDX

10.7 MHz IF

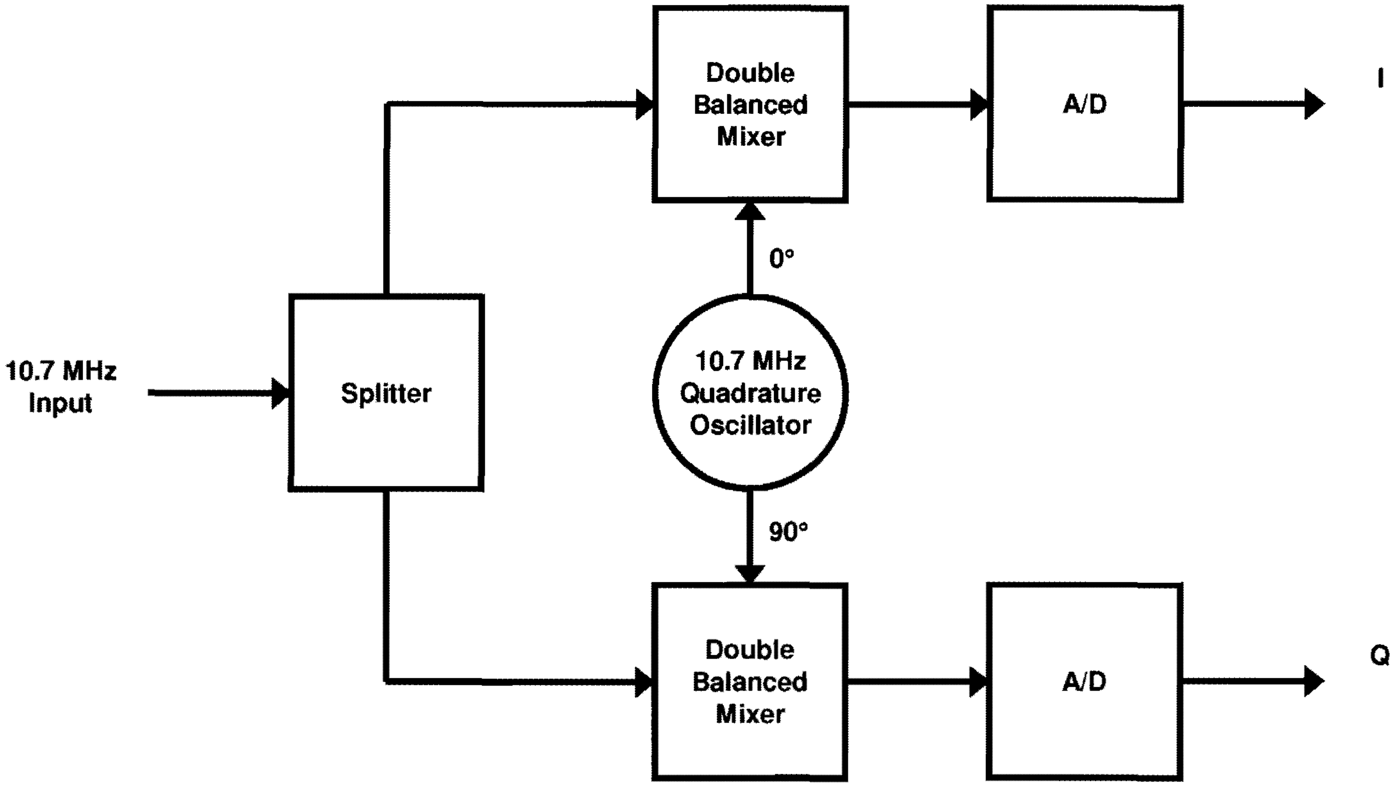
2 m Transmitter

2 m Output

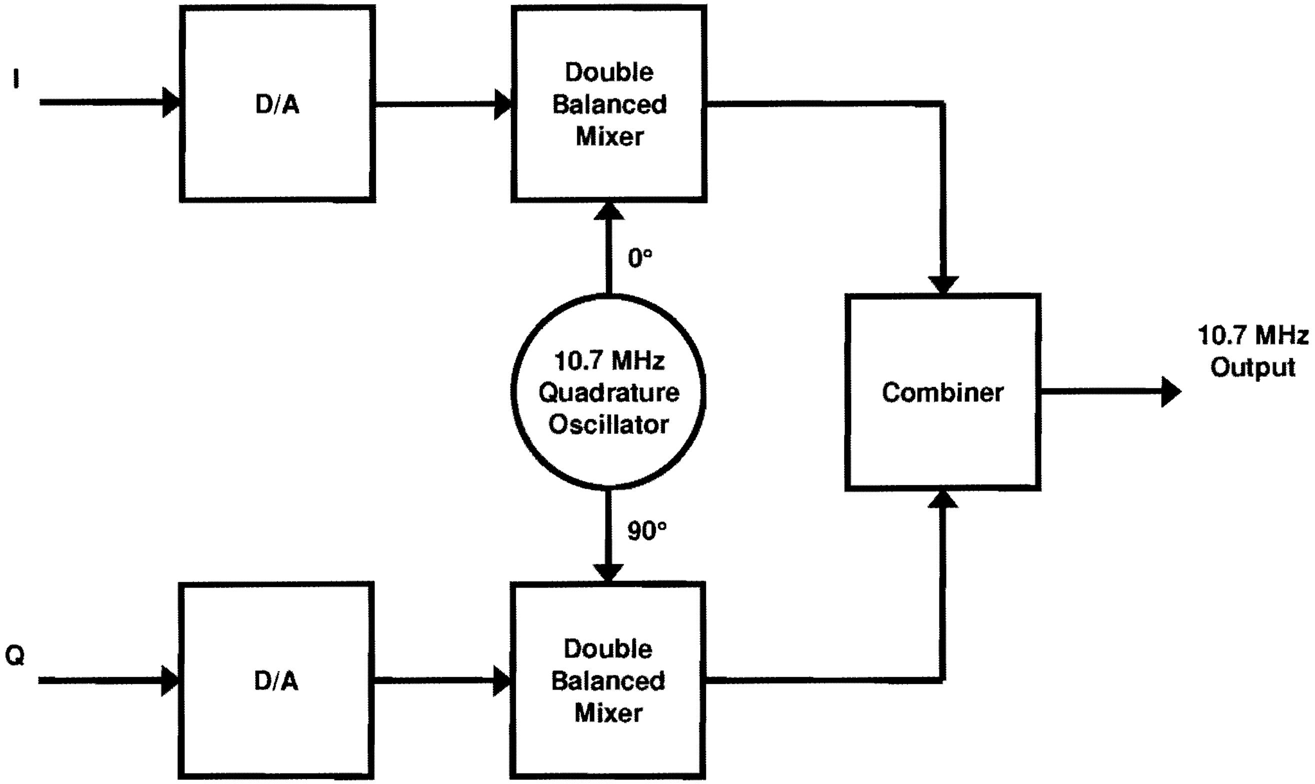
SDX Hardware Architecture



I/Q Demodulator



I/Q Modulator



I

D/A

Double Balanced Mixer

0°

10.7 MHz Quadrature Oscillator

90°

Combiner

10.7 MHz Output

Q

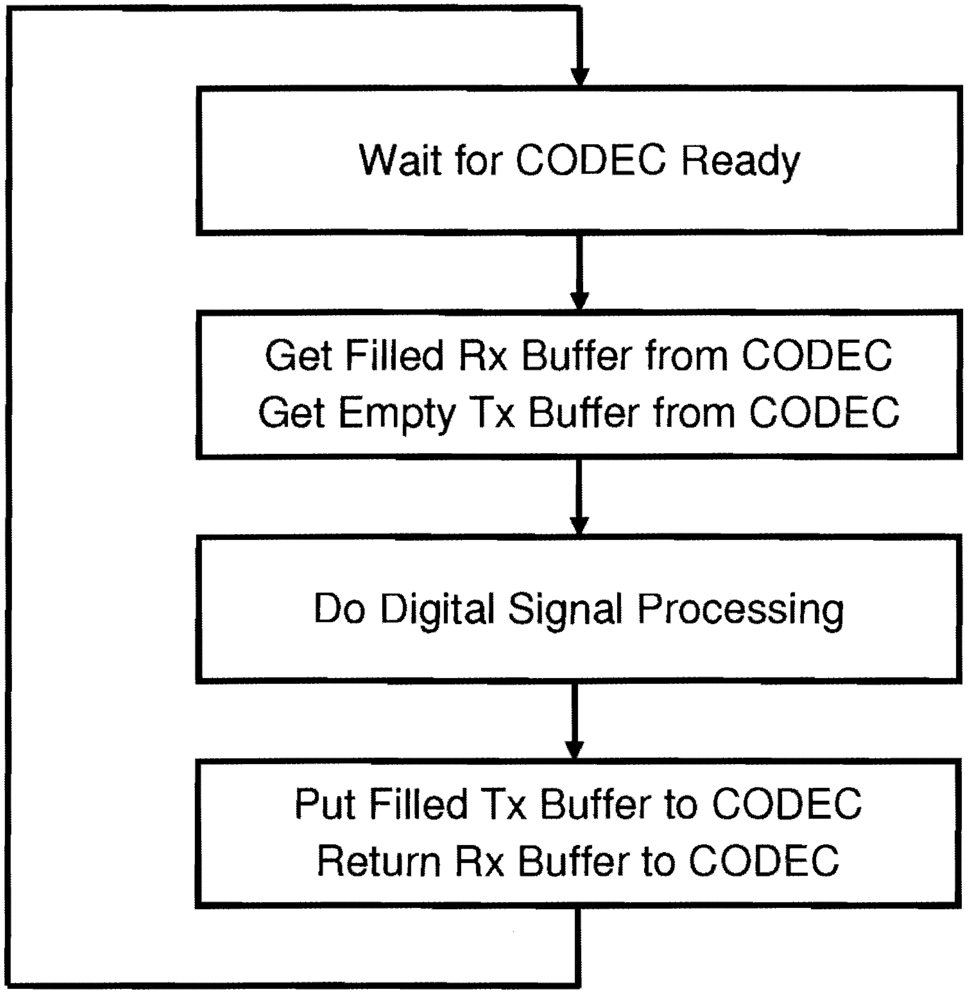
D/A

Double Balanced Mixer

Digital Processor

- Microchip PIC32 (MIPS core)
- 80 MHz clock
- 512k Program memory
- 32k RAM
- On-chip peripherals

Software Architecture



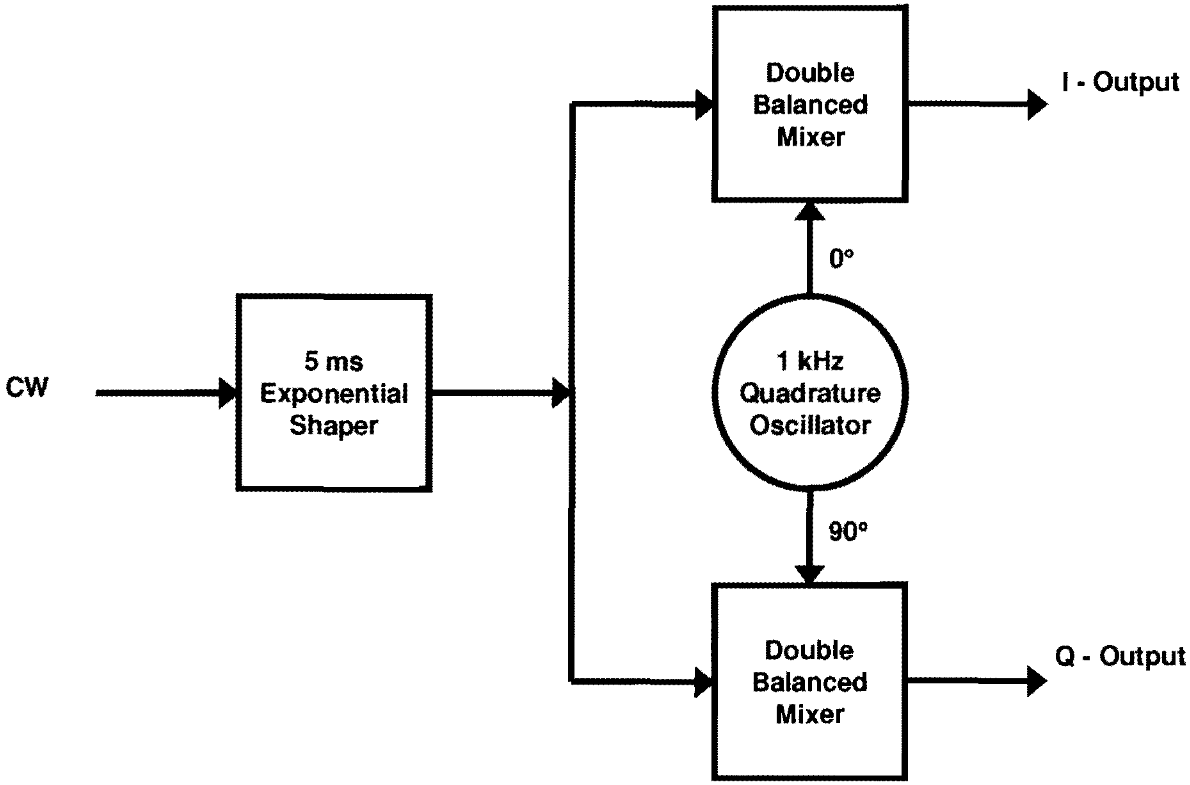
Wait for CODEC Ready

Get Filled Rx Buffer from CODEC
Get Empty Tx Buffer from CODEC

Do Digital Signal Processing

Put Filled Tx Buffer to CODEC
Return Rx Buffer to CODEC

DSP - CW Beacon



CW

5 ms Exponential Shaper

Double Balanced Mixer

1 kHz Quadrature Oscillator

0°

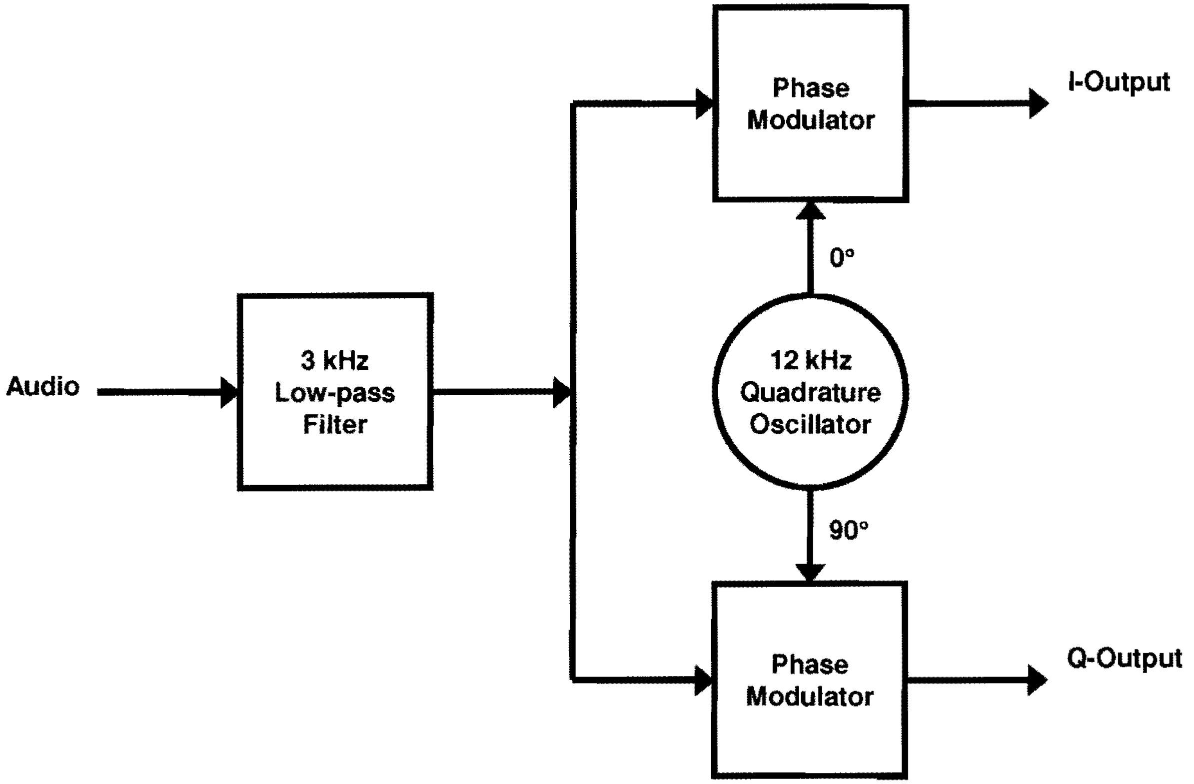
90°

Double Balanced Mixer

I - Output

Q - Output

DSP - FM Audio



Audio

3 kHz
Low-pass
Filter

Phase
Modulator

I-Output

0°

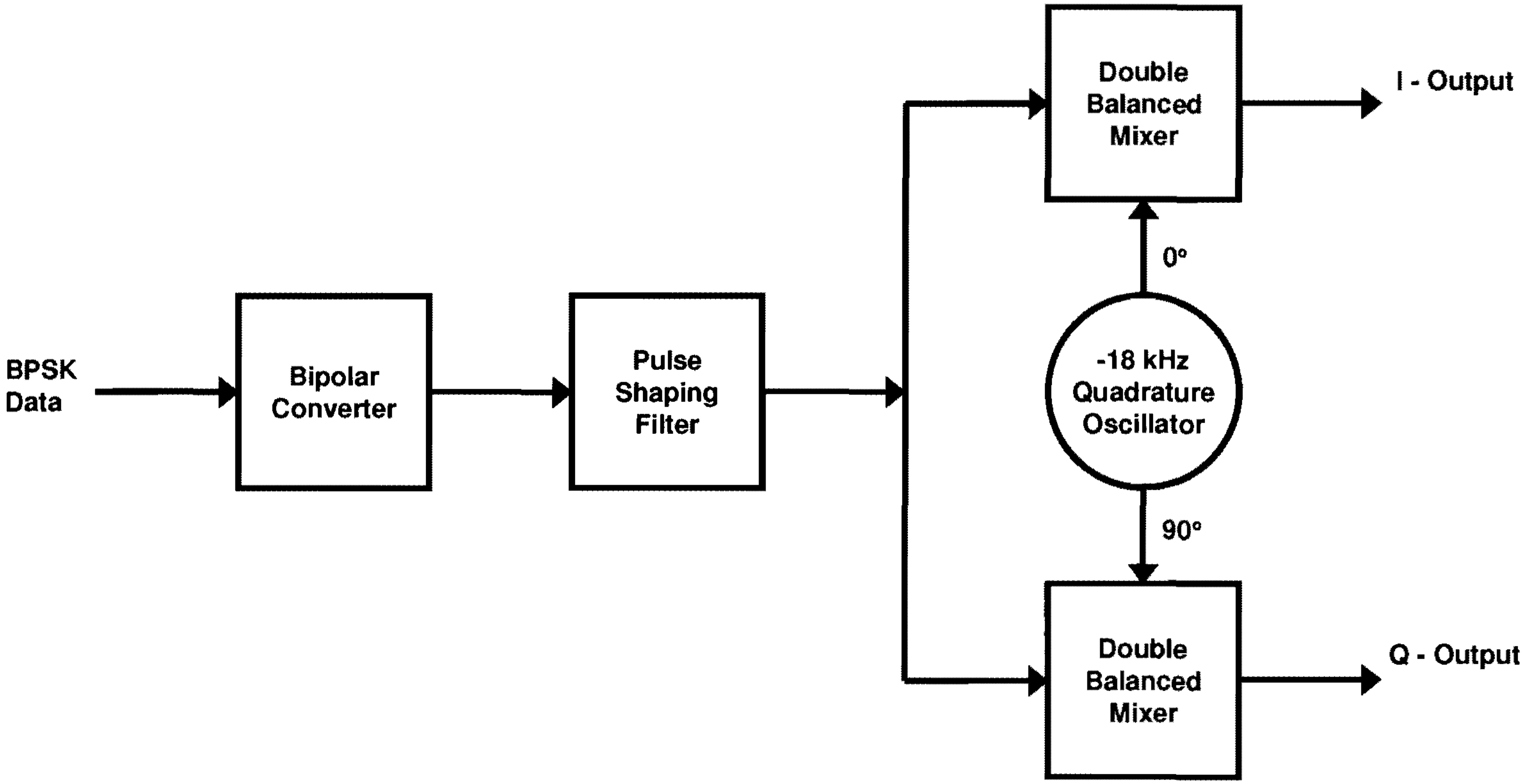
12 kHz
Quadrature
Oscillator

90°

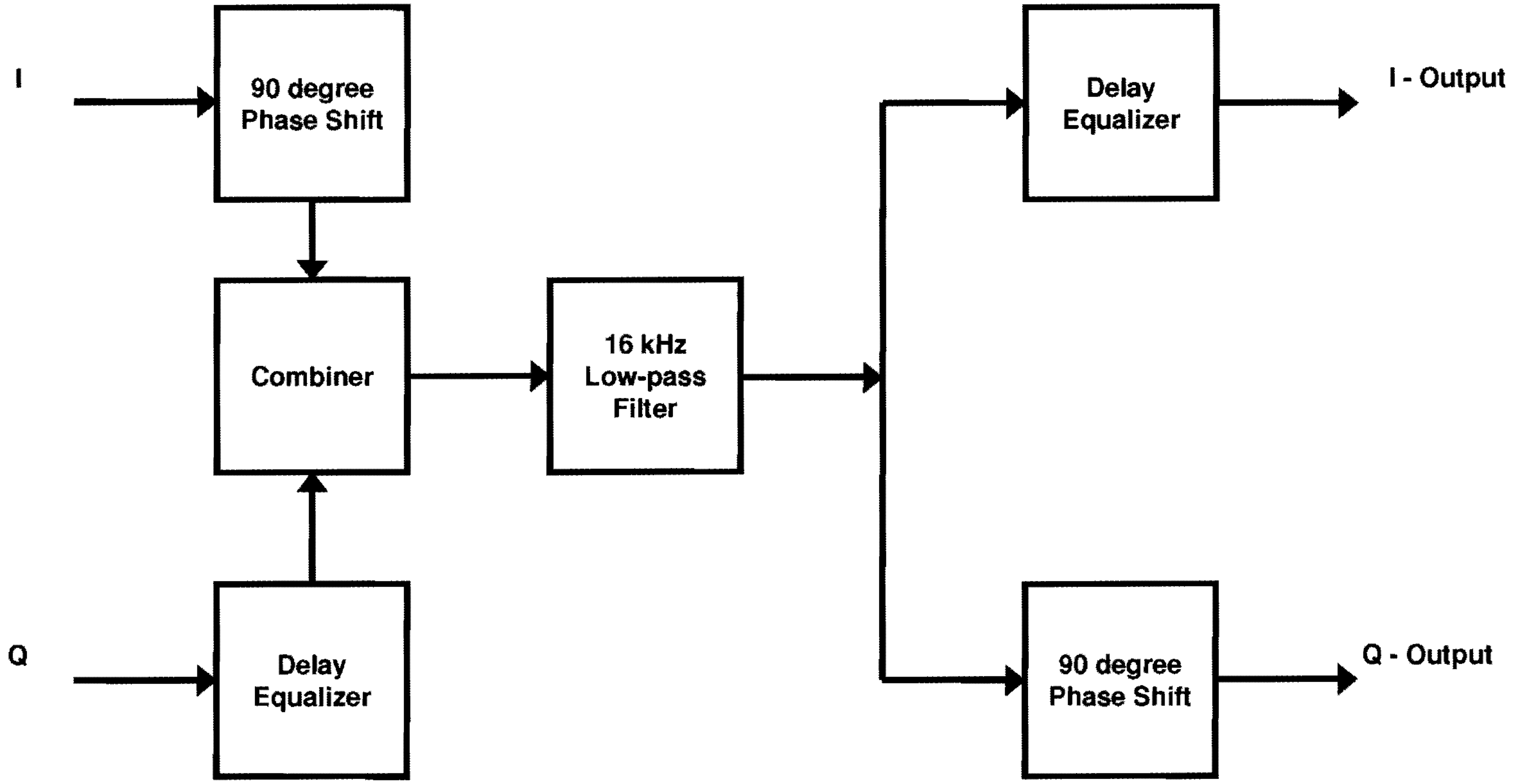
Phase
Modulator

Q-Output

DSP - BPSK


BPSK Data
Bipolar Converter
Pulse Shaping Filter
Double Balanced Mixer
I - Output
0°
-18 kHz Quadrature Oscillator
90°
Double Balanced Mixer
Q - Output

DSP - Linear Transponder



I

90 degree Phase Shift

Combiner

Q

Delay Equalizer

16 kHz Low-pass Filter

Delay Equalizer

I - Output

90 degree Phase Shift

Q - Output

ARISSat-1 SDX Status

- Software Complete
- All Signals Operating
- Integrated with Rx and Tx modules
- Transponder tested for both FM and SSB/CW operation

Software Radio on ARISSat-1

- **Questions?**
- **Thank You!**

Tony - AA2TX

Lessons Learned at LEO: Implications for Future AMSAT-NA Projects

Andrew Glasbrenner, KO4MA
Vice President of Operations

AMSAT-NA has a long, mostly successful tradition of designing, building and flying LEO spacecraft, beginning in 1970 with the launch of OSCAR 5, and continuing through to the construction and deployment of Suitsat-1 in 2006. Along the way, the organization has learned many important, and sometimes painful, lessons about the business of spaceflight. This paper will attempt to record some of the author's observations, experiences and conclusions based primarily on experiences with AO-7, AO-16, and AO-51, but also other satellites in the amateur service. It is the author's desire that this paper also serve as a beginning to a more formal codification of lessons learned, and document AMSAT's institutional knowledge for incorporation into future spacecraft and missions. Corrections, clarifications, and comments are of course welcome.

Spacecraft Orbit

Even without entering to the eternal debate over HEO versus LEO spacecraft, there are considerable differences in utilization of LEO spacecraft depending on their orbital altitude and other parameters. Examining what the apparent preferences are may be beneficial in planning future missions, although the reality is often we must take what is available in our price range and make the best of it.

One of the most striking preferences can be identified by examining the usage of two currently operating satellites, AO-7 and VO-52. AO-7, resurrected after many years an running solely on the solar panels, is in a sun-synchronous orbit (SSO) of 1440x1459km. AO-7 is capable of being commanded, but unlike newer satellites will "self-boot" upon exiting eclipse. The satellite generally is in Mode U/V during eclipse seasons, but alternates between U/V (old mode B) and V/A (old mode A) every 24 hours when in continuous illumination. Mode V/A is relatively weak, and Mode U/V suffers from self generated QRM in the passband, and and the transponder often becomes unstable with even moderate levels of activity. By comparison, VO-52 is also mode U/V but in a much lower 644x604km SSO orbit. VO-52 operates continuously in mode U/V with a very strong and clear transponder downlink.

By observation of activity and comments, it is very obvious that AO-7 is the greatly preferred of the two satellites. Given the differences in quality of the transponders, and the very similar daily pass times, the altitude and hence communications range must be the deciding factor in the satellite's relative popularity.

While not quite as clear, there may be evidence for preference among users for SSO orbits as opposed to those that drift with respect to pass times each day. Satellites like SO-50 and FO-29 often have less consistent use as their passes times drift earlier or later each day. SSO satellites like AO-16 may also see less use when one half of their passes occur during very early morning hours when most users are asleep.

An additional observation is that an orbit does not need to be a high, circular orbit to be popular or useful for long range communications. Elliptical LEO orbits with high apogees are as useful as a similar high circular orbit, but just with less time at that preferred altitude. A brief survey of the current possible launch opportunities shows few if any accessible launches going to the 1000km+ altitude, but both SpaceX and Vega have manifested flights to some elliptical orbit with apogees over 1000km. Unfortunately, in the name of debris mitigation, both of these launches have low perigees that would result in reentry possibly before an AMSAT satellite's end of life.

Mode Selection

Perhaps no topic stirs as much passion and rhetoric as FM versus transponder versus digital. Similarly, arguments for different bands for uplinks and downlinks are nearly as common and strongly held. Let's look at the FM versus transponder debate, and pros and cons for each.

Transponder satellites are the oldest of the three, beginning with Oscar 3 in 1965. Transponders, in this author's opinion, are the epitome of elegant simplicity. Passing signals regardless of mode, transponders are the most flexible and least likely to become obsolete with time (see AO-7). They are inherently multi-user friendly, assuming those users are considerate and do not overpower their co-users. However, there are drawbacks to transponders. Transponders require accurate, precise frequency control to use without causing co-user interference. Current transponder etiquette over North America precludes FM use, and thereby requires SSB or CW capable gear. While in the past VHF and up SSB gear carried a substantial premium, recently more and more mid-level radios include these modes as standard up through UHF.

FM repeaters originally developed as secondary modes on digital satellites, using simple cross connects between uplink and downlink radios (AO-21, AO-27, UO-14), but due to the simplicity of operation and common availability of equipment, the popularity of the mode has rapidly increased. The widespread ownership of simple FM radios allows most hams to inexpensively attempt satellite communications, and these satellites act as a gateway into the larger arena of amateur satellites. With an FM repeater, Doppler tuning is greatly simplified, enabling 5 kHz step radios to be easily used without computer control. Constant downlink carriers aid in manual antenna pointing and Doppler adjustments. The largest limitation of FM repeaters is that they are inherently single channel systems where all users of the satellite compete for access and time on the single uplink. At the same time this is an attraction to some operators, as it is very easy to passively listen to all the traffic, and contact those stations or grid squares of interest. The crowded conditions on the FM satellites are a strong deterrent to many operators, and a strong attraction to others.

Digital satellites such as store and forward BBS systems seem to be in decline with the advent of the internet, although APRS remains a popular mode for many, and DSTAR on satellite has been a popular topic since demonstrated on AO-27 in 2007. MORE

One complaint that has been heard often by the AO-51 command team is that the frequent mode and frequency changes are confusing to those who do not keep up with the schedule posted on www.amsat.org. This is an understandable complaint. AO-51 has a great multitude of possible configurations, and each has it's own enthusiasts. Unfortunately we can usually only run one or two of these at a time. Scheduling the mode selection and timing has been a great act of balancing and compromise, and the AO-51 Operations Committee has done an outstanding job over the five years since launch. The lessons learned here are many and nuanced, but can be mostly stated as a few maxims: Schedule modes for a time period that is not too long or too short. We've found one week to be a good point of aim. Schedule well in advance, and with much warning, so that all may input their needs for hamfests, special events, and demonstrations. Finally, take into account the number of users of each mode as compared to the frequency of running that mode, and the availability of similar modes on other spacecraft. For example, V/U repeater is by far the most popular mode on AO-51, but only AO-51 currently offers anything on L or S band. Adequate time must be given to L and S, especially since V/U is available on two other FM repeater satellites.

On the other hand the wide variety of modes and combinations on AO-51 has probably kept interest among active operators at higher levels than a comparative hypothetical satellite with only a few fixed modes.

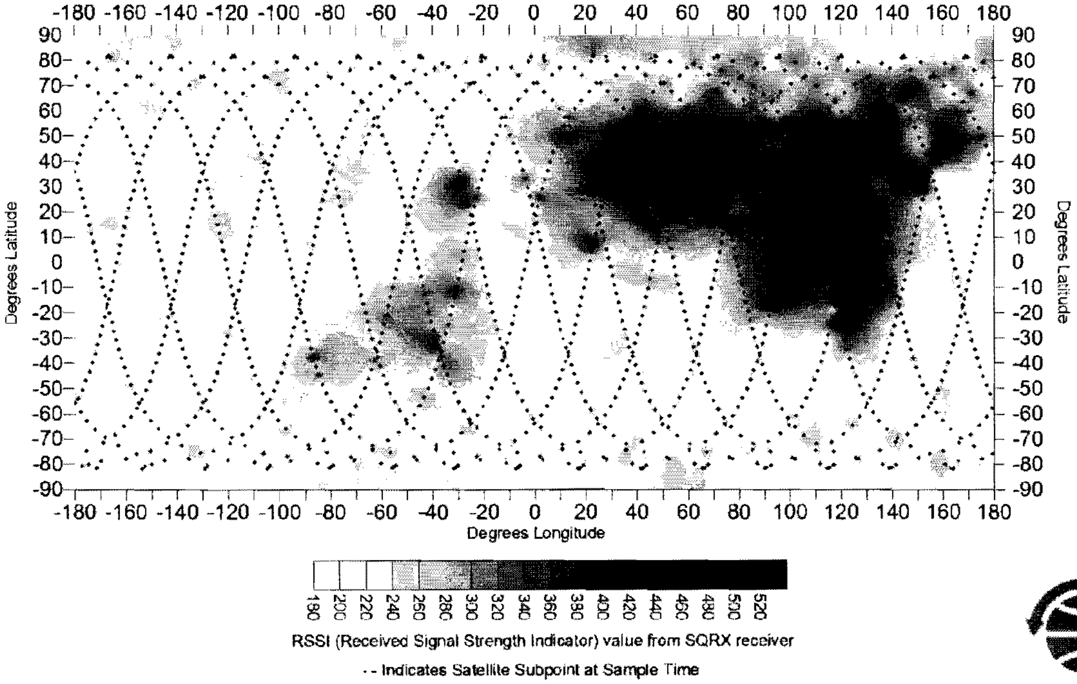
Frequency

A long standing rule of thumb among satellite designers is when choosing frequencies, try to use the lower band for the downlink. There are several reasons that support this strategy. Path loss is proportional to frequency, and lower frequencies result in stronger downlinks. Higher loss on uplinks are easily overcome, as power generation is much easier here on the ground as opposed to in orbit! Doppler shift is lowest on the downlink, which may make listening easier for new operators.

The most obvious exception to this rule of thumb are the current crop of V/U FM repeaters. As explained to me, the foremost reason for this apparent non-optimum frequency selection is related to the digital origin of many of the FM satellites. The use of UHF for the downlink is due to the restrictions on bandwidth on VHF that precludes speeds of over 19.2 kilobaud. The result of this conflict between best design and allowable design is apparent when listening to users on FM voice who can generate plenty of power on the VHF uplink, but do not have sufficient gain to receive the relatively weaker satellite downlink on UHF. Past FM repeater satellites that operated in mode U/V were largely free of this problem.

Worldwide, there are additional problems inherent to using a VHF uplink in the 2m band. In many areas, regulation and enforcement of using the 2m amateur band for non-amateur purposes is weak to nonexistent. In particular this problem is known to exist in Mexico, Central, and South America, as evidenced by the abundant non-amateur QRM heard daily on the V/U satellites. Taxi dispatchers, fishing fleets, and even long range cordless phones manufactured in China, have polluted the band so much that even large HEO class stations can have difficulty breaking through. As bad as it may seem, from personal accounts and data collected via AO-51, the situation over Asia is even worse. Many of the excellent blogs kept by the Japanese V/U cubesat community, often complain about the inability to command effectively due to interference on their uplink frequencies. Figure 1 illustrates the relative signal strength on an unused 2m uplink over the course of 24 hours, as published in the author's article in the January/February 2008 AMSAT Journal.

Figure 1
AO-51 V-band Signal Strength Survey
145.880 NBFM
60 second rate for 24 hours, 17June2005



AMSAT

Courtesy of KO4MA and KE4AZN, AMSAT-NA

While UHF is not free of this type of non-amateur QRM, the situation is somewhat better. This may be attributable to the shared allocation with the military, as well as radar systems both on the ground and in orbit. These radar systems can also be a source of QRM in and of themselves. With narrow-band QRM, the greater Doppler shift on 435 MHz also has a tendency to limit the impact of the offending signals on a fixed uplink. The signal is shifted over 20 kHz during a typical LEO pass, and simply slides out or through the uplink frequency quickly.

Choosing a U/V arrangement for future FM repeater satellites will overall benefit the users in other ways as well. The aforementioned user who cannot hear the UHF downlink will have a much increased likelihood of hearing a VHF downlink. If he or she still does not hear the downlink and continues to transmit without active Doppler control, their offending signal will quickly Doppler out of the uplink of the satellite. Both scenarios result in a lowered level of QRM to other users.

During the development of the Eagle HEO mission, much noise was generated about the relative noisiness of the S downlink due to the proliferation of 2.4 GHz Part 15 devices. This has led to much speculation about S band at LEO. Based on the author's experience with AO-51's S downlink, S band at LEO is still very much a viable frequency selection for missions where small directional antennas and automatic Doppler correction is assumed.

As mentioned in the previous section on modes of operation, during the frequency band selection process, consideration should be given to other modes and frequencies in use at the time, and proposed for other spacecraft under design or construction.

Antennas

A useful observation has been made that portable users often comment on how much stronger AO-27 seems than AO-51 in V/U repeater mode. Both satellites run similar power levels of around 500mw and are in similar altitude orbits. However AO-51 has an antenna array where the downlink signals are circularly polarized (435.150 is LHCP, 435.300 is RHCP), and AO-27 has a linear whip for the downlink. The difference here is most portable operators use an Arrow or some similarly linearly polarized antenna, and assuming they match polarity with the satellite by twisting the antenna, they can see up to a 3db advantage to AO-27 over AO-51. Since a large percentage of FM operators are portable, and larger home stations often have an abundance of gain, this point should be considered for future missions.

Batteries

If there is one thing that's become obvious from AO-7, and proven with DO-64 (Delfi C-3), it's that we don't have to have batteries to have a successful mission at LEO. As long as the satellite retains the ability to be commanded off in case of a shutdown order from the FCC, a batteryless system has real benefits for extremely long missions. While this approach results in a satellite only usable while illuminated, depending on the orbit this could be up to 100% of the time! Perhaps with a clever design, a normal satellite mission could at the end of it's battery life cut those batteries free and begin a second, daylight only mission.

To be successful with this approach, there are several design concepts that must be adhered to. First of all any batteryless design must retain the ability to command all transmitters to off and have them remain so until commanded back on. No one wants to be responsible for a derelict satellite that is also polluting the amateur bands. The arrangement of the solar panels must be such that power is near continuous with respect to attitude and some sort of buffering system (a super capacitor?) must be included to smooth the power supply.

PL/CTCSS control

SO-50 and AO-51 reintroduced us to using subaudible tones for user access on FM satellites, although the Mir UHF repeater also used them for some time. As implemented on SO-50, a 74.4 Hz tone activates the repeater for 10 minutes, and a 67 Hz tone is used to access the repeater just as on a terrestrial system. There is a very short squelch tail, and within this tail you may hear signals on the uplink without the access tone.

A similar system was implemented on AO-51. This time the repeater remained "on" all the time, and depending on the setting selected by the command team, the subaudible tone either simply gates the audio to the continuous carrier downlink, or also controls the transmitter with an adjustable length tail after each transmission. One benefit of the continuous carrier is the ease of discerning the signal and peaking for signal strength when no other traffic is present.

Both systems work, and can be considered a necessary evil if used to avoid broadcasting to whales and penguins and saving power. On AO-51, the Whole Orbit Data tells us the duty cycle using the PL control ranges from 20% to 60% per orbit, depending on whether the ground track crosses populous or desolate areas. However, since the duty cycle changes as well as whether the satellite is illuminated or not, predicting orbit to orbit power demands makes fine management very difficult.

The problem with PL usage comes with many users. Although FM is known for the "capture effect", on spacecraft this effect of the strongest user capturing the receiver is not as prominent as on ground based systems. The dynamic range of the user uplinks is much less due to the distance and maybe the similarity of user equipment. As the numbers of users grows, especially if some percentage are using half-duplex groundstations, more unintentional collisions occur. These collisions often result in neither signal being dominant and capturing the receiver, and the PL ystem does not turn on the downlink. Further exacerbating this problem is the widespread presence in some areas of non-amateur signals on the uplink. These signals are not PL encoded, or at least with the right PL, and can also serve to block access to the receiver by the intended users. This particular problem of PL based logjams can be difficult to diagnose, and is self-sustaining as frustrated users continue to transmit in hopes of breaking through the pile. This logjam effect is the primary reason the author discontinued use of the original PL mode on AO-51 as soon as assuming responsibility for operations.

Two developments in the software on AO-51 will be most beneficial when running PL access. These are the power management and new PL routines. The power management routine adjusts the downlink power between two points based on buss voltage, allowing more power to be expended once the satellite is illuminated and the batteries are charged. The new PL routine uses a 67 Hz tone to activate the repeater with and open access uplink for set number of minutes. This allows the power saving benefits of PL operation, while reducing the opportunities for the logjam effect to take hold. Expect this mode to be tested soon on AO-51.

Bent Pipe Mode

One of the more fortuitous lessons learned came from AO-16. After recovering the satellite, the newly formulated command team, working with remnants of the old command team, discovered the memory system on AO-16 was corrupted. This made a reload of the housekeeping and BBS software impossible. However, Jim White recalled there was a bootloader command that would cross connect a receiver and a transmitter in a bent pipe fashion. Devised by Tom Clark as a means of testing the satellite without running code, this little trick gave AO-16 an extended lease on life until another problem ended the newly discovered mission. This little trick was so popular, ISIS now includes it on all their cubesat RF packages. On digital missions this provides an extended secondary mission which may help avoid drastic orbital debris mitigation measures. Additionally it is a handy trick to use when you suspect your uplink frequency may have QRM affecting your ability to command. The author strongly suggests all satellite builders consider such a measure be included on future spacecraft, preferably with the ability to activate without use of the IHU.

Command and Control

Generally, the less said publicly about specific command and control operations the better. However, based on experience with AO-7, AO-16, and AO-51, command information must be institutionally stored and accessible by those responsible and their as of yet unknown successors. Interests change, and command teams dwindle, until often there is just one responsible individual left. Eventually they may loose interest as well, and a precious resource is as well as lost. Command duties should be spread among a team no smaller than three individuals. These individuals should ideally be in geographically diverse areas to maximize access time to the satellite. With polar orbiting LEOs, the closer to either pole the better, due to increased accessible orbital passes per day.

With AO-51, software reloading operations was greatly improved by the addition of a California based command station to the two existing stations in the southeast US. This effectively halved our time to reload the satellite, and was a real boon to both the command team and the users.

Conclusion

The author hopes these observations have been helpful, and is interested in adding to the "institutional knowledge" of AMSAT by collecting more lessons learned from other spacecraft designers, builders, users, and controllers. Please send gripes, additions, or corrections to ko4ma@amsat.org.

AMSAT: We ARE Rocket Scientists

Tom Clark, K3IO
k3io@amsat.org

Hardly a day goes by that we don't see a comment on AMSAT-BB with a suggestion like

> "***You AMSAT guys should fly a motor to kick our LEO satellites into a higher orbit. Oscar-7 was a perfect bird with great DX capabilities ! ! !***"

In this presentation we will discuss the basic laws of physics that govern rocketry:

1. Conservation of Momentum
2. Energy, Force and Thrust
3. Orbital Mechanics: Kepler's 3 Laws
4. The requirements for attitude determination and control

One of the best, most concise, references to the various topics that AMSAT's erstwhile Rocket Scientists must understand is found on Robert Braeunig's web site at http://www.braeunig.us/space/. When you visit this web site, look at ***Table of Contents*** and click on the ***Basics of Space Flight*** entry and then QSY to the ***Rocket Propulsion*** and ***Rocket Propellants*** pages. You may also find the NASA site at http://www.grc.nasa.gov/WWW/K-12/airplane/specimp.html to be interesting.

One orbit modification possibility has been suggested by David Bowen (G0 MRF): the use of a rocket on a small LEO (~800 km altitude) spacecraft to achieve a 'DX friendly' MEO (~8000 km). He presented his ideas in talks at both the 2008 AMSAT and 2009 AMSAT-UK conferences; his ideas are summarized at http://g0mrf.com/MEOSAT.htm. David's suggested LEO-to-MEO transfer makes use of a pair of burns: a burn to an intermediate 800x8000 km elliptical orbit , followed by a second burn to a circular ~8000 km orbit. David uses an Excel spreadsheet (available at http://gulp.physik.unizh.ch/meosat_propulsion.xls) developed by Achim Vollhardt (DH2VA) to determine that, if a typical spacecraft motor burns half of the spacecraft mass in the two burns, it can achieve the needed 2124 meters/sec of added velocity (called $\triangle$V). The first burn achieves $\triangle$V =1155 m/s to 800x8000 km and the second burn adds $\triangle$V=969 m/s to a circular 8000 km MEO. This two burn maneuver, called a Hohmann transfer, is the most efficient way to use limited propellant to go between two circular orbits.

For the motor to properly deliver its thrust, the axis of the motor must be aligned along the satellite's path to a few degrees. The AMSAT Phase-3 satellites (AO-10, -13 and -40) used spin stabilization. The axis of the spin vector was aligned to the orbit direction at perigee for the first burn. It was then necessary to "flip" the satellite so that the motor axis was again aligned for the apogee burn. In order for a spacecraft to spin stably, the principal moment of inertia had to be along the motor axis (the Z axis on our spacecraft); think of this like dynamically balancing an automobile wheel! To prevent tumbling and wobbling, this means that the principal moment of inertia has to be about twice the two orthogonal axes. You may recall that the shape of the basic design of Eagle morphed from nearly cubic shape to a flattened shape for just this reason.

IMHO (in my humble opinion), the need for precise attitude control and stabilization at the level of a few degrees is 'THE tall pole' hurdle AMSAT's Rocket Scientists face in being able to use a rocket to modify an orbit to meet our 'DX' desires.

