Software Radios, an Enabling Technology for Satellite, Space, and Ultra-Weak Signal Applications

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Document Change History:

Revised

2006 July 11 – Installed Template
2006 July 20 – Finished 1st draft, formatted
2006 July 22 – Additions and revisions
2006 July 25 – penultimate review
2006 July 28 – final edits

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Abstract

Radios such as the SDR-1000, DSP-10, and others, where general signal processing is handled by software (and is thus “infinitely” configurable and adaptable), open vast new frontiers of possibility in amateur space communications. This paper describes the author’s experience with the DSP-10 two-meter radio construction, programming, and operating including satellite tracking, QRPpp moonbounce, and even contesting. Further ideas for developments to the benefit of the Radio Amateur Satellite Service and amateur radio operators are presented.

1 Introduction – Space Communications

In 1952, Wernher von Braun published **The Mars Project**[6], a book describing a way in which a crew of men could be sent to the planet Mars and returned using technology that was available then, just after World War II. He stipulates from the beginning that, unlike the science fiction models common at the time, this would not be the effort of one person or a small team, but would require government-scale resources. Nonetheless, the book demonstrates in every detail that there were in the early 1950s no technological roadblocks; no scientific breakthroughs needed at that time to begin the journey, only the will and resources of a major nation. For better or for worse, this work and others related to it, have formed one blueprint of the space program of the United States, in some form, ever since.

In Appendix F of **The Mars Project**, "Interplanetary Radio Communications," von Braun uses the same physical constants and equations to calculate radio link performance over interplanetary distances that we do today but he takes a different approach. While we consider a given set of equipment over a certain path and compute a resulting "link margin", that is, how much signal is left after the minimums for the desired communications scheme are satisfied, von Braun begins from a set of equipment and signaling scheme and determines the maximum range possible.

Of interest to us here is a quote from the summary near the end of that appendix (in the English translation, 1953). Specifying a frequency of 3 GHz, power of 10 kW, Mars ship antenna aperture of one square meter and earth aperture (at an orbiting station) of four square meters, a noise figure of 10 dB ("Noise Factor" of ten), bandwidth of 5 KHz, and 20 dB SNR for speech, he calculates the maximum range at 1.05 * 10^{13} cm, that is, 105 million km. (He was apparently required to use CGS units.) Following this calculation (Equation 47.1), he says:

> The expedition would reach this limiting range after about 160 days of Marsward travel. Equation (47.1) is based upon the assumption that means have been provided for suppressing image frequencies (see section 46f [on frequency stability and heterodyne techniques]). Such means are relatively simple and effective.
>
> When it is no longer possible to maintain radiotelephone communication by reason of increasing distance, automatic telegraphy can be used. If the bandwidth required therefor [sic] is B = 1,000 cps, and if the signal-to-noise ratio is reduced to a = 20 (13 decibels), the limiting range becomes
>
> `tau(max) = 5.25 * 10`^{13} `cm`
>
> Hence automatic telegraphy is always possible at any distance between earth and Mars, since the maximum distance is 3.77 * 10^{13} cm. The range is, of course, even greater when hand key is used. This is due to the modest bandwidth and signal-to-noise requirement of slow dot-and-dash telegraphy with acoustic or optical signal registration.[6] (page 90)

Among insights into radio technology of the early 1950s, von Braun has claimed that the astronauts can speak with earth for about half of a trip to Mars but that radioteletype will always work, and if all else fails, manually keyed Morse Code! He could have been writing an Op-Ed piece for QST….

I became interested in interplanetary navigation upon reading this book in elementary school but did not realize until reviewing it recently that von Braun and his team had also solved the radio communications problems for deep space travel.

Today, while limited by the same physical constants, we have much better tools at our disposal in terms of radio and signal processing technology. While NASA designs Giga-bit-per-second forward link systems that will allow Mars-bound crews to watch the Super Bowl live, radio amateurs on much more modest resources, that is, individuals and small groups, are also positioned to make progress in their own unique way.

In this paper I discuss one venue for such progress, a modern Software Defined Radio (SDR), its construction, operation, forward-looking applications already implemented, and future potential.

2 DSP-10 Construction

QST for September, October, and November 1999[4] contained a series of construction articles for the DSP-10, a software-defined two-meter radio.[1] When I retired from AMSAT leadership in 1991; I declared that my return to the amateur satellite world would be via a detail-intensive construction and software path. Studying the articles carefully, I realized that this project was as close as I was going to see to fulfillment of that dream. I got in on the first AMSAT DSP-10 kit group buy, managed ably by Dan Schultz, N8FGV. In 2001 I ordered some tools from Jameco and DigiKey. In 2002 I did a little soldering. At the Jet Propulsion Laboratory Amateur Radio Club Christmas Banquet in 2003, incoming president Jim Lux, W6RMK challenged us to "finish up that languishing project in 2004."

Despite best-laid plans, life being what it is, construction progress was made throughout 2004 but by New Year's Day 2005 I was nowhere near "first smoke." I started an "intensive" on 2005 January 8. This involved more parts orders (including the enclosing box itself), much anguish, many late nights, some head scratching and uncharacteristic patience. The blow by blow description of this process, as well as the other results summarized in this paper, are detailed on my website.[2]

The first QSO was with WA6OWM, 30 km to the south on 2005 March 29. I was running 20 milliwatts to a discone at 10 meters.

I was a Heathkit builder decades ago when Heathkit sold radio kits. My most complicated pre-DSP-10 construction attempt was an HW-2036, the late-70s two-meter FM synthesized transceiver. Heathkit-like experience is a necessary pre-requisite to this project, but DSP-10 is a step and a half beyond that in difficulty.

New skills needed:

- Surface mount assembly
- Drilling holes in metal
- Computer interfacing
- Sharp eyesight
- Ability to divine truth from printed material in various stages of obsolescence.
- Scrounging your own (sometimes obsolete) parts and spares.

Personally, I am not a "neat" builder but my DSP-10 works anyway. This is encouraging; the design is solid.

Figure 1 Hardware – DSP-10 ready for debugging – "Front Panel" (not pretty)

3 DSP-10 General Operations

DSP-10 is intended as a 0.144 GHz IF radio for microwave work and many of the builders use it in that way. I have used it exclusively on two meters myself, in conjunction with the "brickette" a linear amplifier (described in June 2000 QST[3]) which takes the 13 dBm transmit output level of DSP-10 and boosts it about 25 dB, to mere "QRP" power levels of 5 – 8 watts.

DSP-10 software has evolved continuously from before the public announcement of the project and is now at Version 3.80 (July 2006). It consists of two main components: UHF3.EXE which runs on the DSP board in the radio and UHFA.EXE, which runs on the host PC. The DSP source code is about 40K lines and the PC source is about 75K lines. The list of features is far too long to reproduce here (see Reference 1) but essentially, it is an "all mode" two-meter rig with all the standard features such as memories and multiple (virtual) VFOs. In addition, it has two classes of features not available on appliance rigs: sophisticated, calibrated signal processing options and a variety of specialized weak signal modes. In addition, special hardware debugging software has been written to assist builders with the task of getting the box going. All software is open source under Gnu Public License (GPL). Although this means that imagination is the only limitation to the appropriately skilled and motivated hobbyist, only the original team has contributed software thus far.

The PC portion of the software is integral to radio operation. All controls from and displays to the operator are routed through the PC. Even the push-to-talk on the microphone is processed through the PC so although it is possible to leave the RF box on and monitoring the last-tuned frequency with the PC off, there is no control (volume level, tuning, transmit) unless the PC and DSP unit are running their respective software and communicating. With this in mind, UHFA.EXE runs under DOS on a '386 class PC. The intent is that a surplus, otherwise obsolete PC of this class will be dedicated for use as an integral part of the radio.

