Introduction

Synchrophasors are time-synchronized measurements of a quantity described by a phasor such as voltage which has a magnitude and phase. These phasors are measured in a Phasor Measurement Unit (PMU) and are time-stamped using a GPS timing signal. Since measurements taken by PMUs in different locations are synchronized with each other, the relative phase angles between different points in a utility system can be determined. A network of PMUs enable grid operations to monitor many parameters such as bulk power transfers across the network.

The concept of a PMU was first developed in 1988 but caught on slowly until 2009 when large federal grants for their purchase were authorized. In 2015, it is estimated that 1700 PMUs are deployed across the U.S. and Canada.

Current PMUs measure data at rates of 30 to 120 records per second. The PMUs are connected to high-speed communication systems to deliver the data to a Phasor Data Concentrator (PDC). Multiple PDCs relay their data to higher-capability PDCs which incorporate analytical applications to visualize the data, calculate state estimators, and implement alarm processors.

PMU Cost

In 2014, the Department of Energy calculated that the average overall costs per PMU (procurement, installation, and commissioning) range between $40,000 and $180,000. The PMU device itself was approximately 5% of the installed cost. Communications upgrades to handle the high bandwidth data were identified as the largest cost driver.

Use of Synchrophasor Network Data

Synchrophasor data can be used for numerous purposes from simple visual monitoring of grid conditions to fully automated control of the grid. Currently most applications are for non-critical functions such as monitoring grid conditions, driving real-time alarms and alerts, and post-event analysis of disturbances and blackouts. Automated protection scheme functions require synchrophasor systems to be designated as critical cyber assets which can cost up to three times that of a system intended for non-critical functions.

For visual real-time monitoring of the grid, current synchrophasor systems represent an overkill in terms of data rate and required bandwidth. In the long term (10 to 20 years), these high data rates may be required when fully automated grid applications are designed, tested, and approved. However, this will be a long slow process. As in aviation, providing current status information to the pilot (airspeed, altitude, attitude, etc.) simply requires reliable instruments whereas providing an autopilot requires costly extensive software testing, verification, and certification.

Origo Low Speed Synchrophasor Network

Origo provides phase identification equipment that allows linemen to determine the phase attribute of any energized conductor. Origo base stations record instantaneous wall socket phase each GPS second to provide a known reference phase for linemen field probes. As such, Origo base stations represent simple

PMUs. Data from multiple Origo base stations can be compared to form a voltage phase synchrophasor network. This low speed network can be used to observe power flow between locations and to detect the propagation of grid anomalies from power outages at distant locations.

