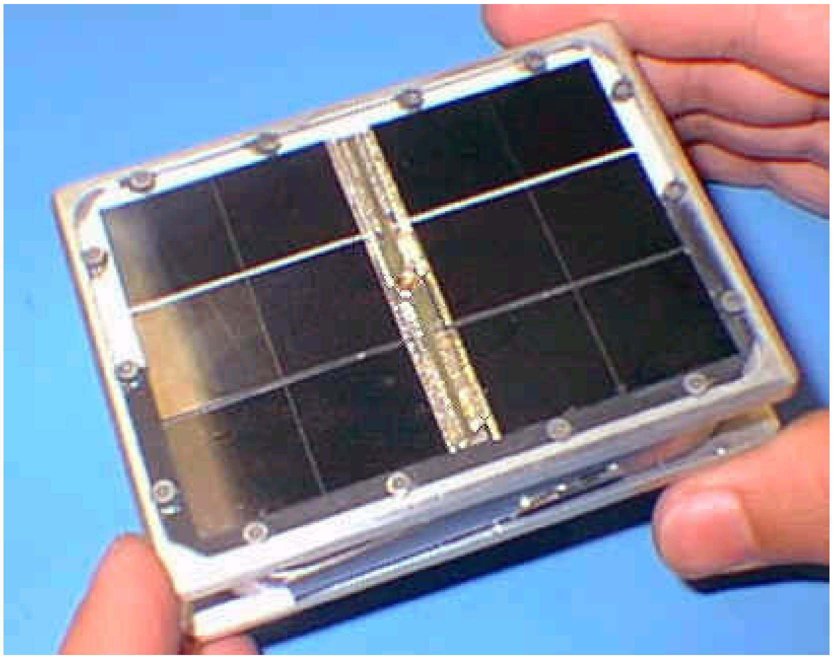

StenSat Picosatellite

StenSat Journal *(Our Experience Building a Picosatellite)*

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StenSat is one of five picosatellites that will be launched from Stanford's Orbiting Picosatellite Automated Launcher (OPAL) satellite after it reaches orbit. A DARPA team built two of the picosatellites (which will be tethered together) and a team of women undergraduate engineers from Santa Clara University (Artemis Team) built the remaining two picosatellites.

Our unexpected foray into the world of satellite design began in early November 1998 when Hank Heidt, N4AFL learned via the AMSAT mailing list that there was a potential satellite design opportunity as part of the Stanford OPAL program. He discounted the message at first, but when the same message went by a week later (again with no response) he decided "well, what the hell".

StenSat Team *("Help! I've agreed to build a satellite!")*

Hank's first move was to ask the advice and help of Kevin Doherty and Dave Niemi, two friends and former housemates. All three at one time shared an old, run-down farmhouse called Stenhouse, which was the focal point of a group of friends with somewhat unconventional outlooks. After numerous E-mails and some discussion, the initial core team of Hank, Kevin and Dave had formed.

Interaction with Stanford: Phase 1

We contacted Bob Twiggs, KE6QMD director of the Stanford Space Systems Development laboratory. Bob was interested, and challenged us to put a mass model of our satellite in his hands within a week. Given the picosat interface document and a cooperative machinist this wasn't too difficult.

Design Concepts ("Hand Waving via the Internet")

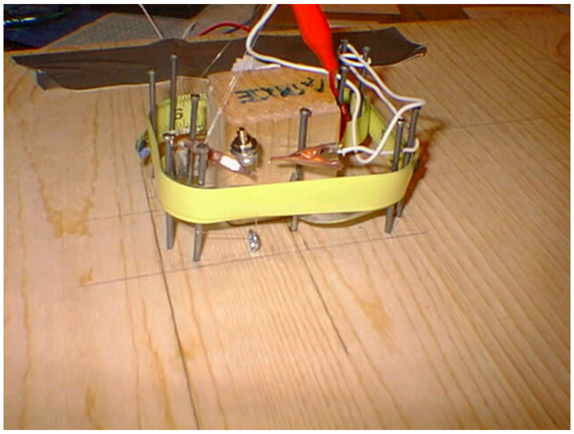
Now that Stanford was taking us somewhat seriously we started to toss ideas around. Via E-mail and the Net we researched a number of missions, but found it difficult to reach consensus. Some of our ideas were too complex, and others impractical, but during the Thanksgiving weekend we started a design notebook and began serious tradeoff studies to focus in on a workable satellite.

