MICE timing and RF phase measurement

CM33

Glasgow 25th – 29th June 2012

P. J. Smith on behalf of the RF group.

Contents

The Timing Problem

Muons travelling through the MICE channel will arrive at the cooling channel randomly within the MICE spill gate period.

Because it is not possible to synchronise the operation of the RF cavities to individual muons the first RF cavity could be at any phase as the muon traverses through it.

The relative phase angles between all eight cavities should be well known [i.e. Control] but we will still want to measure these phase angles directly [i.e. DAQ].

The amplitude of the Electric Field in the cavity should also be well known [i.e. Control] but it may decay during the spill. We will want to measure the Amplitudes within the cavities. [DAQ]

The purpose of the RF DAQ is to establish both what the E phase angle and the E amplitude was within a given cavity when a muon traversed through it.

Constraints

We're working with the following assumptions:

- The amplitude must be known to 1% - The amplitude may decay over time as the RF power is obtained from capacitor banks.
- The phase of the cavity must be known to within 5 degrees as the muon traverses through it.

At 201.25 MHz period = 4.97ns => 5 deg = 69 ps.

After discussing this with the analysis group last week it appears that this measurement error is absolute.

i.e. We have a RF Timing error budget of +/- 69 ps with the DAQ

RF Review

An RF review was held at Daresbury Laboratories on the 16/17th April 2012 to discuss many aspects of the RF system, most of which I won't discuss here!

Of relevance (to this talk!) was the discussion of how to solve the timing problem as described on the previous slide.

A couple of solutions were presented with the favoured one essentially accepted as being the way forward, with some advice given by experts present at the meeting.

