

# **Plishner Radio Astronomy and Space Science Center**

## **The Use of Statistical Process Control to Improve the Detection of Extraterrestrial Radio Sources**

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### **Abstract**

The Plishner Radio Astronomy and Space Science Center is operated by the Deep Space Exploration Society based out of Colorado Springs, Colorado. The largest antenna system is a 60-ft. parabolic reflector. This paper describes the use of statistical process control to troubleshoot the prototype UHF radio telescope and enhance the detection of weak radio sources.

### **1.0 Introduction**

The Deep Space Exploration Society (DSES) is a not for profit organization whose primary purposes are research and education of space communications and radio astronomy. The DSES primary asset is the Plishner Radio Astronomy and Space Science Center which is located in a radio quiet area near Haswell, Colorado. The primary asset of the DSES organization is a 60-foot parabolic reflector that was built in the 1950s for the study of tropospheric communications.

The DSES organization is outfitting the 60-foot reflector with a feed and receiver system designed to measure various radio frequency bands related to astronomical sources. The system will evolve using rapid prototyping. This method necessitated the use of a method to analyze the received data and determine if the data was valid and consistent. Statistical Process Control (SPC) is a methodology that uses statistical tools to analyze large amount of data, determine variability, and provide insight into approaches to correct the issues.

Statistical process Control (SPC) will provide the following to the development effort:

- Improve the performance of the telescope
- Enhance the detection of weak radio sources
- Reduce false positive detections
- Troubleshoot the radio telescope and allow for quick diagnostics of the radio telescope
- Reduce the variability of the data received
- Provide quantitative information on design and product selection

### **2.0 The 60 ft. Diameter Dish**

The multi-band feed is designed to be installed on the 60-foot diameter dish at the DSES site at Haswell, CO as seen in figure 1.



*Figure 1: DSES 60 ft. Dish*

A communications trailer is located next to the antenna pedestal. All receiver equipment is located in the trailer. This allows for shorter feed lines. Remote access to the communications trailer is available through the internet to allow for control and monitoring of radio and power systems. (Figure 2)



*Figure 2: Communications Trailer and Test Rack*

A multiband feed on the dish allows for 1420.406 MHz, 1296 MHz, 435 MHz, and 140 MHz bands (1). (Figure 3)



*Figure 3: Multiband Feed*

### 3.0 Statistical Process Control

Statistical Process Control (SPC) provides tools to achieve process and stability to improve capability through the reduction of variability. (2)

#### 3.1 Prototype Setup

A prototype antenna and receiver system was set up to develop procedures for the use of SPC on the 60-foot dish system. The prototype consisted of a 13 element Yagi antenna with 13 dBi @ 435 MHz. The antenna was connected to a 20 dBi mast mounted preamp, and then to a Kenwood TS2000 transceiver. The audio output of the transceiver was sent to an AudioBox (3) (audio to USB converter) and then to a computer running radio SkyPipe logging software (4).



Figure 4: Prototype Setup

It should be noted that the prototype was not expected to be sensitive enough to receive any astronomical sources.

#### 3.2 Data Gathering

The approach was to conduct drift scan surveys of the visible sky. To determine the variability of the receiving system, data would be taken at the same declination for multiple days. The data was collected on SkyPipe (4), and then converted to delimited files and ported into excel for analysis.

The data was plotted on a Run Chart (Figure 5). The X-Axis is Local Mean Sidereal Time (LMST) and the Y-axis is the received signal level.

