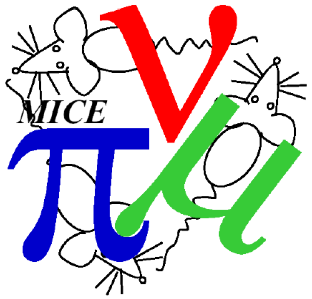


University of Strathclyde Science

# The RF Phase Determination for MICE

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CM 41

# The Timing Problem

- Phase and Amplitude of RF cavities must be known to 0.5º and 1% amplitude
- Muons can arrive in the cavity at any point.
  - so it could arrive at a phase that was not optimal for acceleration
- Phase of the cavity will have to be measured, recorded and be able to be related back to the arrival time of each muon.
- Desire that the random uncertainty <20ps in the relative timing
- Absolute Calibration may be achieved by measuring the Muon momentum shift.

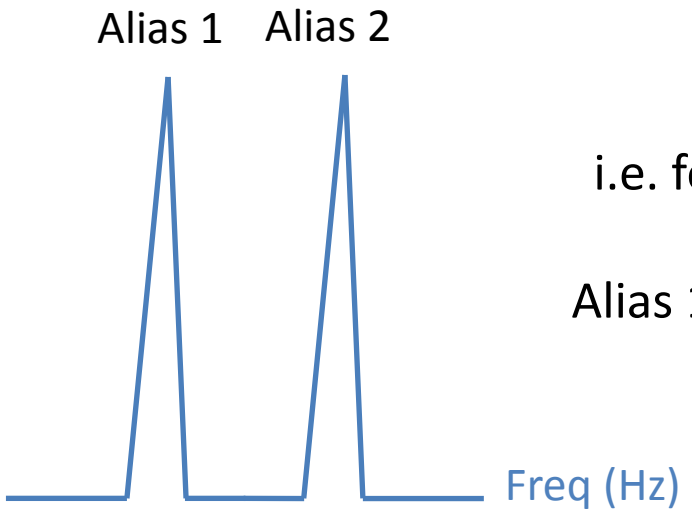
# Sampling

- Frequency of RF – 201.25 MHz
  - 1 Period of RF ~ 5ns
  - Nyquist limit implies ~1GSa/s for 1 ms –1MB
  - Capture, transfer and storage in 1 sec?
- Possible but signal can be reconstructed from undersampled data.
  - Bandwidth is < 5kHz
  - Sample at < 200kSa/s ?
- In Subsampling – Can we rebuild a wave with required accuracy?
- Subsampled Signals
  - Expresses a different  frequency than a signal sampled at Nyquist or above.
- Nyquist rate is 2-3 x baseband signal frequency (201.25 MHz)
  - In our case - ~ 400-600 MSa/s at the bare minimum

# Subsample Manipulation

- Fourier plot shows distinct peaks at aliases of the sample/baseband frequency
- However, off these peaks – The power is very close to zero.
- Could Sub-Nyquist signal peaks be ‘mapped’ to a higher sampled signal?
  - Zero Padding

# Fourier Reconstruction




Undersampled Signal in Fourier Domain

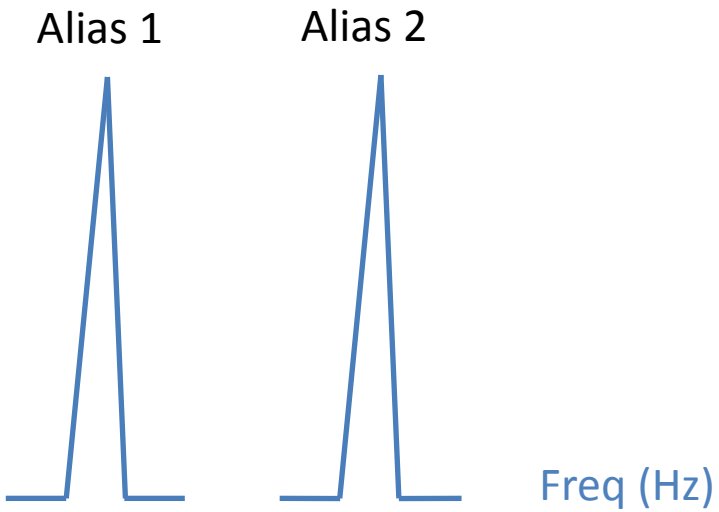
Alias 1 + Alias 2 = Sample Rate

i.e. for a 20 Msa/s sample of 201.25MHz signal

Alias 1 is at 1.25 MHz and Alias 2 is at 18.75 MHz
= 20 MHz or 20 MSa/s

So can we use this information?

