ATLAS NOTE

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Time over threshold with the VMM1 ASIC

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Abstract

Thin Gap Chambers (TGC) will be the primary trigger detectors of the New Small Wheels (NSW). The VMM1 front end IC will provide in real time the time over threshold (ToT) of a signal as an approximate measure of the charge which will be used to determine the hit position with sufficient resolution by charge interpolation. Generally the ToT is a non-linear function of the amplitude. In this note an analytic expression of the shaper waveform is provided in order to facilitate studies and simulations of the ToT based trigger concept. The effect of the of the non-linearity of the amplitude representation of the ToT on the position resolution is also discussed. A brief root program to evaluate such a waveform is given in the appendix.

1 Introduction

The TGC trigger chambers of the NSW will determine, in real time, the track coordinates in each plane by charge interpolation using the time-over-threshold (ToT) provided by the VMM1 as an approximate measure of the deposited charge. The dependence of ToT on the amplitude is non-linear and it is a function of the shaper. Shapers are used to limit the bandwidth and hence increase the signal to noise ratio and, at the same time, limit the signal duration. In most front ends this is accomplished by a time-invariant filter with a number of poles which result in a semi-gaussian waveform. The higher order of such a filter the closest the waveform approaches a gaussian. This is important as it affects the relationship between peak amplitude and ToT. In this brief note the shaper's transfer function and an analytic expression of the waveform in the time domain are given. They can be used to study the ToT performance as a function of the VMM1 parameters and help optimize the track reconstruction algorithms. An example for 25 ns peaking time and a threshold of 5% of the maximum amplitude is given. A short root program that can be used for similar calculations is included in the appendix. The code will be provided by e-mail if useful.

2 The VMM1 Shaper

Time invariant semigaussian shapers are realized using either several real poles (r-shapers) or a combination of real and complex conjugate poles (c-shapers)[1]. The number of poles defines the order of the shaper. The VMM1 utilizes a c-shaper of order 3 with one real pole and 2 complex-conjugate poles. The transfer function $T(S)$ of such a shaper is

$$T(s) = \frac{1}{(s+p_1)\prod_{i=2}^{(n+1)/2}[(s+r_i)^2+c_i^2]} \qquad n = 3,5,7,\ldots$$

The third order transfer function has a real pole and two complex-conjugate poles. The time domain representation of the above is given by the inverse Laplace transform:

$$S(t) = K_1 e^{-tp_1} + \sum_{i=2}^{(n+1)/2} 2|K_1|e^{-tr_i}\cos(-ti_i + \angle K_i) \qquad n = 3,5,7,\ldots$$

For the VMM1 shaper, $n = 3$:

$$S(t) = \alpha^3 |pole_0||pole_1|^2 [K_0 e^{-tpole_0} + 2|K|e^{-t\Re pole_1} cos(-t\Im pole_1 + \angle K_1)$$

The parameter α is related to the peaking time t_{peak} by:

$$t_{peak} = 1.5\alpha$$

the real pole is[2]:

$$pole_0 = 1.263\frac{1}{\alpha}$$

the two complex-conjugate poles are:

$$pole_1 = (1.149 - i0.786)\frac{1}{\alpha}$$

and the parameters $K_0 = 1.584$ and $K_1 = -0.792 - i0.115$.

3 An example

One can now calculate the ToT as a function of amplitude using the equations in the previous section. Fig.1 shows in the left plot the response of the VMM1 shaper to an impulse charge. The right plot shows the ToT as a function of the amplitude (normalized to 1) with the threshold set at 0.05. The parameter $\alpha = 10^{-8}$, i.e., $t_{peak} = 25ns$. The code used to calculate these plots is given in the Appendix.

