Calibration & Flagging

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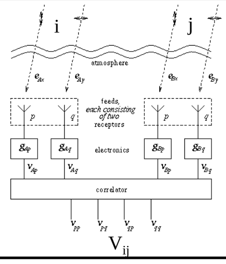
- Theory of calibration
- Practice - RFI & malfunctions
- Flagging (Editing)
- Calibration
- Other effects

The Measurement Equation

$$\vec{V}_{ij} = X_{ij}\left(\mathsf{M}_{ij}\left[\mathsf{J}^{vis}{}_{i} \otimes \mathsf{J}^{vis}{}_{j}{}^{*}\right]\sum_{k}\left[\mathsf{J}^{sky}{}_{i}\,(\vec{\rho}_k) \otimes \mathsf{J}^{sky}{}_{j}\,(\vec{\rho}_k)^{*}\right]\mathsf{S}\;\vec{I}_k + \vec{A}_{ij}\right)$$



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Antenna based:
J^{vis} = B G D P
B = bandpass
G = complex gain
D = pol leakage
P = receptor pos angle
(2x2 matrices)

Baseline based:
A_{ij} = noise + RFI + offsets

Sky Intensity Distribution

Polarization Conversion

Antenna beam + pointing
Faraday Rotation

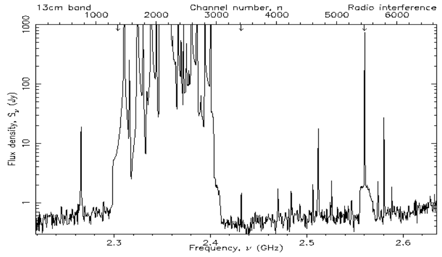
Baseline based errors
Correlation corrections

Visibility Calibration

- Simplified equation: $V_{ij}^{obs} = (J_i \otimes J_j)\, V_{ij}^{mod}$ + noise
- For an unpolarized calibrator: $V_{ij}^{mod} = (S_{cal},0,0,S_{cal})$
  - time independent, but usually frequency dependent
- Equation solved iteratively
  - minimize $\sum_{ij,t} |V_{ij}^{obs}(t) - (J_i(t) \times J_j(t))\, V_{ij}^{mod}|^2$
  - do one component of J (B, G, D) at a time
- This process also works if the model is more complicated
  - e.g. calibrator has some structure (halo, slightly resolved)
  - can use model of field itself ⇒ selfcalibration
  - difference: need to calculate model for all baselines & times instead of using constant value and need overdetermined set of equations

Practical problems

- RFI - interference - mostly signals from terrestrial and satellite transmitters in the frequency bands used by radio



Planning for calibration

- Observe primary calibrator (1934-638 or 0823-500) for 5-15 min, to allow calibration of polarization leakage, bandpass & absolute fluxscale. (Can use other cal for first two of these)
- Observe secondary calibrator for 1-2 min every 15-60 min, for calibration of complex gain: main component is atmospheric phase variation, also track slow electr gain var.
- Decide if you need offset pointing calibration (generally yes if observing above 10 GHz) - do a POINT scan every 30-60 minutes.

Data Reduction Steps

- Choose package:
  - miriad (good, well maintained, but no major new features planned, shell scripting, fortran code)
  - AIPS++ (new, actively developed, user input welcome, guis, glish scripting, C++ code)
- Load the data from the archive format (RPFITS)
- Flag 'bad' data on calibrators
- Calibrate primary cal (G,B,D), transfer to secondary (B,D)
- Calibrate secondary cal (G), transfer to source (G,B,D)
- Flag 'bad' data on source
- Analyze data (imaging, statistics, source fitting)

Flagging/Editing

- Rule 1. No data is better than bad data
  - Corrupted data can reduce the image quality significantly
  - Effect of missing data (even 25%) is often minor and easily corrected in deconvolution
- Rule 2. Flag bad data as early in the reduction as possible
  - Low level errors may be hard to track down later
- Rule 3. Use shortcuts where possible
  - visual inspection of all data can be very time consuming, with limited gains
  - use averaging & automate

Flagging/Editing

- 1st pass: use on-line flags - flags when antennas are off source or sampler stats outside range.
  - use switch in filler (AIPS++) or selection (miriad) to reject shadowed data
- 2nd pass: Use the observing logbook! Saves lots of time later.
  - Note which data is supposed to be good & discard data with setup calibration, failed antennas, correlator problems etc.
- 3rd pass: Check amplitude on calibrators - plot amp-time
  - investigate outliers & flag, flag source as well if you can't trust data
- 4th pass: Check spectrum on calibrators for strange, variable features
- 5th pass: (After calibration) Inspect & flag source data

Calibration I

- Calibrations done for you at reconfiguration:
  - antenna pointing (global pointing model derived from sources in all Az/El directions)
    - generally correct to better than 10", occassional 20" error single ant
    - may need reference pointing with nearby cal above 8 GHz
  - baseline lengths (relative antenna positions)
    - generally correct to better than 1-2 mm (depending on weather)
    - error significant at 3mm - correct phase with nearby calibrator
  - global antenna delay (bulk transmission delay in cables)

Calibration II

- Calibration done at start of observation:
  - delay calibration: correct residual path length for your particular frequency & bandwidth setup
  - amplitude & phase: equalize gains, zero phases (redone off-line), helps to detect problems during observation.
  - polarization: zero delay & phase difference between X & Y feeds, uses noise source on reference antenna to measure phase.
    - generally correct to a few degrees at 3-20cm

Calibration III

- Calibrations done during the observation:
  - round trip phase correction - continuously compares outgoing with returned lo phase and computes corrections, these are then applied in real time (10s lag)
  - T_{sys} correction - estimates system temp by comparison with injected noise - corrects for e.g. ground pickup & elevation, but not for atmospheric absorption
  - (future) WVR path length correction - estimate atmospheric path variation and apply correction on-line
- Calibration data collected during the observation:
  - T_{sys} - system temperature estimate from noise source detection
  - XY-phase difference on each antenna (also from noise source)
    - Can be applied when loading the data

Calibration IV

- Calibration recipe:

```
# solve for gain using secondary
cl := calibrater(msfile);
cl.setdata(msselect="FIELD_ID==2");          #select secondaries
cl.setapply ('P', 10.0);                     # Calculate parallactic angle
cl.setapply ('B', table='cal.B');            # Apply B from primary
cl.setapply ('D', table='cal.D');            # Apply D from primary
cl.setsolve ('G', 30.0, refant=3, table='cal.G', append=T);# Solve for Gains
cl.solve();

# correct the gains for polarization of the secondary
quflux:=cl.linpolcor('cal.G',fields="0450-8100");

# fix the fluxscale of the secondaries
cl.fluxscale('cal.G',reference="1934-638",transfer="0450-8100");          638
cl.done();

# apply calibration to all sources
cl := calibrater(msfile);
cl.setapply ('P', 10.0);                     # Calculate parallactic angle
cl.setapply ('G', table='cal.G');            # Apply G from secondary
cl.setapply ('B', table='cal.B');            # Apply B from primary
cl.setapply ('D', table='cal.D');            # Apply D from primary
cl.correct();                                # fill the corrected data column
cl.done();

cl.done();
```

s)

d gains from

d analysis

  - see aips++ example script

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