# Fourier Reconstruction




Undersampled Signal in Fourier Domain

If we break the signal into 2 halves

Each half is 10 MHz ‘long’ – call this the baseband

There is a mirror at the splitting point

# Sampling Sub-Nyquist

## Testing with Generated signal in MATLAB

- Generate a signal with the same properties as the signal within MICE cavities (201.25 MHz)
  - Sampled significantly above Nyquist.
    - 5 GSa/s
  - Mask this data to create an undersampled signal
    - 20 MSa/s
    - This is close to the sample rate of the digitisers to be used in expt
  - Convert this data into the Fourier Domain
    - Peaks correspond to aliases of the Sample rate – Not the actual signal.

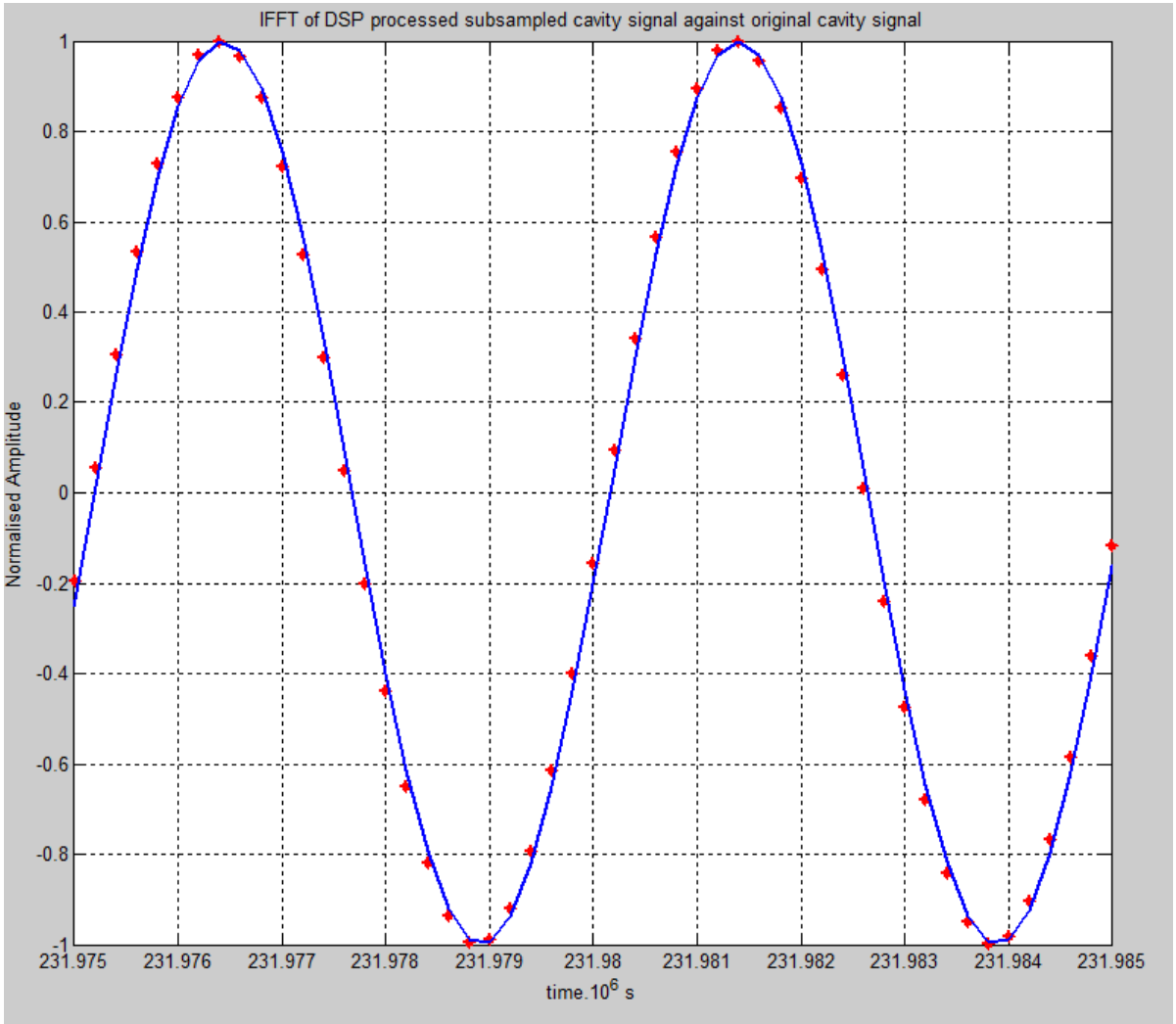
# Sampling Sub-Nyquist

## Testing with Generated signal in MATLAB

- Split the subsampled data into two at the middle point.