Hall Effect Thrusters for Amsat Satellite Missions

A Report from the International Electric Propulsion Conference

Daniel Schultz, N8FGV

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The catastrophic failure of the AO-40 hypergolic propulsion system pretty well guarantees that Amsat will never again launch a satellite with such a hazardous system onboard. Since that time Amsat has studied various options that would allow us to launch satellites to high altitude orbits using propulsion provided by others. To date none of these possibilities has shown any success in procuring a ride for an amateur radio payload to a high orbit

Amsat needs to acquire a high performance but safe propulsion technology to allow future satellite missions to be placed into useful orbits. With this in mind I attended the International Electric Propulsion Conference in Ann Arbor, Michigan last month. The meeting brought together a large number of scientists, engineers and students from many universities and companies around the world actively involved in electric propulsion research. Many of the attendees had heard of Amsat and its history and were supportive of our efforts to launch future satellites. It is my hope that Amsat might be able to partner with one or more of these organizations to fly an electric thruster on an Amsat satellite. Amsat could offer our expertise and experience in satellite construction and radio communications and our large network of hams around the world for telemetry acquisition and satellite command and control in return for access to electric thruster technology. Many research organizations have thrusters under test in laboratory vacuum chambers; some of them may be ready to conduct a flight demonstration on a real satellite in the ultimate vacuum chamber of space.

Electric propulsion (EP) has been studied for as long as mankind has had a serious interest in space flight. Konstantin Tsiolkovsky and Robert Goddard both did serious work on this subject as long as a century ago. Scientists in Russia did extensive development work in the 1960's and 1970's leading to the use of electric propulsion for orbital station keeping in dozens of Soviet era satellites. Beginning in the 1990's their Hall Effect technology has been transferred to western space agencies and companies and is coming into wide use around the world. Electric Propulsion has been used on the US missions Deep Space 1 and the Dawn asteroid rendezvous mission, as well as Japan's Hayabusa asteroid sample return mission and Europe's SMART-1 lunar mission. It is used for orbital station keeping on a large number of commercial geosynchronous satellites, where the propellant savings allow longer satellite lifetime and increased revenue for satellite owners. The European Artemis mission was salvaged when its station keeping thruster was used to maneuver it into geosynchronous orbit after being stranded in a useless transfer orbit by the premature shutdown of the launch vehicle upper stage.

In chemical rockets the propellant (fuel) serves two functions. Combustion of the fuel provides the energy source that heats the gas and the combustion products provide the reaction mass that is expelled from the rocket nozzle to impart forward momentum to the rocket. In an electric rocket this energy is supplied by an external power supply so that the energy source is independent of the propellant flow rate. This allows great freedom in choosing the operating parameters for the rocket engine. The propellant gas is not an energy source but merely provides the reaction mass that is expelled from the back of the rocket to push the rocket forward. A solar powered electric rocket has an almost unlimited supply of energy and can provide low but continuous thrust over very long periods of time. A chemical rocket will exhaust its fuel supply in a matter of seconds or minutes whereas an electric rocket can thrust for months or years. A low thrust applied over a long time can accelerate the spacecraft to high velocities.

Most Electric Propulsion systems require kilowatts of power and satellites propelled by these engines are all characterized by the presence of very large solar arrays. Satellites with kilowatt power budgets are outside of Amsat's reach so we are primarily interested in finding a thruster technology that can scale down to several hundred watts of power input. Nevertheless our solar arrays will need to be large, deployable and steerable to face the Sun for maximum power production during the thrust phase of the mission. The large solar arrays will be the most expensive part of the mission but would be able to provide high power for radios after the satellite reaches its desired orbit. Launches from low Earth orbit would best be done at high beta angle to minimize eclipse periods and allow maximum illumination of the solar arrays, but as a secondary launch customer we may not have the ability to choose the launch time to optimize solar illumination. Keeping the solar arrays edge on to the velocity vector will also help to minimize atmospheric drag in low Earth orbit.

Electric Propulsion offers several other potential benefits for Amsat missions. A very small thruster could have saved AO-13 from the orbital resonance effect that eventually led to its early reentry in 1996. It could also allow the satellite to be nudged into a destructive reentry trajectory at the end of its useful life, allowing Amsat to address the orbital debris mitigation issue, which may be a limiting factor in obtaining permission to launch our satellites in the future.

Electric Propulsion could also provide attitude control with off axis thrust vectors if we ever did build a geosynchronous satellite. The Amsat Phase 3 satellite series had elliptical orbits so that they could do magnetic torquing against Earth's magnetic field at perigee. A satellite in circular orbit at geosynchronous altitude will not be able to use the Earth's magnetic field for attitude control.

One possible Amsat mission could be launched as a secondary payload on a vehicle going to Geosynchronous Transfer Orbit (GTO). The original J-J satellite proposal from 2001 would have involved launching a small satellite with no propulsion system into GTO and leaving it there, until it was discovered that most launch vehicle owners deliberately choose very low perigee altitudes for these launches in order to insure rapid reentry of the spent upper stage to mitigate orbital debris issues. A small electric thruster could allow us to raise the perigee to a survivable altitude on such a mission. One proposal presented at the conference was to launch a demonstration mission on a Soyuz launch vehicle from Kourou, using the electric thruster to LOWER the perigee to assure rapid reentry after the demonstration. After the presentation I ran after the speaker in the hallway and suggested that if they would point the engine in the opposite direction, Amsat would be glad to take over the command responsibilities at the conclusion of the demonstration mission.

Hall Effect Thruster:

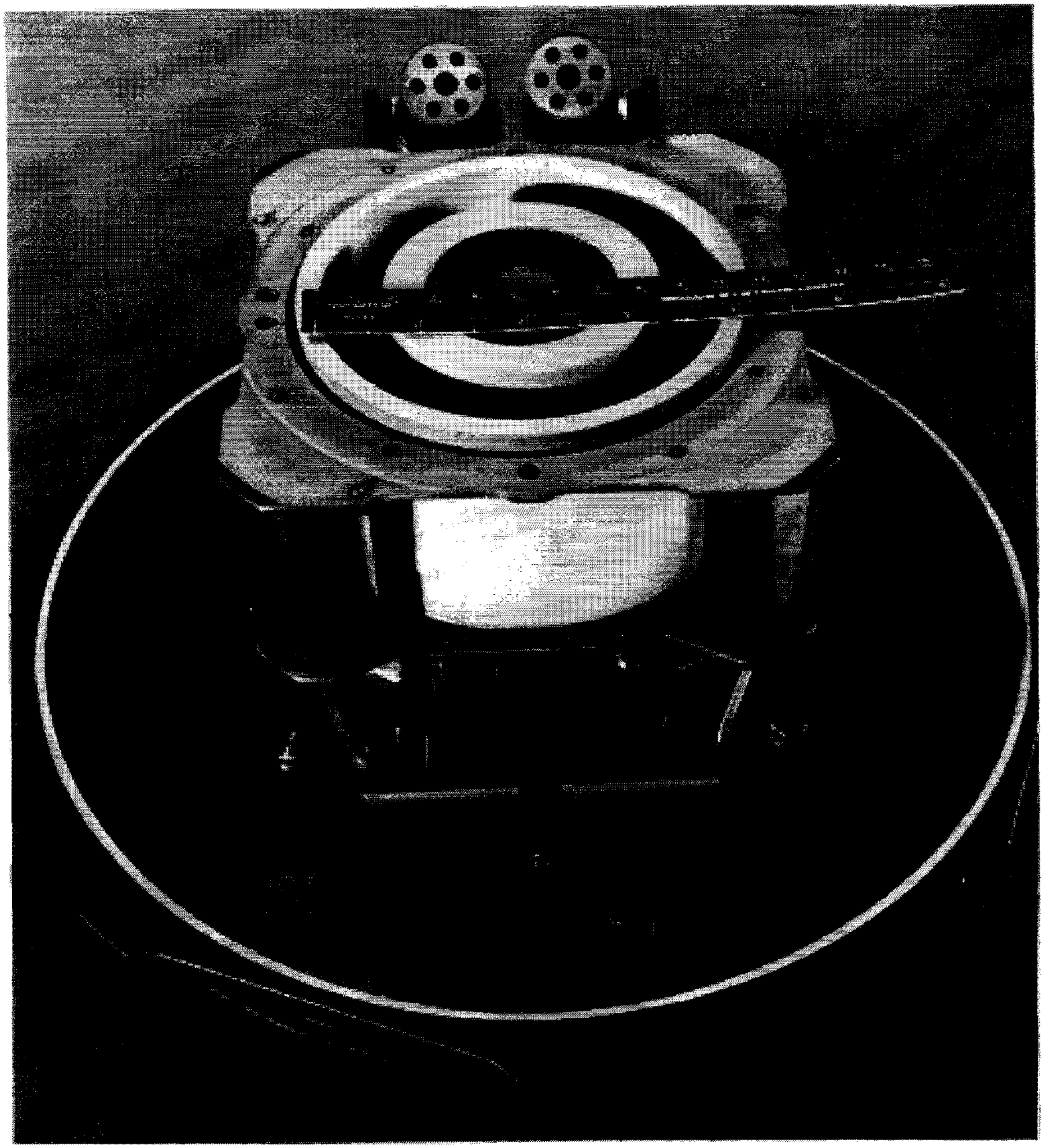

Fig 1. Russian designed SPT-100 Hall Thruster

One particular Electric Propulsion technology, the Hall Effect Thruster, shows promise of being scalable to operate at power levels attainable by Amsat.

Hall Effect Thrusters rely on the confining effect of a radial magnetic field on the electrons to achieve propellant ionization. The cyclotron radius of electrons is much smaller than that of ions, so that a radial magnetic field of appropriate strength confines the electrons without significantly affecting the motion of ions through the device. Perpendicular electric and magnetic fields lead to a circular **ExB** drift of electrons around the open end of the thruster. The resulting electron current, interacting with the magnetic field, leads to a **JxB** Lorentz force, which causes a plasma flow and produces thrust.

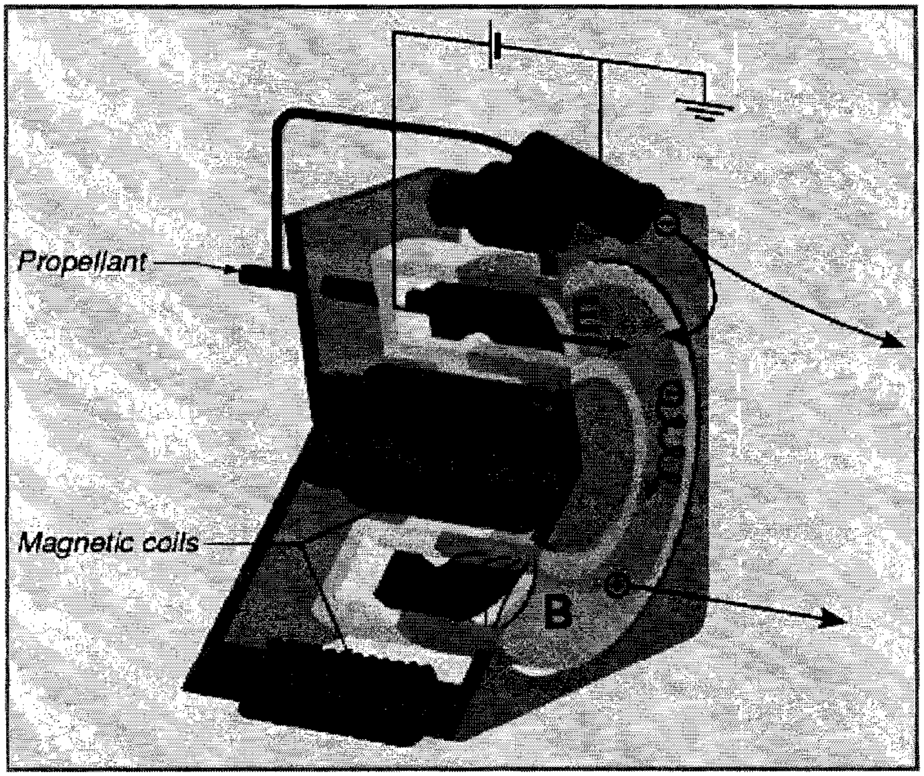

Fig 2. Hall Thruster Operation

The Cathode Neutralizer (electron gun) shoots electrons into the beam. Some of these electrons flow inward to the anode while others leave with the plasma beam to keep the exhaust plume and the satellite electrically neutral.

Xenon gas is used as the propellant in most current thruster systems. The gas is chemically inert and does not contaminate the spacecraft but must be stored in a high-pressure bottle with appropriate pressure metering valves. It is also quite expensive. Laboratory experiments often use cheaper argon or krypton in place of xenon. Older literature often mentions the use of mercury or cesium, both of which are toxic and corrosive and are no longer in use. Some of the research presented at the conference covered thrusters using vaporized metal propellants such magnesium, zinc, indium, bismuth and gallium. These may replace the high-pressure gas storage and delivery system with a simple wire-fed system.

Orbit Adjustment Calculations:

Continuous thrust missions require different mathematical analysis than conventional chemical rocket motor impulsive maneuvers. Conventional orbit maneuver analysis assumes that the thrust duration is insignificant compared to the orbital transfer period, so that Delta-V increments occur instantaneously. Electrically propelled spacecraft move in slowly increasing spiral orbits rather than the more familiar Hohmann transfer ellipse used by conventional satellites.

A MATLAB script "sep_ltot.m" by David Eagle computes performance data for satellite transfers from an initial circular orbit to a final circular orbit. This will need to be modified to model transfers to elliptical orbits. Several circular orbit mission scenarios were modeled with this program:

1. A very modest mission:

25 kg spacecraft, power budget 25 watts (ARISSat-2?) raised from a 400 km 51 degree orbit to a 900 km circular orbit in 50 days.

:

Program inputs:

initial spacecraft mass	25	kilograms
initial orbit altitude	400	kilometers
initial orbit inclination	51	degrees
final orbit altitude	900	kilometers
final orbit inclination	51	degrees
propulsive efficiency	0.45 %	
input power	0.025	kilowatts
specific impulse	1500	seconds

Program results:

thrust	0.0015	newtons
initial orbit velocity	7668.5	meters/second
final orbit velocity	7400.4	meters/second
final spacecraft mass	24.75	kilograms
propellant mass	0.45	kilograms
total inclination change	0.0	degrees
total delta-v	268.	meters/second
thrust duration	50.7	days
initial yaw angle	0.0	degrees
thrust acceleration	0.000061	meters/second^2

2. A much more ambitious mission:

50 kg spacecraft, power budget 200 watts raised from a 400 km 51 degree orbit to a 35787 km circular orbit inclined 0 degrees in 366 days (1 year). This represents the most extreme case that we might attempt.

Program inputs:

initial spacecraft mass	50	kilograms
initial orbit altitude	400	kilometers
initial orbit inclination	51	degrees
final orbit altitude	35787	kilometers
final orbit inclination	0.0	degrees
propulsive efficiency	0.45 %	
input power	0.200	kilowatts
specific impulse	1500	seconds

Program results:

thrust	0.0122	newtons
initial orbit velocity	7668.5	meters/second
final orbit velocity	3074.6	meters/second
final spacecraft mass	29.5	kilograms
propellant mass	20.5	kilograms
total inclination change	51.0	degrees
total delta-v	7756.4	meters/second
thrust duration	366.8	days
initial yaw angle	22.9	degrees
thrust acceleration	0.000245	meters/second^2

Many commercial software packages are available to calculate trajectory analysis for continuous thrust missions. Amsat may need to acquire such software when it comes time for serious mission design. The software will also need to model solar radiation pressure, atmospheric drag, and lunar-solar perturbations (which may actually be exploited to add energy to the orbit if we are sufficiently clever). There are also important tradeoffs to be made between the Thrust to Power ratio (T/P) and the Specific Impulse (Isp) when designing a mission. Those who enjoy programming and running complicated numerical simulations on their computers will find much work to be done here.

Conclusion:

Electric Propulsion, in particular the Hall Effect Thruster, is a mature technology that could enable Amsat to launch satellites on whatever launch vehicle may be available and then move them to more desirable orbits. I am not saying that it will be easy, but maybe this is how we can get Amsat back into space.

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http://richard.hofer.com/electric_propulsion.html

AO-7's Solar Array Power After 35 Years In Orbit

James A. DeYoung (N8OQ)

As of 2009 November 14, AO-7 will have been in orbit for 35 years. The satellite continues to provide linear transponder-based communication service to licensed amateur radio operators worldwide. Spare non-flight photovoltaic solar panels from the National Aeronautics and Space Administration Orbiting Geophysical Observatory program formed the basis for the construction of the AO-7 solar power system. This paper will present information concerning the origins, construction, and related performance details of the solar array. Evaluation of a standard radiation degradation model gives a 33% loss for maximum power, a 15% loss for maximum power voltage, and a 23% loss in solar array current output after 35 years of exposure in its radiation environment. Valid telemetry for the electrical current outputs from the four solar panel facets were received and decoded by several amateur radio service stations during 2009 March. The telemetry was of good enough quality in several instances to allow determination of the radiometer-based spin (roll) rates. On 2009 March 3 the rate was 0.078 revolutions per minute (12.8 minute period) and on 2009 March 16 it was 0.106 revolutions per minute (9.4 minute period). Four AO-7 solar array facet output DC electric currents reported in the 2009 telemetry were compared to the full radiation aged solar array and spacecraft attitude model. The O-C residuals appear to have some periodic structure but in general the aged solar array current output model fits fairly well.

AMATEUR RADIO on the ISS

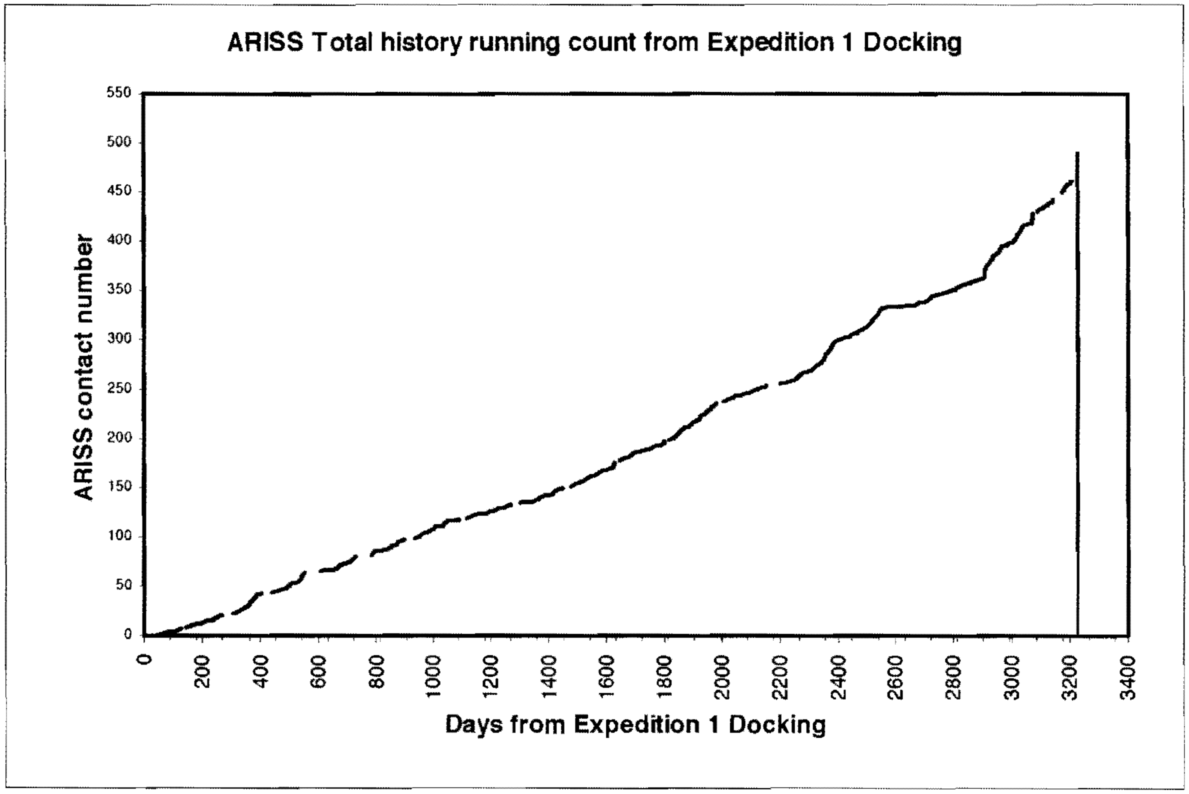
By

Keith Pugh, W5IU

Purpose and Objectives of ARISS –

The primary purpose of Amateur Radio on the ISS (ARISS) is to promote education of our youth in math, the sciences, engineering, and technology through exposure to the International Space Station (ISS) Program. A secondary purpose is to expose students and others to the world of Amateur Radio and the many benefits of this fascinating avocation.

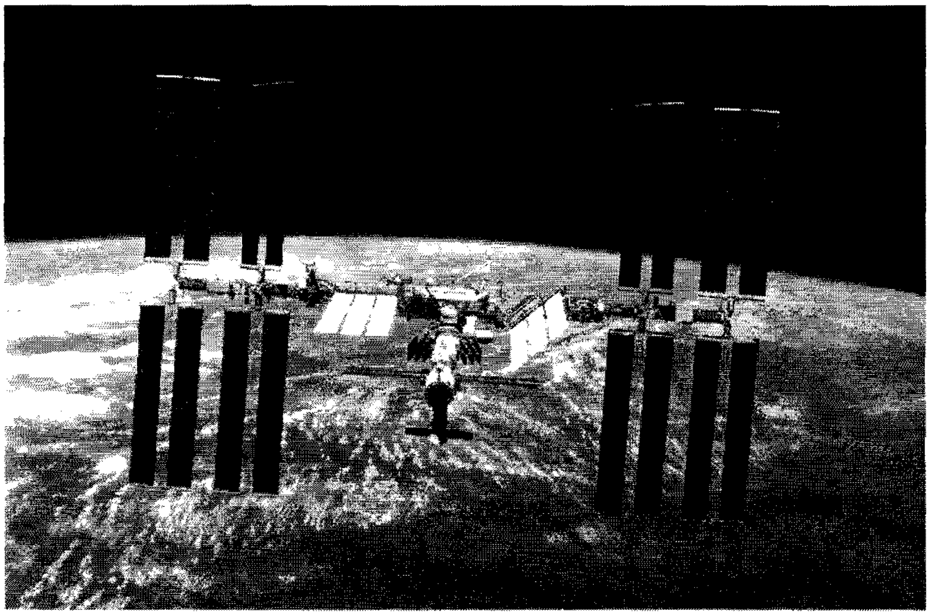
Working with professional educators worldwide and with the Space Agencies of the world, ARISS provides opportunities for students of all ages to talk and exchange ideas with Astronauts on board the International Space Station (ISS) while in orbit. Amateur Radio provides the media for this exchange to occur and the volunteers that facilitate the primary purpose.



470 Contacts at Report Time

A Proud Legacy – Historical Background –

ISS NOW COMPLETE – Starting 6 Person Crew Operations



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AMSAT's 40th Anniversary

ARISS leans heavily on Amateur Radio Satellite Technology and spirit. The first Amateur Radio Satellite, OSCAR-1, was launched on 12 December 1961, just over four years after Sputnik-1 on 4 October 1957. The Project OSCAR Group in California built and coordinated this launch. By 1969 the needs of the Amateur Radio Satellite community had out grown this operation and a group of devoted satellite people in the Washington, D.C., area formed the Radio Amateur Satellite Corporation or AMSAT. The year 2009 marks the fortieth anniversary of the formation of AMSAT.

Twenty Fifth Anniversary of Amateur Radio Human Spaceflight

In 1983, Owen Garroitt, W5LFL, flew on the Space Shuttle Columbia during mission STS-9 and carried Amateur Radio Equipment with him. He made many contacts on this mission including King Hussein of Jordan, JY1. I was one of the eager participants in this operation and planned to make a contact as well. One of the local television stations covered the attempt from my Ham Shack. Only the "Big Guns" within the US (Moonbounce class stations) were successful. We learned first hand about the FM "Capture Effect" on this mission but everyone had fun anyway. This was the start of twenty five years of successful manned spaceflight operations on board the Space Shuttle, MIR, and ISS.

Just 25 years later, Owen's son Richard Garriott, W5KWQ, flew on the ISS to celebrate this occasion. His ten days in space created a memorable event in late October 2008. He made several hundred voice QSOs, a number of school contacts, several special event contacts, and sent down a number of SSTV pictures.

Richard's flight started the 25th Anniversary celebration that was celebrated throughout the end of 2008 and into January 2009. Special modes and operations were exercised on the ISS to commemorate this event and the reaction was very positive.

If you made any kind of contact with the ISS during this event, details of how to apply for special certificates can be found at http://www.ariss.org.

Amateur Radio on the International Space Station (ARISS)
25th Anniversary of Ham Radio in Space
Commemorative Certificate

Presented to

Frank H. Bauer, KA3HDO
Crossband Repeater

November 30, 2008–January 15, 2009

Richard Garriott, W5KWQ
Mike Fincke, KE5AIT
2008
1983
Owen Garriott, W5LFL

Ten Years of Operation on the ISS

The first elements of the ISS were launched in 1998 and eleven years later it is nearly complete. During this time nearly 500 school contacts have been made between students and the astronauts. The 400th contact occurred in January 2009. In addition to the school contacts, several of the astronauts have taken a special interest in making many Hams happy with a space contact and contacts have been made on all continents, all states, and over 130 DXCC countries. The

ISS has also been used as a Digipeater, a Cross Band Voice Repeater, a launch platform for other satellites (PCSAT, SuitSat, etc), and will be used even more in the future. In 2009, the crew has been increased from three to a full compliment of six. The additional crew members have a definite impact on Amateur Radio Operation. This presents a challenge to the scheduling of operations. I'll talk more about that later.

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ARISS Organization –

Based on the legacy of Human Spaceflight dating back to 1983 and Owen Garriott's STS-9 flight, including the Shuttle Amateur Radio Experiment (SAREX), and MIR, ARISS was formed in 1996. Founders were Roy Neal (SK), K6DUE; Frank Bauer, KA3HDO; Rosalie White, K1STO; and Matt Bordelon, KC5BTL. The team is governed by a group of ARISS International Working Group delegates from Canada, Europe, Japan, Russia, and the USA. Delegates are chosen from the Radio Amateur Satellite Corporations (AMSATs) of the world, the National Amateur Radio Organizations (such as ARRL), and the Space Agencies of the world. These delegates meet via monthly telephone conferences, and about once a year in face-to-face meetings (last year in Moscow, this year in the Netherlands). In between, activities are coordinated by e-mail and additional telephone conferences as necessary. These delegates set the policy (with advice from the space agencies) for operation, coordinate equipment for the ISS, coordinate with education organizations, coordinate school selection for contacts, and provide oversight to the ARISS Operations Team – the other major ARISS group.

With the resignation of Frank Bauer, KA3HDO, this year for personal reasons, ARISS has had to pick a new delegate for AMSAT-NA and elect a new ARISS International President. Will Marchant, KC6ROL, stepped into the AMSAT-US slot, and Gaston Bertels, ON4WF, is the new ARISS-I President. In a separate action, Maurice-Andre Vigneault, VE3VIG, became the ARISS-Ca Delegate representing AMSAT-Canada.

ARISS Operations Team

The ARISS Operations Team is made up of ARISS Mentors, scheduling/technical representatives, and an orbital prediction specialist. An ARISS Operations Lead is selected from within the ranks on a periodic basis. This group meets weekly by telephone conference and much more frequently via e-mail and telephone. ARISS Mentors are the volunteers that work with the schools, teachers, and local Amateur Radio groups that actually make the contacts with the ISS. Scheduling/technical representatives work within the space agencies, primarily NASA in the USA and the Russian Space Agency to secure the final schedules for the contacts. These scheduling representatives also coordinate training of the Astronauts in the use of the equipment on board the ISS and procedures for its use. The orbital prediction specialist does the long and short term predictions necessary to support the scheduling of all of the contacts. I will talk more about these functions and their relationships with each other in subsequent paragraphs outlining the scheduling and performance of the contacts.

School Contacts this Year –

School Contacts over the last year have been numerous and varied. We have been blessed with some very enthusiastic astronauts. Mike Fincke, KE5AIT, alone made a record 50 School Contacts. Sandy Magnus, KE5FYE; Koichi Wakata, KC5ZTA; Michael Barratt, KD5MIJ; Frank DeWinne, ON1DWN; and Robert Thirsk, VA3CSA, have each made numerous contacts. These astronauts represent several nationalities and contacts in their home countries and native languages have been very popular. Mike Fincke has family ties with India so several of his Crew Pick contacts were with Indian Schools. Mike also speaks several languages. Koichi Wakata has been popular in Japan, Frank DeWinne has been popular throughout Europe, and Robert Thirsk has made many Canadian contacts. Actually, contacts within the US have been in the minority this year. The previous record for school contacts in a year (2007 with 75 contacts) will be broken by a large margin by years end (2009 is currently at 72 at the end of August).

Mike's India

Student participation at the schools has ranged from Kindergarten to University. During the summer months and at vacation times, a number of contacts have been made with Summer Camps, Scout Groups, Astronomy Groups, Museums, etc. As usual, the student reactions to the contacts are the reward for all of the effort expended by Teachers, Ham Radio Volunteers, and ARISS Volunteers.

Local students reach out to outer space

NASA program links up Fassett with International Space Station

A map indicates the relative positions of the International Space Station and Fassett Middle School during the linkup.

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ARISS Operations –

The wheels start rolling for a school contact with the submission of an ARISS Application for an ISS contact. The latest application form is available at: http://www.ariss.org Ideally, a teacher hears about the possibility of a contact through professional societies, from other teachers, from Amateur Radio Operators within the community, or by many other routes. The teacher, with the help of local Amateur Radio Operators, fills out the multiple-part application and submits it to the regional ARISS organization. The regional organization reviews the application, obtains clarification if necessary, ensures the application is forwarded to the ARISS international education committee, and enters it into the list of applicants in the order in which it was received. A separate list is maintained for each region of the world and candidates are picked from each region in proportion to the number of applicants in the list. Another list is maintained for "Crew Pick" contacts. These contacts are with schools that are picked by the Astronauts for their own reasons and are usually separate from the main list. Astronauts are allocated "Crew Pick" contacts based on their interest in the program and willingness to support contacts from the main list. The main list can be quite long and the waiting period can be correspondingly lengthy. Currently, the wait for US applicants is about one year. Every effort is made to keep the wait to a minimum, but contacts are generally limited to somewhere between one and four a week period depending upon the crew's willingness to support contacts and the workload on the ISS

Another factor to consider is whether the contact is to be "direct" or via "telebridge." For a "direct" contact, a ground station is set up at the school and the contact proceeds directly through that station with the station on-board the ISS. For a "telebridge" contact, the ground station is located remotely (possibly half way around the world) from the school and the ground station is connected to the school and other elements through a telephone conference bridge. ARISS OPS has developed and maintains a list of acceptable telebridge stations around the world (these are currently in the mainland US, Hawaii, Australia, Argentina, Belgium, and South Africa).

The school expresses a preference for the type of contact in their application and ARISS Ops will honor this preference whenever possible. A "telebridge" contact requires much less equipment at the school and is much more flexible on timing of the contact than a "direct" contact; however, it actually requires more coordination on the part of ARISS Ops to carry out. A list of requirements for each contact follows:

1. The ground station must be within the footprint of the ISS during the time of the contact and the ISS should have a peak elevation at the ground station of more than about 15 degrees. Higher passes are more desirable

to maximize the contact time and minimize effects of local obstructions on the contact.

2. The pass selected must occur during normal school hours as stated on the application or within an acceptable alternate time.
3. The pass time selected must be within the crew's normal off duty but awake time. Exceptions must be approved by the Space Agency Medical Personnel. Crew sleep periods are normally fixed, but can be "sleep shifted" during special work periods that coincide with Space Shuttle or other activities.

Picking and approving passes that satisfy the above requirements involve several steps that are outlined below:

1. A list of possible contacts is selected from the prioritized list of contacts maintained by ARISS over a period of time (usually for an ISS Expedition).
2. ARISS Mentors are assigned to each school as soon as possible. The ARISS Mentor establishes contact with the school and local ham volunteers, and verifies the content of the application (many times things have changed at the school since the original application was prepared).
3. The list of candidates is broken up into "direct" vs. "telebridge" contacts.
4. Direct candidates are submitted to the orbital prediction specialist for processing into the "best weeks" list. "Best weeks" are long term predictions that will permit selection of schools that have passes within a certain time frame that satisfy all of the nominal contact requirements above. A school may have several different "best weeks" within the overall time frame.
5. Selections are made based on contact priority and "best weeks" for each school and the ARISS Mentors obtain preferences for the available weeks from each school.
6. The ARISS Mentor continues the dialog with the school to firm up the requirements for the station, answer questions from the teacher and the local Amateur Radio Operators, assist the teacher with resources for lesson plans and in solicitation of questions and names from the students, and obtain a short description of the school and its activities for forwarding to the Astronauts. The ARISS Mentor also prepares the school for filling out a post contact survey for ARISS and NASA.
7. At about four or five weeks before the week selected for a school, detailed pass predictions for the contact are requested from the orbital prediction specialist. These predictions are verified by the ARISS Ops Lead and sent to the ARISS Mentor for forwarding to the school for prioritization within their own school schedule. The passes are ranked #1 through #n by the school and the local Amateur Radio Operators and sent back to ARISS Ops.
8. At this point, the pass ranking, student names, questions, and school description are passed on to the NASA planners by the ARISS scheduling representative for final determination of the selected pass. Usually this

final pass time is available one to two weeks before the contact. In the case of Russian contacts, a similar process is performed with the Russian Space Agency.

9. Before the contact time, a final uplink message is sent to the Astronaut containing the time, station callsigns, frequency information, the school description, and the student's questions, along with their first names, in the order the questions are expected to be asked.
10. At this point, the contact is ready to go from a planning standpoint.

For telebridge contacts this process is modified somewhat. Telebridge contacts are usually fitted into the schedule between the "best weeks" for direct contacts or are scheduled during special times that are specified by the school or event and agreed to by ARISS Ops. Telebridge contacts are usually reserved for schools that either cannot obtain local ham club support for a direct contact or have time requirements that are not flexible. The modified steps for a telebridge contact follow:

1. Telebridge contacts are prioritized by the same process as direct contacts, but they are usually done when direct contacts are not possible.
2. For telebridge contacts, the orbital prediction specialist prepares a list of the passes for each telebridge station that can support a contact during the dates/time frames requested by the school and within crew constraints. This list can contain many passes and can include multiple stations.
3. The ARISS Lead pares down the list when possible and sends the remaining passes to all of the telebridge stations that have passes on the list for verification of support.
4. The ARISS Lead receives the responses from the telebridge stations and prepares a list of available passes for further prioritization by the school. This list is sent to the ARISS Mentor and he forwards this list on to the school.
5. Once the prioritized list is returned by the school, the process continues in much the same manner as for a direct contact.
6. One other step is added – a Contact Moderator is selected by the ARISS Lead to oversee final readiness verification at the school and at the telebridge station. The Moderator also makes sure school personnel and any audience is aware of how the contact will be done and the Amateur Radio involvement in the contact. A Moderator is added since many times the level of expertise at the school during the contact is less than it would be during a direct contact.
7. At the appropriate time, the Moderator turns control over to the telebridge station to establish contact with the ISS.
8. Control is then maintained by the telebridge station operator and the school contact supervisor until the pass is over.
9. The Moderator then completes the process with a closing statement.

In recent years, ARISS has succeeded in including distribution of the audio from the contact over the internet by utilizing EchoLink and IRLP. These are two methods of including many more listeners worldwide in the distribution. Doing this with a telebridge contact is relatively easy. With a direct contact it is a little more difficult, but recently success has been achieved by feeding the audio into a PC at the school and utilizing Skype (an internet telephone) to forward the resulting information to the operator that completes the conversion to EchoLink or IRLP. These operations are also carried out by ARISS volunteers.

The last thing that happens in an ARISS Contact is the enthusiastic response of the school kids, and their increased interest in science and ham radio when the contact is successfully completed. This is the pay the volunteers cherish for their efforts and is the reason we eagerly volunteer for this duty.

Plans for the Future –

SuitSat-2 now ARISSat-1

Since the deployment of SuitSat-1 and the "stir" it created, ARISS has been working on SuitSat-2. This year has been very productive in this effort and the hardware/software will be ready for shipment to Russia by years end. Launch should occur in the spring of 2010. One major change has occurred: the Russian Orlan Space Suit that was to house the remainder of the satellite has been discarded early to make more space available on the ISS. ARISS was able to retain up-mass allocation for the equipment and a reservation for launch during an EVA, but we had to "shift gears" and come up with a new housing for the equipment. This task is well underway and will not impact the schedule. Due to this change, the satellite has been re-named ARISSat-1. It will continue to be called RadioSkaf in Russia and on the documentation. Details of ARISSat-1 are spelled out in other papers.

Columbus Module

The European Space Agency (ESA) Columbus Module was installed on the ISS last year along with the Amateur Radio Microwave Antennas (L and S Band) developed for it. Work continues defining the nature of equipment being developed for eventual use within the Columbus Module. Meanwhile, a dual band (VHF/UHF) antenna will be shipped to the ISS for use on the Columbus Module. First usage of this new antenna will be with the Ericsson Hand Helds (Phase 1 Hardware) that are currently on station to support expanded Amateur Radio Activity from the Columbus Module.

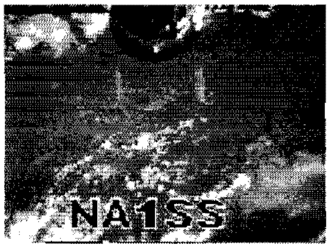
ARISS Project Committee

ARISS maintains a Project Committee to receive, process, and prioritize new proposals for ARISS Projects. Currently, this committee is working on plans for the L and S band equipment for the Columbus Module and for support of the current Phase 1 and Phase 2 hardware. This includes providing power supplies and cables to support radio operation in multiple locations on the ISS and eliminating the dependence upon batteries for the VC-H1 SSTV unit. If you have suggestions for projects, please document them and submit them for action.

Summary –

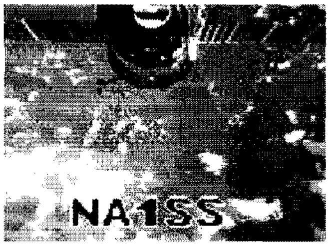
ARISS is alive and well. Now that the ISS is fully populated with a six person crew, expect more activity than ever before. Support this expanded activity by getting out the word to the world and volunteering your time and experience in support of all of the activity. Help bring forth new generations of people with an expanded knowledge of science, space, and technology.

SSTV Video



From W5DID

From VK5ZAI



From G0SFJ

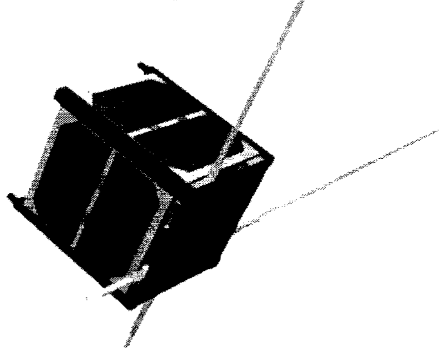
FUNcube project

By

Graham Shirville, G3VZV and Wouter Jan Ubbels, PE4WJ

PREFACE by Jim Heck, G3WGM

About two to three years ago the Radio Communications Foundation (RCF) was left a sum of approximately £40,000 by way of a bequest, limiting the expenditure to a space project, agreed by the AMSAT-UK committee. Over the last couple of years the committee have been soliciting ideas, and the result is a proposal for FUNcube.



The article below is extracted from the formal submission made by AMSAT-UK to the RCF. It highlights the use of the satellite for educational purposes, and this was deliberately done to enable the RCF to accept it as being within their remit. However, readers should note that there is a U/V (mode B) transponder included in the satellite, and from discussions held recently it seems that it might be possible to have both systems running 24/7 simultaneously.

Readers should also note that the project only provides a contribution towards the design, build, and testing of the satellite. To do these tasks will require slightly more that the amount now available from the RCF, and AMSAT-UK will be using some of its reserves to complete the construction of the satellite. Additionally considerable extra funding will be required for items such as a launch, UK Space Act licence, insurance etc. Hopefully resources to cover these will become available over the next year or so.

AMSAT-UK have approached ISIS - Innovative Solutions In Space BV to provide some of the hardware and to manage the integration and verification of the completed satellite, and a contract is at an advanced stage of negotiation. Additionally we have established a number of teams to carry out the project; these are Steering Group, Technical Team, Educational Team and a PR Team. Other groups may be added when a requirement is identified.

More information will be provided as the project progresses but the intention is to have the spacecraft completed and tested by 4Q 2010. To keep in touch with the project, go to www.funcube.org.uk.

Space is FUN!

Overview

FUNcube is an educational project with the goal of enthusing and educating youngsters about radio, space, physics and electronics, by constructing and launching a small satellite, based on the CubeSat standard. The target audience consists of primary and secondary school pupils. It will serve to provide an in-orbit counterpart to GB4FUN. The satellite will be built by an experienced team of radio amateurs and space engineering professionals, using off the shelf, space qualified, components and subsystems, thereby reducing project risk, schedule and cost.

The primary objective is to provide an in-orbit tool for science education outreach and hands-on training in space, science and radio. This would be done through the provision of a telemetry system that is suitable for easy reception by school children using extremely simple hand held VHF receive equipment connected to the USB port or soundcard of a computer or net/laptop. Furthermore, the satellite contains a materials science experiment, from which the school children can receive telemetry data which they can compare to the results they obtained from similar reference experiments in the classroom.

Its secondary objective is to provide a linear amateur radio UHF to VHF transponder which can be used by radio amateurs worldwide and can be used to demonstrate radio communications to schoolchildren and students of all ages. Additionally the satellite will be available for use by GB4FUN for satellite communication, telemetry and command demonstrations.

Introduction

Presently, interest in science and technology is declining among young people. This is quite in contrast with the proliferation of electronic communications, such as cell phones, the internet etc. One of the key elements in today's information age is communication based on electromagnetic waves, i.e. radio. Most young people nowadays use radio in one of its many applications (often without knowing that they are actually using radio), but only a handful actually know about the physical fundamentals. These young people represent tomorrow's workforce, therefore, there exists an urgent need to spark interest among young people about science and technology. The GB4FUN vehicle is an excellent example of providing this type of outreach; this proposal takes this concept even one step further, and into space.

The proposed project is to develop an amateur satellite, based on the popular CubeSat standard. This satellite will serve to provide an in-orbit counterpart to GB4FUN. The satellite will be largely built using off the shelf, space qualified, components and subsystems, reducing project risk, schedule and cost. The primary objective is to provide an in-orbit tool for science education outreach and hands-on training through the provision of a telemetry system that is suitable for easy reception using extremely simple hand held equipment connected to the USB port or soundcard of a computer or net/laptop. The target audience consists of primary and secondary school pupils.

Its secondary objective is to provide a linear amateur radio transponder which can be used by radio amateurs worldwide and can be used to demonstrate radio communications to schoolchildren and students of all ages. Additionally the satellite will be available for use by GB4FUN for satellite communication, telemetry and command demonstrations. The use of VHF for the space to Earth link, combined with approximately 1 watt RF output for the transmitter, and the use of forward error correction for the telemetry encoding will provide a strong, robust and easy to receive signal on the ground.

The proposal is to build the satellite, test and validate it for suitability for a number of different launch vehicles so that any available launch opportunity can be used at short notice.

Project objectives

Primary objective

The project's primary objective is to provide an in-orbit tool for science education outreach and hands-on training through the provision of a telemetry system that is suitable for easy reception using extremely simple hand held VHF equipment connected to the USB port or soundcard of a computer or net/laptop. This telemetry system also provides a means to send received telemetry to an on-line database, which allows school children and other enthusiasts to review telemetry via the Internet.

Furthermore, since the satellite uses a low data rate beacon (which is perfectly audible by ear), simple demonstrations of Doppler shift are possible, which can serve as an excellent tool for explaining radio waves and orbital mechanics.

Educational outreach

The educational outreach opportunities created by satellites are not just restricted to universities and agencies, who might be involved in their construction, but they can also be extremely valuable for secondary and primary school age students. The size of the satellite is not the issue because it does not matter. The whole satellite project from the development and building through the launch and the operation of the satellite can provide a wide range of interesting educational experiments.

The ability to track, receive telemetry information and communicate with the satellite allows for hands-on experience that will sow the seeds for a continued interest all STEM subjects (Science Technology Engineering and Mathematics). The reason is quite simple, what we term a satellite, the educational establishment and students think of as a space craft and the fascination that this holds is worth every hour of effort.

Lesson plans with suitable graphics and videos could be drafted to help understand everything from the orbital mechanics involved and the construction techniques and materials that are required to achieve longevity in orbit. Likewise the issues of launch location and simple orbital dynamics can make for interesting course work. The learning opportunities that are generated can easily extend way beyond that of the project team, allowing students of all ages to come into contact with space hardware and have a better understanding of the challenges that are faced.