Outline of the Proposed Solution

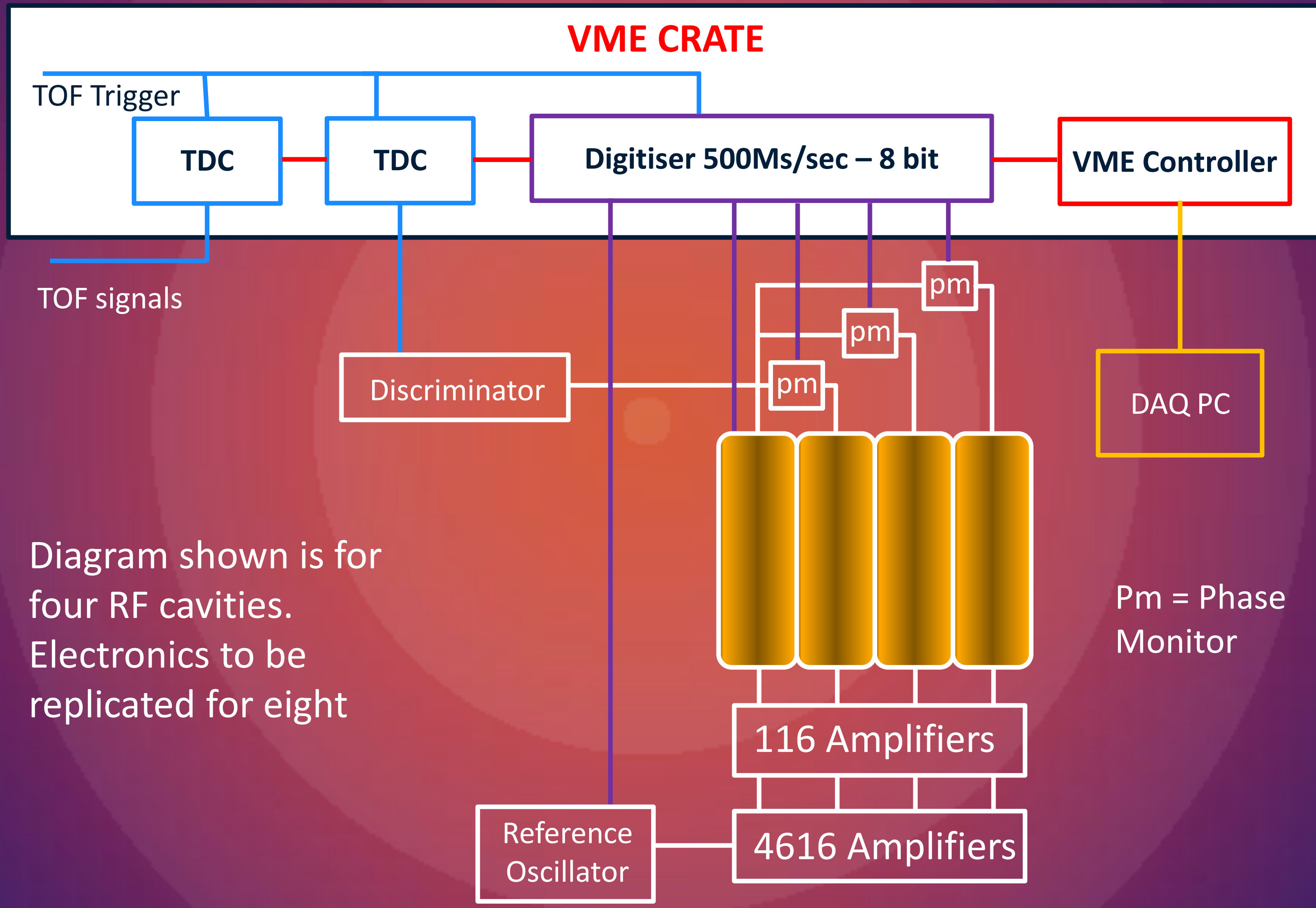


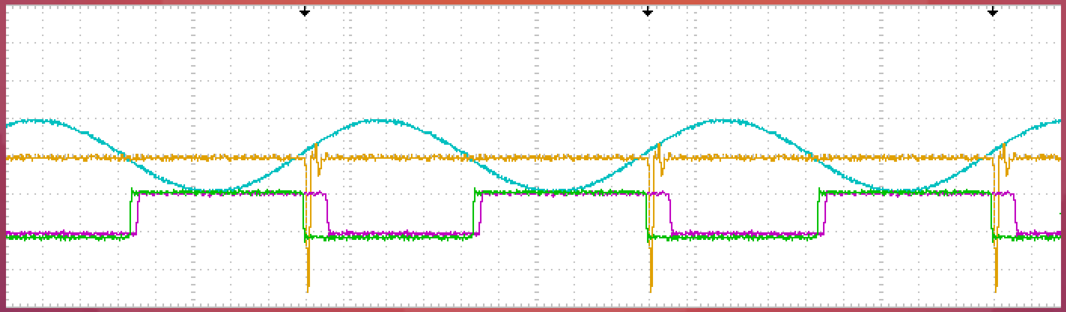
Diagram shown is for four RF cavities. Electronics to be replicated for eight

Pm = Phase Monitor

Discriminator - Function

A fast discriminator (level/zero crossing/fraction) will provide a series of timing pulses that would provide a mechanism to lock a given phase value of the RF to the TOF triggers.

By logging these triggers in a TDC synchronised to the TOF TDCs we should be able to time correlate the phase of the RF to events registered by the TOF TDCs. With this information it should be possible to reconstruct what the phase of the RF was when the muon traversed a cavity.



Note: This is a composite Image of LF Sine Wave (Few MHZ) with a discriminator to demonstrate the principle of generating regular timing pulses from the RF.

Digitisers – Why?

The digitiser is primarily being used to measure the amplitude of the RF signal at the cavity itself but this isn't the only way in which this could be done. For example the amplitude of the RF signal could be measured through the use of a peak detector.

It is clear that the digitiser will provide additional information on the form of the signals at the cavities themselves that would not be apparent using a peak detector. Would this be useful? I think there are a number of modest reasons that suggest using a digitiser would be the better option to consider at this stage.

What happens if there is a systematic drift/error in the peak detector electronics?

The peak detector relies on the equivalent of a few sample points, (i.e. signal peak) whereas the digitiser will have many points to fit to and so would be more immune to any noise or interference. This may/may not be a problem. Any output from a peak detector (analogue or digital) is effectively digitised anyway.