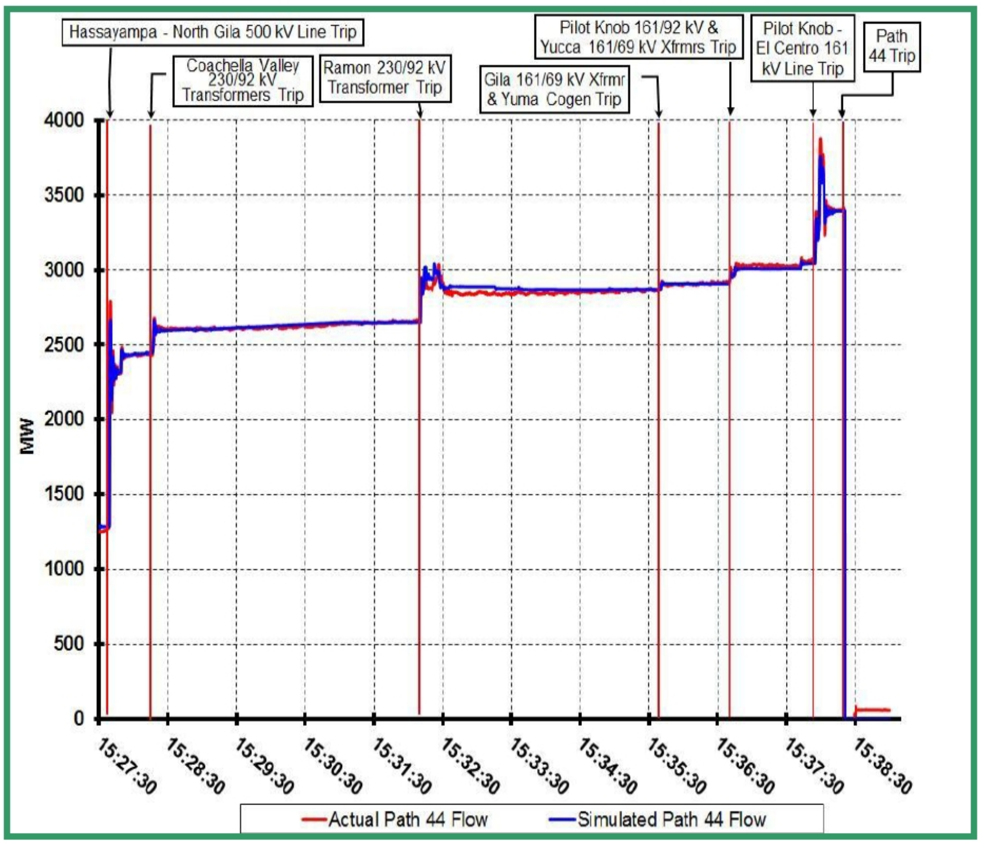
Power Flow Monitoring

An example of power flow monitoring between the Phoenix and San Diego base stations over an 8 day period is illustrated in the Appendix. Since San Diego gets much of its power from Phoenix, and a phase difference between source and load is required for power flow, starting at the 14th hour of a GPS day (7: AM) the static phase difference increases as San Diego wakes up. At night between the 7th and 14th hour (12:01 AM to 7:00 AM), the San Diego load falls as indicated by the reduced phase difference. This cycle repeats each workday except for Saturday and Sunday (1313_6 & 1314_0).

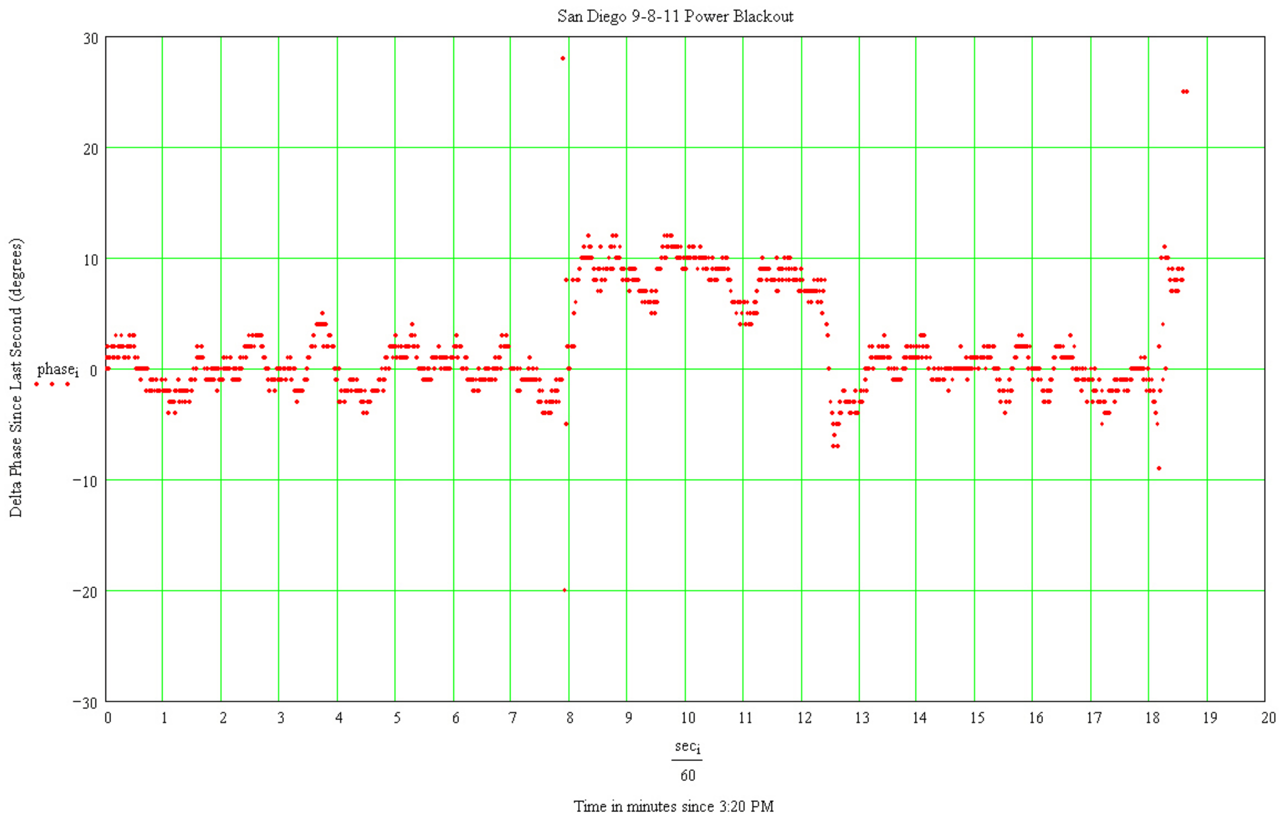
Southwest 9-8-11 Blackout

The 9-8-11 Southwest blackout event was thoroughly investigated, simulated, and documented in the "FERC/NERC Staff Report on the September 8, 2011 Blackout". An overview, from that report, of the sequence of events leading up to this blackout is illustrated below.