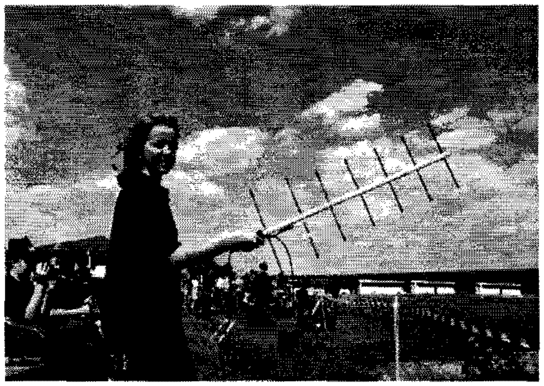


Figure 1 Students receiving real time telemetry

The current LEO satellites allow some of this research but they generally miss out on the how it got there and what effort was required. If on the other hand the whole thing is built on an educational footing the whole project from the early designs through to launch and commissioning would provide an invaluable insight into satellites and a wide range of related technologies. The use of the transponder would also enable the continued access from the educational world through projects like GB4FUN for many years after launch. Furthermore, contrary to the current LEO satellites, the FUNcube satellite will include a dedicated payload (see the section below on the materials science payload) which can be used during physics courses.

The proposal includes for simplified models of the satellite to be made available for demonstrations at schools, and can include the provision of kits for building receivers to be used for telemetry reception and designs for suitable simple hand held antennas.

The excellent work already done by GB4FUN, and the resulting good contacts with schools and teachers, will be of great value to help promote the project to schools in the United Kingdom. The FUNcube satellite could also encourage the development of GB4FUN-like projects in other European countries.

Materials Science payload

Besides the aforementioned objectives, the satellite will also include a simple but appealing payload. The objective of this materials science payload is to demonstrate the loss of heat energy by radiation from two materials with differing surface finishes. This educational experiment will be implemented by anodising or coating two of the outer structural rails of the satellite with surface finishes that have very different thermal radiation qualities, e.g. black / white / 'silver'. Temperature sensors mounted at the mid-point of the rails will detect the reduction in temperature during eclipse and these data will be downlinked as part of the FUNcube telemetry. This experiment is usually carried out in classroom using an apparatus called Leslie's cube, but results are always compromised by convection currents and thermal conduction within the air next to the surface of the cube. However, in space the vacuum eliminates the errors due to conduction and convection of air, leaving radiation as the primary method of loss of heat energy.

In practice, as FUNcube passes through the illuminated sector of its orbit, its surfaces will absorb energy from the sun. The amount of energy absorbed and the specific areas which experience the greatest temperature rise will depend on the surface coating but also the satellites attitude and spin rate. When the satellite passes into eclipse all of its surfaces will be in darkness and energy will be lost primarily due to the surface coatings. Therefore the most accurate results from this experiment will be achieved as FUNcube passes from eclipse through its 'sunrise' into full illumination.

In the UK, convection conduction and radiation are part of the Key Stage 4 science syllabus at GCSE level. The materials science experiment on board FUNcube will provide a "proof of the pudding", showing real world physics to the school children in the classroom. Reference experiments can be set up by the school children on the ground which they can use to compare the results they received from the FUNcube satellite in orbit.

Secondary objective

The secondary objective of the FUNcube project is to provide a linear UHF up and VHF down amateur radio transponder which can be used by radio amateurs worldwide and can be used to demonstrate radio communications to schoolchildren and students of all ages. Providing a linear transponder will provide a valuable and much appreciated resource for radio amateurs worldwide. They will form a distributed groundstation network and they will be able to join the GENSO worldwide network of ground stations which is currently being developed by ESA (www.genso.org). Many radio amateurs are willing to and capable of being involved in the educational outreach activities as well, FUNcube can provide them which such an opportunity, where they can use FUNcube to demonstrate (amateur) radio to schoolchildren and other audiences.

Implementation plan

The FUNcube satellite will be built by an experienced team of professionals and radio amateurs. Since the majority of the components are available off the shelf, building the satellite requires a relatively limited amount of development. The satellite can be considered in two parts;the satellite bus incorporating all vital components essential for the mission, and the educational payload.

The bus will be built using off-the shelf, qualified parts, thereby reducing technical and schedule risk. The goal is to keep the satellite as simple as possible, therefore (and because it is not necessary in order to perform the mission) it will not require a dedicated on-board computer. Industrial grade microcontrollers will be used for controlling the satellite, which is an approach proven by many previous CubeSat projects. The satellite will include a command uplink receiver for remotely controlling the satellite; the uplink channel includes measures to prevent unauthorized users to control the satellite. Furthermore, by including a command receiver, the satellite will comply with the ITU requirement that cessation of transmission be possible at all times.

The payload, which is a custom design, will be built by experienced radio amateurs. Since there is a large amount of design heritage for similar components within the amateur radio community, this can be done on a short schedule and relatively low budget. The payload consists of the linear transponder and a number of sensors which will measure voltages, currents, temperatures and other information.

Since the satellite is built using off-the-shelf electronic components, satellite lifetime is mostly dictated by radiation damage, which is dependent on the orbit. Generally, CubeSats and similar amateur satellites like FUNcube have all been launched into similar Low Earth Orbits, well below the high radiation regions of the Van Allen Belts. These satellites have shown lifetimes of typically well over 3-5 years. A similar lifetime is foreseen for the FUNcube satellite, giving plenty of time to actually incorporate the educational goals into course material, to ensure continuity in achieving the educational objectives.

Project Outline

The FUNcube project itself can be divided into a space segment (i.e. the satellite) and a ground segment. The satellite itself consists of several subsystems, which are split up between the bus and the educational payload. The ground segment includes the GB4FUN vehicle and radio amateurs worldwide. Furthermore, telemetry kits and associated software are part of the ground segment. Note that this proposal does not cover the development of receiver kits, as these are available off the shelf through ISIS. Furthermore the costs of these kits are not included in this proposal since these largely depend on the actual quantity. The development of telemetry decoding and displaying software is included in the proposal however. Finally, the development of course material is not included in the proposal, since this is an activity which is best done together with other parties with the required expertise. The project partners would be glad to assist in the development of course material however.

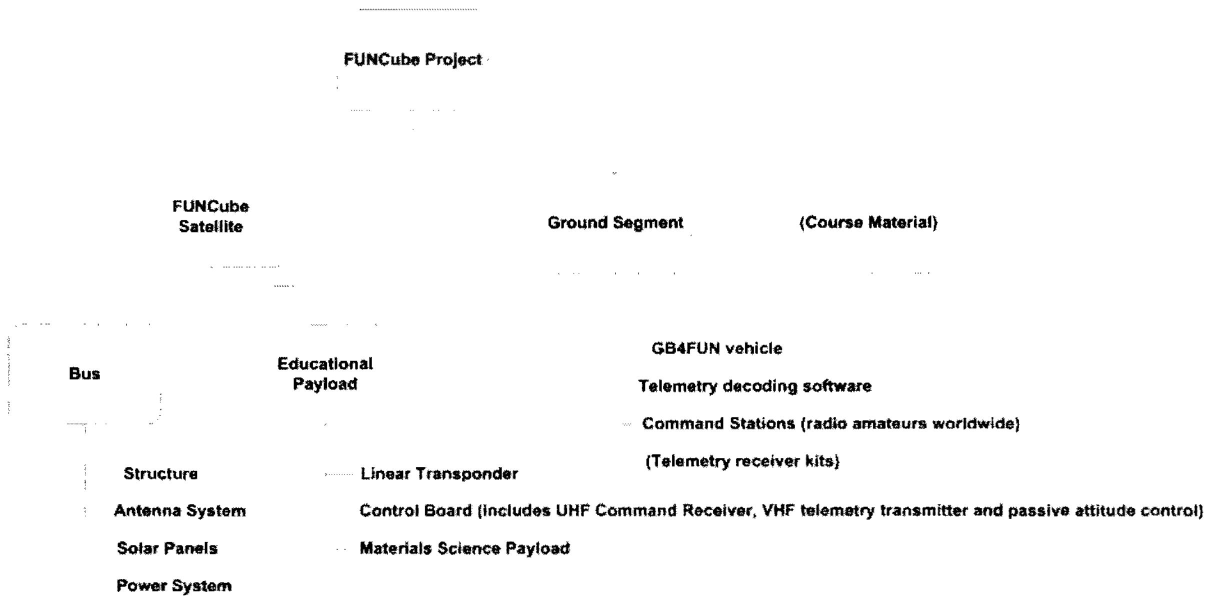


Figure 2 FUNcube Project Outline

The satellite bus will be built from off the shelf components from ISIS. Radio amateurs from AMSAT-UK will perform the development of the educational payload and telemetry decoding software. ISIS will provide assistance during integration of the satellite, and will furthermore arrange environmental testing so that the satellite is qualified to fly on several eligible launch vehicles.

Project Planning & Organization

The project is split up into several phases, as depicted in Figure 7. For all off the shelf items, no breadboards will have to be made since these have been qualified and tested already. For the custom parts (the educational payload), a breadboard will be made, which can later be transformed into a representative satellite breadboard, which can then be used as a demonstration model and reference experiment for the materials science payload for use in GB4FUN.

After this a flight model of the educational payload will be produced, which will then be integrated with the off-the-shelf bus items. After satellite integration, the satellite will be acceptance tested by environmental (vibration, shock and thermal vacuum testing. The satellite will be tested to levels representing the available launch vehicles (presently and in the near future) for CubeSats. Finally, the satellite will be stored in a transport container on the shelf to await a suitable launch opportunity.

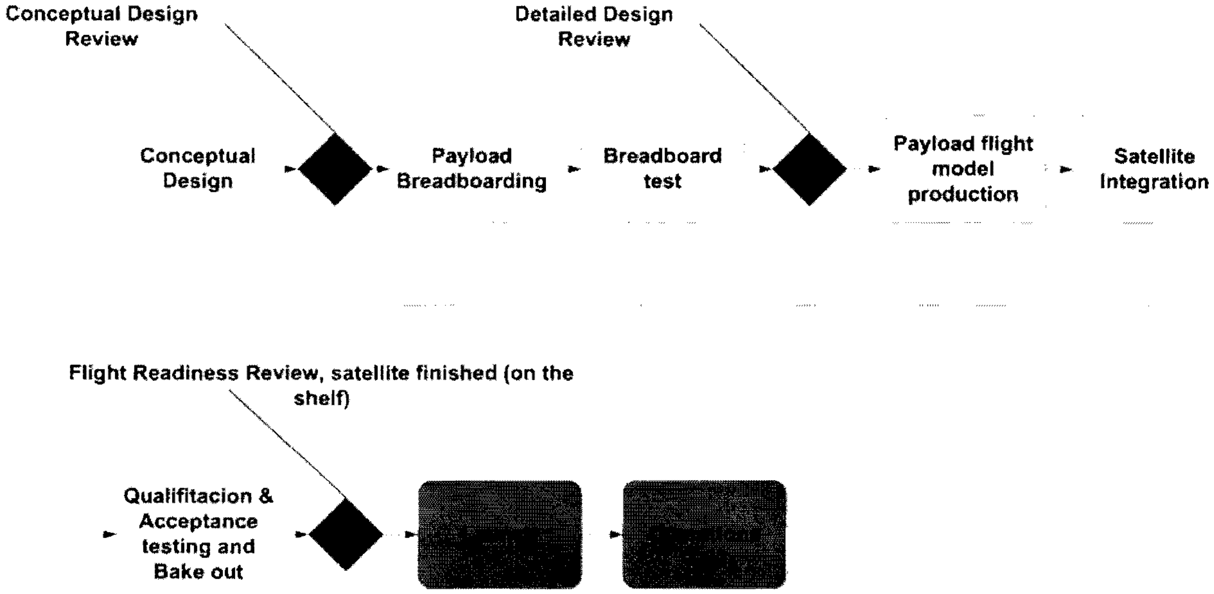
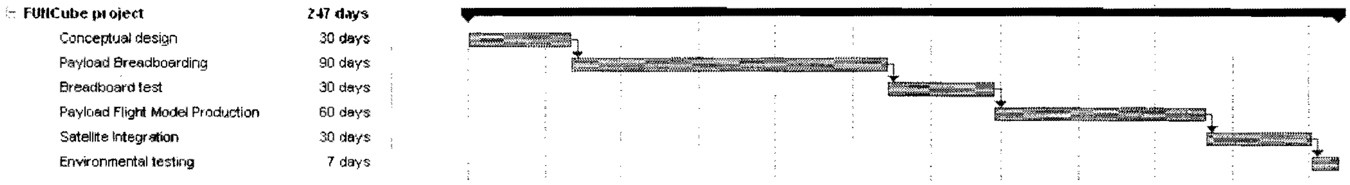


Figure 3 FUNcube Project Flow



FUNCube project	247 days
Conceptual design	30 days
Payload Breadboarding	90 days
Breadboard test	30 days
Payload Flight Model Production	60 days
Satellite Integration	30 days
Environmental testing	7 days

Figure 4 FUNcube Project Planning

Launch

CubeSats are generally launched as secondary payloads. An increasing number of opportunities and launch vehicles are becoming available for launching CubeSats. At this moment, a specific launch has not been planned. The satellite would be completely built and tested, after which it can be put on the shelf waiting for the first launch opportunity to become available. Due to the flexible design of the satellite, it can operate in any high inclination Low Earth Orbit between 400- 1000km so there are no strict requirements on the orbit. Most CubeSat launches go to Sun Synchronous Low Earth Orbits, typically in the 600-700km range. In these orbits, the satellite passes over Europe approximately 3 times in the morning, and 3 in the evening, every day. This would be very suitable for FUNcube as the satellite can be used for demonstrations by GB4FUN in the morning, and used by radio amateurs during the evening passes. The launch itself would be a big event, and it would be perfectly suited for media involvement.

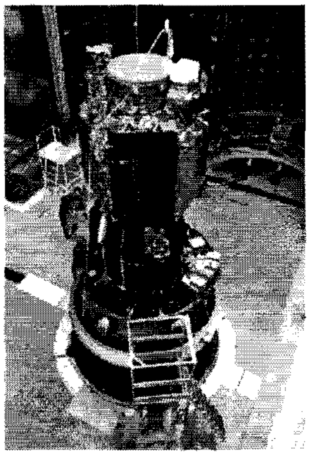


Figure 5 Polar Satellite Launch Vehicle Upper stage showing CubeSat deployers (picture courtesy of ISRO)

Operations

For satellite control and operations no dedicated groundstation will be required. A worldwide team of individual experienced volunteer radio amateurs will be responsible for this function. Additionally the equipment already installed in the GB4FUN trailer is well suited to demonstrate these functions. The satellite will be designed such that it has a large degree of autonomy requiring minimum operator intervention from the ground.

PR / media plan

There will be a requirement for an "outreach" team to be created to ensure the widest possible coverage and general publicity for the project; especially around the time of launch and during early operations. From the experience gained by AMSAT-UK whilst working on the SSETI-Express project we know that mainstream media will be interested in the project and we have recently been approached by the BBC "Blue Peter" researchers who have expressed an interest in working in this area.

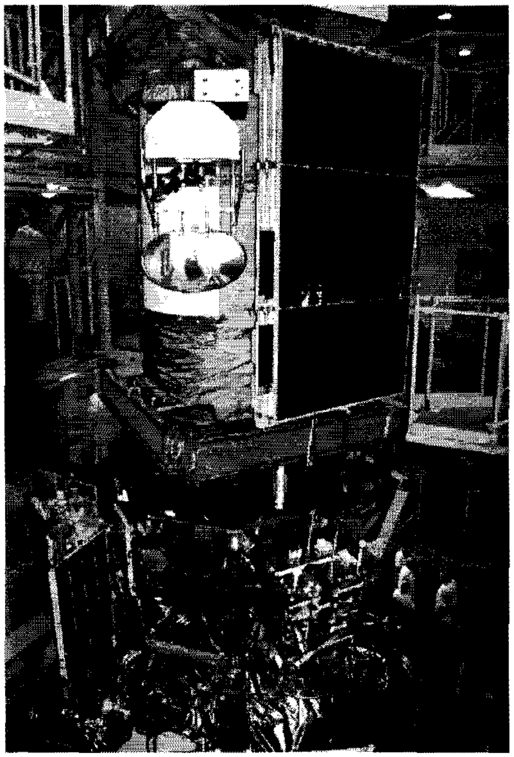
AMSAT-UK have worked with the RSGB in supporting the ARISS (Amateur Radio on the International Space Station) school contacts, where schoolchildren can talk live to astronauts aboard the ISS via amateur radio and we will need to further develop these relationships with the education world.

During the launch phase we envisage the provision of real time launch videos, interviews, demonstrations of ground receivers by school children etc together, of course, the capture of initial telemetry using the GB4FUN trailer from a suitable location.

Figure 6 ARISS school contact at Budbrooke School

SumbandilaSat – the satellite that nearly remained in the clean room

Hans van de Groenendaal ZS6AKV SA AMSAT



SumbandilaSat is just under the main payload

It was with great relief when SumbandilaSat, South Africa's second satellite, was finally launched on 17 September 2009 from the Baikonur launch facility in Kazakhstan. The SumbandilaSat satellite story began in July 2005 when the South African Department of Science and Technology issued the following statement: "A 70 kg micro satellite is presently being developed in Stellenbosch, and will be ready for launch by December 2006. Provision has been made for a small experimental research payload to be incorporated in the satellite. Researchers interested in proposing, or providing part (or all) of the payload are invited to immediately provide the project team with an expression of interest."

With the guidance from the late Prof Garth Milne ZR1AFH, who was the main driver of SunSat 1, SA AMSAT submitted a proposal which was accepted as an experimental payload in November 2005. SA AMSAT was given three months to deliver the experimental payload for incorporation in the satellite.

At first Engineers at Stellenbosch University and at SunSpace decided that the amateur payload was going to be placed external to the main body on the top surface of the space frame. However once all the experiments were considered it was shown that power constraints made a separate amateur transponder not a viable proposition.

Ultimately it was decided that SA AMSAT would share an off-the-shelf Sunspace VU transponder with the other experiments. Andrew Roos ZS6AA and Hannes Coetzee ZS6BZP set to work to develop a control interface that would be integrated with the VU transponder and deliver three different modes under the control of CTCSS

- Voice Beacon programmable from the group through the uplink
- A parrot repeater
- A FM voice repeater.

The unit was developed and tested in record time. Two modules were built. One was kept for reference purposes and the other sent to Stellenbosch University together with a complete kit of components so that the SA AMSAT design could be incorporate in the Stellenbosch University SDR experiment.

The frequencies coordinated with the IARU group are uplink 145,880 MHz and downlink 435,350 MHz. The SA AMSAT original choice was a UV configuration but because an off the shelve transponder had to be used SA AMSAT had to settle for a VU option.

SA AMSAT and the SA Amateur Radio Development Trust arranged a competition inviting scholars to develop the first message to be incorporate in the voice beacon. Anton Coetzee, at the Kimberley Technical High school submitted the winning message which was recorded in his own voice and will soon be heard when the amateur payload is initiated.

"This is ZSOSUM in space. I am the voice of the South African youth. We are knocking on the door of opportunity, marking our place in the orbit of space research and communication. Hear us! Listen to us!

By November 2006 it was all systems go. The satellite had been given its name "SumbandilaSat" which loosely translated from the Venda Language means "Pathfinder". The satellite was soon to find its way to Russia where it was destined to be launched from a Russian Submarine on a Shtil rocket. But it was not to be. Some internal political issues developed and delays upon delays were the order of the day.

South Africa started shopping around for another launch opportunity. But it was ultimately a discussion between the Presidents of Russia and South Africa that decided to shift the launch to Baikonur. More frustrating delays followed but eventual it happened. SumbandilaSat is now in orbit and responding well to instructions from the ground control station in Stellenbosch.

It is expected that the amateur payload will only be activated once the main payload, an imager, has been fully commissioned.

The satellite has a small attitude control unit which operates with butane gas which was loaded on the satellite prior to final integration on the rocket. It is expected that the butane will last approximately 3 years after which it will no longer be possible to control the position of SumbandilaSat and the imager. It is expected that then only the amateur payload will remain operational.

Once the satellite has been fully commissioned an operational schedule will be prepared. At this stage SA AMSAT has requested that weekends and at least one day during the week be dedicated to the amateur payload. At this early stage it is difficult to determine what the final operation schedule will look like.

The Payloads on SumbandilaSat:

A VIOLIN IN ORBIT?

Mark Gordon, until recently a student in the Department of Megatronics at the Nelson Mandela Metropolitan University in Port Elizabeth has devised an experiment that will test the behaviour of a string in space.

Mark responded to an advertisement in a Sunday Paper inviting students and researchers to apply to have their experiment included in the payload. The experiment is the first micro gravity experiment on a SA satellite.

“My research is on string vibration”, Mark said. “I am comparing vibration of a string in microgravity to line vibration of overhead telecommunication and power systems. In space we can measure the true vibration without having the dampening effect of air around it as we experience on the ground. The information will be useful in our study of overhead line behaviour and how to shorten spans.

The SU engineers devised a unique way of measuring the vibration of the string in all directions as well as the lengthening of the string. They called it their “violin project”!

CONNECTING CLINICS IN DEEP RURAL AREAS

An interesting communications system commissioned by the Department of Communications (DOC) will bring data communications to the remotest parts of South Africa.

The Department of Communication worked with the SU to develop a data store and forward system that is able to serve as a test bed for a future satellite network that can, amongst others, assist rural clinics with patient records, provide water affairs with reliable dam capacity records and associated weather conditions, provide email facilities at remote schools and assist other government departments to communicate with outlying posts.

Sunspace has provided the required transceiver facilities and onboard computer hardware as well assuming the overall responsibility for the integration into the satellite while the University has been responsible for the ground station development as well as the onboard computer application software and hardware associated with the communications payload.

The mission is essentially a low-bandwidth data communications system that is accessible from areas in South Africa where there is no communication connectivity of any sort. The system is able to exchange short messages up to 8 k byte and can handle up to 20 ground station nodes with one channel.

AMATEUR RADIO EXPERIMENTAL PAYLOAD TO CREATE INTEREST IN SPACE AT SCHOOL LEVEL

The control unit will command the various functions of the transponder and handle the parrot and beacon messaging. On receipt of a tone from the VHF receiver, the CTCSS tone will be decoded and depending on the tone received the unit will command the VU transponder operation or the parrot repeater. In the transponder mode the satellite will act like a cross-band FM repeater and allow two way communications with other stations on the ground. With SumbandilaSat in 500 km polar orbit Radio Amateurs in SADC countries will be able to communicate with South African Radio Amateurs while radio amateurs in the rest of the world will have a new entry level facility to use to promote amateur radio to the youth.

If the tone received indicates parrot operation, the interface unit will record 20 seconds of audio on its VHF uplink receiver and replay the recorded audio on the UHF downlink.

Should, for a predetermined period, there be no tones received, the controller will initiate a voice beacon, transmitting a pre-recorded message at regular intervals. This facility will offer many opportunities for educational projects.

STUDY OF VLF WAVES

The study of VLF waves is a project initiated by the department of physics at the University of KwaZulu- Natal. The objective of the experiment is to study the transmission of VLF waves through the Ionosphere, the propagation between Hemispheres and the wave content of the magnetosphere. The Geospace Physics Group also operate radio and particle experiments in Antarctica and on Marion Island

STELLENBOSCH UNIVERSITY RADIATION EXPERIMENT

The Stellenbosch University will carry out some ground breaking experiments focussing on the mitigation and measurement of space radiation effects on electronic systems. A part of the experiment will measure the response of reprogrammable logic to space radiation. The data collected will assist the development of improved radiation tolerant space systems by validating experimental results obtained from terrestrial radiation results. The results from space experiments will also aid in developing cost effective terrestrial radiation testing processes to minimise development costs. A further benefit is that system improvement can help solve numerous problems that are currently experienced related to the design of reliable and economically viable satellite systems.

STELLENBOSCH UNIVERSITY SDR EXPERIMENT

In this experiment, an additional SunSpace single-board computer (identical to the satellite's primary on-board computer) is used as digital signal processing platform for a reconfigurable communications system. A daughterboard is added to the computer to allow signal conversion and translation to and from radio frequencies. Radio functionality can be reprogrammed as needed, enabling remote management and upgrading of the communications system.

Software Defined Radio (SDR) is communications architecture where maximum system functionality (including modulation and demodulation) is seated in the digital, or software, domain. This approach provides highly flexible communication systems, where a single hardware platform can be reused for many different applications, and system upgrades can be done through a simple software update. Also, the main focus of system design shifts to software, allowing rapid application development and implementation. SDR is particularly suited to satellite applications, since it allows remote, over-the-air reconfiguration of satellite communication systems. The SDR system can also be programmed to act as an amateur FM transponder.

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AMSAT NA SPACE SYMPOSIUM 2009

Radio Amateurs should get more involved in educational satellites

Hans van de Groenendaal ZS6AKV
IARU SATELLITE ADVISER

With Radio Amateurs having pioneered small satellites in low earth orbits right from the start of the space programme, it is not surprising that educational institutions around the world saw an opportunity to incorporate satellite projects in their academic programme.

The CubeSat Project was started by a partnership between the California Polytechnic University in San Luis Obispo and Stanford University in Palo Alto to develop a standardised space platform for academic satellite projects. It has since grown to become an international partnership of over 40 institutes that are developing CubeSats containing scientific payloads.

A standard CubeSat is a 10 cm cube with a mass of up to 1 kg. In recent years some institutions have found the need to build larger CubeSat and double or triple the size by stacking 2 or 3 standard cubes.

Developers benefit from the sharing of information within the community. Resources are available by communicating directly with other developers and attending CubeSat workshops. Developers could however benefit even more if they attended the AMSAT NA Space Symposium and other amateur events in their countries and if radio amateurs became more involved during the development process of a CubeSat.

With many institutes participating in the CubeSat programme, the educational benefits are tremendous. Students, through hands on work, will develop the necessary skills and experience needed to succeed in industry after graduation. The CubeSat programme also benefits private firms and governments by providing a low-cost way of flying payloads in space.

Spectrum was an issue and in most countries' regulators (Administrators) have allowed the use of spectrum in the Amateur service albeit it in many instances being by default rather than by decision.

Amateur Radio frequencies are generally well organised into segments to promote efficient use and preventing mutual interference between the various modes of operation. Band planning is not a concept generally understood by non amateurs who tend to see what in their eyes is a huge chunk of spectrum. It is to the credit of the amateur fraternity and national associations that a greater understanding of band planning exists today. The IARU some years back appointed a satellite adviser who with a panel of experienced radio amateurs works together with the CubeSat fraternity to coordinate frequencies in sections of the 2m and 70 cm to be compatible with other amateur radio activities.

When CubeSats are launched, news reports in the amateur service often talk about a number of amateur satellites having been launched. In fact most of them are pure experimental educational satellites operating in the amateur spectrum. Most of these CubeSats have no relation to amateur radio and only use amateur spectrum for communication with their ground stations. They should therefore be referred to as educational satellites and not amateur satellites.

There is no doubt about the desirability of the educational CubeSat programme as besides benefitting development of people in the space sciences it also rubs off on amateur radio as many of the students progress to becoming licensed amateurs.

RADIO AMATEURS SHOULD SHARE THEIR EXPERTISE

Many radio amateurs have expertise and experience in satellite technology which would be valuable input to the institutions developing and building CubeSats. Besides technical and operating experience they also understand the amateur radio environment and can assist in the development of a more inclusive payload that may serve both communities better.

In many instance students and their tutors develop a scientific experiment and use off-the-shelf radio equipment to provide the RF link with the ground. Often after a few months the experiment has been completed and the satellite is no longer used. By working together it would be possible, without too much extra effort, to turn on an amateur radio activity which could operate for the balance of the satellite's time in orbit.

While initially the academic world may not see the benefits but in the long term it will encourage their students to become licensed amateurs and continue to enjoy the fruit of their endeavours by staying involved at another level and continue to build expertise and experience in space sciences.

From an Academic perspective radio amateur involvement has many other benefits. Perhaps the Delfi project of the University of Delft (The Netherlands) is an excellent example. There was a significant amateur involvement which paid a dividend in that after launch they received so much telemetry from radio amateurs world-wide that it kept them busy for months elevating the results of a solar panel experiment which was the main objective of the project.

Radio amateurs with their understanding of interference mitigation can also assist with the development of adequate command facilities to manage a payload that may have developed problems and is causing interference with other systems using the same spectrum. The IARU satellite advisory Panel has developed several papers that will be useful when starting a satellite project. (www.iaru.org/satellite)

While off-the-shelf RF equipment may seem an easy way out, it limits the frequency choice. Most CubeSats developers opt for the 145 and 437 MHz bands which are already heavily congested. With radio amateur involvement the higher frequency bands may become accessible.

Greater partnership between radio amateurs and academic institutions can only benefit both groups. Local clubs should seriously consider visiting their local technical institutions and becoming involved. Besides adding value, the club will benefit from greater involvement in technology which can only auger well for their own growth and providing greater scope for their members.

AMSAT NextGen Satellite Project

Evolutionary Leveraging of Assets and Opportunities

Presented at The Amateur Radio Satellite Corporation (AMSAT) Symposium
Baltimore, MD, USA
October 9-11, 2009

Alex Harvilchuck,
Systems Engineer and I/T Architect, IBM Corporation
Dr. Roger Westgate,
Professor, Binghamton University, Electrical & Computer Engineering Department
Dr. Eileen Way,
Associate Professor, Binghamton University, Systems Science & Industrial Engineering Department
Kurt Rodgers,
Lecturer, Binghamton University, Electrical & Computer Engineering Department
Colin Selleck,
Lecturer, Binghamton University, Mechanical Engineering Department

AMSAT

NextGen CubeSat Proposal

Evolutionary Leveraging of Assets and Opportunities

Contact: A. Harvilchuck, N3NP
(amsat@elkmtn.org)

AMSAT needs to . . .

- Increase number of in-orbit spacecraft
- Leverage current design objects
- Creatively approach launch opportunities
- Increase educational outreach
- Maintain experimental edge
- Provide a stable technical program office

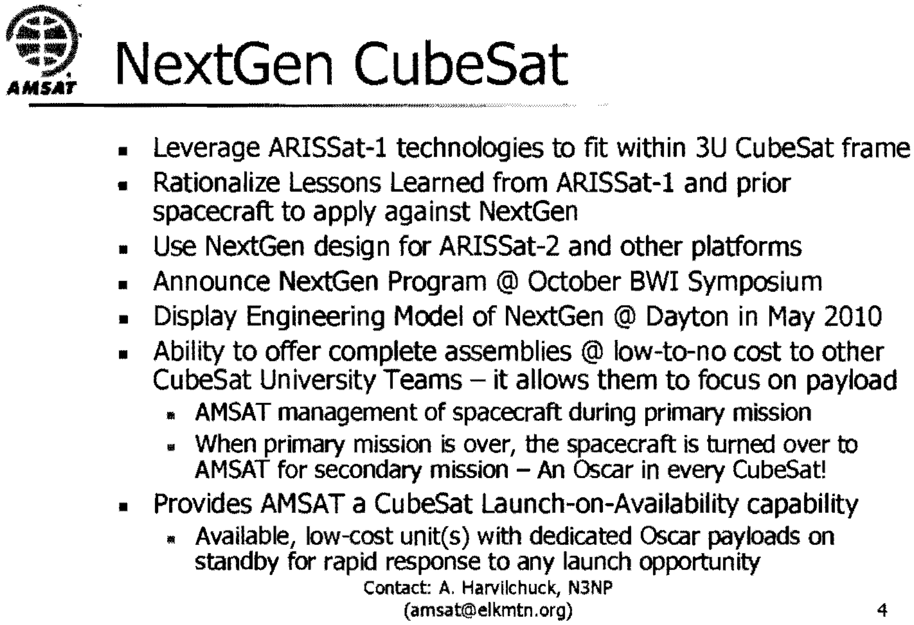
Contact: A. Harvilchuck, N3NP
(amsat@elkmtn.org)

How to meet the needs . . .

- Engage University Participation
- Leverage Current & Future Volunteers
- Maintain Evolutionary Design Principles

All Working Together as a Team

Contact: A. Harvilchuck, N3NP
(amsat@elkmtn.org)



NextGen CubeSat

- Leverage ARISSat-1 technologies to fit within 3U CubeSat frame
- Rationalize Lessons Learned from ARISSat-1 and prior spacecraft to apply against NextGen
- Use NextGen design for ARISSat-2 and other platforms
- Announce NextGen Program @ October BWI Symposium
- Display Engineering Model of NextGen @ Dayton in May 2010
- Ability to offer complete assemblies @ low-to-no cost to other CubeSat University Teams – it allows them to focus on payload
  - AMSAT management of spacecraft during primary mission
  - When primary mission is over, the spacecraft is turned over to AMSAT for secondary mission – An Oscar in every CubeSat!
- Provides AMSAT a CubeSat Launch-on-Availability capability
  - Available, low-cost unit(s) with dedicated Oscar payloads on standby for rapid response to any launch opportunity

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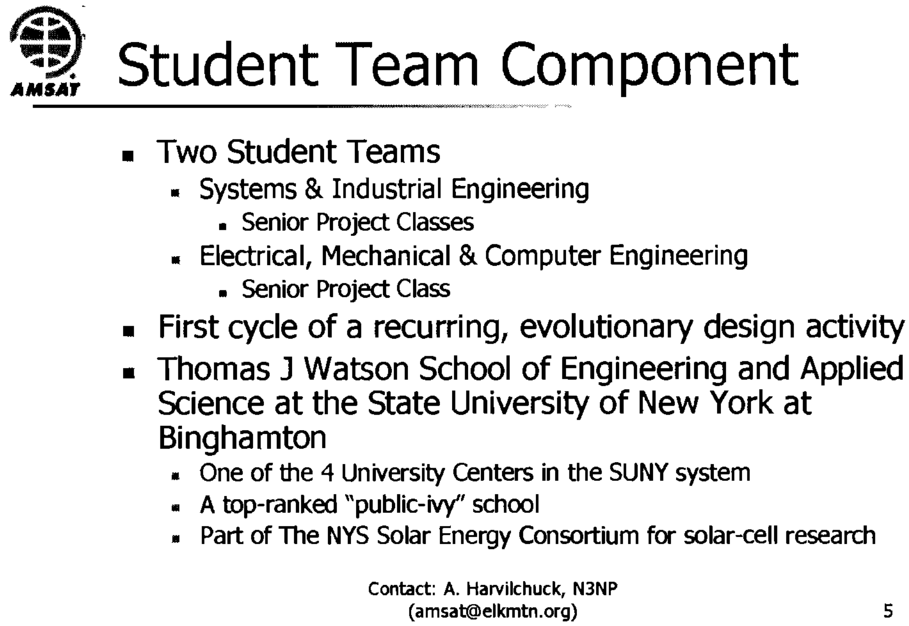
- Evolutionary not Revolutionary Design
- Use existing or Define New Microsat Standards



Student Team Component

- Two Student Teams
  - Systems & Industrial Engineering
    - Senior Project Classes
  - Electrical, Mechanical & Computer Engineering
    - Senior Project Class
- First cycle of a recurring, evolutionary design activity
- Thomas J Watson School of Engineering and Applied Science at the State University of New York at Binghamton
  - One of the 4 University Centers in the SUNY system
  - A top-ranked "public-ivy" school
  - Part of The NYS Solar Energy Consortium for solar-cell research

Contact: A. Harvilchuck, N3NP
(amsat@elkmtn.org)

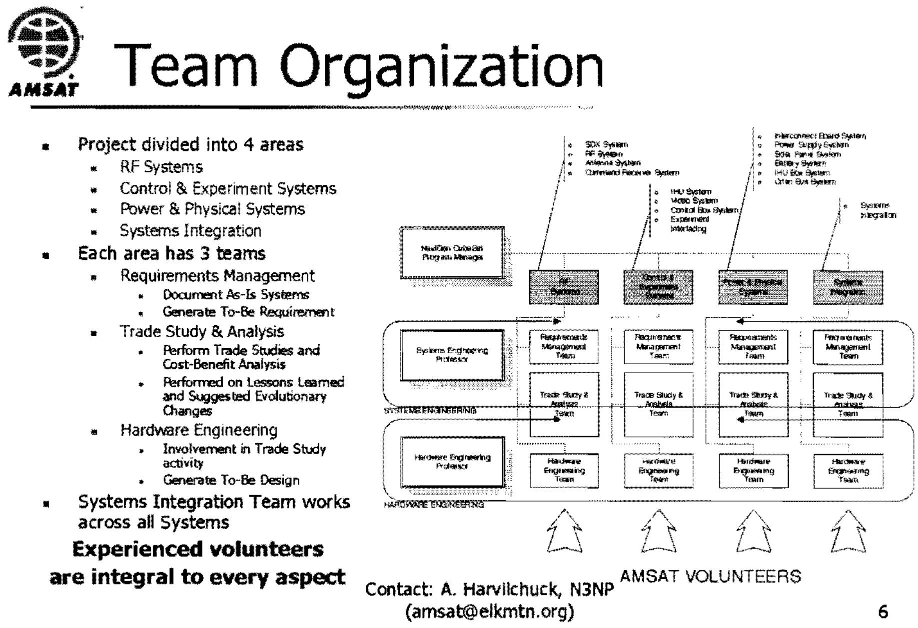
The **State University of New York**, abbreviated **SUNY** is the largest public university system in the United States with 64 campuses across the State of New York. SUNY campuses include universities, colleges and four University Centers: Albany, Buffalo, Stony Brook and Binghamton. The State University of New York at Binghamton, also known as Binghamton University, was founded in 1946. Binghamton has a reputation of high academic standards coupled with affordable tuition, with independent reviews such as:

- Kiplinger's Personal Finance Magazine, Binghamton was ranked the #1 best value for 2009.
- Spring 2008, Forbes Magazine ranked Binghamton 16th among all public schools and 57th among all schools public and private.
- Listed on Greene's Guide to Colleges as one of the "Public Ivies".
- Fiske Guide to Colleges labeled Binghamton as "The Premier Public University in the Northeast"
- Ranked 77th among all 4-year schools in US News & World Report's America's Best Colleges and Universities

Binghamton comprises the following schools and colleges:

- Harpur College of Arts and Sciences
- College of Community and Public Affairs
- Decker School of Nursing
- School of Education
- School of Management
- Thomas J. Watson School of Engineering and Applied Sciences

The Thomas J. Watson School of Engineering and Applied Science, also known as the Watson School, was founded in 1983. Thomas J. Watson founded the International Business Machines Corporation (IBM) in the Binghamton/Endicott area in the early 20th Century and was instrumental in founding Binghamton University. The IBM Corporation was instrumental in founding the Watson School. The school offers ABET accredited departments offering undergraduate and graduate degrees in mechanical engineering, electrical engineering, computer engineering, bioengineering, industrial and systems engineering, and computer science.



Team Organization

- Project divided into 4 areas
  - RF Systems
  - Control & Experiment Systems
  - Power & Physical Systems
  - Systems Integration
- Each area has 3 teams
  - Requirements Management
    - Document As-Is Systems
    - Generate To-Be Requirement
  - Trade Study & Analysis
    - Perform Trade Studies and Cost-Benefit Analysis
    - Performed on Lessons Learned and Suggested Evolutionary Changes
  - Hardware Engineering
    - Involvement in Trade Study activity
    - Generate To-Be Design
- Systems Integration Team works across all Systems

Experienced volunteers are integral to every aspect

Contact: A. Harvilchuck, N3NP
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AMSAT VOLUNTEERS

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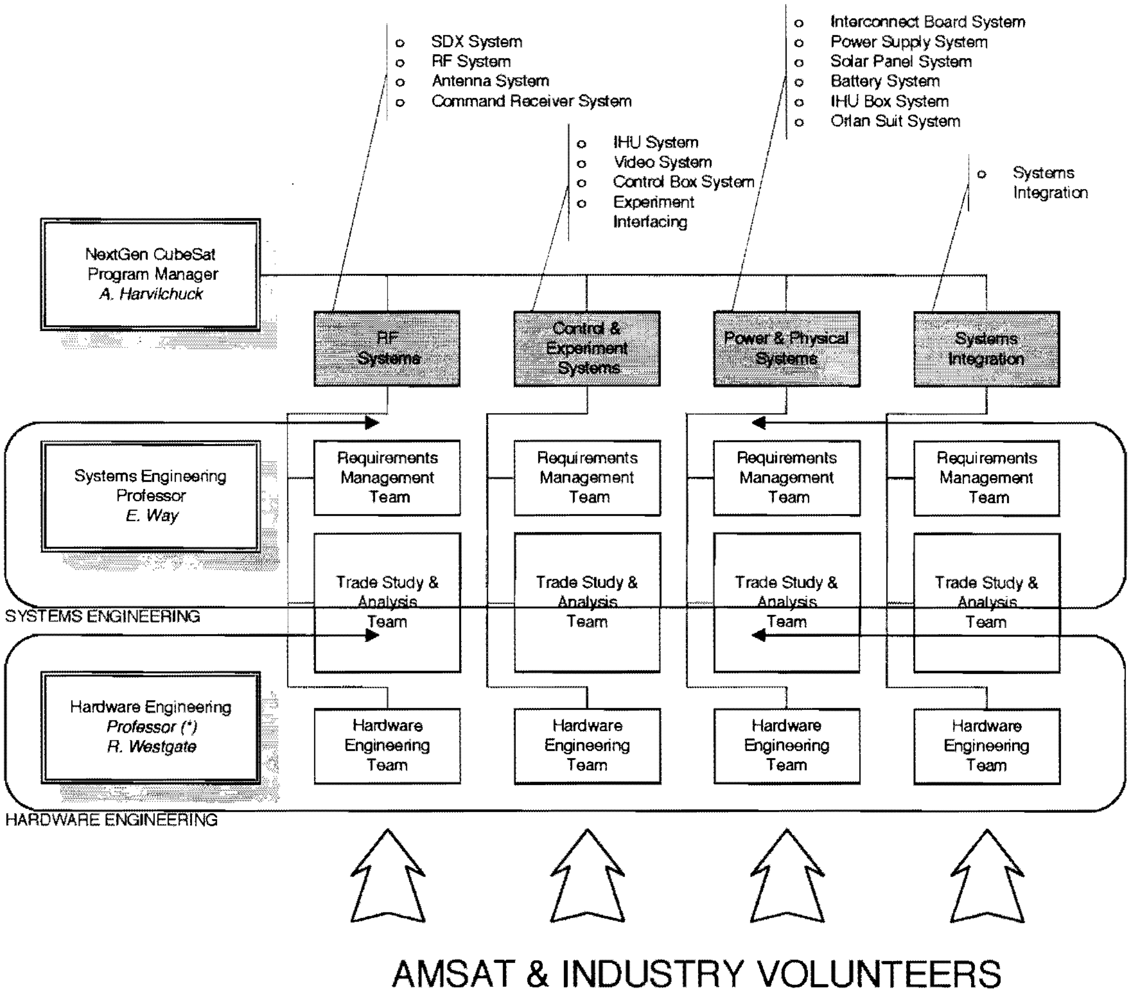


Dedicated Volunteer NextGen Program Office staffed by Experienced Systems Engineering

Undergraduate student teams from the Electrical & Computer Engineering and Systems Science & Industrial Engineering Departments are involved in the project with assistance from volunteers from regional industries and professional associations, such as the International Council of Systems Engineering – Finger Lakes Chapter (INCOSE – FLC). The teams are focused on Systems, Industrial, Electrical, Mechanical and Computer Engineering aspects of the project.

The IBM Corporation is involved in a number of aspects of the Watson School. One of those aspects is the relationship that IBM Global Services' Systems Engineering, Architecture & Test organization involvement in the undergraduate Industrial & Systems Engineering program with focus on improving Systems Engineering education at Binghamton in addition to other Universities. The program, called the Systems Engineering Integration Center (SEIC), through volunteer IBM professionals, to augment the curriculum through guest lectures and participation in student capstone projects. Students who demonstrate good Systems Engineering ability are offered a chance to participate as paid members of IBM Global Services delivery teams as a flexible staffing resource (OnDemand).

Mr Harvilchuck's involvement with the SEIC is as its Lead Systems Engineer. His eighteen years of experience in the Systems Engineering and Computer Science fields for IBM and Lockheed Martin managing a range of small to large projects and programs.

Power & Physical Systems

Project Objectives

- Power Systems
  - Application of Supercapacitors
    - Redesign of ICB & PPT Boards
    - Revisit PSU board to determine if modifications are needed
  - Increased Solar Panel Area
    - Revisit PSU & PPT boards to determine if modifications are needed
- Physical Systems
  - Deployable Solar Panels
    - Modify structure to fit within constraints

Contact: A. Harvilchuck, N3NP
(amsat@elkmtn.org)

Power & Physical Systems

High-Level Project Schedule

- Preliminary Design Review
  - Mid November 2009
- Critical Design Review
  - Late December 2009 / Late January 2010
- Test Readiness Review
  - Mid March 2010
- Engineering Model Ready
  - Late April 2010
- Dayton Hamvention
  - 12-14 May 2010

Contact: A. Harvilchuck, N3NP
(amsat@elkmtn.org)

RF Systems

Project Objectives

- Documentation of Existing Requirements
- Analysis of Evolutionary Change
  - Applicability of Prior Lessons Learned
  - Member Suggestions for Improvement
- Coordinate Implementation of Selected Changes
  - AMSAT & Industry volunteers needed!
  - Other University Teams needed!

Contact: A. Harvilchuck, N3NP
(amsat@elkmtn.org)

RF Systems

High-Level Project Schedule

- Preliminary Design Review
  - Late December 2009
- Critical Design Review
  - Mid February 2010
- Test Readiness Review
  - Late March 2010
- Engineering Model Ready
  - Late April 2010
- Dayton Hamvention
  - 12-14 May 2010

Contact: A. Harvilchuck, N3NP
(amsat@elkmtn.org)

Control & Experiment Systems

Project Objectives

- Documentation of Existing Requirements
- Analysis of Evolutionary Change
  - Applicability of Prior Lessons Learned
  - Member Suggestions for Improvement
- Coordinate Implementation of Selected Changes
  - AMSAT & Industry volunteers needed!
  - Other University Teams needed!

