TITLE: Project Final Report (Award Number 2002LTBXK009) Non-Lethal Technologies Inc. Road Sentry Improvement

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Detailed Project Information

Award Title:	Non-Lethal Technologies Inc. Road Sentry Improvement
Award Number:	2002LTBXK009
Awardee:	Non-Lethal Technologies, Inc
Awardee Contact:	Bradley Boyer Non-Lethal Technologies Inc 1815 Higgins Road Dundee, IL 60118
Original Funds:	**Year:** 2002-2004, Amount: $100,000.00
Categories:	Less-than-Lethal Technology Vehicle Stopping Technology
Project Location:	Dundee, Illinois
Project Description:	In this project, engineering developmental work will be performed by Non-Lethal Technologies (NLT), Inc, on the Road Sentry device to improve its effectiveness in immobilizing commercial motor vehicles. A specific objective of this project is to modify the design of the device to improve its capability to inflict a "hard kill" in an initial encounter with any given commercial motor vehicle will be increased to about 85%. In NIJ-sponsored field-testing of prototype Road Sentry devices in the summer of 2000, the "hard kill" effectiveness of the device was observed to be about 44%. (A "hard kill" is produced when a vehicle is rendered incapable of moving under its own power unless electrical repair work is undertaken). This project will require NLT to undertake engineering analyses, design, fabrication, and testing of Road Sentry devices and their component parts to ensure that this objective will be achieved.

Photo 1 Road Sentry unit is forward deployed into path of target vehicle

Photo 2: Composite Materials Asphalt Camo Prototype Unit

Photo 3: Reinforced Poly Garbage Can Lid Prototype Unit

Physical Operation: The Road Sentry is a low observable low profile device, which is typically rolled over or bridged by the target vehicle. The device is remotely fired upon vehicle approach. Electrodes direct inject high amplitude ESD like electrical pulse into engine undercarriage, which disables critical engine control electronics. The vehicle comes to a safe controlled stop as the engine gas injection fails, disabling the vehicle drive train.

Project History and Background:

- 1993-1995: NLT developed the Road Sentry concept
- 1998: NIJ lab testing of Road Sentry
  (US Army ARL Adelphi was test engineering activity)
- 2000: NIJ field-testing of Road Sentry
  (ARL was test-engineering activity)
- 2002: continued development of Road Sentry (increase Its effectiveness)
- 2004: Anticipated field testing of redesigned Road Sentry

•**2000 field-testing of Road Sentry**:
Involved test vehicles moving under own power (up to 60 mph)

Summary of test results (initial application of device against all test vehicles):

44% hard kills, vehicle stopped and inoperable (requires vehicle repair to start)

44% soft kills (engine shut-off but can be restarted with key)

6% stumbling (transient disruption of engine operation with out shut down)

6% No effect (Honda 94)

EM fields within IEEE standards

2002 – 2004 Road Sentry Improvement

NLT Inc. Made design improvements to increase kill ratio. A 1994 HONDA was hard killed in lab testing to demonstrate improvements.

2004 Joint agreement (with NIJ and AF) to test Road Sentry with Air Force Research Laboratory at Kirkland AFB.

Photo 4. Vehicle mounted on dynamometer

- 1998 lab testing of Road Sentry:

intended to assess the feasibility of the device

Multiple tests conducted on vehicles w/chassis dynamometer
  Observed mostly hard kills and soft kill (engine shut-off) outcomes
  Measured EM field levels were within allowable IEEE standards

Performance deemed sufficient
  to subject Road Sentry to
  Subsequent field-testing

Photo 5 Vehicle approaches Road Sentry UUT.

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6% No effect

EM fields within IEEE standards

2002 to 2004: Non-Lethal Technologies performs Design Improvements and Lab testing: Honda 1994 that was unaffected in 2000 field tests was hard killed.

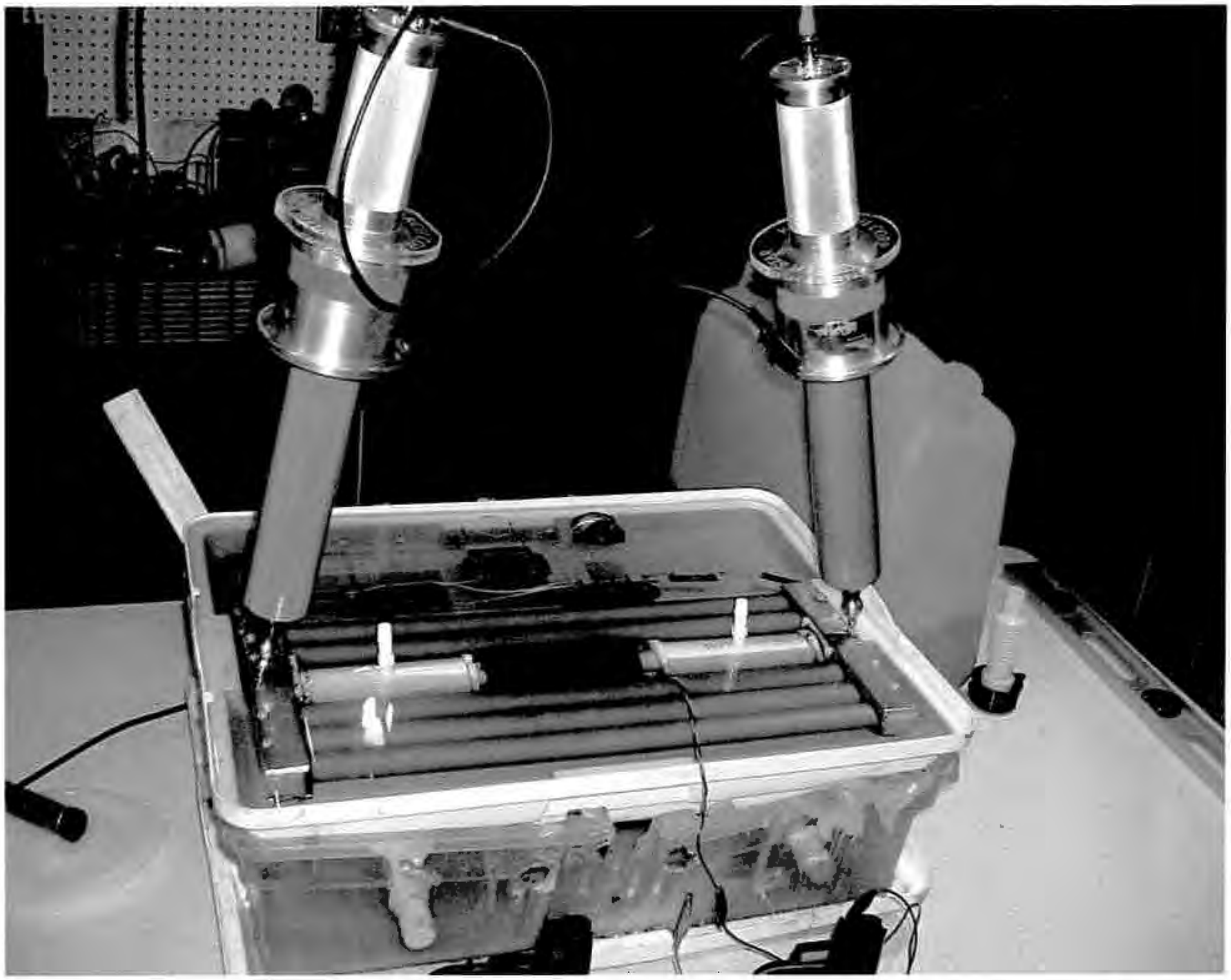
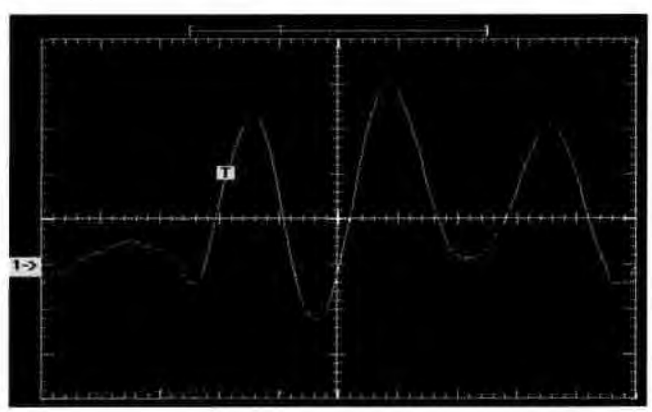


Photo 6:High voltage test stand, showing HV probes. Chassis is filled with HV transformer dielectric oil for arc and corona observation and testing.

Photo 7 Die

Photo 8: Captured waveform with digital scope



Technical Description and Summary of Engineering Design Goals

The Road Sentry directly injects multiple pulses of high current and voltage into the underside of the target vehicle. The device is light- weight , man-deployable and is easily carried in a squad car trunk. The device is forward deployed into the path of the suspect vehicle, typically by direction of the tactical command authority by a designated law enforcement officer. The device can be situated were the lane is restricted and the pursued vehicle is chased toward the point of interdiction where the device is located. The device appears to the driver as a road bump or plastic lid such as is found on urban and suburban roads.

Upon approach of the target vehicle the officer engages the remote arming switch and a high internal electrical potential is generated. This potential is electronically coupled as a pulsed waveform across the output electrodes. The driver typically bridges the low profile obstruction presented by the device; driving over the object. Spring-loaded electrodes make contact with the frame and engine oil pan. High current and fast rise time pulses are injected into the underside of the vehicle. This electrical discharge causes secondary damped sinusoidal waveforms to be developed over the circuits and components of the electronic engine control (EEC) module and its associated circuits.

In modern vehicles; the electrical engine control, EEC, controls the injection of fuel into the engine (and other critical engine operations). If the EEC is destroyed or its resident firmware detects a significant electrical sensor malfunction; the engine stops or goes into a "limper" mode, which only allows operation at idle speeds. Physical destruction of critical electronic components results in a "hard kill" and the vehicle can only be restarted after repairs are made. Electrical disruption (without permanent damage) of digital signals or the micro-controller program operation in the electrical system may stop the engine but allow restart if the key is turned off and on.

In the new NLT Road Sentry design, the high- energy pulses will be applied at a nominal 100 Hz pulse repetition frequency (PRF). Simulations of electromagnetic pulses applied during military testing of electronics based systems have revealed that if the change in current over time of the applied high- energy pulse is rapid (fast pulse rise time): a wider and higher frequency band of "impulse noise" is applied to the affected circuits and the amplitude of this noise is higher. This results in greater disruption of the targeted electrical system, which will yield a high kill ratio.

4.2 Major subsystems and their commercial availability/readiness.

The following is a block diagram of the Road Sentry system, showing the major functional subsystems.

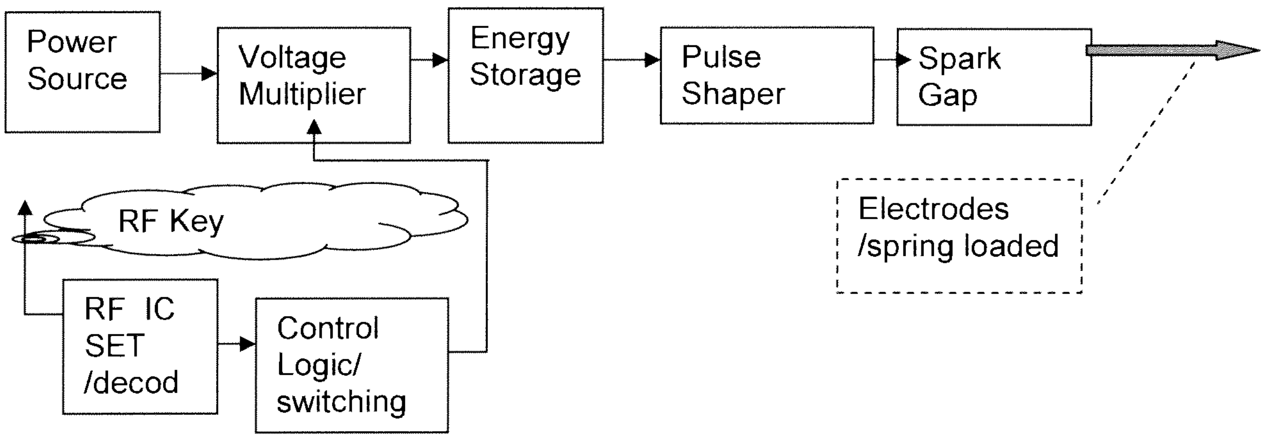


Figure I. Road Sentry Functional Block

Prime Power Source

The prime power source for the Road Sentry can be an internal rechargeable battery pack, external DC battery or DC electrical system or AC electrical line. 12 VDC to 48 VDC can also be provided for running off of law enforcement vehicles electrical systems. For installed site applications, the AC power line option is recommended. Any standard line voltages and frequencies (international and USA) can be used if the power input is reliable. Gas powered generators can also be used to power either the AC line input or recharge circuits as required for remote area or back up operation.