  - One ‘baseband’ of 10 MHz
- Create signal with zeroes to the point 200 MHz
  - 200 MHz/baseband gives number of zero sections to be created
    - in this case 20 zero sections
- Gives first half of 5 GHz signal
  - Read in signal backwards to recreate second half.
- We now have a high sampled signal!
  - How does it compare?

# Sampling Sub-Nyquist

## Testing with Generated signal in MATLAB




- Phase looks promising
  - It is out slightly but this is by the same amount everytime.
  - Work ongoing

~40 ps difference in zero crossing

Red – Generated Signal
Blue – Undersampled Signal after zero padding

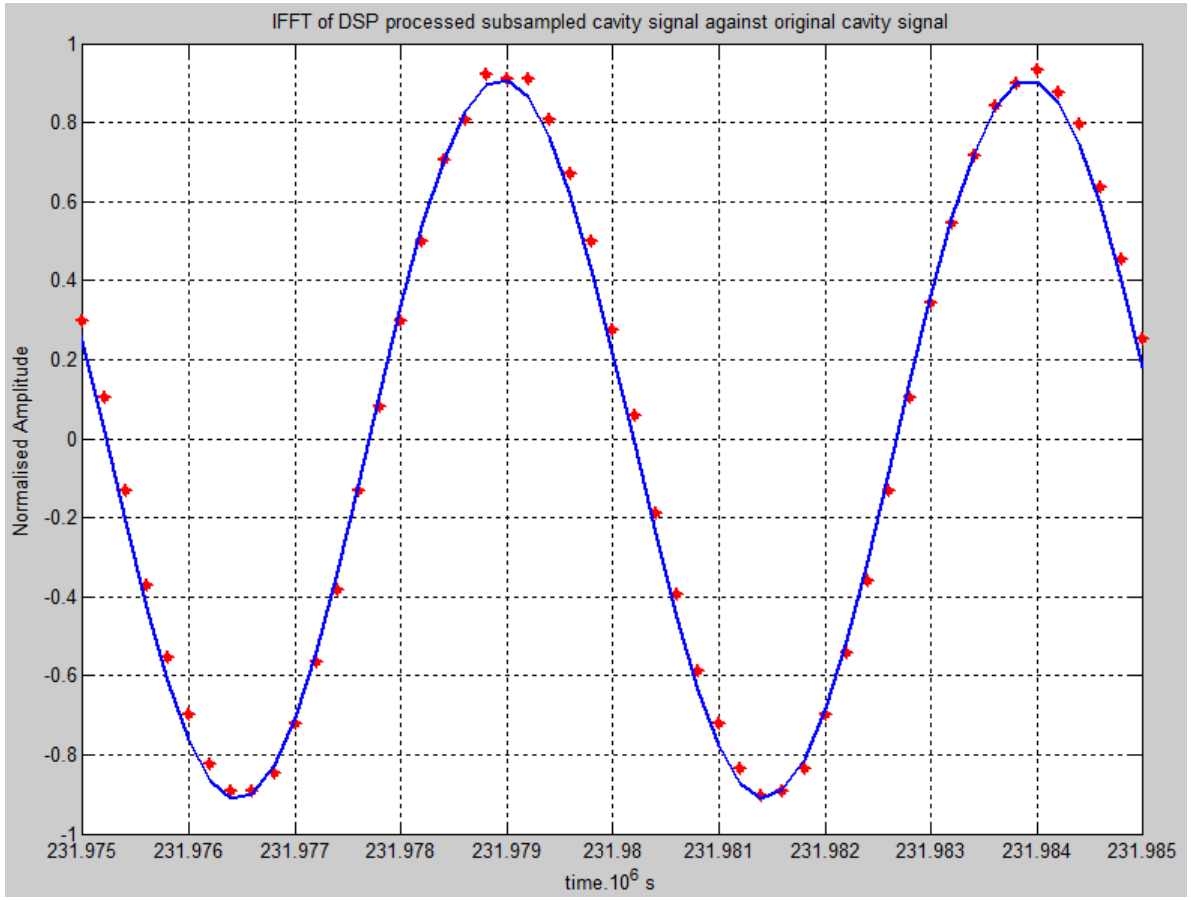
# Sampling Sub-Nyquist

## Testing with Cavity signal from SCTS

- Same process as before but with real signal from the high power tests at FNAL
  - Signals taken at 5 GSa/a
  - We mask down to 20 MSa/a