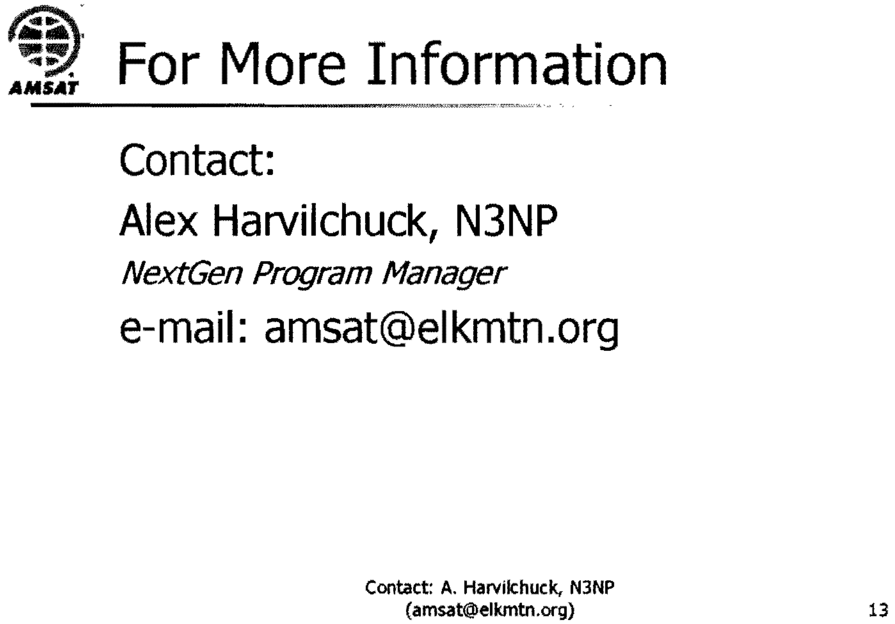
Contact: A. Harvilchuck, N3NP
(amsat@elkmtn.org)

Control & Experiment Systems

High-Level Project Schedule

- Preliminary Design Review
  - Late December 2009
- Critical Design Review
  - Mid February 2010
- Test Readiness Review
  - Late March 2010
- Engineering Model Ready
  - Late April 2010
- Dayton Hamvention
  - 12-14 May 2010

Contact: A. Harvilchuck, N3NP
(amsat@elkmtn.org)



For More Information

Contact:

Alex Harvilchuck, N3NP

NextGen Program Manager

e-mail: amsat@elkmtn.org

Additional Volunteers are needed in areas such as:

- RF Systems
- Guidance, Navigation & Control Systems (Magnetorquers, Sun Sensors, etc.)
- Software Defined Radio Systems
- Power Systems
- Satellite Structure / Deployable Panels
- Experiments

Evolutionary design ideas are needed in all areas

This is your chance to get involved in whatever capacity you are able to do

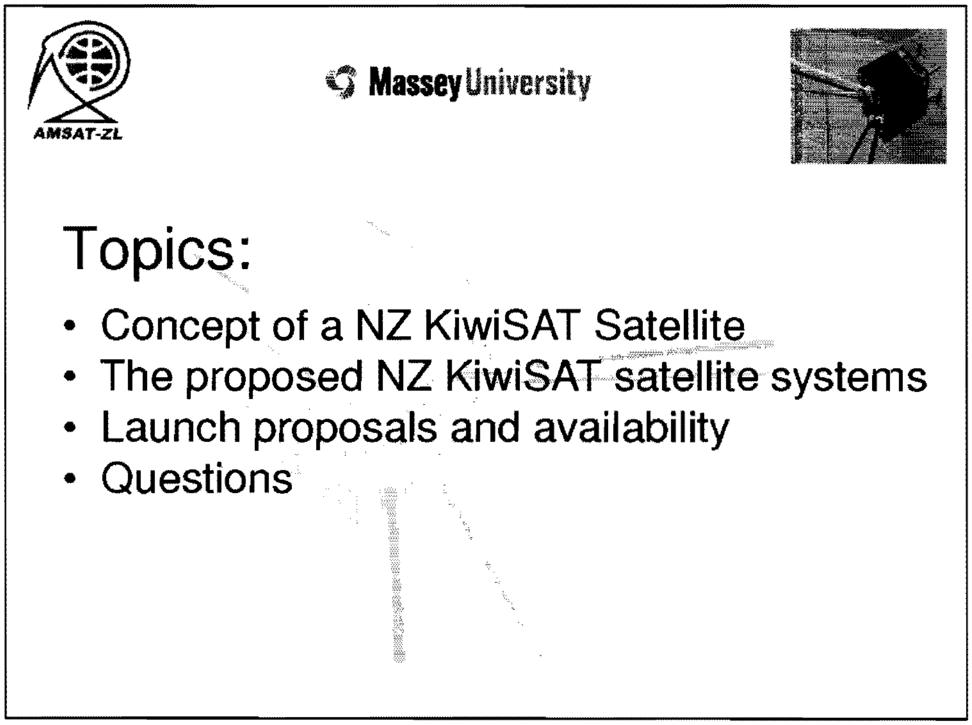
KiwiSAT A communications satellite for New Zealand

http://kiwisat.org/index.html

2009 Update Provided by
Kiwisat Project Leader
Fred Kennedy (ZL1BYP)
AND HIS TEAM

Presented by
Bill Ress N6GHZ
for AMSAT-ZL

Presentation for the AMSAT- NA Space Symposium
9 -11th October 2009



Topics:

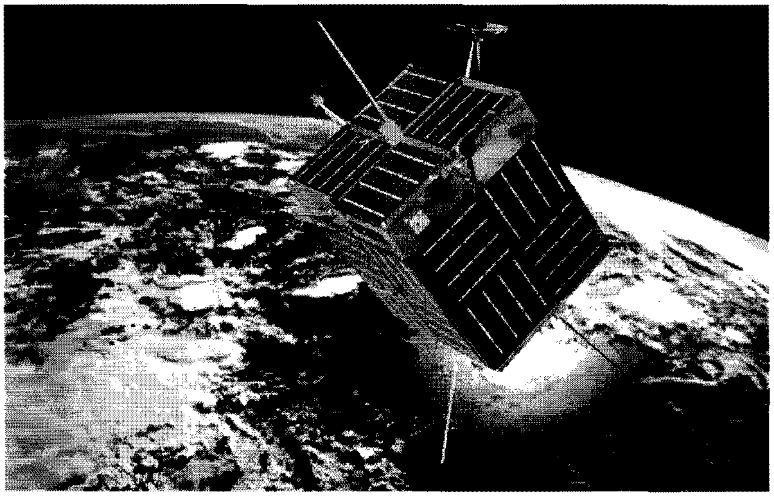
- Concept of a NZ KiwiSAT Satellite
- The proposed NZ KiwiSAT satellite systems
- Launch proposals and availability
- Questions

KiwiSAT Project

A New Zealand communications satellite
for Low Earth Orbit

AMSAT-ZL

Massey University



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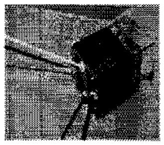
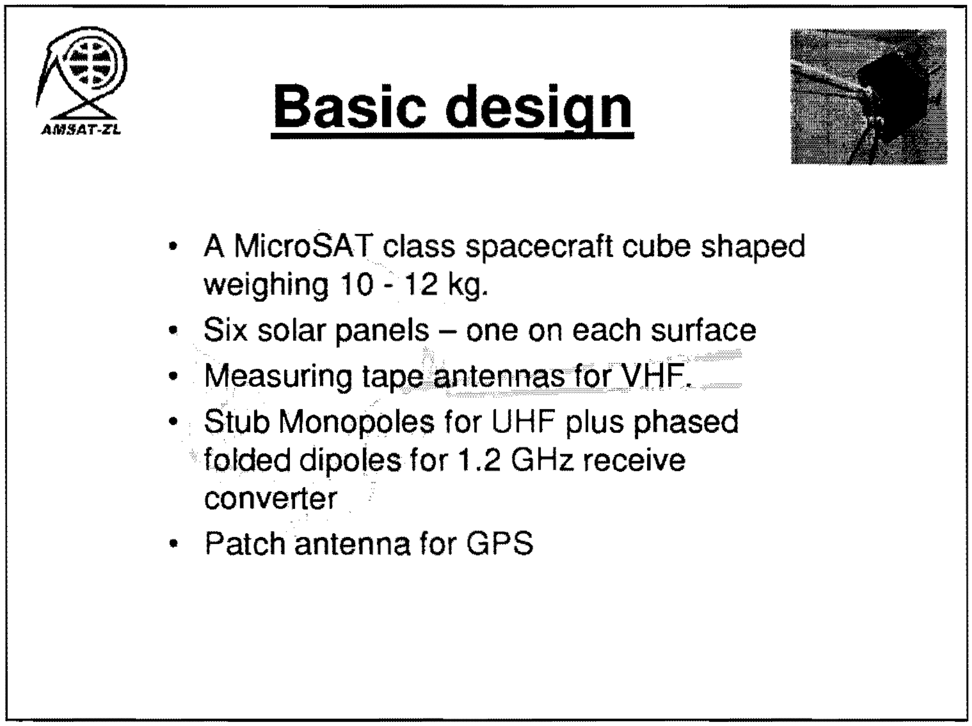
KiwiSAT – Review

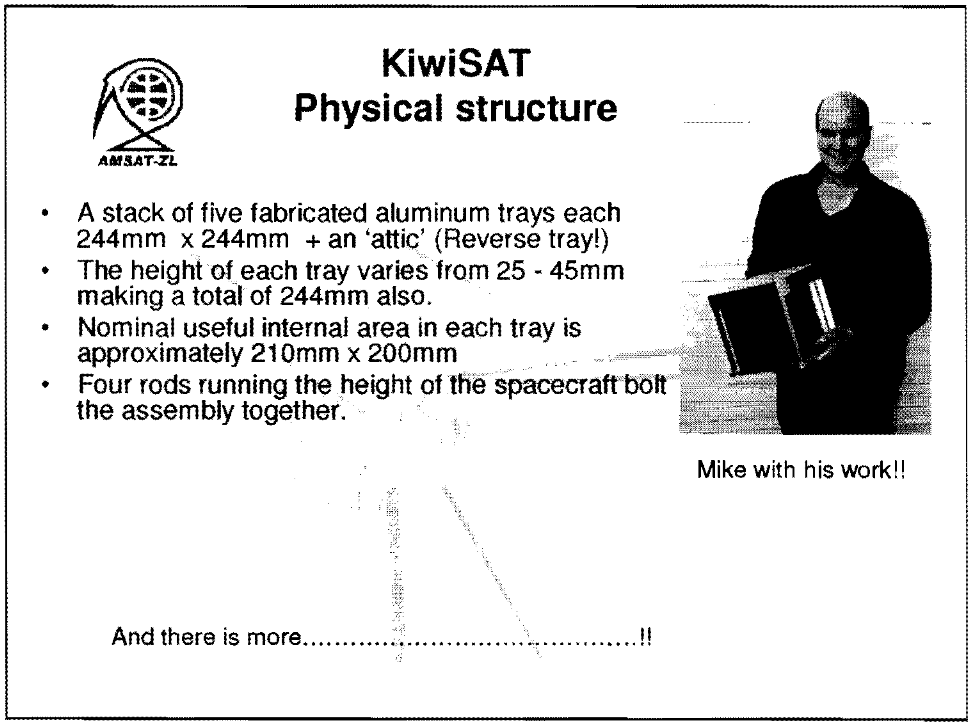


- **KiwiSAT** – the first satellite from New Zealand
- Basic communications fit approved and now complete
- Science package determined and 95% complete.
- Launch agency – SLC Kosmotras (Russia) selected.
- Launch funding to be actively sought when satellite is ready to go. (Volunteers and launch deadlines do not mix!!!)
- AMSAT-ZL are very optimistic that funding WILL be found.



Basic design

- A MicroSAT class spacecraft cube shaped weighing 10 - 12 kg.
- Six solar panels – one on each surface
- Measuring tape antennas for VHF.
- Stub Monopoles for UHF plus phased folded dipoles for 1.2 GHz receive converter
- Patch antenna for GPS



KiwiSAT
Physical structure

- A stack of five fabricated aluminum trays each 244mm x 244mm + an 'attic' (Reverse tray!)
- The height of each tray varies from 25 - 45mm making a total of 244mm also.
- Nominal useful internal area in each tray is approximately 210mm x 200mm
- Four rods running the height of the spacecraft bolt the assembly together.

Mike with his work!!

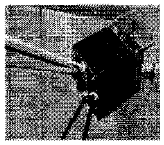
And there is more..!!

Machining the solid trays

March 2009

AMSAT-ZL

KiwiSAT – Modules

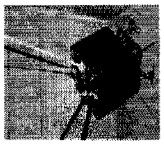


From the top down –

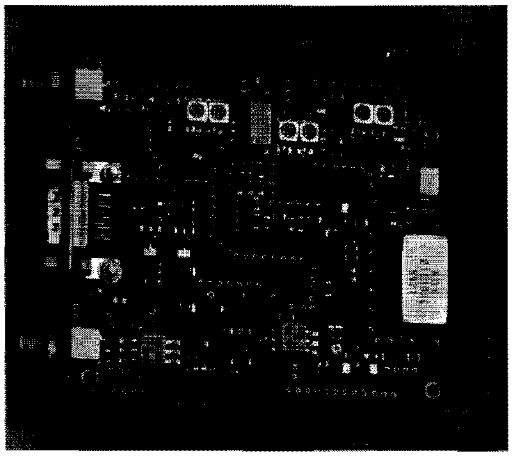
- Receivers on 70 cm and 23 cm and sensors. (+ GPS)
  Science package – ADAC using Geomagnetic Field
- IHU (Integrated Housekeeping Unit – Command Computer) includes 1200 and 9600bd modems
- Battery tray
  NiMH battery 4.5 Ah 12 volt
- Battery Charge Regulator (BCR)
- 2 m transmitters (Linear and FM) + U Band Beacon and target Sun Sensor.

Receivers
Linear and FM

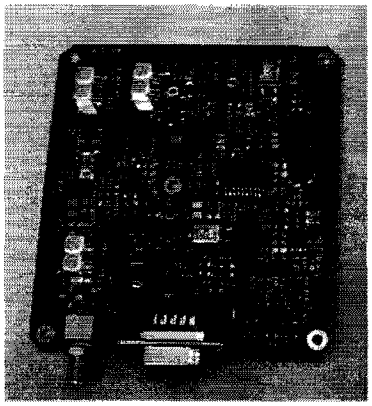
Complete.



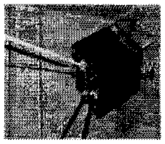
Linear – UHF (30 kHz bandwidth)



FM - UHF
(2 off)

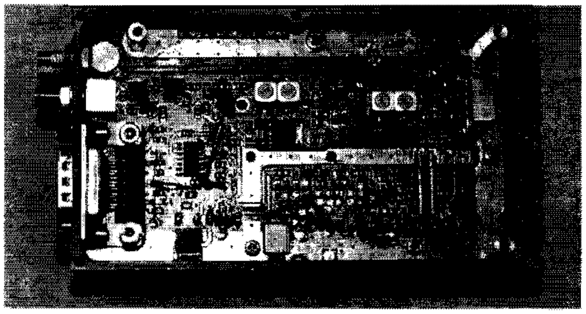


U Band Beacon.



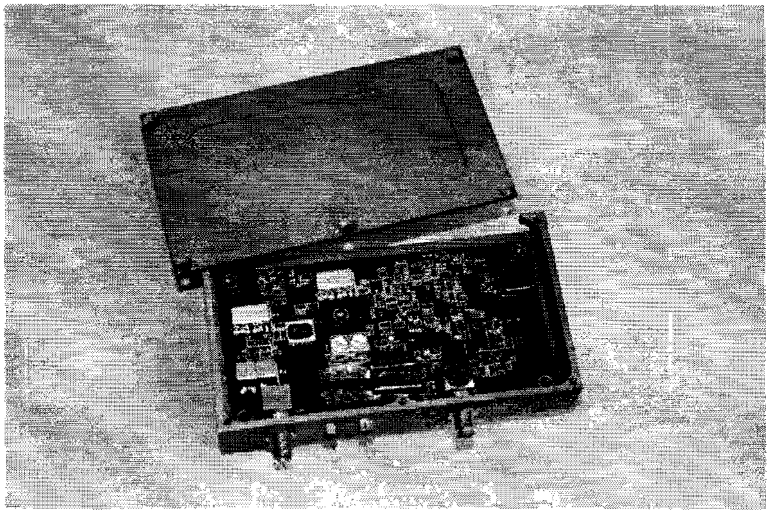
Complete.

- Needed for Faraday Rotation and TEC measurements for Science Package

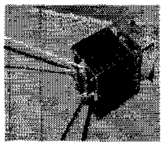


L Band Converter

Complete.



TRANSPONDER ON TEST!



- The KiwiSAT linear flight transponder is now "on the air" from the Massey University 'clean room' with beam antennas pointing to the Command Station provided by Ian (ZL1AOX.)

  * Transponder: Inverting type (Orbital Doppler shift compensation)
  * Transmit Power: 2 Watts PEP.
  * Beacon frequency: 145.885 MHz
  * Uplink: 435.265 to 435.235 MHZ **LSB**
  * Down link: 145.850 to 145.880 MHz USB
  * 30 Khz transponder bandwidth

- **Note**: A trial transmission on 435.2544 **LSB** comes out at 145.860 **USB**

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Planned Operating Frequencies

(Subject to licensing confirmation.)

- **Linear Transponder Downlink** :
  Frequency: 145.850 MHz to 145.880 MHz.
  Output Power: 2 Watts PEP.
  Radiated Power: 2 Watts (+33dBm) EIRP PEP.
  Bandwidth: 30 KHz. Emission Type: Depends on Uplink: CW, SSB etc.
  Antenna pattern: Omni directional in all planes.

- **Linear Transponder Uplink 1** :
  Frequency: 435.260 MHz to 435.230 (Inverting Transponder).
  Bandwidth: 30 KHz.
  Noise temperature: 273 degrees K.
  Emission Type: typically CW, SSB.
  Antenna Pattern: Quarter wave whip on +Z face (Omni in X-Y plane, Null in +Z and -Z direction).

- **Linear Transponder Uplink 2** :
  Frequency: 1268.880 to 1268.850 (Inverting Transponder)
  Bandwidth: 30 KHz.
  Noise temperature: 273 degrees K.
  Emission Type: typically CW, SSB.
  Antenna Pattern: 4 Dipole array (Omni in X-Y plane. +3 dbi Gain in +Z and -Z direction).

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Planned Operating Frequencies (Cont.)

(Subject to licensing confirmation.)

- **FM and Data Transmitter** :
  Frequency: 145.865 MHz.
  Output Power: 1 Watt.
  Radiated Power: 1 Watt (+30dBm) EIRP.
  Bandwidth: 20 KHz.
  Emission Type: 9600 bps data (G3RUH Packet standard) Telemetry and Data (various modes) scheduled with FM Voice or 1200 bps AFSK packet telemetry.
  Antenna pattern: Omni directional in all planes.

- **F.M Receiver Uplink 1**:
  Frequency: 435.245 MHz.
  Bandwidth: 20 KHz.
  Noise temperature: 273 degrees K.
  Emission Type: 9600 bps data, FM Voice,
  Antenna Pattern: Quarter wave whip on +Z face (Omni in X-Y plane, Null in +Z and -Z direction).

Planned Operating Frequencies (Cont.)

(Subject to licensing confirmation.)

- **F.M Receiver Uplink 2**:

Frequency: 1268.865 MHz.
Bandwidth: 20 KHz.
Noise temperature: 273 degrees K.
Emission Type: 9600 bps data, FM Voice,
Antenna Pattern: 4 Dipole array (Omni in X-Y plane, +3 dbi Gain in +Z and -Z direction).

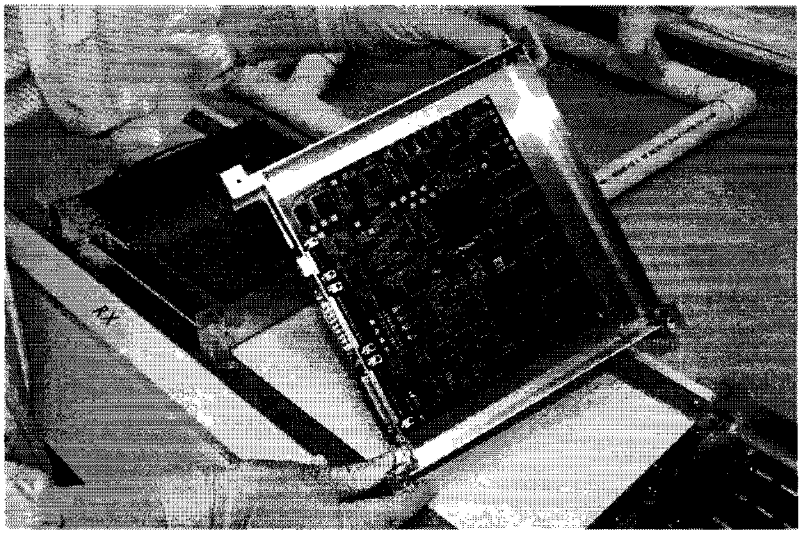
- **Beacons:**

Beacon 1:
CW Beacon Attached to Linear Transponder:
Frequency: 145.885 MHz.
Emission Type: CW standard morse code.
Power: 50 mW (+17 dBm) EIRP

Beacon 2 (Data Beacon):
Frequency: 145.865 MHz.
Output Power: 1 Watt.
Radiated Power: 1 Watt (+30 dBm) EIRP.
Bandwidth: 20 KHz.
Emission Type: 9600 bps data (G3RUH Packet standard)
scheduled with 1200 bps AFSK packet telemetry.

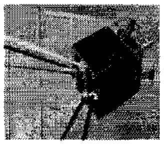
Beacon 3 (UHF Beacon):
Frequency: 437.425 MHz.
Bandwidth: 20 KHz.
Emission Type: 9600 bps data (G3RUH Packet standard).
Radiated Power: 100 mW (+20 dBm) EIRP.
Antenna pattern: Quarter wave whip on -Z face. (Omni in X-Y plane, Null in +Z and -Z direction).

Protoflight IHU – Computer and RAM Disk



Trial mount in engineering tray. (Ramdisc (same footprint) sits on top)

Power System



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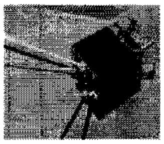
Comprises:-

- **Power generation**
  GaAs photovoltaic cells will be used.
- **Battery**
  10 x 4.5Ah NiMH cells with a nominal battery voltage of 12 V DC.
- **Battery Charge Regulator (BCR)**
  to manage battery charge and protection.

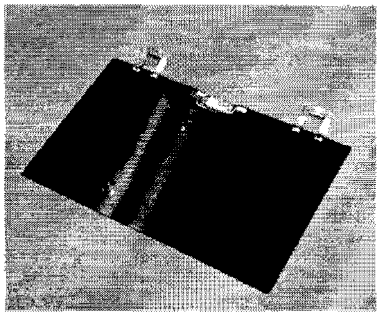
Solar Cells for Flight



AMSAT-ZL

Spectrolab 28% Triple Junction
Cells selected and nearly 30% of the cost
-which was approx. US$24,000-
was fundraised in NZ.
It was "chopped" by ITAR Jan 2005!

We will fly 22% GaAs ex Tecstar cells
(US$850 for 200 by way of Ebay!!!!)

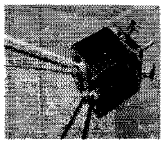


Our thanks to
Dave (G0MRF) – for spotting 'em.
Bill (N6GHZ) – for nerves of steel bidding for 'em and
Reinhold – of The Aerospace Corp for sorting out the (free) export details.

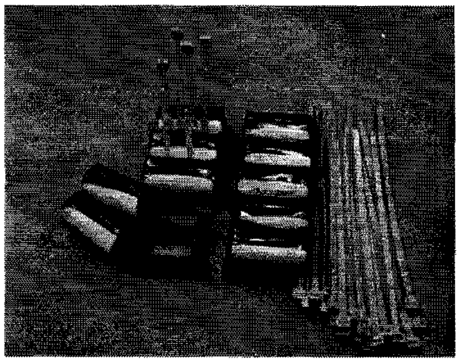
(We (still!) owe you, Guys!)

AMSAT-ZL

Flight Battery



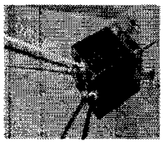
- Capacity requirement – 4.5 Ah at 12 Volts
- Flight set in course of selection
- Cells to be stripped of supplied insulation and re sleeved with space rated heatshrink. Cable ties and Delrin trays fully baked and outgassed.



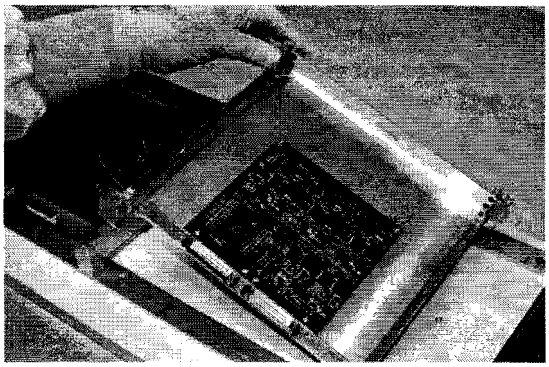
AMSAT-ZL

Battery Charge Regulator (Flight Unit.)

Complete.

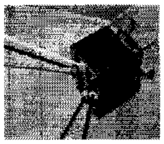


- Switching design by Hans (ZL1HB) - 89% efficiency.
- Operates autonomously.
- CPU to fine-tune default parameters.



NOVOZONE
OZONE SYSTEMS

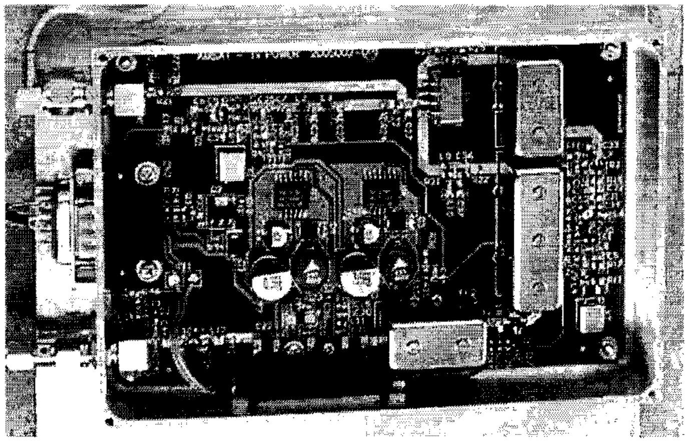
Transmitter Linear (Mk 1)



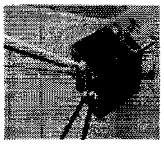
Linear – VHF
(30 kHz bandwidth)
4 Watts.

By Dr Phil Wakeman
of TRD Consultants

Complete.



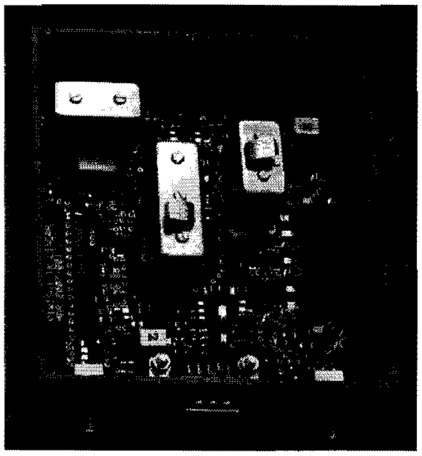
Transmitter Linear (Mk 2)



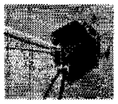
Complete.

Linear – VHF
(30 kHz bandwidth)
4 Watts.

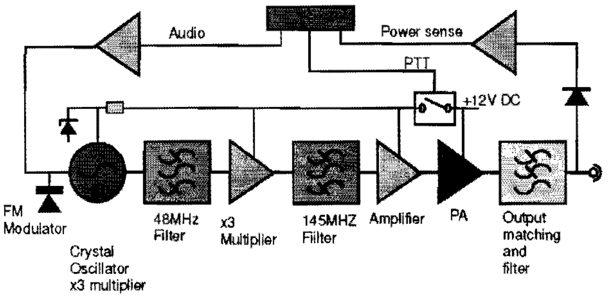
By Dr Phil Wakeman
of TRD Consultants

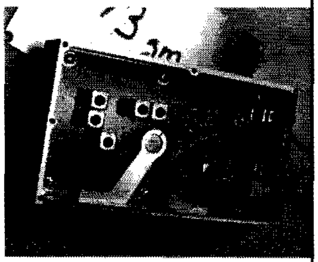


Transmitter
FM



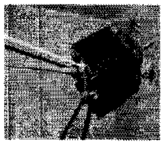
Complete





- Frequency 145.865 MHz
- Xtal frequency 16.2072 MHz
- Output power 1W
- Spurious outputs -35 dBc
- DC input 12V at 260 mA
- Modulation FM up to +/-5 kHz
- Temp range -20 +60 degrees C
- Freq stability over temp range +/-10 ppm (1.4 kHz)
- Audio input frequency DC – 15 kHz (-3 dB)

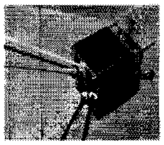
Science Package



supported by

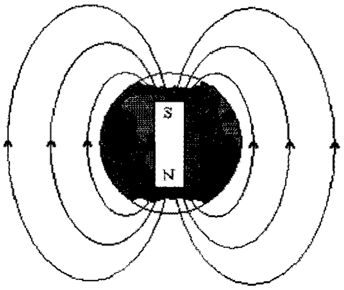
Massey University Auckland

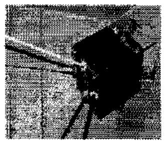
- An Attitude Determination and Control (ADAC) system using the geomagnetic field plus
- a Faraday Rotation and an ionosphere total electron content experiment.



Science Package
Attitude Control System.

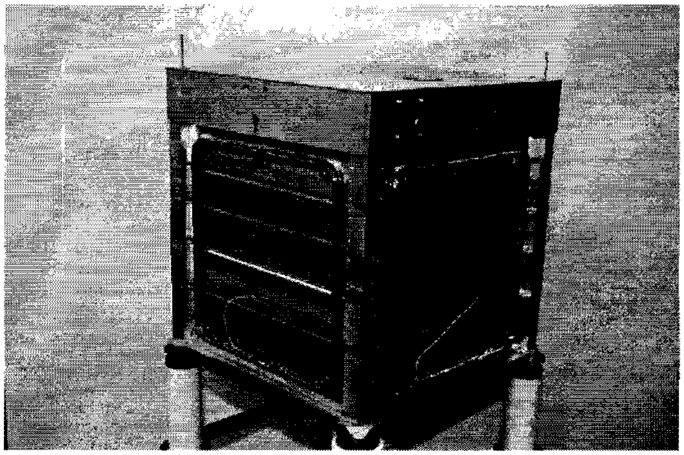
- A 3 axis 'air cored' coil system will be fitted with coils on X,Y and Z faces. These will be energized – as required – providing an active attitude control by interaction with the geomagnetic field.



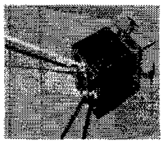


Torque Coils – X and Y

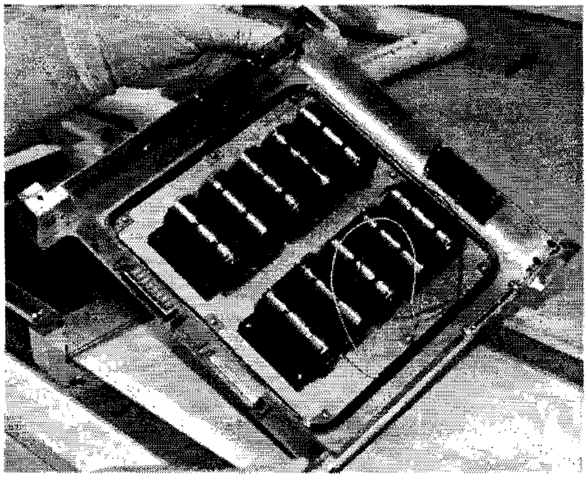
on engineering mock-up

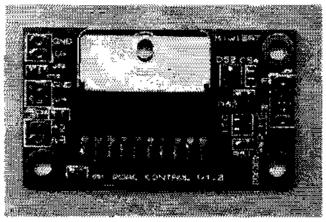


Torque Coil - Z

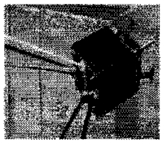


Located in Tray (No 3) with the Battery and the three (X,Y and Z) Coil Driver PCB's (below) attached to the tray walls.



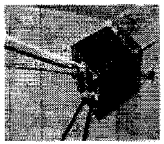


Science Package
Attitude Determination Sensors



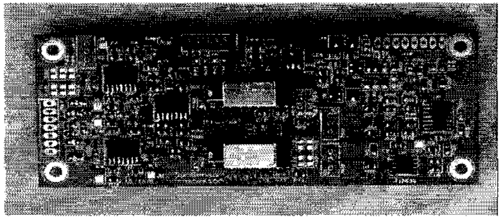
- Sun and Earth/Horizon sensors will provide reference information to 'fix' the satellites position/attitude in space.
- A 3 Axis Magnetometer will record attitude information using the Earths magnetic field.
- A (high speed/altitude) GPS receiver is to be flown for both positional and time data.
- A CMOS fixed focus camera to confirm the attitude -using a horizon image - is being flown.

Sun Sensor Processor

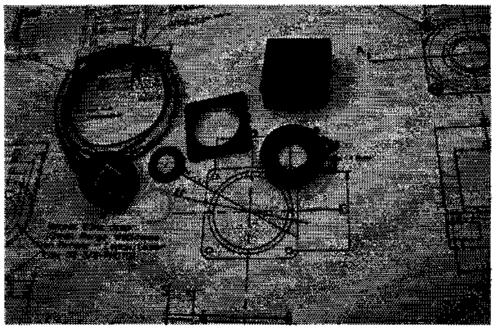


Complete

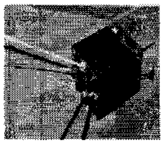
- Based on an original circuit by Alan (N1AL) for use in Phase 3D.
- PCB and assembly by Clayton (ZL3TKA)



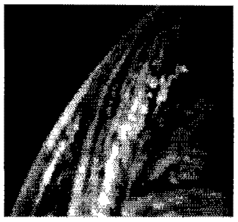
Sun Sensor Head

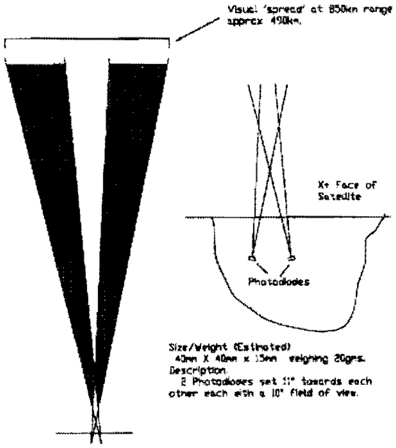


Earth/Horizon Sensors – Fields of view – I/R and Visible



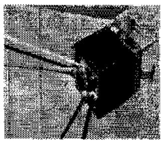
Required to establish the X/Y Axis attitude in relation to the Earth.



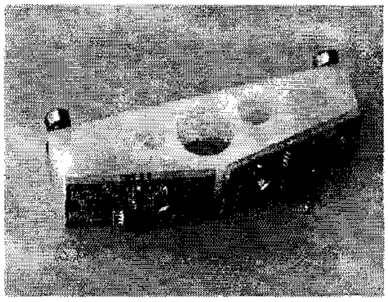


AMSAT-ZL

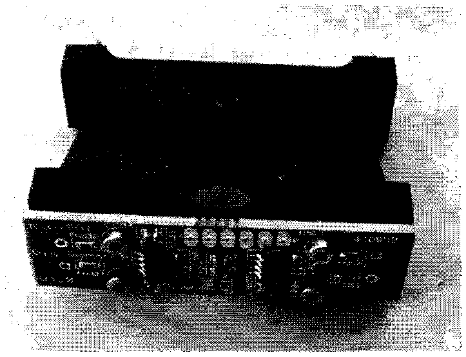
Earth / Horizon Sensors



Heads with sensors for visible and I/R wavelengths.



I/R Sensor head

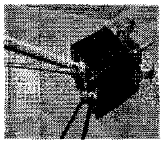


Visible light head

Mounted in the Attic wall on X+ face adjacent the camera.

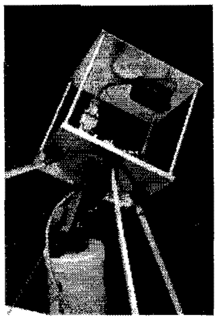
AMSAT-ZL

Magnetometer

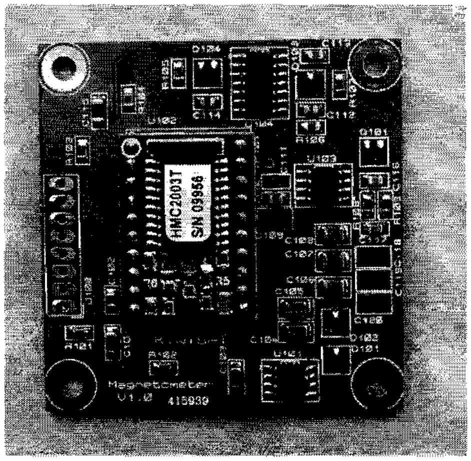


Based on the HMC2003

3 Axis unit from Honeywell

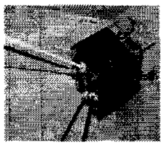


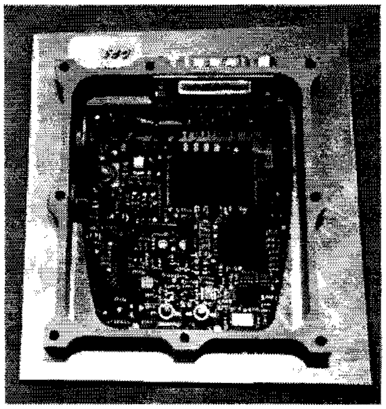
Adjacent ferrous metal affect test rig,



AMSAT-ZL

Flight GPS Rx





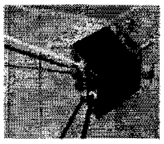
1. Availability of suitable GPS investigated. NZ $14,000! (plus ITAR license if unit from US!)
2. Out of the question!
3. Three 'old' Navman 'sport' units with duplex port access were found.
4. Enter:
   Kelvin (ZL3KB) (Navman)
   and programmer Mark (Navman)
5. Dwell a short pause.
6. A fully simulator proven High Altitude, High Speed Flight Unit and two spares ready for thermal vacuum and vibration testing.

They passed! **GPS will fly!**

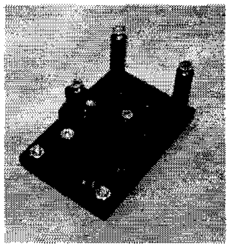
AMSAT-ZL

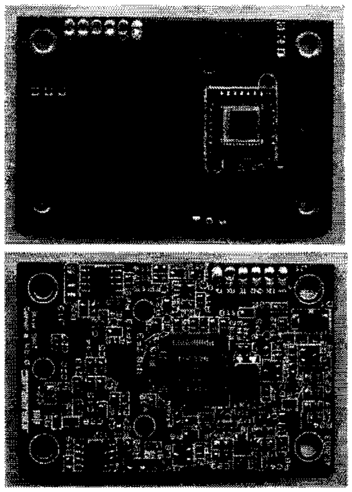
Science Package - Camera

Complete.



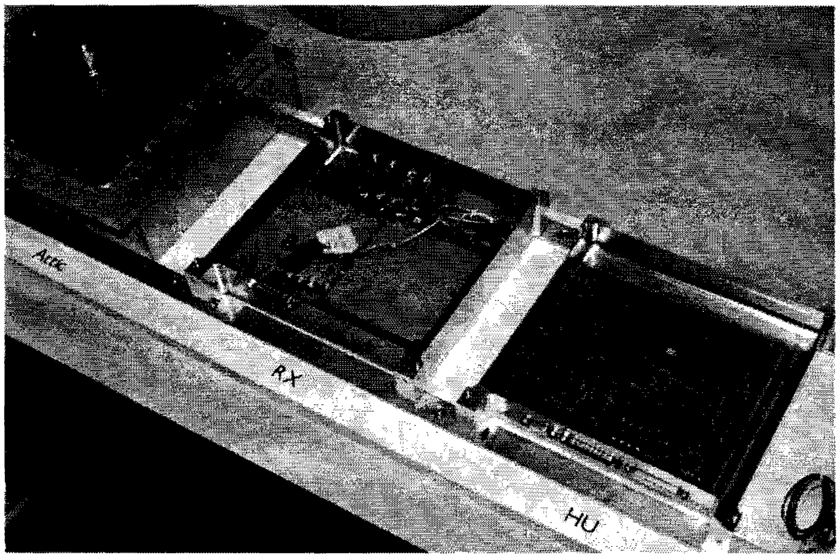
- A small colour camera module has been located via the University of Tokyo. Used on their first CubeSAT XI - IV.
- Re engineered by Clayton (ZL3TKA)
- Camera body – by Fred(ZL1BYP).



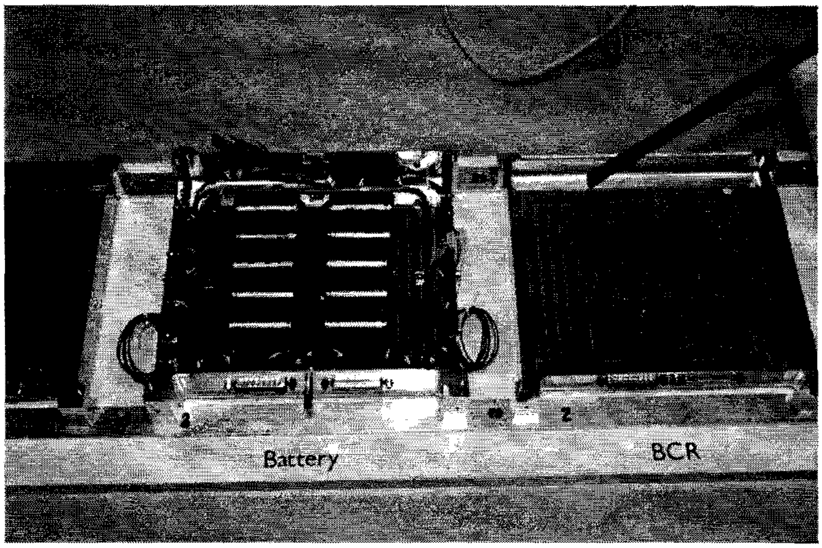


camsensor

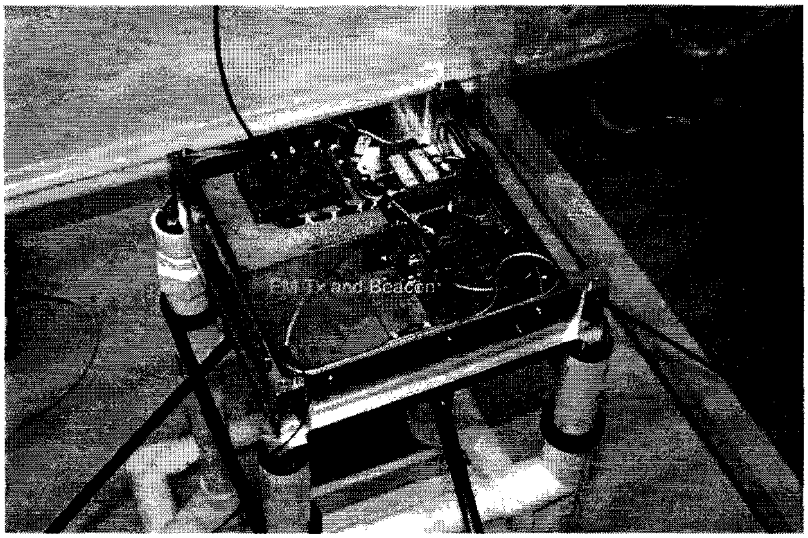
Flatsat – Tray 4,5 & Attic



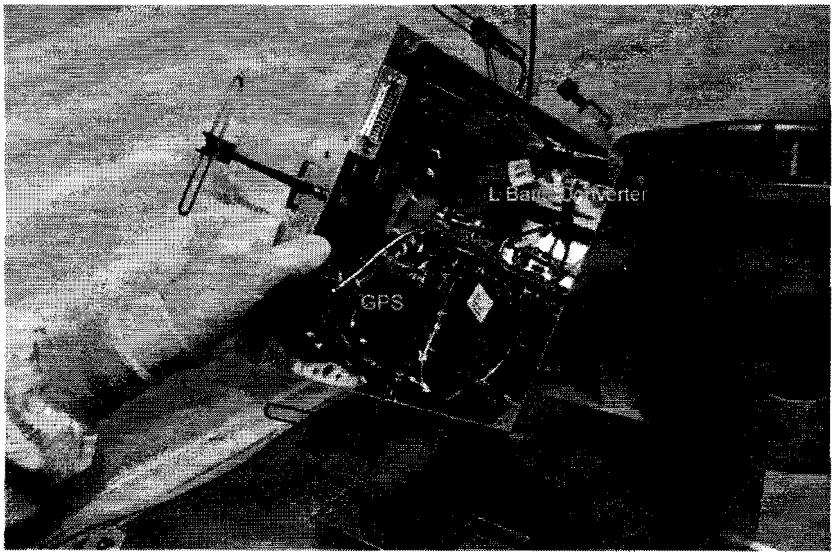
Flatsat - Trays 2 and 3



Flatsat Tray 1 (Base)



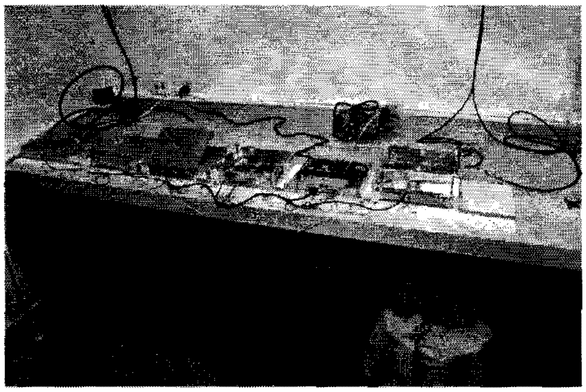
Flatsat - Attic (under)



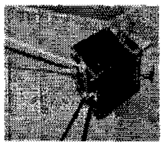
Clean Room

MasseyUniversity

- First moves towards a "flat-sat" using flight trays.(Aug 09)
- Currently the 'flatsat' communication systems are operating 24/7 using the clean room antennas. (below)



Note. Manual switch plate for IHU and mains switchmode PSU for power - using engineering trays.