For the current prototype we used a solid state high frequency AC line inverter that was developed by our engineering staff to power portable induction heaters for our commercial sister company, Induction Innovations. A 50 KHz AC output is used and transformer coupled to the input of the voltage multiplier, described as follows. The inverter is energized using a pneumatic operated foot switch which provides complete electrical isolation for the operator.

Voltage Multiplier Circuits

The voltage multiplier circuits generate the high D.C. voltage potentials required, which are in excess of 100 K.V. This potential is generated in stepwise increments by solid-state Diodes, IGBT or FET transistor switching arrays that "pump" a capacitive ladder. Due to recent developments in IGBT (insulated gate bipolar transistor) and FET (field effect transistor) technology: high power and reliable transistors are now commercially available from several sources. It is expected that only small multiplier output voltage increase, if any, will be required in the improved design. High voltage diodes were chosen for the voltage multiplier as they proved to be the most reliable.

Control Logic Circuits

The voltage multiplier is started, sequenced and stopped by the control logic circuit states. For the current prototype, the control functions are performed by the pneumatic switch and associated circuits in the AC inverter section.

RF IC SET and **Remote Control**

Remote wireless control is provided by an off the shelf radio frequency integrated circuit set. The embedded RFIC set allows transmitted (by the remote control unit) encoded RF pulses to be received and decoded. The RFIC components can operate in the allocated ISM (industrial scientific and manufacturing) frequency bands of the radio frequency spectrum or be modified for low power operation (as in home appliance remote control). The RF IC set incorporates a digital decoder that is activated by a correctly keyed digital pulse sequence that is transmitted by a "remote RF key" which matches the pre-programmed "digital key". A small battery powered remote controller transmits this "digital key" when the remote operator closes a simple button or key switch (designated tactical officer).
NLT engineering sets the digital key sequence such that the remote control unit will operate the Sentry system it is sent with. This allows independent simultaneous control of multiple deployed road sentry units to cover multiple lanes or approaches. The RFIC set components are off the shelf commercially available items.
Perimeter protection in advanced site installed systems may automatically control vehicle access and authorization by the use of RF vehicle identification transponders.

Several simpler means of unit arming and triggering are currently available, including direct- wired switch and pneumatic foot pedal switch pump actuation, which is currently used for safety reasons. The RF key was developed but not incorporated into the current EDM prototype, as it was not required for the goal of demonstrating increased hard kills.

Energy Storage Improvements:

The energy storage subsystem operation is critical to development of a high kill ratio vehicle- stopping device. Energy is stored in smaller increments and accumulated for each successive high-energy pulse delivered to the vehicle.

The energy storage circuits utilize advanced electrical capacitor technology. Capacitors store electrical charge in an electrostatic field contained in the space volume provided by an insulating dielectric medium between two electrically opposed charged conductive plates or electrodes. These capacitors must withstand the high voltage stress without arc-over or failure of the insulating dielectric materials. The amount of current stored is dependent on plate area and the dielectric parameters.

All actual capacitors have parasitic inductance and resistance as a consequence of material and construction constraints. As capacitors charge or discharge, high currents flow through the plate sections and interconnecting means, which pose a nominal resistance to the electrical current. These conducting elements also have inductance, as a local magnetic field is set up in a vector perpendicular to the current flow. When used in high-energy rapid pulsed discharged applications, capacitors can exhibit high impedance to this pulsed current: which limits the rise and fall times and peak power of the output pulses. The capacitors must be designed to have a low ESR and ESL or effective low series resistance and inductance. ESR and ESL can result in considerable power being dissipated as heat within the capacitor, resulting in damage to the capacitor. This (ESR) can limit pulse output power and degrade pulse rise times.

There are major reliability and material considerations in the design of compact high-energy storage capacitors. As high voltage potentials exert strong physical forces on the charged plates and the dielectric (which is mechanically bonded to the plates): large amplitude acoustic and mechanical resonance can be set up within the capacitors. This is because during rapid and multiple charge-discharge cycles, high dynamic mechanical forces are present. These forces and the resultant resonance's can cause fracturing of the dielectric with subsequent dielectric breakdown and arc through.

NLT plans to develop with our capacitor vendor improved compact capacitors. We are going to use a "clam shell" structure to limit ESR and inductance and to use superior modern dielectrics. These dielectrics will have improved mechanical and electrical properties over the traditional oil impregnated papers currently used. These will include improved polypropylene films and related polymer films. Recently PFT or Teflon like polymers has been developed using molecular "radiation cross linked" polymer chains for improved thermal and mechanical stability. NLT works with a local Chicago area high technology business partner, which develops custom capacitors to our specification. This vendor's performance has been excellent and NLT is confident in the vendor's ability to develop and deliver these improved capacitors.

Pulse Shaper: the pulse shaper is a tapped inductive line with each tap terminated by a discrete capacitance; commonly called a pulse-forming network or PFN. Each tap performs a filtering function for a discrete Fourier function or band of frequencies, which results in a smoother, and more uniform pulse rise and fall and also provides more constant output impedance. This also aids in the forward coupling of energy into the spark gap by helping to minimize backward or reflected standing waves generated by the dynamic impedance discontinuity presented by the spark gap and the subsequent electrode and vehicle body circuit paths. Components for the PFN are off the shelf and commercially available.

Spark Gap

The spark gap is a seemingly simple component that rapidly switches the stored-energy into the output when a sufficient voltage potential is present to cause the gas or air in the gap to break down or arc over. The electric arc is maintained until the voltage and current drops bellow the ionization point of the gap and the spark is extinguished. Typically, the spark gap is shown in high school physics class as two conductive ball electrodes with a small air gap in between.

The actual operation of a spark gap for the production of high- energy pulses is very complex. The correct design of the spark gap is essential if a high kill ratio is to be obtained. There are two major modes of operation in a spark gap. The initial ionization build up and the streaming or arc over mode during which a spark can be seen. During the ionization period the current flow grows exponentially as the gas is ionized and motile electron flow is established. This process continues until the multiple channels of current flows form, drastically reducing the gap electrical impedance and a spark occurs, super-heating the gas and causing photons to be emitted. After the spark occurs the gap is said to have arced over and the gap acts as a switch with a low forward voltage drop (typically less than 150 volts) capable of conducting large currents.

Far from being a simple switch, the spark gap is a highly reactive component that both dissipates and stores energy. During the ionization time the impedance of the gap changes in a non-linear manner over time and so too does the voltage across the gap. For a sharp rise time output pulse to be achieved the transitional ionization phase must be of a short duration to prevent degradation of the output pulse rise time.

The rise time of the voltage applied across the gap (provided by the stored energy source) as well as the amplitude of the voltage effects the point at which the gap breaks over or arcs. The chemical composition, temperature, humidity, purity and pressure of the gap gas medium all have a determining effect on the operation of the gap as well as the construction of the gap electrodes. Further, in multiple pulse repetition systems, gap recovery time and changes due to continued operation must be taken into consideration.

Hyperbaric spark gap

Use of different (Vs air) gases at different pressures can radically improve the operation of the spark gap. As gap gas density or pressure increases the length of the gap can be reduced for a given voltage firing point and the cross section of the electrodes can be reduced for a given current flow. Changing the gas mixture or composition can also change the ionization characteristics. Hydrogen gas is the best for rapid ionization as the one electron in a hydrogen atom is easily 'striped off' by an electric field. If the hydrogen is compressed the gap distances can be decreased and the current handling ability of the gap can be increased with a reduction in pulse rise time. This type of gap is called a hyperbaric spark gap. Both compressed atmospheric gaps and hydrogen gaps were tested, with hydrogen producing the best results. However, the atmospheric air gaps can also be constructed to give satisfactory performance by using a planner surface discharge gap structure or coaxial structure to minimize parasitic inductance. Liquid spark gaps were also investigated but were found to be too complex to implement as an added hydraulic circuit using pumps and filters had to be incorporated into the design.

"Gap Sharpening"

A compound spark gap that is actually two gaps in electrical series can be used. When one gap fires or arcs over the voltage across the opposing gap undergoes a rapid rise in a short time. This in turn accelerates the break down process in the second gap, providing a pulsed output with an improved fast rise time. This is a form of pulse compression, which leads to an output pulse with a greater energy density over time. Using multiple section gaps of differing break down voltages allows us to "wave erect" the output pulse for a more controlled waveform with less pulse-to-pulse jitter.

Using recent improvements in spark gap technology with the changes in circuit topology described above we believe that we can generate more damaging (to the target vehicle) output pulses with rapid di/dt characteristics.

Probes (vehicle contact electrodes) the contacting probes represent considerable impedance to the high frequency pulse components. Improved probe topology, such as making them rectangular in cross sectional area, can reduce probe impedance to fast rise time pulse components. NLT will also study the physical probe placement and vehicle contact dynamics using high-speed photographic and electronic instrumentation to help improve probe design. The testing of vehicle dynamics must be done during open road field-testing.

TECHNICAL CHARACTERISTICS

Device Name: .... *ROAD SENTRY*™ Vehicle-Stopping Electrostatic Discharge (ESD) Prototype

Applicant's Name: .... Brad Boyer

Applicant's Organization: .... Non-Lethal Technologies, Inc.

White Paper Title:.................... Nonlethal Technologies Inc. Road Sentry Improvement, Phase III Follow on Design for Electrical Vehicle Stopper Program.

Physical Device Characteristics:

Dimensions: .... 26 in wide x 17 in deep x 2.5 in high

Weight:....................................... 38 LB (approximate, varies with style of housing)

Configuration: .... Semi-Automatic (attended) control

Functional Device Characteristics at Onset of Phase III Testing: *with Redesign Characteristics*

Estimated Time to Re-Deploy Device between Test Trials: .... 0.5 min

Hazardous Materials or Operating Conditions: .... None.

Estimated Device Redesign Prototype Cost, per Unit $6,000.00

Duty Cycle: .... ≈ 0.001

Pulse Train Duration: .... ≈ 10 µs (exponentially damped)

Pulse Width: Ringing waveform....................... (Frequency is vehicle dependent)

Repetition Frequency: .... 100 Hz (nominal)

Rate of Rise Time: .... ≈ 40-kA/µs (vehicle-dependent)

Improved Rate of Rise Time. ....≈ 90-kA/µs (vehicle-dependent)

Discharge Voltage: .... 100 kV peak *Improved: 150 kV peak*

Discharge Current: .... 10-kA peak *Improved: 15 kA peak*

Work Performed: The design and testing work were summarized in a series of lab reports submitted to the NIJ and included in the following appendix A. Bench Experimentation was followed by actual construction and test of a series of prototype circuits and chassis. Each Phase of the work was summarized by a lab report covering that phase of development. The culmination of the project occurred when we caused a hard kill in the Honda 94 using a prototype Road Sentry at the end of 2002. The Honda was the only vehicle to be unaffected by the Road Sentry test conducted in the year 2000. Subsequent out of pocket work has been conducted on advanced Marx generators and planar surface spark gaps as well as in near field radiating structures, which is beyond the scope of this report.

