

Bunch Shape Systematic Effects in the Tevatron BLT

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Abstract

I have simulated the effects of bunch time-position correlations on the digital signal-processing algorithm used in the Tevatron BLT. A systematic skew of 1 mm over 2 ns in the orientation of the bunch leads to a systematic bias in the position estimate of 20 microns. This bias is on the order of the resolution of the device and should not have any significant impact on its utility during operations.

Valeri Lebedev has expressed concern that the digital signal-processing algorithm used to process strip-line signals from the Tevatron BLT is sensitive to the orientation of the major axis of the bunch as it passes through the device.

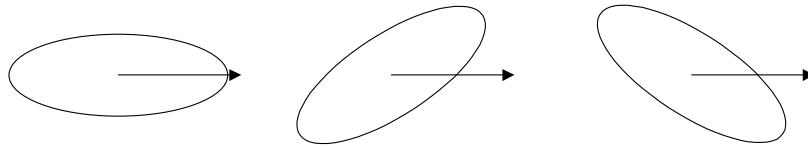


Figure 1: Un-skewed and Skewed Bunches

For example, of the three bunches shown schematically in Figure 1, Valeri has suggested that the processing algorithm will correctly determine the position of the centroid of the first only. For the other two bunches, he is concerned that the time-position correlation will lead to systematically biased estimates of the position of the centroid. I have simulated this effect and I find that while the effect is real, it is small.

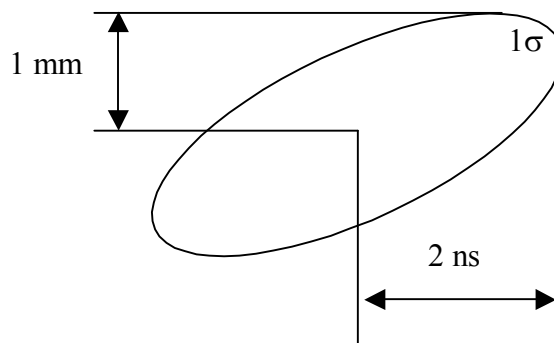


Figure 2: Orientation of the Simulated Bunch

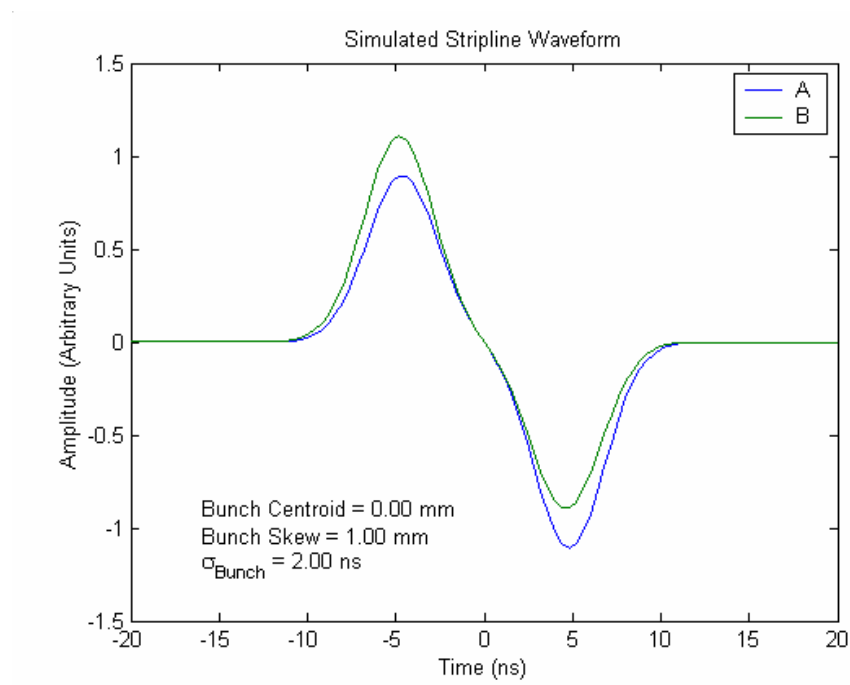


Figure 3: Simulated Strip-line Signals

The orientation of the simulated skewed bunch is shown schematically in Figure 2. The transverse centroid of the bunch is at zero. The transverse position of the bunch is correlated with the longitudinal position such that the head and the tail of the bunch are transversely skewed by ± 1 mm respectively from the centroid of the bunch at $\pm 1\sigma$.