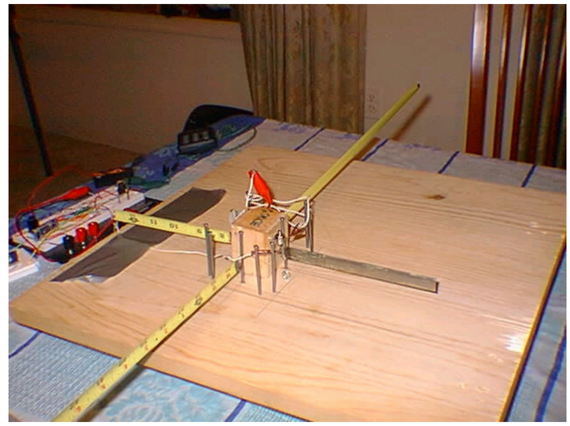
Discussion with Stanford: Phase 2

On December 15th the team met with Bob Twiggs at Goddard SFC. During the meeting Bob confirmed that we were a backup to another amateur team (which we had already suspected). Another alarming bit of information was that flight hardware would be required no later than April 1, 1999 – less than four months away. At this point we drastically reduced our plans – there simply wasn't time to implement anything complicated. During the meeting we walked though design concerns such as attitude control, power, and antenna release. At the end of the meeting Bob generously offered to send us a batch of GaAs solar cells for our satellite as well as a batch of Si solar cells that were left over from the Mars Explorer project. After the meeting we nailed down our basic mission to a narrow band mode "J" FM transponder with DTMF control and AX.25 packet telemetry downlink.

OK, build it! (Problems, problems, more problems)

One of the first design problems that we tackled in January was our picosat antenna release. Inside of the OPAL mothership two picosats will be positioned end to end in each launch tube, and Stanford required that no external structures be exposed or released from the picosat until after it has completely cleared the launcher. But some sort of deployable antenna was going to be necessary. Numerous impractical ideas later, we settled on the following scheme: the antennas, composed of ½ inch wide carpenters measuring tape, were coiled about the perimeter of the satellite, tied down with fishing line, and released by heating a short nichrome wire to melt the fishing line. To evaluate the concept we built a crudely constructed test bed out of nails, measuring tape, and 8 pound test fishing line. With a little experimentation we discovered that the fishing line could easily be melted by briefly connecting three tiny 1/3 Af Nicad batteries across the nichrome, controlled by a FET switch connected to a basic stamp PIC processor.





Prototype Ant. Release Before Deployment **Prototype Ant. Release After Deployment**

So far so good, we are definitely making progress. Activating our test bed would cause the antennas explode from their pre-deployment position with a frighteningly loud 'sproing' and snap into their post-deploy position. We decided that we had suitably proven the concept, and got busy finalizing our structural design and putting together our mechanical drawings.

