Muon- RF Phase Determination

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Contributions from many MICE:
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Requirements for Muon-RF Phase Timing

- ToF detectors provide 50ps resolution time stamp for the particle
  - Systematic delays well understood
- Trackers define muon orbital trajectory
  - Predict delay to first cavity- this is the time we want to 'perform' our RF phase measurement
- In order to not compromise the current resolution
  - Ideally want accuracy to be 50ps/3, ~15ps, ~1^o.
  - May be relaxed subject to advice from analysis group

- Worst case scenario- cavity linewidth is ~50kHz in 201MHz centre,
  - That is 2.5 parts in 10000
  - Max phase shift in 1 cycle is ~0.1^o.
  - Can therefore project about 10 cycles from measurement point
    - Adding only 1^o to the error
  - Requires accurate measurement as baseline for projection
  - May be eased by the LLRF feedback loop gain bandwidth

Phase Detection Schemes

- RF zero crossing easiest to define and provides best trigger edge
- Detector clock should be synchronised with ToF
- Use external clock (from LLRF?) and LLRF Feed-Forward complete trigger to zero all timebases
  - No interesting data till LLRF enters closed loop for phase
  - Confirms peak gradient achieved

- Could use existing Caen TDC’s and LeCroy Discriminators used for ToF
  - Known hardware and programming interface
  - Minimises electrical length uncertainty and thermal variability
  - Limited to 25ps resolution
    - Requires unproven resolution enhancement
    - Either enhanced digital Vernier or Analogue (requires knowledge of amplitude) interpolator
    - Requires discriminators tested in 201MHz environment
- Use alternative, faster TDC
  - Agilent semi analogue device
  - Is unproven, new programming and hardware interface
  - Has different hardware limitations to understand

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- Could use digitisers to record waveform
  - Would involve a lot of data if we require Nyquist on 201MHz
    - But since narrowband- have options
    - Sequencial burst acquisitions on a regular periodicity
    - Undersampled waveforms and DSP signal reconstruction
    - Both techniques require proving
    - Give amplitude data

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Time delays

- If we introduce new electronics into the system, we will need to assess the delays and the delay stability cf. the ToF electronics
  - In any case we will need to use network analysers and simulations to define the systematic delays in the RF system
  - One key component we can try to match is the cable used in the ToF system
    - RG213, 40m long
  - This has acceptable bandwidth
  - Could take cavity signal to ToF, or LLRF reference oscillator signal to ToF on high performance cable
  - Use RG213 laid in parallel with ToF cable to achieve maximum equalisation of the thermal response
  - Measure to define electrical length after installation
  - Provide redundant spare cables to test for variation in electrical length
  - Useful to check cable performance as here we wish to achieve a stability of less than the ToF detectors resolution

RG213 Cable Tests

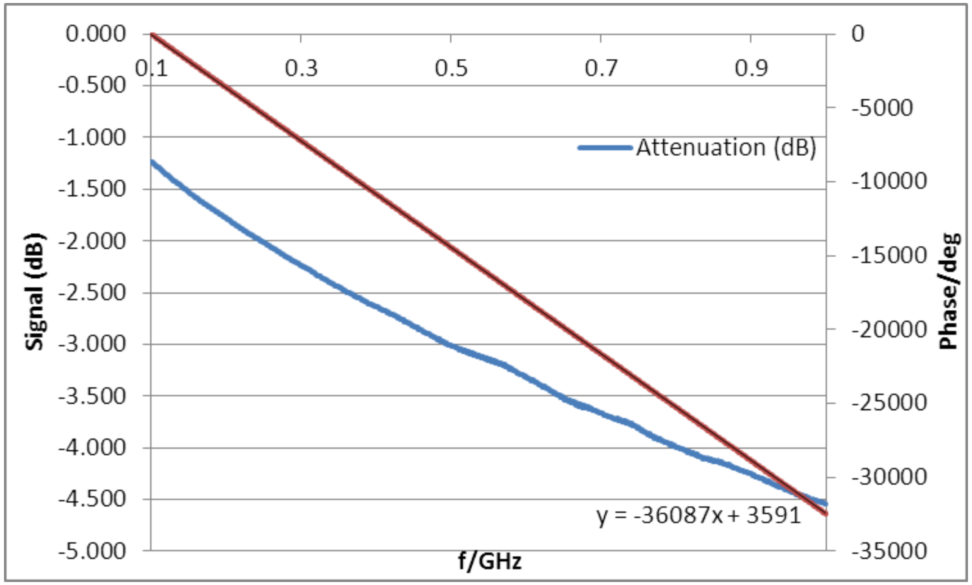
- RG213 Cable is used on the ToF signal returns

