

Getting Ready for SETI

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Abstract The SETI research conducted by SARA member and Green Bank Observatory volunteer Skip Crilly has been extended to the Deep Space Exploration Society's Plishner Radio Astronomy and Space Science Center located in Haswell, Colorado. The SETI research involves the use of the Green Bank Observatory's 40-foot radio telescope to detect various types of pulses and determine if there is any intelligible potentially shared information apparent. The astronomical object of this study is currently the -7.6 declination arc, containing 40 Eridani. The use of a second medium-sized radio telescope at Haswell provides a unique capability. This aids the resolution of RFI and the better refinement of pulse and triplet detection.

Overview

40 Eridani is located at 4.25 RA and -7.65 DEC and is located approximately 16.5 light years from Earth. Observations of 40 Eridani at the Green Bank 40-ft. telescope have been undertaken because of some interesting triplet frequencies that have been observed. [1] [2] [3] The use of a second medium-sized radio telescope at Haswell provides a unique capability to improve the resolution of RFI and the better refinement of pulse and triplet detection.

The Green Bank 40 ft. telescope is set up for drift scan only [4], with the azimuth at 180 degrees. Many SETI observations have been taken with this telescope over the last couple of years. [5] [6]

The next level of observations require that a second radio telescope simultaneously observe 40 Eridani, and the -7.6 declination arc. This technique allows for validation of received pulses by the simultaneous observations from two telescopes over a long baseline. This also allows for identification of RFI. The long baseline and synchronized clocks and frequency allow for the pulses received simultaneously by both antennas to be valid signals from deep space in the direction of 40 Eridani, and the easy identification of local pulses near the Earth.

The 60-ft. dish at Haswell, Colorado is operated by the Deep Space Exploration Society. (www.DSES.Science) The dish was outfitted with a 1420 MHz feed system and an identical backend digital signal processing system as used at the Green Bank 40 ft. dish.

Description of Triplets

There is more than one definition of a triplet used in the SETI community, depending on whether the pulses are in frequency or time. The definition used here is three simultaneous tones spaced in frequency, occurring in the same time capture. Each tone in the triplet is thresholded above 11.2 dB per bin SNR and >12 dB composite SNR of over four time captures of the bin, -3 to -1 to +1 to +3 time captures, depending on the position of the 11.2 dB bin hit in four adjacent time captures. A triplet is made up of three elements called pulses. Each of the three pulses is on a different frequency, i.e. the tone that exceeds the 11.2 dB SNR threshold.

The software posts a record to the file for each pulse, and calculates characteristics of a triplet from the lower bin spacings of two threshold-crossing pulses.

Why Look for Triplets

A frequency triplet is thought to be a "simple" way to encode "information" in one set of Nyquist-adhering time samples of a signal's occupied bandwidth. One or two pulses do not seem adequate to encode information without a-priori shared knowledge.

It is thought that seeking "encoded information" to establish the source of an intentional signal is more effective than using raw measurements, e.g. power, frequency. Information is guessed to be encoded in a way that is easy to notice. The bin spacings of a triplet might be one of these simple ways of encoding information.

The system is designed to capture single pulses to observe other phenomena, as we cannot be sure what we are looking for.

Threshold Choices

File size and post processing limit affects the setting of thresholds. The file size grows quickly with each 0.1 dB decrease in SNR. Using a combination of 11.2 dB SNR threshold for each pulse and 12 dB composite one second SNR further limits file size. A fast connection between telescopes would allow a lower SNR. Work is underway to implement this capability.

Information may be encoded in triplets in the form of a ratio, and mathematically related quantities

It appears that ratio of two bin spacings, equal to a ratio and 1/ratio are mathematically simple. One guess is that triplets are sent with various ratio, 1/ratio, e^{ratio} , etc. to increase channel capacity.

Trying not to be Fooled

It is helpful to generate "random" triplets using a system one author (Skip) has named the Prestage-Beardsley Switch, named after two astronomers who urged Skip to implement such a system. Random triplets are generated in software and posted to the file, without knowledge of their location in the file. The switch allows one to train oneself to try not to be fooled by noise when looking for what might be transmitter-receiver shared information. The system has been shown to be very useful.