The team discovered quite early that the basic stamp controller was not going to meet all of our needs, so we decided to build our controller around the much more powerful PIC16C73 controller. After much hair pulling Hank had implemented basic Morse code telemetry and some of StenSat's command uplink functionality in PIC assembly language. He had also started to take a crack at implementing AX.25 packet telemetry as well, but it quickly became apparent that he would not have everything implemented by April 1st. Fortunately we had been looking at alternative controller options and we had contacted Carl Wick, N3MIM an Associate Professor at the US Navel Academy and the designer of the Clement, Micro Interface Module (MIM) an AX.25 packet radio telemetry unit. We were pleasantly surprised to learn that he was interested in our project despite the tight delivery schedule. Meeting with Carl at the Naval Academy in mid February we explained our basic design, showed him our antenna release prototype and controller prototype and he agreed to develop the StenSat controller software by modifying the software he had already developed for the Clement MIM. With Carl's assistance we quickly finalized our controller design. The controller would be connected to a microprocessor supervisory circuit that acts both as a low voltage cutoff monitor and also as a 100ms external watchdog timer to help guard against radiation latchups. We allocated four pins on the PIC processor (via switching FET's) to control the antenna release, TX power level, RX squelch (RSSI) and the main power bus. The remaining pins on the PIC processor would be used to support the following telemetry: temperature, bus current, bus voltage, receiver RSSI and three sun sensors (top face, long and short sides).

One of the things that we dreaded doing was sending in a Part 97 notification. Since none of us went to law school we were a bit intimidated by the FCC notification procedure, but with some help from Perry Klein, W3PK and Bob Bruninga, WB4APR (who was puzzling through his own FCC notification) we had few problems completing the paperwork. We are also very grateful to Graham Ratcliff, VK5AGR, the IARU Amateur Satellite Frequency Coordinator who found us satellite frequencies and then vetted the frequencies with authorities on three continents, and all in less than a week!

From this point on we faced another crisis. Five days before the March 7th structural model delivery milestone our machinist informed us that, due to unforeseen circumstances, he would not be able to machine our chassis for us. Calling just about every machine shop in the Washington Area Yellow pages, we were very lucky to find a shop that accepted small orders and that also happened to have some available time. The machine shop completed our order the evening before our structural model was due. We then worked until 2 AM knocking a structural model together. We shipped our model to Stanford that same morning, and crossed our fingers that our late night construction project would not violently fly apart during Stanford's OPAL preliminary launcher integration and shake tests.

Panic mode *(What do you mean, we're the primary?!?)*

After delivering our structural model to Stanford on March 1st. Hank received a phone call from Bob Twiggs informing us that the other ham team had dropped out and that we were no longer a backup satellite. Hank quickly shared the good news with the rest of the team. Between exchanges of congratulations and curses we tried not to panic! We only had one month left to finish our flight ready satellite.

By the time that we had reached this stage in our project we decided that we should rename our picosat the "Digikey Satellite". With the hours ticking by to the delivery date we really counted on the FED-X packages to show up on our doorsteps each morning. Circuit board turnaround times were fast, but not fast enough – while we had circuit boards for the controller and solar panels, it was quickly determined that the flight RF deck (the most complex assembly on StenSat) would need to be built using breadboard techniques.

Kevin spent most of his time for the next few weeks working with tweezers under a stereo microscope, carefully positioning flea-sized components on and about the transceiver chipset. The transmitter, receiver, and power amplifier designs were pulled directly out of the data sheets and application notes for the devices used. These designs did have to be modified to use components we had on hand; we couldn't wait on backorders.

Kevin Working on StenSat

We had some astounding luck. The receiver and transmitter both came up and worked on the first try! We quickly coupled them together with an audio network and tested the transponder. Then apparently disaster struck for when we powered up the transponder and keyed the Yaesu dual band handheld all we heard was high pitched screeching noise and the receiver and transmitter were both working a minute ago! We quickly figured out that what we were hearing was an audio feedback squeal through the handheld. We plugged in some headphones and discovered that the transponder worked fine (good audio quality too)! Kevin quickly integrated our power amp, fiddled with its bias circuit and set our transmitter output to half a watt. We were not able to get suitable coupling transformers in time so we decided to use home-brew bead baluns instead. Kevin added the receiver squelch and audio mixer for the downlink and designed an elliptical filter (using MicroSim) to eliminate processor noise on the signal coming down. He also threw together a narrowband preselector/amplifier – we need to filter out all those megawatt TV stations. It took several attempts, but we eventually fit everything into the chassis.

