Possible Calibration Scheme for the 21cm CRT

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Calibration Goals

- The goal of a calibration system is to measure variations from the ideal:
  - Amplifier gain
  - Antenna response
- It is most likely that the telescope will have to be calibrate continuously with an update rate on the order of 10 minutes

FFT Telescope Gain

- The output of an FFT telescope with N channels is N real numbers

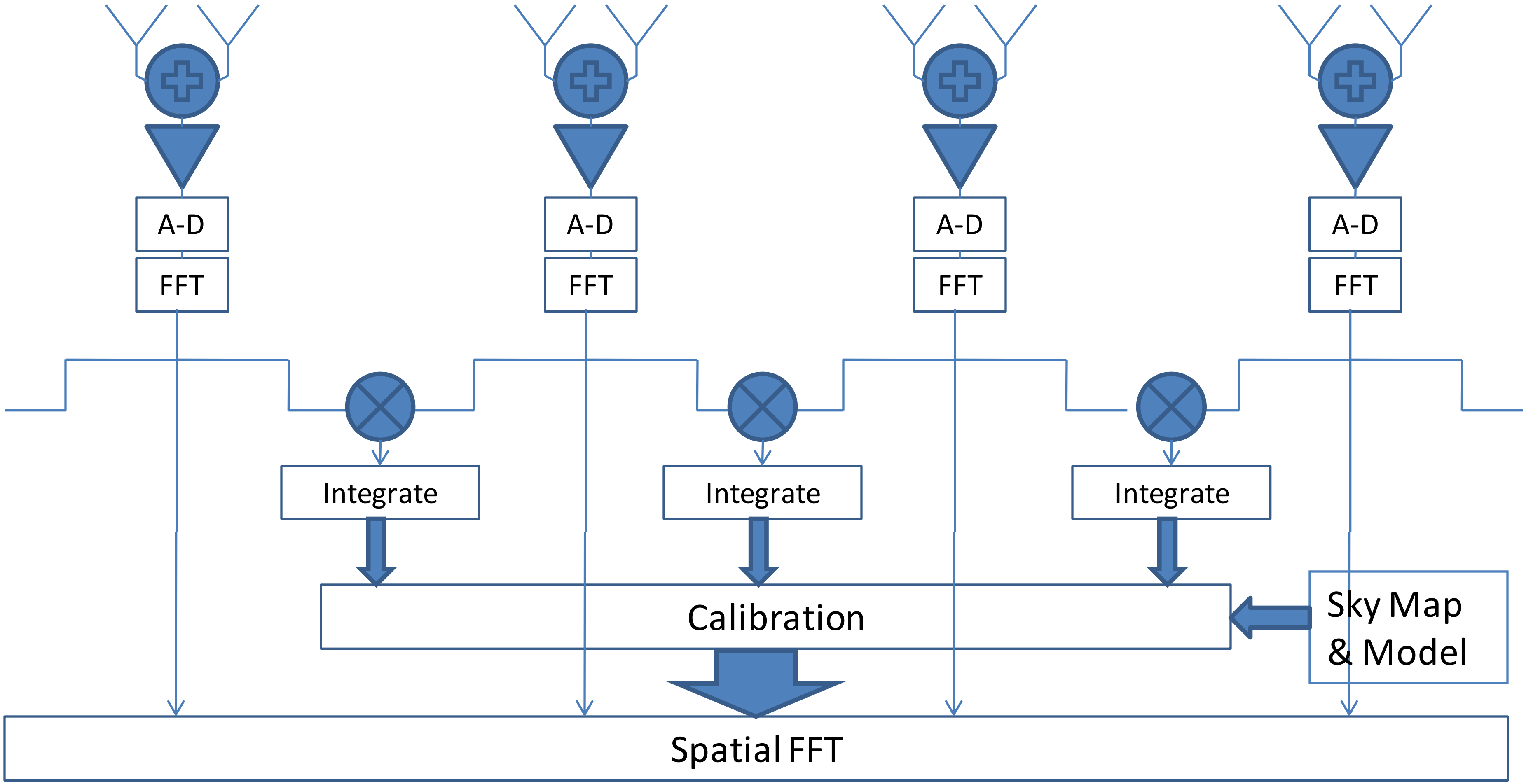
$$\langle \mathrm{P} \rangle_{\mathrm{k}} = \sum_n P_{z_n} + \int_{-1}^{1} S(x) \left| \sum_n g_n(x)\, e^{-j2\pi n \frac{d}{\lambda} x} e^{j2\pi \frac{n}{N} k} \right|^2 dx$$

- However, since the feed gain is a complex number, there are 2N unknowns.
  - You would need two independent sky measurements of different well known sources to be measured in fairly rapid intervals
- It will also be difficult to tell the difference between small sky signal variations and gain variations,
  - i.e. calibrating out the signal you want to measure

Another Calibration Concept

- Since the feeds are equally spaced,
  - The visibility between adjacent pairs is redundant
  - By comparing adjacent visibilities, this redundancy could be used to match the gain of the feeds
  - Since the visibility is a complex number, and if there are enough known calibration sources, there are enough equations to solve for all of the gains
- To calculate the adjacent visibilities, N calculations would have to be done which is small compared to N x ln(N) of the FFT
  - However, the N gain corrections would have to be stored which would add a substantial burden on data storage if the calibration is done often.