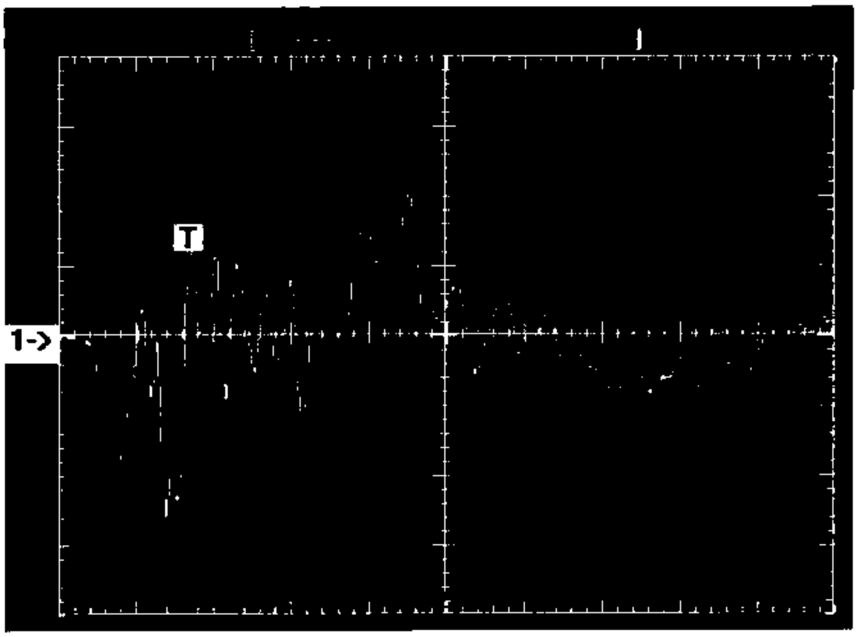
Future Activities: The NIJ and Air Force Research Labs will sponsor and conduct field-testing of improved Road Sentry devices at Kirkland AFB. Follow on field-testing is to be performed by law enforcement agencies.

Appendix A: NLT Lab Session Reports:

10% scale model, charge voltage 15 KV

Simulated Vehicle Wave Form Scale = 1KV, 25nS.
Phase III Follow On Scale Model Prototype Circuit

Figure 1
Output across taped load line.



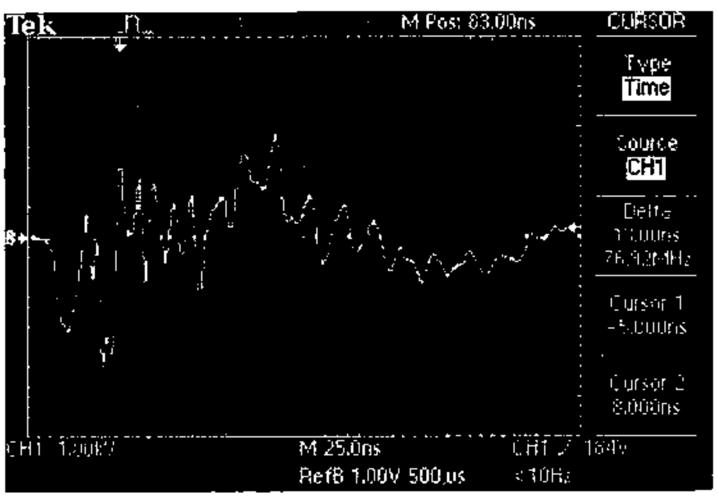


Figure 2
Screen setup showing cursor extraction of damped ringing waveform (76.92 MHz)

PURPOSE: This document describes a laboratory set up for pulse measurement using a digital oscilloscope and computer system for data acquisition and analysis of pulses. This setup is performed using low voltage waveforms for safety considerations.

REQUIRED EQUIPMENT:

Tektronix TDS-2024 Digital Storage Scope

Tektronix P22O PROBE

Tektronix TDS 200 Extension Communications Module

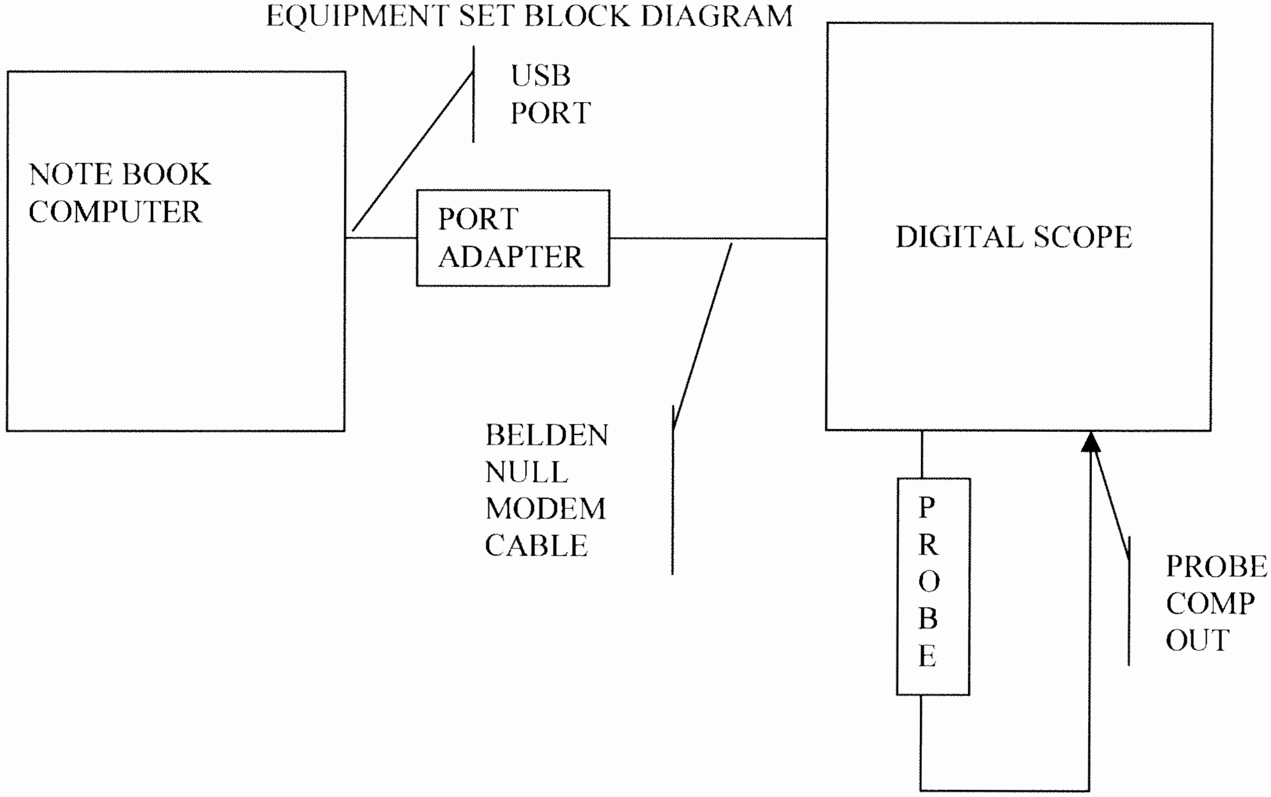
Tektronix Wave Star Software for Oscilloscopes

KEYSPAN USB to RS-232 PORT CONVERTER
With included software driver and data monitor.

BELKIN Null Modem cable set.

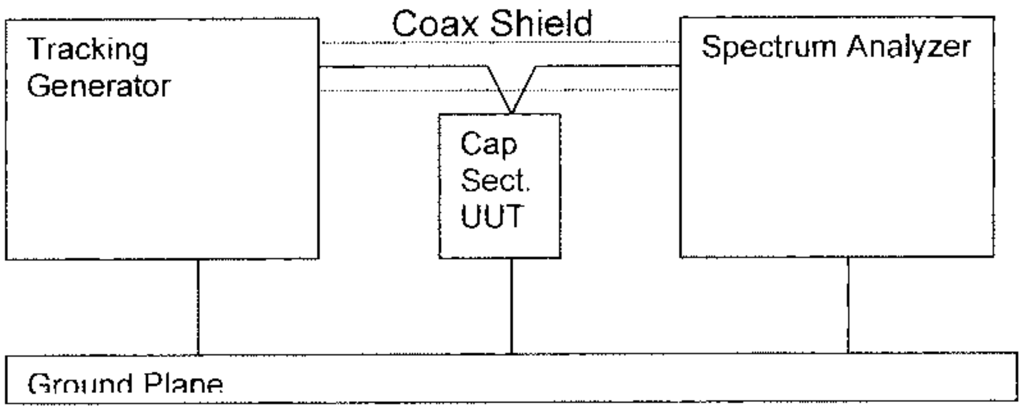
Note Book Computer (P5) (Running Windows 2000 operating system)

EQUIPMENT SET BLOCK DIAGRAM

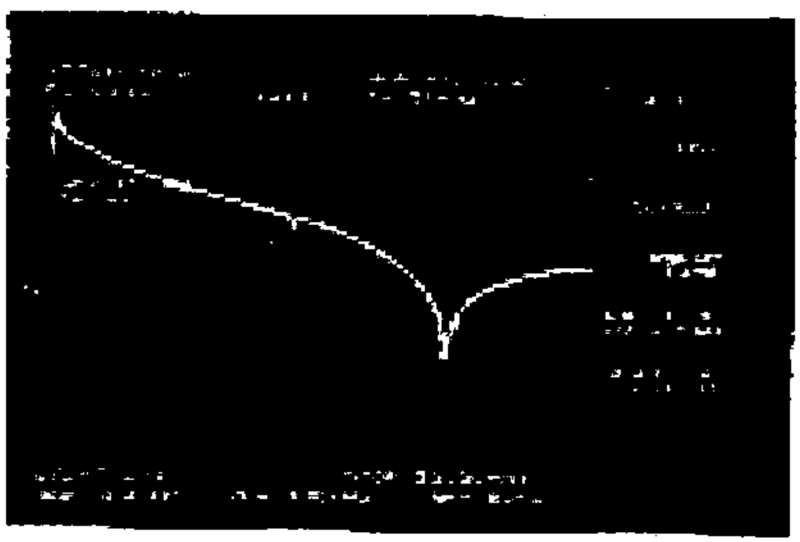


Resonance Test of Capacitor Section:

Test Set Up Block Diagram:
Note: The coax is series terminated in 50 ohms.



Method Formula: $ESL = 1 / 4\Pi^2 F^2 C$



Data:
Photograph of spectrum sweep with tracking generator.
SWEEP is from 0 to 20 MHz. Resonant point is at 17MHz.

Equipment Setup: see embedded PDF.

High_Voltage_Test.jpg

METHODE: The voltage was adjusted upward until spark gap fired. This occurred at a nominal 65 KV, 130 KV peak to peak. Two prototypes were tested.

RESULT: Internal arching was evident in the capacitors. Test wa discontinued. No parametric measurements were recorded but probes were bench tested using meters and scopes.

Actions: A meeting was held with vendor engineering staff and NLT principle investigator (Boyer) to discuss capacitor failure mode. A fault analysis is now in progress, which will require dissection of the units. It was decided to add more sections and increase the radius of each section. This will result in less electrical stress on the dielectric. Initial electrical tests (however) do not show dielectric breakdown, it is suspected that the arch over is occurring across the section surfaces. New capacitors will be built within a two to three week period.

Brad Boyer will track vendor progress in resolution of problem.

1.0 Purpose and Scope

This document reports on current progress of Road Sentry prototype design and construction. Lab activity on the night July 29, 2003 is shown and described.

2.0 Introduction

The Road Sentry prototype has been assembled with new pumped liquid or hydraulic dielectric spark gaps and an improved design for the energy storage capacitors. The unit was prepared for initial alignment and bench operation of the hydraulic circuit and fitted with instrumentation on an insulated test stand. A full electrical test was not conducted, pending completion of final machining and assembly at the end of the month.

3.0 Hydraulic Spark Gap Circuit Operation

The hydraulics system provides the spark gaps with a flow of filtered dielectric for the purpose of refreshing the gap dielectric and removing any carbon compounds or metal particles that could foul the gap.

It is intended by this means to switch over 150 KV in excess of 10,000 amps for a nominal pulse period of 25 nanoseconds with nominal rise times of 5 to 10 nanoseconds. This will also provide for multiple pulse operation at a high PRF of 100 Hz and operation periods of several seconds duration.

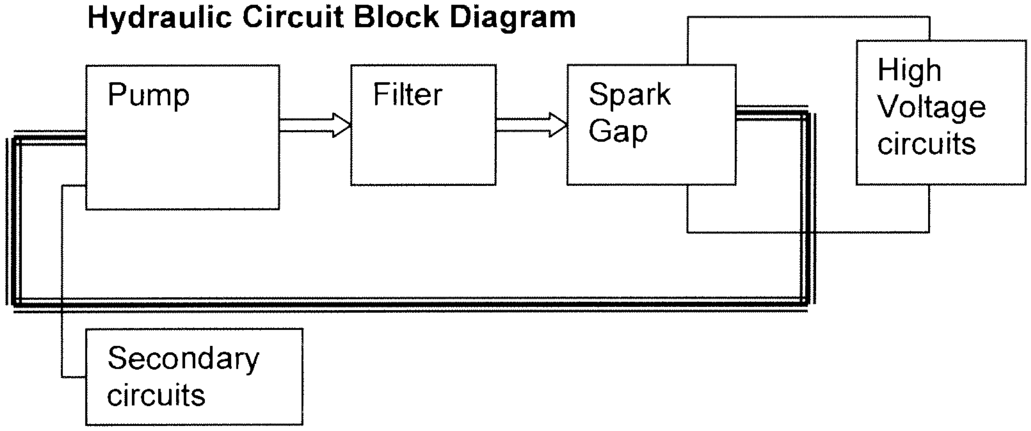
It is well known in the art that liquid dielectrics can sustain high currents that are at least one order of magnitude higher than pressurized and exotic gases. Although advanced solid-state dielectrics have been explored: these have not yet demonstrated the capability to sustain this power level (1GW) without damage. This would preclude its use in repeating pulse rate applications.