Pulse, Doublet and Triplet Statistics

The pulses that exceed a threshold are expected to be Poisson distributed in frequency spacing and Rician/Rayleigh distributed in complex IQ amplitude, resulting in exponential distribution in power and SNR, depending on assumptions about noise, tone+AWGN or AWGN only. Many files use digital AWGN noise applied in the SW itself, to help to understand the behavior of the software.

Doppler Correction

Doppler correction of 675 Hz is applied during post processing, to compensate for the approaching Haswell sixty foot telescope, compared to the Green Bank Observatory forty foot telescope.

Accuracy of Frequency Measurements

Each reported bin hit is an integer, i.e. quantized, determined by the 2^{25} FFT and sample clock rate, LO, Doppler, and transmitter frequency. It is possible to interpolate adjacent bins to get a better estimate of frequency but difficult at low SNR.

Accuracy of Ratio Calculation

Ratio accuracy, after quantizing to a bin, is based on the number of digits in the numerator and denominator that comprise ratio, $1/\text{ratio}$, e^R etc., based on the time to calculate. A guess is made that a transmitter may be able to compensate for various channel impairments, and measure receiver standard frequencies, to transmit numerators and denominators that are intended to be received as transmitted. For this reason, 1000 bits of precision is used in triplet calculation in the capture software, which provides around 350 digits or precision. Other post processing can carry this farther. More precision in calculation increases channel capacity. Fine digits in ratio, for example, allows more messages that have readily identifiable potentially shared information to be transmitted.

What has been Seen so Far

In post-processing of approximately fifteen hours of observations no signals have appeared that specifically compel follow-up observations. One interesting simultaneous pulse with an offset of 34 Hz, after Doppler and clock correction, was seen. The 34 Hz pulse appears to be associated with an outlier of RFI at the Haswell site. The RFI is being addressed. The triplet was fascinating as the Green Bank associated triplet had 888 in the first digits of 1/ratio and contained a 73657373 sequence in its calculated digits at around the five hundred digit point. Early transmitted Phillips codes of 73, 88 and our year of 365 are candidates of potential shared information. The Doppler corrections are thought to be accurate to approximately five Hz, so a 34 Hz offset rules out a simultaneous pulse at celestial distances. There are many possible explanations for this pulse and associated triplet that are not due to ETI.

Two simultaneous pulses have been seen in post-processing November observations that have a corrected pulse frequency within ± 3.7 Hz. These pulses and their associated triplets are being examined for potential shared information, and the pointing direction to nearby stars as the pulses were recorded. Follow-up observations are planned.

A sample procedure to post process capture files from the simultaneous system

Note: C code has been written to essentially do the calculations up to step 11

1. In each file, extract location (Green Bank =sample phase.1, Haswell = sample phase.2) from the first column and place location into its own column.
2. Calculate the Haswell corrected tone frequencies using the bin number, corrected for Doppler offset at parallel beams direction and Haswell ADC clock offset.
3. Calculate the Green Bank corrected tone frequencies using the bin number, corrected for Green Bank ADC clock offset.
4. Combine the Green Bank and Haswell files into one spreadsheet.
5. Sort the combined file by: tone frequency derived from 1. and 2., then by GPS time.
6. Calculate the difference in GPS time between adjacent rows, with GPS time difference placed in a new column.
7. Convert formula results to values by copying the sheet to another worksheet, posting values.
8. Sort the file by difference in GPS time, lowest first.
9. Subtract row-adjacent location i.e. Green Bank & Haswell location values, into a new column.
10. There should only be a few same-time close-frequency tones at the top of the file (a few bins offset) if only noise is present.
11. Scan the file from the top and look for a change in location in adjacent rows.
12. Excise strongly-suspected RFI, frequency calibration tones and/or anything else that looks internal to the system and/or calculation algorithm.
13. Find the records in the original files that produced any close-frequency simultaneous tones, and verify the calculations.
14. Search for doublets and triplets happening at or around the same time as the tones in 13.
15. Search for information and unusually low or unusually high Shannon Entropy in triplets' ratios, e^{ratio} , e^{ratio} and in inverse ratios, $e^{\text{inverse ratio}}$, $e^{\text{inverse ratio}}$.
16. Look for similarities in tones, SNRs, triplets etc.

The Haswell System Configuration

The Haswell system is shown in figure 1. The feed system and dish are the only differences between the Green Bank system and the Haswell system. The signal generator used as an LO is either an HP 8648B.