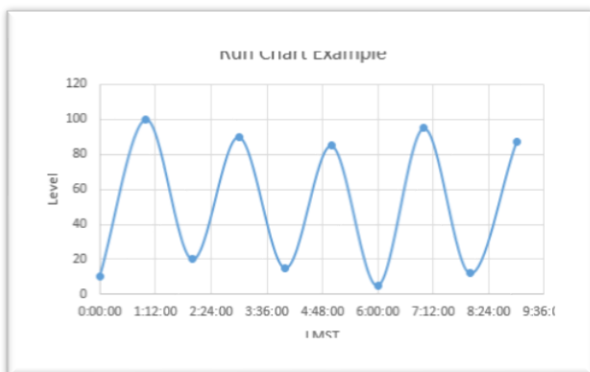


Figure 5: Run Chart

### 3.3 Control Chart

A control chart provides a method to analyze variability in the data. The control chart starts with a run chart and then adds a mean plus upper control limit (UCL) and lower control limit (LCL) lines. The UCL and LCL will both be 1 standard deviation ( $\sigma$ ) above and below the mean. Data that breaks through the UCL or LCL is considered to be an issue that needs to be resolved. The larger the standard deviation, the greater the variability in the data. An example control chart is shown in Figure 6.

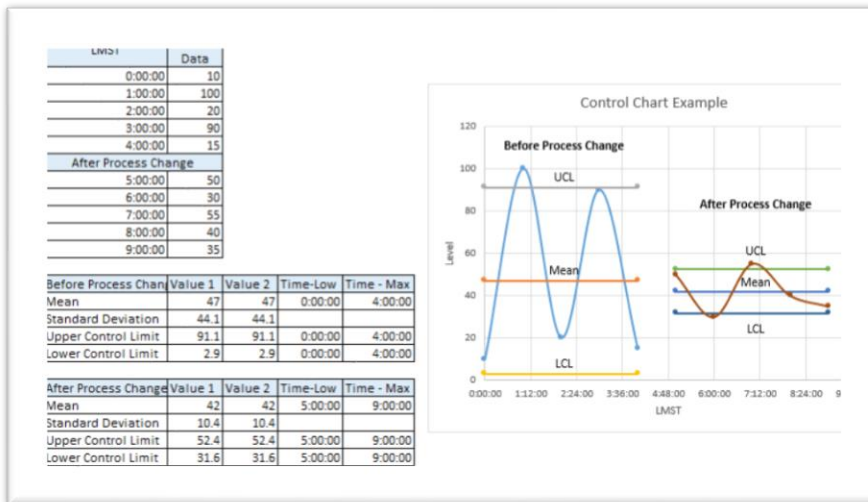


Figure 6: Control Chart Example

For the prototype system, the goal is to reduce the variability of the noise signal by taking data and then modifying components and processes. The comparison of the before and after control charts standard deviations will show if the process modification reduced the variability.

Note: While there are various approaches for calculating UCL and LCL, (2), (5), (6) the use of the standard deviation ( $\sigma$ ) above and below the mean is used for the prototype for simplicity.

Figure 6 shows an example of the before and after control chart when there is a process change that decreases the variability. Other control chart rules are used to verify that the processes are in control. (2 p. 205)

- 1 or more points outside of control limits
- Four of five consecutive points beyond the one segment limit
- A run of eight consecutive points on one side of the center line
- Six points in a row steadily increasing or decreasing
- An unusual or nonrandom pattern in the data

The assumption for the prototype is that the majority of the data received would be background noise caused by the environmental temperature variations of the antenna, preamp and receiver.

### 4.0 50 Ohm Test

A 50-ohm resistor was installed at the end of the antenna cable. Data was taken on the resultant signal level and outside temperature. Figure 7 shows the 50-ohm connection.



Figure 7: 50 Ohm Terminator

Figure 8 shows the data taken on the prototype radio telescope. The X-Axis is the LMST and the Y-Axis is the uncalibrated signal level from the receiver at 420 MHz and continuous wave modulation. The mean is the average level of the data. The Upper Control Limit (UCL) is the  $mean + 1\sigma$ , while the Lower control limit (LCL) is the  $mean - 1\sigma$ .