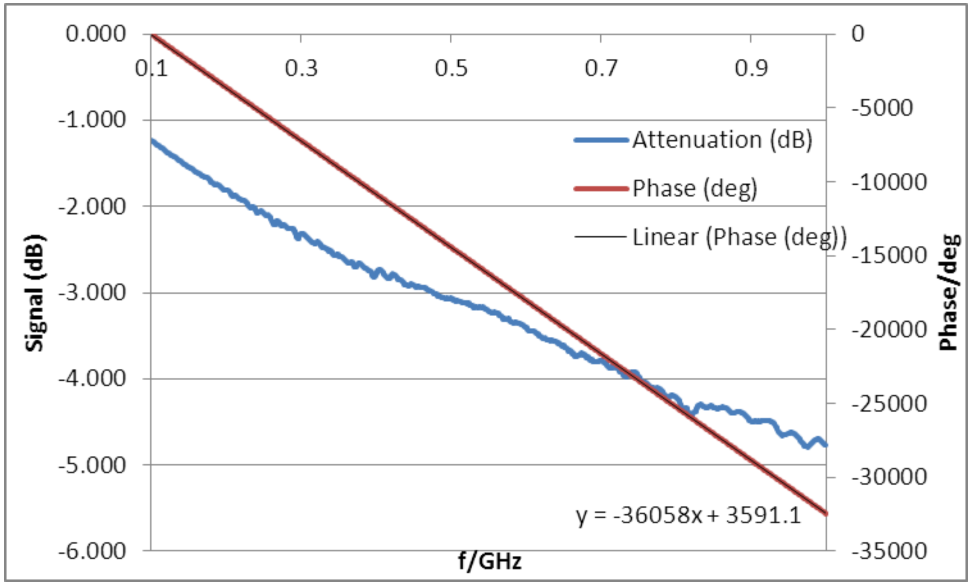
- RG213 is also a good RF cable up to ~1GHz
  - Could also use for RF signals
  - But it was not designed for high phase stability
    - Either against mechanical distortion nor thermal excursion

- The accuracy of the differential between the ToF and RF is the vital requirement
  - Hence using high performance (semi rigid) RF cable will not help
  - Unless also contemplate rewiring the ToF detectors

- Thermally controlled environment built at Strathclyde
  - 20m RG213 cable tested over 14 to 30^{o}C
  - Tests also undertaken in three configuration of mechanical stress