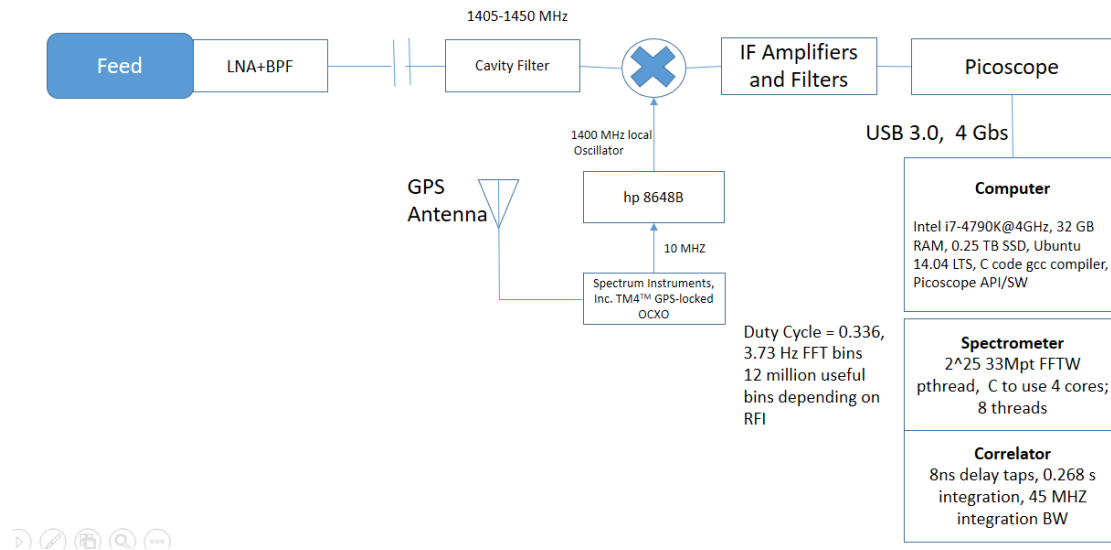


Figure 1: Haswell System Configuration

Haswell 60-foot Antenna

The Haswell telescope (figure 2) was originally built by the National Bureau of Standard to study radio propagation of the ionosphere. It was built in the late 1950's and was transferred to the Air Force and the Army before it was declared as surplus in the 1970s. It was sold to Radio Research in the 1980s and was donated to the Deep Space Exploration Society (DSES) in 2009. The original group of DSES volunteers performed maintenance and refurbishment on the telescope to bring it back to operation. The original gear train for the antennas elevation and azimuth axis was retained. As part of the refurbishment a 3.5 KW 300-volt AC servomotor was installed in the azimuth drive to replace the original azimuth motor. A motor control chassis was built to handle the Azimuth Motor Controller and the Elevation Variable Frequency Drive units. A hand paddle was built to perform manual control of the azimuth and elevation circuitry. [7]



Figure 2: Haswell 60-ft dish

Pointing System

The 60-foot antenna position indicator system (figure 3) is vital to provide scientific grade observations for radio astronomy. The system is based on the use of 12-bit encoder accuracy that is converted to azimuth and elevation as well as right ascension and declination. The outputs are displayed at the operator station in the communications trailer. The position data is combined with the output data to provide scientific grade radio astronomy observations. [7]

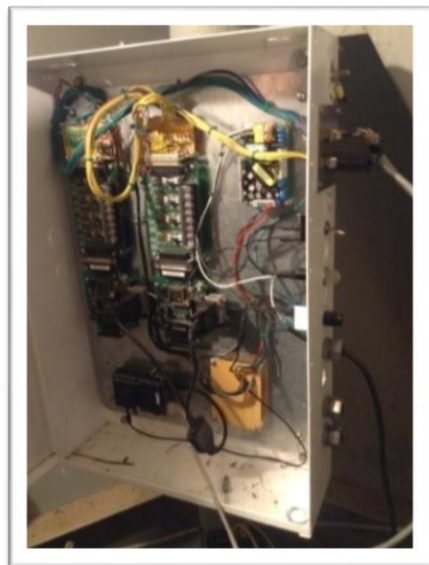


Figure 3: Pointing System

Haswell Feed System

The Haswell antenna required a 1420 MHz capable feed system. Steve Plock built the feed based on the design shown in the SETI League Technical Manual [8]. (figure 4)

This is a standard SETI feed utilizing three separate LNA's and a quadrature hybrid coupler to combine the orthogonal probe signals to obtain circular polarization receive capability. It includes a scalar ring adjusted for minimum noise for dish F/D. A radome cap was installed to prevent static buildup.