Adjacent Visibility Calibration Concept



Problems with the Adjacent Visibility Calibration Concept

- The effective temperature of a point source is given as:

$$I_{point} = \frac{kT_{eff}}{\lambda^2} = \frac{S_{point}}{\Omega} \approx S_{point}\frac{W}{\lambda}$$

- The ratio between Boltzman's constant (k) and 1 Jansky ($1J=10^{-26}W/m^2/Hz$) is:

$$\frac{k}{J} = 1360\frac{m^2}{Kelvin}$$

- For a cylinder width of 12.5 meters at 750Mhz, the strength of a point source would have to be greater than 2700 Jansky's to compete with an average sky temperature of 10K

Relative Adjacent Visibility Calibration Concept

- Visibility between channel (n) and channel (n+k)

$$\langle p_n, p_{n+k}{}^* \rangle = \int d\phi \int_{-1}^{1} s(x,\phi) g_n(x,\phi)\, g_{n+k}(x,\phi)^* e^{j2\pi k \frac{d}{\lambda} x} dx$$

- Compare visibility at (n,n+k) and (m,m+k) and adjust gain corrections to make them equal.

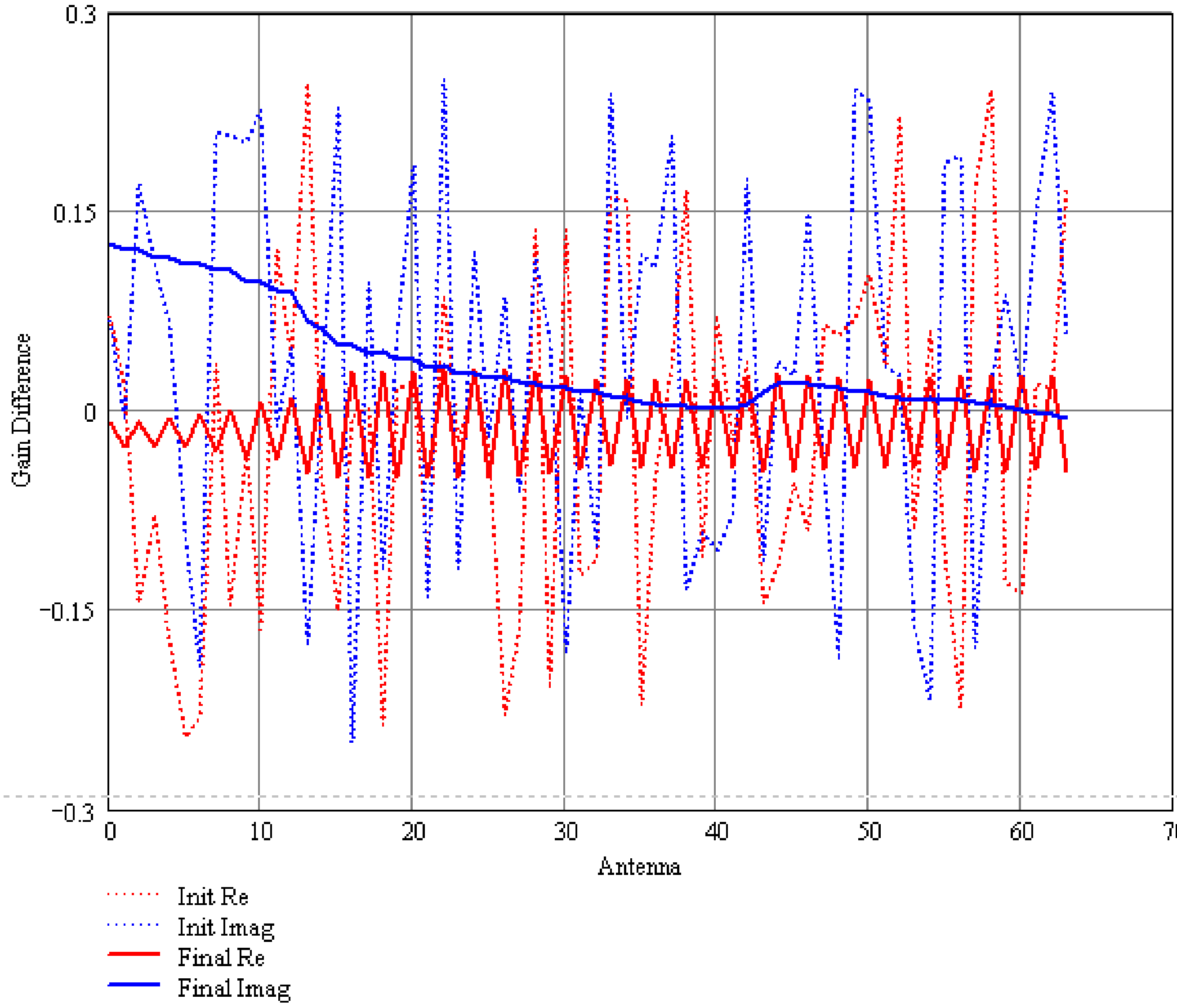
$$\chi_k = \sum_{n} \sum_{m>n} \left| \langle p_n, p_{n+k}{}^* \rangle - \langle p_m, p_{m+k}{}^* \rangle \right|^2$$

