SIGNAL PROCESSING MEANS FOR DETECTING AND DISCRIMINATING BETWEEN STRUCTURAL CONFIGURATIONS AND GEOLOGICAL GRADIENTS ENCOUNTERED BY KINETIC ENERGY PENETRATING PROJECTILES

14 May 08

APPLIED RESEARCH ASSOCIATES, INC.
An Employee-Owned Company

Program Overview

- **Develop a Signal Processing Method to:**
  - **Detect and Discriminate between**
    - **Natural & Structural Layers Encountered During Terra-Flight**
  - **Distinguish Gradients Encountered During Flight**
- **Verify the Algorithm (method) Against Multiple Real World Event**
- **Patent the Algorithm**

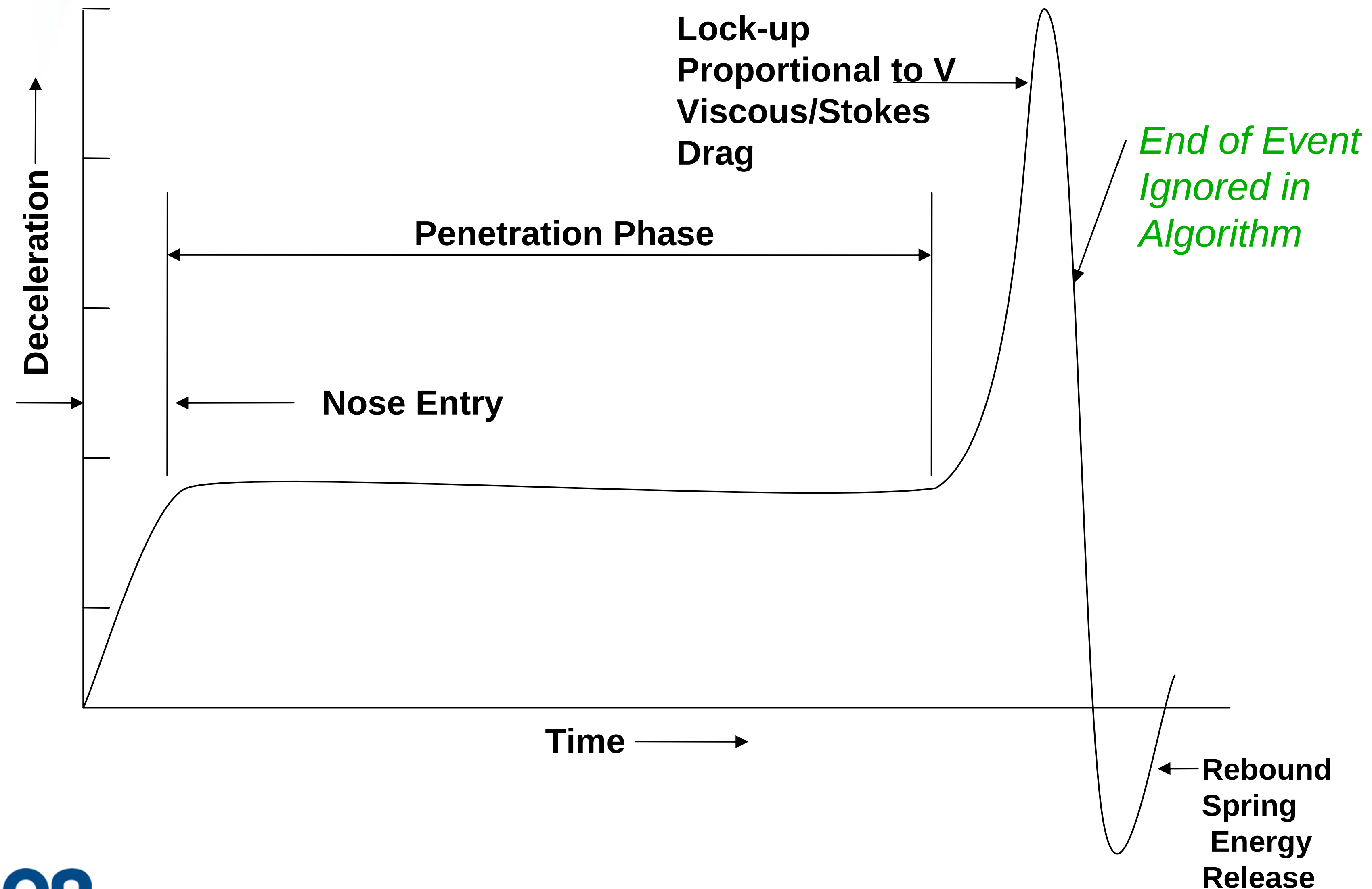
Program Goals

- *Set-up a Matlab Simulink Algorithm Simulator*
- *Verify the Algorithm (method) against Multiple Real World Events (digital signals)*
- *Transfer Algorithm to ‘g’ Hardened DSP Controller Chip*
- *Develop Operator Interface for DSP Chip*
- *Verify Chip Operation with Real World Analog Signal Inputs*

The Acceleration Measurement

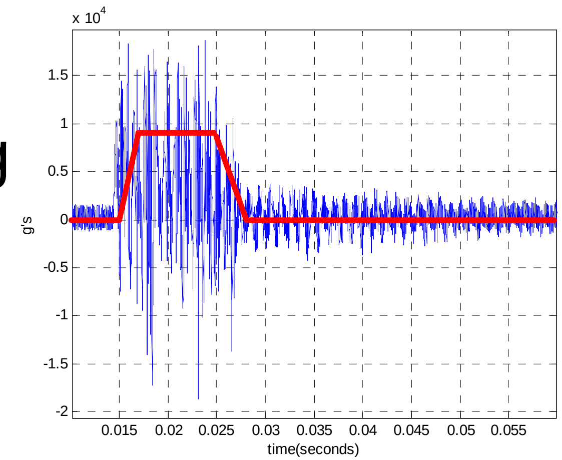
- Rigid Body (RB) Movements (Tape Measure) form basis of the Algorithm
  - Body encountering a resisting target with a force of opposite sense as velocity and proportional to V^2
  - Rise time equal to crater depth (Nose Length)
  - RB Waveform a non-structured trapezoid (= low frequency <100 Hz)

Characteristics of RB Acceleration Records



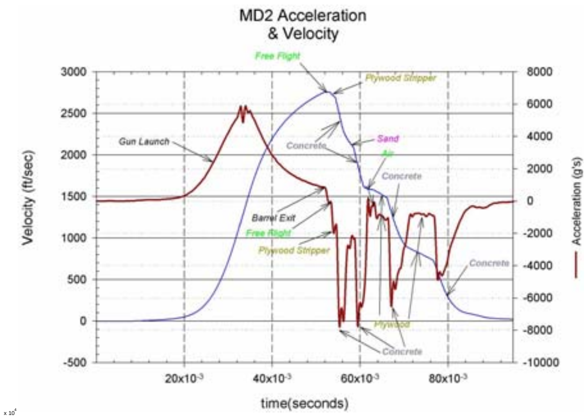
Superimposed On the Measurement & Masking the Rigid Body are:

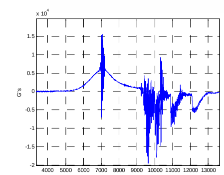
- KHz signal movements representing (i.e., measured by micrometers)
  - Vibrational modes of the penetrator structure
  - Mounting of the transducer
  - Internal Component Freight Training
- Some MHz signals representing
  - Steel on Steel contact
  - Kinematic Mass Property Changes



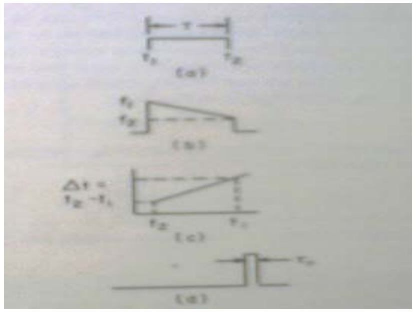
Un-Masking the Rigid Body Movement

- It is known (One Way) that an integral will detect layers
  - But slope detection merely returns the signal





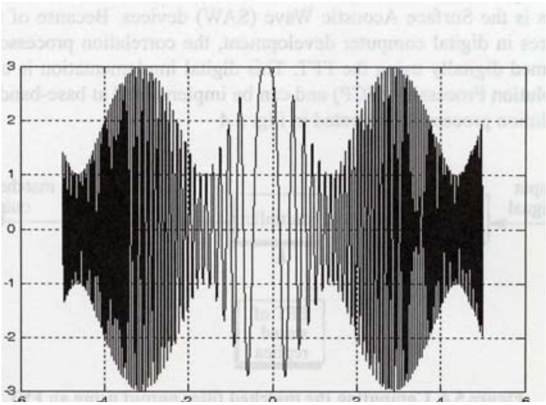
- What Venue supports detection of targets masked by High Frequency Content signals?
  - Answer
    - Radar Targets
    - LFM Acquisition (Purposely Masks LF Target) and detected by Pulse Compression (An Integration)



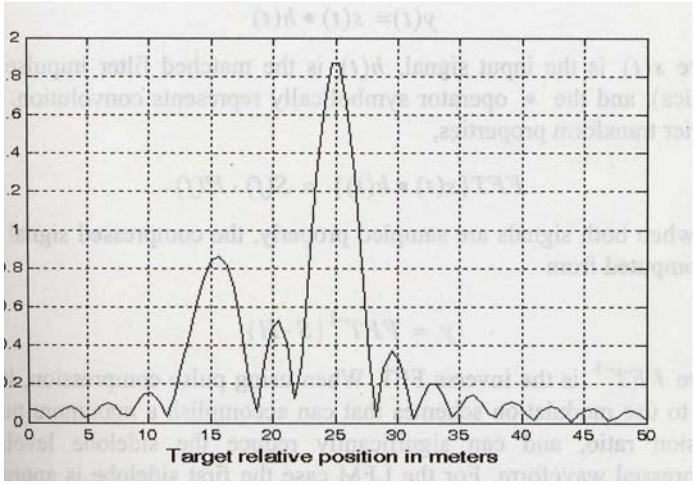
Pulse Compression It's Analog to Deceleration

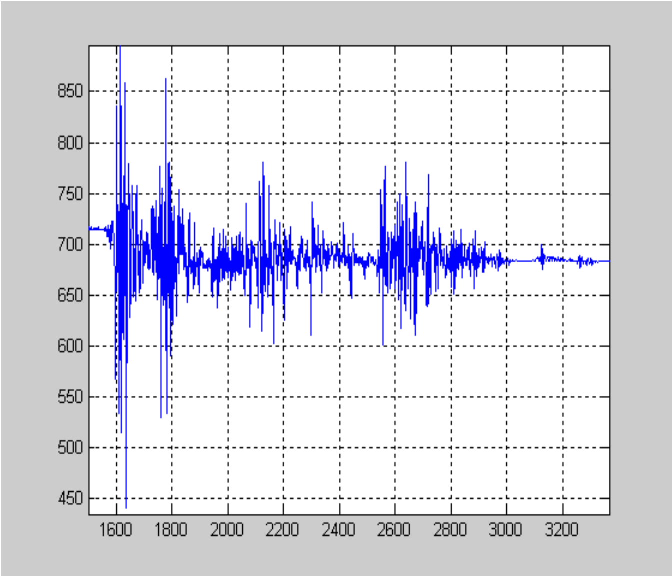
- Energy to a target has been purposely modulated with multiple frequencies. Multiple Freq Sources in Projectile.
- The target is hit with the energy and returns a high frequency content (HFC) signal. Penetrator strikes target & returns HFC Signal
- Each 'f' contains target information, both cases – Goal = Extract
- The return pulse is compressed by slowing down the high frequencies and speeding up the low frequencies using analog devices or
  - A matched filter used but this is an autocorrelation
- Due to the high frequency of the return radar signal analog pulse compression is easier then digitizing and running an autocorrelation.
- Due to the relatively low frequency of a penetration event KHz versus GHz, digitization and autocorrelation is more appropriate.
- Results are the same:
  - Target resolved in range (ringing removed and info stored in low freq range resolved pulse)