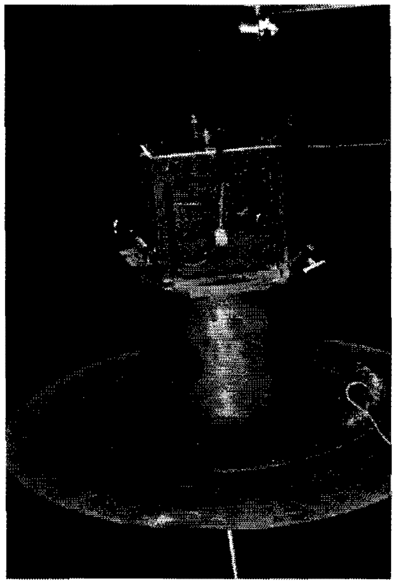


KiwiSAT – Launch proposals.

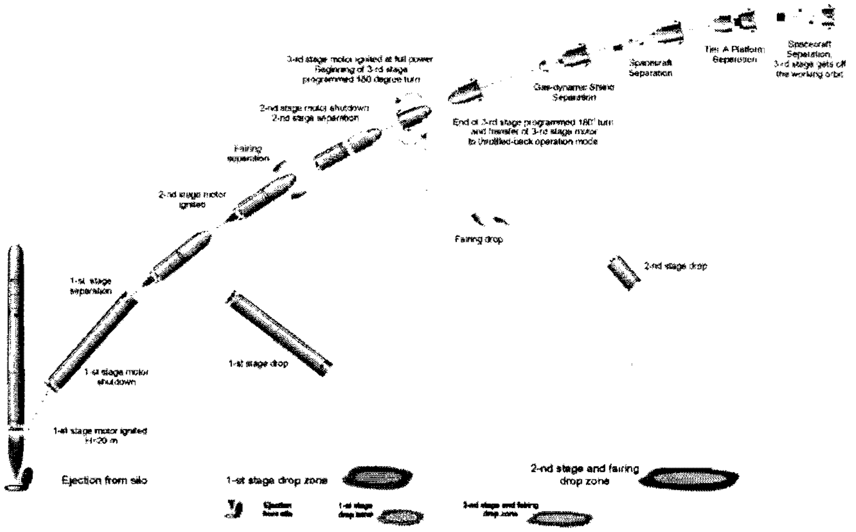
Russian DNEPR Space launch system

AMSAT-ZL

KiwiSAT on test launch adaptor undergoing vibration prelim. check

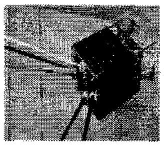


KiwiSAT Launch Sequence



Dnepr lift off from Baikonur

AMSAT-ZL Would Graciously Accept and Appreciate Your Donation To KiwiSat



Donations to help fund the various stages of KiwiSAT development can be made by mail to the Treasurer of AMSAT-ZL at:

The Treasurer, AMSAT-ZL
894 Ponga Road
RD 4 – Papakura

Auckland 2584
New Zealand

Or via PayPal on their web site at http://kiwisat.org/funding.html

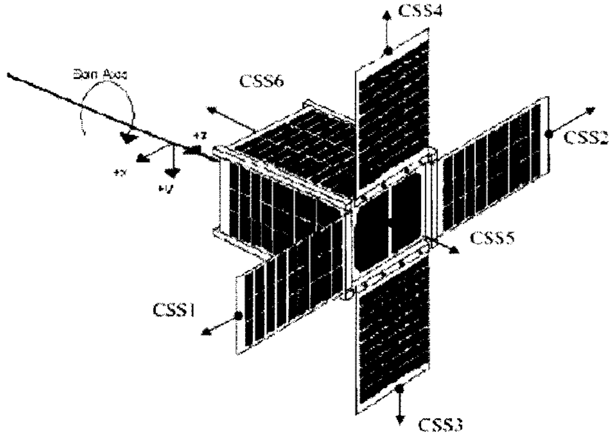
Thanks and Now For Your Questions

PSAT, A Low-cost Data Communications Satellite With Sun Pointing Attitude Control

Dr. Julie Thienel and Bob Bruninga, WB4APR

ABSTRACT: Parkinson Satellite is a CubeSat being built by students of the United States Naval Academy. The mission is to serve as a dedicated satellite transponder on 145.825 MHz for the relay of remote station information, messages and other low duty-cycle data to the internet via a global network of volunteer ground stations. A 5 Watt downlink assures good link budget to mobile, portable and sensor omni-directional antennas. Although this mission can work at lower power without deployable solar arrays, this design doubles the power budget by using deployable solar panels and then having an attitude control system to keep it sun pointing. The attitude control system consists of a three axis magnetometer, a suite of coarse sun sensors, and three orthogonal coils for magnetorquing under the control of a simple BASIC-Stamp microprocessor.

The Parkinson Satellite is named in honor of Dr. Brad Parkinson, a US Naval Academy graduate famous for his work with the GPS system architecture. Named PSAT for short, the primary payload is the dedicated satellite transponder for the relay of low duty-cycle data to the internet via a global network of volunteer ground stations as shown in figure 1. The transponder operates in the Amateur Satellite Service to encourage cooperation from students, educators and experimenters around the world.



By providing this common VHF data relay capability, there is a leveraging effect that can involve far more students in space applications. Many schools and students involved in aerospace cannot afford to design and launch their own satellites, but in many cases, a good portion of the design and development of any spacecraft system involves the ground segment as well. In this case, students and experimenters around the world can take advantage of PSAT and other 145.825 packet relay satellites to experiment with space communications.

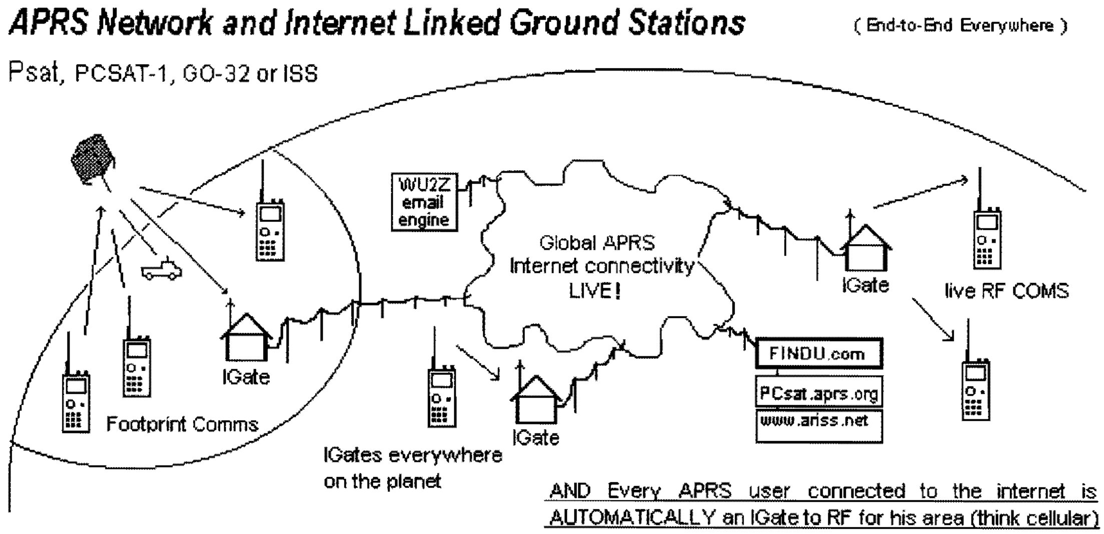


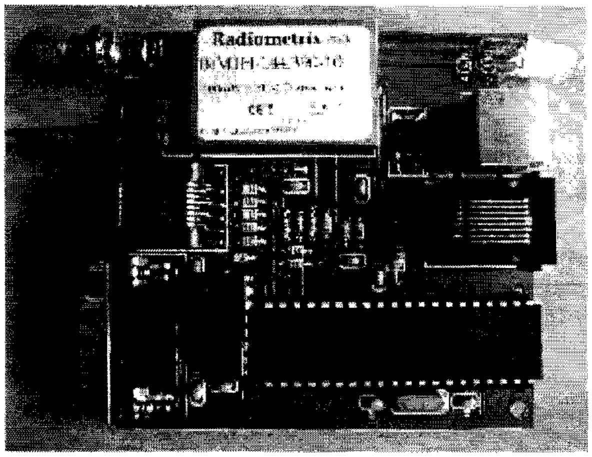
Figure 1. Automatic Packet Reporting System (APRS) Operational Scenario for PSAT Payloads

The Naval Academy has successfully operated four previous AX.25 packet radio transponders on 145.825 and has been involved in the operation of the similar transponder on the International Space Station (ISS). But each of these missions was short lived and did not provide the continuity of service needed for this world-wide satellite data relay capability. The first spacecraft, PCSAT1, was launched in 2001 and is still occasionally operational during periods of full sun. PCSAT2 was deployed for a year on the outside of the ISS and then returned to earth. The ANDE and RAFT satellites in 2006 also provided similar transponders for experimenters around the world but de-orbited in under a year due to their low deployment altitude from the Space Shuttle.

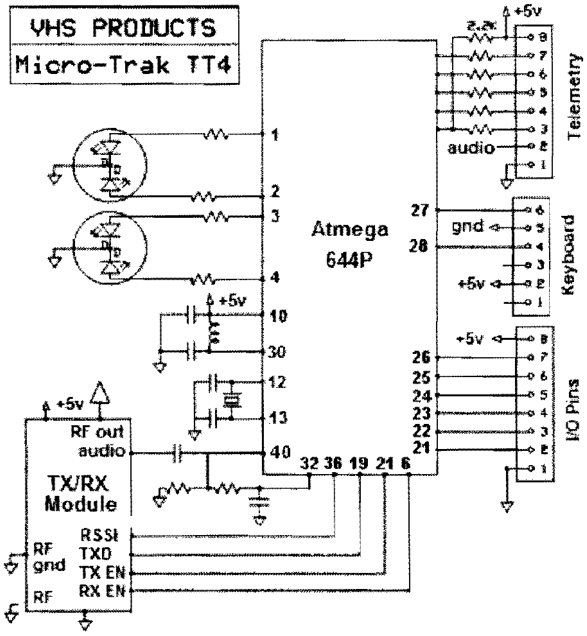
PSAT will be the first in hopefully a series of follow-on spacecraft to provide a permanent presence in space for the relay of data from ground users and experimenters. By using a commercial-off-the-shelf (COTS) communications transponder which is readily available to other schools and universities, it will hopefully lead the way for others to include this transponder mission on their spacecraft. The complete Byonics MT-TT4 AX.25 Packet Radio system consisting of transmitter, receiver and AX.25 modem fits on a 3.4 inch square card and is shown here. [Byonics.com]

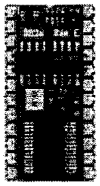
The MT-TT4 system contains the same 5 channels of analog telemetry inputs as our previous flights plus 8 lines of discrete I/O for other spacecraft functions. The MT-TT4 module can be the basis for any number of cubesat spacecraft with a variety of primary missions. Yet it can also serve as an element in the constellation of spacecraft providing continuous data relay capability for remote sensors, users and ground based data experiments.

PSAT will also be the first Naval Academy satellite to have an active attitude control system. The goal is to establish a slow spin about the spacecraft z axis and maintain a sun pointing attitude to within 40 degrees. Operating within 40 degrees of the sun will allow the generation of at least 85% of maximum sun power to support the 5 watt packet transponder. The attitude control system consists of a magnetometer, six photo cells as sun sensors, three magnetorquer coils all coded on a Parallax Basic-Stamp BS2pe processor. The challenge will be simplifying the control algorithms and codes down to fit in the small processor. [Parallax.com]



Byonics MT-TT4 AX.25 Packet Radio Transponder TX/RX on 145.825 MHz. 5W with external PA. Telemetry, Command and Control on serial and parallel ports.





Parallax Basic-Stamp Microcontroller

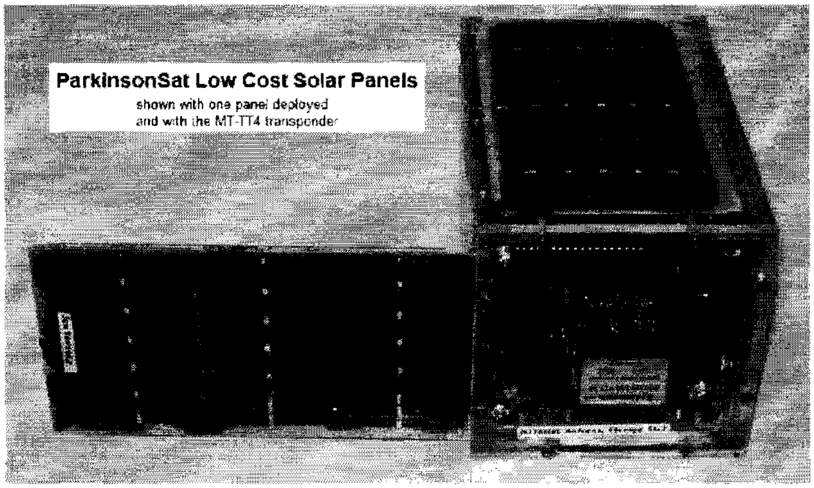
- Processor Speed: 20 MHz
- Program Execution Speed: ~4,000 PBASIC instructions/sec.
- RAM Size: 32 Bytes (6 I/O, 26 Variable)
- Scratch Pad RAM: 64 bytes
- EEPROM (Program) Size: 8 x 2 K; ~4,000 instructions
- Number of I/O Pins: 16 + 2 dedicated serial
- Current Draw @ 5 vdc: 25mA Run, 200 µA Sleep
- Source/Sink Current per I/O: 30 mA / 30 mA
- Source/Sink Current per unit: 60 mA / 60 mA per 8 I/O pins

Key Specifications:

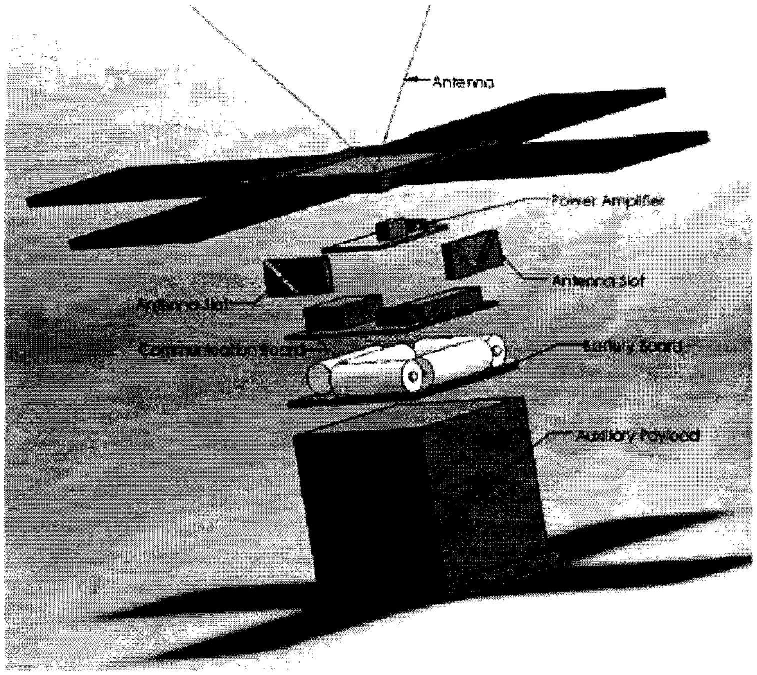
- Power Requirements: 5.5 to 12 VDC (Vin), or 5 VDC (Vdd)
- Communication: Serial (9600 baud for programming)
- Dimensions: 1.20 x 0.63 x 0.15 in (30.0 x 16.0 x 3.81 mm)
- Operating Temperature: -40 to +185 °F (-40 to +85 °C)

Spacecraft Overview:

PSAT is built to the CubeSat standards. For redundancy, there are two identical spacecraft, each measuring *10 x 10 x 8* cm with a mass of 2.2 kg to fill a single P-Pod launcher. PSAT employs four deployable solar panel-pedals. For low cost, the solar panels are inexpensive commercial off-the-shelf (COTS) single crystalline cells that cost about $30 each instead of $6,000 for space grade triple junction cells. The performance trade-off is 2-to-1 for a cost savings of 50-to-1.


ParkinsonSat Low Cost Solar Panels
shown with one panel deployed
and with the MT-TT4 transponder

Each of the deployed solar pedals as shown here has solar panels on both the front and back surfaces. Solar panels are also placed on the four sides of the spacecraft, for a total of 12 panels. Each spacecraft provides 5 watts of average power when the top four solar panels are within 40 degrees of the sun. Prior to sun acquisition, the other 8 panels will provide an average of 2.5 watts of power. Also depicted in the figure on page 1 is the spacecraft body coordinate frame, the spin axis, and the six photo detectors sun sensors. Photo resistive cells are used because the CPU can directly read the resistance and convert this to a value proportional to the cosine of the angle between the Sun and the normal to the sensor face. The value is normalized with the maximum observed value to produce readings between 0 and 1 for corresponding angles between 0 and 90 degrees. The observed sun vector is formed by subtracting the readings from photo detectors facing in opposite directions on each of the three body axes. Since there will be earth reflected sunlight too, the processor will have to have additional threshold logic to mitigate these effects.



The exploded view to the right shows the spacecraft components including the 56 cm^3 available for an additional payload. The batteries are Nickel Cadmium and provide up to 1700 mA-hrs of capacity. The attitude control system is currently budgeted to receive up to 300 mA of current. The additional payload is relegated 0.5 kg of the total mass and 2 watts of power. With placement on the bottom of the satellite, the payload also has access to the space environment.

Three orthogonal coils are used to torque the spacecraft against the Earth's magnetic field to the desired attitude. These coils will be operated at a 50 percent duty cycle so that the magnetometer can read the Earth's magnetic field between pulses. The magnetometer will be sampled every other second and the coils will be energized for up to one second. The maximum magnetic dipole impulse under these conditions averages to 0.05 amp-m^2.

Attitude Control Design:

PSAT will have three control modes. The first is often referred to as a "modified Bdot" control that will pulse the coils as needed to reduce the spin rate about each axis and at the same time establish a 6 deg/sec spin rate about the z axis. The second mode is a coarse sun acquisition mode, which will slowly precess the spin axis towards the sun and maintain rate control on the other two axes. The third control mode maintains the spin axis rate and provides additional nutation and precession control. An overview of the control algorithms is presented here with more thorough coverage in references 4 and 5. The specific adaptation to the Psat bus is given in reference 6.

A. Modified Bdot Control

The magnetic rate damping control law is used to establish a desired spin rate about the +z body axis and remove rates in the other two axes. The magnetic field is sensed by the magnetometer and the required torque field is computed numerically by differencing consecutive magnetometer readings, separated by the two second control cycle. The modified Bdot control law will be applied for several orbits until the rotation rates (estimated on the ground) have converged to approximately the desired rate on the +z axis and the orbital rate on the x and y axes.

B. Sun Pointing Control

Two control modes are used to precess the +z axis towards the sun and maintain sun pointing. As described in references 4 and 5, the first mode drives the +z coil such that the instantaneous angle between the sun vector and the torque vector is always less than 90 degrees. The magnetic dipole from the modified Bdot control, is maintained for rate control. The second sun pointing mode controls precession and nutation and maintains the spin rate about the z axis.

The spin control logic is a simple proportional control law. The magnetic dipole in the x and y body axes is chosen such that it is perpendicular to the magnetic field vector in the x-y plane. The z magnetic dipole provides the precession and nutation control with a PD control law designed to drive the x and y sun vector components to zero. The z magnetic dipole component is derived by minimizing the error between the desired torque and the actual torque. A de-weighter is applied to the process based on the angle between the magnetic field and sun vectors in the x-y body plane. The weight is selected linearly between 0 and 1 for angles ranging between 0/180 degrees and 90 degrees, respectively [4,5]..

When the spacecraft rotation rate converges, the control mode will be switched from the modified Bdot method to the first precession control mode outlined above. The coarse precession control will be applied as long as the estimated angle between the measured sun vector and the +z body axis is greater than 10 degrees. Once the observed sun angle is less than 10 degrees, no control is applied. As the sun angle starts to increase beyond 20 degrees, the control switches to the second precession and nutation control logic until the estimated sun angle exceeds 60 degrees. At that point control reverts to the first sun control mode and the process repeats.

C. Control Implementation

The full control cycle is 2 seconds. During the first second the magnetometer and sun sensors are sampled. The desired control law is then applied for one second. The control algorithms above are used to determine the desired magnetic dipole. PSAT is limited to 0.1 second pulses of +/- 0.1 amp*m^2 applied for up to 1 second, resulting in a maximum magnetic impulse (magnitude) of 0.1 amp-m^2-sec over the two second control cycle. The calculated dipole will be used to determine the number of 0.1 second pulses.

The sun sensor data is used to estimate the spin rate by calculating the time period between two successive zero crossings of the x (or y) component of the measured sun vector. A running average of the estimated spin rate is maintained when the spacecraft is not in eclipse, the running average is used in the sun pointing control mode. During eclipse, the modified Bdot control maintains the desired rotation rate.

Simulation

The proposed attitude control approach for PSAT is tested with a simulation developed in Matlab. The orbit is circular with an altitude of 600 km and inclination of 56 degrees. The simulation is run for 18 hours. The onboard processing will convert the magnetometer and sun sensor observations using 8 bit precision. In order to simulate the data, measurements are first generated using models of the Earth's magnetic field and sun location.

The true magnetic field is computed with a 10th order International Geomagnetic Reference Field. The true sun vector is extracted from a solar ephemeris. The true magnetic field and Sun vectors are then transformed into the body frame with the current true attitude matrix. The transformed magnetic and sun vectors are corrupted in order to simulate the expected truncation and quantization errors expected on orbit.

A constant bias selected at the start of the simulation from a normal distribution with zero mean and standard deviation of 300 nT is applied to the magnetometer data. An additional disturbance of white noise with zero mean and a standard deviation of 200 nT is also added. The simulation includes a misalignment of the magnetometer frame from the body frame. The resulting vector components are converted to an 8 bit word and are then converted back to a 3 component vector for use in the simulation.

The onboard processing will also convert the sun sensor measurements using 8 bits. However, for the purposes of the simulation, the sun vector is corrupted by converting each of the six photo detector readings into a 3 bit word, and then back into the components of the observed sun vector. The resulting vector is normalized to provide a unit vector. The 3 bit digitization results in an angular error between the true and observed sun vector of up to 7 degrees, simulating the potential error in-flight. Gravity gradient torque is included in the truth model as a disturbance torque.

The modified Bdot control is applied for just under 3 hours, at which point the precession control is initiated. As described earlier, the precession control is maintained until the estimated angle between the z axis and the sun is less than 10 degrees at which point no control is applied. If the estimated sun angle exceeds 20 degrees, the second sun control algorithm is implemented until the error exceeds 60 degrees and the control switches back to the first precession control logic.

As detailed in reference [6] the simulation was repeated 100 times with different initial conditions and random errors in each test. The initial orientation is random, and the initial angular velocity is selected from a normal distribution with zero mean and standard deviation of 8 deg/sec to simulate the potential tip-off rates from the P-POD launcher.

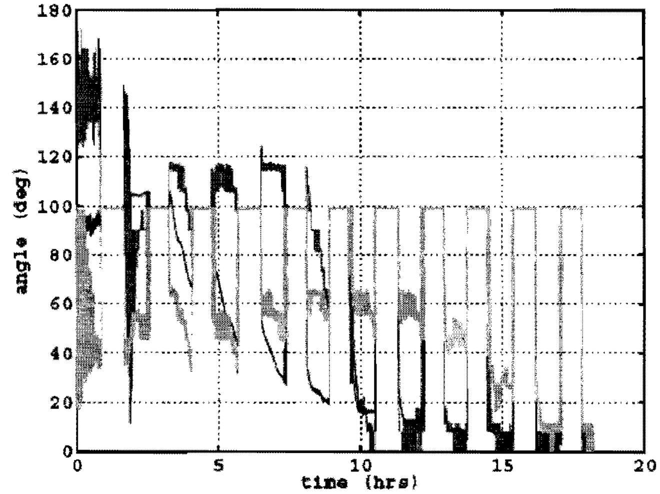


Figure 5. Estimated Sun Angle for 100 Test Cases. Blue = Average, Red = Maximum Tip-Off Rate. Green = Largest Final Sun Angle

Figure 5 shows the actual angle between the spacecraft z axis and the sun vector. During eclipse the values are forced to "99" so they are clearly visible. The blue line is a plot of the average angle for each of the 100 cases, the red line represents the case with the highest initial tip-ff rate, and the green line represents the case with the largest final sun angle. In all 100 cases the sun angle converged to less than 40 degrees in under 15 hours , meeting the power requirement. The approximate 7 degree error resulting from the 3 bit digitization of the six photo detectors is evident in the red and green data.

Finally, figure 6 shows the true angular velocity components. The z axis angular velocity is within approximately 0.25 deg/sec of the desired 6 deg/sec spin rate.

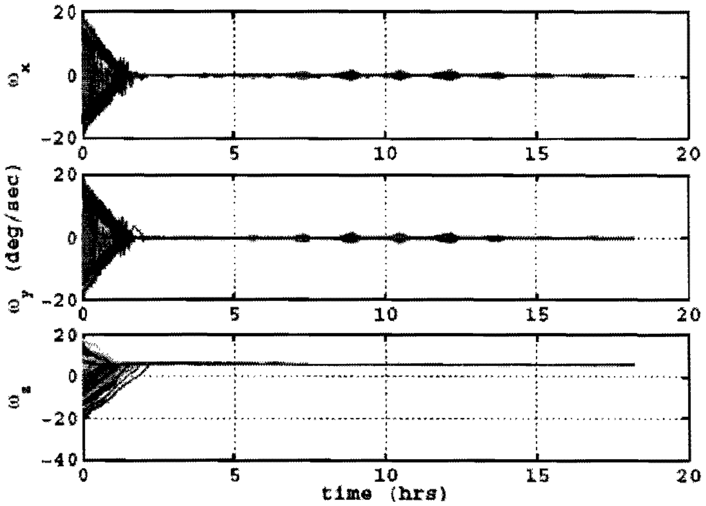


Figure 6. True Angular Velocity for 100 Test Cases

Conclusion

The low cost Cubesat ParkinsonSat design represents a significant evolution in the AX.25 packet radio relay transponder. Since the first PCSAT in 2001, the comms package has been reduced in size by 15 or so to 1, and the power has been doubled while still using COTS solar panels with a 50-to-1 cost savings. Having been reduced to less than the size of a cubesat, this transponder also provides all command and control as well as telemetry functions making it an ideal platform basis for other cubesat projects independent of their other primary missions. Multiple such cubesats can contribute to the overall APRS data relay mission for all students worldwide and provide continuity and near real-time connectivity via the global internet linked volunteer ground stations.

In Psat, the power budget has been doubled using deployable solar panels and a sun facing attitude control system. The desired spin rate is 6 deg/sec about the z body axis which is to be within 40 degrees of the sun for full power generation. The cubesat is equipped with a magnetometer, coarse sun sensor suite, and orthogonal magnetorquing coils. The +Z axis will be maintained sun-facing using three control modes which rely only on the available sensor data.

A simulation with Matlab using 100 test cases was conducted, each with a random initial attitude and random angular velocity plus additional random errors added to the sensor data. Gravity gradient torque was included in the truth model as a disturbance torque. In all 100 cases the sun pointing angle was reduced to less than 40 degrees and the spin rate was maintained within +/- 0.25 deg/sec of the desired spin rate.

During the academic year 2009/2010 the final structural design will be completed and additional testing will be conducted in readiness for flight. At this time, ParkinsonSat has not yet manifested, but hopes to take advantage of any short-fuse opportunities that may arise. See: www.aprs.org/psat.html [7]

References:

[1] The Aerospace Corporation, "GPS Architect", Bradford W. Parkinson, website, www.aero.org/publications/crosslink/summer2002/profile.html.
[2] Aerospace Engineering Dept, California Polytechnic State University, www.cubesat.org.
[3] Pumpkin, I., "CubeSat Kit," website, www.cubesatkit.com.
[4] Creamer, G., "The Hessi Magnetic Attitude Control System," *AIAA Guidance, Navigation, and Control Conference*, Portland, Oregon, August 1999.
[5] Li, G., Fernandes, S., and Creamer, G., \Design and On-Orbit Performance of the RHESSI Magnetic Attitude Control System," *AAS/AIAA Astrodynamics Specialist Conference*, Big Sky, Montana, Aug 2003.
[6] J. Thienel, R. Bruninga, R. Stevens, C. Ridge, C. Healy, *The Magnetic Attitude Control System for the Parkinson Satellite (Psat) A US Naval Academy Designed Spacecraft,* AIAA Guidance and Control Conference, Chicago Illinois, 10-13August 2009.
[7] www.aprs.org/psat.html

Using a Software Defined Radio with Integrated VHF/UHF for Satellite Operations

Stephen Hicks - N5AC, Greg Jurrens - WDØACD, and Ken Simmons - K5UHF

INTRODUCTION

A 144MHz-only transverter was part of the planning for the FlexRadio FLEX-5000 from the beginning. Even before all the details of the transverter were ironed out, a BNC connector for the 144MHz transverter had been placed on the back of the rig and space was made for an additional board in the radio itself. In the time between when the FLEX-5000 was released and work on the transverter itself started, conversations with various VHF groups and many AMSAT members occurred causing FlexRadio to decide that a combination 2m and 440Mhz V/U module makes more sense. It would provide a second band as well as allow for multi-mode satellite communications that often requires cross-band duplex.

Late this year, FlexRadio Systems will release the FlexRadio V/U module for the FLEX-5000, but we wanted to provide the AMSAT community with a sneak peak at the V/U module and the engineering behind it. One of us (Ken) is the principal designer of the module, both from an electrical and mechanical standpoint.

The architecture of the FLEX-5000 makes it uniquely qualified to enable easier VHF/UHF operations through an integrated V/U module. To understand the advantage, we need to look at some "conventional" amateur radios. While a select few radios come with an integrated VHF/UHF transverter or transceiver, generally only radios designed for satellite operation allow the simultaneous operation of multiple all-band VHF/UHF transceivers in a single package. Unlike most HF transceivers, however, the FLEX-5000 is designed as a full-duplex radio—it can transmit and receive at the same time even without a second receiver module (RX2). With a second receiver module, an additional frequency can also be received. This affords a unique opportunity to leverage this capability in the VHF/UHF arena, especially for satellite operation.

FLEX-5000 V/U BASICS

The V/U module for the FLEX-5000 functions like most transverters. It has an integrated local oscillator (LO), but in this case it is synchronously derived from the internal 500MHz oscillator in the FLEX-5000, which can be phase-locked to a 10MHz reference. Depending on the band, the LO is produced directly from an on-board Direct Digital Synthesizer (DDS) or by mixing two outputs from the DDS.

The frequency for the LO was selected to place a 144MHz signal in the receiver at 19MHz (LO frequency is 125MHz) and a 430MHz signal at 30MHz (LO frequency is 400MHz). PowerSDR™, the software portion of the FLEX-5000, will recognize the internal V/U and will make the appropriate adjustments in the frequency readout so that the proper 144/432 MHz frequency is displayed automatically.

There are a series of gain stages and filters that are used to clean up and amplify the LO as well as the V/U module output. A block diagram of the V/U module is presented in FIGURE 1.

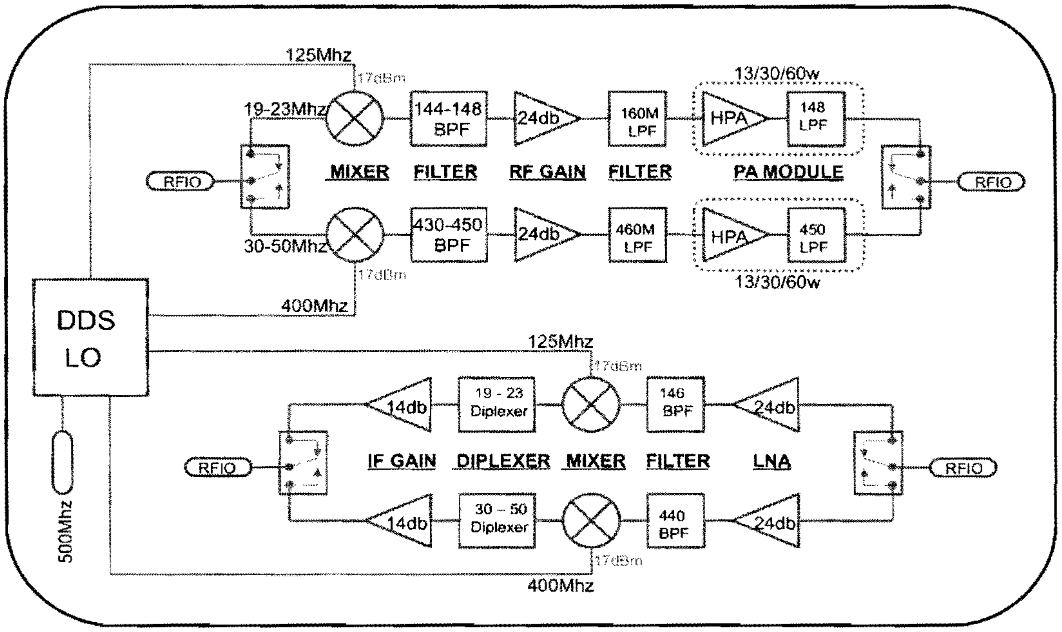


FIGURE 1 – FLEX-5000 V/U MODULE BLOCK DIAGRAM

The LNA used in the V/U module, an RFMD SPF-5122Z, has a noise figure of 0.5dB from 0.1GHz to 4GHz. The resulting system noise figure on both bands is a very respectable <2dB.

Since the V/U module is integrated in the radio, the hassles generally attributed to external transverters such as setting drive levels, IF gain, and frequency offset in radios have been eliminated.

DETAILED V/U MODULE ARCHITECTURE

As mentioned previously, the FlexRadio V/U module uses the internal 500MHz reference in the FLEX-5000 as it's reference source. This source may also be phase-locked to an external 10MHz reference for additional frequency accuracy. An Analog Devices direct digital synthesizer (DDS) is used to create the 144MHz LO (125MHz) and to create a 100MHz LO which is mixed with 500MHz in an ADE-1HW from mini-circuits to yield a 400MHz LO. These two LO's are then split to provide LO signals for both the upconverter and downconverter on each band.

Another key feature of the V/U module is replaceable output modules. As can be seen in the mechanical diagram of Figure 2 below, both the 144MHz and 432MHz module are replaceable. This allows for the possibility of different output power levels (two are anticipated today) and easy repair. As shown in Figure 2, the modules rest on a common heatsink and two fans below the heatsink pull in air and direct is along the length of the heatsink for cooling.

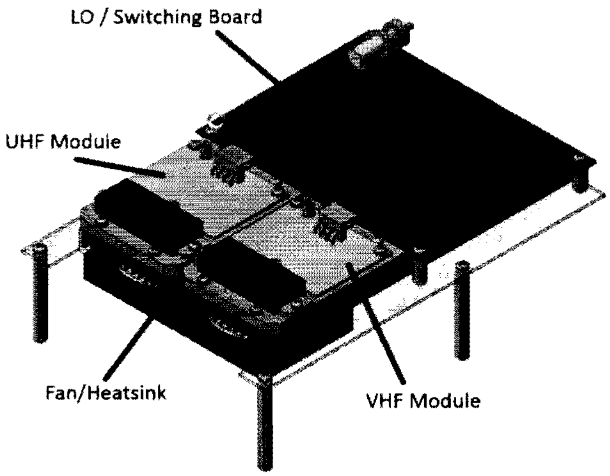


FIGURE 2 – V/U Module CAD Drawing

The entire module sits atop the HF PA and optional tuner in the FLEX-5000 on a set of stand-offs. Figure 3 below shows the V/U module inside of the FLEX-5000A with some pieces either transparent or removed for illustration.

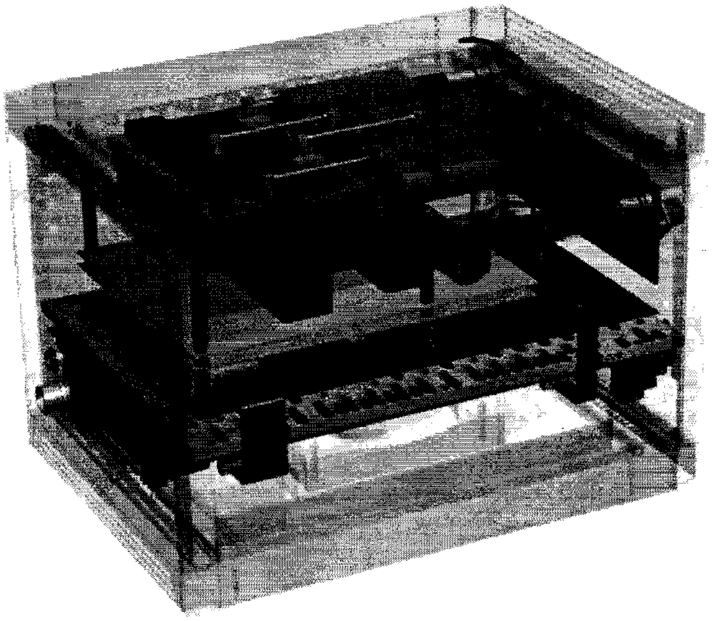


FIGURE 3 – FLEX-5000A with Integrated V/U Module CAD Drawing

INTERFACE CHALLENGES

Initially when the FLEX-5000 was first designed, only a 144MHz transverter was anticipated and so three BNC connecters were placed on the back of the radio: A transverter IN/OUT for an external transverter and a single common 144MHz transverter TX/RX port. With the decision to go to an integrated V/U module, the management of these connectors has become a bit more complex. The I/O connections on the FLEX-5000 are managed on the RFIO board. A block diagram is presented in FIGURE 4.

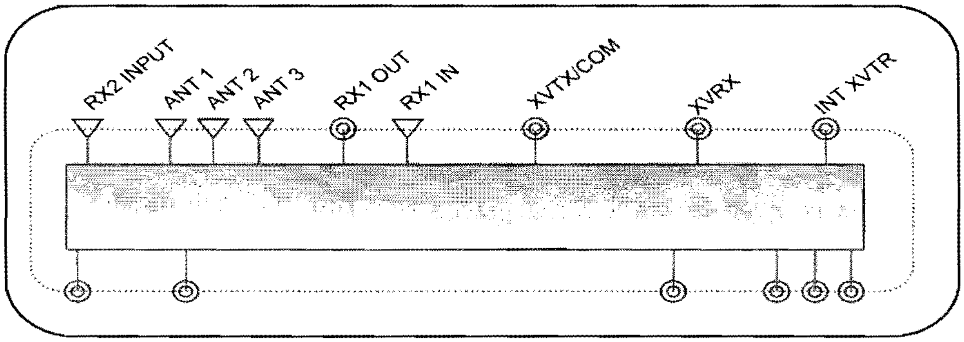


FIGURE 4 – FLEX-5000 RFIO Block Diagram

Figure 5 shows the back of the FLEX-5000 including these BNCs.

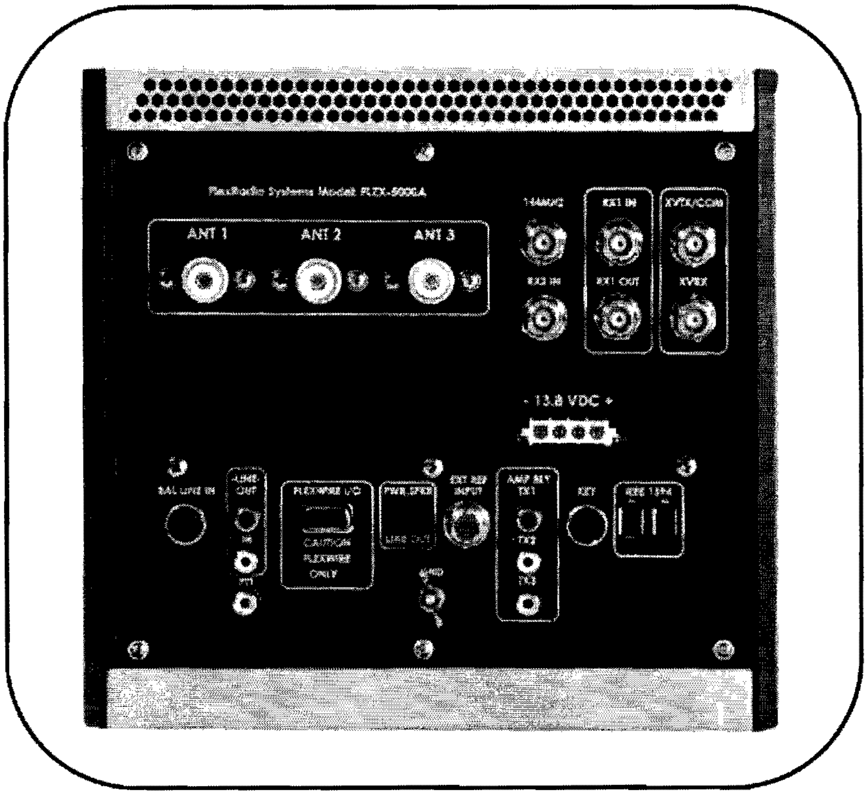


FIGURE 5 – FLEX-5000 Rear Panel

BNCs are just fine for VHF or UHF so it's simply a matter of routing the proper band to the XVTR COM BNC. For "FMer" or single band operation, this works just fine. FIGURE 6 shows a typical "DUAL BAND" antenna connection.

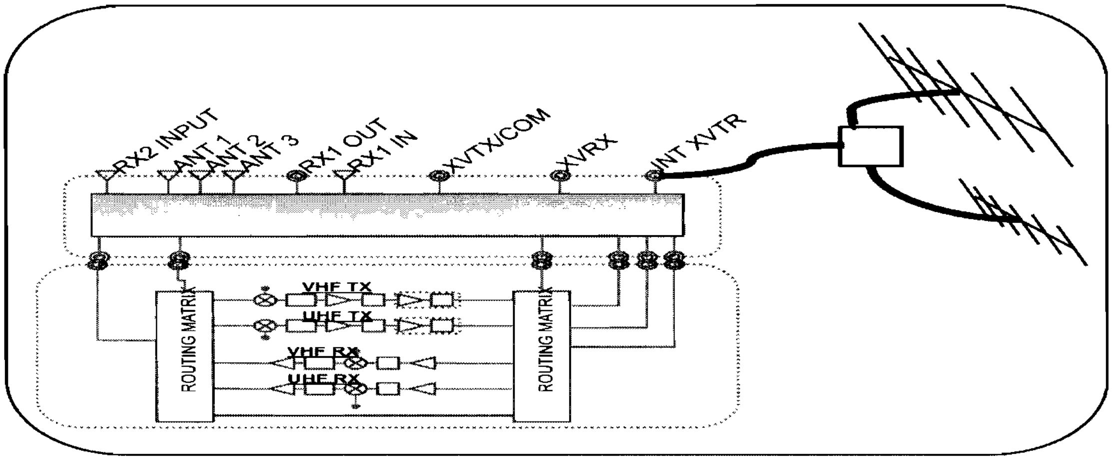


FIGURE 6 – FLEX-5000 V/U Module showing Simple Antenna Connection

For more sophisticated satellite operation, a single high power V/U connection could prove problematic. To address this, an interesting multiplexing/routing scheme was developed to work in concert with the existing RFIO board. An optional external antenna interface module will be available that provides separate "N" connectors for both VHF and UHF. Additional features such as the ability to add a switchable inline attenuator for microwave transverters and the much-beloved UCB ports are added. Figure 7 shows this expanded configuration.