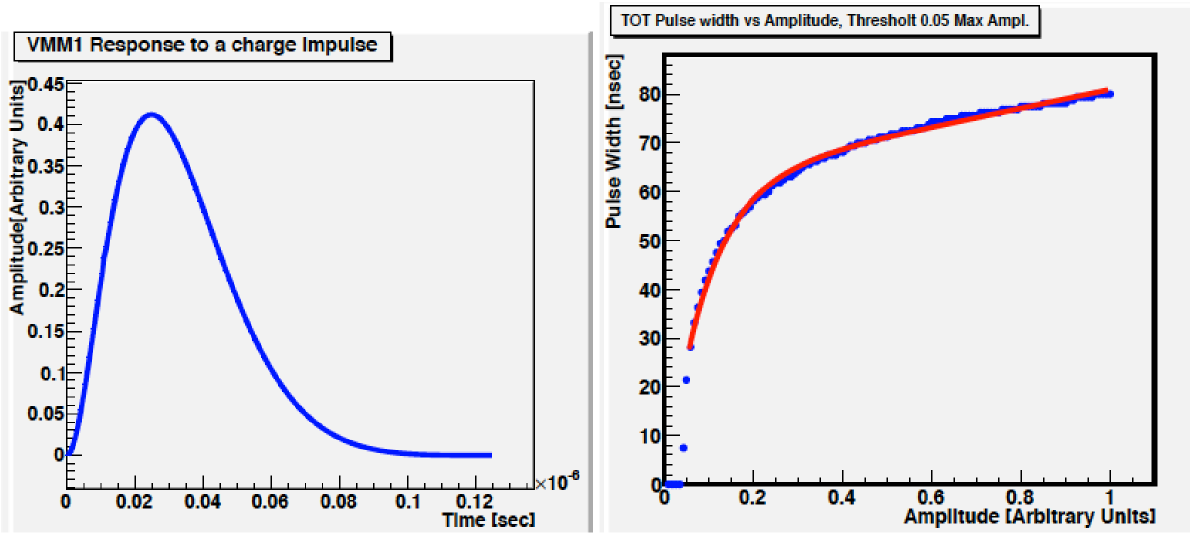

Figure 1: Left plot, the VMM1 shaper response to an impulse charge. Right plot, the time-over-threshold as a function of amplitude normalized to 1, threshold set at 0.05, for $t_{peak} = 25ns$. The superimposed curve is a fit to an empirical function described in the text.

The superimposed curve (in red) is a fit to the following empirical formula:

$$S(t) = (a + bt) - ce^{-dt}$$

where:

$$a = 61.8$$

$$b = 19.1$$

$$c = 64.1$$

$$d = 10.9$$

One can see that for the highest half of the dynamic range the amplitude determination by the ToT deteriorates. Fig.2 shows the uncertainty of such an amplitude determination as a function of the amplitude (normalized to 1) if we assume that the ToT digitizer resolution is 1 nsec.

It should be noted, however, that in all algorithms used for the position determination by charge interpolation, the contribution of the central (highest) amplitudes to the precision of the position determination is less important than the smaller amplitudes on either side of the peak of the charge distribution. Consider, as an example, the case where the three central strips of a charge distribution have amplitudes A_l, A_c, and A_r representing the charges on the left, center, and right strips. Both ratios A_l/A_c and A_r/A_c provide a measure of the position of the hit. The error in these ratios determines the hit position resolution. Let us