The RF portion of DSP-10 is a dual conversion transceiver with intermediate frequencies (IF) at 19.655 MHz and 10-20 KHz. The second IF is quadrature sampled and processed by an Analog Devices evaluation board based on the ADI 2181 processor. These boards, the "EZKIT-LITE" were initially sold at a loss-leader price of $99 which was an enabler for the DSP-10 community. When the price for this product was raised and, later, it became obsolete and unavailable, Lyle Johnson, KK7P, stepped in and produced an ADI-2185 based replacement, the DSP-x, which continues to be available from TAPR.[5]

CW - SSB

As soon as I had my unit functioning, I set the beacon mode to call CQ on 144.200, the two meter calling frequency, at 20 mW. Eventually, the local community became annoyed enough with this that WA6OWM answered me. We had a pleasant, Q-5, CW QSO. After several weeks of trying to check into SSB and FM nets or make arranged contacts, it became clear that 0.020 watts output was insufficient for general operation.

ARRL The national association for AMATEUR RADIO

VHF/UHF

CONTEST AWARD

N5BF

SINGLE OPERATOR LOW POWER

LOS ANGELES SECTION

2005 ARRL SEPTEMBER VHF QSO PARTY

WINNER

144

MHz

Harrison W5ZN

PRESIDENT, ARRL

Figure 2 DSP-10 Wins the Contest! (Well, Single-Op, Low Power, LAX, 144 MHz only)

Using the June 2005 ARRL VHF QSO Party as the deadline, I built the “Brickette” (or “slippers”) and the combined rig did well, netting 30 QSOs in four grids squares.

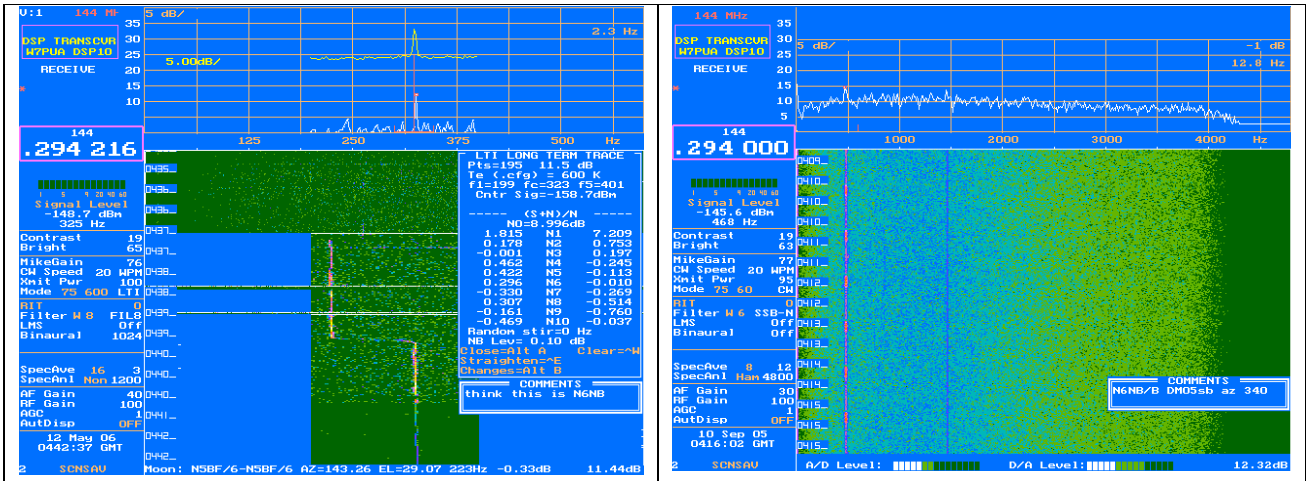
Signal reports often include comments on the “good audio.” It is clear that other operators cannot tell that this is not a store-bought rig with respect to clean signal performance.

For the ARRL September VHF QSO Party, an M^2 2M12 replaced the old Telex-Hygain Oscar beam and the DSP-10 “won the contest” with 33 QSOs in six grids, one of them difficult from my location (eastern DM04 to CM94). (As discussed below, I have also copied a beacon over the mountains in DM05 but have not heard or worked any stations there.)

Beacon DXing

Of course, operation as a “normal” two-meter rig is just the checkout phase. Our interest in this paper is to open and explore new frontiers in the art of amateur radio, particular in the direction of space. Space being truly vast and the inverse square law for the propagation of energy still being in effect, one aspect of this new frontier will involve weak signals, sometimes *very* weak signals.

About 100 km from my QTH on the other side of a mountain ridge is the Tehachapi two-meter beacon well known throughout California. One day when propagation was unusually good I was able to copy it's entire CW transmission, "N6NB/B DM05sb" followed by a string of dits. Normally, this beacon is not loud enough to be copied in audio at my location.



```
DSP TRANSCVR
W7PUA DSP10
RECEIVE
144
.294 216
Signal Level
-148.7 dBm
325 Hz
Contrast        19
Bright          65
MikeGain        76
CW Speed    20 WPM
Xmit Pwr       100
Mode   75 600  LTI
RIT              0
Filter W 8    FIL8
LMS            Off
Binaural      1024
SpecAve   16     3
SpecAnl  Non  1200
AF Gain         40
RF Gain        100
AGC              1
AutDisp        OFF
12 May 06
0442:37 GMT
2     SCNSAV
Moon: N5BF/6-N5BF/6 AZ=143.26 EL=29.07 223Hz -0.33dB      11.44dB
```

```
LTI LONG TERM TRACE
Pts=195  11.5 dB
Te (.cfg) = 600 K
f1=199 fc=323 f5=401
Cntr Sig=-158.7dBm

-----   (S+N)/N   -----
      N0=8.996dB
  1.815   N1    7.209
  0.178   N2    0.753
 -0.001   N3    0.197
  0.462   N4   -0.245
  0.422   N5   -0.113
  0.296   N6   -0.010
 -0.330   N7   -0.269
  0.307   N8   -0.514
 -0.161   N9   -0.760
 -0.469   N10  -0.037
Random stir=0 Hz
NB Lev= 0.10 dB
Close=Alt A    Clear=^W
Straighten=^E
Changes=Alt B
COMMENTS
think this is N6NB
```

```
DSP TRANSCVR
W7PUA DSP10
RECEIVE
144
.294 000
Signal Level
-145.6 dBm
468 Hz
Contrast        19
Bright          63
MikeGain        77
CW Speed    20 WPM
Xmit Pwr        95
Mode   75 60    CW
RIT              0
Filter W 6   SSB-N
LMS            Off
Binaural       Off
SpecAve    8    12
SpecAnl  Ham  4800
AF Gain         30
RF Gain        100
AGC              1
AutDisp        OFF
10 Sep 05
0416:02 GMT
2     SCNSAV
COMMENTS
N6NB/B DM05sb az 340
```

Figure 3 An LTI view and a normal CW waterfall view of N6NB/B.

Figure 3 shows two DSP-10 displays of this beacon on days when it was detectably but not copy-ably audible. On the right, the normal waterfall display shows several minutes of activity just below 500 Hz. The darker (blue) parts of the line are periods when dits are being sent. The solid pink parts are when the ID and location are being sent, using more energy per unit time.

On the left is a "Long Term Integration" display of the same signal at a similar level. In the waterfall you see where I've been tuning around to center the signal in the integration window. You can also see a little frequency drift. Is this at the beacon transmitter, my receiver, or both? The box on the right of that display contains statistical information for the long-term integration.