Figure 1: Comparison of Actual and Simulated Path 44 Flows



The data below was collected by the Origo San Diego base station which was located at an apartment in the UTC region of San Diego. The UTC region is a highly industrialized area with very reliable power. This area was one of the first to have power restored after the blackout.



Starting at 3:20 pm, each data point indicates the wall socket instantaneous phase difference between the last GPS second and current GPS second wall socket instantaneous phase. If the line frequency was exactly 60 Hz, all points would fall on the zero degree line. However, in all grids, the points slowly oscillate around 60 Hz as loads vary and generators attempt to maintain power at 60 Hz.

At 3:28 pm when the 500 KV line tripped, it is obvious a grid anomaly occurred followed by another one approximately 4.5 minutes later when the Ramon transformer tripped. Power died at 3:38:30 pm.

These grid anomalies indicate a change in power flow to the UTC region as power is sourced from different sources as the original source is interrupted. If hundreds of PMUs had been providing data and alerts, it would have been obvious how the power flow was being re-routed in the grid to compensate for the loss of the original power source. Operators may have then been able to switch power or drop loads sometime during the 10 minute period between the 500 KV line trip and the resulting San Diego blackout. The blackout might then have been contained to a much smaller region.

Unless one is using PMUs for automated real-time control, this blackout example illustrates that current PMU sampling rates of 30 to 120 times per second is an expensive unnecessary overkill. During normal grid operation, the Origo one second sampling rate is adequate for any observational purposes. The instantaneous grid frequency simply does not vary enough or fast enough to warrant faster sampling. Also, the time required for grid operators to make a switching decision and to manually switch in or out circuits is on the order of multiple seconds. Increasing a 1 Hz sampling rate to a 30 Hz sampling rate will not reduce this human manual operating time.

Origo Low Cost Synchrophasor Network

Currently, PMUs are deployed primarily on the transmission system, but the industry is beginning to explore the use of PMUs at the distribution level for power quality, demand response, microgrid operation, distributed generation integration, and enhanced distribution system visibility. However, at an average installed cost of $40,000 per PMU, implementing synchrophasors at the distribution level is many years away using current PMUs. Fully automated PMUs at the distribution level are even further away.

During the many years before high sample rate PMUs are finally implemented throughout the grid, our Origo base station PMUs are available for a fraction of current PMU costs.

The Origo base station PMU is illustrated above and consists of a small 6" x 3.5" x 1.5" low cost table-top box that plugs into any wall socket, can be placed anywhere, and sends wall socket instantaneous phase to a server once each GPS second. The one-cubic-inch GPS module can be placed on or next to any window.

The table-top box plugs into any Ethernet LAN port and sends data via UDP to a central server. Origo envisions hosting the synchrophasor network on a large redundant server such as provided by Amazon Web Services (AWS) or others. Many graphical synchrophasor products could be designed and viewed by all Network participants in real time over the Internet. This would eliminate each utility having to provide a server, maintenance, redundancy, software, or support.

An Origo base station PMU synchrophasor network would be very low cost because there are no installation costs. The PMUs can be simply plugged into any existing wall socket and Ethernet LAN port. Since data is outgoing UDP only, no port forwarding or network permissions are required. The data can be sent to as many designated servers as desired which can be placed anywhere. For example, UK PhaseID demos have sent base station data from the UK to our Window's PC server in Phoenix.

The Origo PMUs do not have to be located at substations (many of which may not have communications). Origo envisions locating the PMUs near desired grid locations by placing them in nearby business establishments as the power, size, and data requirements are minimal.

The example presented here of the 9-8-11 Southwest blackout event illustrates that informative data can be collected essentially anywhere on the grid. Origo has post-witnessed a number of grid outage and disruption events over the last 10 years through inquiries from our PhaseID customers who happened to be collecting phase identification data during a disruption.

Any Industry Interest

A transmission synchrophasor network is best implemented over a large portion of a regional grid since disruptions propagate into adjacent utilities. However, a distribution synchrophasor network within a single large utility may also be useful.

The base station PMUs are available as standard stock units. All that is required is the synchrophasor network hosting software on a commercial server such as AWS or others, and the application software products to visualize the data.

While the Utility Industry waits another decade or so for the current high speed synchrophasor network to be broadly deployed, I would like to determine if there is any interest in the low-cost low-speed synchrophasor network just described. A network of many thousands of Origo PMUs could be implemented within a few years and could provide even the smallest Coops the benefits of synchrophasor information.

Please call or email me with any questions, interests, or comments you may have. Thanks.