# Sampling Sub-Nyquist

## Testing with Cavity signal from SCTS




~70 ps difference in zero crossing

- Work ongoing to see if consistent phase delay or if algorithm can be improved

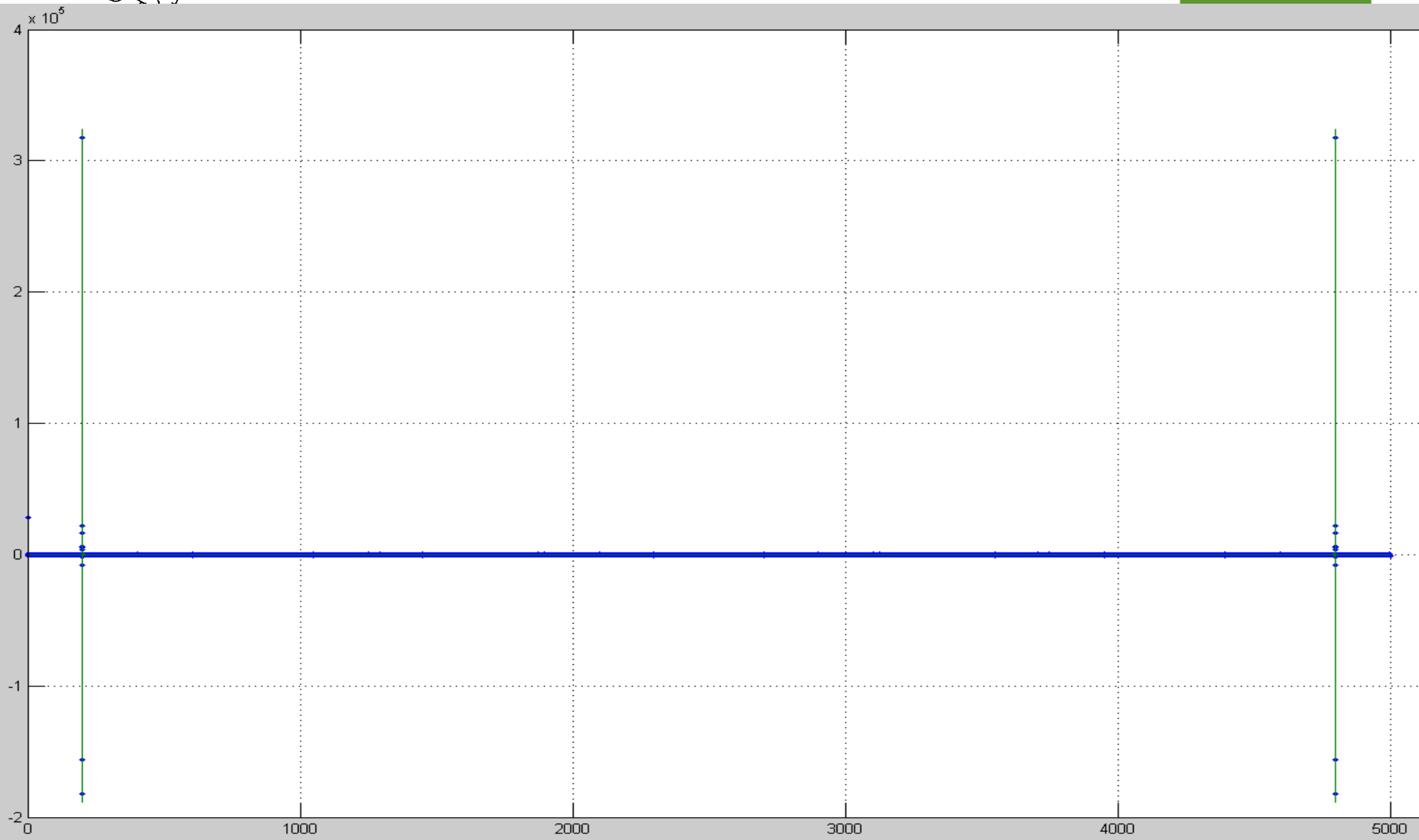
- Slight differences in amplitude – Is this noise, digitisation, an issue with the process or another frequency component ?