In addition to replenishing the gap of ionized and damaged dielectric polymers, the constant flow of fluids across the gap cools the gap electrodes and thus minimizes pitting and erosion of the gap electrode surfaces. This should increase the operational life of the spark gaps.

Finally, use of a sealed gap hydraulic circuit eliminates the problem of compensation of gap distance required by open gaps over changes in barometric pressure or altitude, as is common in open-air gap systems such as are used in classic Marx generators. The problem of detecting leaks in the dielectric seal of hydraulic systems is easy compared to determining whether pressurized gas gaps are properly pressurized or leaking.

Standard USP mineral oil was used as an initial working fluid. Mineral oil has good dielectric properties, a low viscosity over a wide operating temperature and is transparent, nontoxic, economic and readily available. Mineral oil has been used as a dielectric and high voltage insulator for many years and poses no environmental or health hazards. However, recent developments in liquid dielectrics for high voltage transformers and capacitors may have better electrical characteristics or work over wider temperature ranges. These dielectrics should be easy to substitute after initial tests are run using mineral oil.

Hydraulic Circuit Block Diagram



The hydraulic circuit consists of three elements: a pump, filter and oil filled Spark gap chamber. The pump is powered and controlled by a secondary 12VDC circuit and powers the flow of dielectric oil through the filter and spark gap sealed chamber. The pump outlet is connected to the filter inlet. The filter outlet is connected to the spark gap oil chamber inlet. Hydraulic tubing is used to complete the fluid path back to the pump inlet, providing a constant flow of oil through the system when the Road Sentry is armed.

The spark gap electrodes are thus bathed in flowing oil and are connected to the high voltage circuits. When the gap breakdown voltage is reached an electric arc appears across the gap that rapidly switches a high current pulse.

Spark Gap Problems and Trade Offs

The basic concept of a spark gap is simple. A spark gap is formed between two high voltage electrodes, when the voltage potential rises to a sufficient high potential to ionize or electrically break down the gap an electrical arch appears across the gap until the charge is dissipated. Thus, the gap can be used to switch high voltage and currents and is used in many high power pulse-forming circuit applications. Typically, the electrodes are two metal balls with an air gap between them, adjusting the gap distance determines the nominal voltage potential that will cause the gap to conduct or “fire”. Often multiple gaps are used in Marx Generators to develop very high potentials. The gaps are used to discharge a stack of capacitors in series that had been charged up in parallel.

In practice, spark gap operation is much more complex. Spark Gaps not only have a voltage threshold but ionization time and the rise time or charging slope of the applied potential efects the voltage at which the arc "breaks over" The process of ionization is not a sudden switch but occurs over time. Micro channels first form, which in turn ionizes adjacent paths until the arc becomes observable, as an explosive spark. This initial process bleeds off the charge of the storage circuits and degrades the pulse rise times. The gap losses energy as the gap medium ionizes and kinetic energy is imparted to the gas as well as intense photon emissions. As electrons and ions are accelerated across the gap RF is also generated and the gap electron and charged ion flow resists changes in current, which will give the gap inductive electrical characteristics. This inductance will further degrade pulse rise and fall times.
This (gap inductance) means that the gap has an intrinsic resonate frequency associated with the driving circuit storage capacitance, which limits the delta I/T of the output pulse.
Thus, to any given rate of rise in current the gap will exhibit effective series circuit impedance. This impedance can range up to several hundred ohms, which means that the gap can have very high values of power dissipation that degrades the power density of the pulse. In Marx generator circuits the effective resistance of each gap is in series and is therefore additive. This means that for HV designs that use spark gaps the dissipation of the gap and the resonate frequency formed by the gap inductance and circuit energy storage capacitance is the dominating factor in degradation of pulse power density and rise times.

To counter these difficulties, the NLT design uses solid-state voltage multipliers (to minimize series gaps) to pump up a capacitive energy storage bank that has low ESR/L (effective series resistance, inductance) and uses liquid filled gaps to minimize gap power dissipation. For a given gap surface area and distance, liquid dielectric gaps can handle up to 11 times the current.

FIG 1 Road Sentry Prototype Chassis Assembly
Showing Major Components:

The Road Sentry is shown above with all major components assembled into the top of a plastic lid such as is often seen on suburban and urban roadways during garbage collection. The orientation shown is inverted from the operating configuration so you are looking down from what will be the bottom of the chassis.

The energy storage capacitor bank (orange colored tubes) is attached to output rails on either side. These rails will be connected through conductive fasteners to the output electrodes, which will come into contact with the target vehicle chassis as it rolls over. In this manner a high amplitude electromagnetic discharge pulse is directly injected into the target vehicle oil pan and chassis.

The electronics package consists of an input coupling transformer, solid-state voltage multiplier and control logic including any required remote or wire control means. The spark gaps are connected to the capacitor bank rails and the charging network output. The charging network input is the voltage multiplier output. The hydraulic circuit components, pump, motor and filter are interconnected with the spark gaps to provide dielectric flow across the spark gaps.

The low target profile of the plastic "garbage can lid" is seen as a low and light threat by most drivers (if it is noticed at all) and is usually driven over in a "bridging" maneuver with the vehicle chassis passing over the center. For operational observation and testing the chassis lid is filled with high voltage dielectric oil to prevent corona damage and arc over between high voltage components. In the production version a semisolid wax based dielectric and added polycarbonate stiffeners will be used to reinforce the chassis to withstand road damage from vehicle roll over. Alternatively, the unit can be embedded with in the road

substrate or formed as a speed bump "road patch" with polycarbonates simulating asphalt.

FIG 2 Input Transformer and HV Multiplier Circuits

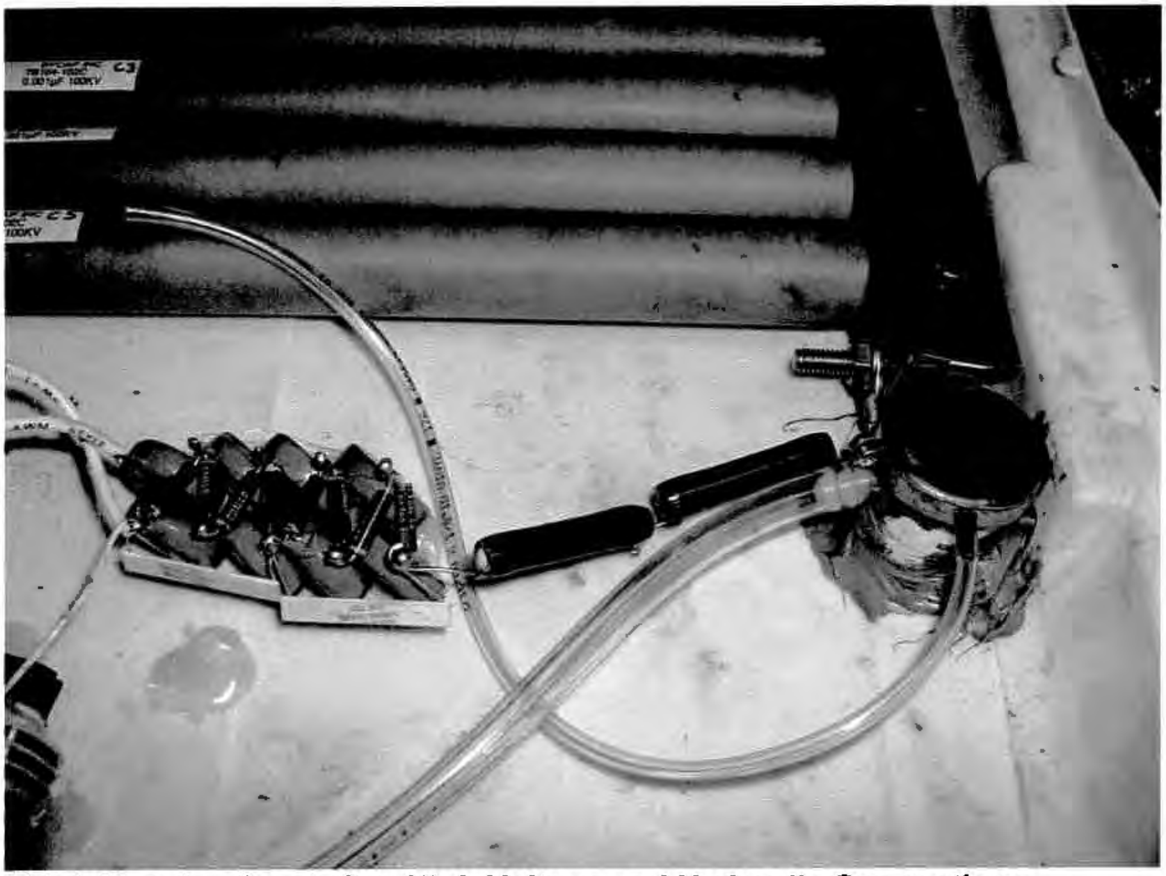


FIG 3 Showing Spark Gap High Voltage and Hydraulic Connections

The voltage multiplier array is coupled via power resistor network to spark gap input. The output is electrically bonded to the storage capacitor array. Hydraulic tubes connected to the inlet and outlet of the spark gap chamber provide a constant flow of dielectric oil across the gap. The gap adjustment shaft goes through to the bottom surface of the chassis.

Figures 4A and 4B Showing Mineral Oil Fill Cycle Preparation

Mineral oil dielectric fluid is loaded into the hydraulic subsystem with vacuum pump. The gap adjustment screw can be seen next to the electrode mount rail.

FIG 5 Showing 12VDC Connection for Internal Dielectric Pump Drive

The hydraulic pump motor is driven via a 12 VDC power source during the fluid load cycle by connection to insulated banana jack input posts.

FIG 6 Spark Gap Adjustments

Resistance and capacitance meters can determine internal gap distance.

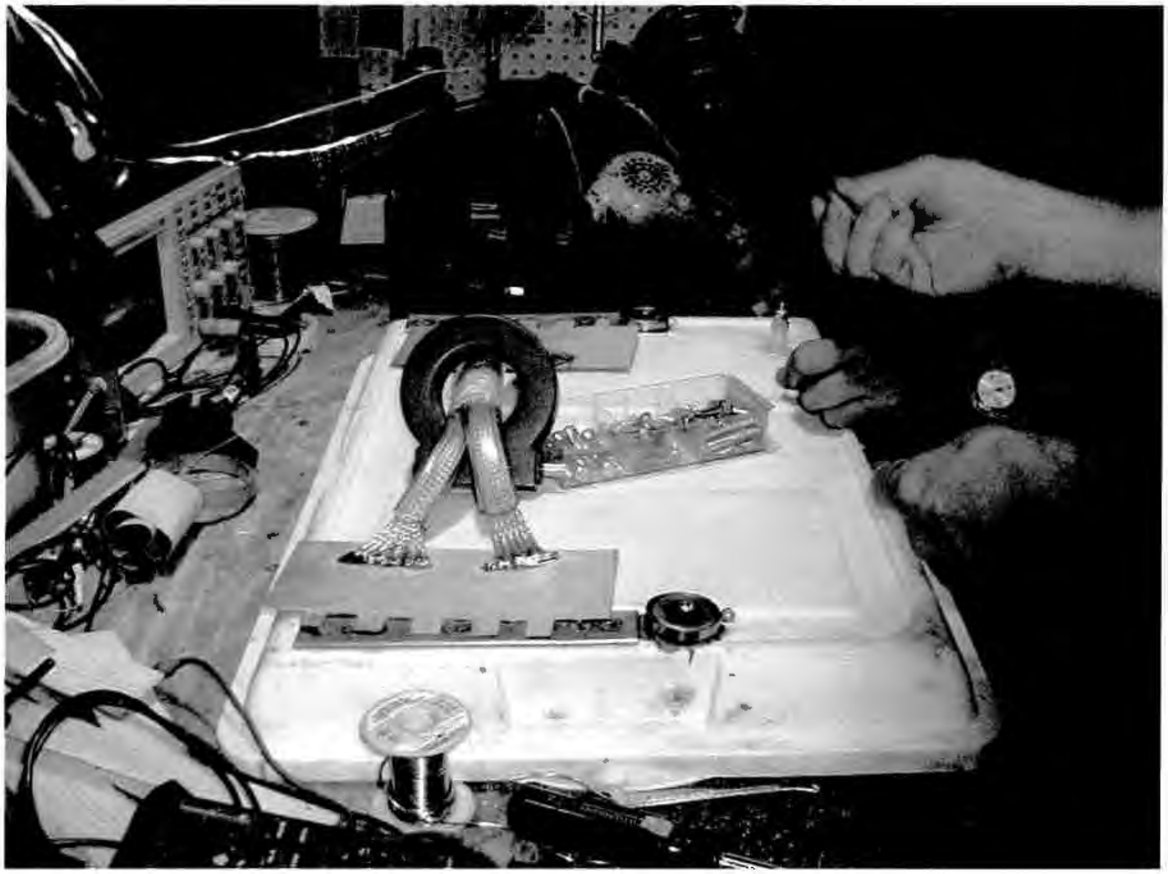


FIG 7 Assembly of Shorting Plane and High Current Probe

For bench testing a shorting plane with torridial current sensor is employed.