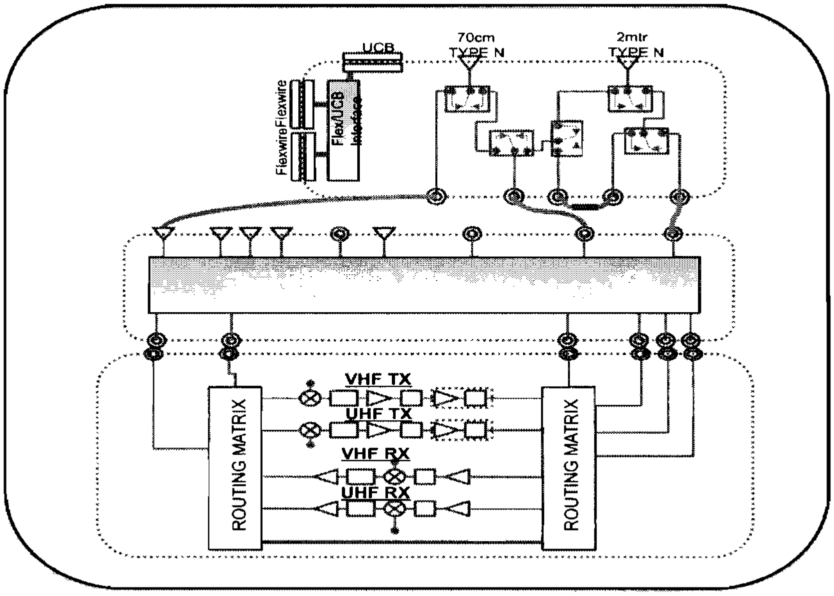


FIGURE 7 – Advanced RF Routing Using the V/U Antenna Interface Module

POWER OPTIONS

Considerable thought went into the availability of different power levels. For most, a 30W 144/432 version will provide a solid 30 watts on both bands. This version is user installable and the DC power for the PA modules is obtained from an accessible internal connector. This version can be easily placed in an existing FLEX-5000 on-site with basic tools.

Customer feedback on the V/U module was that 30W is not sufficient as a driver for an 8877 amplifier with 13dB of gain. A 60W module capable of providing at least 60W is required to achieve the full 1500W output of the amplifier. To this end, a 60W version of the V/U module will also be made available. One issue, however, is where to obtain the required DC current for the modules. The only place to get the required current is under the PA board. Further, the only way to get at this point is to disassemble the radio, remove solder from a location on the board where a power connector could go, add the connector, and route it to the V/U module. So in the cases where the full 60W is desired, the radio will need to be returned to FlexRadio where the power connection and installation of the V/U module will be done by a FlexRadio technician. For those that need it, this modification will provide the necessary power to drive the larger amplifiers.

SUPPORTED MODES AND BENEFITS

Like most transverters, the capabilities of the IF radio being used set the mode functionality for the V/U module. The FLEX-5000 currently supports SSB, CW, FM, FMN, AM, SAM as well as a number of digital modes including JTxx and other WSJT modes through software. A key difference in using the FLEX-5000 for these modes is that even with external control and interface software, no sound card is required. What? Did you say a sound card mode without a sound card? How is that possible? Let us explain:

FlexRadios are basically direct conversion receivers. The RF is converted directly to digital audio using FlexRadio's Quadrature Sampling Decoder - QSD. The resulting baseband samples are sent to the PC via a FireWire (5000/3000) or USB (1500) cable. At this point these signals already exist in the radio as digital information so no conversion from analog to digital is required. We do, however, have to "fake out" programs like SATPC32, WSJT, and MixW to think they are talking to a sound card. To do this without wires, we use a software "virtual audio cable" or VAC. VAC takes the digital samples from the radio and presents them to other programs as if they were samples from a sound card. Since the information is digital through this software, there is no additional level setting or loss of signal. For the transmitted signal, the opposite occurs: A virtual line-in is presented by VAC to the digital mode software that believes it is sending the signal to a sound card. The samples are just handed to PowerSDR™, which then inserts them in the correct place in the passband and then hands off the samples to the radio for transmission.

In addition to the virtual audio cables, it's also a simple matter of adding virtual serial COM port programs to easily integrate radio control. There are several programs available for download. Com0com and VCom are 2 popular ones. "CAT" type commands can then be passed between PowerSDR™ and programs like SATPC32 without consuming physical COM ports. PowerSDR™ supports several CAT formats for easy interface. FIGURE 8 shows an example of PowerSDR™ being controlled by

SATPC32, tracking TX and RX Doppler in the 2 active VFOs. The final presentation is a great combination of PowerSDR™ with it's panadapter waterfall modes showing all the active signals and beacons on the "bird" plus familiar satellite tracking and rotor control. This is a perfect time to consider a dual monitor configuration so you can "SEE" everything going on at once.

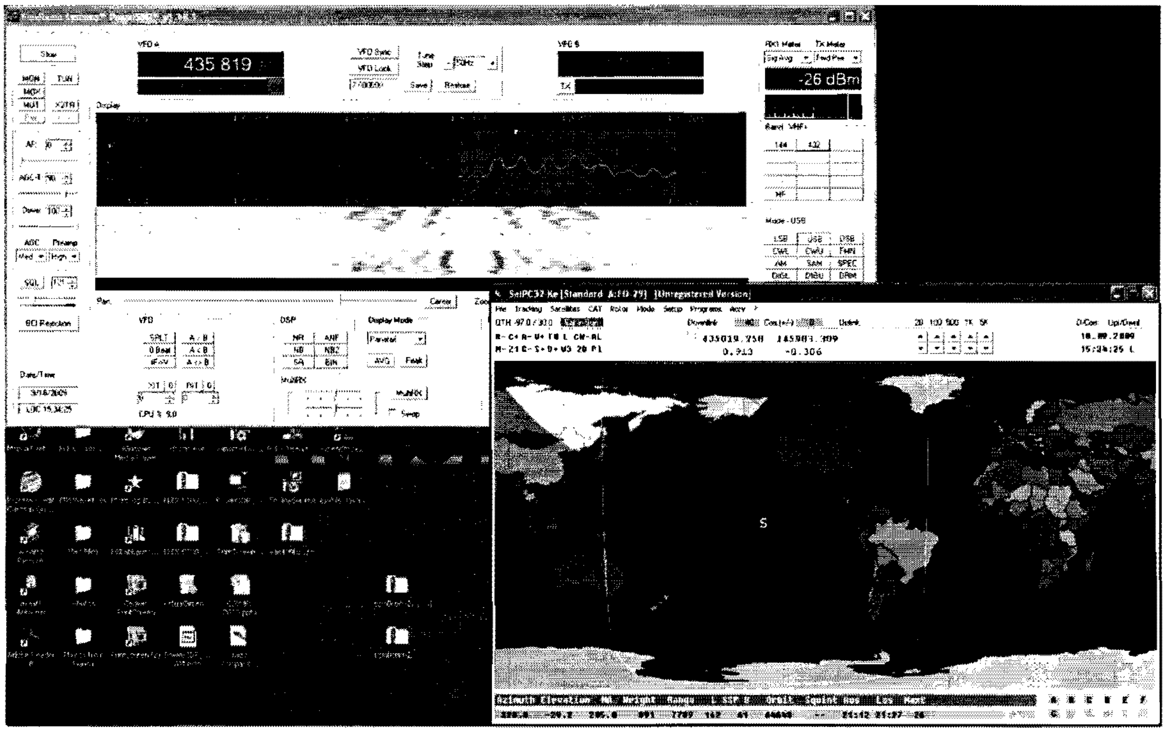


FIGURE 8: Integrated Control of PowerSDR™ by SATPC32 using Com0Com Virtual COM Ports

Finally, from an operational standpoint, the FLEX-5000 is fundamentally a full-duplex radio. It can transmit on one HF frequency and listen on another even without the RX2 second receiver. Satellite modes are easily accomplished including the VHF/HF modes. With just a "bare" FLEX-5000 plus the V/U module, cross-band satellite operation on 144/432 is possible. Listening to any two of the three VHF bands in the radio (50, 144, 432 MHz) will also be possible as a result.

SUMMARY

The FlexRadio FLEX-5000 V/U module is not just a transverter that can be connected inside of the FLEX-5000. It is also highly integrated in many other aspects such as frequency readout, power level settings and direct connection via software to third-party satellite and digital mode applications. The V/U module adds a new level of capability to the FLEX-5000 for satellite and weak signal VHF/UHF operators.

AMSAT Eagle – Building a Mission for Education

In order to be able to afford the launch of AMSAT-Eagle we need to excite potential funding sources. This paper will examine how Eagle could drive the exciting potential for the future of Amateur Radio in space and education. A geostationary Amateur Radio satellite would give educators an out of this world opportunity to bring space communications into the classroom. Funding by an organization supporting an educational mission would also enable the Amateur Radio communications capability sought by AMSAT members.

JoAnne Maenpaa, K9JKM (k9jkm@amsat.org)

Introduction

Traditional Amateur Radio has found an application in the classroom by allowing the teacher to introduce topics in science, mathematics, and social studies with fun and interesting educational methods. One of the most visible applications of Amateur Radio in education is the highly successful Amateur Radio on the International Space Station Project (ARISS) which connects students with the astronauts via Amateur Radio.

The second path of education in Amateur Radio involves our own community of radio operators. We continually pursue self-learning in topics such as electronic theory, communications methods, technology, and radio law to earn our Amateur Radio license and to improve our station and operating capabilities. Being a curious group of people, most hams have embarked on a journey of self-directed lifetime learning.

The proposed Geo-Eagle satellite offers Radio Amateurs the opportunity to teach and learn on an ongoing on-demand basis with our own "Learning Channel in Space".

The AMSAT Eagle Advanced Communications Package

AMSAT-NA's engineering team has proposed to take a dual approach to the mission concept of the Phase 3 Eagle Satellite development project. The original approach of a high-earth orbit (HEO) mission has been expanded to also include the possibility of a ride-sharing mission attached to a geostationary communications satellite. The Eagle communications payloads apply equally well to either mission and the entire package is being developed to be ready for the first opportunity – HEO or GEO – that becomes available. One of the primary payloads aboard either the HEO or GEO Eagle mission is planned to include the Advanced Communications Package.

The AMSAT Eagle design team has proposed a communications payload that utilizes the amateur microwave allocations. With Tom Clark, K3IO's "strawman" design[1], the digital ACP channels would also be accompanied by some more conventional "bent pipe" linear transponder channels. Realizing that microwave earth station design is beyond the scope of most hams, one option to make an ACP-capable earth station within reach of most radio amateurs is that station components could be distributed along

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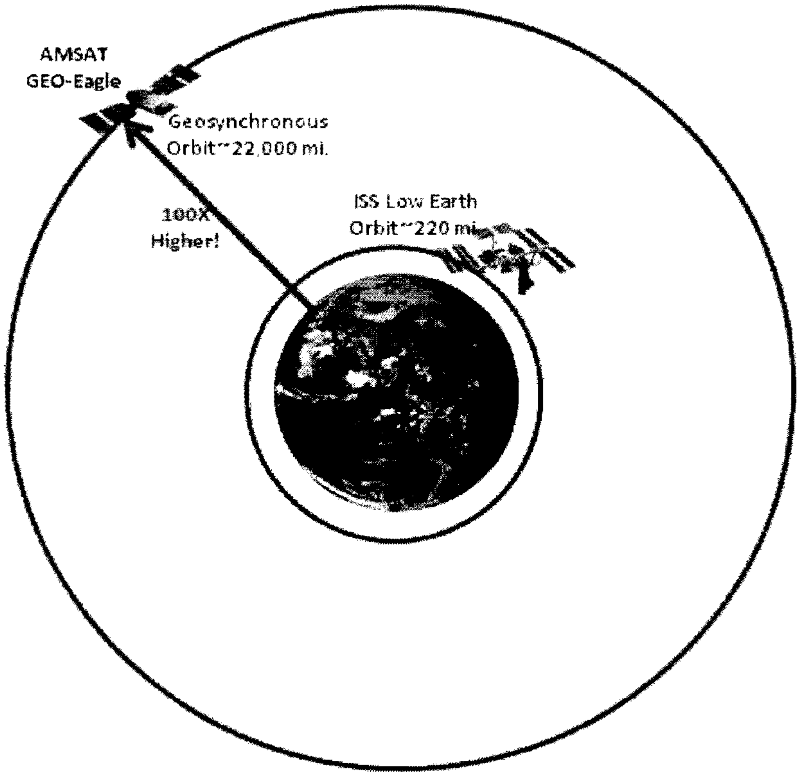
[1] K3IO 2008 AMSAT Symposium Paper

the lines of the project kits offered by the Tucson Amateur Packet Radio group (TAPR). Radio link budgets are being designed so the average earth station can leverage the use of 0.9 – 1.0 meter diameter dishes (36 – 40 inches) and would appear similar to installations used for home satellite television.

A rideshare opportunity for the Eagle ACP means that AMSAT would be allowed to attach its radio payloads to a geostationary communications satellite. The "mother ship" would provide hundreds of watts of DC power over a span of 10 to 15 years. The main satellite would also perform all station keeping and earth pointing navigational duties for keeping high gain antennas pointed at earth. For the amateur operator on earth, within the satellite's footprint, it means that no tracking will be required once the signal is acquired. You will be able to aim your antenna at a predictable, fixed point in the sky.

Launch opportunities under study will place the amateur radio payload over the equator, offering 365/24/7 amateur satellite availability for stations within the ~11,000 mile wide footprint on the earth below. Future geostationary rideshare opportunities over the upcoming years will allow AMSAT to expand the Eagle constellation to provide 365/24/7 worldwide amateur satellite coverage with additional satellites spaced along Earth's equator. Exciting times are ahead for amateur radio in space!



Refer to Figure 1 to compare the differences between Low Earth Orbit (LEO) and Geosynchronous Earth Orbit (GEO)

Once AMSAT achieves GEO orbit we will be 100 times higher above the earth than a LEO orbit. Everyone is certainly looking forward to the increase in communications range because of the increase subsatellite footprint.

Figure 1 is not drawn to scale because of page size limits. Imagine that the LEO orbit shown is 1/8 inch or 0.125 inch. If drawn to scale, a 100X increase in orbit would be at 12.5 inches away – off the page!

ARISS Brings Amateur Radio in Space Down to Earth and Into Your School

The 10-Minute LEO Direct Contact Limitation

One of the main features of the Amateur Radio on the International Space Station Project (ARISS) has been to enable direct contacts between the on-orbit crew and the students. The 220 mile high orbit of the ISS gives the crew a view of about 2000 miles in diameter. ARISS amateur radio contacts use frequencies around 146 MHz and 437 MHz which means that the maximum range of these line-of-sight radio waves is also limited to a circle 2000 miles in diameter. You can only make a direct contact with the ISS when your earth station is within its subsatellite footprint.

Given the height of the orbit and the orbital velocity of 17,500 miles per hour the maximum time available to make a direct contact with the ISS is 10 minutes. Then, ready or not – they are gone!

Using the example shown in Figure 2 you will be able to talk to the ISS crew only as long your earth station is within its radio footprint. This is shown as the white circle approximately 2000 miles in diameter. The coverage circle "moves" across the surface of the earth at about 5 miles per second.

Alternatively, when a school ARISS contact needs to be conducted when the ISS is not within range a telebridge station is used to provide the radio link and the audio is relayed via telephone line to the students. This allows additional contact opportunities with the ISS but the telebridge station is also facing that same 10 minute time limit.

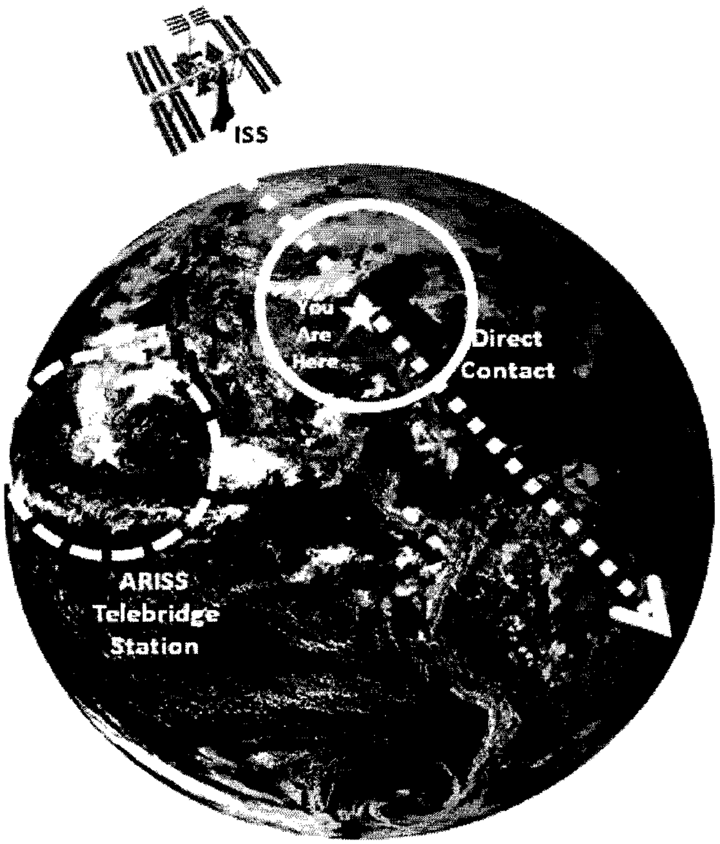


Figure 2. A direct contact with ISS is only 10 minutes for everyone.

GEO-Eagle Enables 30-Minute ARISS Contact

Longer continuous contact with the ISS can be maintained if there are enough adjacent telebridge stations. During this phase the ARISS ground stations will continue to maintain contact with the ISS using the established methods, i.e.: 145.800 MHz. This way each telebridge station can hand off to the next station as the subsatellite footprint moves out of range. Each of the telebridge stations, along with the target school for the ARISS contact, could be connected via a telephone conference circuit. To free ARISS contacts from the limitation of a single telephone circuit, Figure 3 illustrates how the GEO Eagle can be used to provide extended ARISS coverage via telebridge-handover. The only thing required would be that both the telebridge stations and the school be within the 11,000 mile wide footprint achievable from geostationary orbit.

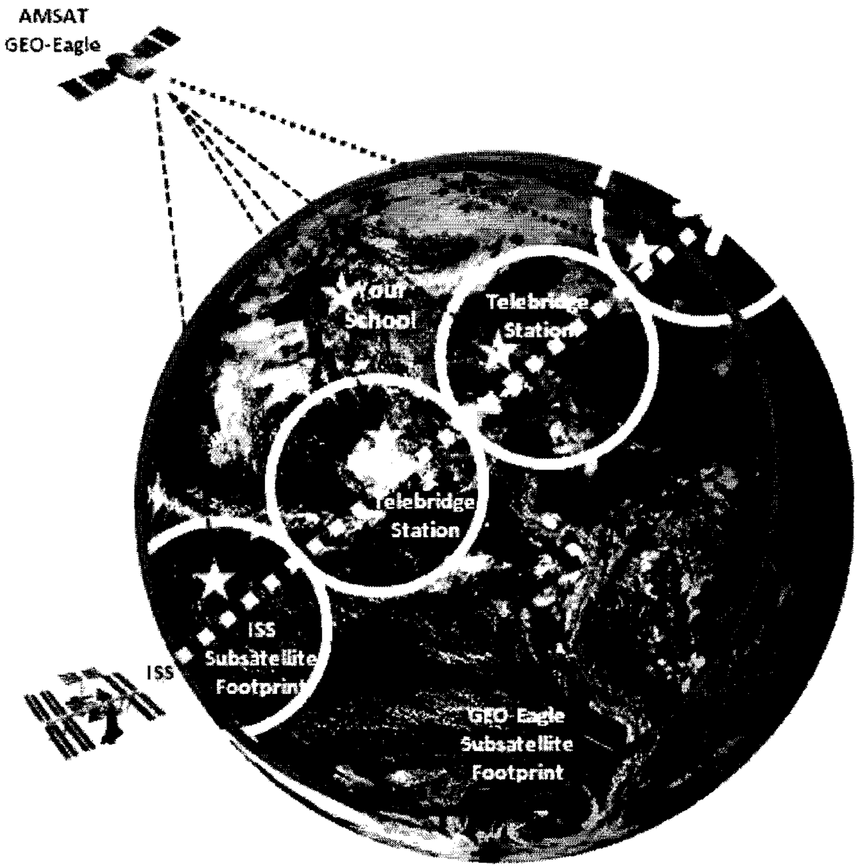


Figure 3. GEO Eagle links multiple ARISS Telebridge stations with their 10 minute window and the target school. Handover capability provides up to 30 minutes of contact time with the students. The Eagle ACP provides voice, data, and video

The telebridge station (or your school station) would be busy tracking the low-orbit ISS but your radio link to the GEO Eagle satellite will be remain stationary. As many stations as needed to help complete the contact (or those interested in listening in) only have need to aim their Eagle earth station at the satellite when initially configuring your station.

The current generation of amateur radio transceivers used on earth and the ISS limit communications modes to those which fit into an audio pass band. Voice communications, slow-scan television pictures and 1200 baud data traffic are examples of what is currently done. The Advanced Communications Package on Eagle will provide multi-media access depending on the capability of the ground station. Low rate data, voice, and video are planned to be available to users.

The Future: GEO-Eagle Constellation Enables Continuous ARISS Coverage

AMSAT plans to grow its geostationary constellation to provide full-earth coverage. This requires at least three satellites. Once completed, amateur radio operators and school programs will have continuous contact with an Eagle-tracking ARISS amateur radio station aboard the ISS. This will provide schools with TDRSS-like[2] capability allowing whole-orbit access to space based scientific experiments from the classroom or school laboratory. These experiments can be located inside the environment of the ISS or can be on the outside of the station. Continuous earth and space observation will become available in the classroom.

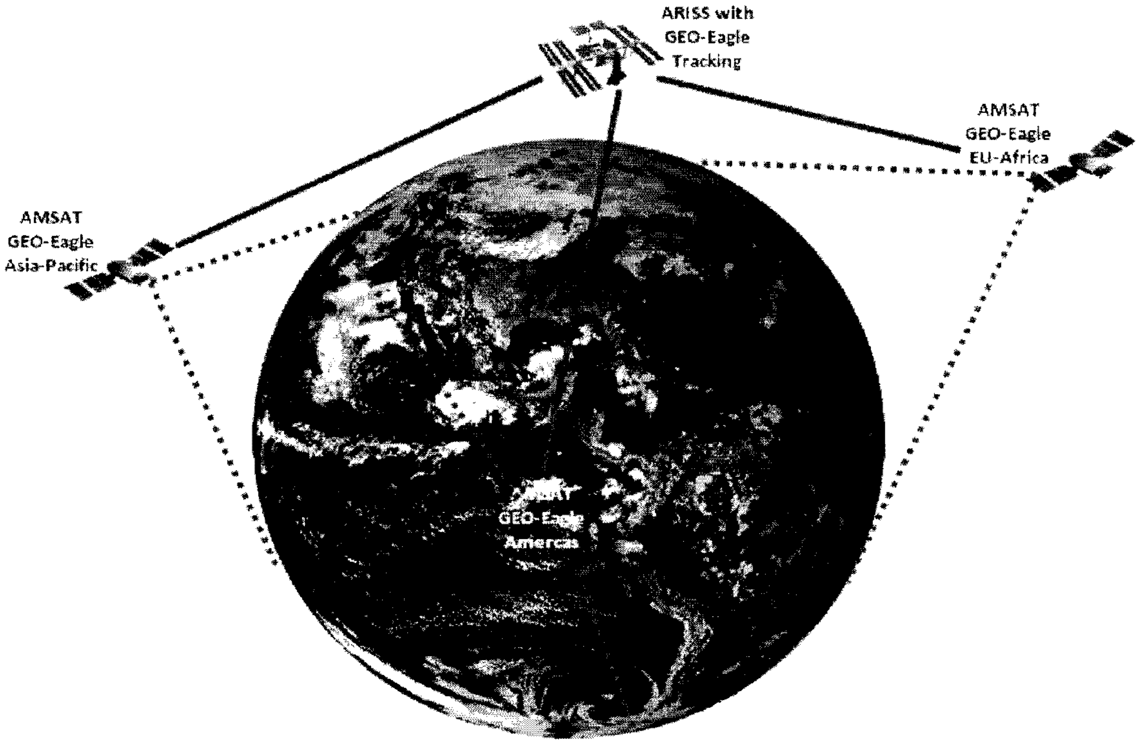


Figure 4. Imagine the possibilities! Of course we need to build and deploy AMSAT GEO-Eagle-Americas, AMSAT-GEO-Eagle-EU-Africa, AMSAT GEO-Eagle-Asia-Pacific, along with GEO-Eagle tracking capability for ARISS on-board ISS to access our birds.

An Example of Amateur Radio Communications Coverage From Geostationary Orbit

If a geostationary ride-share opportunity becomes available, AMSAT will need to accept any orbital parameters being offered. The good news is that perhaps opportunities for several geostationary ride-share orbital slots will arise over the years as the primary satellites require periodic replacement. These future opportunities will allow us to build our GEO-Eagle constellation.

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[2] TDRSS – Tracking Data Relay Satellite System which provides NASA's geostationary network relay for ISS systems and experiments.

Tom Clark, K3IO discussed his "strawman" proposal for GEO-Eagle in his paper, "Taking Eagle to New Heights" and accompanying presentation at the 2008 AMSAT Space Symposium. Tom presented examples of coverage based on a hypothetical situation which offers us a ride-share to a geostationary slot over the equator at 130° W. Table 1 shows estimated antenna elevations for selected cities around the perimeter of the subsatellite footprint.

Sample Elevation Angles to GEO-Eagle at 130° W	
Cities	**Estimated Antenna Elevation**
Boston	14.7°
Chicago	26.3°
Quebec	13.0°
Anchorage	18.5°
Newfoundland	0.5°
Auckland, NZ	18.1°

Table 1. Antenna Elevation Angles to GEO-Eagle

Introducing Amateur Radio's Classroom in the Sky

As you can see in Figure 5, the GEO-Eagle proposes multiple access to many amateur radio ground stations. One of the access methods under study for the Advanced Communication Package involves multiple stations uplinking via the 5650-5670 MHz band. A broadband downlink on 3400-3410 MHz transmits a multiplexed signal which is decoded by your ACP ground station. This is analogous to the downlink method employed by DirecTV or Dish network where all the television channels are delivered simultaneously and your set top box selects your desired channel. The communications payload also proposes to include bandwidth to support the conventional, linear bent-pipe transponders.

The ACP digital channels proposed user classifications determined by how well you can access the satellite based on your location, antenna configuration, and station equipment. The basic access class includes voice transmission and reception while advanced access class includes video capability.

GEO-Eagle can deliver on-going learning and training right to your shack. These can be live presentations with the instructor uplinking at scheduled times, or with a little computer server work stored presentations could be delivered on-demand. Imagine having training such as this delivered to your shack...

- New Ham Classes (you'll have to invite them over to your shack_
- License Upgrade Classes
- FEMA basic preparedness training classes
- Specialized topics such as digital signal processing, antenna design, station improvement

- ARRL's on-line classes

Various amateur radio news services delivering the latest information could be available ...

- AMSAT Nets
- ARRL Bulletins
- Amateur Radio Newsline
- This Week in Amateur Radio

And finally, the ACP will provide opportunities to provide coverage for special events never before available in high quality in your shack, including ...

- AMSAT Meetings
- Symposium and Colloquium coverage
- Launch coverage

Actually the list is endless, limited only by our imagination. First of all, we will need to build and launch the GEO-Eagle constellation. This is where you come in. Please consider joining the AMSAT team and see where you can help!

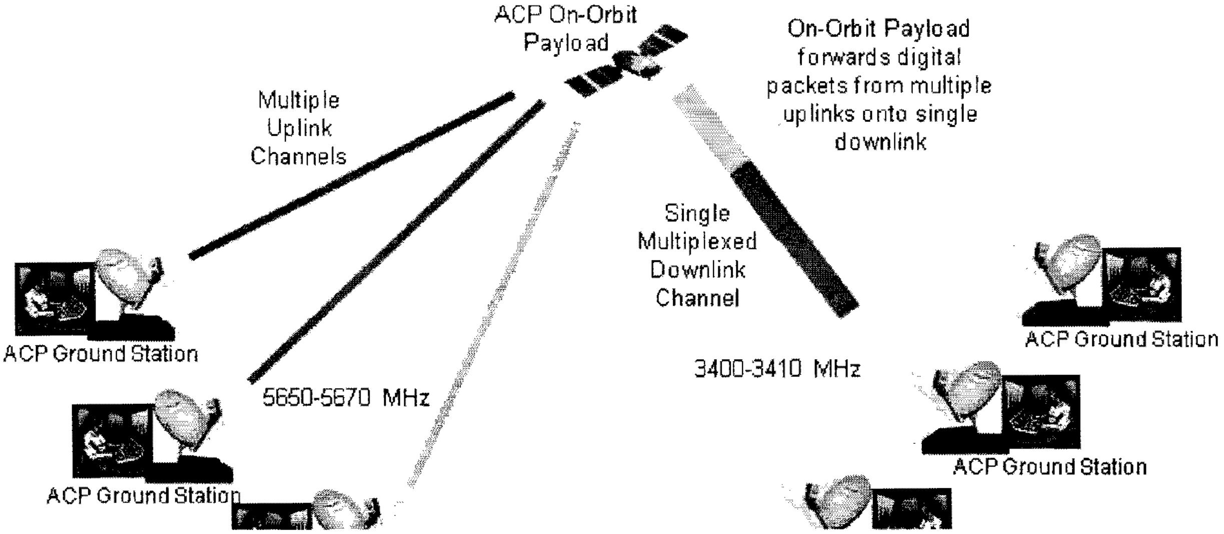

Figure 5. Advanced Communications Package multi-user network design proposed by Tom Clark, K3IO. Tim Salo, AB0DO[1] proposed an IP-based design for the earth stations and satellite, greatly expanding the transport of multiple user applications such as voice, video, and data. Both papers were presented at the 2008 AMSAT Space Symposium in Atlanta, Georgia.

References

1. "Taking Eagle to New Heights – A Strawman Design for a Geostationary Amateur Radio Satellite", Tom Clark, K3IO. Proceedings of the AMSAT-NA 2008 AMSAT Space Symposium, Atlanta, Georgia. October 24-26, 2008.

2. "Proposed Network-Centric Architecture for the Advanced Communications Package (ACP)", Timothy Salo, AD0DO. Proceedings of the AMSAT-NA 2008 AMSAT Space Symposium, Atlanta, Georgia. October 24-26, 2008.

The potential of adapting AMSAT-NA Activities into lesson plans for U.S. K-12 Education

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ABSTRACT

AMSAT activities represent an exciting intellectual challenge to any technical hobbyist that encompasses several disciplines in the traditional portfolio K-12 STEM Subjects. While an experienced and educated engineer would find it a fun set of activities to pursue, for young newcomers to the hobby, the "learning curve" is often a steep one and due to lack of adequate mentorship/exposure initial interest may wane rapidly unless they are given positive feedback and can generate results on their own. To address the need for greater exposure of the benefits of AMSAT activities in STEM education and to facilitate its potential inclusion in formal syllabus in U.S. Schools, a new proposal is hereby presented to package AMSAT knowledge into lesson plans, in a format similar to the aviation centric syllabus taught to Grade 4/5 Students at STARBASE Academies in the U.S. and an example of such content being delivered with interactive, multimedia IT applications such as the prototype "Learning Resources Navigator" is presented.

INTRODUCTION

As this is my first paper at an international Radio Amateur Satellite conference, I would like to acknowledge two relevant issues that should serve both as an introduction to my background, and explain the motivation behind the proposal for a academic adaptation of AMSAT activities in K—12 in the US that I will propose and attempt to highlight with a live demonstration if possible of a related, on-going K-12, Aviation-centric STEM education development initiative entitled, "Learning Resources Navigator", which I am the principal developer of.

The first issue I would like to highlight is that, I have been very fortunate to advance my career as a Computer Engineer, Network Engineer, a VSAT Satellite Engineer, a recognized Entrepreneur within the Internet Service Provider, Telecom and Fixed Satellite Services industries and an IT Public policy and strategy author, since the 1980s, due in large part to the skills and knowledge I learnt outside of my formal schooling through the pursuit of Ham Radio as a challenging hobby. In addition, as most of you are likely to relate to this, I learnt a lot of advanced topics and subjects from my over-the-top interest in Space Exploration, most probably due to early exposure to Sci-Fi TV Shows in the 1970's and 1980's such as "Star Trek" and "Space: 1999" and a fortunate packet of promotional material from NASA that I received after writing a letter in Grade 7 from Bangladesh in the mid 1970's. As I became deeply involved as a policy maker, project manager of satellite networks "from West Africa to East Asia" for a number of years in the middle part of my career, I worked with mission critical satellite operations, management and technical issues and taught all levels of field and in-house project personnel. I began to feel the nagging notion that "something was missing" in my portfolio of skills – and I have now realized that I will be more happier in a research/development and teaching environment, involving aerospace and communication systems. These is why, after my relocation to the U.S., I chose to go back to school and have earned a MS degree in Space Studies and as a next step, will continue on to a Ph.D program. Since

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[1] Director, Broadband Technologies, B2 Technology and Consulting Services, Inc. Sterling, VA

my I am resuming my studies after a long time, it is obvious that I get stares from other students less than half my age, and at the same time, I continue to be impressed by the speed and intellectual sharpness of the youngest generation in middle-school and high school and of course, my own children who it seems are capable of teaching me a lot through SKYPE calls and showing of their knowledge as found through Google. Perhaps one day they will be interested to ask my father about the old 1960's typewriter he wrote his Ph.D on, with manual index cards serving as notes on thin double/triple spaced sheets of paper, or the history of the very first commercial e-mail message from Bangladesh to the Internet, sent at 1200 bps over an analog international *dial-up* phone connection in 1993, which I facilitated to help out a certain visiting consultant for the United Nations Development Program wanting to send a message to a network called "Compuserve".

In light of my own non-traditional learning history summarized above, I believe now strongly that without mentorship at certain early stages in a child/youth academic development, a student is not likely to understand the steps necessary to take up in order achieve their dreams, despite having all the will and excitement to do so. As schools are focused on teaching general subjects with occasional forays into after-school activities, unless a student/youth has an enabling environment, they will not typically be able to realize their dreams into action plans. This is a well understood requirement and is addressed in some detail in [1] and the advantages of mentorship are outlined in [2].

CHOOSING A TEACHING METHOD

As new generation youth are unlikely to be able to grasp immediately all of the dimensions required to plan, design, develop, manufacture, negotiate, procure, deliver, launch, deploy and operate a satellite system as explained in portions in [3], [4] and any number of issues of the *AMSAT Journal* and AMSAT conference proceedings, I would like to initiate a discussion within our community to take more formal steps to adapt AMSAT learning activities into miniature lesson modules similar to the format/requirements of the Department of Defense sponsored STARBASE Core Curriculum which is a long-standing, aviation-centric 5-day course to teach children STEM subjects [5], and employ them into a Information Technology (IT) delivery platform that is suitable to their modern day preferred mode of communication: Multimedia, interactive, media-rich web-based applications through which the "students" can socialize and be highly mobile. In this paper, I would like to describe the functionality of the "Learning Resources Navigator", an application I have been developing recently and is suitable for conveying the knowledgebase of Ham Radio engineering and Satellite engineering in an effective format.

CONTENT PROPOSAL: AMATEURS AND SATELLITES

For those new entrants to the world of "Radio Amateur Satellites" many are surprised to learn the breadth and depth of our specialty field, and soon realize that it is *a hobby that provides far more intellectual challenges than most*, including the hobby of Ham Radio itself. Due to the low exposure of Radio Amateur Satellites in the global press, new hobbyists have to be introduced slightly to the history first which should actually be mandatory reading for all.

The linkage between "ham radio operators" or "amateur radio operators" and satellites in orbit, began simultaneously at the same time as the launch of the first Man-made object to successfully orbit the Earth, Sputnik, when Soviet journals such as Radio, in mid-1957 published articles containing details about the beacon frequencies (e.g., 20.005 MHz and 40.010 MHz) and an estimate of the launch date (e.g., late September) for public information, targeting electronic enthusiasts. As secrecy of the upcoming launches was not particularly on the Soviet Agenda, translation of the articles from Russian into English and their subsequent publication in English language technical magazines such as the venerable QST with key phrases [4] such as, "Since radio amateur observations will be of a mass character they can secure extremely important data on the satellite's flight and the state of the ionosphere", served two purposes: it allowed Ham Radio Operators to utilize their budding technical skills and comparatively basic equipment to calculate trajectories, track the artificial satellite to downlink the radio signals, establish the vital principle that scientific observations can be received from Space using instrumentation flown aboard an orbiting spacecraft, and to satisfy the penultimate promotional objective that the Soviet Union was ahead of the United States in technology. However, as both Russian and US missions to Space began to be more regular, the interest in tracking launch vehicles and orbiting spacecraft bloomed such that an increasing number of Ham Radio Operators successfully designed and built their own tracking systems and/or communications hardware for monitoring both orbiting spacecraft and missions to the Moon and Planets such as Mars independently of any particular national Space initiative. It is instructive to note that amateur radio enthusiasts were able to design and fabricate antenna and radio systems that successfully monitored voice communications directly from the Apollo 15 Command Service Module in August 1971 and also participated in the monitoring activities of the 437.13 MHz beacon from the Mars Global Surveyor spaceship en-route to Mars launched in 1976. As a full catalog of the number of Amateur satellite radio projects is outside of the scope of this research paper, the reader is referred to the comprehensive history of various key amateur satellite radio projects from 1960s to current time in [4], [6]. New projects such as ARISS/Suitsat or successors should be introduced in modular project fashion.

CONTENT PROPOSAL: THE GENESIS OF AMSAT

AMSAT, also known by its formal registered name as "Radio Amateur Satellite Corporation", was formed in 1969 to facilitate the application of space-related expertise and facilities of the United States (particularly in the Washington, DC area) to the amateur space program worldwide and followed the successful the efforts of the Orbiting Satellite Carrying Amateur Radio (OSCAR) Association activities. In particular the formation of AMSAT was an enabling factor in the launching of the Australian originated Australis-OSCAR 5, or AO-5, project from the University of Melbourne which was an already built and tested satellite needing launch facilities that were hard to come by at that time. The satellite had been under development prior to 1966 and was battery powered with manganese-alkaline power supply, indicating it was expected to have a short operating life. AMSAT volunteers aided in the re-engineering of the satellite for a NASA launch vehicle and the mission was flown into space on January 23, 1970 and performed admirably taking directions from the numerous amateur radio ground stations which allowed operators to prove the remote control capability to send commands to the spacecraft on the uplink, in order to turn the 29 MHz beacon on or off as desired. This was an important requirement for laying the foundation for obtaining FCC approval for future amateur radio satellite missions [4]. The spacecraft was the fifth in a series of amateur radio spacecraft projects, and was granted the designation OSCAR which is an acronym of "Orbiting Spacecraft Carrying Amateur Radio"4. Current generations of spacecraft are only granted the OSCAR designation when they successfully reach orbit transmitting from space and are requested such designation by the spacecraft operator.

CONTENT PROPOSAL: STEM TOPICS

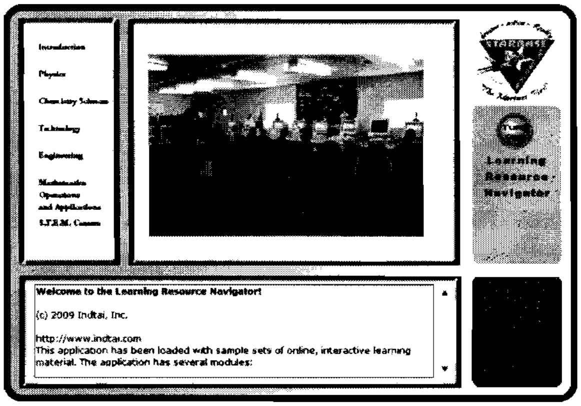
In the United States, there is wide variety in the topics/lessons that are permitted to be taught within School Districts, but in general AMSAT activities should be considered non-controversial, and due to the mix of STEM subjects could be very beneficial to a school syllabus. In fact, the published 2009 Core Curriculum for the STARBASE program could be a model to base our own curriculum on. The STARBASE syllabus is as follows:

- (a) Physics (3.5 contact hours)
    - a. Newton's Three Laws of Motion
    - b. Fluid Mechanics and Aerodynamics
- (b) Chemistry Sciences (3.5 contact hours)
    - a. Building Blocks of Matter
    - b. Physical and Chemical Changes
    - c. Atmospheric Properties
- (c) Technology (4.0 contact hours)
    - a. Innovations
    - b. Navigation and Mapping
- (d) Engineering (4.0 contact hours)
    - a. Engineering Design Process
    - b. 3-D CAD
- (e) Mathematics Operations & Applications (2.0 contact hours)
    - a. Number and Number Relationships
    - b. Measurement
    - c. Geometry
    - d. Data Analysis

Additional potential AMSAT activity related topics could be included in this syllabus: Radio Frequencies, Transmission, Reception, Antennas, Orbits, Batteries, Propulsion, Guidance/Navigation/Control, etc.

AN EXAMPLE OF A CONTENT DELIVERY SYSTEM: LEARNING RESOURCES NAVIGATOR®

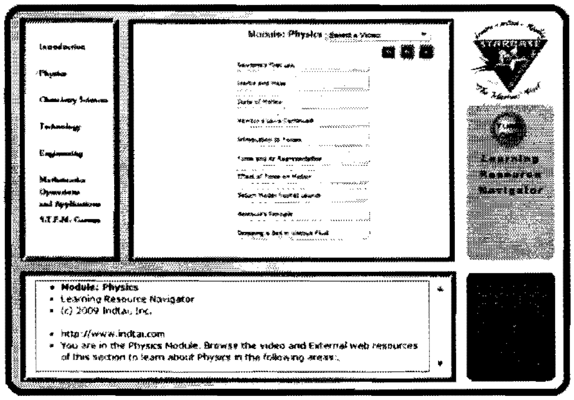
I developed the Learning Resource Navigator® (LRN) application for my employer in 2009 with interactive communication and various forms of multimedia in mind, as a potential substitute of an instructor-mentor should a "student" or youth be interested in a STEM Subject but not have access to them locally. The K-12 educational environment I studied was the STARBASE Academy at MCAS Beaufort, which has taught nearly 10,000 students over a decade and in the last five years alone have taught 5,499 students with a 47:53 Male: Female student of grades 4/5 with "hands-on, minds-on" activities". Both online and offline instruction delivery methods are supported, and the application can be programmed to work on a stand-alone basis if desired. I chose to use a Flash enabled customized application for Internet use, allowing students to access interactive course material, see content in a media-rich environment, interact with a keyboard/mouse, see live/prerecorded video clips of subject matter related content, and hear associated recorded audio streams, tuned to an STEM academic environment



Welcome to the Learning Resource Navigator!

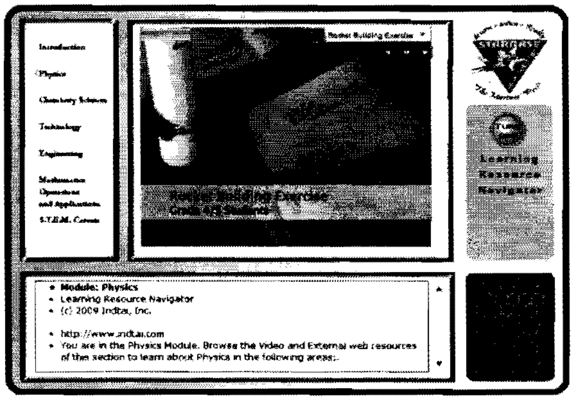
(c) 2009 Indtai, Inc.

http://www.indtai.com
This application has been loaded with sample sets of online, interactive learning material. The application has several modules:



- **Module: Physics**
- Learning Resource Navigator
- (c) 2009 Indtai, Inc.

- http://www.indtai.com
- You are in the Physics Module. Browse the video and External web resources of this section to learn about Physics in the following areas:



- **Module: Physics**
- Learning Resource Navigator
- (c) 2009 Indtai, Inc.

- http://www.indtai.com
- You are in the Physics Module. Browse the video and External web resources of the section to learn about Physics in the following areas:

At the current time, an initial preview of this application with *sample* content is publicly available at http://www.starbasebeaufort.com. The LRN application has been demonstrated to public audiences at the STARBASE Academy in Beaufort, SC in August 2009 and feedback has been incorporated in our development plans with respect to the User Interface. Further development may include customized voice streams (audio narration) and live motion/animated actors that will overlay the content being displayed to provide a means for educational content developers to provide 'digital teaching assistants' that engage and bring clarity to student inquires.

In order to manage the underlying syllabus and content database, an Administrator application is used to catalog and develop academic program syllabi, suitable for use by Instructor-mentors feeding content that will be accessed through the Learning Resource Navigator.

The application can be used in a variety of ways, and allows the creation of Relational Databases that track: (1) Lesson Materials; (2) Lessons; (3) Topics; (4) Subjects; (5) Syllabus Revisions; and (6) Academic Program details. The application should eventually allow future researchers to be able to compare the outcomes of different syllabus programs, account for the variation in syllabus programs amongst School Districts or curricula, to allow material from one program to be assigned/ duplicated/used in another program, or revisions to lesson materials be adapted to existing programs over the lifespan of a particular syllabus.

CONCLUSION AND RECOMMENDATION

Students/Hobbyists that want to expand their knowledge are likely to choose Radio Amateur Satellites as an intellectual challenge, and therefore should be encouraged to learn properly to advance the discipline and save it from obsolescence. The method for teaching the vast content/knowledgebase of this hobby could potentially be (1) adapting AMSAT activity/knowledge to course modules/lesson plans (2) delivering it through a web-enabled Learning Resource Navigator or similar IT application. Questions for future:

- What type of content should be packaged as AMSAT Academic Content?
- Who will be AMSAT academic content be targeted for?
- What will be the delivery method for AMSAT academic content?