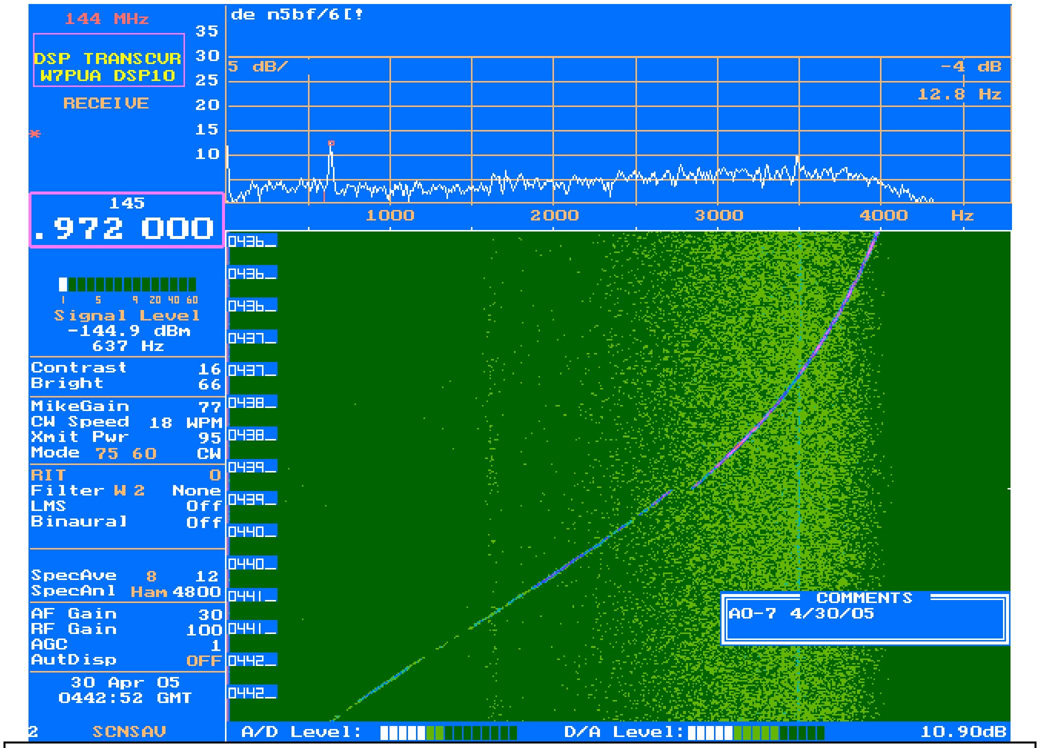
The frequency drift highlights an issue in long-term integration. For the averages to be meaningful, the signals have to be fixed, or at least have to be modeled in such a way that comparable quantities are being added with each sample. Otherwise the results become "smeared."

In the spectral display at top the lower white line is the latest instantaneous spectrum. It is of the same form but with different averaging properties and different background noise level than the spectrum on the right. The yellow trace at the top is the result of 195 averaged points (as seen in the LTI statistics box). Notice how the noise has averaged down to a flat line with ripple at a fraction of a dB while a clear signal peak has formed about 8 dB higher. This integration demonstrates the first 10 dB of improvement in signal detection available through signal processing. Additional improvement and signal modeling will be discussed further below under EME2.

AO-7

The first satellite I actually used as a licensed radio amateur was AO-7, back when it was new in the 1970s. As I was getting DSP-10 going, word came that AO-7 was in a favorable illumination cycle and was being heard again. I was lucky to find AO-7 transmitting on two-meters on one of my earliest listening attempts. A trace of the carrier signal from Acquisition of Signal (AOS) to Time of Closest Approach (TCA) is shown in Figure 4. As with the Tehachapi beacon trace, this signal was barely, sporadically audible. Any CW modulation that was there was not readable. The characteristic Doppler signature in the display is quite clear, however.

In the section below titled AMSAT Tracking Network, techniques for using data such as this for calculating satellite orbital elements will be discussed.



144 MHz
DSP TRANSCVR
W7PUA DSP10
RECEIVE
145
.972 000
Signal Level
-144.9 dBm
637 Hz
Contrast 16
Bright 66
MikeGain 77
CW Speed 18 WPM
Xmit Pwr 95
Mode 75 60 CW
RIT 0
Filter W 2 None
LMS Off
Binaural Off
SpecAve 8 12
SpecAnl Ham 4800
AF Gain 30
RF Gain 100
AGC 1
AutDisp OFF
30 Apr 05
0442:52 GMT
2 SCNSAV
de n5bf/6[!
5 dB/
-4 dB
12.8 Hz
COMMENTS
AO-7 4/30/05
A/D Level:
D/A Level:
10.90dB

Figure 4 AMSAT-OSCAR 7 carrier trace, AOS through TCA.

4 QRPpp EME2

Von Braun begins his Appendix F, “Interplanetary Radio Communications”[6] with an attempt to establish credibility for the very notion of interplanetary radio communications through the existence proof of radio reflections from the moon:

> In 1946 American scientists for the first time succeeded in transmitting radio signals to the moon. These were echoed from the moon and received and recorded on earth. The moon intercepted only a very small quantity of the directed intensity of the transmitter, and only a fraction of the energy actually intercepted was reflected. The power of the “moon

> transmitter" corresponding to the actually reflected power would have been low indeed. It is therefore obvious that a powerful transmitter in space would have no trouble being received on earth, even at a distance many times that between earth and moon.[6] (page 81)

He then goes on to derive mathematically how this works, cleverly using the same equations he will later employ to demonstrate that earth to Mars communications is eminently practical.

The "Silver Anniversary 25th Annual ARRL International EME Competition"[7] results given in QST for April 2003 gives a brief history of the first amateur radio EME QSO, between W1FZJ and W6HB on July 17, 1960. As has been well known since then, "moonbounce" (or Earth-Moon-Earth, EME) is within reach of a sufficiently ambitious radio amateur.

Space being truly vast and signals propagating through it becoming quite weak, one frontier of space for radio amateurs is the frontier of ultra-weak signal work. EME is near the bottom of the challenge ladder.

Like many amateurs, I daydream about one day owning a station capable of working "OSCAR-0" but the power and antenna needed to hear one's own echoes in an audio bandwidth are fairly large, at least by amateur satellite (what we used to call "AO-13 Class") standards. In the late 1980s, Tom Clark, W3IWI and Bob McGwier, N4HY used early signal processing hardware (25 MHz TI 32010 parts on Delanco Spry boards that plugged into a PC) to demonstrate QRP EME. This showed that digital processing of audio from normal satellite-class radios could bring a form of EME into reach for such stations.

After getting my DSP-10 settled into routine operation and proving to myself that it was a "pretty good radio", I was reading the user manual[8] one day and came across an operating mode called "EME2". This mode is described in detail in the user manual[8] and in **Experimental Methods in RF Design**[9], Chapter 12.5.

The aim of EME2 is to aid the operator in detecting self-echoes from the moon that are far below audible levels. Schematically, it works like this: The round-trip light time to the moon is 2.575 seconds. DSP-10 keys up and sends a carrier for two seconds, then waits 0.575 seconds, then integrates the receiver pass band for two seconds. At five seconds elapsed, it begins the cycle again and continues this, collecting frequency bin sums indefinitely until terminated by the operator. DSP-10 calculates the expected two way Doppler shift from the moon for the selected transmit frequency and adjusts the receive frequency accordingly. It also hops successive transmissions around in a pseudo-random frequency pattern in order to reduce the effect of any low level birdies. Finally, it uses one five-second slot every few minutes to send a station-ID in high speed Morse.

Noting that the moon was up and near the horizon (DSP-10 also calculates and displays moon azimuth and elevation), I turned the beam and activated the mode. I was hoping to see something like Figure 3 above indicating a detection of my reflected signals. Running 7.5 watts to a single yagi, I knew that this might take some time. I was disappointed to discover, and have confirmed by other DSP-10 users, that it would take more than the hour or two attempted in that first session, maybe a lot more. W7PUA claimed a statistically significant echo detection using DSP-10 and Brickette but using a stacked array of four antennas similar to my one and aimed in azimuth and elevation for seven or eight hours of data collection. This was at least 10 dB beyond what I had informally attempted.