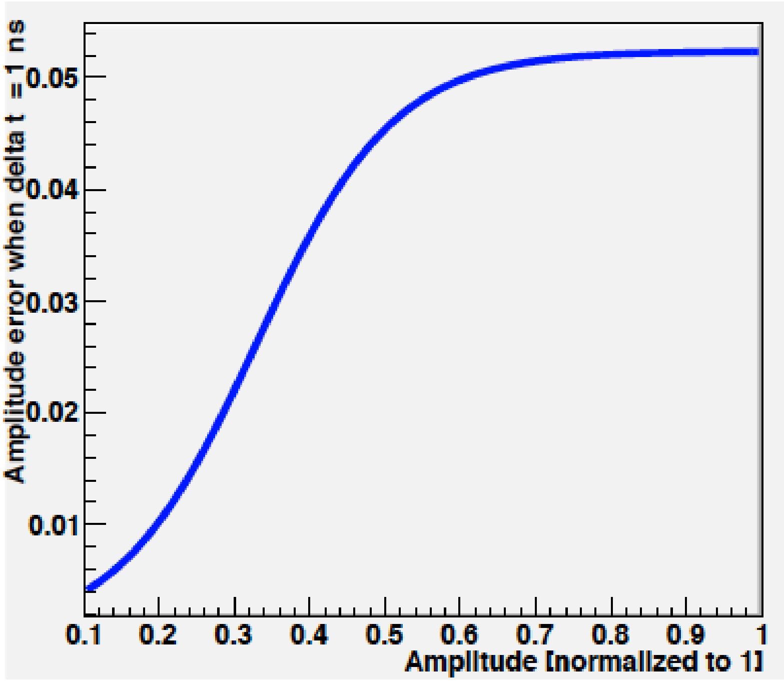

Figure 2: Uncertainty of the amplitude determination by the time-over-threshold method (assuming that ToT is measured to 1 nsec) as a function of the amplitude normalized to 1

assume that $A_c = 0.65$, $A_l = 0.25$, and $A_r = 0.15$ and consider the ratio A_l/A_c. If σ_l and σ_c are the errors of the amplitudes A_l and A_c respectively, the error of the ratio σ is:

$$\sigma = \frac{1}{A_c}\sqrt{A_c^2\sigma_l^2 + A_l^2\sigma_c^2}$$

The error σ multiplied by the strip pitch (assumed here to be 3.5 mm) gives the position error σ_x. From Fig.2 we get, roughly, $\sigma_l = 1.5\%$ and $\sigma_c = 5\%$. The first row of Table 1 has the results for the amplitude values and errors chosen above. If we assume that both amplitudes are measured to 5% we get the results shown in the second row. The error in the ratio is much larger and therefore the position resolution. If we now assume that the central strip is measured with precision of 1.5% but the smaller amplitude is still measured at 5% the resolution does not significantly improve as shown in the third row of the table.

σ_l	σ_c	σ	σ_x
0.015	0.05	0.024	85 μm
0.05	0.05	0.054	187 μm
0.05	0.015	0.050	176 μm

Table 1: Dependenace of position resolution on the precision of the amplitude determination using the ratio method showing the importance of the lower amplitudes and the relative insensitivity of the precision of the central (higher) amplitude. The strip pitch is assumed to be 3.5 mm

4 Conclusions

The transfer function of the VMM1 shaper is provided along with its inverse Laplace transform time domain representation. A root program that calculates the waveform and the time-over-threshold approximation of the amplitude is appended. It appears that ≈5-bit resolution of the amplitude can be achieved with this shaper. The derivative of the ToT function is also calculated. It represents the uncertainty of the amplitude determination assuming that the ToT is measured with precision of one nanosecond. It is shown that the reduced sensitivity of the ToT method at the high end of the dynamic range has relatively small effect on the position resolution.

References

[1] G. De Geronimo, *et al.*, IEEE Trans. Nucl. Sci. **58** (2011) 2382.