FIG 8 Showing Pearson Probe with HV Insulated Current Shunt

Low inductance strapping is insulated with PVC tube and polypropylene based wrap. This prevents damage to probe and provides an isolated sensor to a digital oscilloscope which provides data acquisition and measurement of current pulse amplitude and rise and fall times.

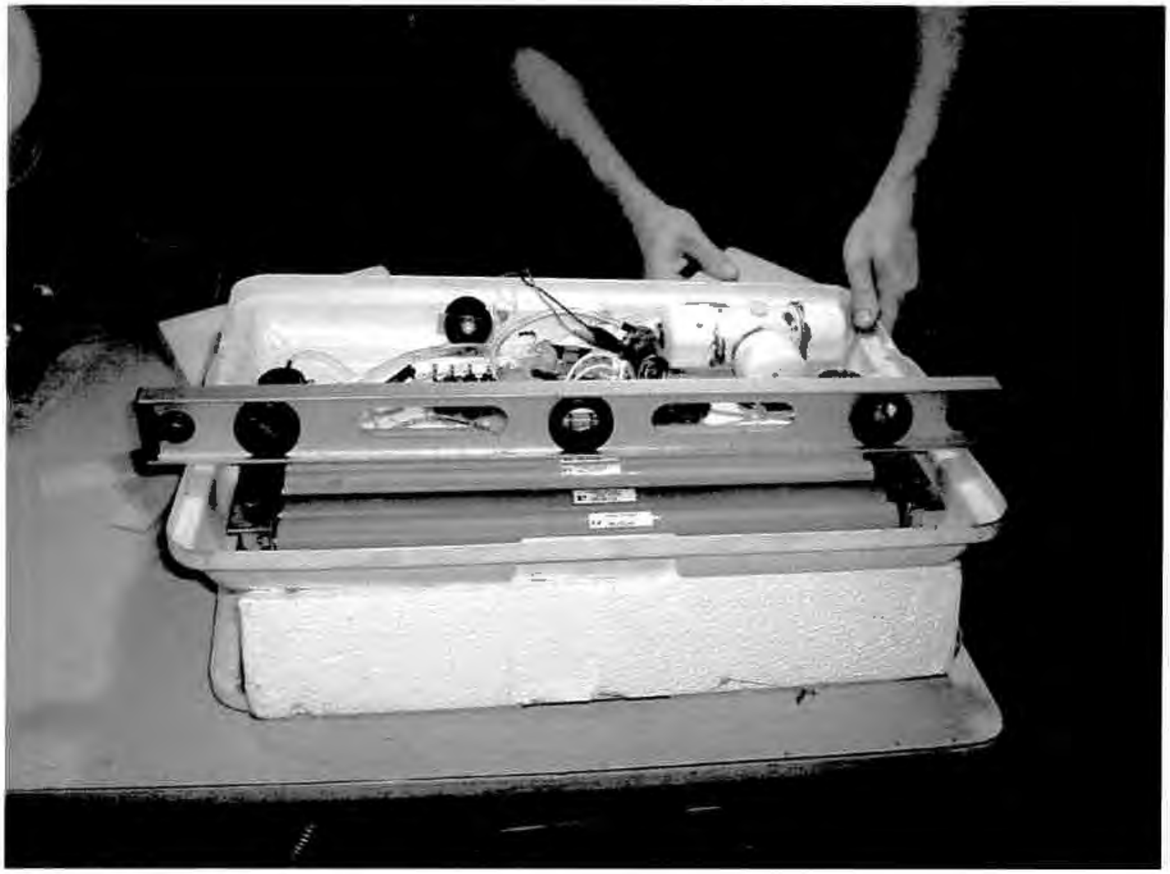


FIG 9 UNIT IS LEVELED ON INSULTED TEST STAND

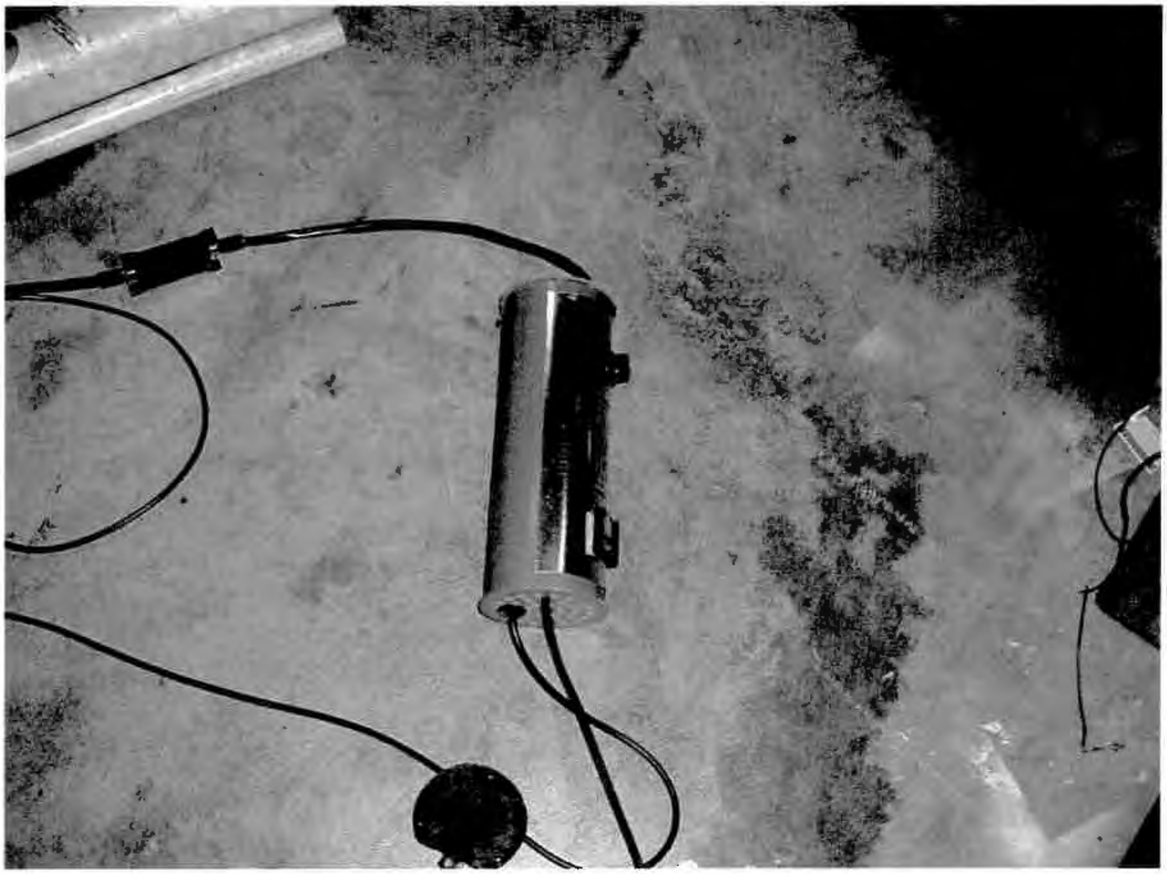


FIG 10 EXTERNAL POWER INVERTER PROVIDES 400 VAC @ 5KHz

A pneumatic foot switch is used to control power switching and arming. The operator is electrically isolated from the line and any generated high voltages. The four hundred VAC line can be run over long distances with minimal circuit attenuation. This inverter works with line voltage for lab use. In the field a 12V battery operated inverter or AC generator can be employed or unit can be powered off of standard squad car electrical connection. A wireless interface that works in the ISM band can also be used in conjunction with an onboard rechargeable battery. This will provide an integrated man deployable unit with no external connections. Power control can also be automated for unmanned operation upon vehicle approach or under IFF transponder control systems.

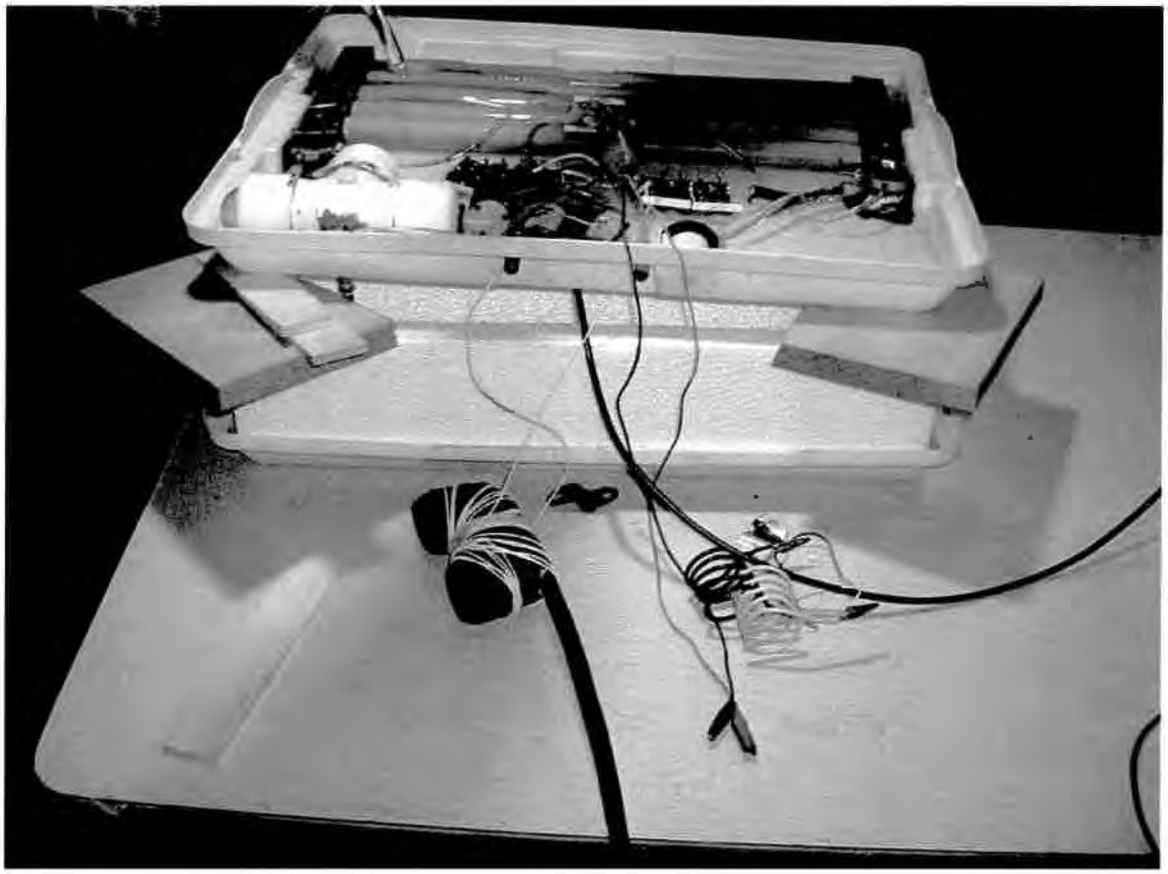


FIG 11 EXTERNAL ELECTRICAL CONNECTION PREPERATION

An isolation transformer is employed for lab testing as an added safety measure. 12VDC connections for hydraulic pump and coax current probe output for connection to instrumentation are provided.