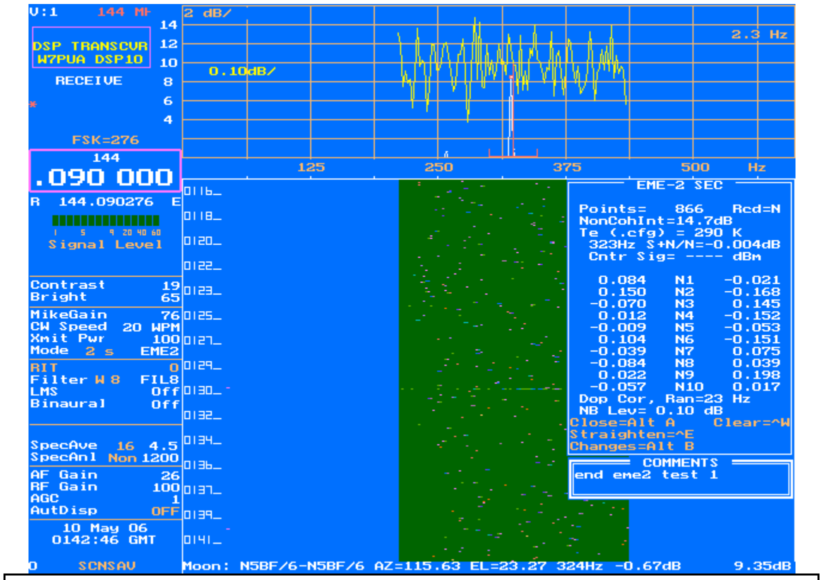
It was suggested that I run more power initially to verify that the station was working right or that I add an elevation rotator so I could track longer. Such improvements are planned, but I didn't want to rush into them just for this whim.

The EME2 implementation does not presently allow sessions to be saved and restarted, a feature that would allow longer integrations without the elevation rotator. DSP-10 does support saving of tracking files in several modes, including EME2, for later analysis, however. No program then existed to do such analysis, but it occurred to me that I could write a post-processing program to parse in several of these files and perform the same sorts of data screening and averaging algorithms on them that DSP-10 does in real time.

The end result, DSP-10_EME2_Post, is a prototype C++ program of about 7000 lines. This was my first project using Xcode on a Mac PowerBook G4.

I made a list of moonrises and moonsets that were at reasonable hours when I could be at home and started capturing files of each EME2 session. While the rig was sitting there pinging at the moon, I worked on the post-processing software. (I also consulted Meeus[10] Chapter 45 and other sources for more hints as to why I wasn't seeing anything in one or two hours.)

All of the individual sessions ended up looking something like the screen capture in Figure 5.



```
Contrast      19
Bright        65
MikeGain      76
CW Speed  20 WPM
Xmit Pwr     100
Mode   2 s  EME2
RIT            0
Filter W 8  FIL8
LMS          Off
Binaural     Off
SpecAve  16  4.5
SpecAnl Non 1200
AF Gain       26
RF Gain      100
AGC            1
AutDisp      OFF
  10 May 06
 0142:46 GMT
```

```
            EME-2 SEC
 Points=    866   Rcd=N
 NonCohInt=14.7dB
 Te (.cfg) = 290 K
  323Hz S+N/N=-0.004dB
  Cntr Sig= ---- dBm

   0.084    N1   -0.021
   0.150    N2   -0.168
  -0.070    N3    0.145
   0.012    N4   -0.152
  -0.009    N5   -0.053
   0.104    N6   -0.151
  -0.039    N7    0.075
  -0.084    N8    0.039
   0.022    N9    0.198
  -0.057    N10   0.017
 Dop Cor, Ran=23 Hz
 NB Lev= 0.10 dB
Close=Alt A    Clear=^W
Straighten=^E
Changes=Alt B
            COMMENTS
end eme2 test 1
```

```
Moon: N5BF/6-N5BF/6 AZ=115.63 EL=23.27 324Hz -0.67dB        9.35dB
```

Figure 5 Screen capture from one EME2 session. No detectable result.

The yellow trace represents the average over the 866 points taken (72 minutes). The red marks around and centered on 323 Hz show the 21 frequency bins that are recorded into the capture file. Any peak from a lunar reflection would be in the center bin marked by the taller red line. Not only is no such peak beginning to appear here, the central bin actually has a little less than average signal so its relative power is less than 0 dB at this point in summing!

After about twelve EME2 tracking session, a few hours work on my program, and a few moments of despair, I thought I might be seeing a peak emerge. After some more refinement and adding more data, the result improved to the point where I thought I could claim a QRPpp detection. Figure 8 is the plotted result. Notice that the scale is somewhat finer than the scale in Figure 5. The noise bins have averaged down far enough for the tiny return signal to begin to emerge clearly.

The control input to the post-processing program is:

Figure 6 Text file input to EME2 post processing program

```
# Version 1.1, 2006 June 13, n5bf/6.  This is the master file for all
of the EME2 data captured to date. #
PD Summary
PT 600
PX Off
```

```
PN 13.05
# These constraint times are from horizon mask to 20 degrees. #
PI 2006 5 21 1918 00 2006 5 21 2038 00
PI 2006 5 26 0000 00 2006 5 26 0128 00
PI 2006 5 26 1320 00 2006 5 26 1351 00
PI 2006 5 27 0100 00 2006 5 27 0236 00
PI 2006 5 27 1406 00 2006 5 27 1442 00
PI 2006 5 28 0203 00 2006 5 28 0348 00
PI 2006 5 28 1500 00 2006 5 28 1536 00
PI 2006 5 29 0303 00 2006 5 29 0448 00
PI 2006 5 30 1700 00 2006 5 30 1733 00
PI 2006 6  1 0606 00 2006 6  1 0657 00
PI 2006 6  2 0557 00 2006 6  2 0623 00
PI 2006 6  2 0630 00 2006 6  2 0730 00
PI 2006 6  3 0627 00 2006 6  3 0745 00
PI 2006 6  3 2039 00 2006 6  3 2121 00
PI 2006 6  4 0651 00 2006 6  4 0757 00
PI 2006 6 10 0203 00 2006 6 10 0348 00
PI 2006 6 11 0324 00 2006 6 11 0509 00
PI 2006 6 12 0400 00 2006 6 12 0621 00
PI 2006 6 13 0500 00 2006 6 13 0713 00
PI 2006 6 13 1145 00 2006 6 13 1345 00
# The data files. #
PF 5_21_set.dat
PF 5_26_set.dat
PF 5_26_ris.dat
PF 5_27_set.dat
PF 5_27_ris.dat
PF 5_28_set.dat
PF 5_28_ris.dat
PF 5_29_set.dat
PF 5_30_ris.dat
PF 6_01_set.dat
PF 6_02_set.dat
PF 6_03_set.dat
PF 6_03_ris.dat
PF 6_04_set.dat
PF 6_10_ris.dat
# PF 6_11_ris.dat
PF 6_12_ris.dat
PF 6_13_ris.dat #
PF 6_13_set.dat

# End with a comment to prevent end-of-file parse errors. #
```

All comments begin and end with “#”. Some data files are commented out.

‘PD Summary’ sets the amount of output to be produced.

‘PT 600’ sets the system temperature to 600K for signal level calculations. This only affects the final signal level estimate and is not involved in the statistics.

‘PN’ sets the maximum noise level permitted from an input point. Points at a higher noise levels are discarded.

‘PI’ sets an inclusive time interval. For a point to be included it must be within one such interval.

‘PF’ names a data file to be processed (possibly recursively in that the file named can contain other file names for inclusion).

As implied by the PN and PI directives, two forms of data editing are performed automatically during processing.

Time intervals are set to restrict the data processed to be when the moon is in view and within the beam width of the antenna. The particular set of “PI” instructions shown here prevents data from below my measured horizon mask or from above 20 degrees elevation from being used. Such data, if used, would add noise to the result but not signal and so would reduce the final SNR.