[2] A. Ohkawa *et al.*, Nucl. Instrum. Methods **138** (1979) 85–92

APPENDIX

```
// VMM1 response to a charge impulse and calculation of the ToT
// V.P. 7/18/2012

gRoot->Reset();
void tot_vs_amplitude_analytic() {
 TCanvas *c1 = new TCanvas("c1","shaper",200,10,1300,500);
 c1->Divide(2,1);
 Double_t t[200], s1[200], s2, s12[200], tau[200], amp[120];
 Double_t t1, Gain, Q=0.606, deltat, width[120];
 Double_t th_flag, deltatau, th1, th2, t1=1.44e-8;

 Double_t PeakingTime = 25;
 Double_t thresh = 0.05;

 //  Pole Parameters
 Double_t a = PeakingTime*1e-9/1.5;
 Double_t pole0 = 1.263/a;  // real pole
 Double_t Re_pole1 = 1.149/a, Im_pole1 = -0.786/a; //complex pole

 Double_t K0 = 1.584, Re_K1 = -0.792, Im_K1 = -0.115;
 Double_t pole1 = Re_pole1*Re_pole1 + Im_pole1*Im_pole1;
 Double_t K1 = sqrt(Re_K1*Re_K1 + Im_K1*Im_K1);
 Double_t argK1 = atan2(Im_K1, Re_K1);

 deltat = 2.5*PeakingTime*1e-11;

 for (Int_t k=0; k<120; k++) {
   Gain = (k+1)*0.025;
   th_flag = 0;
   for (Int_t i=0; i<200; i++) {
   t[i] = (i+0.5)*deltat;
   s1[i] = exp(-t[i]/t1)/2;
 s12[i] = a*a*a*pole0*pole1*(K0*exp(-t[i]*pole0)+(2*K1*exp(-t[i]*
 Re_pole1)*cos(-t[i]*Im_pole1+argK1)));
 s2 = s12[i]*Gain;
   if (s2>=thresh && th_flag==0){
   th1 = t[i];
   th_flag = 1;
   }
  else if(s2<thresh && th_flag == 1){
  th2 = t[i];
  th_flag = 0;
  }
   }
   width[k] = (th2 - th1)*1e9;
   amp[k] = Gain/3;
 }

Int_t n = 200;
 c1-> cd(1);
   TGraph *gr0 = new TGraph(n,t,s12);
   gr0->SetTitle("VMM1 Response to a charge impulse");
   gr0->SetFillColor(1);
   gr0->SetMarkerColor(kBlue);
   gr0->SetMarkerStyle(20);
   gr0->GetXaxis()->SetTitle("Time [sec]");
   gr0->GetYaxis()->SetTitle("Amplitude[Arbitrary Units]");
   gr0->GetYaxis()->SetTitleOffset(1.3);
```

```
    gr0->Draw("ALP");

    c1-> cd(2);
    Int_t n1 = 120;
    TGraph *gr2 = new TGraph(n1,amp,width);
    gr2->SetTitle("TOT Pulse width vs Amplitude, Thresholt 0.05 Max Ampl.");
    gr2->SetFillColor(1);
    gr2->SetMarkerColor(kBlue);
    gr2->SetMarkerStyle(20);
    gr2->GetXaxis()->SetTitle("Amplitude [Arbitrary Units]");
    gr2->GetYaxis()->SetTitle("Pulse Width [nsec]");
    gr2->GetYaxis()->SetTitleOffset(1.3);

    TF1* f = new TF1("f", "([0]+x*[1])-[2]*exp([3]*x)", 0.05,1);
    f->SetParameter(0,80);
    f->SetParameter(1,1);
    f->SetParameter(2,3.8);
    f->SetParameter(3,-3.6);
    gr2->Fit("f","R");
    gr2->Draw("AP");

    Double_t p0 = f->GetParameter(0);
    Double_t p1 = f->GetParameter(1);
    Double_t p2 = f->GetParameter(2);
    Double_t p3 = f->GetParameter(3);


    TF1* f1= new TF1("f1",  "1/(([0] - [1]*[2]*exp([2]*x)))",0.1,1.0);
    f1->SetParameter(0,p1);
    f1->SetParameter(1,p2);
    f1->SetParameter(2,p3);
    TCanvas *c2 = new TCanvas("c2","Amplitude error",200,10,500,500);
    TGraph *gr3 = new TGraph(n1,amp,width);
    gr2->SetTitle("TOT Pulse width vs Amplitude, Thresholt 0.05 Max Ampl.");
    gr2->SetFillColor(1);
    gr2->SetMarkerColor(kBlue);
    gr2->SetMarkerStyle(20);
    gr2->GetXaxis()->SetTitle("Amplitude [Arbitrary Units]");
    gr2->GetYaxis()->SetTitle("Pulse Width [nsec]");
    gr2->GetYaxis()->SetTitleOffset(1.3);

    f1->Draw();


}
```