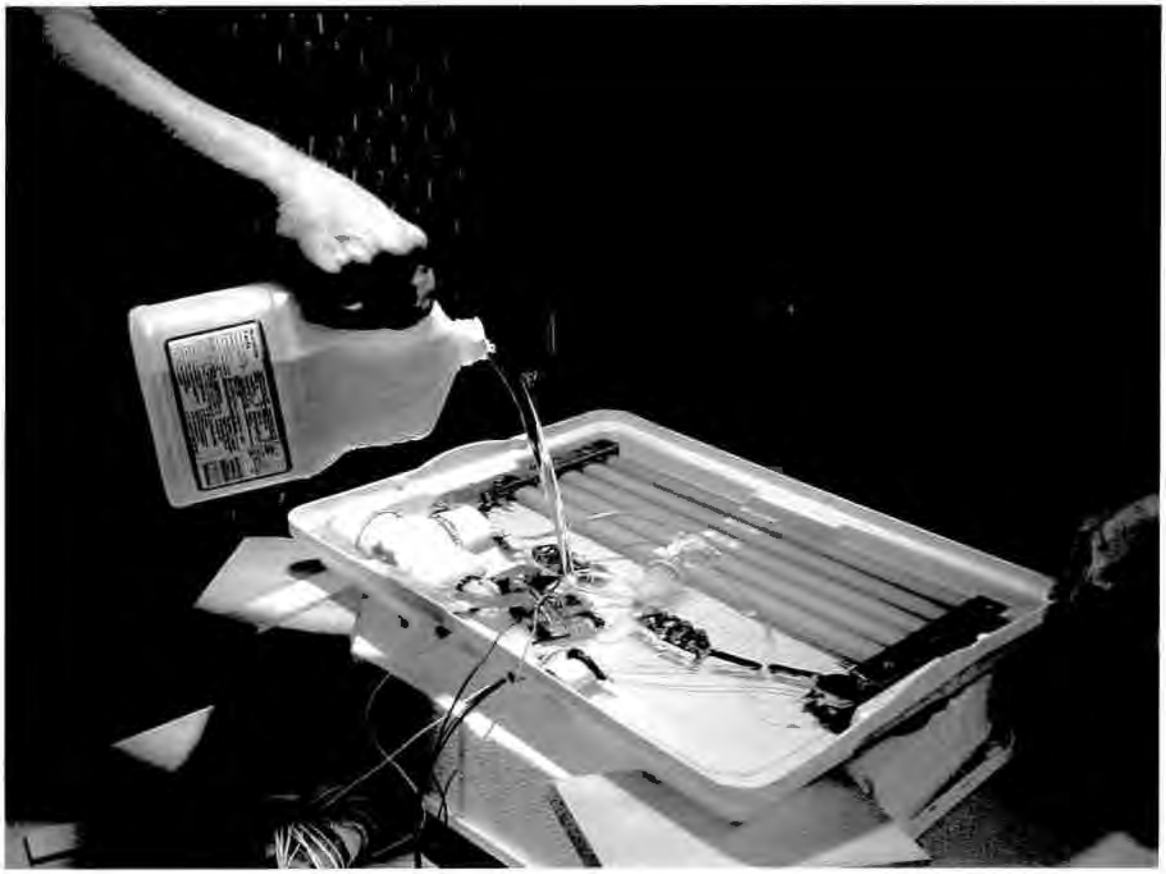


FIGURE 13 CHASSIS IS FILLED WITH HV DIELECTRIC OIL

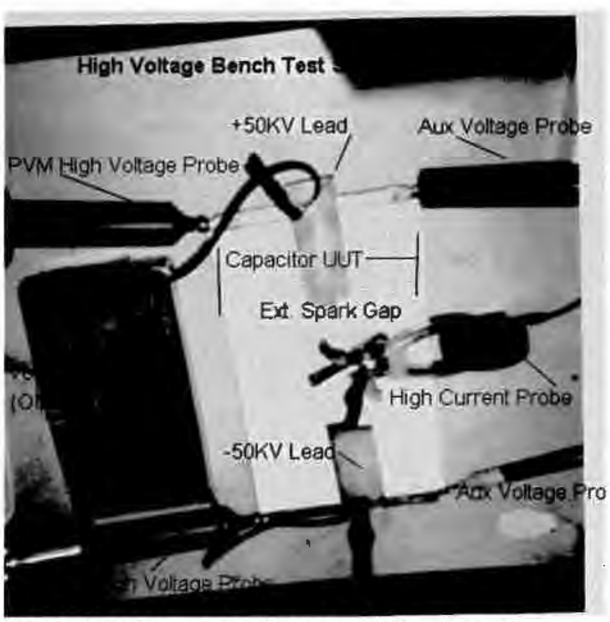


FIG 14 Bench Test of Capacitor Section

Prior work tested voltage withstand and operating characteristics of energy storage capacitors. This type failed the test!

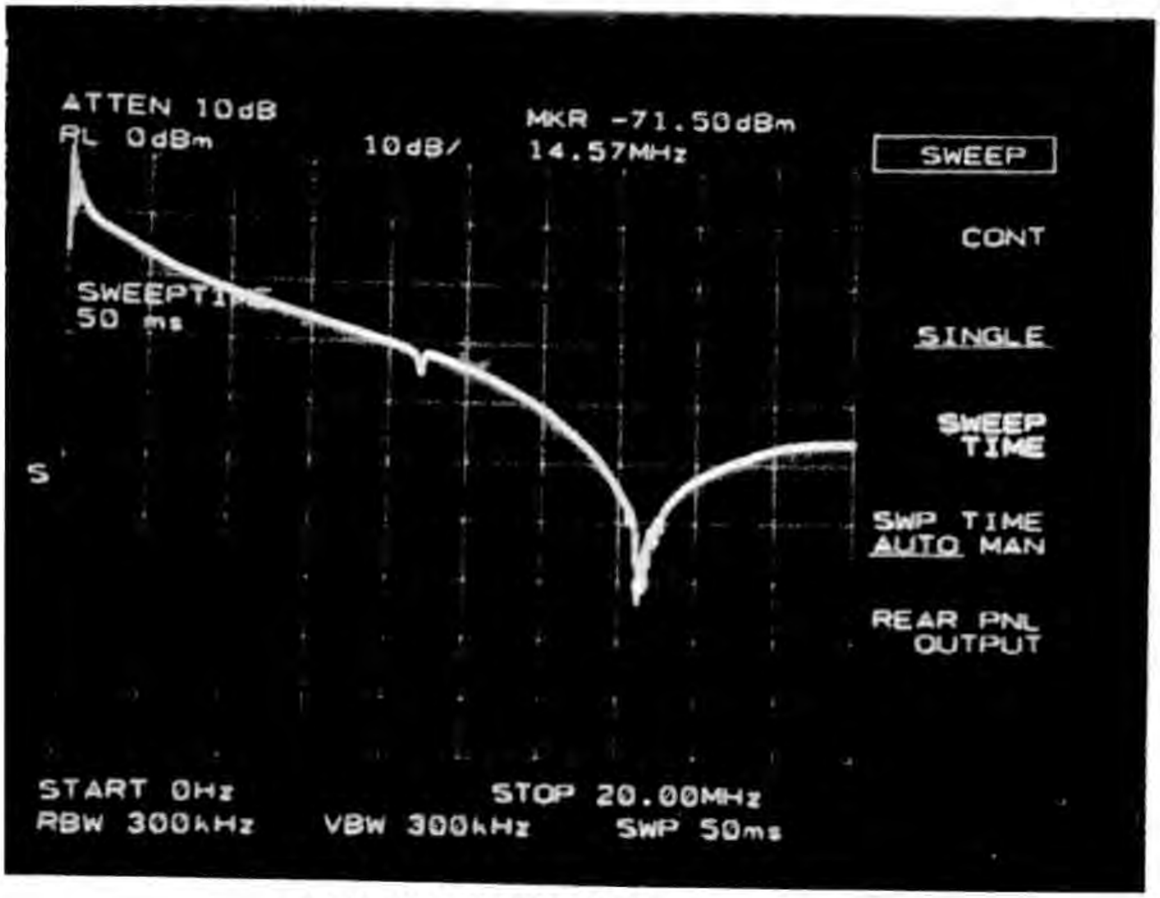
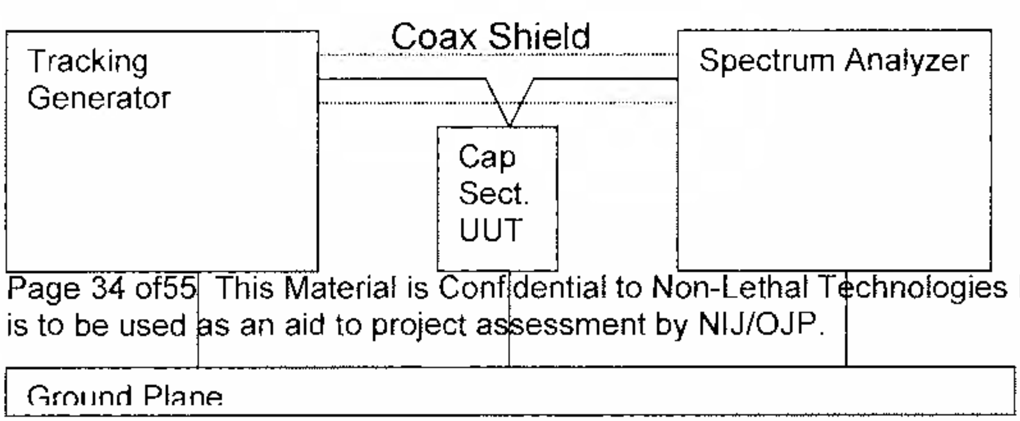


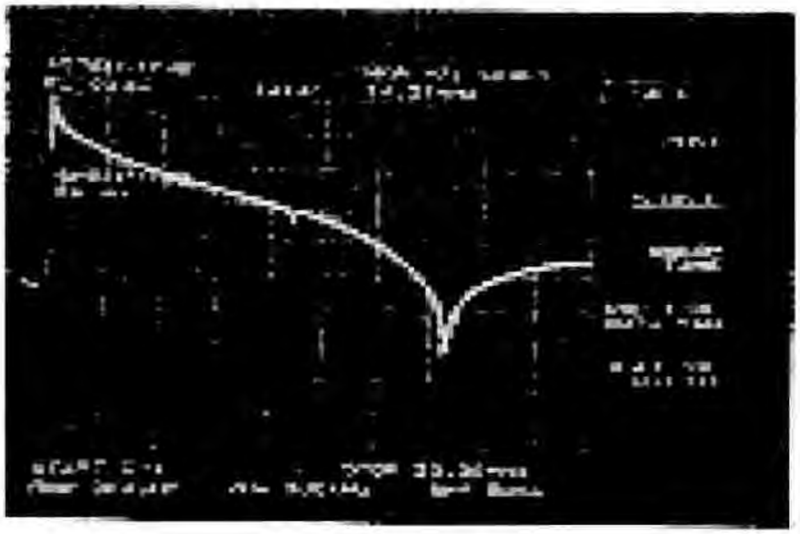
FIG 15 CAPACITOR SECTION RESONANCE TEST DATA

Resonance Test of Capacitor Section:

Test Set Up Block Diagram:
Note: The coax is series terminated in 50 ohms.



Method Formula: $ESL = 1 / 4\Pi^2 F^2 C$



Data:
Photograph of spectrum sweep with tracking generator.
SWEEP is from 0 to 20 MHz. Resonant point is at 17MHz.
Conclusion:

ESL (old Road Sentry capacitor) = 136nH

ESL (one section of new cap) = 26.7nH

Predicted value (series / parallel, 15 sections) = 16nH

Predicted di/dT improvement = (cap only) 8.5 to 1.

Reduction of the Effective Series Inductance (L) is essential for obtaining fast rise time output pulses. Fast rise time pulses mean that higher frequency resonance can be set up in the targeted electrical system.

Future actions:
The capacitor sections will be assembled into a series parallel compound circuit assembly to form a high voltage energy storage capacitor. The expected ESL is to be as good as the section tested. The new capacitor assembly should have an ESL that is as low. Testing under high voltage will be performed after assembly.