Would it be easier to apply subsequent 'corrections' to a fit than it would be to a single value?

Assume 500Ms/sec, 50ns sample time per muon, 100 muons per sec – 2.5kB per spill – (150MB per day?) so data rate is not an issue.

MICE

Digitisers - Function

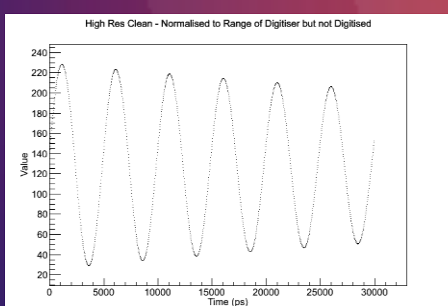
The University Of Sheffield.

By digitising the output monitor from the first cavity in each bank of cavities during the time-of-flight of a muon through MICE we would end up with a short record of the cavity signal during this period.

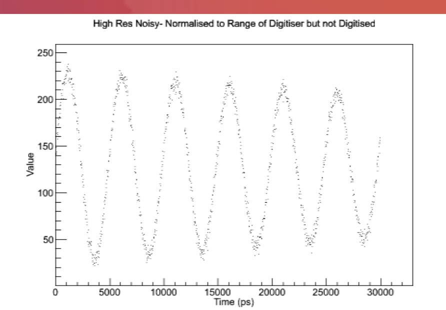
A fit to the digitisation would permit the amplitude of the RF signal to be determined. This may also provide a mechanism to provide a second check on the delta t of the discriminator timing (i.e. the possibility of reducing discriminator jitter) although more study is needed here.

The digitisation process is to be controlled by TOF events.

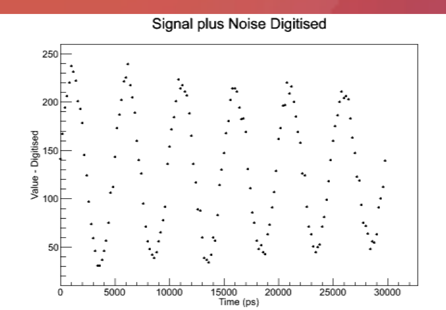
SIMULATED 5Gs/sec with white noise



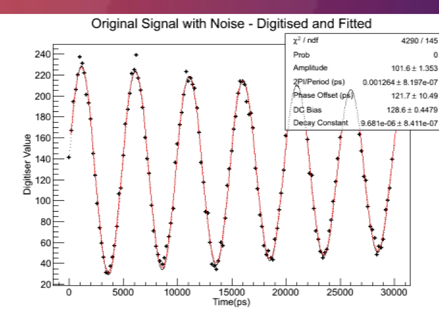
1) High Res Master – **Note Exponential Decay is Exaggerated.**



2) Same Plot with noise added where 1σ = 0.05



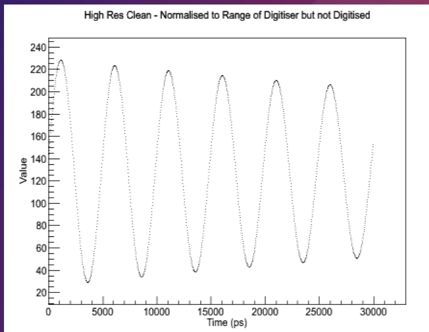
3) Master Plot digitised, 8 bit 5Gs/sec – noise added as 2)



4) Fit plotted to digitised sample. Fit parameters are then compared with 1)

Digitisers - Function

SIMULATED 5Gs/sec with white noise



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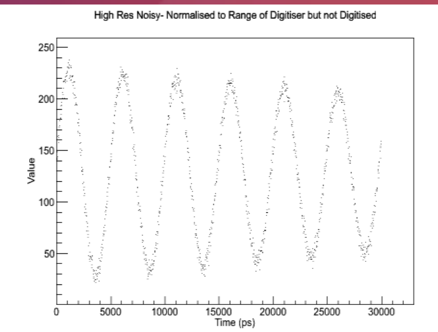