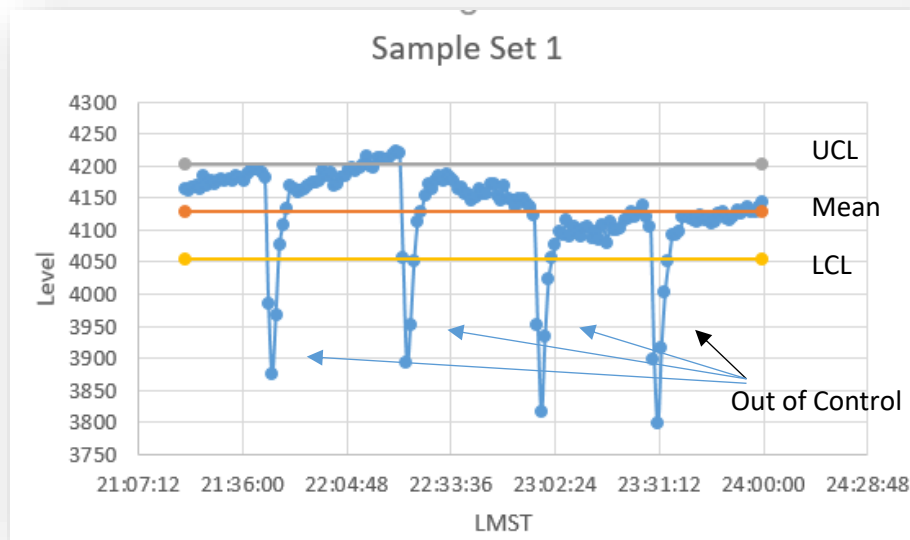


Figure 8: Temperature Data - Sample Set 1

The data indicates two different effects, variations inside the control limits and multiple crossings of the LCL. The analysis of the data shows the following:

- Data cycles below the LCL about every 37 minutes
- Multiple consecutive points above the mean or below the mean

This data indicates that the current prototype process is “out of control” which is an indicator of a process and/or a component defect. SPC uses a cause and effect diagram as a methodical approach to coming up with causes and solutions for an out of control system.

#### 4.1 Cause and Effect Diagram

The Cause and Effect diagram is a brain storming activity that helps to develop and track issues with a system. The cause and effect diagram (2) for the 50-ohm test is shown in figure 9.

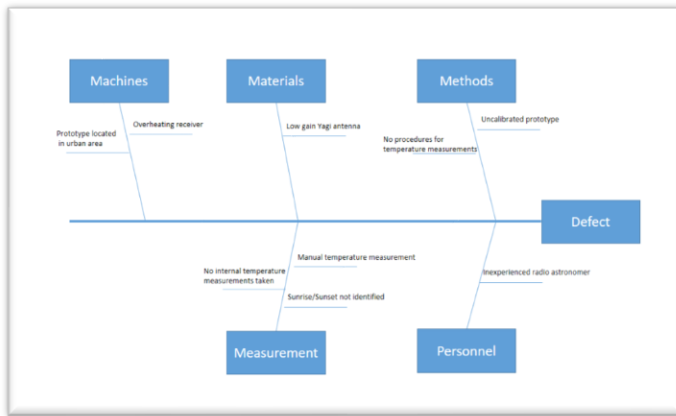


Figure 9: Cause and Effect Diagram

The cause and effect diagram uses brainstorming activities to develop as many potential causes of the problems and then classify them into some basic categories. The resultant causes are then rank ordered with solutions identified. For the prototype data above a subset of the cause rankings and corrective actions are: (Table 1)

Rank	Cause	Corrective Action
1	Receiver overheating	Add external fan
2	Manual Temperature measurements	Add weather station with automatic data collection
3	Sunrise/Sunset not documented	Add step in procedures

Table 1: Cause and Corrective Action Rankings

The top ranked cause solution was to add an external fan to the receiver. Figure 10 shows the results of the corrective action. The negative spikes were eliminated and the receiver internal fan no longer cycles.