Pulse Compression = Auto Correlation

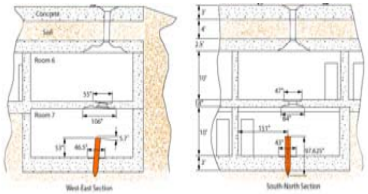


Pulse Compression

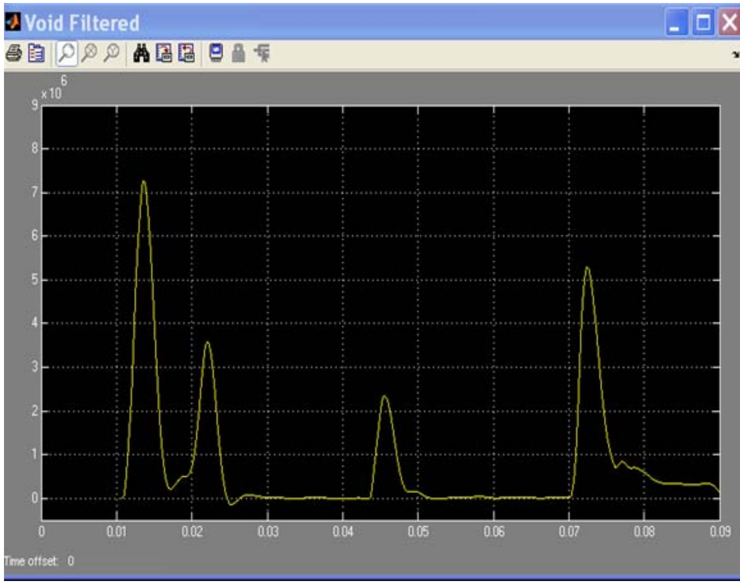


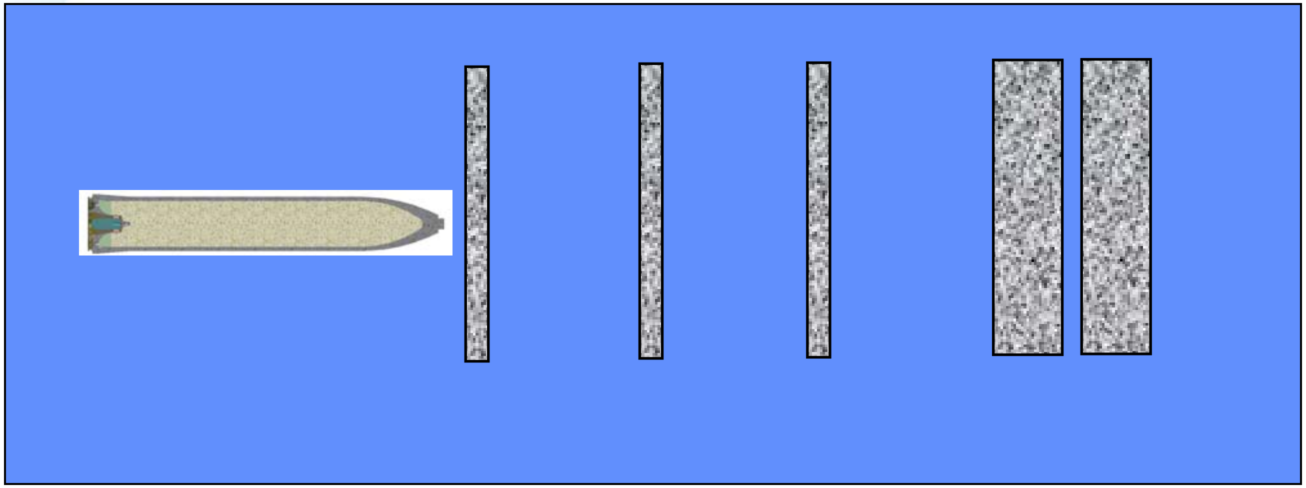


Pseudo

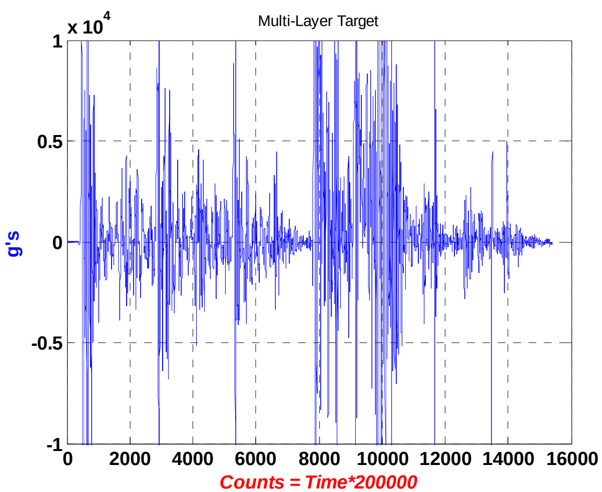


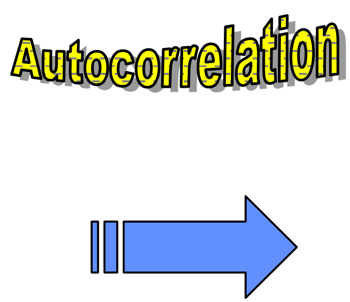
Autocorrelation

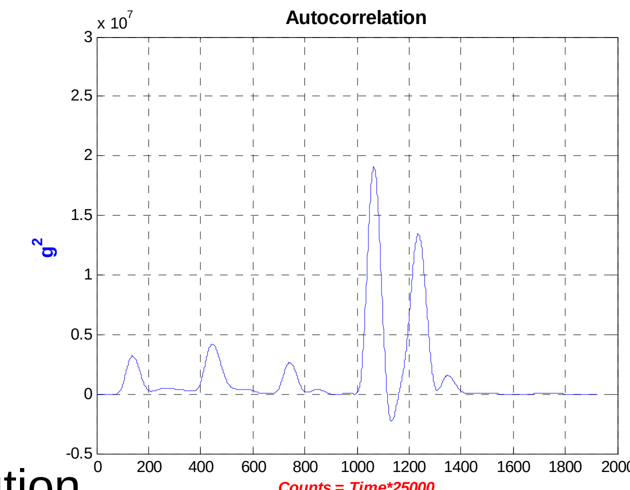




0.75ft (5ksi) + 13ft air + 0.75ft (5ksi) + 13ft air + 0.75ft (5ksi) + 13ft air + 4 ft (10ksi) + 1.7ft air + 4ft (10ksi)



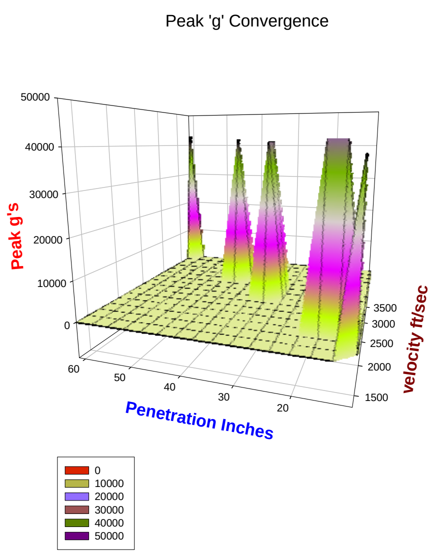


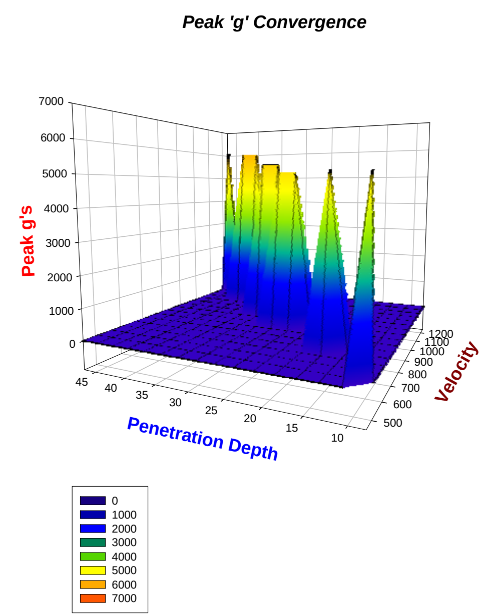


+ Nice Range Resolution

Where is the Uniqueness?

- In a sphere, cylinder, plane, concrete?
- In a radar system each target is identified by a unique number (its RCS)
- In a penetrating system each target is identified by a unique unit less value called peak ‘g’
- This identifier is independent of striking or draining velocity and only dependent on geometry and target resistance
- ***Therefore penetrator targets (for the same penetrator geometry) that are not the same are different***