Figure 3 shows simulated strip-line signals induced by the skewed bunch. The skew suppresses the leading pulse of the doublet on the signal from the A plate and enhances the trailing pulse. The skew has the opposite effect on the signal from the B plate. The bunch skew changes the relative amplitudes of the waveforms by as much as 20 percent.

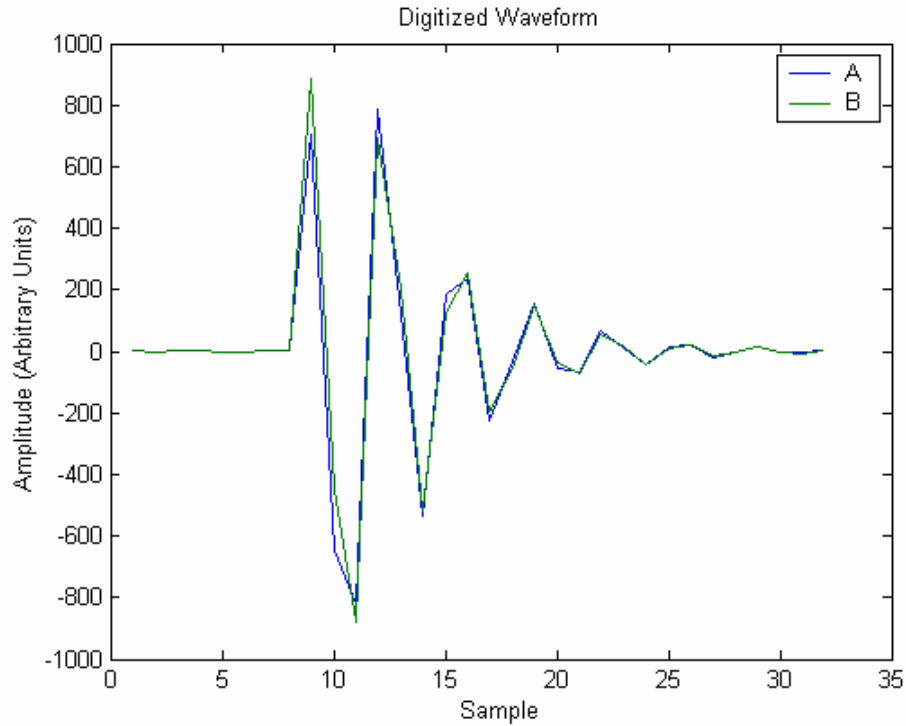


Figure 4: Simulated Digitized Signal

Figure 4 shows the simulated strip-line signals after passing through a 30 MHz ringing filter and being sampled at a rate of 100 MHz. Again significant differences between the waveforms from the A and B plates are visible.

In the BLT signal processing, the sampled signals are base-banded followed by matched-filtering. Base-banding process effectively rectifies the pulse along some direction in the complex plane. Filtering smooths the rectified pulse.

Figure 5 shows the real component of the base-banded signal. For clarity, this signal has been multiplied by a complex phase so that the rectified portion of the signal lies entirely in the real plane. For some samples, the A signal is larger than the B signal. For others the opposite is true. The matched filter will smooth most of these differences.