Summary:

The bench electrical testing of the prototype is in its final stages. After we are satisfied that the basic operating characteristics demonstrate that electrical operation meets the project engineering goals: work will proceed with a study of output electrode geometry and interface to the target vehicle chassis.

This will culminate in a garage stationary or low speed roll (without a driver) over bench test shot on the selected target vehicle. The test vehicle electrical system will be instrumented to determine engine operation functional waveforms and secondary electrical waveforms resulting from the initial test shot on the vehicle. A failure analysis will be conducted on any damaged components or subsystems on the vehicle.

The selected vehicle will be the Honda Accord that has been purchased. This is the same type that we had poor results with during phase III evaluation. A hard kill on the Honda will demonstrate improved Road Sentry performance and NLT contribution to progress in the state of the art for direct injection.

It is expected that the Government will sponsor test track road testing using driven vehicles at different speeds and with a limited set of fuel injected models. It is our hope that Phase IV testing and evaluation will be conducted during limited deployment by authorized police and or military agencies by the beginning of FY 2005. This may require follow up investigation depending upon results and the features desired by the involved agencies.

NLT expects to develop follow on designs including powered target vehicle interception under the Road Patriot development program. Development of remote and unmanned systems for installed peripheral protection of critical assets such as military bases, harbors, federal office complexes, oil refinery, nuclear power stations and designs adapted for border control and checkpoint control.

THE ROAD PATRIOT™

*The **Road Patriot** is a rocket powered unit designed to fit into its own articulated launching carrier, easily mounted underneath the bumper of a pursuit vehicle (as shown). The rocket is fitted into the rear of the unit and acts as a propelling device. Custom mounting brackets underneath the hood hold the spool and dynamic clutch assembly containing the power and guidance wire.*

The Road Patriot is deployed by the officer pressing a triggering device. This lowers the unit to ground level where it is then launched.

As soon as the Road Patriot is deployed, the retractable articulated launching system smoothly sets the unit to road level in less than one second. The unit is then launched by the triggering mechanism.

The rocket propels the
20 miles per hour faster
vehicle. Current wire
100 foot lengths, with
available. This al
vehicle to launch at
lengths behind the veh

Non-Lethal Technologies Lab Report 26 September 2004

Bradley X Boyer: Principle Investigator

Non-Lethal Technologies Inc.
1815 W. Main Street
Sleepy Hollow IL.

Attn: Amon Young NIJ/OJP Program Manager.

1.0 Scope This document reports on recent staff and Lab activity current to this report date.

2.0 Project Activity Summary: The following is a summary of recent activity.

2.1 ADV Consortium Presentation at Virginia Beach:

On August 27th 2003 Mr. Amon Young (NIJ/OJP) and Brad Boyer (NLT) gave a presentation on current Road Sentry project development work and related program and technical information on ESD based direct injection vehicle stopping technology. The presentation was well received and was an excellent opportunity to inform the broader technical community and concerned government agencies of our work.

2.2 Design, Construction and Testing Activity: The Road Sentry prototype was rebuilt with improved spark gaps and tested in the Lab on September 03, 2003 as shown in the following report.

2.3 Summary of Results:

1. A comprised high- energy discharge was generated and recorded which approaches project-engineering goals and demonstrates improved performance over the Road Sentry design as tested in Phase III. The following characteristics were noted.

    a. Primary pulse current rise time 43 X 10^{-9} Seconds (43 nano-seconds).

    b. Primary Pulse current amplitude: 8.5 K Amps peak. 17 KA Peak to Peak.

    c. Primary Pulse Voltage amplitude 90 KV peak, 180 KV Peak to Peak

    d. Primary Pulse Power: Peak 765 X 10^{+6} (765 million) Watts. Peak-to-Peak 1.6 GW nominal.

    e. Secondary Pulse damped sign wave frequency (resonate) 4 MHz nominal. (With a simulated vehicle path inductance of 209 nano-Henries).

f. Spark gap fouling was noted due to inadequate pump pressure and slow flow rate of dielectric fluid. A rotary gap is now being designed to keep gaps from fouling. This will also limit the range of inter-pulse jitter and control the PRF.

3.0 LAB TEST LOG

List of test equipment:

1. Tektronics TDS 2024 Four Channel Digital Oscilloscope with 10 to1 Probes. Max sample rate is 2GS per second.
2. Pearson High Current Probe: 100 to 1 (.01V/amp), 100 MHz Probe
3. (2) PV4 North Star Research High Voltage Probes.
4. Test Plate Assembly
5. UUT: Prototype Road Sentry chassis with inverter power supply and pneumatic safety switch.
6. Miscellaneous: Hook Up Wire, Coax cable and connectors, insulated test stand with oil pan. 120 RMS 60 Hz VAC Power with 20 amp service with power strips and standard electrical connection hardware. Insulating HV oil.

⚠ DANGER

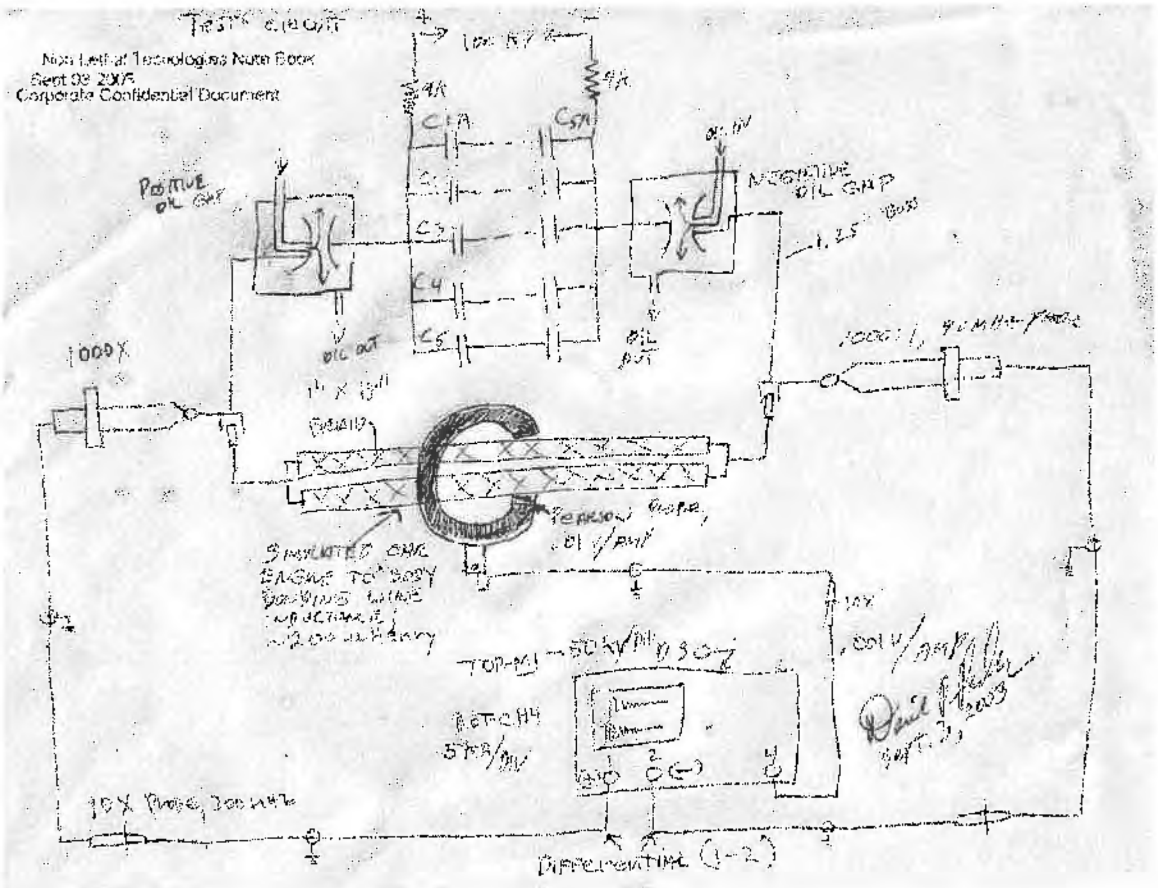
The following test uses extremely high electrical voltages and currents. Use extreme caution. Sever Injury or death could result in case of contact or close proximity with energized or charged conductors. Only use insulated pneumatic control switch and stand back from test fixture when energizing equipment under test. Only work on high voltage section when all equipment is not energized. The energy storage capacitors are capable of storing lethal electrical charges after power is removed: always make sure capacitor bank is safely discharged before working on UUT. Non-Lethal Technologies Inc. does not assume any responsibility or liability for safety of personnel who attempt to replicate these experimental tests. Only perform these experiments if you have been trained in or are experienced in the safe use of high voltage and high current circuits.

The inverter circuits and power coupling means have a high magnetic field. Stand back from inverter and transformer circuits if you have a surgical implant.

The oil used in this experiment can generate dangerous fumes and squirt into eyes causing injury if an internal electric arc occurs. Use OSHA approved eye and breathing protection in a well-ventilated area, when performing these tests. Do not stand over chassis when energizing the UUT. The oil used in this experiment is volatile and may ignite causing sever injury and death and or extensive damage to property. Use extreme caution and have a working chemical fire extinguisher type ABC on hand.

TEST SET UP: see test circuit and set ups bellow. Hook up Channels one and two of Oscilloscope, voltage and scope probes to give differential measurement of pulse output. Adjust scope for best view as required for measurement taken. The combined attenuation for voltage measurement is 10,000 to 1. Connect current probe BNC output to Channel 4 via coax cable. Mount chassis to test stand, level and fill chassis with insulating HV oil. Hook up power inputs to inverter output and complete all AC power connections as required. Ground all instruments to common ground point to avoid current loops. Power up oscilloscope and set as required for measurements. Stand clear of any connecting conductors and equipment, use pneumatic switch to energize UUT.

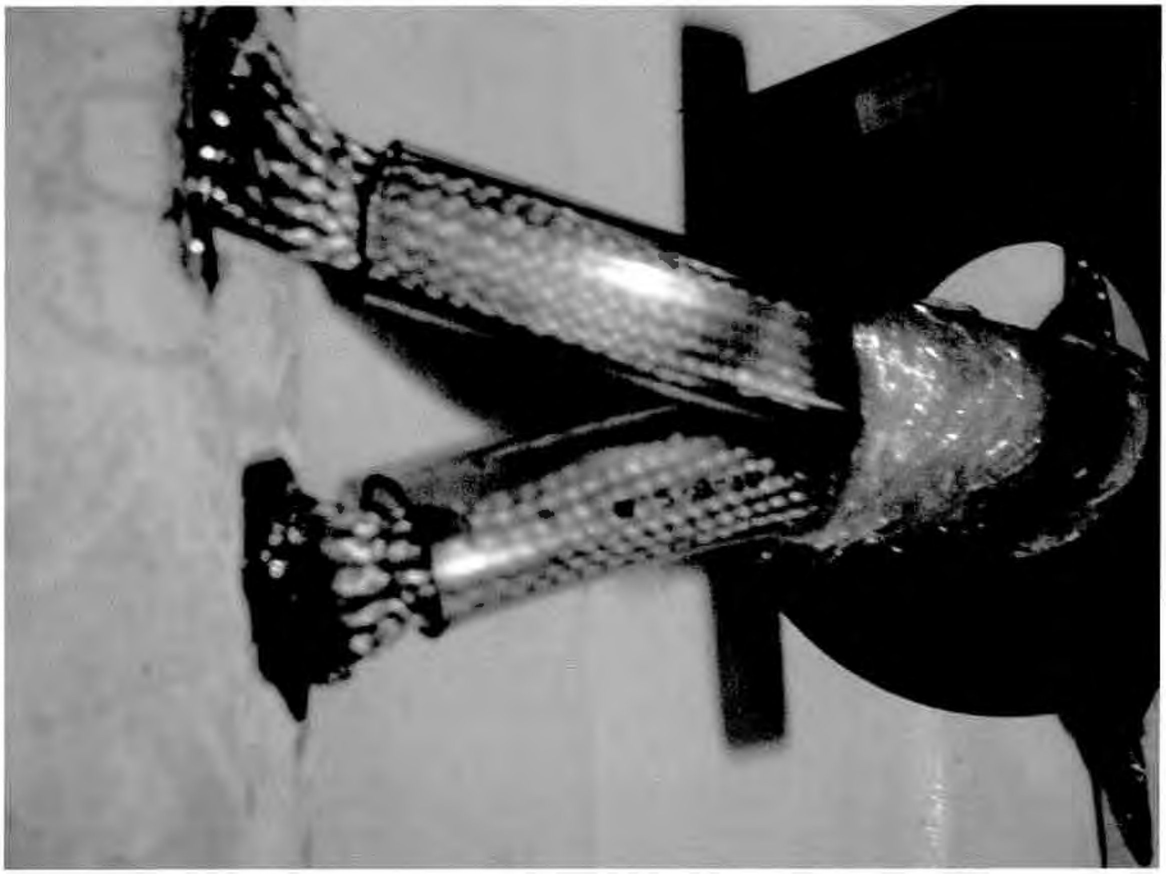
Measure Voltage amplitude and current amplitudes of output pulse waveforms. Measure primary pulse rise times, secondary resonance frequency and compute peak and peak-to-peak power levels (Power = voltage X current).