Each data point captured by DSP-10 contains a power average sum from all 478 bins processed for screen display. This can be used as a measure of background noise from manmade or other sources. (This can also be used as an indicator of whether an antenna is connected or not.) When data are taken with significant background noise, any signal is easily overwhelmed by this noise. This is the same as not being able to hear the satellite when your neighbor turns on his blender. DSP-10 has a feature that excludes data that is significantly noisier (typically 1 dB) than the recent result of a running average. The post-processing program, by contrast, discards all points above the threshold set by the “PN” instruction, regardless of the levels in nearby points. Since we are taking the average noise (measured noise (power ratio) of 11.4172 shown in the output below) as 600K, the “PN 13.05” instruction is equivalent to saying, “Ignore all points above 686K, and this is equivalent to saying, “Wait until my neighbor turns his blender off and try again!”

Without the PI and PN directives, no peak is detected. Some of the files were taken at noisy times. This PN directive causes their data to be discarded entirely.

In the future I plan to measure my actual DSP-10 noise figure to better calibrate these measurements and understand how a good preamplifier or avoiding certain noise sources might help processes such as these. An absolute noise measure is unimportant to the statistical result here so long as there are enough quiet measurements in the entire set.

The raw, tabulated output from the program is:

Figure 7 Text file output from EME2 post processing program

```
[Session started at 2006-07-15 18:24:11 -0700.]

Set System Temperature to 600K

Set time interval from 2006 05 21 1918 00 2006 05 21 2038 00
Set time interval from 2006 05 26 0000 00 2006 05 26 0128 00
Set time interval from 2006 05 26 1320 00 2006 05 26 1351 00
Set time interval from 2006 05 27 0100 00 2006 05 27 0236 00
Set time interval from 2006 05 27 1406 00 2006 05 27 1442 00
Set time interval from 2006 05 28 0203 00 2006 05 28 0348 00
Set time interval from 2006 05 28 1500 00 2006 05 28 1536 00
Set time interval from 2006 05 29 0303 00 2006 05 29 0448 00
Set time interval from 2006 05 30 1700 00 2006 05 30 1733 00
Set time interval from 2006 06 01 0606 00 2006 06 01 0657 00
Set time interval from 2006 06 02 0557 00 2006 06 02 0623 00
Set time interval from 2006 06 02 0630 00 2006 06 02 0730 00
Set time interval from 2006 06 03 0627 00 2006 06 03 0745 00
Set time interval from 2006 06 03 2039 00 2006 06 03 2121 00
Set time interval from 2006 06 04 0651 00 2006 06 04 0757 00
Set time interval from 2006 06 10 0203 00 2006 06 10 0348 00
Set time interval from 2006 06 11 0324 00 2006 06 11 0509 00
Set time interval from 2006 06 12 0400 00 2006 06 12 0621 00
Set time interval from 2006 06 13 0500 00 2006 06 13 0713 00
Set time interval from 2006 06 13 1145 00 2006 06 13 1345 00
Parsing file 5_21_set.dat
Parsing file 5_26_set.dat
Parsing file 5_26_ris.dat
Parsing file 5_27_set.dat
Parsing file 5_27_ris.dat
Parsing file 5_28_set.dat
Parsing file 5_28_ris.dat
Parsing file 5_29_set.dat
Parsing file 5_30_ris.dat
Parsing file 6_01_set.dat
```

```
Parsing file 6_02_set.dat
Parsing file 6_03_set.dat
Parsing file 6_03_ris.dat
Parsing file 6_04_set.dat
Parsing file 6_10_ris.dat
Parsing file 6_13_set.dat
Total points seen:         14664
Points processed:          5476 37%
Points skipped:            5604 38%
Points skipped for noise:  3584 24%
Biggest noise value:       13.049

values fixed:      0 0
values not fixed:  0 0

Noise Bins:  11.4172 0.0409501 10.5756

noise 10.5369, 1.36597

bin    mean    sigma   -noiseMean  noise sigmas    dB
-10, 11.4275, 5.45858,  0.0103158,   0.251911,  0.00392222
 -9, 11.3520, 5.42430, -0.0652031,  -1.59226,  -0.0248735
 -8, 11.4601, 5.45164,  0.0429619,   1.04913,   0.0163115
 -7, 11.4011, 5.51495, -0.0160590,  -0.39216,  -0.00611293
 -6, 11.3565, 5.45260, -0.0606998,  -1.48229,  -0.023151
 -5, 11.4670, 5.44087,  0.0498330,   1.21692,   0.0189146
 -4, 11.4368, 5.44843,  0.0195957,   0.478526,  0.00744755
 -3, 11.4127, 5.47705, -0.00448739, -0.109582, -0.00170728
 -2, 11.3962, 5.36449, -0.0209911,  -0.512601, -0.00799208
 -1, 11.5256, 5.53730,  0.1084100,   2.64736,   0.0410431
  0, 11.5888, 5.61291,  0.1716360,   4.19134,   0.0648022
  1, 11.4736, 5.49392,  0.0564111,   1.37756,   0.0214052
  2, 11.3676, 5.49562, -0.0495403,  -1.20977,  -0.0188855
  3, 11.4038, 5.52712, -0.0133888,  -0.326953, -0.0050959
  4, 11.4400, 5.55434,  0.0228347,   0.557622,  0.00867734
  5, 11.3677, 5.39753, -0.0495004,  -1.2088,   -0.0188702
  6, 11.4105, 5.54007, -0.00668708, -0.163298, -0.00254442
  7, 11.3927, 5.40443, -0.0245146,  -0.598644, -0.00933504
  8, 11.4739, 5.49146,  0.0567019,   1.38466,   0.0215153
  9, 11.4973, 5.52794,  0.0801300,   1.95677,   0.0303739
 10, 11.4459, 5.46449,  0.0286985,   0.700816,  0.0109028

max 0 4.19134
nxt -1 2.64736
min -9 -1.59226

noise temperature 600K is -167.225 dBm in 2.3 Hz

signal plus noise level of -167.16 dBm over 10952 seconds implies return
signal power of -187.358 dBm which is 5.81949K


DSP-10_EME2_Post has exited with status 0.
```

The first several lines show the PT, PI, and PF instructions being carried out. This is followed by summary data.

The total number of points seen, 14664, represents over 20 hours of EME2 tracking or 8 hours of carrier transmit time at 40% duty cycle. Of these, 5476 points were used in the sums. This is over 7.6 hours of EME2 or about 3 hours of key-down time. The final result, then, is the result of integration over nearly 11000 seconds of carrier representing about 80 kJoules of energy transmitted.

“Points skipped” means that they were discarded because they were outside of all specified time intervals. “Points skipped for noise” means that they exceeded the specified noise limit. Overall, 62% of points were judged to be in range geometrically and 60% of those were suitable for use in the averages.

The table summarizing frequency bins is interpreted as follows: In the mode I was using, each bin is 2.3 Hz wide so the 21 bins, numbered -10 through +10 represent 48.3 Hz of spectrum. The return from the moon is supposed to be entirely contained within the center bin, numbered 0. This is because, at two-meters, the various calculation errors and physical effects such as librations should be limited to about one Hz. The "square wave modulation" (on for two seconds, off for three) will have a first null at around plus and minus a fraction of a Hz so most return energy should be well contained within the central 2.3 Hz bin.

The row labeled "Noise Bins" are the statistics of the row sums given in the following table in bins -10 through -2 and 2 through 10. These are not supposed to contain signal whereas bins -1, 0, and 1 should, particularly bin 0. These values are calculated directly from the power ratios found in the DSP-10 output files. The value 11.4172 corresponds to some voltage on the analog to digital converter in the radio. The value 0.0409501 is the standard deviation on the 18 bins used in the noise calculation. The value 10.5756 is the mean expressed in dB.

The columns in the table have the following meaning:

Column one is the bin number, multiple of 2.3 Hz from the expected reception frequency.

Column two is the mean value measured in that bin.

Column three is the standard deviation of all 5476 values in that bin.

Column four is the difference between column two and the noise mean explained above.

Column five is column four expressed in noise standard deviations as explained above.

Column six is column four expressed in dB. These are the values plotted in Figure 8.