- If the antenna is calibrated χ_k is zero for all k

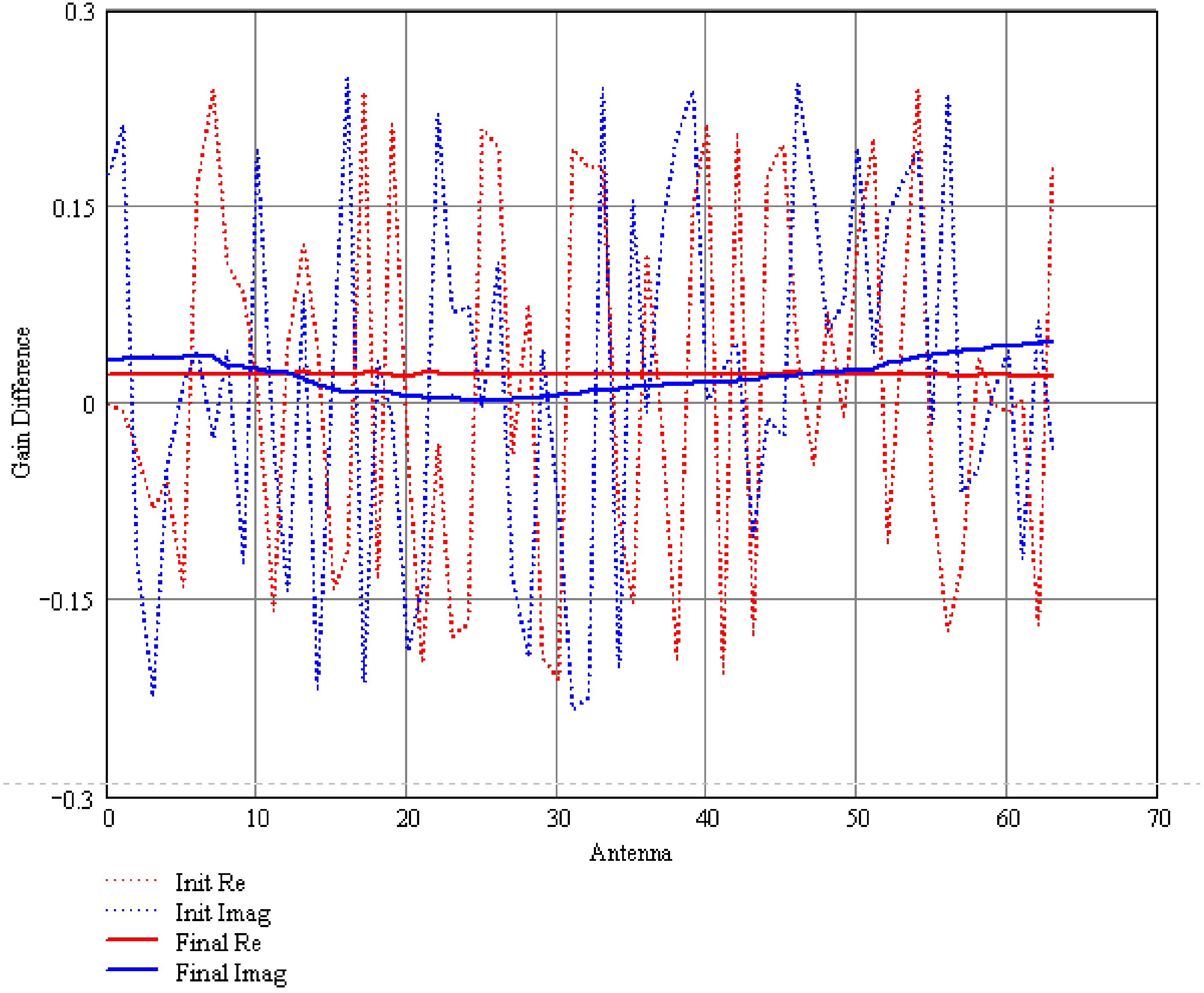
Relative Adjacent Visibility Calibration Concept

- Because the average sky temperature is large(~10K), few averages are needed to beat down the thermal noise.
- First order k=1 does not have enough equations to determine all the coefficients
- Need to use at least use k=1 and k=2.
- Also the absolute gain and phase shift is not constrained.
  - Constrain the average gain magnitude = 1
  - Constrain the average gain phase = 0.