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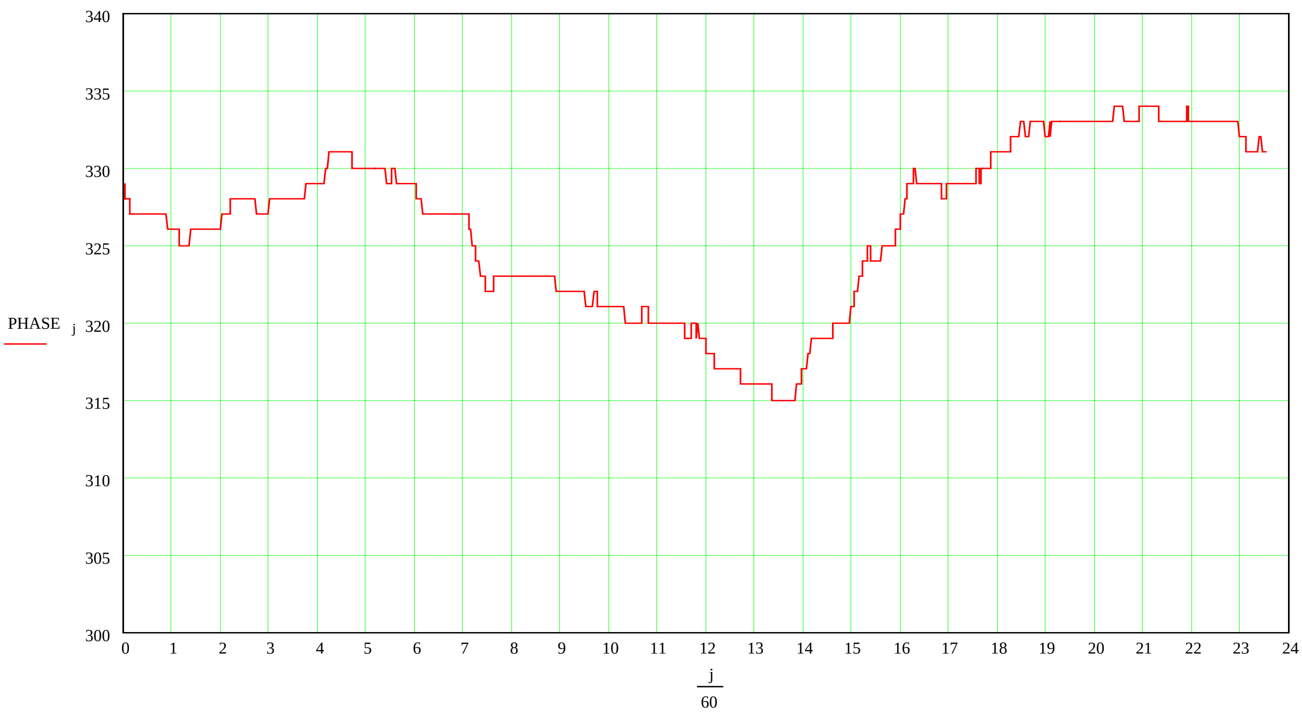
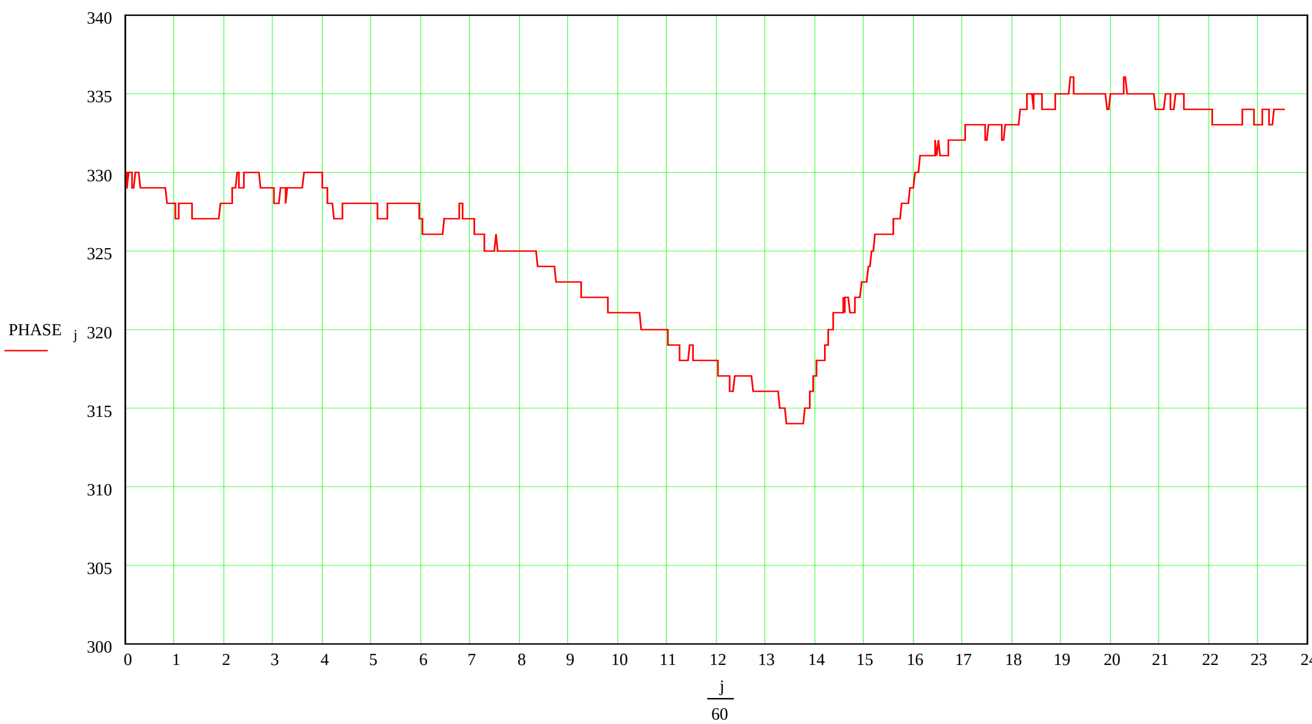
APPENDIX