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High Altitude Balloon Launch from The Astronauts Memorial Foundation Center for Space Education

By David Jordan, AA4KN

Introduction

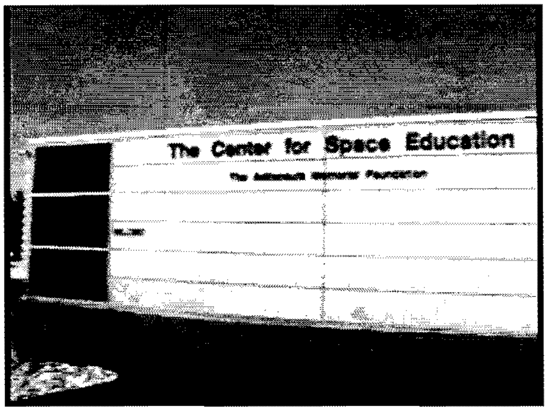
The Kennedy Space Center Visitor Complex serves as a tribute to our national space program and the courageous men and women that have been a part of it. Serving as a "living memorial" to our fallen astronauts within the complex is the Astronauts Memorial Foundation Center for Space Education (CSE); A facility which from its inception in 1994, had one mission; "to foster an understanding of space exploration and to improve education through technology."

The Center for Space Education

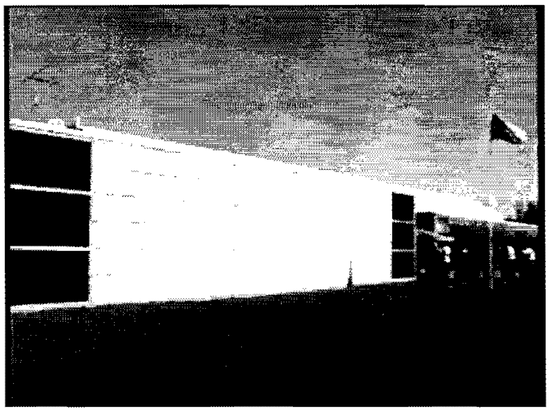
Its construction was funded through the Astronauts Memorial Foundation. The foundation exists to honor those astronauts who have sacrificed their lives for the nation and the space program. The CSE is home to three space-related organizations. Space Florida, the Florida Space Grant Consortium and the Florida Space Institute. Space Florida helps to increase visibility, coordinate strategy and streamline communication between the space industry and the State of Florida. The Florida Space Grant Consortium mission is to expand and diversify the space industry through grants, fellowships and scholarships for both students and teachers from many of Florida's schools of higher learning. The Florida Space Institute or FSI was founded by the University of Central Florida in Orlando. Many of Florida's schools of higher learning have become affiliates of FSI. The purpose of FSI is to provide a focus on space for the research and education programs of the institutional affiliates. All three of these organizations located within the CSE, are separate, but hold common interests.

Amateur radio station at the CSE

To compliment the operations at FSI, an amateur radio station has been assembled at the Center. This was carried out under the direction of George Cannon, KF4XB, Lee McLamb, KU4OS and UCF/FSI technical manager, Bob Eppig. The station equipment was initially acquired for assembling a satellite control station to use with UCF's Knightsat program. A student satellite design entry for the University Nanosat Program competition sponsored by the United States Air Force. The station had originally been located at the Spacehab (now Astrotech Corp.) facility in Titusville where UCF had been allowed an area to conduct work on their Knightsat program. Later, it was moved to the CSE in an effort to further consolidate FSI operations at a single location. Station equipment consists of a 2 meter/70cm transceiver, separate computers using SatPC32 for satellite tracking and APRS packet. Also, S-Band receive capability and an array of directional antennas on the roof. The station is mainly being used at this time for acquiring and recording real time analog ATV and digital APRS GPS location information from balloon flights originating at the CSE.

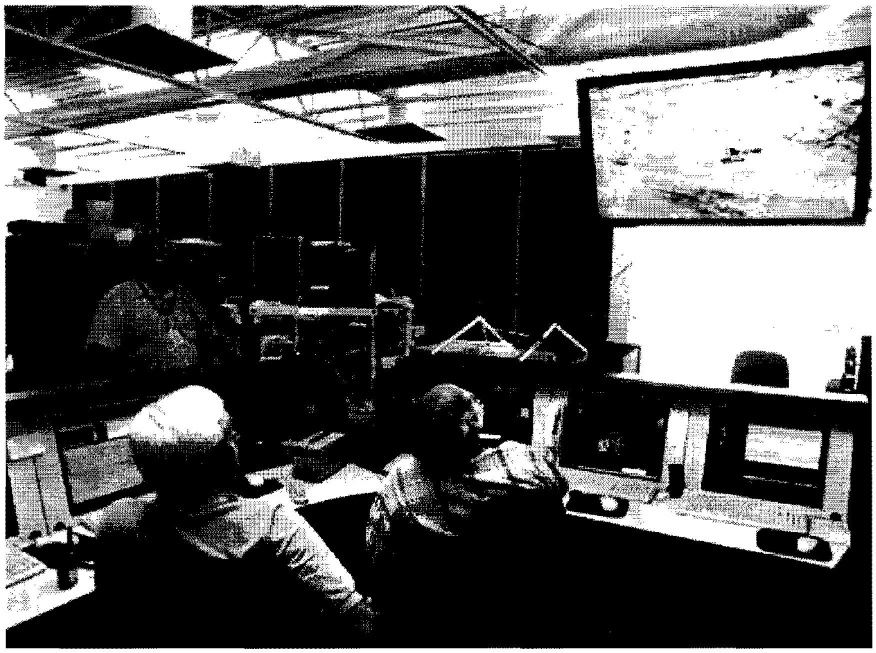


CSE Building



CSE Building showing antenna. Arrays (left) and main entrance (right)

[Photos by David Jordan, AA4KN]



FSI Amateur Radio Station, at console: George Cannon (L), Lee McLamb (R)

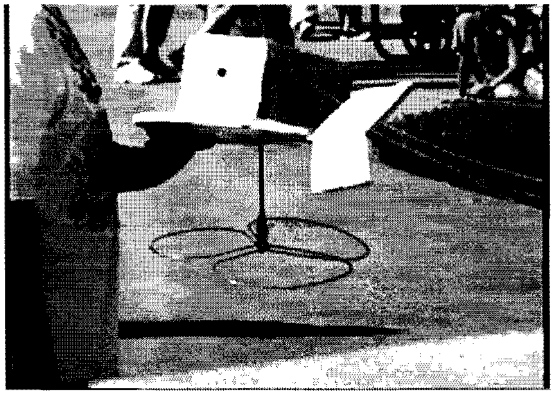
[Photo by David Jordan, AA4KN]

After seeing that there could be opportunities to further compliment the educational operations at FSI using amateur radio, David Jordan, AA4KN and Carl Zelich, AA4MI, along with some local amateur radio clubs have begun meeting with FSI staff to explore ways of expanding FSI related projects to local secondary schools in the regional area.

Balloon launch from the Center

My initial introduction to the Center for Space Education facility came by way of an email sent from Lee, KU4OS on July 16, 2009, notifying local hams of the proposed balloon launch from the CSE the next day. Another local ham, Joe KJ4JIO, and I had been discussing launching a balloon with amateur gear and I saw this as a chance to see what a launch was all about.

During summer months and throughout the year, classes and workshops are offered at the CSE. In mid July, 2009, a student group from Savannah, Georgia met at the CSE as part of their summer camp program in space technology and put the finishing touches on two payloads. On July 17th, the group's last day of camp, they helped in the launch of the payloads using a 1200 gram weather balloon. Once launched, the students would help in monitoring video from the balloon and GPS position data at a temporary station set up just outside the CSE main entrance. Using a hand-held beam, receiver, and monitor, they would be able to acquire an ATV signal and view the surrounding area around the Space Center. I arrived at the CSE around 09:00 ET. I was directed to the north end of the building where I found George Cannon and Lee McLamb working to complete the configuration of the station before launch time. They gave me a quick tour of the amateur radio station console and gave details about how the launch would proceed. Helping to direct the event were FSI staff members, Dr. Jaydeep Murkerjee, Dr. Larry Chew and Robert Eppig, technical manager at FSI. With the help of the students, under the direction of Dr. Chew, the balloon launched into clear skies promptly at 10:00 ET.



2 meter ATV payload for earth viewing

2 meter ATV video image over KSC as seen on the amateur station's wide screen monitor

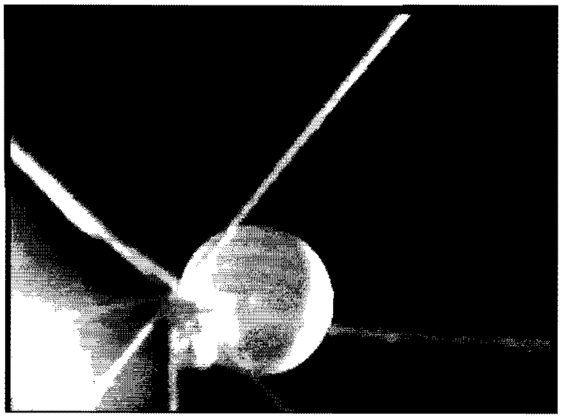
[Photos by David Jordan, AA4KN]

The white balloon, with parachute and two payloads trailing 35 feet behind, rose very quickly at an initial rate of 1000 ft/minute. The payloads consisted of a 2 meter ATV video transmitter viewing the ground, a 2.4 GHz video transmitter with a view of the balloon itself and finally, a GPS transmitter sending APRS packets every few seconds indicating the current longitude, latitude and altitude of the balloon. I proceeded back inside where a group had gathered to view a wide screen monitor mounted above the station console. Here, we could see the 2 meter video signal randomly panning between a panoramic look at the Atlantic Ocean and the Kennedy Launch Complex which it borders. At this point and for some unknown reason, the 2.4 GHz ATV transmitter had become very intermittent due to a weak signal problem and its video had become quite useless. Little did we know at the time that, another source in the area with a more robust listening capability had been recording the 2.4 GHz video and later shared it with us.

As a result of very low upper level winds, the payloads remained almost straight overhead throughout most of the mission. Finally, as it neared an altitude of 90,000 feet, the balloon burst and began an extremely rapid descent sharing some very spectacular views from the 2 meter transmitter during its fall. Monitoring the GPS APRS telemetry, we could see that the craft was beginning to drift west toward Mims, Florida, about 18 miles from our location at the Cape. Finally, after a 2 hour and 19 minute flight, the balloon came to rest at 12:19 ET about 18 miles northwest of our location.

Conclusion

After some detailed analysis and a week to think it over, George, Lee and I using GPS data, Google Earth and a hand-held GPS unit, proceeded to Mims to search for the payloads. After an hour or so of plodding through 6 foot high Sawgrass and swamp water in 97 degree temperature and with nothing to show for our effort, we decided we had given it our best. We are already discussing a long duration beacon for locating payloads before the next flight.



Balloon just seconds before burst
(Photo from 2.4 GHz ATV video)

George Cannon presses on in search for the payloads

[Photos by David Jordan, AA4KN]

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Kennedy Space Center, FL 32899

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Presented at 27th Annual AMSAT Space Symposium, Oct. 9-11, 2009, Baltimore MD
Key Words: Maya, Venus, "Dresden Codex"

Mayan Observations of Venus

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Abstract

This paper describes a method that the Maya may have used to uncover the recurring patterns in the motion of Venus described in the Dresden Codex.

Introduction

A statement by Michael Coe succinctly summarizes the current consensus on Maya astronomy – "Science in the modern sense was not present. In its place we find ... a combination of fairly accurate astronomical data with what can only be called numerology, developed by Maya intellectuals for religious purposes." [1]

The Dresden Codex, referred to by Anthony Aveni as "The crowning achievement of Maya astronomy", is one of the few existing direct links to the Post-Classic Maya world available today.[2] A large part of the Codex is devoted to observations of Venus.[3] The existence of this material attests to the special significance that Venus had for the Maya. The factors that stimulated this interest (discussed in next section) appear to be well understood. And, the enormous effort devoted to interpreting the information contained in the Codex over the last several decades has revealed that the Maya knew a great deal about the behavior of Venus.[4]

However, the related question – How did the Maya collect, store and process the quantitative data needed to discover the repeated patterns in the motion of Venus? – has received very little attention. A statement by Anthony Aveni remains apt – "One of the great mysteries of New World astronomy lies in comprehending just how these people could have charted their tropical sky." [5] What Michael Coe referred to in the opening quote as "numerology" turns out to be a significant endeavor.

Extracting meaningful patterns from raw data can be a formidable undertaking. With respect to Venus, the Maya accomplished this task with minimal computational aids and without any scientific understanding of the physical structure of the cosmos. The primary goal of this paper is to offer an explanation of how this could have been accomplished.

Motive and Opportunity

A brief summary of the factors underlying Maya interest in Venus provides hints as to the methods they employed. Classic Maya civilizations supported a shaman (astronomer-priest) class. A primary function of the elite members of this group was to engage in activities that "justified" the rights of the kings/lords to total and perpetual reign. To achieve this aim shamans constructed a mythology and oversaw ceremonial events. Shamans were also called upon to make predictions concerning factors of central importance to society such as the success of future harvests and propitious times for military exploits. A shaman who played his/her cards well could, with a little luck, expect to enjoy a comfortable lifestyle and a position of influence. However, one or more incorrect predictions could quickly change the shaman's status.

For a shaman the Holy Grail was to identify an area of expertise that society acknowledged as being important where predictions could always be correct and where the veracity would be directly verifiable by all citizens.

Cosmic events, which are both deterministic and central to Maya mythology, offer a perfect arena for such predictions. Once heavenly patterns are discerned there is no element of randomness. Almost all civilizations have recognized the obvious patterns involving the sun and moon. For example, from a specific location sunrise and sunset will appear at a slightly different position on the horizon each day making it easy to identify the longest and shortest days of the year. Using these dates as reference points, cycles of the moon could then be used to predict the appearance of migrating animals and wild berry crops, and other important events that repeat on a yearly basis.

In Mesoamerica the daily number of hours of darkness exceeds the number of hours needed for sleep on a year round basis so the fact that the Maya are very aware of the night sky and that it occupies a central role in their mythology is not surprising.

Following knowledge of the sun and moon the next level of astronomical awareness among almost all cultures is recognition of the fact that not all points of light in the heaven move in conjunction with the great majority (the fixed stars). The most prominent of these nonconformist objects are called planets and one of the brightest is Venus. Note that no scientific concept of the structure of the heavens is needed here to explain the observations. Mythological constructs work fine.

A shaman who could make accurate predictions about the movement of the maverick object known as Venus would appear to have a deep understanding of the behavior of the gods and his/her reputation would be greatly enhanced.

Historically, trade guilds are structured around carefully guarded secrets that are central to the member's source of power. For example, potters would go to most any lengths to learn a new low temperature glazing technique that produces beautiful colors and an extremely hard surface. Shamans who discovered methods for making predictions about Venus would likely guard the knowledge. As a result, even among Maya living at the time, few would be aware of how shamans had identified the repeated patterns in the motion of Venus. This suggests that attempts to uncover a documented explanation of the methods involved are likely to be futile and that to discover these methods other approaches need to be pursued. Possibilities include investigating the Maya interest in, and involvement with, geometric patterns, searching for analogous situations in other cultures, and engaging in reverse engineering. The explanation suggested here relies on all these approaches.

Narrative

We turn first to an analogous situation. At the beginning of the space age (late 1950's) western scientists monitoring the first space satellites launched by the USSR speculated as to the nature, purpose and details of each new spacecraft as it appeared. At the same time a number of individuals devised methods enabling them to identify patterns in the motion of artificial satellites without employing knowledge of the underlying physical laws. These patterns were then used to make predictions about future orbital behavior. One of these groups, sited at the Kettering Grammar school in England, achieved a degree of international fame by providing detailed information about early Russian launches which, in many cases, was more accurate and perceptive than that available from the professionals.[6] The methods this group employed to acquire and process their data provide a model for an approach that could have been used by the Maya to construct the Venus tables.

The science master at Kettering was Geoff Perry. As Perry explained it, the group combined data acquisition techniques adopted from the radio amateur community, which involved noting times when radio signals from a spacecraft were acquired (AOS = acquisition of signal) and lost (LOS = loss of signal) with an innovative data processing approach. The time between AOS and LOS is known as the pass length. By themselves, the piles of AOS and LOS data (see example shown in Table 1) provide little insight. [7]

If the time at the midpoint of each pass is graphed as shown in Figure 1 one notes that passes appear to be grouped in morning and evenings subsets. Re-plotting the morning passes in more detail (Figure 2) reveals a number of patterns. The maximum time for a pass is about 22 minutes. Pass times tend to repeat on a two day cycle advanced about 5 minutes. Pass times tend to repeat on a 23 day cycle advanced about 1 minute. And, a pass event can be followed for about 180 days. When it first appears, the pass duration is about 1 minute; this grows to about 22 minutes and then decreases until it disappears. Keep in mind that the motion of this specific satellite is of no real interest to us. It's just an example to illustrate the key point.

A creatively constructed visualization approach can reveal patterns hidden in data to an observer who has no knowledge about the physical laws involved.

Once underlying recurring patterns are identified it's possible to make accurate predictions about future motion. The accuracy is entirely independent of whether we care to explain these predictions in terms of physical laws or marbles rolling off the back of a giant tortoise.