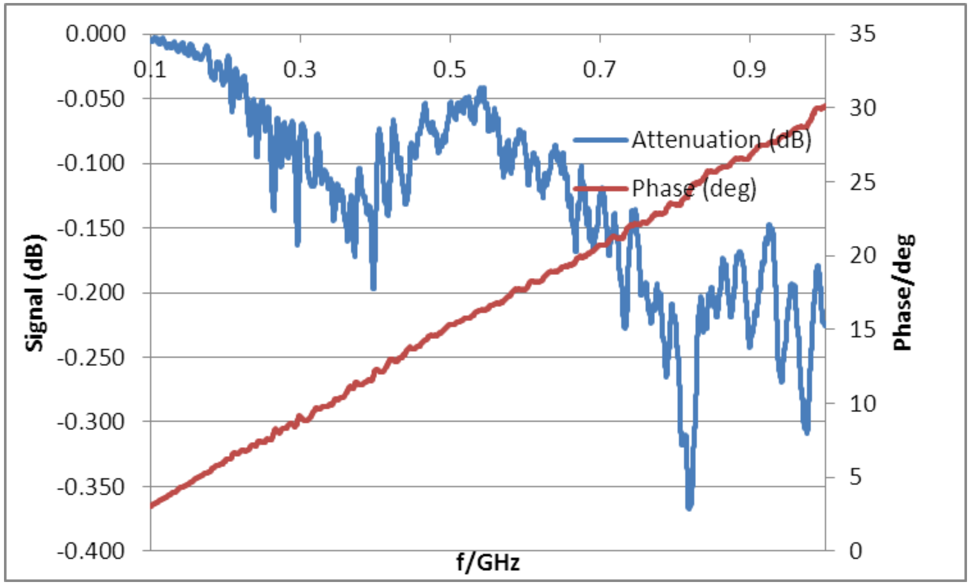
RG213 Cable Tests: Measurements





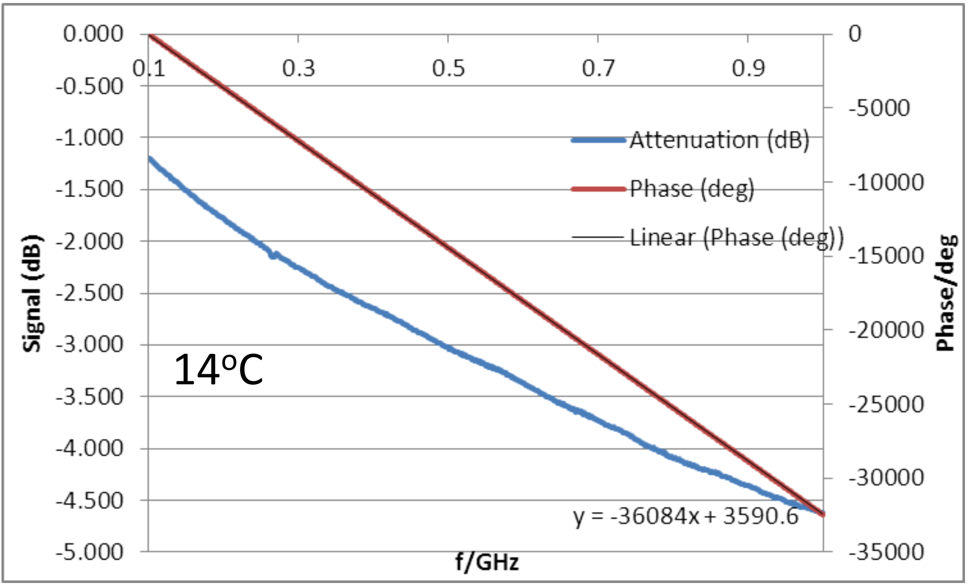
- Loose Windings (mean radius 3m) and Tight Windings (5.5cm to 7.5cm)
- Fitted Line shows Phase angle in degrees versus frequency
- Gradient is (essentially) reciprocal phase velocity
  - Note significant difference
- Phase is 'unrolled', so ignore absolute values on vertical phase axis- only gradient is interesting
- Data Taken at room T ~17^{o}C