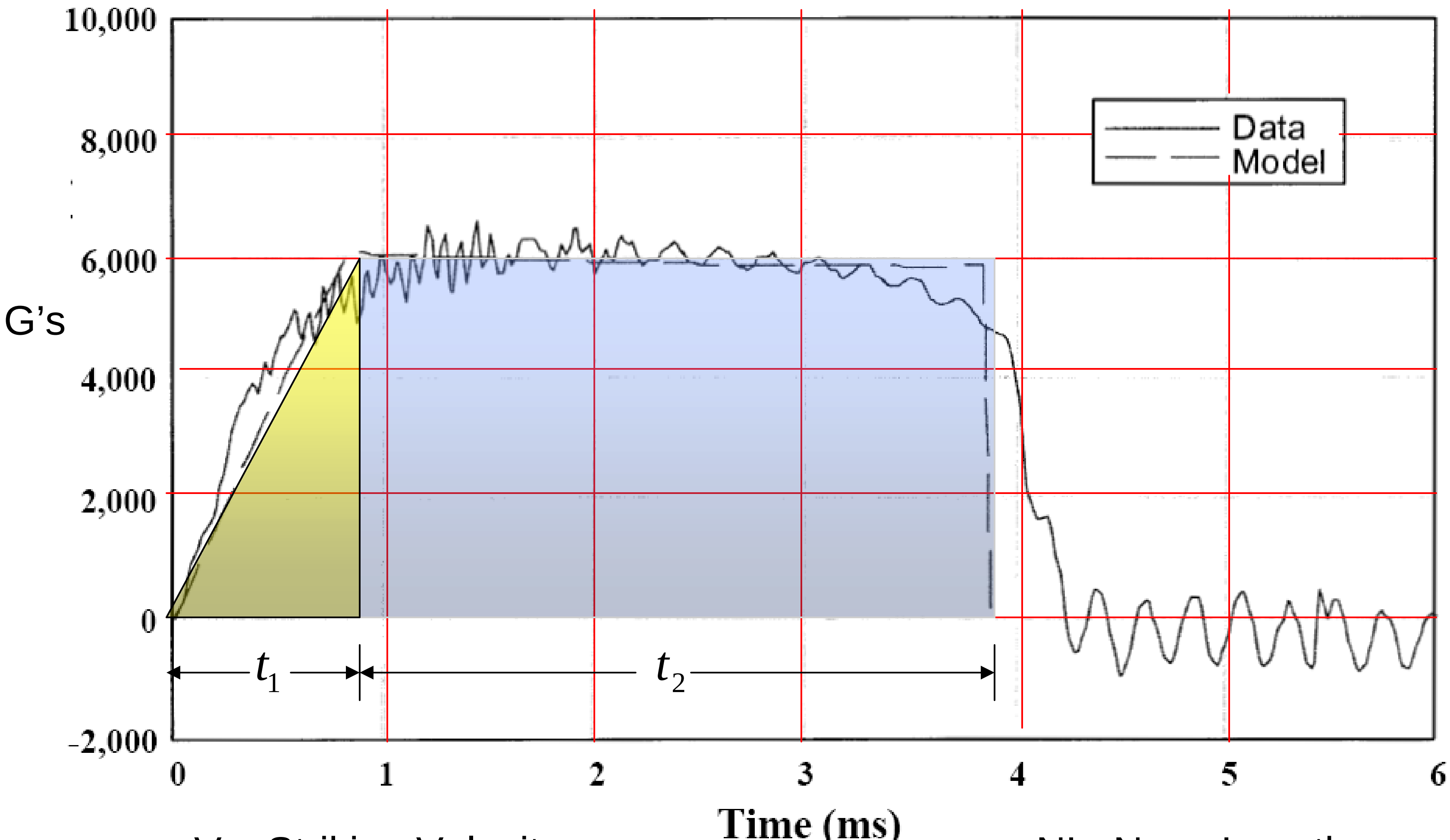




$$NL = \frac{t_1 (Vs - \frac{32.2 g t_1}{4})}{2}$$

$$Vs = \frac{32.2g[t_1 - 2t_2]}{2}$$

$$DF - NL = \frac{32.2g(t_2)^2}{2}$$

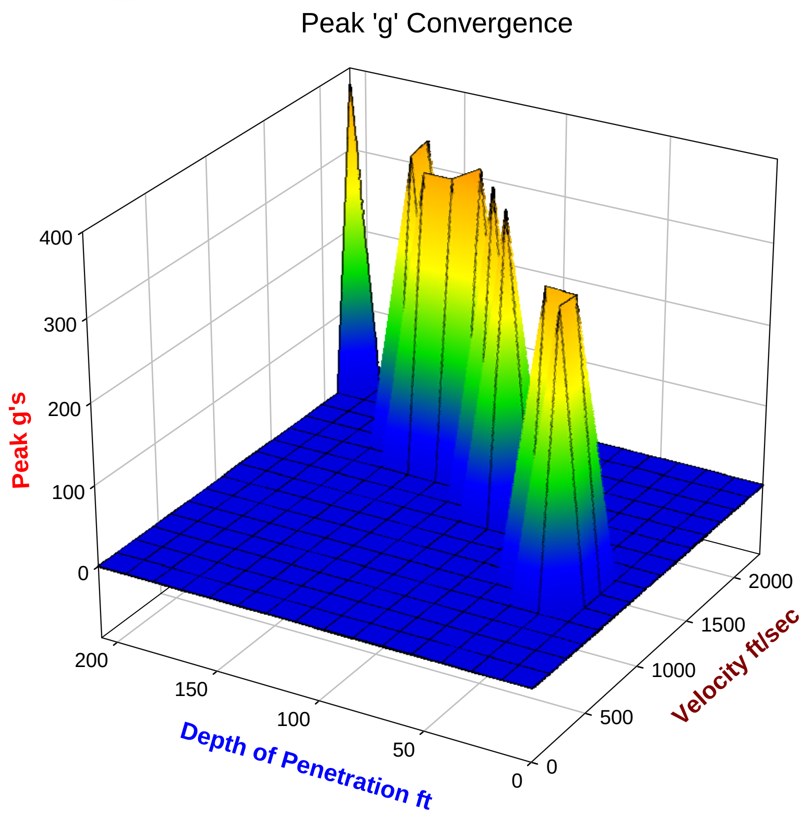


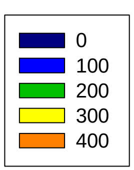
Vs=Striking Velocity