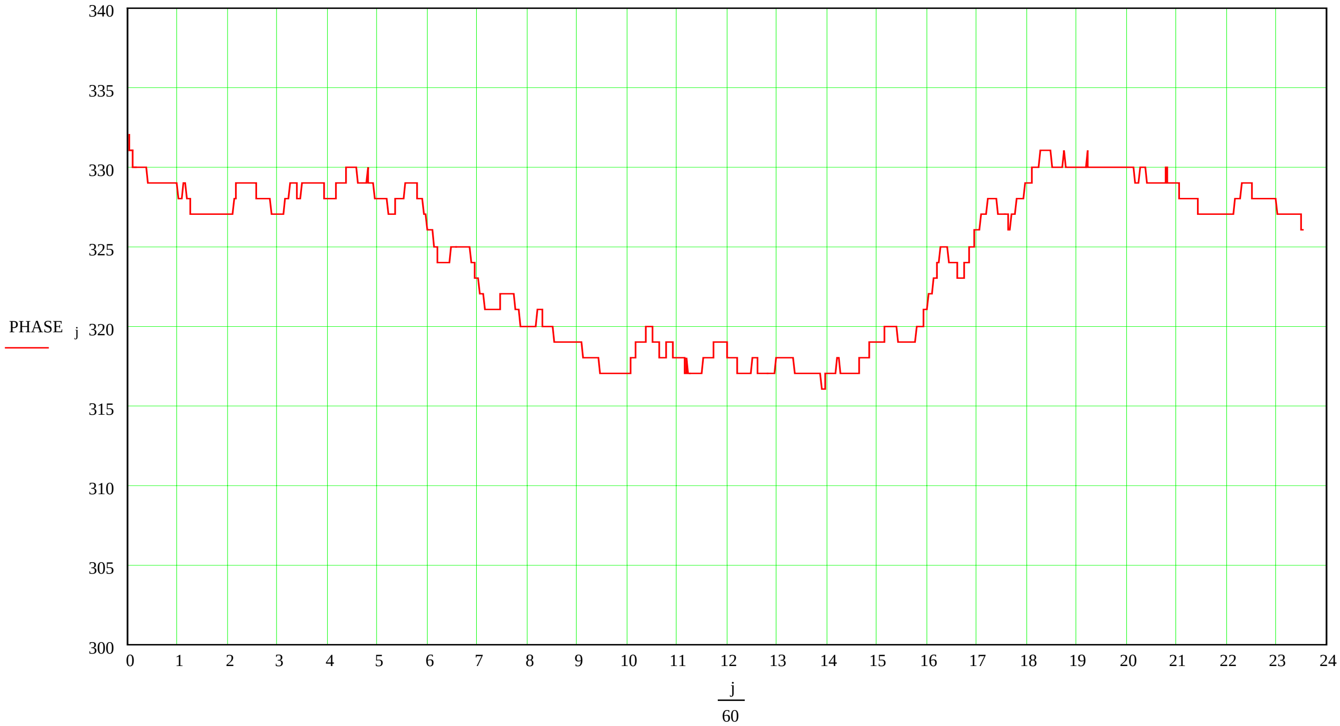
Phoenix to San Diego

Hours of GPS day 1313_4



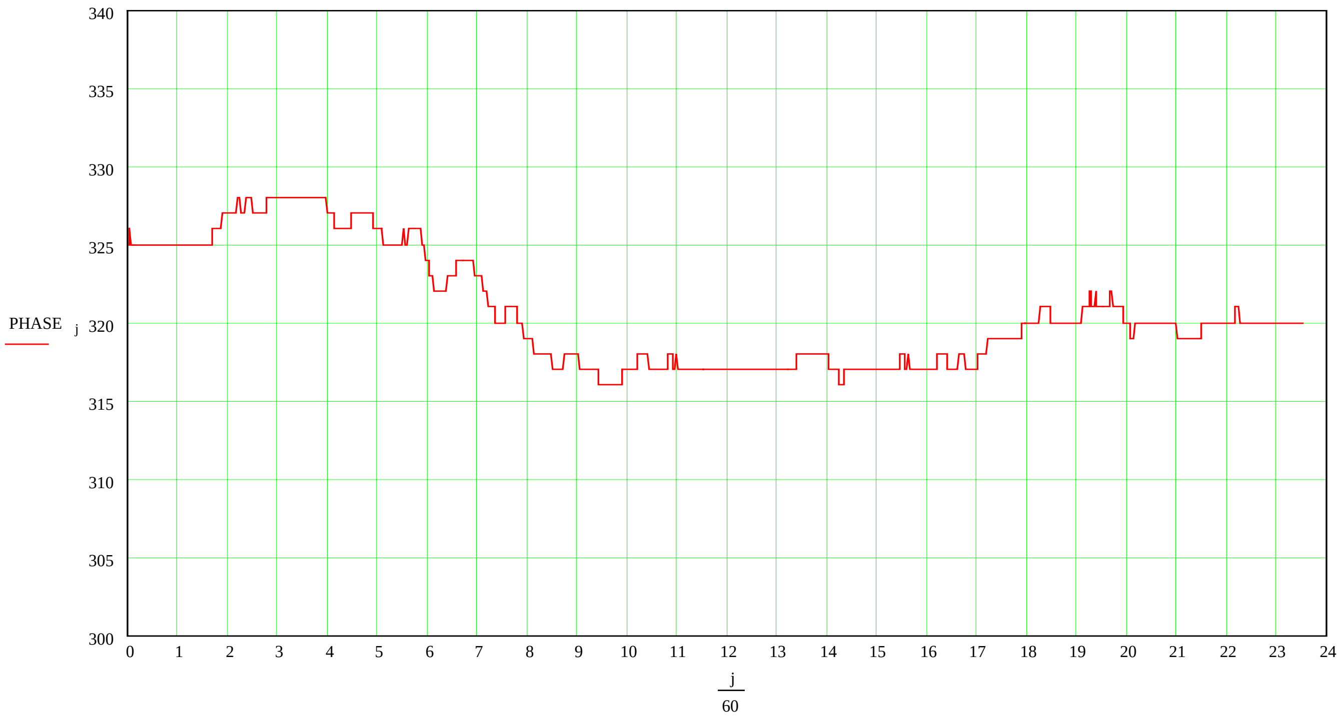
Phoenix to San Diego