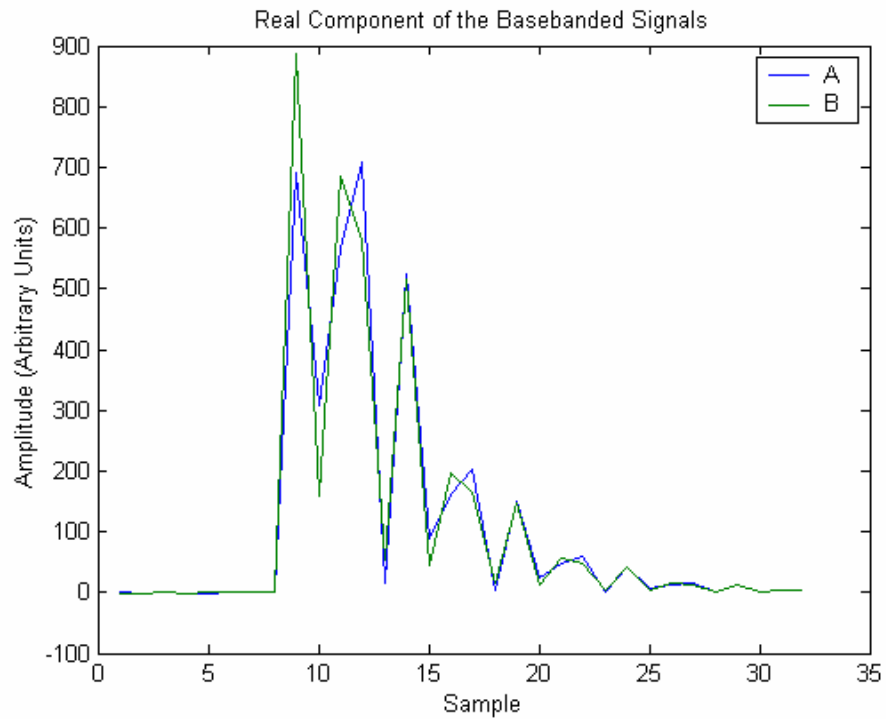


Figure 5: Real Component of the Base-banded Signal

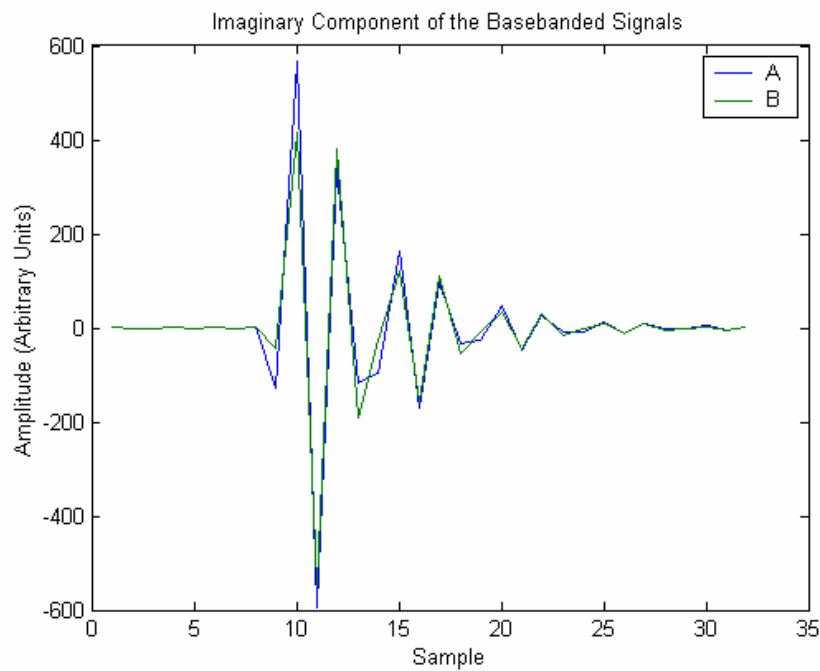


Figure 6: Imaginary Component of the Base-banded Signal

Figure 6 shows the imaginary component of the base-banded signal. This rapidly oscillating signal will be averaged to something close to zero by the matched filter.