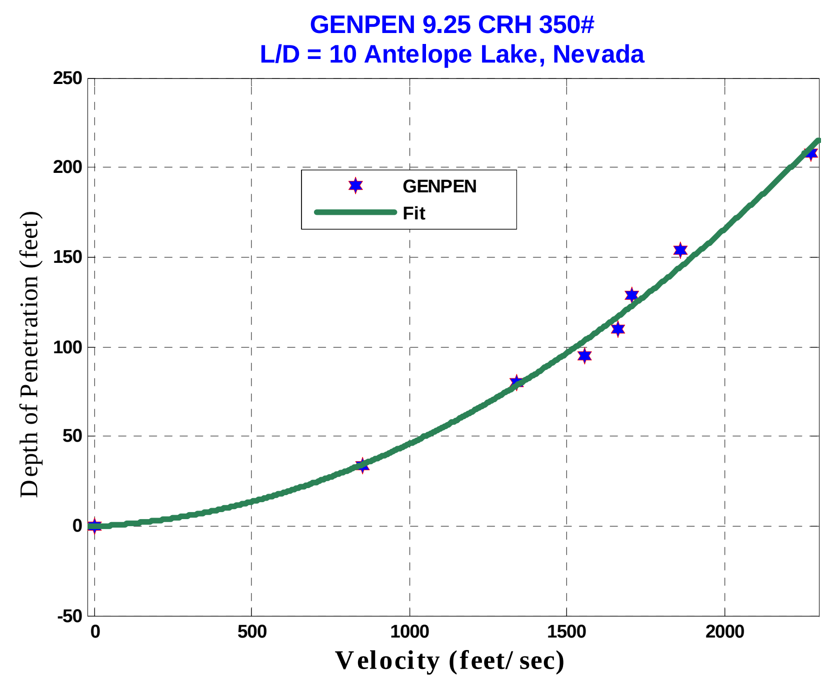
NL=Nose Length

DF=Final Depth of Penetration

If Correct Data Should Converge to Single Value

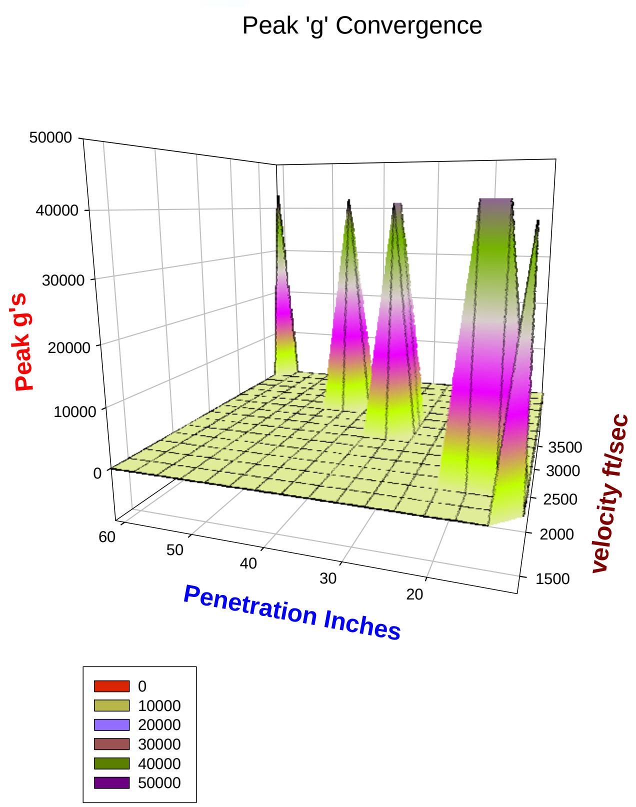


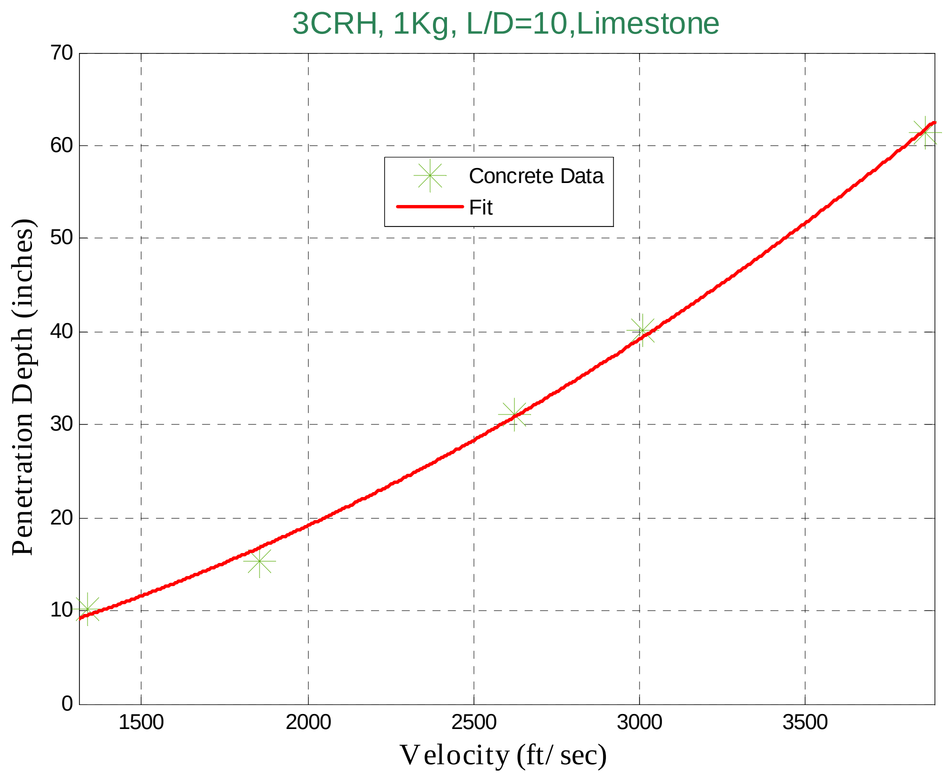




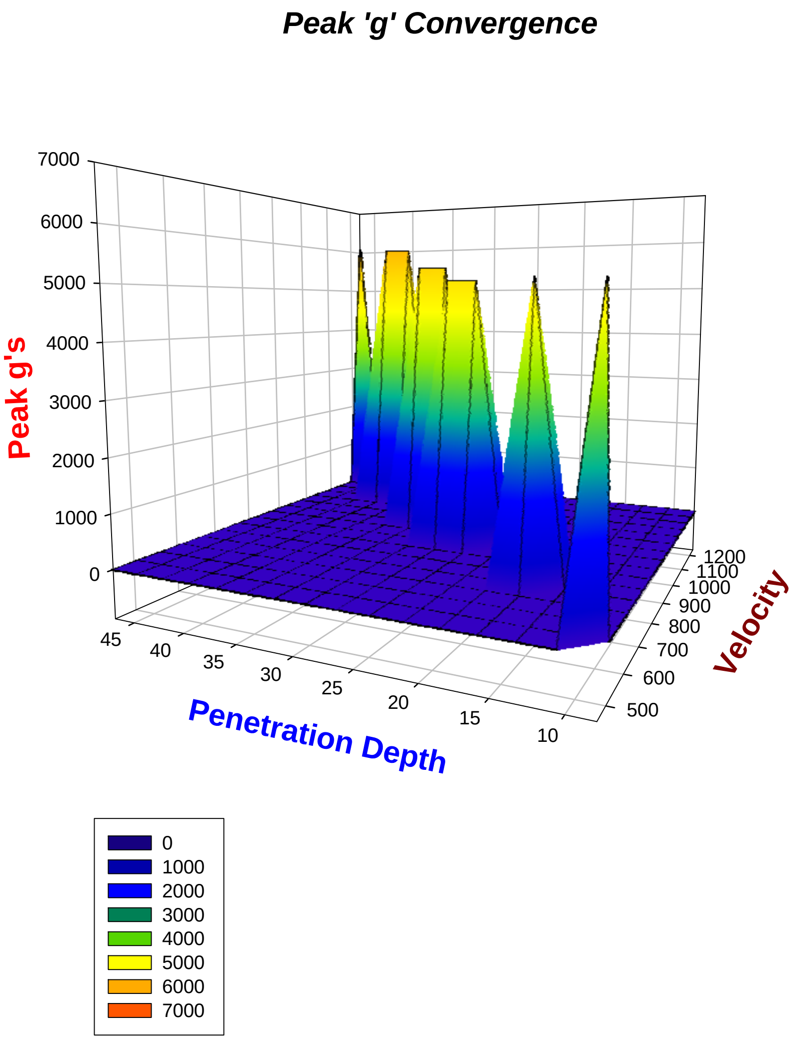
Velocity Stepped thru Natural Cemented Sand Target