Hours of GPS day 1313_5



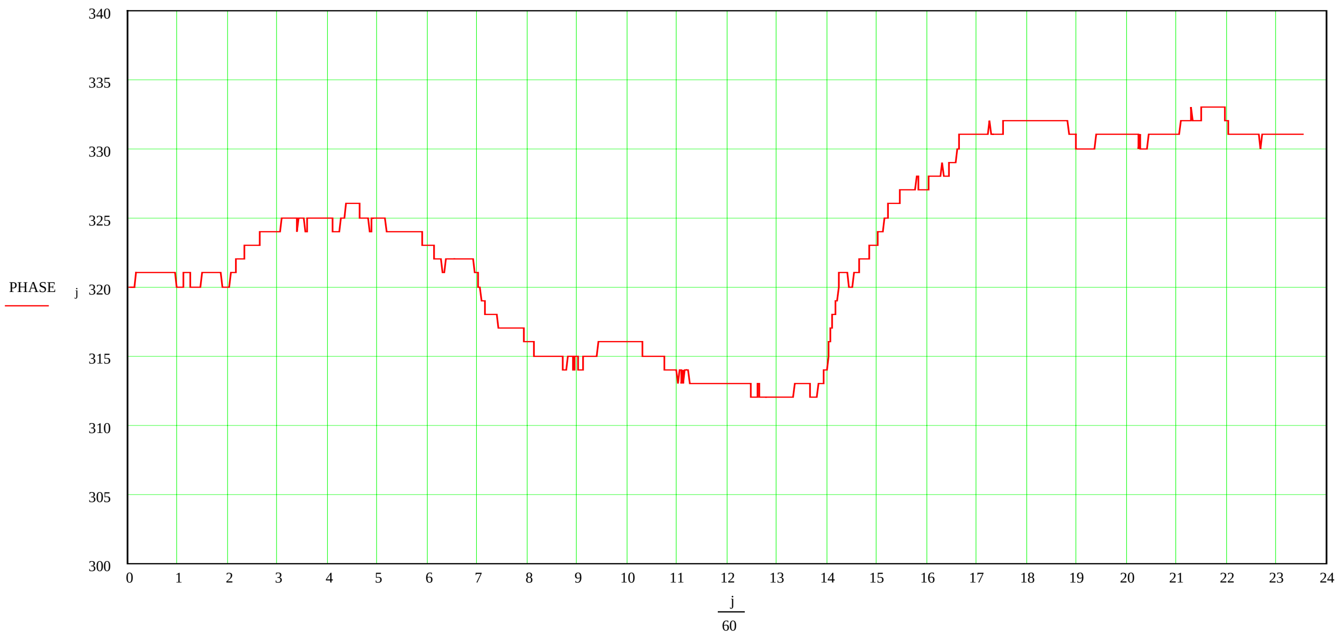
Phoenix to San Diego

Hours of GPS day 1313_6



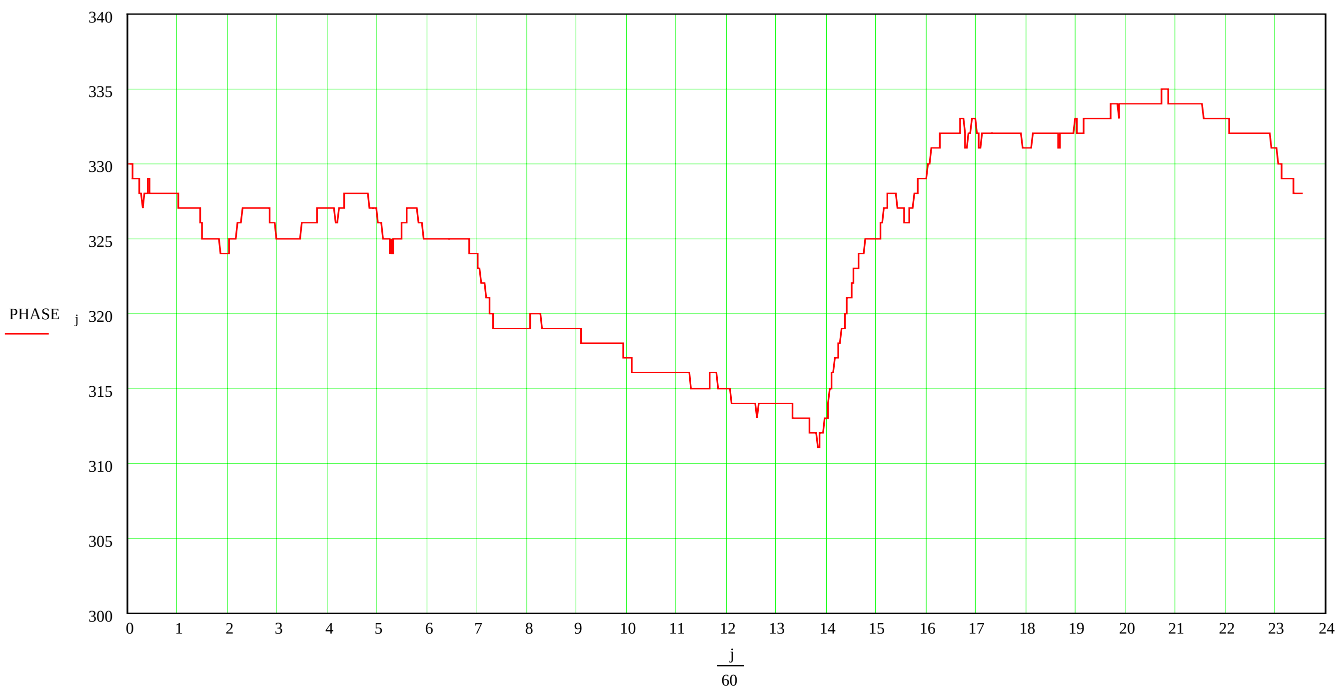