The Low Noise Amplifier (LNA) specifications are [9]:

- 0.7-6.0 GHz Operational Bandwidth
- Ultra Low Noise Figure, 0.4 dB NF at 1.95 GHz
- High Gain, 20 dB Gain at 1.95 GHz



Figure 4: Haswell 1420 MHz Feed

The output of the feed system was amplified at the communications trailer and then routed through a cavity filter system. (figure 5)

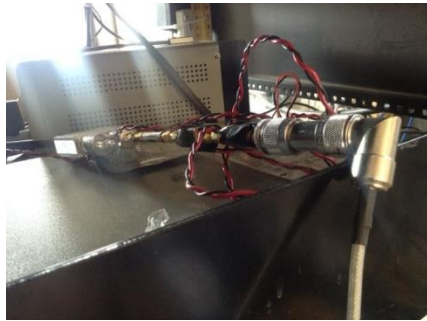


Figure 5: Added Amplifiers and Bandpass Filter and the Cavity filter

GPS Timing

The capability to simultaneously observe an astronomical source over a long baseline required a precision timing system that can be synchronized at both locations. The Spectrum Instruments TM4 was chosen. The TM4 specifications [10] are shown in figure 6.



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- Optional Nelson Time Protocol output
- Optional RIG and NASA-36 time codes
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- Very low phase noise (OCXO version)
- Small size (4.125 x 4.0 x 1.58" excluding connectors)
- Available as OEM board-only product
- Simple RS-232C ASCII command and message set, includes navigation information and NMEA-0183 subset
- Wide input power range: 9-35 VDC
- Standard input and output connectors
- Windows[®] based control software included
- Choice of GPS antenna (external kit sold separately)
- Optional multiple sine wave outputs
- Highly customizable

PHYSICAL (In Enclosure)

HEIGHT: 1.50 in. (38.1 mm)
WIDTH: 4.125 in. (104.8 mm)
DEPTH: 4.00 in. (101.6 mm)
WEIGHT: 1.20 lbs. (0.368 kg)

ENVIRONMENTAL

OPERATING TEMPERATURE: -20 to +70°C, external edge cooling
STORAGE TEMPERATURE: -40 to +85°C
HUMIDITY: Up to 85% R.H., non-condensing

POWER

INPUT SUPPLY VOLTAGE: 9 to 35 VDC, 24 VDC nominal
INPUT CONNECTOR: DE-9HD (female)
POWER CONSUMPTION: 2.4 watts after warm-up, Low-power option available
ANTENNA POWER OUT: 5 VDC, 20 mA
GPS BACKUP: Rechargeable lithium battery

OSCILLATORS

HIGH-PERFORMANCE OCXO: standard
LOW-POWER OCXO: optional
TCXCO: optional
STANDARD FREQUENCY: 10 MHz
OPTIONAL FREQUENCIES: 5, 10, 15, 13 MHz
Consult factory for additional oscillator options

PERFORMANCE (GPS)

RECOVER TIME: Twelve parallel channels, cold + warm-starting, 20 sec. to 10 min.
TIME TO FIRST FIX (Typical):
Hot Start: <15 seconds (cold start: 10 min. to 1 hour)
Warm Start: <10 seconds (cold start: 10 min. to 1 hour)
Cold Start: <10 seconds (cold start: 10 min. to 1 hour)
POSITION UPDATE RATE: Once per second, nominal
POSITION ACCURACY: Less than 25m CEP

PERFORMANCE (TIME)

1 PPS OUTPUT: (Referenced to UTC)
Accuracy: 20ns RMS
Accuracy while coasting: Same as primary frequency output

ACCESSORIES

- GPS antenna kit
- Power/Control cable
- 1U Rack mount kit
- Distribution amplifier
- Connector (BNC) kit
- 1A0 power adapter, US or EU country
- Rechargeable battery pack/UPS