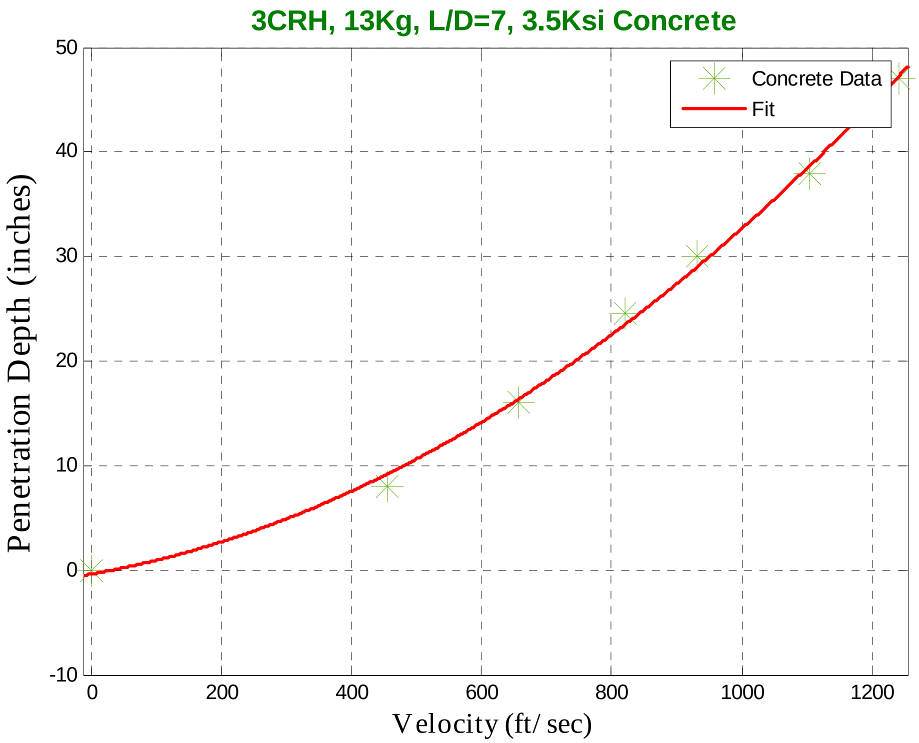
Velocity Stepped thru Limestone Target





Velocity Stepped thru Concrete Target





Notes:

DFlipFlop

1. The D flip-flop block has the following characteristic table:

Q(t)	D(t)	Q(tnext)
0	0	0
0	1	1
1	0	0
1	1	1

Q(tnext) refers to the output on a clock pulse (CLK) rising edge and when the chip is enabled (!CLR~=0). The D flip-flop transfers "data" into a memory element (flip-flop) on each clock pulse (CLK). The chip enable input signal, !CLR, is sometimes given the designation G (for gate) to inidcate that this input enables the gated latch allowing data entry into the flip-flop.

DLatch

2. The D latch flip-flop block has the following characteristic table:

Q(t)	D(t)	Q(tnext)
0	0	0
0	1	1
1	0	0
1	1	1

The D latch transfers "data" into a memory element (flip-flop). The D latch flip-flop is sometimes called a gated D-latch. The chip enable input signal, C, is sometimes given the designation G (for gate) to indicate that this input enables the gated latch allowing data entry into the flip-flop.

3. Convert blocks match logic signals between blocks. Example: Booleon True/False to digital one/zero.

4. Smart Fuze Algorithm is enabled on "g" switch closure at impact.

5. Depth Subystem velocity constant is target striking velocity.

6. A modified dead zone dynamic block only outputs a digital zero when the signal is within the dead zone (between upper and lower set limits).

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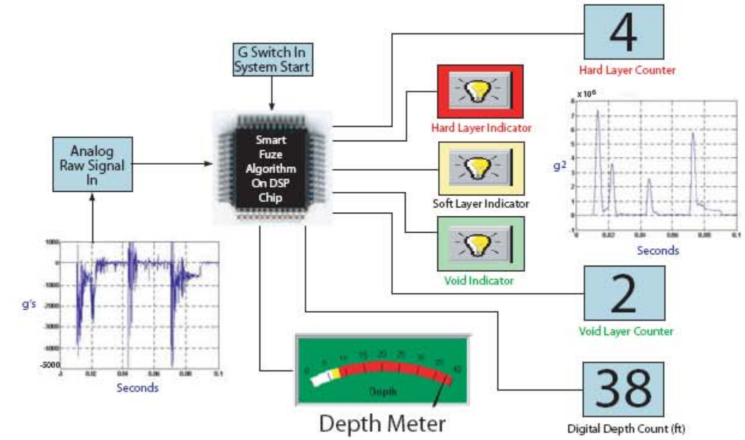
Title	SMART FUZE ALGORITHM SCHEMATIC		
Drawing Classification: PROPRIETARY	Size: O	Drawing Number: RGL010106	
Status Rel - 02-FEB-06		Origin: Lundgren	