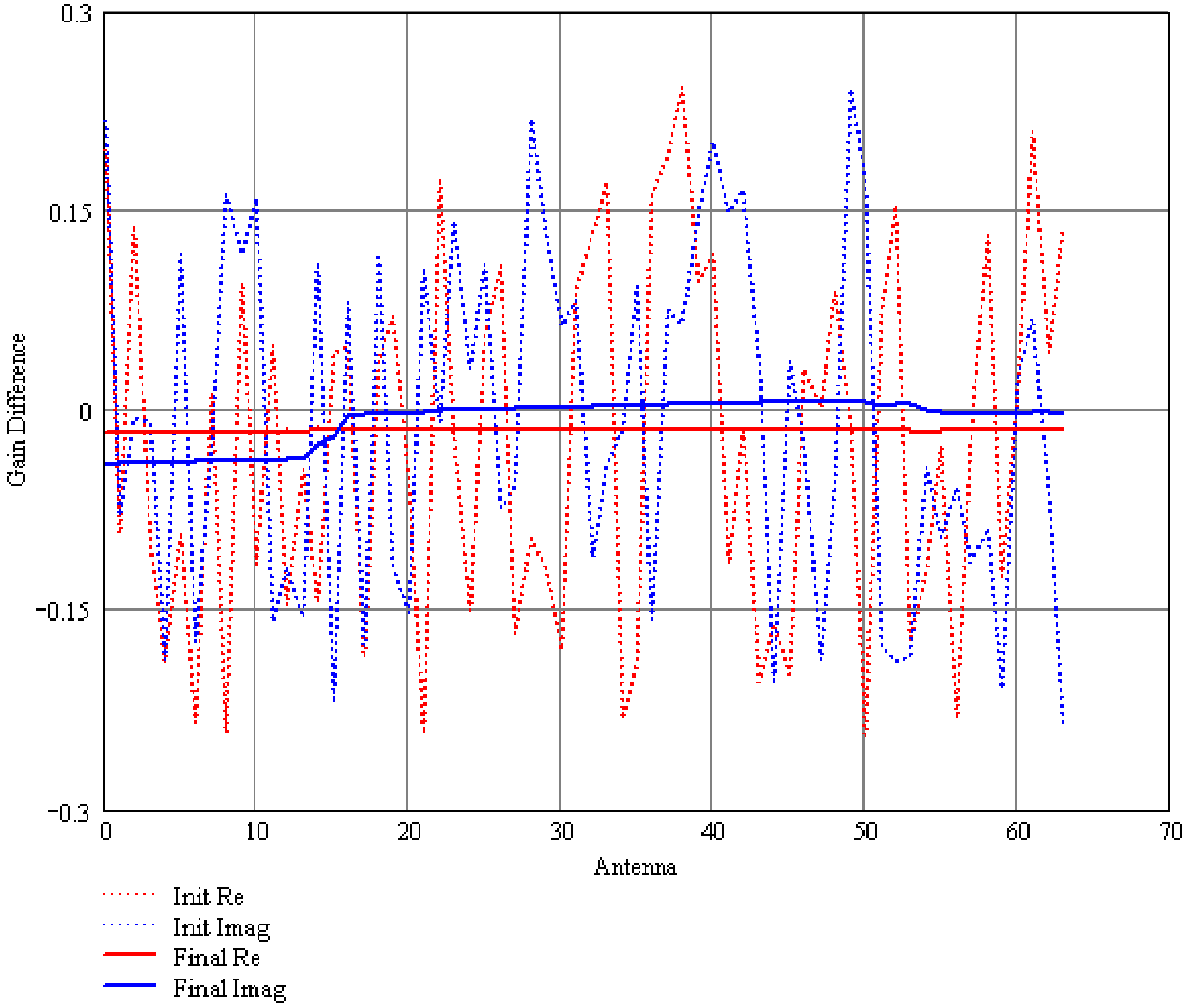
Simulation using k=1 Only



Simulation for k=1 & 2



Simulation for k=1,2, & 3



Conclusions and Questions

- Because the FFT telescope loses or obscures phase information, we will probably need a real time calibration system instead of relying on offline calibration only.
- How often do we need calibrate?
- To what level do we need to calibrate?
- By comparing relative adjacent visibilities, the variations in gain between channel can be reduced.
- Comparing relative adjacent visibilities does not calibrate out your signal as point sources will.