Table 1

Table 1

Satellite: AMSAT-OSCAR 6 Period Covered: Dec 1975 (Times/ Dates are EST)
altitude: 1450 km ; inclination: 105.5 °
Data Source: 1975 Orbital Predictions for AMSAT-OSCAR 6 by Skip Reymann
Observation from: Baltimore MD Latitude: 39°N Longitude: 76.7°W

```
   Date
AOS     LOS
hh:mm   hh:mm

 1 Dec 1975
07:19   07:37
09:10   09:32
11:04   11:22
13:03   13:04
16:31   16:43
18:19   18:37
20:09   20:31
22:06   22:22

 2 Dec 1975
06:23   06:32
08:12   08:33
10:06   10:25
11:59   12:13
17:22   17:42
19:10   19:32
21:06   21:24

 3 Dec 1975
07:14   07:31
09:05   09:27
10:59   11:17
12:55   13:07
16:39   16:57
18:13   18:32
20:04   20:26
22:01   22:17

 4 Dec 1975
06:19   06:26
08:07   08:28
10:00   10:21
11:55   12:08
17:18   17:33
19:05   19:27
20:59   21:19
23:02   23:06

 5 Dec 1975
07:03   07:26
09:01   09:22
10:54   11:13
12:53   12:56
16:25   16:32
18:09   18:27
19:59   20:20
21:55   22:13

 6 Dec 1975
06:16   06:19
08:02   08:21
09:55   10:16
11:45   12:03
17:23   17:27
19:01   19:22
20:54   21:15
22:57   23:02

 7 Dec 1975
07:06   07:21
08:56   09:18
10:45   11:08
12:44   12:52
16:20   16:27
18:04   18:22
19:54   20:16
21:50   22:08

 8 Dec 1975
07:57   08:13
09:50   10:11
11:44   11:59
17:09   17:22
18:56   19:17
20:48   21:10
22:49   22:59

 9 Dec 1975
07:00   07:16
08:51   09:13
10:45   11:04
12:40   12:48
16:28   16:31
17:59   18:17
19:49   20:11
21:45   22:05

10 Dec 1975
07:52   08:12
09:45   10:06
11:39   11:54
17:04   17:17
18:51   19:12
20:44   21:09
22:44   22:54

11 Dec 1975
06:55   07:10
08:46   09:08
10:40   10:59
12:34   12:43
16:12   16:26
17:55   18:22
19:44   20:06
21:40   21:55

12 Dec 1975
07:47   08:08
09:40   10:02
11:34   11:50
16:59   17:11
18:45   19:06
20:37   20:59
22:37   22:48

13 Dec 1975
06:49   07:04
08:40   09:02
10:33   10:51
12:28   12:38
16:07   16:10
17:49   18:06
19:38   20:00
21:33   21:52

14 Dec 1975
07:42   08:02
09:34   09:56
11:28   11:44
16:54   17:06
18:41   19:01
20:32   20:54
22:32   22:44

15 Dec 1975
06:45   06:58
08:35   08:57
10:29   10:48
12:23   12:33
17:44   18:01
19:33   19:55
21:28   21:47

16 Dec 1975
07:37   07:57
09:29   09:51
11:23   11:39
16:50   17:01
18:36   18:56
20:27   20:49
22:26   22:40

17 Dec 1975
06:40   06:53
08:30   08:52
10:23   10:43
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19:29   19:51
21:23   21:44

18 Dec 1975
07:32   07:51
09:24   09:46
11:18   11:35
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22:21   21:36

19 Dec 1975
06:35   06:47
08:25   08:46
10:16   10:39
12:14   12:26
17:35   17:51
19:24   19:46
21:18   21:38

20 Dec 1975
07:27   07:46
09:19   09:41
11:13   11:30
13:10   13:11
16:41   16:51
18:26   18:46
20:18   20:40
22:15   22:30

21 Dec 1975
06:31   06:41
08:20   08:42
10:13   10:34
12:08   12:20
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19:19   19:41
21:13   21:33

22 Dec 1975
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09:14   09:36
11:08   11:26
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18:21   18:41
20:12   20:34
22:10   22:25

23 Dec 1975
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08:15   08:37
10:09   10:29
12:03   12:16
17:26   17:41
19:14   19:35
21:08   21:28

24 Dec 1975
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09:09   09:31
11:03   11:21
12:59   13:04
16:32   16:41
18:17   18:36
20:06   20:30
22:05   22:21

25 Dec 1975
06:22   06:25
08:11   08:32
10:03   10:24
11:58   12:12
17:21   17:36
19:05   19:31
21:03   21:23

26 Dec 1975
07:13   07:30
09:04   09:26
10:58   11:16
12:54   13:00
16:28   16:35
18:12   18:31
20:03   20:25
21:55   22:16

27 Dec 1975
06:19   06:24
08:05   08:26
09:58   10:19
11:53   12:06
17:16   17:30
19:04   19:25
20:57   21:19
23:00   23:04

28 Dec 1975
07:07   07:24
08:58   09:21
10:53   11:11
12:48   12:55
16:23   16:30
18:07   18:25
19:57   20:19
21:53   22:10

29 Dec 1975
06:15   06:16
08:00   08:21
09:53   10:14
11:47   12:02
17:11   17:25
18:59   19:20
20:51   21:12
22:54   23:00

30 Dec 1975
07:02   07:19
08:54   09:16
10:47   11:06
12:43   12:50
16:19   16:25
18:02   18:20
19:52   20:14
21:48   22:06

31 Dec 1975
07:55   08:15
09:48   10:09
11:42   11:57
17:07   17:20
18:54   19:15
20:47   21:08
22:40   22:56
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Figure 1

Figure 1

Passes (midpoint) of AMSAT-OSCAR 6 during December 1975.
Observed from Baltimore, MD 39°N 76.7°W

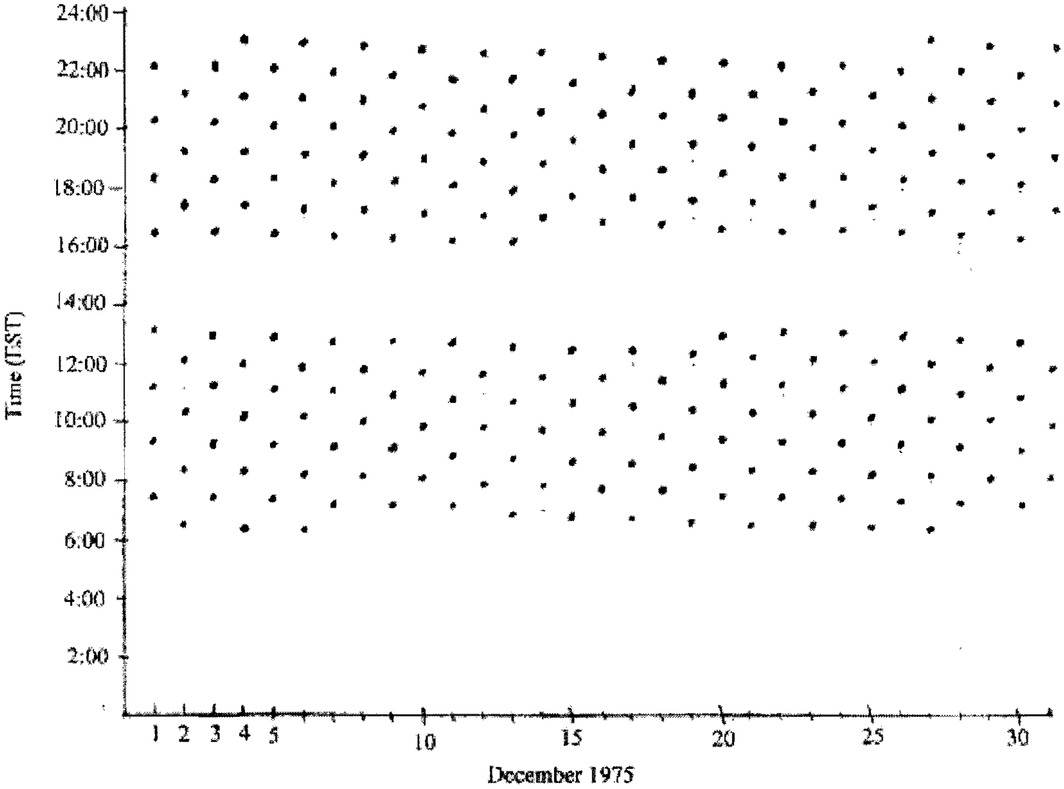


Figure 2

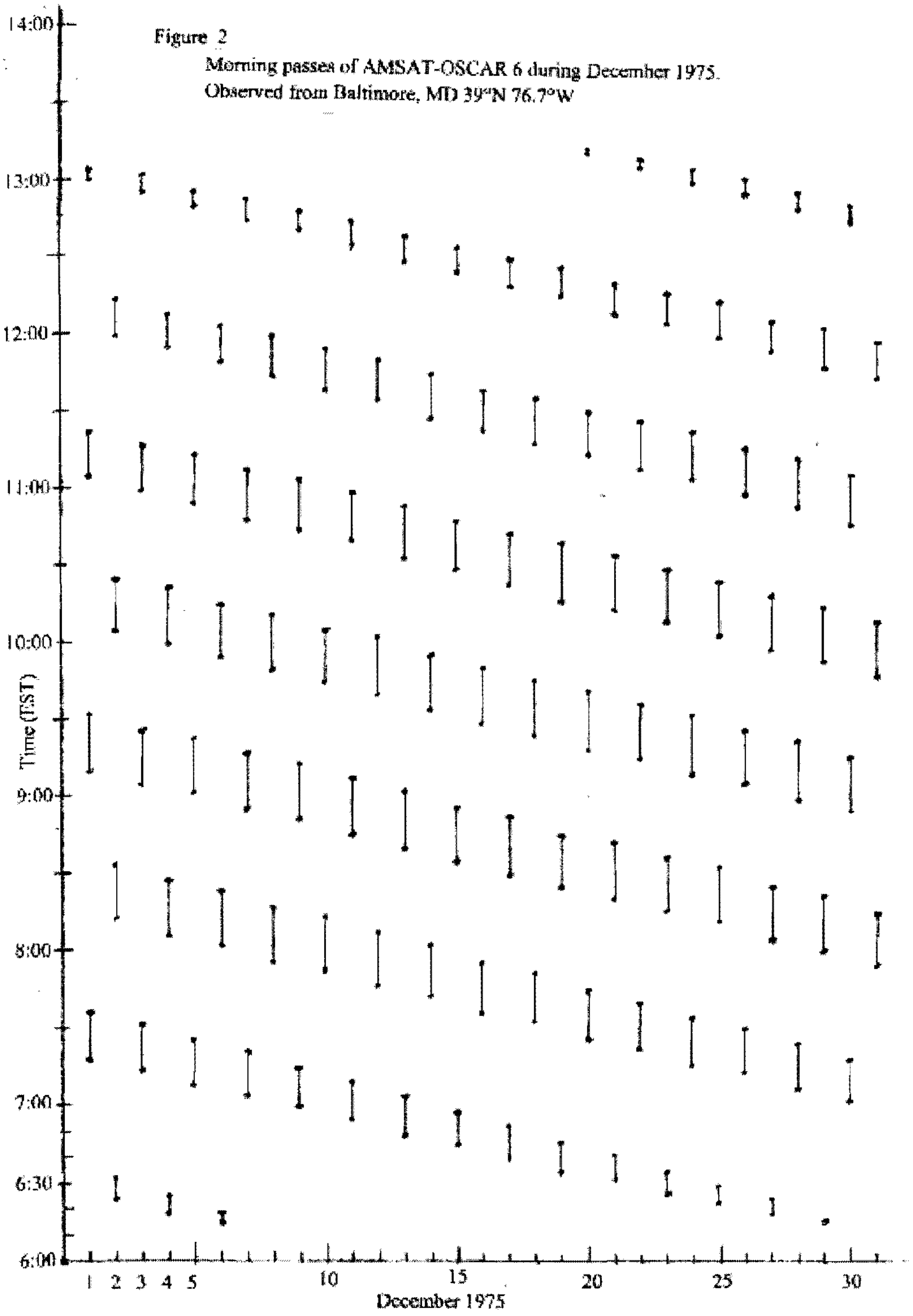


Figure 2
Morning passes of AMSAT-OSCAR 6 during December 1975.
Observed from Baltimore, MD 39°N 76.7°W

Edward Tufte, known for his work on extracting patterns from quantitative data, provides a foundation for understanding the activities of both The Kettering Group and the Maya.[8] One of Tufte's main points is that the search for patterns, often a key first step in the quest for scientific understanding, is a creative undertaking that deserves more emphasis, recognition and attention than it generally receives. There are several elements common to most search situations. These include: Do underlying patterns actually exist? What is one capable of measuring? Is this data sufficient to reveal the patterns? How can the data be stored over a considerable length of time? How should the data be organized and processed? Can one devise a presentation format that will summarize the data in a way that reveals the underlying patterns and how can this format be discovered?

The students at the Kettering school had access to very modest equipment – a short wave radio receiver similar to those used at simple radio amateur stations and a clock. Using these they noted the times when a satellite entered and left radio range. They could not reliably measure the direction from which the radio signals were being received nor the strength of the radio signals, and they had no idea of the contents of the information encoded in the satellite signal. Yet, as the example shows, once this minimal information is acquired and presented in an appropriate manner one is able to accurately predict when signals will again appear.

What could the Maya measure? Although New World astronomers are frequently characterized as lacking technology the truth is that that the narrow tubes and windows built into precisely oriented structures that remained in place for hundreds of years constituted a sophisticated technology. Structures like the Caracol of Chichén Itzá and the Palace of the Governor at Uxmal appear to have been designed, oriented, and located specifically for astronomical observations of Venus.[9] However, any building existing over a long period of time could be used to define a reference frame for astronomical measurements. From a fixed observation position one can with the unaided eye measure elevation and azimuth of Venus at, for example, its highest point during a night. For this purpose, angles measured in terms of equal size stones are as useful as those measured using degrees or radians for the metric. Although Maya could associate times with specific events, like sun or moon rise or set, or when the sun was at its highest point, there is no indication that they routinely used reproducible standard measures of elapsed time. So, we do not consider the possibility of measuring and recording azimuth and elevation on an hourly basis. The question is -- does, for example, measuring azimuth and elevation of Venus at the point of maximum elevation on a nightly basis provide enough information for recognizing patterns and making predictions?

From our 21st century vantage point we know that measurements of Venus would have to be made for a period of at least 1.6 years before recurring patterns began to be observed. (This is the time it takes for one complete cycle between a major conjunction of Venus and Earth). To discern patterns the Maya would have had to record data for at least two sun based years and then organize the data in a way that would reveal internal patterns. To uncover patterns with respect to the fixed stars would take about 8 years. The Dresden Codex describes events occurring over more than 33 years.

The Maya had several methods for handling the quantitative data required by their calendars, ceremonial events, and most likely for daily use associated with food distribution and taxation including carving numbers in stone, tying knots in strings, piling pebbles or beans, and hieroglyphic writing on paper like material. However, none of these methods seems appropriate for maintaining and manipulating thousands of data points over a period of years. Imagine encountering a greatly enlarged version of Table 1 encoded in hieroglyphs and trying to discern patterns.

Data Storage and Visualization

What the Maya needed was simple Cartesian graph paper like that used by the Kettering school students. What they had was a tradition of weaving. And, a weaving is in many ways equivalent to Cartesian graph paper.

To establish a connection between a weaving and a Cartesian graph we associate the warp with a vertical axis (column) and the weft with a horizontal axis (row). If we thread one or two wefts (horizontal lines) per night we have a graph of time (vertical axis) vs. the information encoded in the horizontal line. By dividing the horizontal axis into sections, each encoding a specific measured quantity, such a weaving can be seen as a composite of several parameters vs. time.

If, each night, a Maya shaman would encode certain aspects of that night's observations of Venus into one or more rows on a weaving, after a few years repetitive patterns would begin to appear.

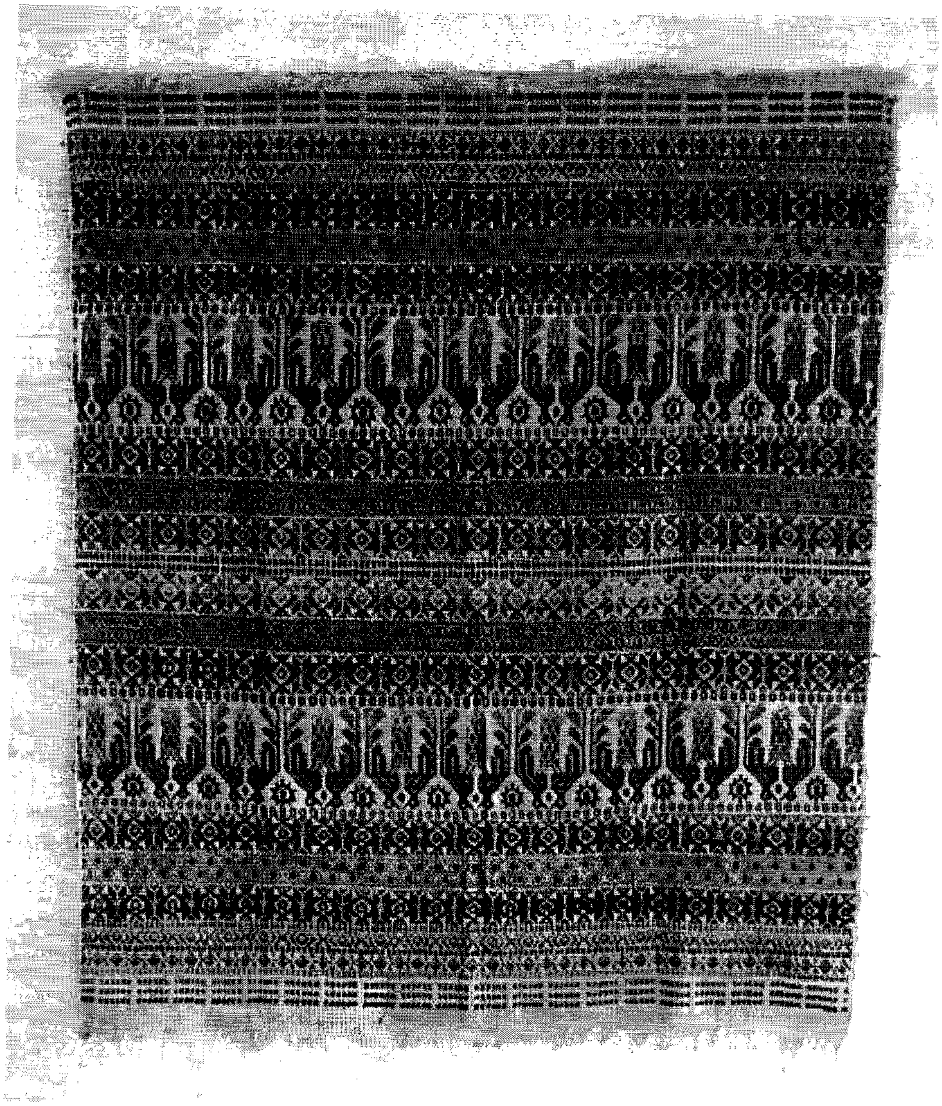
The data encoded in the weaving would be the data that could be observed by the naked eye. And, since the observer doesn't know in advance which parameters are critical, it would be desirable to encode as many as possible in the composite weaving. For example, segments (columns) could represent:

(1) whether Venus was visible as morning star,
(2) whether Venus was visible as evening star,
(3) maximum elevation of Venus over the course of the night,
(4) maximum azimuth east or west of a reference over the course of the night,
(5) maximum change in azimuth that transpired during the night,
(6) azimuth at time of maximum elevation,
(7) direction Venus was moving at its maximum elevation,
(8) moon phase which would serve as a time stamp.

Sample Mayan Weaving

Figure 3 shows a typical finely detailed weaving purchased in Tecpan, Guatemala in 2006. Although this weaving was acquired purely for its pleasing aesthetic qualities, and is not thought to encode data about Venus, its structure can provide information when considering the use of a weaving as a graph.

Figure 3



The weaving measures approximately 1.1 m by 0.9 m and has a weft density of approximately 7 double threads per cm. The design contains two types of obvious symmetries: displacement (both horizontal and vertical) and rotational (about vertical axes which are generally not shown explicitly). The rotational symmetries consist of two types: local (extending over limited horizontal region) and global (about center of weaving). These symmetries are probably for aesthetic reasons. However, it should be noted that if the vertical dimension of the weaving corresponds to a time axis then a vertical displacement symmetry represents a repeated observation pattern.

Can a weaving like the one shown in Figure 3 be used to encode sufficient information to make predictions about Venus and how is this likely to be done? With a weft density of 7 threads per cm one can encode 365 days of data in 52 cm so the weaving shown could easily encode data for at least one year. Local rotational symmetries could serve in place of multiple vertical axes to delineate columns representing different pieces of physical data. Each "invisible" symmetry axis would serve as a reference axis. I suspect that aesthetic concerns would lead the Maya to use symmetry to imply each of several vertical axes instead of actually exhibiting a vertical axis for each column of data.

Since astronomical information encoded in a weaving design would be a valuable commodity it's likely that the methods of interpretation would be a closely guarded secret and that such weavings would avoid obvious hints as to the true content. Therefore I would not expect weavings of interest to contain images of the heavens or the Venus star sign as seen at the ruins of Chichéen Itzá. Anyone viewing the weaving would just see a unique design, one likely to be favored by, and passed down through, a particular family or village. Also, since it's likely that at any time very few people would know how to decipher the information encoded in a weaving, it's possible that after several generations the decoding algorithms could be lost. The design itself could continued to appear because of family and/or village traditions and the interest in patterns among weavers and shamans as stressed by a museum curator in Tecpan.[10]

Testing the Hypothesis

As mentioned earlier, the ideas presented here are based on analogy, reverse engineering, and the Maya interest in patterns as evidenced in their weaving, pottery and calendar work. A plausibility argument is always tentative. However, the explanation offered in this paper is amenable to testing since one can search for evidence that could be used to confirm or contradict the central theme.

One possible approach is to use about 3.5 years (just over two cycles) of Venus data as observed from a terrestrial site at 15°N 90°W (current data is fine – there is no need to use historical data). Consider all parameters that the Maya could conceivably measure. The eight parameters listed earlier will serve as a starting point. Look for the simplest way of encoding each parameter. Plot each as a single Cartesian graph using the vertical axis for discrete (one day) time steps.

A set of such graphs can be related to the attractive designs seen in most weavings through the following steps. For each parameter, rotate the graph about the vertical axis to produce a symmetry axis. Delete the vertical symmetry axis (its location is now implied). Compress the figure horizontally to produce a column. Combine a set of such graphs by adjoining the vertical columns (i.e., set them adjacent to each other). Rotate the entire design (around left or right vertical edge) to form a global symmetry. The resulting pattern is generally very pleasing aesthetically and similar to that seen in many Mayan weavings. For example, the weaving shown in Figure 3 can be thought of as being composed of roughly five columns (in this case identical) of data. Note that it is relatively simple for a shaman to include these various rotational symmetries when adding a row to a weaving at the end of each night's observations.

Search for Mayan weavings that have similar patterns.

Final Thought

In Maya mythology the first responsibility of the goddess Chak Chel, wife of Itzamnaaj, the supreme deity, is weaving.[11] Could this association be more than just a coincidence?

Acknowledgement

The ideas presented in this paper are a direct consequence of the author's experiences while participating in "Maya Worlds: On-Site in Chiapas, Guatemala, Honduras and Belize"; June 18 – July 28, 2006; a National Endowment for the Humanities Summer Institute sponsored by The Community College Humanities Association. The Institute provided access to an excellent copy of the Dresden Codex at the Popol Vuh Museum in Guatemala City, a small archeological museum in Tecpan, Guatelmala [12], directed by a mathematics instructor with close ties to shamanism and a profound interest in the geometric patterns found in pottery and weaving, and presentations by art historians that emphasized recurring patterns associated with familial groups and or villages.

1. Coe, Michael D. The Maya, Seventh Edition, (London: Thames & Hudson, 2005), p. 211. ISBN-13 978-0-500-28505-3

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3. Aveni, Anthony F. Stairways to the Stars, *op. cit.,* Chapter Four "Power from the Sky: Ancient Maya Astronomy and the Cult of Venus".

4. Aveni, Anthony F. Stairways to the Stars, *op. cit.*, pp. 110 – 127.

5. Aveni, Anthony F. Stairways to the Stars, *op. cit.*, p. 102.

6. http://www.nytimes.com/2000/01/22/world/geoffrey-e-perry-dies-at-72-monitored-soviet-satellites.html?n=Top/Reference/Times%20Topics/People/G/Glanz,%20James&pagewanted=print
also see
http://www.space.com/peopleinterviews/jperry_obit_000120.html

7. It's interesting to note that during the early years the Kettering group did not publicize their methods. A key reason was that Perry, in order to support the ongoing work of his group, had signed an exclusive contract with London based Independent Television News (ITN) which restricted his ability to publish. Perry related details of the methods employed during an informal discussion attended by Leo Labutin (USSR RS satellite program) and this author at a conference on small satellite design at the Sixth AMSAT-UK Colloquium, 1991, University of Surrey, 25th-28th July 1991.

8. Tufte, Edward R. (2001) [1983]. The Visual Display of Quantitative Information (2nd ed.). Cheshire, CT: Graphics Press. ISBN 0961392142.

9. Aveni, Anthony F. Skywatchers, (Austin: Univ. of Texas Press, Revised Edition 2001), pp. 273 – 288. ISBN 0-292-70502-6.

10. Pakal B'alam Rodriquez Guajan, director of Museo Kumatzim Jay, 2a Calle 5-17, zona 3, Tecpan, Guatelmala.

11. Coe, Michael D. The Maya, Seventh Edition, *op. cit.,* p 216.
"His [Itzamnaaj] wife was Chak Chel, "Lady Rainbow," ... goddess of weaving, medicine, and childbirth; ... ."

12. Pakal B'alam Rodriquez Guajan, director of Museo Kumatzim Jay, *op. cit.*

SERVER SKY - Computation in Orbit

Keith Lofstrom keithl@ kl-ic.com http://server-sky.com 2009 September 28

Abstract

It is easier to move bits than atoms or energy. Server-sats are ultra-thin disks of silicon in earth orbit, powered by a large solar cell, propelled and steered by light pressure, networked and located by microwaves, and cooled by black-body radiation. Arrays of thousands of server-sats form redundant computation and database servers, connected by phased array antennas to millions of ground transceivers.

First generation server-sats are 20 centimeters across (about 8 inches), 0.1 millimeters (100 microns) thick, and weigh 7 grams. They can be mass produced with off-the-shelf semiconductor technologies. Radio chips provide intra-array, inter-array, ground communication, and precise location information. Server-sats are launched stacked by the thousands in solid cylinders, shrouded and vibration-isolated inside a traditional satellite bus.

The Computing Energy Crisis

Traditional data centers consume almost 3% of US electrical power, and this fraction doubles every five years [DATA]. Computer technology is improving - new hardware delivers the same computation for half the power of two-year-old hardware. The demand for computation increases more rapidly.

Most computing growth now occurs outside of the United States, in rapidly developing countries such as China. Some estimate that total computing power for the planet doubles every year, implying that world computing energy demand doubles every two. We are not constructing enough clean power plants to meet this rapidly growing demand. Global competition for diminishing fuel supplies may grow deadly in the coming decades. The U.S. may generate less power in 20 years, while data center and communication power grows to 40% of total load.

A likely outcome is power rationing. In the best case, virtualized computers will get smaller and smaller time slices on crowded hosts, increasing response time. While fiber internet to the home is capable of enormous bandwidth, the optical network terminals at the customer end and the switches and routers at the ISP end may be slowed down to reduce power, increasing response time.

Unless we learn from recent history, the actual outcome may be worse. During the California energy crisis, utilities reacted to high demand by shedding customers. Data centers are often powered with battery-backed uninterruptible power supplies, but these systems are limited, expensive, and inefficient. Data centers will shed compute load during blackouts, and go dark during long power outages.

Packets travel through dozens of switches between the data center and the end user. The internet is agile, and can route around failed links, but too many un-powered switches results in inefficient routes, increasing the load on the switches that remain. The result is an increasingly slow, unreliable, and unpredictable internet. As “smart power” grids become increasingly dependent on computing and internet communication to extract maximum efficiency from limited generation, we may get into deadly positive feedback loops, leading to cascading failure of the combined computing and generation grid.

Alternative energy systems such as ground-based solar photovoltaic intercept sunlight that otherwise feeds the biosphere. Generating the world's energy needs (estimated at 40 Terawatts by 2050 [SMAL]) with solar cells requires millions of square miles of solar arrays. The estimated roof area for the entire United States is about 30,000 square miles, and paved area is around 60,000 square miles [AREA]. Covering many times that area with solar collectors will cost more than all our roads and buildings. Most importantly, solar power goes away at night - storing 12 hours worth of electrical generation also requires huge amounts of infrastructure. Terrestrial solar is not a practical way to generate Terawatts of electricity.

The Sun fills space with 360 trillion Terawatts of unused energy. Space solar power satellites [SSPS] may someday capture some of this energy and beam it to earth. SSPS transmit antennas produce intense microwave beams, focused on large "rectennas" on the ground, which converted the power to electricity for the grid. If the satellites are in geosynchronous orbit, the beam-spread at the ground is large, requiring large rectennas.

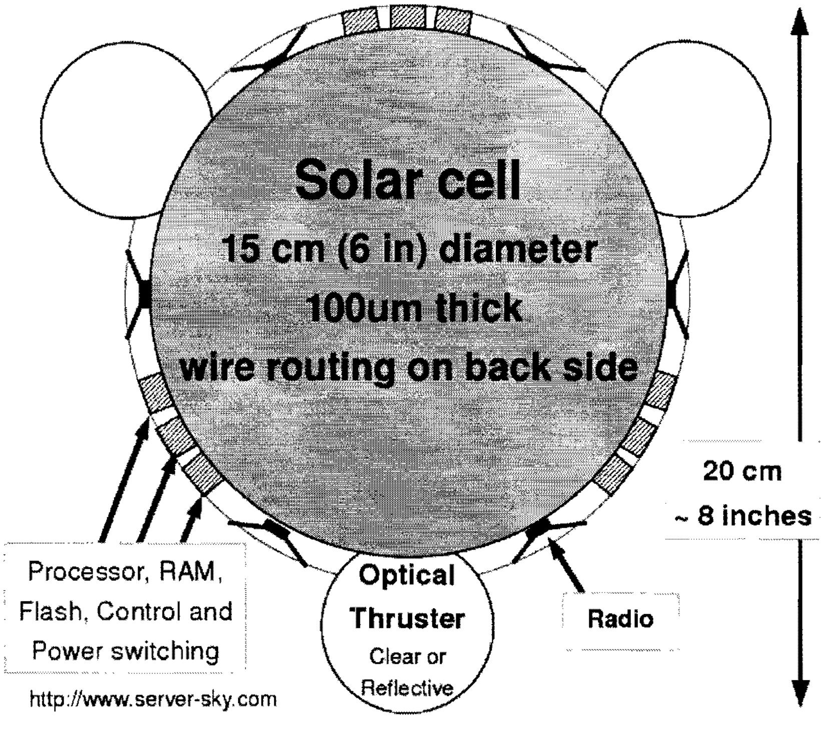
SSPS power could drive data centers. However, the path from orbit to end usage is inefficient, with losses from transmission, side lobes, power conversion, data center cooling, etc. A 20% efficient, one meter square solar cell in orbit intercepts 1300W of sunlight. Of the 260 watts of electricity produced, minus inefficiencies and the energy needed to supply and maintain the SSPS, perhaps 4% reaches the compute load in a data center.

Server Sky

What if the conversion steps between the solar cell and the compute load could be eliminated, and all 260 watts per square meter could be turned into computation? Moving the computer and the data center functions into space eliminates the intermediate steps Solar cells directly produce the high current, low voltage power that a modern CPU needs. The cost-effectiveness of space-generated power goes up by almost 30 times. If the data are radioed to and from points on the Earth, much of the power and resource-consuming communications infrastructure on the ground can be eliminated as well.

Server Sky computes with space solar energy. It strips away the mechanical structure, power transmission and conversion, and large power transmitters of a solar power satellite, so it is cheaper to launch and easier to make.

Server Sky builds many arrays of ultra-thin (100µm) 7 gram satellites. Each "server-sat" maneuvers by light pressure, and converts electricity from a 15cm (6 inch) solar cell directly into computation and radio transceiver power. Server satellites are mass produced by the millions or billions, and are launched in dense stacks with conventional rockets to a 6411 kilometer altitude orbit. The server-sats deploy into large arrays to form phased array radio beams that can address many small spots on the ground. Recent advances in distributed array computing, CMOS radiation resistance, error detection and re-computation, and electro-chromic light shutters allow server-sats to be manufactured cheaply with existing factories, some idled by recent economic troubles. Although expensive to launch, they will be vastly cheaper and more power-efficient than traditional satellites. Server sky infrastructure and power savings quickly pays for launch costs.



Server Satellites

Solar cells, integrated circuits, and interconnect are two-dimensional systems. Modern IC die are thinned to increase thermal conductivity and reduce package height. The target thickness for the first server-sats is 100 microns. 10,000 server-sats are stacked in a solid 1 meter column.

Decreasing server-sat weight reduces launch cost and makes a more effective solar sail. The current thickness target is 100 microns. Production silicon wafers are thinned to as little as 20 microns for some applications. 100 micron thick silicon is flexible, and can be rolled to diameters less than a centimeter without breaking. Future server-sats may become thinner than 10 microns, weighing less than a gram.

Server-sats are uniformly planar, for stacking during launch. The integrated circuit chips are arranged around the edge, and power feeds outwards (in separated zones) from the solar cell. If a portion of the solar cell shorts out or is otherwise damaged, the remaining circuitry still works.

Electronics: Large databases will be distributed over many server-sats. A server-sat used for database or web service may need as much as a terabit of flash memory. That is about 20 cm^2 of silicon area. Computational server-sats need much less. While some high-performance processors and chip-sets use hundreds of watts, Giga-instruction-per-second level machines can get by with far less. For example, the PC Engines ALIX, based on the AMD X86 Geode processor, is a complete 4 watt system (including IO and power conversion losses) with 990 bogo-MIPS performance [ALIX] . Optimized server-sats can do far better.

Because the server-sat is very thin, some common electronic components cannot be used: electrolytic capacitors, cored inductors, etc. Components such as crystals for oscillators may be replaced by surface acoustic wave (SAW) devices and MEMs resonators. Processors and radios can be operated at low voltages and low impedances. If some devices need higher voltages at trickles of current (such as LCD electrodes) they can be powered with capacitive charge pumps. At microwave frequencies, resonators can be made from strip-lines.

A server-sat uses a small array of radios (many more than the six shown) to communicate with neighbors in the array, with other arrays, and with the ground. Server-sats measure radio propagation time to neighbors to accurately compute spacing and orientation, with additional location information provided by other arrays, ground stations, and GPS. Multiple bands will be used, with atmosphere-penetrating bands used for down-links, and atmosphere-opaque bands used for server-sat to server-sat communication. Server-sats do *not* have dishes, but act together as a phased array antenna. A server-sat array in a 4 hour orbit is 7 times closer than a geosynchronous com-sat, so there is a 50x advantage in beam power and ground spot area. Round trip ping time to mid-latitudes is 70 milliseconds, less than U.S. transcontinental ping time through optical fiber.

Light Pressure and Optical Thrusters

Server-sats maneuver by light pressure. Solar illumination is 1300 Watts per square meter at the Earth's distance from the sun. For absorbed light, the light pressure is the power divided by the speed of light, about 4E-6 N/m^2 or 4 micro Pascal. If the light is reflected, the pressure doubles to 8 micro Pascal. The pressure is tiny (sea level atmospheric pressure is 100 kilo Pascals) but it is continuous. Light pressure pushing on a small, low-mass server-sat can add significant velocity over hours, weeks, and years. The areal density of a 100 micron thick server-sat is $0.233 kg/m^2$, and the albedo of a solar cell is around 0.15. The acceleration is approximately 20 $\mu m/sec^2$, or 7 cm/min^2, or 256 m/hr^2. That permits significant local maneuvering.

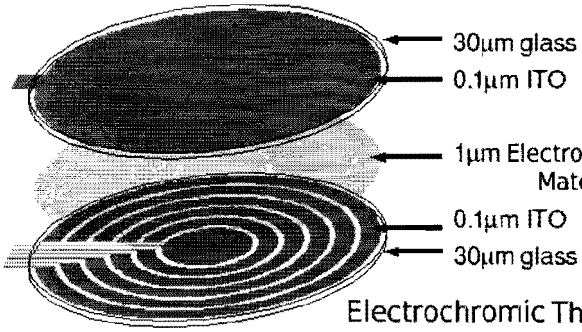
Large orbital changes are harder. Server-sats are in orbit, and light pressure accelerates them directly away from the Sun. That adds to orbital velocity as their orbit takes them away from the sun, but subtracts from orbital velocity as they approach it. If they are tilted in relation to the sun, less area is exposed to light pressure, and the "albedo vector" of reflected light tilts also, which adds a small sideways thrust.

Server-sats get the most power if they face directly into the sun. They tilt to maneuver. and that reduces the thrust. A 45 degrees sideways tilt produces 30% less power for computing and radio functions, which accommodate by slowing down. A 60 degree tilt produces half power (cooling significantly). The server-sat also absorbs infrared light from the earth, creating additional light pressure.

The version 2 design has three round optical-shutter light-pressure thrusters at 120 degree angles around the periphery. These are either reflecting or transparent. They are 5 cm in diameter, about 2 inches. An ideal thruster produces 16 nano-Newtons when fully reflective, and zero thrust when transparent. Real materials show some reflection in transparent mode, and some transparency in reflective mode. Earth radiation (albedo and infrared) also reduces the effective thrust.

Achievable thrust may vary between 4nN and 12nN (WAG) per thruster. If a thruster on one side is reflective, while the other two are clear, the thrusters together produce a torque of 8nN times 10 cm or 800 pico-Newton-meters. If the entire server-sat has a mass of 7g and an average radius of 8 cm, the angular acceleration is 70 micro-radians per second squared. Accelerating for 36 seconds, then decelerating (applying opposite acceleration) for 36 seconds, turns the server-sat 10 degrees. Accelerating for 90 seconds, then decelerating for 90 seconds, turns the server-sat 60 degrees (not quite, as the thrusters are moving out of plane and become less effective when turned away from the sun). Roll control is indirect, by combinations of pitch and yaw [SSAT].

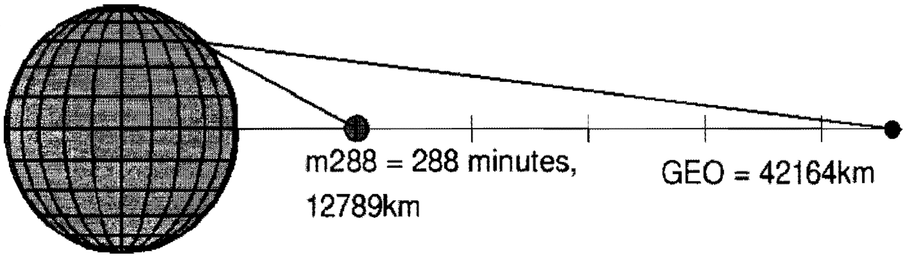
Optical thrusters are made from two thin (30 micron) layers of glass coated with of transparent Indium Tin Oxide (ITO) conductor on inner surfaces. The bottom layer glass is coated in separately controlled strips to permit partial functionality in spite of top to bottom shorts. In typical applications, a 1 micron gap is filled with electro-chromic shutter material and 1 micron diameter glass beads. A different spacing may be chosen if that improves performance or survivability.



Electrochromic Thruster

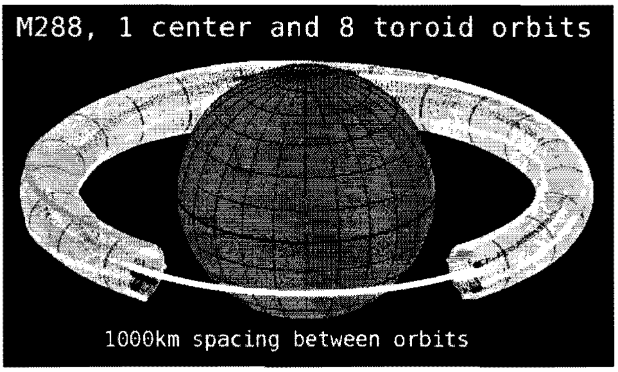
Correcting for tidal forces: At the four "45 degree" points in the orbit, tidal forces accelerate the server-sat. The near end is pulled inwards by slightly more gravity and slightly less centrifugal acceleration, and the far end is pushed outward by slightly more acceleration and less gravity.

For thin, low-mass server-sats, optical thrusters are more powerful than tidal forces, and easily keep the server flat towards the sun. The maximum angular acceleration of the server-sat is $\ddot{\theta}_{max} = (3/2)\omega^2$ or 0.29 μradians/s^2 for the m288 orbit, while the 5 cm thrusters can provide angular accelerations of 70 μradians/s^2 to a 7 g server-sat. The first experimental server-sats can be thick and heavy, up to a kg or so, but their altitude must be high enough so that light pressure exceeds residual atmospheric drag.



Deployment Orbits

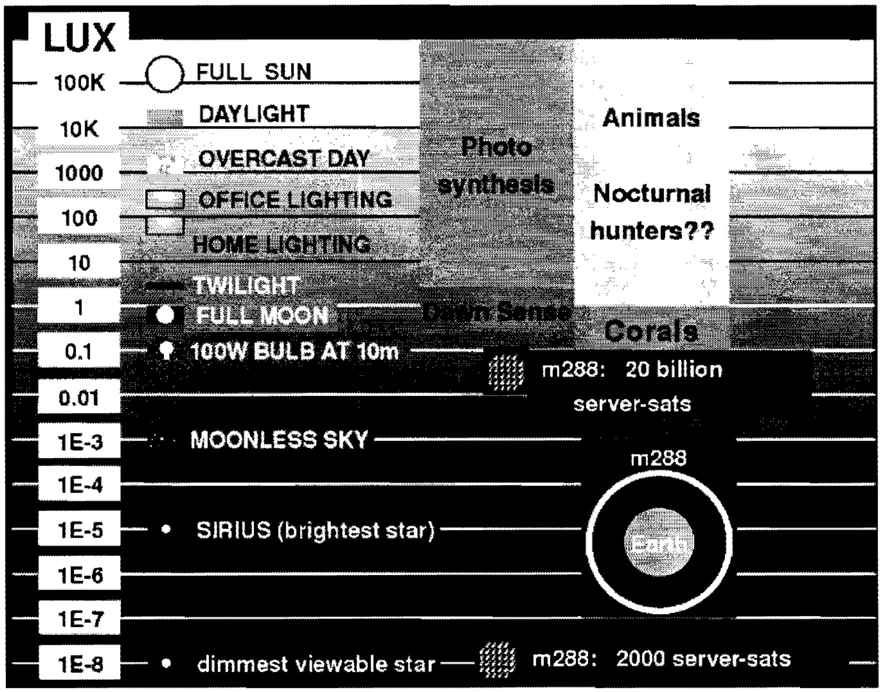
The first server-sat arrays will be deployed in a "4 hour" equatorial orbit, or more precisely a 14360.7 second sidereal orbit. This orbit passes over the same spot on earth 5 times per day (= 6-1, the earth turns underneath once per sidereal day), for a repeat time relative to the ground of 288 minutes (an **m288** orbit). A 4 hour equatorial circular orbit has a radius of 12789 kilometers, and an altitude above the equator of 6411 kilometers. This puts it in the "gap" of the Van Allen belt, with an estimated unshielded radiation dose of 1Mrad/year [citation needed]. Higher and lower orbit constellations are possible, but have higher radiation doses. Periods that are integer fractions of a day simplify launch and communication logistics.



Defining "property" within the m288 toroid: Many orbits can be mapped on toroids surrounding a central orbit. If they all have the same semi major axis as the m288 central orbit, they have the same 288 minute synoptic period. If the orbits are mapped correctly, every object in them maintains the same approximate spacing to neighbors in three dimensions, even as the whole constellation makes one orbit around the earth and one axial rotation around the central orbit. This allows very large numbers of server-sats to be deployed in the 600 million cubic kilometers of m288 server sky. Properties can be assigned much like ICANN assigns IPV6 address space. Indeed, we may map IPV6 addresses onto particular orbital volumes, and know where in the sky a particular server-sat is from its IPV6 address, or vice versa. 60 bits of address space maps to 1 meter cubes.

The m288 central orbit can be seen at 58 degrees north and south latitude, at a distance of 10500 km. The round trip ping time to 58N is 70 milliseconds. The ground ping time through optical fiber across the United States is faster in theory, but ground networks are slowed by switches, the slower speed of light in glass, and indirect routes. Some server sky packets may route "around the cloud". Without local caching in the "near" arrays, some pings may need 200 milliseconds to reach the far side of the orbit. This is still better than the 250+ millisecond ping time through a geosynchronous satellite, and up to 600+ milliseconds for multiple-satellite hops.

Night Side Temperature: When a server-sat orbits into the night side of the earth it shuts down. Thermal radiation from the earth's night sky heats it, and deep space cools it. At m288, the night temperature of the server-sat drops to 127K (-146C). Higher orbits have colder and longer "nights" and much longer "days".



Nighttime Illumination: Server-sats reflect some light. Oriented directly at the sun, most of the light reflects back towards the sun, but some will diffuse off angle. The sum of the diffuse reflected light from billions of server-sats may appear as cloudy light in a thin band around the equator, interrupted by the Earth's shadow.

Normally, the array will be under control, and night-side server-sats will be oriented to reflect incidental light away from the earth. Front surface treatments will reduce night-time illumination further. However, circumstances change, civilizations collapse, and the server sats may stay in orbit for millions of years, long after we lose the ability to control them. In the worst case, micro-meteor bombardment may damage surface treatments, and server-sats could tumble and scatter light in all directions.

Life evolved to adapt to existing cycles of day and night, full and new moon. Light pollution can alter this balance drastically, and perhaps destroy major ecosystems. The total number of server-sats in at m288 will be limited by **light pollution** and its effects on **corals** and **nocturnal animals**. Corals spawn synchronously to the monthly moonlight cycle, triggered by some fraction of full moon light. Confusing that process with light pollution could kill coral reefs, vast swaths of ocean life, and damage the oxygen generation processes that keep us alive. This may limit the **near-earth constellation** to less than **20 billion server-sats**. This problem needs more study, with oceanographers, botanists, and astronomers helping space engineers determine safe limits.

Deployment at the earth-moon L3, L4 and L5 Lagrange points reduces light pollution by 3600 times. These locations are 120 degrees apart, and follow the monthly lunar cycle. Three constellations of 5E12 server-sats will reflect 3E13 watts, and shine with 2% of the brightness of the full moon, in worst-case out-of-control conditions.

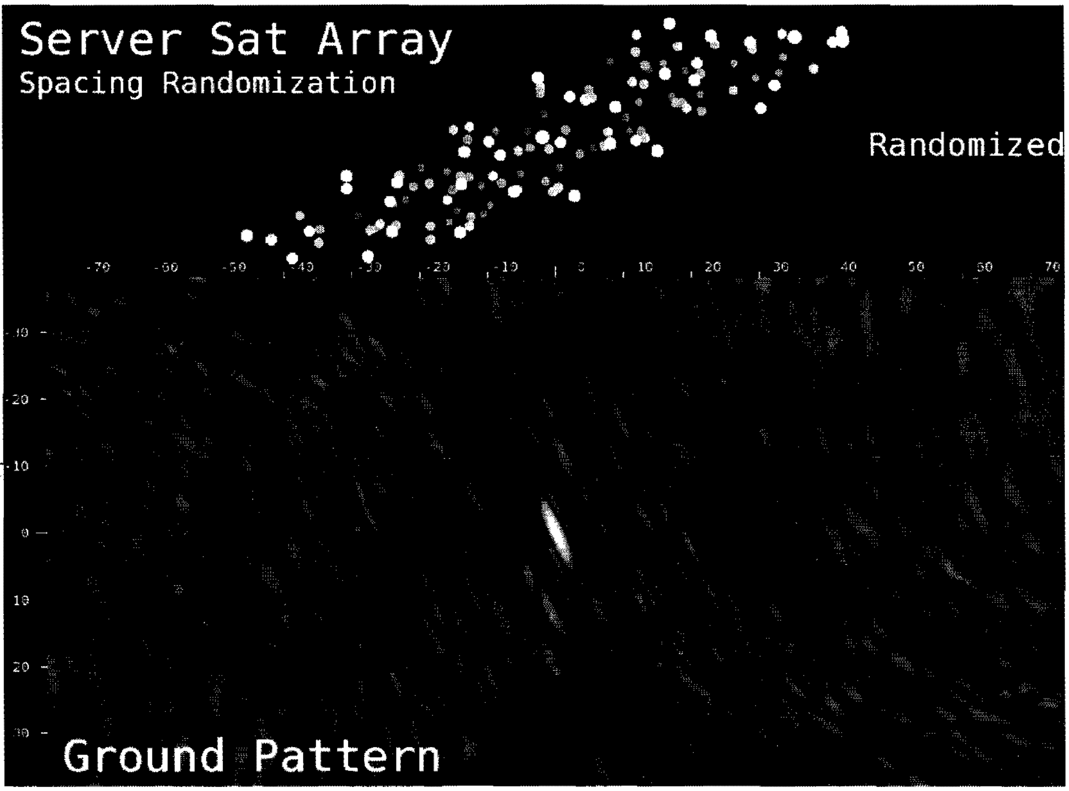
Radio Arrays

Server-sat radios will have multiple low-power outputs and connect to many printed-circuit antennas and resonant impedance matching structures. They will talk on multiple bands, for downlink, uplink, femtosecond-precision array timing, micron-precision server-sat location and orientation within the array, and orientation to other arrays and to GPS and ground systems. Accuracy derives from continuous monitoring and averaging, differential and quadrature analog signal processing, and the ultra-low vibration and perturbation of a completely predictable nano-gee space environment.

Down-link communications: As a new service, server sky may be allocated EHF frequencies [EHF] for the down-link. Assuming a frequency of 38GHz and a wavelength of 8mm, each individual server-sat antenna array can direct radio energy into an angle of about 6 degrees, for a 600km ground spot.

Server sats in **phased arrays** are more directional. Arrayed transmitters can beam the sum of many different phased signals to city-block-sized ground spots. The I and Q signal for each element is computed from the sum of many base-band signals representing different spatial channels. Digital vector processors combine many data channels and compute phased sums at high speed, recomputing transmit angles to accommodate the movement of the orbiting array relative to the ground (angles change 21 micro-degrees per millisecond).

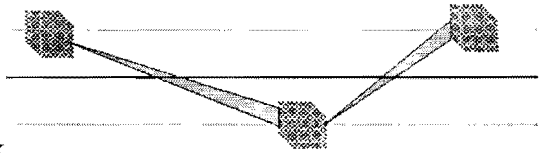
Three Dimensional Phased Arrays: Server Sky server-sat arrays are widely spaced relative to the radio wavelength. Array spacings are large compared to a radio wavelength, so they can scatter side-lobe energy into grating lobes. However, the spacing in the array can be continuously adjusted in 3 dimensions and 3 rotations, while avoiding radio and solar shading.



The brightest grating lobes can be smeared out and flattened by **randomizing** the spacing of the server-sats in the array, as shown in this **intensity plot.** This has the same effect as a sparsely populated array of much more closely spaced server-sats. A larger array suppresses the "clutter" noise by the square root of the number of server-sats. Precision maneuvering of the server-sats permits accurate random spacing, but a careful study of non periodic spacing functions will likely lead to a flatter spatial noise floor

Server sat arrays will communicate from satellite to satellite with individual high bandwidth 60 GHz beams. All the satellites within an array will need precision timing information, and each will get copies of receive and transmit packets for computing the phased array beams.

Communication between arrays will be difficult - not technically, but primarily due to licensing. The server-sky orbits will be approximately in-plane with equatorial communication satellites, which also use in-plane methods to communicate. This means that beams between server-sky arrays continue beyond the server-sky orbit and up to GEO, causing interference with receivers there.



This can be partially ameliorated by using very narrow, **oblique**, and fractional-orbit beams between server-sat arrays, such that the beams are pointed well above or below the orbital plane, and relatively weak when they reach GEO altitudes anyway. Space-to-space communications can use the 60GHz band, where the atmospheric absorption of oxygen is high. This isolates the space links from potential jamming on the ground.

The speed-of-light propagation time around the ring is 136ms. If packets are 1400 bits and running 10Gbps, the packet time is 140nsec. Assume that switching, re-route, queuing and beam forming time add a latency of 5 microseconds to each relay. 1000 hops adds only 5 milliseconds or 4% to the path latency, permitting an array spacing of 41 km. The increased path length of the diagonal adds more delay. If the oblique beams pass out of the ecliptic at a 19° angle (avoiding geosats), they add 6% to the total delay. As arrays get denser and larger, the beam size gets smaller, but inter-array traffic increases faster than the number of communication paths.

Ground communication via other satellite services: Server-sky operates near the equatorial plane. This restricts its usefulness for communications to ground sites at latitudes below 58 degrees, which precludes much of northern Europe. Existing services like Iridium, Globalstar, TDRSS, and the many satellites in GEO may be used as relays to extend the reach of the array, if permitted by the geometries and transponder configuration of these existing satellites.

Radar - locating space debris: The server sky array can help locate space debris and other satellites. Server sat antennas are too noisy and non-directional to make good radar receivers. However, they make dandy transmitters. Working in conjunction with existing radar satellites and ground stations, server sat arrays produce tight beams with high power density. Reflections off small bits of space debris can be detected by optimized radar receivers This permits accurate location and characterization of much smaller debris objects.

Orientation to other arrays, GPS, and ground stations: Server sky is blind. It does not have star trackers or ring laser gyros. It may have some MEMs gyros and accelerometers, but those are fragile and expensive to develop and the thinning needed may cost too much for Commercial Off The Shelf (COTS) devices. However, server sats can estimate the sun angle from solar cell output. Surface gratings can be added to sense sun direction. An isolated server-sat has some limited optical orientation capability.

A server-sat's main "sense" is radio. It shares timing information neighboring server-sats, permitting precision orientation and location computations. It can also measure signals from ground stations and GPS. Modulated radio and sub-wavelength fringes are used in commercial surveying equipment to measure distances with high precision. Server-sky does the same with the 60GHz intra-array communication links. If a server-sat measures phase within 1 degree at 60GHz, it can locate its many antennas with 20 micron accuracy. Continually upgraded software improves measurement capabilities.

Server Sat Mechanical Behavior

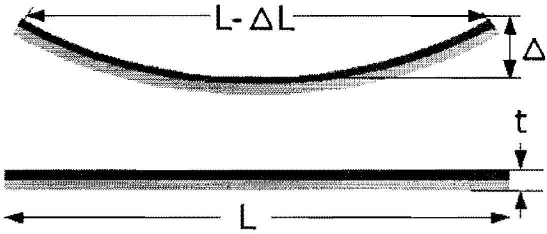
Silicon is the construction material of choice. The solar cell is silicon , as are the processors and memory. Since the server-sat undergoes wide temperature changes when it passes in and out of shadow, or undergoes thermal annealing, reliability improves if the non-silicon portions are made of composite materials that match silicon's 2.6E-6/K coefficient of thermal expansion (CTE).

Server sats need transparent materials and conductors that closely match silicon. The metals have very high CTEs, while SiO2 has a very low CTE, so slotted metal wires with SiO2 in the gaps can make a "material" that is both conductive and has the same CTE as silicon.

Stack compression during launch: Booster systems vibrate during launch. Regions of higher and lower compressibility and mass density may result in standing waves and resonances in a stack of server-sats. An ideal design matches the mechanical properties of all the materials used. The materials should have the same ratio of compressibility (modulus) to mass density, that is, the same speed of sound. This minimizes shear forces on the connections from the solar cells to the electronics and thruster ring. Stacks may also be resonance isolated from the boosters with springs and spacers, reducing the payload fraction. Mismatches restrict the number of server-sats that can be stacked between spacers.

Matching to **glass** rather than silicon may be better. Borosilicate glass has a speed of sound of 5.3km/s, silicon has a speed of sound of 8.0km/s, and pyrolytic carbon has the very low speed of sound of 1.5km/s. Thinning the silicon from 100 microns to 95.8 microns, and replacing the remaining 4.2 microns with pyrolytic carbon, results in the same 5.3km/s average speed of sound as glass. The "elastic impedance" is proportional to the energy stored by propagating sound. Sound waves reflect at impedance discontinuities. The impedance of borosilicate glass is 11.9 $\mathrm{Kg/mm^2s}$. Composite silicon-pyro-C is 12.4 $\mathrm{Kg/mm^2s}$. The composite also has 50% better thermal conductivity than silicon, because pyro-C is an excellent thermal conductor.

Curling occurs if the front and back sides of a server-sat (especially the solar cell) have different CTEs. The server-sat undergoes repeated thermal cyclings. There is nothing inherent in a server-sat that establishes "flat" - it flexes until tensions and compressions are minimized.



A slightly curved server-sat is not a severe operational problem. Turning up the edges a few degrees has little effect on collected solar energy. However, substantial curling changes the spacing of the radios at opposite sides of the curl, lifting them above the plane of the radios at the center of the curl.

Assume two materials with equal thickness and Young's moduli (the worst case for curl). Defining β as Δ CTE $\times \Delta T$, then the curl is approximately $\Delta L \approx (1/6) \times (\beta/t)^2 \times L^3$ and $\Delta Y \approx (1/4) \times (\beta/t) \times L^2$. A 150 millimeter solar cell, 100 microns thick, with ΔCTE =1E-6 and ΔT=100K, will have ΔL=0.56mm and ΔY=5.6mm. Server-sats should be designed for better CTE matching by balancing layer stack on both sides of the silicon, optimizing β towards zero. Work hardening should also be matched; materials that stretch and un-stretch repeatedly will deform over time, and this can also curl a server-sat.

Radiation

The M288 orbit (4 hour sidereal, 5 orbits per day relative to the earth) is located between the inner and outer van Allen belts. This is a high radiation environment compared to low earth orbit. Ionizing radiation damages semiconductors and data: Latchup, Single Event Upsets (SEU, bit flipping), oxide charging , and flash memory errors. Traditional satellites are damaged by this much radiation, and there are few satellites operating in these orbits. Server sky resists these effects.

The space radiation environment is well characterized with computer models such as AF-GEOSPACE [AFGE]. Radiation effects are tested empirically in ground laboratories, at high dose rates, and extrapolated to years of space radiation exposure. Ionizing radiation does nasty things to semiconductors, including latchup, gate oxide charging, and Single Event Upsets (SEU, bit flipping).

Latchup: SCR paths do not activate if the supply voltage is less than a diode turn-on voltage (typically more than 0.7V). The electronics in a Server-Sat are powered by a single-junction solar cell, which is a large forward-biased silicon diode. It cannot produce more than about 0.6V. Server-sats do not latch up!

Gate Oxide Charging: Silicon dioxide develops a positive charge when irradiated. An ionizing particle passes through, and generates hole-electron pairs. The electrons are highly mobile, and diffuse or drift out, while the holes get trapped, and leave a positive charge. Hafnium oxide develops a negative charge, trapping electrons. Recent work by Dixit [DIXI] shows that a combination of both materials produces a rad-hard gate oxide stack, withstanding 10Mrad from a Cobalt 60 source with minimal shifts.

Single Event Upsets: The charge deposited by an ionizing particle can temporarily overwhelm a logic gate, or change the state of a register bit. This causes incorrect computations. Sometimes, the cost is small. A calculation error in the I and Q signal of a software defined radio creates a little noise. CPU state errors are more costly. RAZOR error correction technology [RAZ] is being developed by the University of Michigan, MIT, and Intel. Digital integrated circuits are typically designed for high "noise margin", with extra power and voltage swing added, and clock rates reduced, to reduce the chances of a logic failure to infinitesimal probabilities. RAZOR reduces the noise margin, greatly improving the performance, at the cost of frequent errors. RAZOR adds error detection circuitry, and repeats calculations when errors occur. The performance improvement exceeds the cost of extra calculations, doubling overall performance. RAZOR technology will be common in microprocessors in a few years. Radiation-initiated single event upsets may be detected and corrected by RAZOR-like technology.

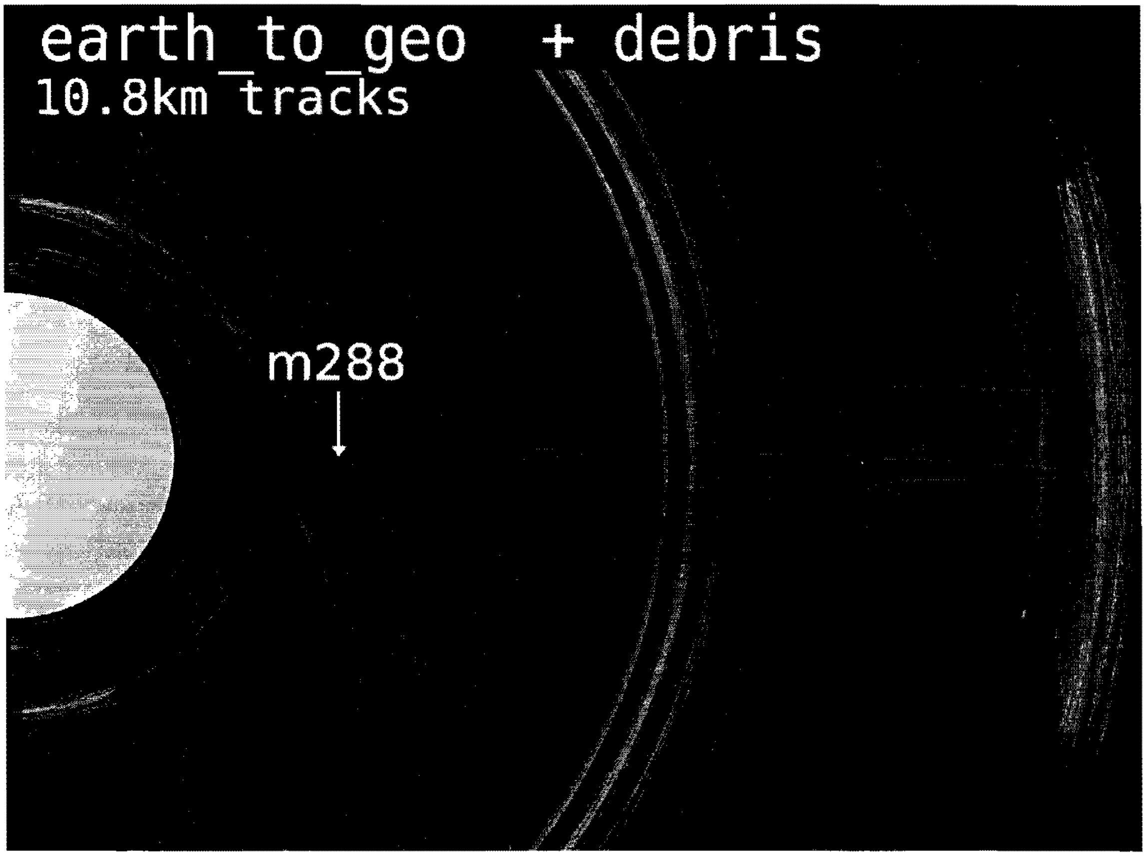
Space Junk and Debris

Collisions are a problem, especially for arrays like server sky which put huge numbers of assets into carefully defined and controlled orbits. Server Sky cannot be permitted to come close to such expensive assets as the Iridium communication satellites. The consequences of a collision are too costly.

Server-sats are cheap, and destroying one in a collision is unfortunate but not expensive. The main cost of a server-sat collision is more space junk, which can damage other server-sats. More robust objects (like traditional big-iron satellites) encountering server-sat fragments may lose a solar cell or two on the skin, but won't be destroyed. Still, it is bad manners to add to the debris problem.

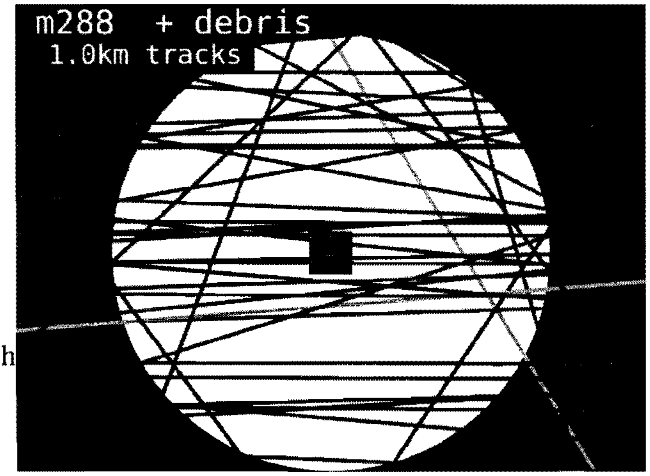
Server-sats can be maneuvered out of the way of accurately predicted collisions. Light pressure provides an unlimited supply of low thrust - in few hours, they can change orbit more than a kilometer away from a tracked impactor. Server sky will be deployed in orbits higher than most space junk. The vast majority of space debris is in lower orbits - it requires high launch velocities to even reach those altitudes.

This plot shows objects tracked by NORAD in orbits up to geosynchronous altitude. This is an "HV" plot. The horizontal H component represents the radius in the equatorial plane, and the vertical V component represents the distance north or south of the plane, of the locus of each orbital track.



The distances represented by the plot are vast - 44000 kilometers wide, 33000 kilometers high, more than 10 times the land surface of the earth. The volume of space represented is enormous, 200 trillion cubic kilometers, or 400 thousand times the volume of atmosphere in which we fly all the world's airplanes. Except for the bands of navigation and communication satellites above LEO, the density of tracked objects drops off exponentially with altitude. The collision problem decreases greatly at altitudes above 1000km.

This plot shows just the m288 region. The square in the center of the plot is 10 kilometers on a side, as big as the city of San Francisco. If Server Sky orbits are threaded through the white spaces, they will <u>never</u> encounter a NORAD-tracked space object.



NORAD does not track everything, especially small sub-centimeter objects difficult detect with ground-based radar. Orbiting radars can do better using very short wavelengths and large aperture antennas. Until that detailed mapping is available, unavoidable collisions will occur. Centimeter objects that merely destroy a solar cell or two on a large satellite may shatter a server-sat. Perhaps server-sats can be designed to survive a sub-centimeter collider passing through them. If a collider only hits one segment of the solar cell, the server-sat can keep functioning at lower power.

Possibilities

Long term speculation follows. We can bypass many limits to growth by moving more computation, communications, power production, and manufacturing into space and away from the biosphere.

Tera scale Arrays and Beam Power: Big compute jobs like weather prediction or animation rendering are not real-time. Larger latency is tolerable. Server-sats in the Earth-Moon Lagrange positions are 60 times further away from earth than m288, so they produce 1/3600 of the worst case night-time illumination. Trillions of server-sats may be deployed in the Lagrange positions, with round trip ping times of 2.5 seconds. Later generations of server-sats may become "compute-light" and "transmit-heavy", beaming the power as microwaves to rectenna arrays on the ground, making power for the electrical grid.

Lunar Materials: Most of the mass of a server-sat is silicon, glass, and aluminum, which are the principal constituents of lunar rock. Integrated circuits will be made on earth for a long time, but lunar-manufactured solar cells are a possibility. A cubic meter of lunar regolith could be used to manufacture perhaps half a million 3 gram solar cells, which could be mated to earth-manufactured integrated circuits in an automated facility in orbit. Orbiting those server-sats with an electromagnetic launcher requires about 18 billion joules, energy they can produce in 10 hours. Astoundingly rapid investment payback is possible with lunar materials.

Deep Space Arrays: Server-sats orbiting between Earth (1.5E11 meters from the sun) and Mars (2.3E11 meters) could capture much of the light of the sun. Server-sats at 1.9E11 meters distance from the sun, receiving 800 watts per square meter, have an equilibrium temperature of 270K. If they cover 2% of the sky, they raise the average deep sky temperature from 2.7K to 100K, which raises the Earth's equilibrium temperature by 1C. These septillions of server-sats can generate 1E24 watts of usable electric power for computation and space manufacturing, millions of times the solar power received by the Earth.

Low cost launch: The launch loop [LOOP] is an electrically powered earth-to-high orbit launch system. The main construction and operating cost of a launch loop is electricity. At 10 cents per kilowatt hour, and a quick payback of capital, a launch loop can put a kilogram into orbit for about $5, and a small launch loop can launch 80 tons into high orbit per hour.

A 7 gram, 2 watts-to-ground-collector server sat can be orbited for 12 cents. Collected by a rectenna for 5 cents per watt, with a lifetime of 20,000 hours, a one dollar investment produces 100 kilowatt hours. This cheap electricity drops the cost of further launches. Thinning the server sats down to 1 gram saves more.

Conclusions

Server-sky is speculation. There are many unsolved problems, and more will appear during implementation. Fortunately, the problems encountered so far have shown signs of solution. With enough imaginative contributors, other problems and solutions will emerge, often from unlikely places elsewhere in the world.

Server-sky may be the near-term commercial application that pays for the permanent expansion of life and civilization into space. It may also save the biosphere from destruction, by removing large scale computing and power generation from it.

Server sky is open technology. The idea will affect the entire world, and the world must be engaged in doing it right. Working together, we will succeed.

References

[AFGE] **http://www.kirtland.af.mil/library/factsheets/factsheet.asp?id=7899** AF-GEOSPACE is a collection of programs that model the radiation environment near earth

[ALIX] **http://wiki.keithl.com/index.cgi?SL5Alix** The 4 watt ALIX board from PC Engines, using an AMD Geode X86 processor, producing 900 bogo-MIPS performance.

[AREA] **http://www.osti.gov/bridge/product.biblio.jsp?osti_id=764362** An estimate of road and roof area in the region around Sacramento; multiply by the population ratio of 230 for the US. WAG.

[ATOM] **http://www.intel.com/products/processor/atom/** Intel Atom low power processor.

[BEKE] **http://www.thespacereview.com/article/131/1** Advanced Space System Concepts and Technologies: 2010-2030+, Ivan Bekey, 2004.

[DATA] **http://www.energystar.gov/index.cfm?c=prod_development.server_efficiency_study** E.P.A. estimate of data center power usage.

[DEBR] **http://apollo.cnuce.cnr.it/rossi/publications/iau/node2.html** A 1994 estimate of space debris. There is more now, but it follows the same pattern.

[DIXI] **http://www.isde.vanderbilt.edu/content/muri_2008/dixit_muri2008.pdf** Sriram Dixit et. al. at Vanderbilt University. Recent work on HfO/SiO2 stacked gates and radiation resistance.

[EHFR] **http://en.wikipedia.org/wiki/Extremely_high_frequency** 30 to 300GHz. Short wavelengths permit better focusing, and are above most communication bands, facilitating license assignment.

[HOTB] **http://en.wikipedia.org/wiki/Hot_Bird_9** Hot Bird 9, a modern TV direct broadcast communication satellite.

[LOOP] **http://launchloop.com** The Launch Loop wiki website.

[RAZO] **http://deepblue.lib.umich.edu/handle/2027.42/62283** Razor II variability tolerant computing design.

[SMAD] **http://www.smad.com/about/smad3.html** Space Mission Analysis and Design, Wentz et. al., 3rd edition.

[SMAL] **http://www.researchchannel.org/prog/displayevent.aspx?rID=3427&fID=345** An excellent lecture video about the Terawatt Challenge by scientist Richard Smalley.

[SSKY] **http://server-sky.com/RollControlV01** Roll from pitch and yaw

[SSPS] **http://gltrs.grc.nasa.gov/cgi-bin/GLTRS/browse.pl?2004/TM-2004-212743.html** Space solar power satellites

[TOOLS] **http://server-sky.com/tools** The open source tools used to create the website and this document.

More information, and longer versions of this paper, can be found on the wiki at **http://server-sky.com/** The website is a wiki. Please feel free to correct or enhance it. This document was created with OpenOffice.org, and may be downloaded from **http://server-sky.com/slides/serversky12p.pdf**. This is version **20090928-03 .**

AMSAT Colombia

Guillermo Cortes, HK6IOP

Translation by Constanza Schultz

The Federation of Amateur Radio Clubs of Colombia "FRACOL" is the National Amateur Radio organization in Colombia. Currently in Colombia there are 13 clubs affiliated with the organization, with about 150 people affiliated, of which at present there are 22 interested in making communications via satellite.

Currently on the satellites the following colleagues are active:

Guillermo Cortes E HK6IOP in Neiva
Yhon Fredy Vargas HJ8BCB in Florencia
Aquilino Torres HK3GXI in Bogota
Juan Carlos Muñoz HJ8JM in Florencia

Every day our program "Mañanitas con FRACOL" airs on our VHF network and EchoLink room in Colombia to provide information of contacts made by colleagues working on the satellites. We are launching a program on the VHF network to encourage colleagues to use this medium.

On November 16 we are celebrating 30 years of FRACOL. We have planned a contest in different modes including satellite contact. We have issued a special QSL card to commemorate this special anniversary.

Each week we are motivating more colleagues by sending information through the Google mail network FRACOLGROUP. We are active on AO-51, AO-7, SO-50, FO-29, especially we have contacts with Argentina, Brazil, Peru, Venezuela, Puerto Rico, Mexico and the United States.

We hope you can collaborate with us to form the group AMSAT-HK, which would be supported by FRACOL. That will make us bigger and stronger in satellite communications.

HK6IOP demonstrates AO-51 operation in Medellin Colombia, June 13, 2009