INPUTS & OUTPUTS

1 PPS OUTPUT
Connector: BNC
Drive: TTL, max into 50Ω
Rise Time: 10 ns, maximum
Pulse Width: Positive pulse, 1 sec nominal
Falling edge on-line, PPS connector can be taken as input or output instead of PPS

10 MHz OUTPUT
Connector: BNC
Drive: High speed, frequency drive into 50Ω, max
Rise Time: 10 ns, maximum
Pulse Width: Positive pulse, 1 sec nominal
Falling edge on-line, PPS connector can be taken as input or output instead of PPS

GPS ANTENNA
Connector: TNC
Control and Auxiliary I/O
Connector: DE-9HD (female)
SERIAL CONTROL I/O: RS-232C, 9600bps
ALARM OUTPUT: Open collector
SERIAL TIME MESSAGE: RS-232C, 1000, 1200, 300, 600, 1200, 2400, 4800, 9600, 19200, 38400, 76800, 153600, 307200, 614400, 1228800, 2457600, 4915200, 9830400, 19660800, 39321600, 78643200, 157286400, 314572800, 629145600, 1258291200, 2516582400, 5033164800, 10066329600, 20132659200, 40265318400, 80530636800, 161061273600, 322122547200, 644245094400, 1288490188800, 2576980377600, 5153960755200, 10307921510400, 20615843020800, 41231686041600, 82463372083200, 164926744166400, 329853488332800, 659706976665600, 1319413953331200, 2638827906662400, 5277655813324800, 10555311626649600, 21110623253299200, 42221246506598400, 84442493013196800, 168884986026393600, 337769972052787200, 675539944105574400, 1351079888211148800, 2702159776422297600, 5404319552844595200, 1080863910568918400, 2161727821137836800, 4323455642275673600, 8646911284551347200, 17293822569102694400, 34587645138205388800, 69175290276410777600, 138350580552821555200, 276701161105643110400, 553402322211286220800, 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Figure 7: TM4 Installation

The HP 8648B signal generator [11] provides a 1400 MHz signal to the mixer. (figure 8)



Figure 8: HP 8648B

PicoScope

The RF signal from the cavity filter was routed to the Picoscope 3207B which digitizes the signal and sends the digitized data to the tower computer over USB 3.0. The Picoscope specification and installation are shown in figure 9.



Figure 9: Picoscope Technical Data Sheet and Installation

Computer Control and Antenna Position Indication

The tower computer receives the picoscope data and then processes and stores the data into files. These files are later downloaded onto thumb drives and sent to Skip for post-processing and comparison to the Green Bank observations. The tower computer installation as well as monitor as well as the position indication monitor are shown in figure 10.



Figure 10: SETI and Pointing Control Stations with the Computer Tower Installation

Testing Results

To test the capability of the two telescopes to simultaneously point measure an astronomical source, a measurement of the supernova remnant W41 was attempted. W41 is a 90 Jansky source

at 1400 MHz and is located at RA 18h 34m 45s Dec -8d 48m (J2000). The timing of the observation allowed for both antennas to observe W41 without having to reposition for 40 Eridani.

The plot shown in figure 11 is of the continuum of the W41 supernova remnant measured simultaneously at Haswell and Green Bank. The back-end integration time and bandwidths are almost identical at the two sites.

The Declination of W41 is -8.8 degrees, so the -7.6 pointing we used is not at the peak of the expected response. A future goal could be to adjust Declination at both sites to -8.8 degrees and observe. The expected noise increase, at 90 Janskys, is 0.4 dB, matching closely what we observed at each site.

Figure 11 shows the results of the W41 measurements:

- 11/25/2017 simultaneous observations
- W41 RA 18h 34m 45s Dec -8d 48m (J2000)
- Continuum (dB rel.) of Haswell 60 Foot (red) and Green Bank 40 Foot (blue) vs MJD
- 1404-1448 MHz one second integration
- W41 70 Jys. (@1 GHz) expected at 58082.81623