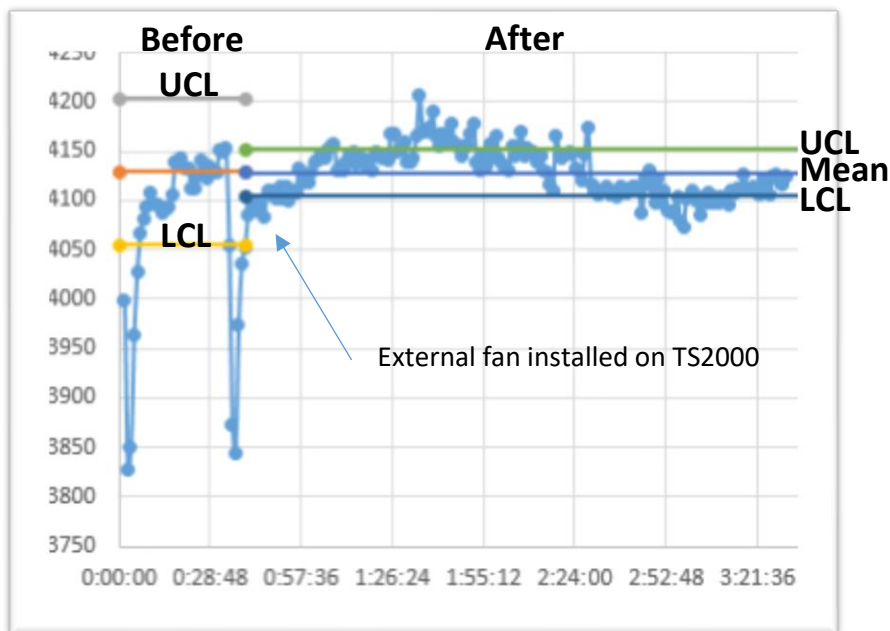


Figure 10: Control Chart showing data before and after the External Receiver Fan was Installed



The before and after statistics are shown in Table 2. A couple of results are of interest.

- The before and after mean did not change significantly
- The standard deviation was reduced from 74 to 24, a 68% reduction.
- The after data reveals new UCL and LCL crossings which require additional brainstorming at a different level.

Sample Set 2				
Parameter	Level-Start	Level-End	LMST-Start	LMST-End
Old Mean	4129	4129	0:00:00	0:40:00
Old Stdev	74			
Old UCL (Mean+stdev)	4203	4203	0:00:00	0:40:00
Old LCL (Mean-Stdev)	4054	4054	0:00:00	0:40:00
Parameter	Level-Start	Level-End	LMST-Start	LMST-End
New Mean	4128	4128	0:40:00	4:00:00
New Stdev	24			
New UCL (Mean+stdev)	4151	4151	0:40:00	4:00:00
New LCL (Mean-Stdev)	4104	4104	0:40:00	4:00:00

Table 2: Before and After Test Data

Note that the SPC process has now reset the standard to the new lower variability. This data can be used to continue corrective actions and quantitatively show the effect of corrective actions.

## 4.2 Ambient Temperature Variation Analysis

This analysis also used the 50 ohm resistor on the end of the antenna cable. It also coincided with a significant drop in outside temperature. The goal of this analysis was to determine the variations associated with external temperature on the data. The data was taken over a day with the same parameters that the section 4.1 data was taken and was documented in the control chart on figure 11. The temperature range is also noted.