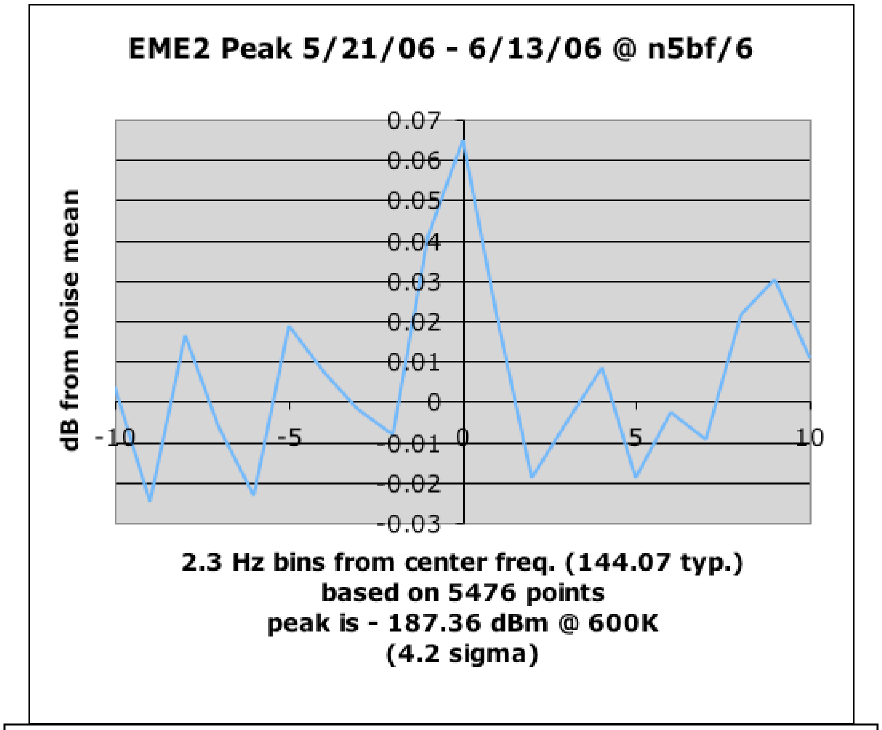


Figure 8 "Yellow Trace" equivalent from 16 moon rise/set data files.

At the end are some ancillary calculations to estimate actual signal level based on assumed noise temperature.

News of this claimed detection was met with kudos from most of my colleagues in the DSP-10 and other amateur radio communities and a few in-depth peer reviews. From these comments, several items were added to the list for follow-on experiments.

This is, as expected, detection of a tiny signal. It might be more convincing if the signal had a different design, such as a pair of tones at different frequencies and possibly different power levels. Peaks at bins -5 and +5 would make a more convincing presentation. Circular polarization, with T/R coordinated switching (because the return signal is a reflection), could increase the response by 3 dB (depending on the reflective properties of the moon) and in addition remove the 3 dB Faraday rotation loss.

In "normal" (audible) EME operations, it is possible for smaller (i.e. "Oscar-class") stations to work larger ones, but the entry point for serious participants is to be able to hear their own echoes. Stations that hear their own echoes can, in theory, hear other stations who can hear *their* own echoes.

In this test, although I have detected my own echoes, it will require more equipment, namely a higher level of time and frequency synchronization with a partner station, for me to attempt to work another similarly equipped amateur. Support for such synchronization is one of the major features of the latest DSP-10 software release, Version 3.80.[1]

EVE240

Back in the TRS-80 era, when Tom Clark, W3IWI was president of AMSAT, he editorialized that with the advent of personal computing power it might soon be possible for amateurs to detect reflections from other astronomical objects beyond the moon, the best next candidate being Venus. Now we consider the engineering problem of performing "Venus bounce" from an amateur station.

Radar contact with Venus was first reported during the inferior conjunction of 1961. A brief announcement by Duane O. Muhleman, California Institute of Technology, Jet Propulsion Laboratory[11], made the following report:

Figure 9 85-foot (26-meter) aperture at JPL – Goldstone used for first Venus Radar experiments.

- Range was determined accurately resulting in a significant revision of the Astronomical Unit (the average distance of earth from the sun).
- Daily tests were conducted from March 10 to May 10, 1961 at 1.25 cm wavelength.
- Bi-static (separate transmitting and low-noise receiving sites).
- Doppler measurement determined Venus rotation to be synchronous or near synchronous.
- Radio reflectivity (L-Band) was 10% that of a perfectly reflecting sphere, compared to 2% for the moon.

This information will be useful in designing an amateur Venus bounce detection experiment.

I digress briefly to mention that what I am discussing here is not a result from amateurs working on their own time at government installations such as Algonquin, Goldstone, or Jordrell Bank. While these count as amateur operations, they are not in the class of “individual” or “club” station and so are in a different category. Muhleman does not say how much power they ran in these tests, but it was certainly more than the kilowatt level available to amateurs, as was the cryogenically cooled receiving equipment. Under the banner of “Solar System Radar[13],” radar returns have been detected from Venus, Mercury, the Sun, Mars, and the rings of Saturn. (State of the art in this decade is transmitter power levels approaching half a Megawatt and total receive system temperatures below 30K.)

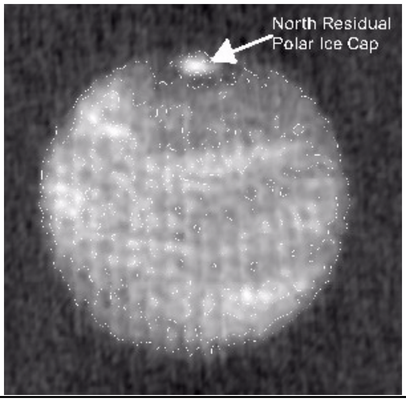


Figure 10 Radar Image of Mars made by transmitting 0.35 MW CW at 3.5 cm wavelength from Goldstone 70 m. dish and receiving at the VLA in New Mexico.[13]

In addition, I am not talking about new science (see Figure 10). Rather, we use “old science,” that is, results such as those given above, to aid in comparatively modest detections. Still, we learn useful engineering skill from these endeavors.

I believe that signal processing techniques such as EME2 which are in turn enabled by software defined radios, bring Venus bounce within the range of a well equipped EME station today.

How much harder is a reflection from Venus?

At inferior conjunction (closest approach) Venus is 120 times further away than the moon. At that time, however, it is in the sun, making measurements noisy. We will need several weeks of integrations and Venus will not always be that close. For this back-of-the-envelope analysis, let’s say that Venus is 180 times as far away as the moon (effective mean) and note that the radar effect goes with R^{-4}.

Venus is about the same size as earth, approximately four times the radius of the moon and is, per Muhleman, five times as good a radio reflector. (It is acknowledged that Muhleman’s result was at L-Band and that the relative reflectivity at VHF may be somewhat different. For now, we still use the factor of five as an estimate.) Combining these terms we have:

Table 1 Earth – Venus – Earth relative to Earth – moon – Earth

Effect	value	dB	Note
Distance	180	-90	R^{-4}
Radius	4	+12	R^2
Reflectivity	5[11]	+ 7	
Total		-71	

For comparison, here are some guesses at other likely objects. All quantities are "EME Relative."

Table 2 EME – Relative Signals Reflected from Nearby Planets.

Planet	"Effective" Distance	(Best)	Radius	Reflectivity	dB EME	Note
Venus	180	120	4	5[11]	-71	In the sun
Mercury	320	240	1.5	2[19]	-94	Even nearer the sun
Mars	380	210	2.1	4[19]	-91	Opposition is at night (quiet)

Venus is the next "reasonable" target by at least two orders of magnitude.

My QRPpp EME station runs 7.2 watts to a beam that claims 12.8 dBd gain, approximately 250 watts EIRP. After 10,000 seconds equivalent of carrier integration, I claim a lunar-reflection detection in a presumed 600K receiver. What would it take to improve this by 71 dB?

Table 3 From QRPpp EME2 to EVE, Station / Operational Improvements.