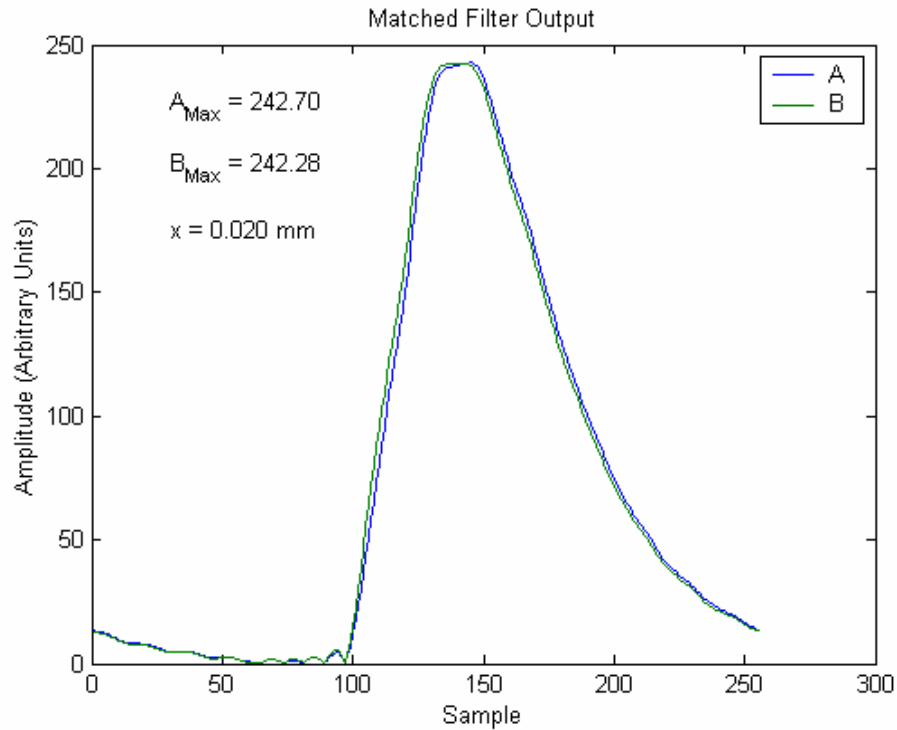


Figure 7: Output of the Matched Filter

Figure 7 shows the magnitude of the output of the matched filter. The peak values of the two channels are very close. The difference between them corresponds to a systematic position bias of 20 microns. This is on the order of the resolution of the device and should not have any impact on its utility during operations. More sophisticated pulse-stretching could almost eliminate this effect completely.

