Outline

- Case 1 – noisy frequency signal
  - Resolution limitations
- Case 2 – noisy frequency signal
  - Introduced oscillation
- Case 3 – data dropout with pattern
  - Communication bandwidth limitation
- Case 4 – scaling error
  - Comparison with other measurements
- Case 5 – timing error
  - Signal has undetected loss of sync
Case 1: Apparent noise in frequency signal

- Plot resolution
- With overall scale of 200 mHz, plot appears smooth
- Change resolution to 16 mHz and plot appears rough & “steppy”
- .001 Hz steps due to resolution of data
- Added “half-steps” due to plotting algorithm
Case 1: Reporting resolution

- Require floating point reporting
  - Maximum resolution
  - Avoid “steppiness”
- Report looked “steppy”
- Resolution:
  - Report from PMU is integer
  - TO PDC converts to FP
  - Final report is FP, but still has integer resolution
Case 2: Different aspect of measurement ‘noise’

- Another “noisy” frequency signal has an obvious oscillation aspect

- Modal analysis showed this to be a 10 Hz mode
Case 2: Noise investigation

- Oscillation was in voltage & current as well as frequency
  - Only visible in frequency
- Found in several stations in the somewhat isolated transmission section
- 10 Hz is a rather high modal frequency
  - Cause would have to be a controller or resonance
  - Would typically not “travel” well, so we should be able to locate source and path
- Was not always the same amplitude in different stations, but did not show pattern as emanating at one station
- Phase angles did not correlate showing areas in-phase and areas anti-phase
Case 2: Further investigation

- Modal data came from same kind of PMU with same settings
- Other PMUs nearby showed no mode (but were not directly connected)
- Mode was almost exactly 10 Hz with slight frequency movement correlating with change in the nominal system frequency
- DFR data from some of the same substations did not show the 10 Hz mode, but the analysis was not conclusive (record too short)

DFR – point on wave, 2400 s/s. For analysis rescaled by 1/20 so 60 Hz appears as 3 Hz and 10 Hz mode at $3 \pm .5 = 2.5$ and $3.5$ Hz.
Case 2: Noise investigation conclusions

- Tested PMU with test set
  - Same settings showed 10 Hz mode
  - Other settings showed less or no 10 Hz mode
- Conclusions:
  - The oscillation is from an internal process in the PMU
  - It is small but big enough to be annoying
  - It can be resolved by using another setting in the PMU processing
Case 2: Noise investigation recommendations

- Validate measurements that show unexpected system behavior
- If observed, carefully check for supporting evidence--
  - Data from other measurement devices
  - A source of the unusual system behavior
  - Logical interaction between other parts of the system as observed by other measurement
- Be wary of oscillations at higher frequencies, particularly even integer frequencies
- If there are no other causes located or corroborating evidence, the data is probably something from the measurement processing (PMU)

Other PMUs showing 10 Hz modes
Case 3: Security Camera Issue

- In Mid-March, a Transmission Owner installed new security cameras at a site where a PMU was installed.
- The communication data link to the control center overloaded (saturated).
- Both RTU and PMU traffic was effected.
- Resolution managed traffic; included an implementation of QoS.

While saturated, data lost & frequency flatlined

Saturation resolved, data & frequency good
Case 4: Scaling Error

- Comparison of PMU with EMS data showed error factor ~1.73
- Investigation showed PMU current reading was mis-scaled by √3
- PMU – EMS data comparisons are an important part of MISO’s standard verification process
Case 5: Time error problem

- PMU receives unsync time
  - No time quality provided with time signal
- PMU reports data with bad time but sync error flag not set
- PDC synchronizes data by reported PMU time
- PDC time deviates between PMUs
  - Good data is lost
  - No way to distinguish since all times marked good
Case 5: Time synchronization of data

- Data is sorted by time (data put into table by time stamp)
  - If time is in error data is displaced
- PDC must determine there is a time error
  - Flag in data warns that there is a time error
  - Time error must be large enough to detect without flag
- PDC can take action to minimize effect of time error
  - Apply local “best guess” time stamp (sort by arrival)
  - Place data in separate data store
  - Discard data

Example:

PMU1 – good time, in sync
PMU2, PMU3 – not in sync, time does not match data

Key:
TS – time stamp provided in data
Data – actual time of measurement

<table>
<thead>
<tr>
<th>Table</th>
<th>PMU1 in sync</th>
<th>PMU2</th>
<th>PMU3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Data 11:34:20.1</td>
<td>Data 11:34:18.8</td>
<td>Data 11:34:20.0</td>
</tr>
<tr>
<td></td>
<td>Data 11:34:20.2</td>
<td>Data 11:34:18.9</td>
<td>Data 11:34:20.1</td>
</tr>
<tr>
<td>11:34:20.3</td>
<td>TS 11:34:20.3</td>
<td>TS 11:34:20.3</td>
<td>TS 11:34:22.7</td>
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<tr>
<td></td>
<td>Data 11:34:20.3</td>
<td>Data 11:34:19.0</td>
<td>Data 11:34:20.2</td>
</tr>
<tr>
<td>11:34:20.4</td>
<td>TS 11:34:20.4</td>
<td>TS 11:34:20.4</td>
<td>TS 11:34:22.8</td>
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</tbody>
</table>
Case 5: Time synchronization chain

- The PMU needs to detect and flag time errors
  - Time directly from GPS provides time quality
  - Time indirect must include time quality
    - Eg: IRIG-B or IEEE1588
  - PMU provides sync information to PDC & applications

```
<table>
<thead>
<tr>
<th>Local clock</th>
<th>PMU</th>
<th>PDC/Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;I'm not in sync, but IRIG-B ok&quot;</td>
<td>&quot;I have IRIG-B ok, must be in sync&quot;</td>
<td>&quot;Phasor data in sync, time ok&quot;</td>
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<td>&quot;I'm not in sync, notify users via IRIG-B or 1588&quot;</td>
<td>&quot;IRIG-B with 37118 profile or 1588 code&quot;</td>
<td>&quot;Phasor data not in sync; flag/sort with time error&quot;</td>
</tr>
</tbody>
</table>

Time synchronization source (GPS)

Direct GPS

Standard IRIG-B

"Phasor data not in sync; flag/sort with time error" |

"Phasor data in sync, time ok"

"I have IRIG-B (or 1588) but not in sync; flag time sync error"

"IRIG-B with 37118 profile or 1588 code"

"I have IRIG-B ok, must be in sync"

"I'm not in sync, but IRIG-B ok"

"I'm not in sync, notify users via IRIG-B or 1588"

"Phasor data not in sync; flag/sort with time error" |

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Case 5: Time error problem resolution

- Assure PMUs receive time quality
  - Check they report time error correctly

- Set PDC to detect time errors
  - Must be accurately and reliably timed
  - It must make allowances for reporting delays

- Check that PDC detects PMU time outliers
  - Responds correctly
Questions??