Improvement	Value	Over	dB gain	note
Full Gallon	1500 W	7.2 W	23	
Mighty Big Array[12]	32 boomers	single yagi	17	30 – 12.8 dBd
Mighty Big Array[12]	on receive	single yagi	17	
10^6 second integration	10^6	10^4	10	Non-coherent
Good preamp	60K	600K	10	Difficult on array?
Total			77	

(Note that at two meters, W5UN's Mighty Big Array has about the same aperture as the 26-meter dish at Goldstone, pictured in Figure 9., about 500 m^2.)

Although this seems to be more than enough to reach Venus it must be understood that the uncertainties in these estimates are large enough that in reality there may be no extra margin at all. Also, we might find it more practical to use an antenna somewhat smaller than the Mighty Big Array or an integration time less than a million seconds.

During a measurement season, Venus would only be visible 10 – 12 hours a day and unless the experiment were bi-static, that is, separate transmitter and receiver sites, duty cycle could only approach 50%. Under these conditions, a million seconds of carrier integration would take 6-7 weeks. This could be longer if there were significant periods of high noise as in my EME experiment. Six to seven weeks is a reasonable (high end) for an amateur radio experiment of this type and fits into a Venus inferior conjunction season, similar to the 1961 JPL experiment mentioned above.

Of course, the EME2 software could not be used as is. Unlike the moon, the two-way light time to Venus would change by several minutes over the course of the experiment. Meeus[10] has tables for Venus too, so modeling the range and Doppler of Venus is relatively straightforward (except for the verification testing.)

The rotation rate of Venus adds only about two meters per second (two Hz at two meters, two-way) of spreading to the return signal. In this respect, Venus, like the moon, is a very fortunately cooperative target. Mars on the other hand has a day similar to earth's meaning that Doppler spreading, even at two meters, would be hundreds of Hz. For a case like this, additional signal processing, such as a matched filter, would be required to aid in detection. Such processing is the venue in which the SDR excels.

Use of a higher frequency such as X-Band for this attempt would also lead to the need for better signal modeling since all the Doppler effects would be 72 times greater than at two meters.

Some will be concerned with the regulatory aspects of such an experiment. The most restrictive interpretation of our regulations is that the only legitimate use of amateur radio is to conduct two-way contacts of little value with other amateurs on permitted modes and frequencies. Toward the more liberal readings is that this sort of experiment is well within the meaning of "advancing skills in both the communication and technical phases of the art."[20] While the EME2 experiment is properly identified periodically in high speed CW and is fully attended by a control operator, it is not an attempt to engage in two-way communications with another amateur station nor is it a beacon under the rules for beacons. I will not go into this further here except to note that a Special Temporary Authorization (STA) could be secured for such a test if needed and that I would expect more trouble from the neighbors of a large dish transmitting a kilowatt carrier day after day than I would from the FCC.

The claim here is not that earth-Venus-Earth (EVE) is something that a well-motivated amateur can easily accomplish. The claim here is that signal processing techniques now readily available at the amateur level through software defined radios bring EVE detection within range of high-end EME stations now in existence. The level of effort and expense required to design and conduct such an experiment is doubtless smaller than that required to build and deploy an amateur satellite or conduct a high-end DXpedition. The claim, then, is that such an attempt is now within reach of amateur radio and we only await the person or group with the skill, motivation, and resources to tackle it.

To paraphrase from von Braun, actually working another similarly equipped station at destinations such as Venus or Mars would be comparatively simple. While we wait for repeaters or crews, however, "radar" will have to do.

5 AMSAT Tracking Network

Weak signals from space are not the only area in which SDRs can contribute to the state-of-the-art at the amateur level. One of the fundamental needs in the amateur satellite community is practical knowledge of where the satellites are.

When I was first licensed (1972), the state-of-the-art in amateur satellite location was the Oscarlocator[17]. In a simple, analog, graphical device made only of polar graph paper, transparency materials, and a marker, pass times and antenna-aiming coordinates sufficient for amateur use were available. "Reference orbits" were transmitted by CW bulletin from W1AW daily and these could be extrapolated, with hand calculations, into the future to initialize this calculator.

Today we take Keplerian elements direct from the government, distribute them via the internet, feed them semi-automatically into personal computers, and watch 3-D maps of several satellites orbiting the world while our antennas are automatically pointed at the selected one.

In both of these cases, data about the satellite trajectory has come from somewhere outside of our amateur stations, in fact, nearly always from outside of the amateur service itself. A few years ago (early 2003) as various provisions of the Patriot Act and related legislation were taking effect, there was a scare that we would lose our access to government-generated satellite ephemeris data. Fortunately, this has not occurred, at least not yet.

On this scare, I started thinking of ways that we could, within the amateur community, determine and disseminate information about our own satellites. Several methods of estimating ephemerides are possible within amateur resources.

- Listening on the air and making educated guesses.
- Phase tracking beacons.
- Phase tracking transponded signals.
- Ranging transponded signals.
- Optical tracking.
- Monostatic or bi-static (passive) radar.

The first two require a satellite that is transmitting a signal based on an oscillator that can be modeled sufficiently well (parts per million).

The next two require a working transponder with deterministic delays that can be modeled sufficiently well.

The last two would work on objects that are not transmitting, down to a certain size-reflectivity product, which would be determined from experience. Amateur-sized payloads could be within that range.

Radio Tracking

The power of a software approach to tracking and demodulation of signals is that arbitrary levels of control can be achieved without resorting to intractable and inflexible hardware schemes. For example, when first tracking AO-16 some fifteen years ago, many of us used a bi-phase-shift-keying (BPSK) demodulator built from a kit at the audio output of our receivers. This demodulator locked on a 1600 Hz tone and demodulated 1200 bit per second (bps) data while providing frequency stepper outputs that were intended to keep the radio output at 1600 Hz by pulsing the radio microphone “frequency down” function.

There were many problems with this approach. It had to be started manually. Stepping the radio could cause the modem to lose synchronization on the signal. When signals were strong, the modem could lock incorrectly on a modulation side lobe rather than the central carrier. None of the hardware in the process was aware of the product, a stream of AX.25 packets and so tracking sensitivity to demodulation needs was not possible. And, for orbit determination purposes, there was no reasonable way to extract sufficiently accurate RF frequency information.

If all of these functions from tuning to demodulation to decoding are hosted in an SDR such as the DSP-10 or SDR-1000, a much more seamless approach is possible. The software demodulator, for example, can be aware of data side lobes and choose the correct signal peak to track. The DSP-10 switches intermediate frequency (IF) in 5 kHz steps. Any resolution below that is determined in DSP. Several such steps would be required in tracking a full 437 MHz pass. If such a frequency step resulted in tracking or decoding problems, the software could be aware of these problems and “schedule” such switches to occur between bits or even between packets so that data was not lost. Phase could be estimated across the break so as to produce a seamless record or at least an indication of the quality of the record. With sufficiently well disciplined SDR time and frequency, the process could be entirely automated (the SDR can even do the orbit predictions) such that a data collection process might need operator attention only every few days rather than every few seconds during each pass.

The end product enabled by an SDR in this case is a radio that can track satellite carrier frequency for orbit determination purposes automatically, without the need for operator intervention between or during passes, that would also demodulate the data stream on the side.

None of this was possible in the early AO-16 era on amateur resources. If it is not possible today it is only because the SDR software for this particular application has yet to be developed.

Additional complexity like this comes at a price. The software is harder to develop, understand, and maintain than the much simpler hardware from the past. This is a matter receiving considerable attention in the professional software development field today. Such tricks as I have just described, on the other hand, are either impossible or prohibitively expensive in hardware, hardware that would then be single-use. In an SDR, by contrast, a user can be working the weak ones in the VHF QSO Party one minute, and taking data from AO-7 to refine knowledge of its orbit in the next.