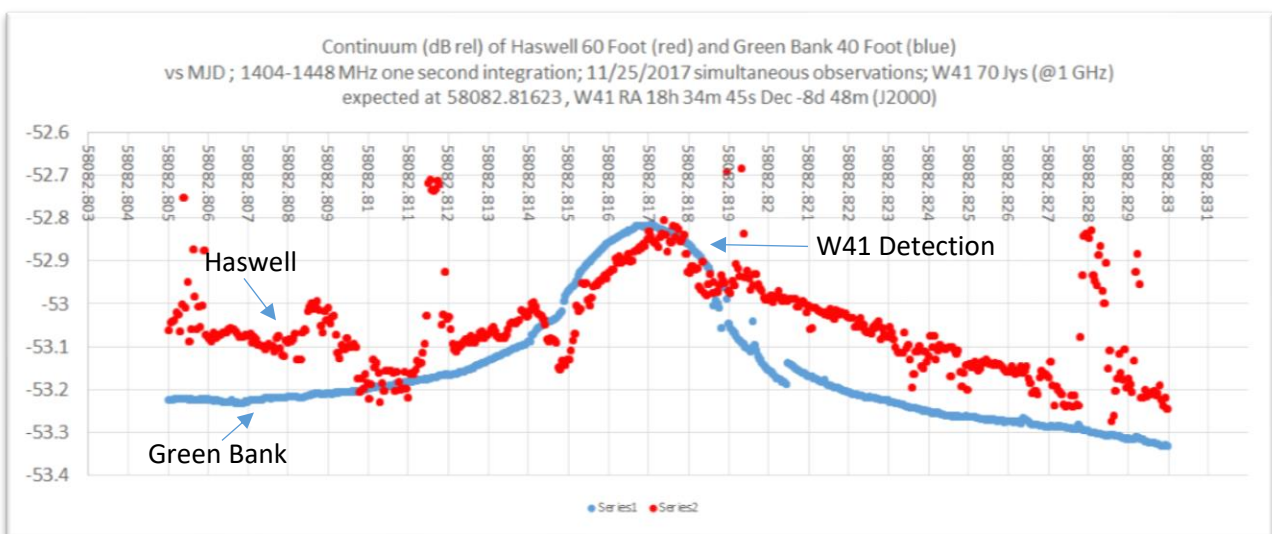


Figure 11: Simultaneous Observations of Green Bank and Haswell Antennas of W41

The observations indicate a close pointing and timing correlation between the two sites! This provides the needed confidence that the Green Bank and Haswell antenna systems are properly configured to provide simultaneous observations for future observations, starting with 40 Eridani, and other potential transmitting sources along the -7.6 declination arc.

Summary

Haswell was configured to support the SETI measurement of 40 Eridani and other potential sources at the initially observed -7.6 declination. The back-end system was duplicated based on the Green Bank system. Both antenna sites were synchronized with the GPS time signals.

Final testing was accomplished by simultaneously observing super nova remnant W41. This test yielded close results between the two antenna sites.

The Green Bank and Haswell antenna systems are now ready to make simultaneous observations in support of SETI.

Works Cited

- [1] S. Crilly, "Shannon Entropy Measurements of Radio Telescope Signals," Green Bank, W.V., 2015.
- [2] S. Crilly, "NRAO Green Bank Forty Foot Telescope Update," in *SARA Annual conference 2016*, Green Bank, W.V..
- [3] S. Crilly, "Narrow Bandwidth Radio Bursts Observed using the Green Bank Forty Foot Telescope and Home-built Five Meter Telescopes," Prescott, AZ, 2016.
- [4] B. M. S. A. H. Richard F. Bradley, "National Radio Astronomy Observatory 40-Foot Radio Telescope Operator's Manual," NRAO, Green Bank, W.V., 2011.
- [5] S. Crilly, "Pulsar Observations at 1400 MHz using the Forty Foot Telescope at the Green Bank Observatory," Green Bank, W.V., 2017.
- [6] S. C. Tom Hagen, "SARA Mobile Interferometer at NRAO Green Bank," Green Bank, West Virginia, 2016.
- [7] G. D. R. R. Dave Molter, "Plishner Radio Astronomy and Space Science Center - 60-Foot Dish Position Indication System Development," Socorro, N.M., 2016.
- [8] H. P. Shuch, "SETI League Technical Manual," 1997.
- [9] Qorvo Inc., "TQP3M9037 Ultra Low-Noise, High Linearity LNA".
- [10] "Intelligent Reference/TM-4™ and TM-4/OEM™," Spectrum Instruments, [Online]. Available: <http://www.spectruminstruments.net/TM4.pdf>.
- [11] "HP 8657B," [Online]. Available: <http://www.testequipmentdepot.com/usedequipment/pdf/8656B.pdf>.