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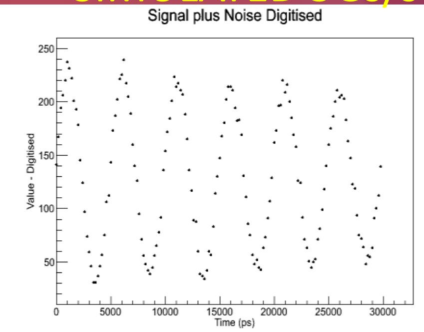

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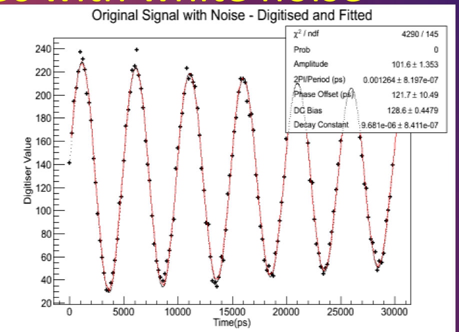

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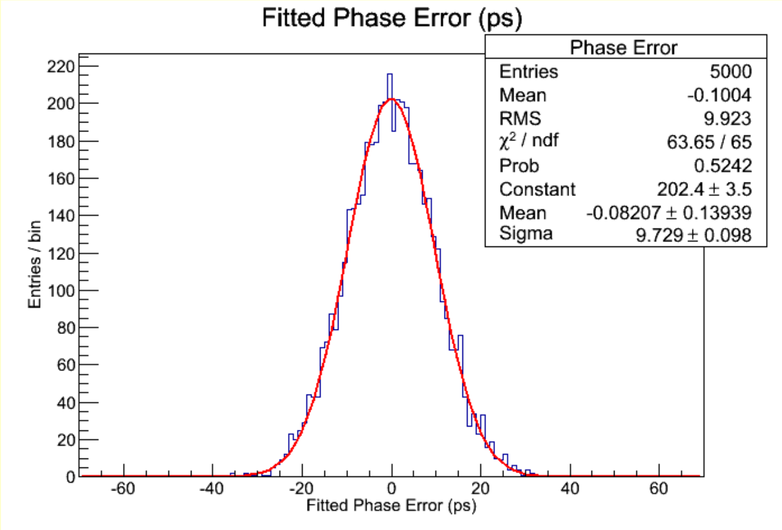
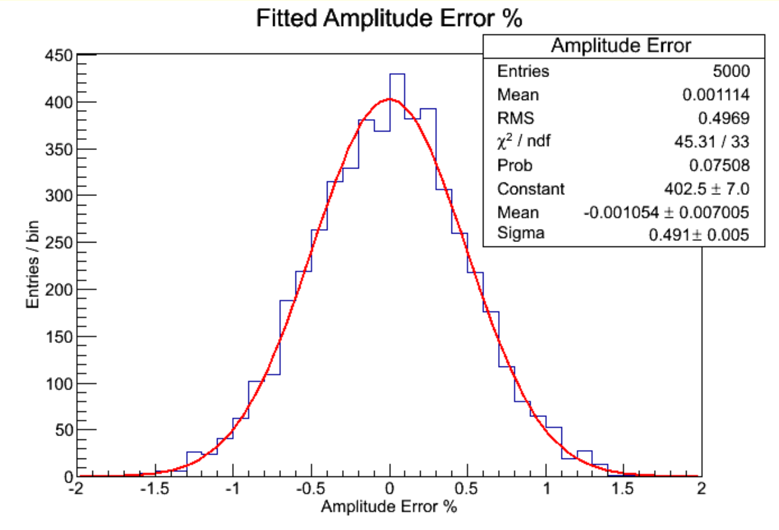


Fitted Phase Error at 5 Gs/sec, 8 bit digitiser with significant noise.



Same Simulation showing fitted Amplitude Error.