Once the satellite was assembled, we were amazed – we were using less than half the available volume! We had room for at least one more board, and potentially two more, and we weren't using the undersides of the solar panels for anything except the battery overcharge limiter. After spending much of the weekend outside in the sun performing final integration testing we used a syringe to get epoxy in, on, and around every component as Kevin summed up the operation, "pot that sucker 'till it's a solid brick". We carefully wrapped the antennas and tied them down for the last time. One last session with the syringe, and now StenSat was as close to a solid mass of epoxy as we could manage without fouling the antenna release mechanism. One last look inside and then the top cover was fastened down and the screws staked with more epoxy – no one will ever see the inside again. Not surprisingly, the satellite was due at Stanford the next day. One hallmark of our effort – nothing was every ready early, but we always managed to come through at the last minute.

StenSat was placed in it's light-tight storage bag (to keep StenSat from deciding that it had been launched, and deploying its antennas). The bag was rolled in bubble wrap, then nestled into foam peanuts in a large cardboard box for shipping to Stanford. Kevin then took the package to local Parcel Plus. Kevin decided to insure it for $1,000 and the proprietor looked at Kevin strangely. "It's going to cost you more for insurance than it will to ship it – what is it, anyway?". "Ah…well, it's a satellite – it's going up this October". "Oh", he replied, "This is our first satellite. I guess I should mark the box 'FRAGILE'.".

Summary of Our Design

The receiver and transmitter designs were directly out of Motorola's data sheets for the 13136 and 13175 FM receiver and transmitter chips. The RX preamp was based on one presented in the data sheet, but modified to have a more narrowband response. The TX power amp was very loosely based on an RF2155 sample design; the device was targeted at 900 MHz applications, and making it work at 70 cm was a cut-and-try operation. Receiver to transmitter audio coupling and telemetry mixing was managed with a passive network, and squelch was accomplished using an open-collector parallel output pin from the PIC to crowbar the receiver audio in the mixer.

Our total out of pocket expenses for StenSat were about 2,000 dollars. Other than paying for a lot of next day shipping, the most expensive components were the chassis ($375 each, times two) and RX and TX crystals (several hundred dollars for custom frequencies). The solar cells were donated from Stanford. We ordered enough components (excluding the chassis) to build five picosatellites. This turned out to be a lifesaver as many components were destroyed, lost, sacrificed, or used in some other way.

Future opportunities

Both Bob Twiggs, KE6QMD and Rick Fleeter, WA8VGK are big proponents of the micro/picosatellite concept. In his article the Home-Brew Ionosphere (AMSAT Journal January February 1999), Rick Fleeter outlines his ideas on clusters of tiny (under 10 Kg) satellites that can be launched inexpensively by piggybacking on large launch vehicles or as hitchhikers and "Get Away Specials" on shuttle flights. Those mini-satellites could be standardized around a specific geometry such as OPAL's (1 by 3 by 4 inch cube) and could be offered as build-it-yourself kits that could be constructed by local Amateur Clubs and Students. With just a few of those satellites in orbit we would be begin to have many periods a day of good coverage. Eventually by launching clusters of those inexpensive satellites as low power (<5 watt) FM transponders you could have nearly continuous coverage mirroring that of your local FM repeater but covering hundreds of miles around you. Satellite cost including launch would be on the order of a few thousand dollars, within the reach of most amateur clubs.

Notes

Home-Brew Ionosphere, Rick Fleeter, WA8VGK, The AMSAT Journal, January / February 1999

StenSat http://www.erols.com/hheidt/

Stanford OPAL project	http://ssdl.stanford.edu/opal/index.html
Radiation modeling	http://www.spenvis.oma.be
Micro Chip PIC resources	http://www.geocities.com/SiliconValley/Way/5807/
Express printed circuit boards	http://www.expresspcb.com/
PartMiner search engine	http://www.partminer.com
Nichrome wire	http://www.wiretron.com/
Fishing line	http://www.sportsauthority.com/
Spring steel carpenters tape	http://www.hechinger.com/