Phoenix to San Diego

Hours of GPS day 1314_0



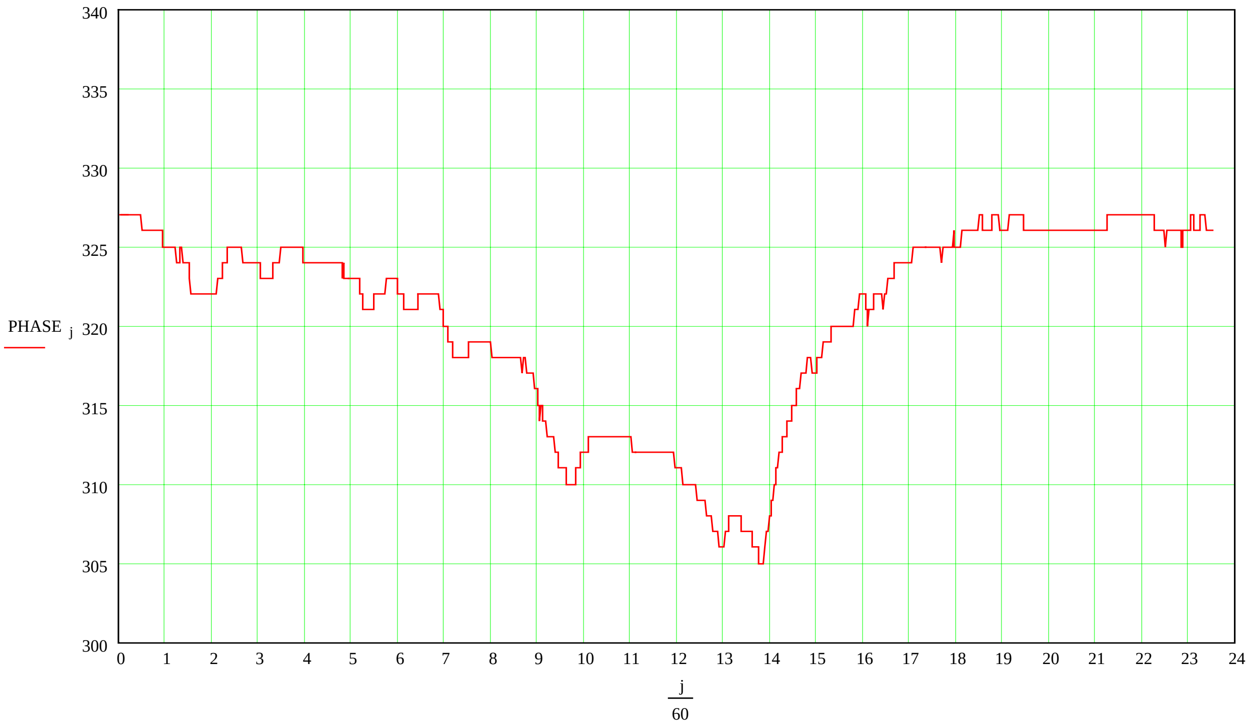
Phoenix to San Diego

Hours of GPS day 1314_1



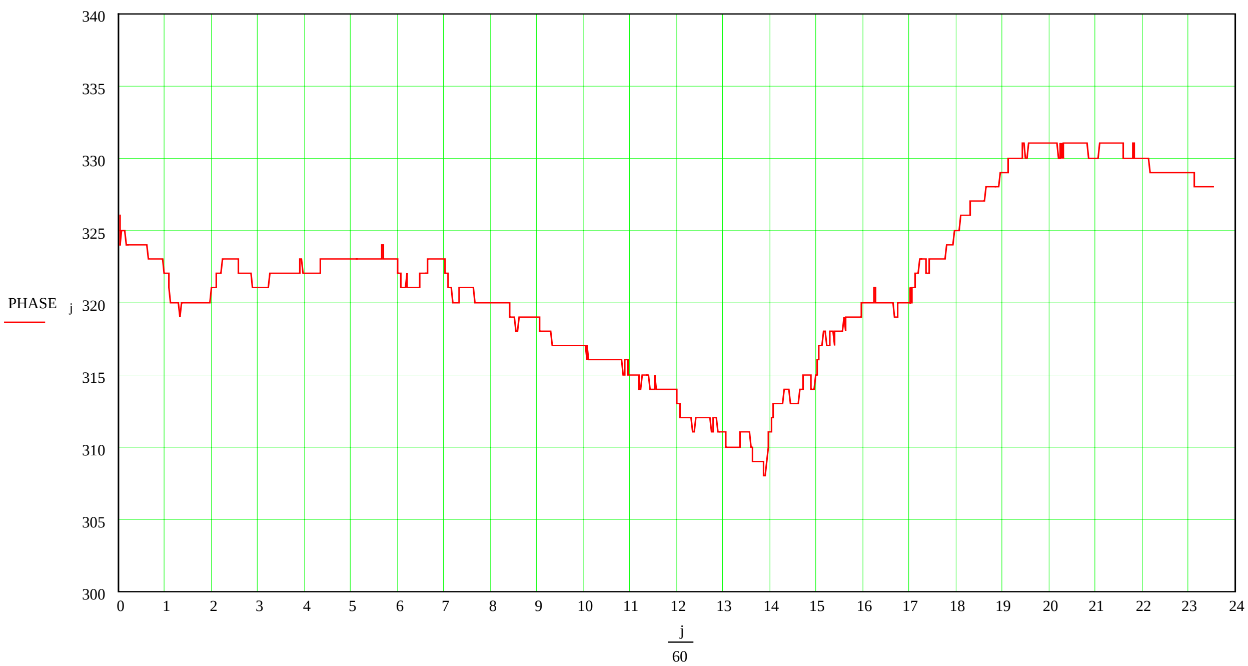
Phoenix to San Diego

Hours of GPS day 1314_2



Phoenix to San Diego

Hours of GPS day 1314_3



Phoenix to San Diego

Hours of GPS day 1314_4