RG213 Cable Tests: Measurements

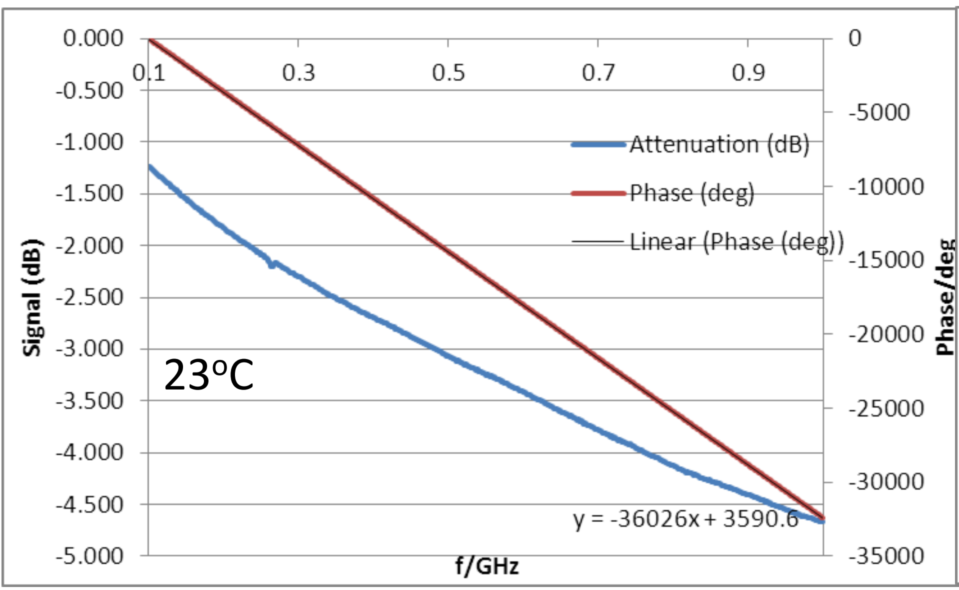


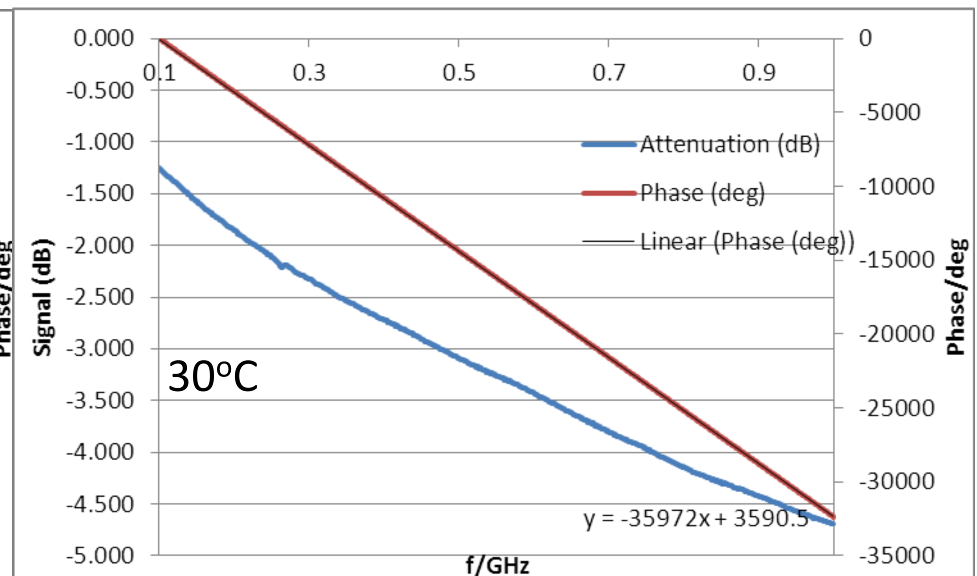
- Difference in phase and magnitude (Tight-Loose)
- At 200MHz phase shift is 7^{o} over 20m (recall we have 40m)
- We want 1^{o} accuracy

RG213 Cable Tests: Measurements



- Similar results at T=14°C, 23°C and 30°C, but again with a significant change in gradient
- Here bend radius is 6cm





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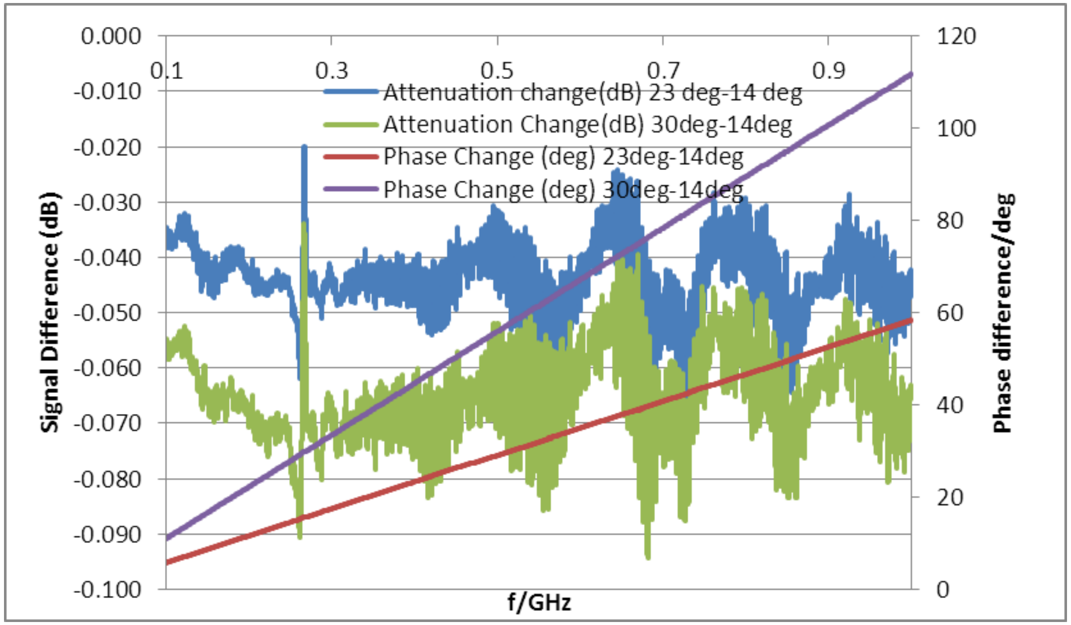