Simulation Display of Figure 1 Overall Diagram

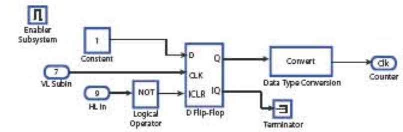


Figure 7
Double Void Elimination System

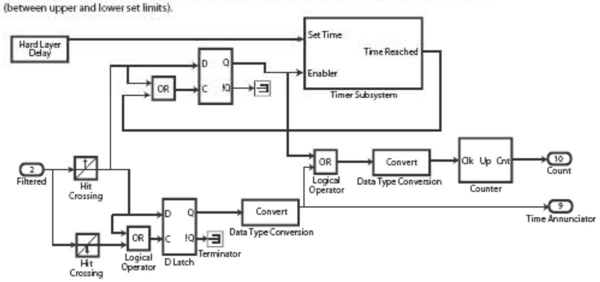


Figure 5
Hard Layer Detection

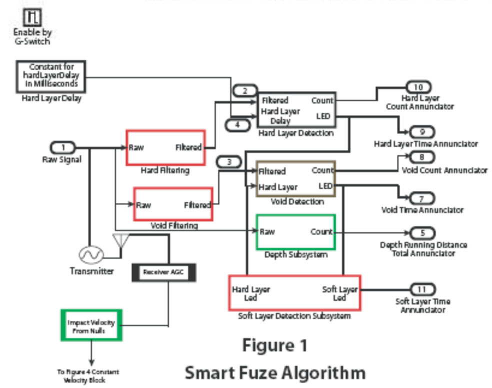


Figure 1
Smart Fuze Algorithm
Overall Diagram

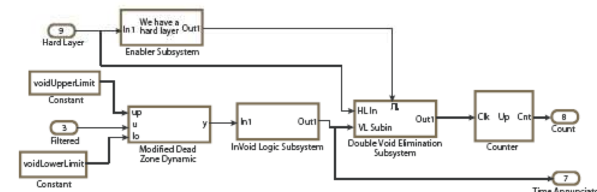


Figure 6
Void Detection

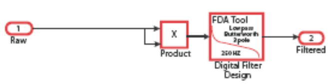


Figure 2
Auto Correlation & Hard Filtering

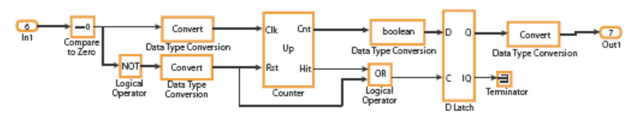


Figure 8
In Void Logic System

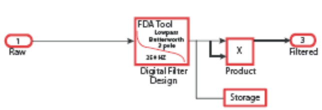


Figure 3
Auto Correlation & Void Filtering

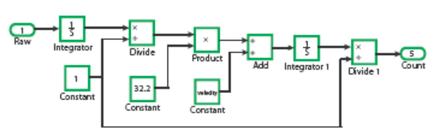


Figure 4
Depth Subsystem

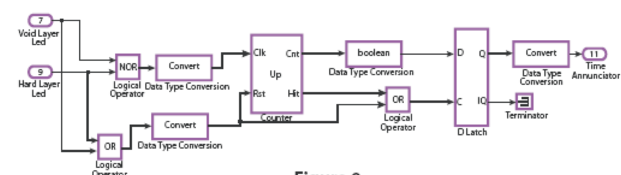
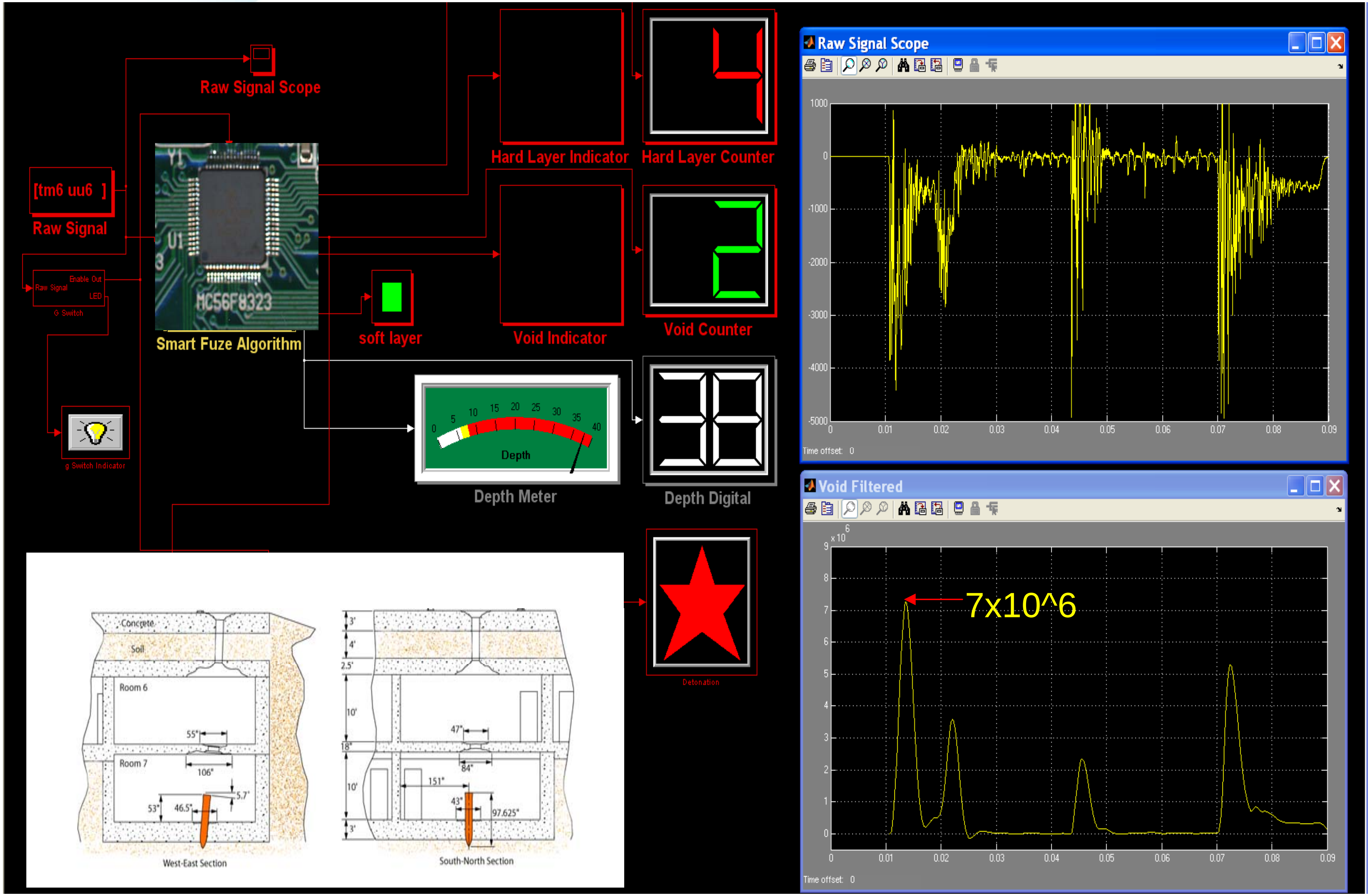
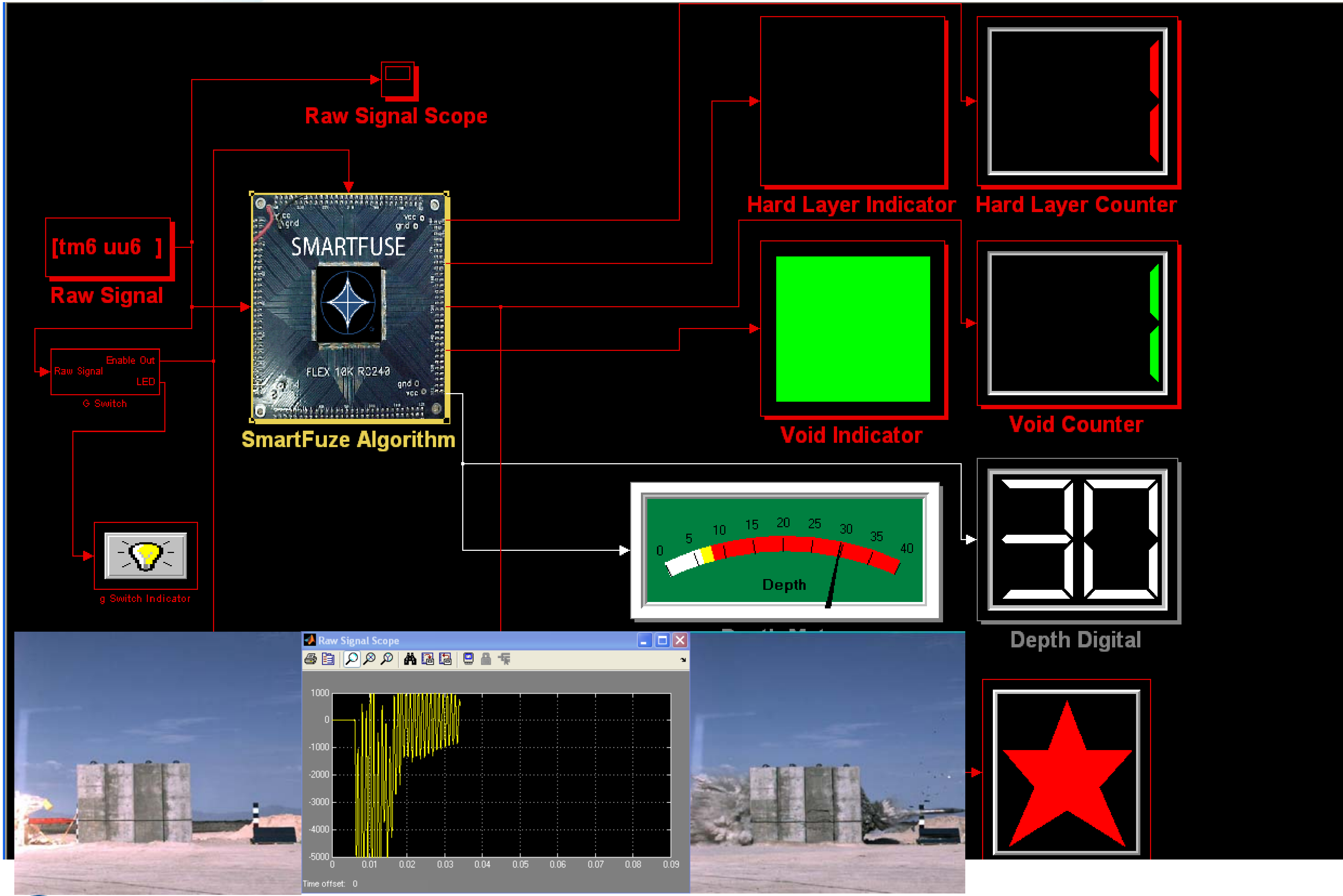
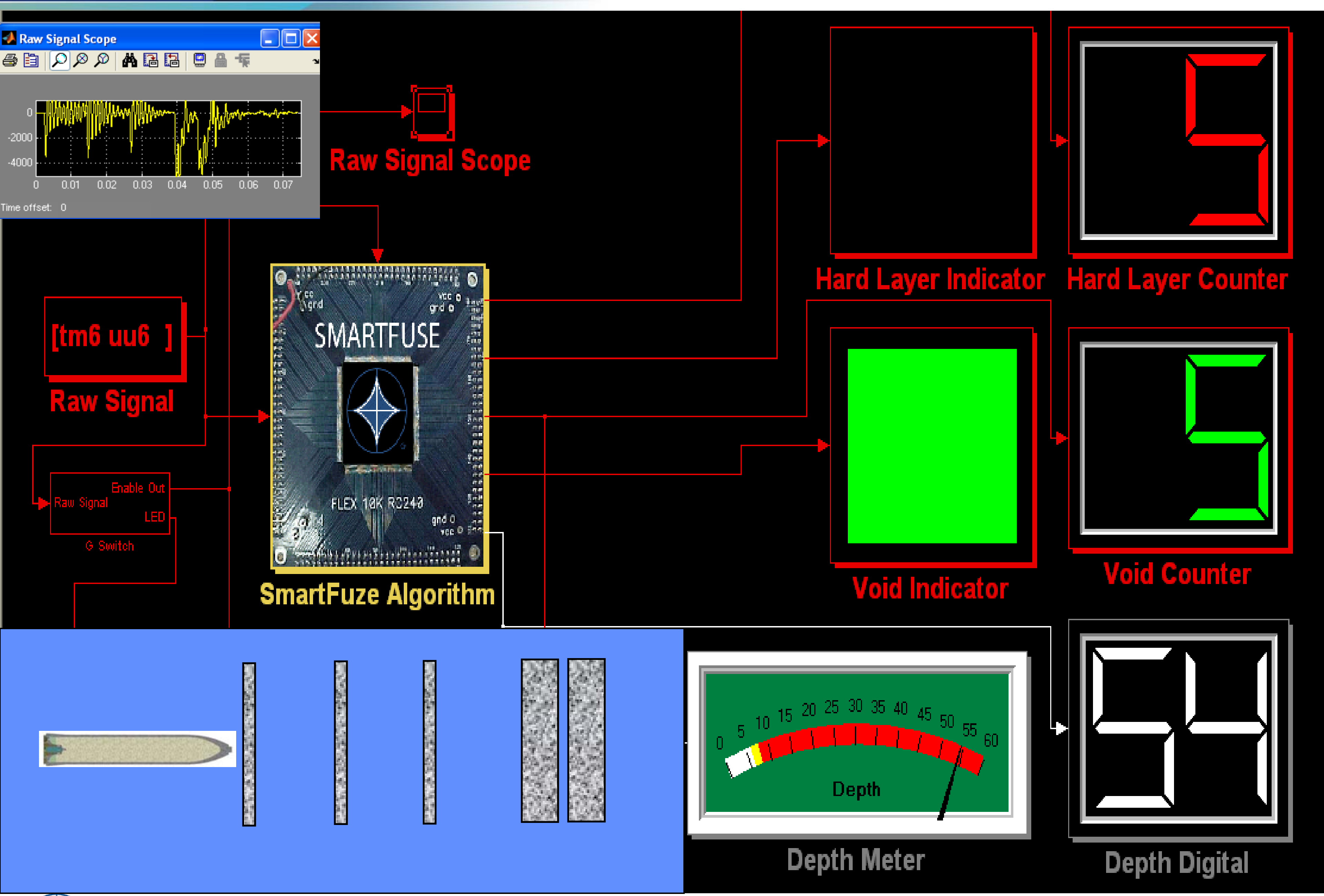