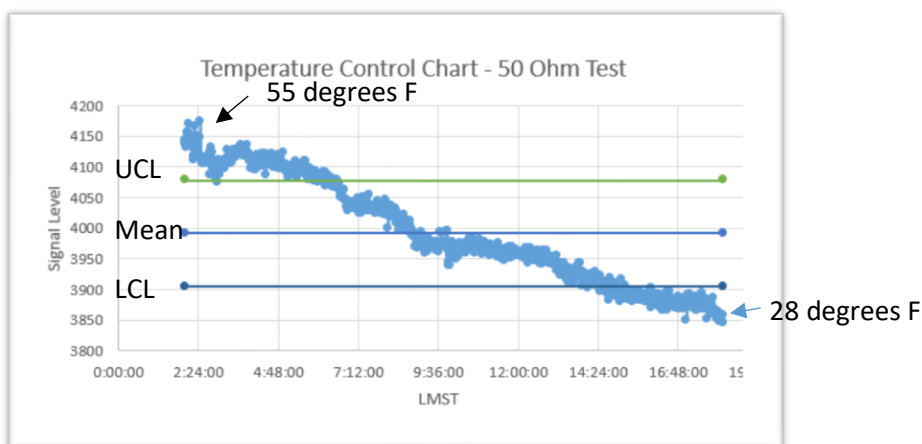


Figure 11: Control Chart: Temperature Test - 50 Ohm Resistor

The calculated control chart statistics (Table 3) shows that the  $\sigma$  from data taken at 55°F to 28°F was almost as large as the overheating receiver of section 4.1.

Temperature Variation Analysis				
Parameter	Level-Start	Level-End	LMST-Start	LMST-End
Mean	3991	3991	2:00:00	18:11:00
Stdev	86			
UCL (Mean+stdev)	4078	4078	2:00:00	18:11:00
LCL (Mean-Stdev)	3905	3905	2:00:00	18:11:00

Table 3: Temperature Test Control Chart Statistics

Without going through the details of brainstorming, it was decided to model the temperature effect on signal level and then add an offline correction factor to the data.

The temperature effect was modeled and plotted in figure 12.

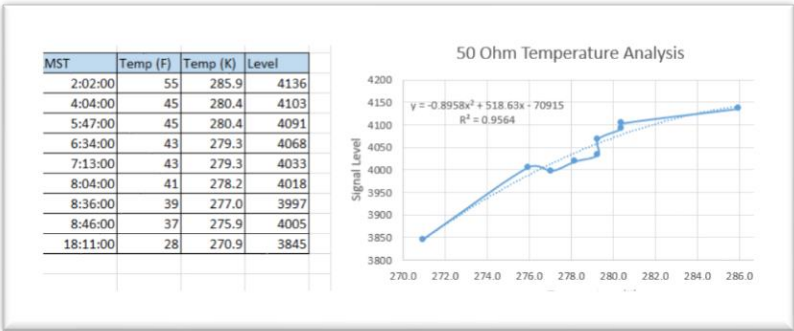


Figure 12: Model of Temperature vs. Signal Level

The corrected data was plotted in figure 13 with the resultant control chart statistics in table 4.