Tracking a carrier originated from a satellite (“one-way”) or originated on the ground and transponded by a satellite (“two-way”) are the same process in the ground receiver. A similar but different technique is ranging via transponder in which features of the signal originated on the ground, such as some modulation pattern, are correlated at reception to measure the two-way “light time” and, from that, the range or distance. Sequences or histories of phases or ranges are used to improve orbit knowledge as described below. Ranging (pseudo-random code) was performed on AO-13 in the early days as an experiment, but the technique was never made operational on an ongoing or widespread basis.

Optical Tracking

Satellites can be tracked optically near the morning and evening terminators where the ground observer is in darkness while the satellite is still in sunlight. Amateur satellites such as AO-7 and AO-8 would be visible in a modest telescope if and when the orbital geometry was right. Images from charge coupled devices (CCD) at the focus of such telescopes could be analyzed using techniques similar to those we are using here to extract weak signals from radio noise. Of course, optical tracking is not amateur radio, but advanced amateur astronomy hobbyists are already doing much of this problem, producing intriguing images of the International Space Station and the planets, for example. Radio amateurs might well find collaboration with other such hobbyists useful to their own purposes.

RADAR Tracking

Full gallon amateur transmitters do not produce much return signal from small objects in orbit, but if the T/R sequencing can be made fast enough (on the order of a millisecond or less) an SDR should be able to detect and make coarse measurements of turn-around range from sufficiently large objects, such as the International Space Station. This is called “monostatic” because transmission and reception are from one site.

Possibly more useful is bi-static or passive radar where phase predictions are used to intercept signals from powerful broadcast or other stations reflected from objects in joint view, then arrival times of the direct versus reflected signals are compared (aided by the broadcast modulation, such as "Rock-N-Roll") to inform the geometry problem leading to a trajectory solution or refinement. Eric Blossom, K7GNU[18] has, on an amateur budget, had some success detecting airplanes with this technique, as has anyone who uses an analog television set for over-the-air reception near a major airport! The next steps would be to detect objects in orbit using such techniques, then make time delay measurements of sufficient precision.

Orbit Determination

For any such observations, the technique for improving ephemerides works like this:

- A prediction is used to detect or acquire the object. (This can range from plain luck within a large survey to successful acquisition from a narrow search based on well-refined ephemerides from prior tracking.)
- Numerical data is taken while the object is in view. This can be ranges, "pseudoranges" or Doppler signatures, reflection delays, or pixel interpolations on a CCD.
- A computer program is used to "model" what these observations should be based on the prediction and knowledge of the sensor being used (radio and antenna, telescope and CCD, pointing, and so forth).
- The modeled values are subtracted from the observed values to form a "residual," that is, difference between what we think the observation should be and what it actually is.
- Linear algebra is used improve the "estimate" of the ephemerides (and other relevant quantities such as oscillator frequency) based on these residuals. This process is an art/science known in the navigation community as "filtering" (e.g. "Kalman filter", etc.). (Software for navigation filtering of deep space missions is what I do professionally.)
- Several sets of observations may be taken from one or many locations to improve "the solution." The fact that an observer is moving with the surface of the earth in a well-understood way makes one location into multiple locations over time.
- The internet (or other means) can be used to collect observations from multiple locations semi-automatically.
- The solution is transformed into an appropriate format (i.e., Keplerian elements in "two line" arrangement).
- This feeds the existing amsat-keps distribution network.

Apart from Figure 4 and this outline, I have done no work toward an early demonstration of the first steps of this process with DSP-10. Perhaps my paper at next year's AMSAT Symposium will be a description of results from such work.

I have only touched on two SDR applications here: Ultra-weak signal work and satellite tracking. The ARRL Software Radio Working Group[16] has a long list of interesting ideas such as electronically steered antenna arrays which are also enabled by variants on SDR technology.

6 Other Platforms, Institutional Incentives

While this paper deals with my experiences and ideas for the DSP-10 platform, there are several other experimental platforms in place today, including the SDR-1000[14], the USRP and GNU Radio[15], and others in various stages of availability, deploy-ability, and adaptability. As these are developed they seem to gravitate heavily towards the application interests of their developers. The DSP-10, for instance, is largely directed towards VHF through microwave weak signal work while the SDR-1000 is a modern low band radio, useful on crowded HF bands.

There is nothing in principle that prevents any of these for being used on the new frontiers discussed here. The main roadblocks appear to be

- Availability. While it was "fun" for me to spend a few hundred hours building and debugging my own radio, others prefer to spend their limited hobby hours in other ways. SDR-1000 is more accessible. Others are less accessible.
- Development environment. The environment in which software is developed for a particular platform is often problematic. There is little portability or compatibility across different platforms. Sharing algorithms is not yet "easy."
- Motivation and focus of the developers. Occasionally, someone in the DSP-10 community will do some work on a new user interface and most successful builders conduct on-the-air tests with existing software, but so far there is very little community-wide signal and data processing software development. This is mostly a problem of finding the proper cross section between motivation, skill, and availability discussed above.

For weak signal or navigation work, there are some issues in station design that should be kept in mind:

- All frequencies should be kept to a single reference. The phase relationship between local oscillators (LO) in the radio and any converters should be coherent and understood. (This is not common in amateur practice except inside single radios.)
- Time and frequency discipline of that reference is required, as in GPS or other standards-derived references.

Commercial rigs have some potential for this sort of work as well, either through internal processing or external interfaces like the increasingly common computer soundcard interface. These rigs are often optimized for other uses, however, and those optimizations often work against applications for which they weren't intended. For instance, the highly selective filtering that makes a rig good for contesting adds amplitude and phase characteristics to the signal that must be accounted for in processing and such accounting always introduces additional processing error. Internal signals may or may not be coherent. An external reference input may or may not be supported. Commercially produced rigs are more difficult (and risky) to modify and internal software development in the larger experimenter community is practically impossible both for proprietary and logistical reasons. Most of the internal software is typically for speech processing, filtering, and noise reduction though some are beginning to handle digital modes "in the box."

A larger issue in my mind is the incentive structure within amateur radio. DXCC, for example, has been around for several decades and has been a very successful program in terms of encouraging considerable on-the-air operation, some of it quite challenging. These challenges are well choreographed in manageable steps (such as endorsements) and provide motivation for individuals and groups to upgrade station components, for manufacturers to produce equipment in support of these types of operation, and for organizations to stage on-the-air tests to improve participation even more. DXpeditions costing hundreds of thousands of dollars are staged. When a new amateur band, such as 17- or 60-meters becomes available, the first thoughts of many operators are towards DXCC and other similar operating achievements on that new band. Much of the capability of the current SDR-1000 software suite is directed towards this type of operation.

On the new frontier under consideration here, the next 20-30 dB into what is now our noise floor, are there institutional incentives that can encourage the operations, stations, equipment, and operating events that can motivate and focus the experimenters and manufacturers in new directions? Can we formulate a set of goals that will lead us in the right directions in the right sized steps? My QRPpp EME achievement was in some ways like Worked All States or a clean sweep in the ARRL Sweepstakes in difficulty. Would a graded set of awards (like DXCC endorsements), “Self Echoes,” “Worked Someone Else,” “Worked Someone Else at Some Distance,” … “EVE,” … motivate the equipment and operating opportunities that we want to see produced? A solid EVE attempt would cost less than a major DXpedition does now. With broader support and a graded system of achievements, the size of the experimenter community can increase and the cost can become even more reasonable. We need only to cleverly induce the motivation.

The old ARRL Official Observer (OO) program was certified through an operating event called the Frequency Measuring Test (FMT). Today, a set of amateur satellite tracking events could be used to certify those who would participate in the AMSAT Tracking Network. This would allow interested operators to compare and contrast different techniques on different platforms and make improvements to the system that we haven’t yet even thought of.

It is endeavors like these that will spearhead the vibrant Amateur Radio Service and Radio Amateur Satellite Service of the future. One of the enabling technologies, the Software Defined Radio, is now here, waiting to be fully exploited. After removal of a few minor roadblocks, all that we lack is imagination and properly orchestrated motivation to venture on past these frontiers into new, exciting regions. Let’s go!

7 References

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