Figure 9
Soft Layer Detection Subsytem


Raw Signal Scope
Hard Layer Indicator
Hard Layer Counter
[tm6 uu6]
Raw Signal
Enable Out
Raw Signal
LED
G Switch
MC56F8323
Smart Fuze Algorithm
soft layer
Void Indicator
Void Counter
g Switch Indicator
Depth
Depth Meter
Depth Digital
Detonation
Concrete
Soil
Room 6
Room 7
West-East Section
South-North Section
Raw Signal Scope
Time offset: 0
Void Filtered
7x10^6
Time offset: 0


Raw Signal Scope
[tm6 uu6]
Raw Signal
SMARTFUSE
FLEX 10K RC240
SmartFuze Algorithm
Enable Out
Raw Signal
LED
G Switch
g Switch Indicator
Hard Layer Indicator
Hard Layer Counter
Void Indicator
Void Counter
0 5 10 15 20 25 30 35 40
Depth
Depth Digital
Raw Signal Scope
1000
0
-1000
-2000
-3000
-4000
-5000
0 0.01 0.02 0.03 0.04 0.05 0.06 0.07 0.08 0.09
Time offset: 0



Raw Signal Scope
0
-2000
-4000
0 0.01 0.02 0.03 0.04 0.05 0.06 0.07
Time offset: 0
Raw Signal Scope
[tm6 uu6]
Raw Signal
Enable Out
Raw Signal
LED
G Switch
SMARTFUSE
FLEX 10K RC240
SmartFuze Algorithm
Hard Layer Indicator
Hard Layer Counter
Void Indicator
Void Counter
0 5 10 15 20 25 30 35 40 45 50 55 60
Depth
Depth Meter
Depth Digital

Program Accomplishments

- ***A Robust Matlab Simulink Algorithm Simulator was set-up***
- ***The Algorithm was Tested against Multiple Real World Events (digital signals)***
- ***The Algorithm was transferred to a 'g' Hardened Freescale DSP Controller Chip with Operator Interface***
- ***Chip Operation was verified with Real World Analog Signal Inputs to the Chip***
- ***The Algorithm is Patent Pending***