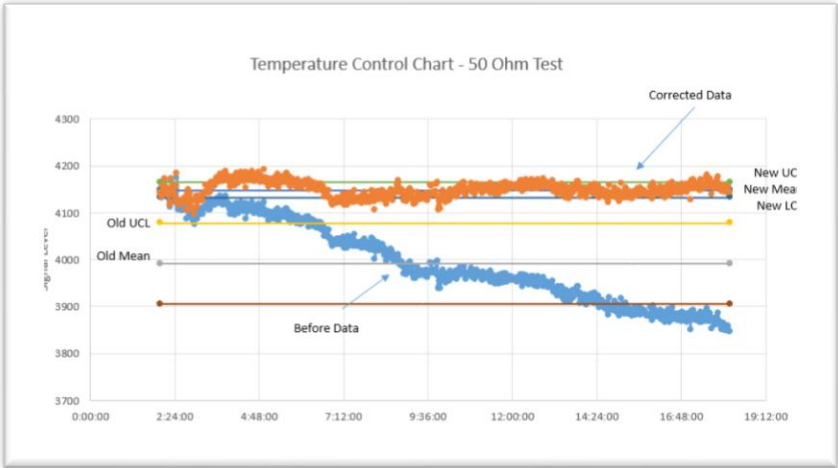


Figure 13: Temperature Analysis Control Chart



Temperature Variation Analysis				
Parameter	Level-Start	Level-End	LMST-Start	LMST-End
Old Mean	3991	3991	2:00:00	18:11:00
Old Stdev	86			
Old UCL (Mean+stdev)	4078	4078	2:00:00	18:11:00
Old LCL (Mean-Stdev)	3905	3905	2:00:00	18:11:00
Parameter	Level-Start	Level-End	LMST-Start	LMST-End
Corrected Mean	4148	4148	2:00:00	18:11:00
Corrected Stdev	16			
Corrected UCL (Mean+stdev)	4164	4164	2:00:00	18:11:00
Corrected LCL (Mean-Stdev)	4133	4133	2:00:00	18:11:00

Table 4: Temperature Analysis Control Chart Statistics

The  $\sigma$  in the data was reduced from 86 to 16 using this method, an 81% reduction.

It should be noted that this is only an interim solution. A more permanent solution would be to continuously measure temperature and correct the data real time. The development of a Dicke Switch may be a more permanent solution (7), (8).

### 4.3 Antenna Variation Analysis

The tests and corrective actions from sections 4.1 and 4.2 above used a 50-ohm resistor in the place of the antenna in order to characterize the preamp and receiver system from the antenna and external signal sources. The prototype system was installed in an urban area surrounded by trees and houses. The goal of this analysis was to determine the variability of the antenna based on elevation angle while pointed at the meridian.

In order to reduce the effect of temperature change as noted in section 4.2, the data was taken during a steady external temperature with 10-12 minute sample periods at 10° elevation angle changes. The mean and  $\sigma$  for each sample elevation was documented in table 5 and plotted in figure 14.

Elevation	Mean	Stdev
uth 0 Deg	2139	374
uth 10 Deg	1810	488
uth 20 Deg	1104	214
uth 30 Deg	496	40
uth 40 Deg	486	55
uth 50 Deg	388	26
uth 60 Deg	558	46
uth 70 Deg	490	66
uth 80 Deg	722	492
uth 90 Deg	640	38
orth 80 Deg	809	72
orth 70 Deg	579	56
orth 60 Deg	608	47
orth 50 Deg	1293	187
orth 40 Deg	560	141
orth 30 Deg	471	25
orth 20 Deg	560	30
orth 10 Deg	527	11
orth 0 Deg	496	18

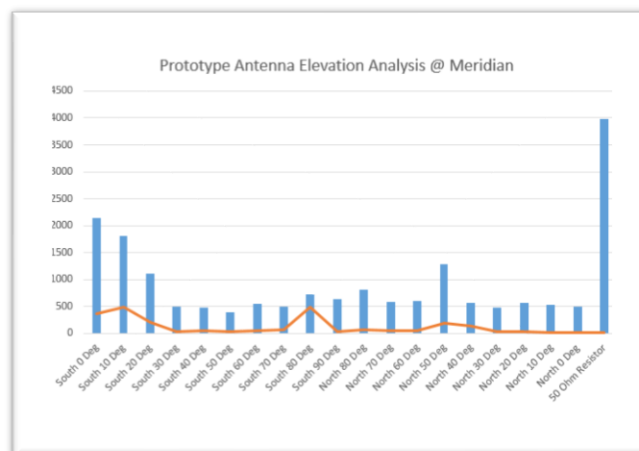


Table 5: Antenna Elevation

Figure 14: Mean and Standard Deviation vs. Elevation Angle

Angle vs. Mean Signal Level

This data shows that at certain elevation angles, there is a significant ambient signal level as well as higher  $\sigma$ . Figure 15 plots only the standard deviation to the elevation angle.