Figure 8 gives a source listing of the script used to obtain the results shown here.

```

sigma = 2E-9;           % Bunch Length (seconds)
RF = 53.0E6;            % RF Frequency (Hz)
f = 2.5E9;              % Data Generation Sampling Rate (Hz)
fsample = 100.0E6;      % Processing Sampling Rate (Hz)
dn = f/fsample;         % Processing Sampling Interval (Samples)
t = (-100:699)/f;       % Generation Time (seconds)
tSample = t(1:dn:length(t)); % Sampling Time (seconds)
fFilter = 30E6;         % Pulse Stretching Filter Resonant Frequency (Hz)
tFilter = 40E-9;        % Pulse Stretching Filter Decay Time (seconds)
x0 = 0;                 % Beam Centroid Position

R = 22.7;              % Effective Stripline Radius (mm)
dx = 1;                % Bunch Skew (mm)

x = x0 + (dx/R)*(t/sigma); % Bunch Transverse Position (Dimensionless)
L = 0.25/RF;           % Stripline Length (seconds)

a = (1+x)/2;           % Amplitude of the A Signal (Arbitrary Units)
b = (1-x)/2;           % Amplitude of the B Signal (Arbitrary Units)

% Signals from the A and B Plates
sa = a.*(exp(-0.5*((t+L)/sigma).^2)-exp(-0.5*((t-L)/sigma).^2));
sb = b.*(exp(-0.5*((t+L)/sigma).^2)-exp(-0.5*((t-L)/sigma).^2));
norm = 0.5*max(abs(sa)+abs(sb));
sa = sa/norm;
sb = sb/max(norm);

% Response of Pulse Stretching Filter
f = (sin(2*pi*fFilter*t).*exp(-(t/tFilter)).*(t>0));

% Stretched and Sampled Signals
qa = real(ifft(fft(sa).*fft(f)));
qb = real(ifft(fft(sb).*fft(f)));
scale = 100.0;
ra = scale*qa(1:dn:length(qa));
rb = scale*qb(1:dn:length(qb));

% Down Converted Stripline Signals
ua = ra.*exp(-2*pi*i*fFilter*tSample);
ub = rb.*exp(-2*pi*i*fFilter*tSample);

% Matched Filtered Stripline Signals
t1 = (0:length(tSample));
reference = tSample.^2.*exp(-tSample/(tFilter/3)).*(tSample>0);
w = t1.^2.*exp(-t1/(1/3)).*(t1>0);
reference = reference/max(abs(reference));
pad = zeros(1,(8-1)*length(reference)/2);
va = ifft([pad fftshift(fft(ua)).*fft(reference)) pad]);
vb = ifft([pad fftshift(fft(ub)).*fft(reference)) pad]);

% Final Position
A = max(abs(va));
B = max(abs(vb));

xout = (A-B)/(A+B)*R;

plot(abs([ua;ub;reference*4].'))

figure(1);
plot(t(51:151)*1.0e9,[sa(51:151);sb(51:151)].');
title('Simulated Stripline Waveform');
xlabel('Time (ns)');
ylabel('Amplitude (Arbitrary Units)');
legend('A','B');
xlim = get(gca,'XLim');
ylim = get(gca,'YLim');
text(xlim*[0.90;0.10],ylim*[0.7;0.1],sprintf('Bunch Centroid = %.2f mm',x0))
text(xlim*[0.90;0.10],ylim*[0.8;0.1],sprintf('Bunch Skew = %.2f mm',dx))
text(xlim*[0.90;0.10],ylim*[0.9;0.1],sprintf('\sigma_{Bunch} = %.2f ns',sigma*1.0e9))

figure(2);
plot([ra;rb].');
title('Digitized Waveform');
xlabel('Sample');
ylabel('Amplitude (Arbitrary Units)');
legend('A','B');

figure(4);
plot([real(ua.*exp(-i*angle(mean(ua))))...
      real(ub.*exp(-i*angle(mean(ub))))...
      ].');
title('Real Component of the Basebanded Signals');
xlabel('Sample');
ylabel('Amplitude (Arbitrary Units)');
legend('A','B');

figure(5);
plot([imag(ua.*exp(-i*angle(mean(ua))))...
      imag(ub.*exp(-i*angle(mean(ub))))...
      ].');
title('Imaginary Component of the Basebanded Signals');
xlabel('Sample');
ylabel('Amplitude (Arbitrary Units)');
legend('A','B');

figure(6);
plot(abs([va;vb].'));
title('Matched Filter Output');
xlabel('Sample');
ylabel('Amplitude (Arbitrary Units)');
legend('A','B');
xlim = get(gca,'XLim');
ylim = get(gca,'YLim');
text(xlim*[0.90;0.10],ylim*[0.1;0.9],sprintf('A_{Max} = %.2f',A))
text(xlim*[0.90;0.10],ylim*[0.1;0.8],sprintf('B_{Max} = %.2f',B))
text(xlim*[0.90;0.10],ylim*[0.1;0.7],sprintf('x = %.3f mm',xout))

```

Figure 8: Matlab Source Listing for the Simulation