

# Re: Q about noise in time interval measurement averaging

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- *From:* "Ian" <[ian\\_bucknerNOT@xxxxxxxxxxx](mailto:ian_bucknerNOT@xxxxxxxxxxx)>
  - *Date:* Tue, 10 Apr 2007 10:33:54 +0100
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"colin" <[colin.rowel@xxxxxxxxxxxxxxxxxxxx](mailto:colin.rowel@xxxxxxxxxxxxxxxxxxxx)> wrote in message  
[news:X\\_tSh.1049\\$t12.340@xxxxxxxxxxxxxxxxxxxxxxxxxxxx](mailto:news:X_tSh.1049$t12.340@xxxxxxxxxxxxxxxxxxxxxxxxxxxx)

<[bill.sloman@xxxxxxx](mailto:bill.sloman@xxxxxxx)> wrote in message  
[news:1176133466.968761.305280@xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx](mailto:news:1176133466.968761.305280@xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx)

On Apr 7, 2:44 am, "colin" <[colin.ro...@xxxxxxxxxxxxxxxxxxxx](mailto:colin.ro...@xxxxxxxxxxxxxxxxxxxx)> wrote:

<[bill.slo...@xxxxxxx](mailto:bill.slo...@xxxxxxx)> wrote in message

[news:1175902280.854739.222930@xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx](mailto:news:1175902280.854739.222930@xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx)

On Apr 6, 8:42 pm, "colin"  
<[colin.ro...@xxxxxxxxxxxxxxxxxxxx](mailto:colin.ro...@xxxxxxxxxxxxxxxxxxxx)> wrote:

Hi,  
I have a PIC measuring a  
time interval to 25ns  
resolution,  
the interval is totally  
asynchronous to the PIC  
clock.

So say if I average over  
25000 measurements that  
will give me a limit  
of  
1ps  
resolution.

Im trying to do a system  
noise analysis and im  
wondering how to work

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this  
out,  
I cant seem to recall how the  
noise reduces with  
increasing samples,  
is it  $1/\text{samples}$  ? this would  
be too good to be true,  
or  $1/\sqrt{\text{samples}}$  this  
seems rather low.

Noise decreases as one over the square root  
of the number of samples,  
if the noise on successive samples is  
uncorrelated.

The square root of 25000 is 158.1, so you'd  
reduce your 25nsec  
quantisation error to 158psec rather than  
1psec, if you averaged 25000  
independent samples.

Ah yes ofc I must of forgoton how to think for a while,  
I was getting mixed up with the number of available bits for  
resolution.

there is also a lot of noise in  
the signal as it is from an  
optical  
encoder,  
seems mostly mechanical, I  
need to reduce this by  
averaging over a  
long  
time  
too.

I'm trying to work out the  
optimum rate of pulses per  
revolution to  
use.

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The optimum number of pulses per revolution is probably one, unless you need to know the sense of the rotation as well as it's speed.

not too worried about the sense of rotation as I know that anyway,  
however im seeing a standard deviation of about 10ns per revolution  
averaged  
over 2000 pulses per rev,  
Im working on fixing the mechanics to reduce this,  
but 1 pulse per rev would give me 25ns error,

im looking for .1ps resolution,  
to reduce my SD of 10ns to this amounts to  $100000^2$   
revolutions wich  
would  
take 3 years at 6000rpm  
id rather it only took a few days, as im not quite that patient.

The advantage of one pulse per revolution is that you are looking at one fiduciary mark on your shaft, so you don't have to worry about the spacing of the fiduciary marks around the shaft, or the centering of a radially striped disk on the shaft. and the interval between the signal edges that define the period of rotation is as long as possible, so your quantisation noise is 10nsec in 10msec, rather than 10nsec in a shorter period.

If you put an array of detectors around the shaft, so you get one pulse per revolution from each sensor, you end up with more observations per revolution with independent quantisation noise on each value for the period of rotation,

Obviously, if there is noise on the rate of rotation – such as might be caused by a minimally elliptical shaft rotating in a minimally elliptical journal bearing – at a frequency that isn't an integral multiple of the frequency of rotation, the noise on the output of each sensor in the array would be correlated with the noise on the output of its nearer neighbours, and averaging wouldn't do as much good as it would on uncorrelated noise.

well I average all the pulses over exactly one revolution,  
so any eccentricity wich is there should null out in the average.

I have tried 2 sensors on the same disc, oposite eachother,  
and you can see the error due to disc misalignment etc.

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however averaging this out over 2000 pulses over 1 revolution gave a standard deviation of just 500ps.  
which corresponds well to the reduction of  $25\text{ns}/\sqrt{2000}$ .  
{i had initially put this down to mechanical/electrical noise}

Interestingly if I feed it with the same signal as ref and compare it drops down to 25ps,  
im not sure if there isnt some peculiarity with the PIC of pulses arriving at the same time.  
If I use alternate edges its still quite low.

My own inclination would be to go for a faster clock – using Motorola's ECLinPS emitter-coupled logic you could build a very wide synchronous counter (you'd need 23 bits – four MC100E016) that could follow a 500MHz clock, which would give you 2nsec of jitter rather than 25nsec, and drop your three years down to a week.

Peter Alfke of Xilinx – a guru on comp.arch.fpga – programmed a Xilinx programmable logic device to work as a 1GHz counter a few years ago – and this might be a better way to go.

If you were in a position do a serious amount of work, you could combine a fast clock with a time-to-voltage converter, and get the timing resolution down to around a few tens of picoseconds. Some years ago, when I was working on a stroboscopic electron microscope with a digital timebase, we set up such a system that digitised time intervals with a resolution of 10psec. Our 800MHz clock was not crystal-controlled, and our jitter never got better than about 50psec before the project was cancelled. I believe that John Larkin (Inland Electronics) sells toys that can do better.

Yes my initial approach was to use a time to voltage converter, but the voltage corresponding to 1ps was very small, and gave rise to its own noise problems.

the other problem which actually precluded this and made some of the things you mentioned much more difficult is that the phase of the 2 signals varies by more than 180°.

I need to keep track of the total phase change, which might be up to 20 cycles.

the PIC handles this surprisingly well, as it timestamps every edge with input capture.

it may still be possible to do this with a PLD at high clock rate using a similar technique.

however compared to the simple PIC approach this seems very involved.

however atm as my mechanical noise is much more than my quantization

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noise,  
so I think the PIC will suffice.  
I also think the risetime and bandwidth of the electronics and opto devices contribute noise which is best averaged out too, although I have no specs on this.

My main concern at the moment is to re do the mechanical side of things, but I needed to know more about how the noise is reduced etc, so hopefully I can find room to make it easier to improve the mechanical precision without losing it in quantisation noise.

The 10ns noise is mechanical and this is what will cause it to take 3 years to average out.

with your help I think I understand it well enough now thanks, also I did a simulation generating computer data with 10ns variation derived by a random number generator, the FFT showed a noise floor corresponding to  $1/\sqrt{\text{samples}}$ .

Although I need to work out how I can reduce this further as my signal has a minimal bandwidth.  
I'm also not exactly a specialist in FFT (yet).

Colin =^.=

Your "two sensors opposite each other" reminded me of a couple of techniques: you can use a single source, a light pipe arrangement to transfer the optical signal so that it passes through the encoder twice at opposite sides of the rotating shaft, and a single receiver. This takes out eccentricity effects, and reduces some other things a bit. That was a way of commercialising the original idea, which was to do a similar thing but distributed all round the rotating shaft. This is a much better technique, but more expensive.

I might still have the original patents kicking around, this was from the mid-1970's, I'll have a look tonight.

Regards  
Ian

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