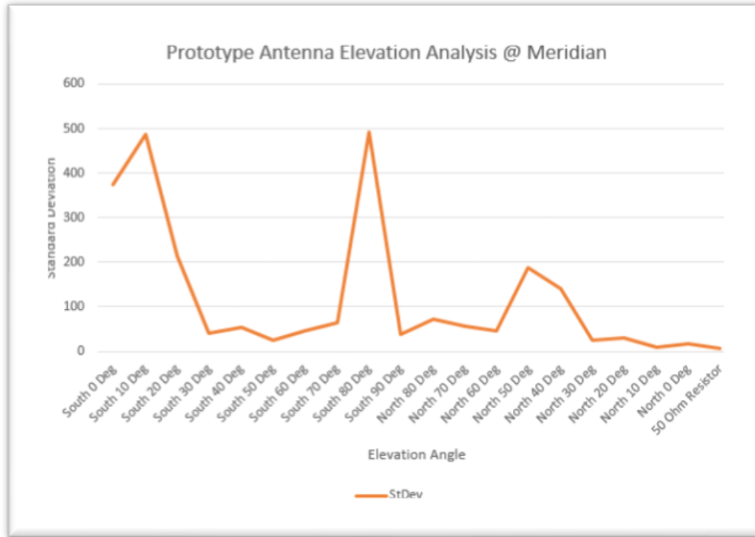


Figure 15: Elevation Angle Vs. Standard Deviation

The results show that there was a higher signal level and  $\sigma$  between south 0° to 20° elevation as well as south 80° and north 50°. The preliminary cause and effect analysis included some obvious issues such as ground temperature contributions as well as the close proximity of pine trees.

The results of this test show that the best elevations to conduct drift scans with the lowest variability are where there are low mean signal levels and low  $\sigma$ .

## 5.0 Lessons Learned for the Prototype Analysis

The lessons learned from the above SPC analysis shows that the best configuration to conduct a drift scan on the prototype antenna includes:

- The receiver fan causes data spikes in signal level - External fan on receiver to maintain temperature
- External temperature variation is a significant factor – limit observations to a steady state temperature
- Elevation angle has a significant effect on the signal levels – only take data at low mean and  $\sigma$  as noted

## 5.1 Recommended Process Changes

The purpose of the prototype SPC analysis was to identify processes and procedures in order to apply to the 60-foot dish system at the Plishner Radio Astronomy and Science Center. The By combining the cause and effect and ranking data and corrective actions, the following table of processes are recommended. (Table 6).

#	Recommendations
1	Process to automatically measure and record external temperature
2	Process to switch between the 60 ft. dish feed antennas and the installed 50-ohm resistor
3	Process to measure the receiver temperatures and maintain at a constant temperature
4	Process to characterize the signal level and $\sigma$ for 60 ft. dish system at various elevation angles along the meridian
5	Process to characterize signal level vs. external temperature with correction factors
6	Process to maintain control charts for various configurations of the radio telescopes and to show how modifications change the control charts and variability
7	Process to document configuration changes on each aspect of the radio telescope configuration

Table 6: Recommended Processes

These process changes will help reduce the variability on the radio telescopes so that small signals from real astronomical sources will be easier to differentiate. More processes will be added as the operators use the telescopes and start taking astronomical measurements.

## 6.0 Summary

The use of SPC provides a quantitative approach to measure and analyze the variability of a radio telescope system. The data shown in this paper shows the methodology that will be used on the 60 foot antenna system. The prototype tests show how SPC can be used to significantly reduce the variability and accuracy of the radio telescope data. Control charts are well suited for radio astronomy drift scans and can help reduce variability in the data which allows for increased sensitivity of differentiating real astronomical sources from background noise. SPC provides a significant troubleshooting capability as well as a quantitative approach to evaluating corrective actions.

The use of SPC allow the radio telescopes to be continuously improved by reducing the variability. Proper use of SPC will allow for continuous process improvement which over time means that the radio telescopes will become more sensitive and provide more astronomical source detections.

## References

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