Digitisers - Function

Given that the RF signals should be clean, digitisation at a relatively low sample rate, i.e. greater than the Nyquist Rate (2 x frequency), over several cycles should be sufficient to reconstruct the RF wave to within a few ps accuracy. We are initially going to try at 500 Ms/sec as we are able to borrow a VME card that can sample at this rate.

5 degrees = 70ps Amplitude ~1%

Simulation						Fit (1σ)			
						Phase (ps)		Amplitude %	
Sample Time	Digi Bits	Sample Rate	Number of Iterations	Noise Fraction	Exp Amp Decay	Mean	Sigma	Mean	Sigma
30ns	8	500Ms/s	5000	Gaus 0.05 (1σ)	No	-1.18	25.4	-0.01	0.693
30ns	8	1Gs/s	5000	Gaus 0.05 (1σ)	No	0.189	19.76	0.003	0.508
30ns	8	2Gs/s	5000	Gaus 0.05 (1σ)	No	0.221	14.11	0.001	0.365
30ns	8	5Gs/s	5000	Gaus 0.05 (1σ)	No	-0.023	9.04	0.003	0.233
30ns	8	8Gs/s	5000	Gaus 0.05 (1σ)	No	0.095	7.08	0.008	0.185

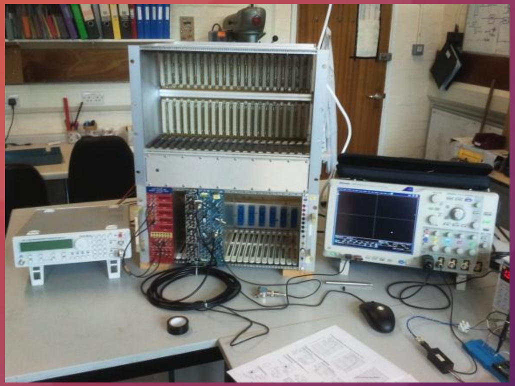
The phase accuracy is very sensitive to sample rate over a 30ns period.

I wanted to rerun this simulation with low noise at 500Ms/sec this weekend but I wasn't entirely happy with output – Suffice to say that the amount of acceptable noise with 500Ms/sec (Signal noise plus jitter) needs to be small at this sample rate to get the necessary resolution.

Assembling a Test-Bench

We've spent a significant amount of time and effort putting together a test bench at Sheffield. We're getting there…

- 1 GHz Scope. ✓
- Sign Gen - Borrowed one but has had to be returned. ✗
- 500Ms/sec digitiser VME module - On loan from EMR. ✓
- 25ps TDC VME - On loan from TOF. ✓
- VME Crate – Borrowed one from RAL but it is damaged – We need another. ✗
- VME Link. ✓
- PC. ✓
- Discriminator - 100MHz CF/ZC/level but will probably require a new one >200MHz. ✓
- Software – To Discuss with Yordan. ✓



Plans

Once we have a full test bench it will be easier to plan a full schedule of the work. At the moment I'm spending some time (when I can prise Ed away from it!) with the new scope familiarising myself with it and seeing how accurately I can measure cable delays/phase differences.

In the immediate future I wish to do the following:

1) Bench testing the phase monitors (evaluation boards from Hittite on loan from DL)

2) Bench testing the discriminator and evaluating the requirement for a faster one!

3) Setting up the software to talk over the VME and establish communication with the TDC and digitisers.

4) Feeding back what we find into the simulation to try and get a better model.

However all of this does require a complete Bench Test Setup which remains my priority. Hopefully we will be in a better position to report a more detailed plan by the next CM.

Conclusion

We have established a method of tackling the RF timing problem for MICE and have a clear way forward – good agreement amongst experts on the method at the RF workshop.

We have some simple simulation models that have pointed us in the direction as to what specification of hardware we need.

We are in the process of setting up a test-bench at Sheffield to make some measurements on the proposed hardware to see what performance we can actually achieve. Obtaining a fully functioning test bench is our current priority.

Although we have a good outline of what we want to achieve the 'Devil will be in the detail'. The construction of the test bench and some initial testing will drive the subsequent detailed plan for the RF timing. We hope to be much closer to this by the next CM.