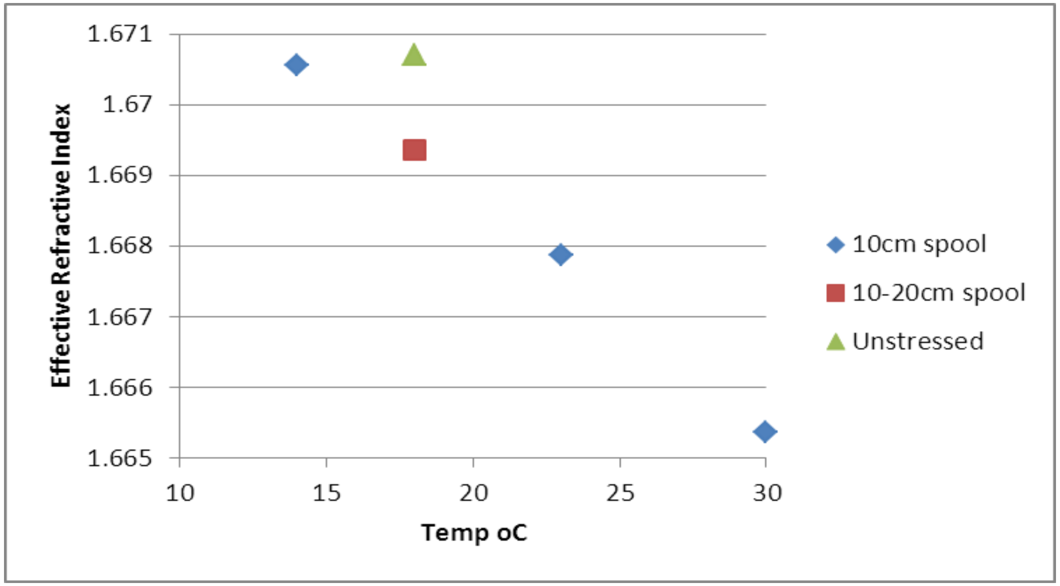

- Very little amplitude variation caused by the thermal excursion
- Attenuation almost independent of T
- Phase shift over 20m, from 14 to 30^{o}C at 200MHz is ~20^{o}
- Recall we want 1^{o}
- This cable has worked well for ToF- requirement 50ps (equiv 3^{o})
  - Is it OK for 1^{o}, ~20ps?
- Plotting effective ‘n’ against T- well defined line
- Need to check hysteresis and long term stability
- Need to check sample to sample variation

Summary

- Four routes have been defined to achieve accurate phase of the RF signal at arbitrary time
  - All will be investigated in parallel for now
  - Preferred route is additional interpolation on Caen TDC's/LeCroy Discriminators
    - Needs to be proven experimentally
  - Supported by one of two digitisation approaches
    - Interpolation approaches are being investigated at this time

  - Interaction of the LLRF will bring benefits
  - Hopefully analysis will ease the accuracy requirement

  - The cable long term stability and batch variability needs to be understood
  - Changing to high performance RF cable would probably require a similar change for the ToF detectors