Red – SCTS Signal

Blue – Undersampled Signal after zero padding

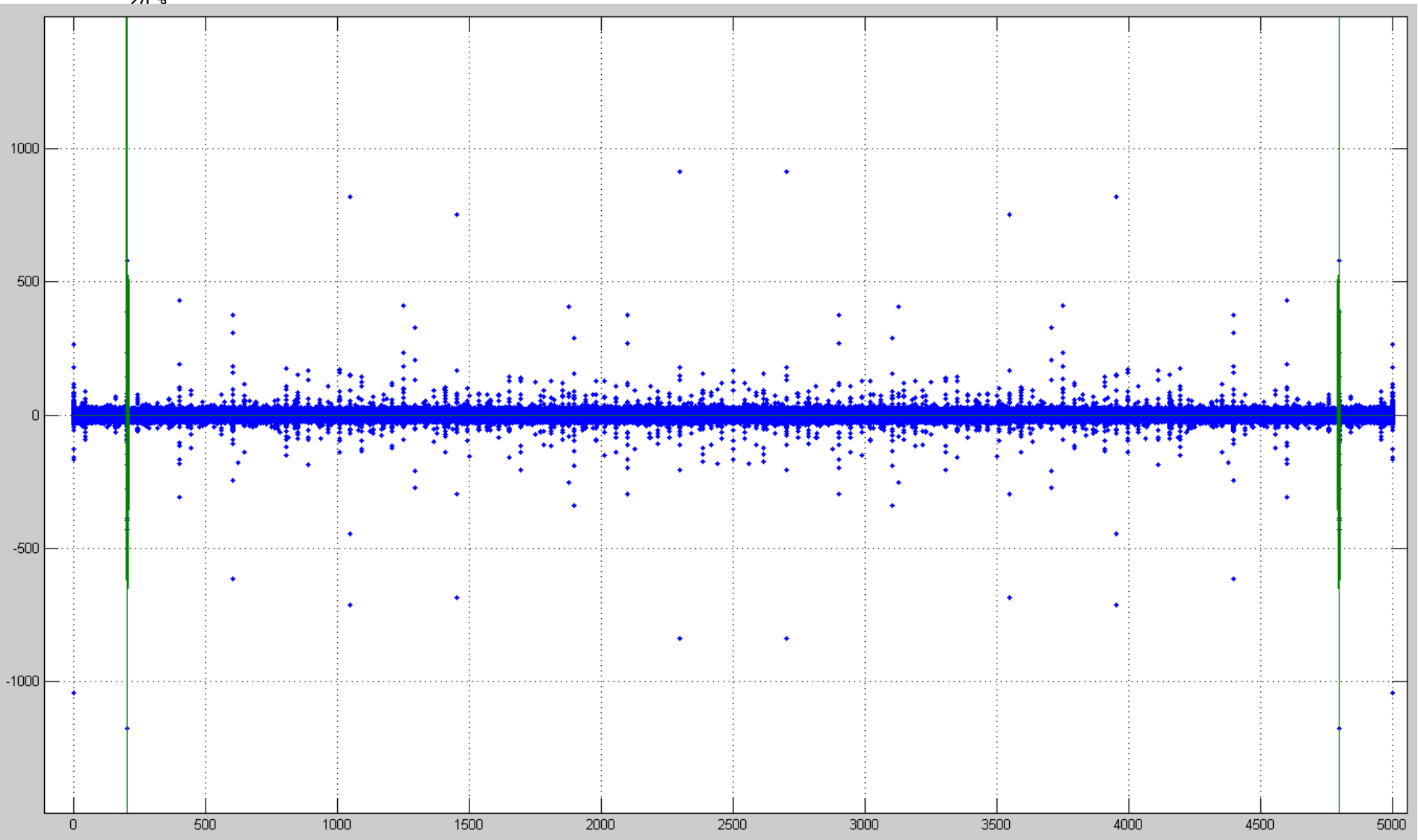
# Sampling Sub-Nyquist

Frequency comparison of SCTS 5GSa/s FT and 20MS/s Undersampled FT



# Sampling Sub-Nyquist

Frequency comparison of SCTS 5GSa/s FT and 20MS/s Undersampled FT (Zoomed)



# Conclusions

- Undersampling looks promising
  - Process works automatically to zero-pad a low sample rate signal into a high sample rate one.
  - Phase needs further investigation to see if consistant phase difference
    - If so, a delay can be folded into the process.
- More testing needed