TEST CIRCUIT SETUP for High Voltage Pulse Output Characteristics (power inputs and control not shown) measurements.

TEST SET UP Showing UUT on test stand, High Voltage Probes and Digital Oscilloscope in engineering lab. The chassis has been leveled and filled with an organic based insulating oil to prevent corona and arc damage to chassis components.

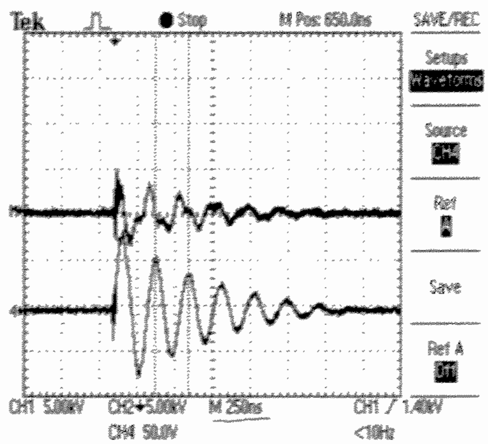
Digital Scope with traces photographed. Red trace is differential voltage probe outputs, CH1 & CH2. Green trace (lower trace) is the current probe output waveform CH4.



Pearson Current Probe with braid bonded to copper plates load assembly emulates the inductance of typical battery to engine block grounding strap. Inductance of assembly was measured at 209 nH.

TEST DATA FOLLOWS: The following print outs are digitized scans of print outs driven by the digital oscilloscope, with explanatory text. The scales and dimensions of the plots have not been altered so this is true raw data.

Print out of oscilloscope traces at 250 nS per horizontal division. Primary and secondary resonance, voltage and current amplitudes are shown. Differential Voltage trace is top trace (CH1+/CH2) and current trace is at bottom CH4



A = 50KV per div

B = 5KAmp per div

Non Lethal Technologies Lab Note Book

Sept 03 2003

CH 1 + /CH2 50 KV per Division

CH4 = 5KA per Division

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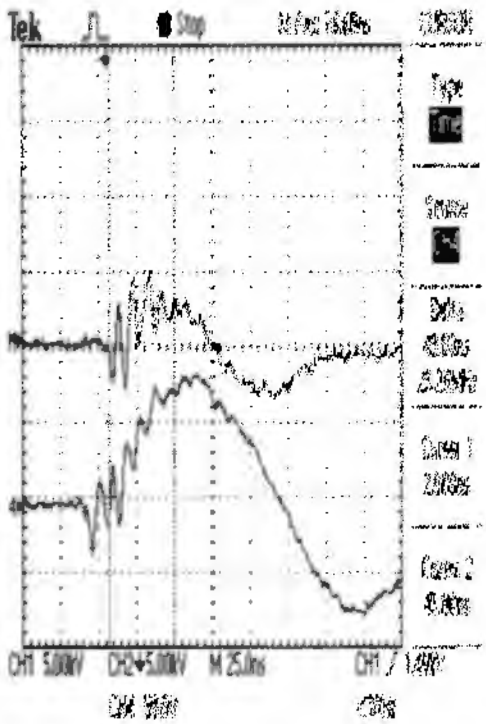
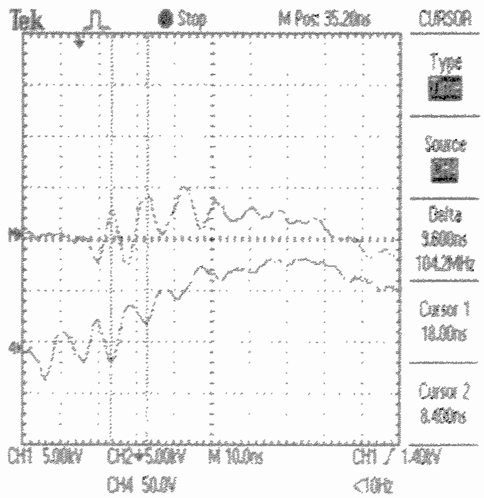


CH1 + /CH2 50 KV Per Division

CH4 = 5 KA Per Division

Horizontal Sweep is 25 nS per division

25 ns Horizontal division trace. 100 MHz ripple on both waveforms shows excellent high frequency compliance and response of all probes used. Current leading voltage is an artifact of coax lead lengths. Primary current pulse rise time is 43 nanoseconds. Taken at a nominal 10% and 90% points on the rising edge.



Non Lethal Technologies Lab Note Book Sept 03,2003
CH4 Data: Current Wave Form Rise Time = 43 nS
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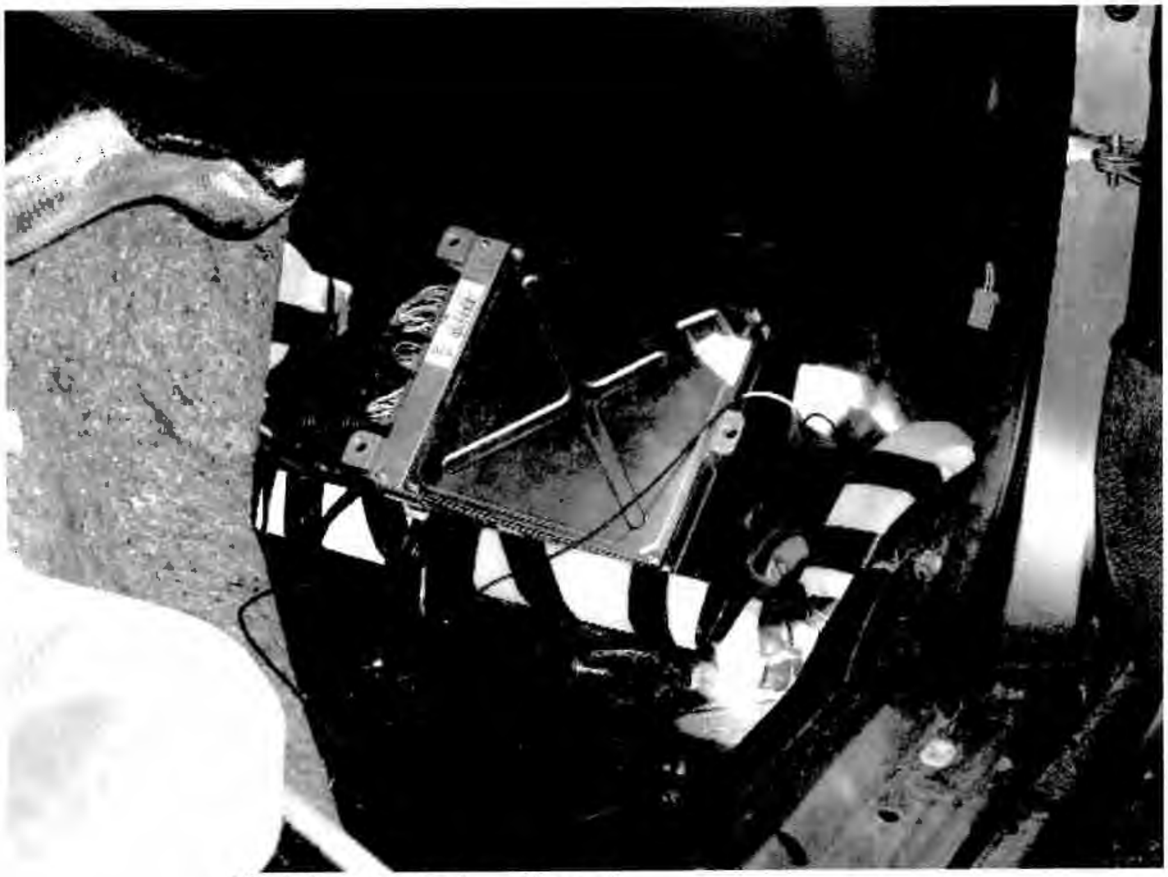
10 ns per Horizontal division gives close up of fast ripple. This rapid ripple (100MHz) is of little practical consequence but does show off the excellent broad- band response of the probes and instruments used. Note that the sinusoidal ripple waveform is not clipped. This also demonstrates that resonance is excited out to 100 MHz.

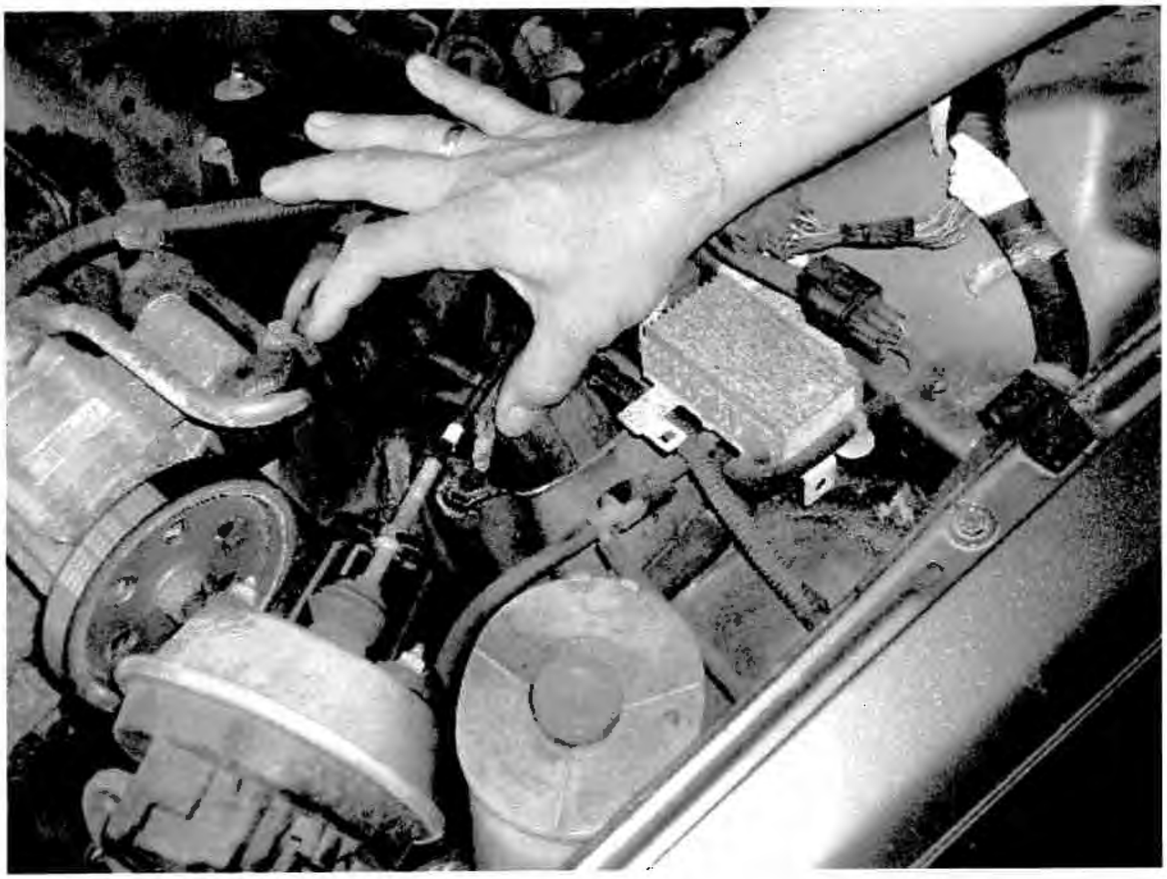
The above data set clearly shows that the new design has improved electrical performance. The production of fast rise time, high amplitude pulses, should excite multiple and complex resonance in the vehicle electrical system.

Testing of the improved rotary gaps will follow.

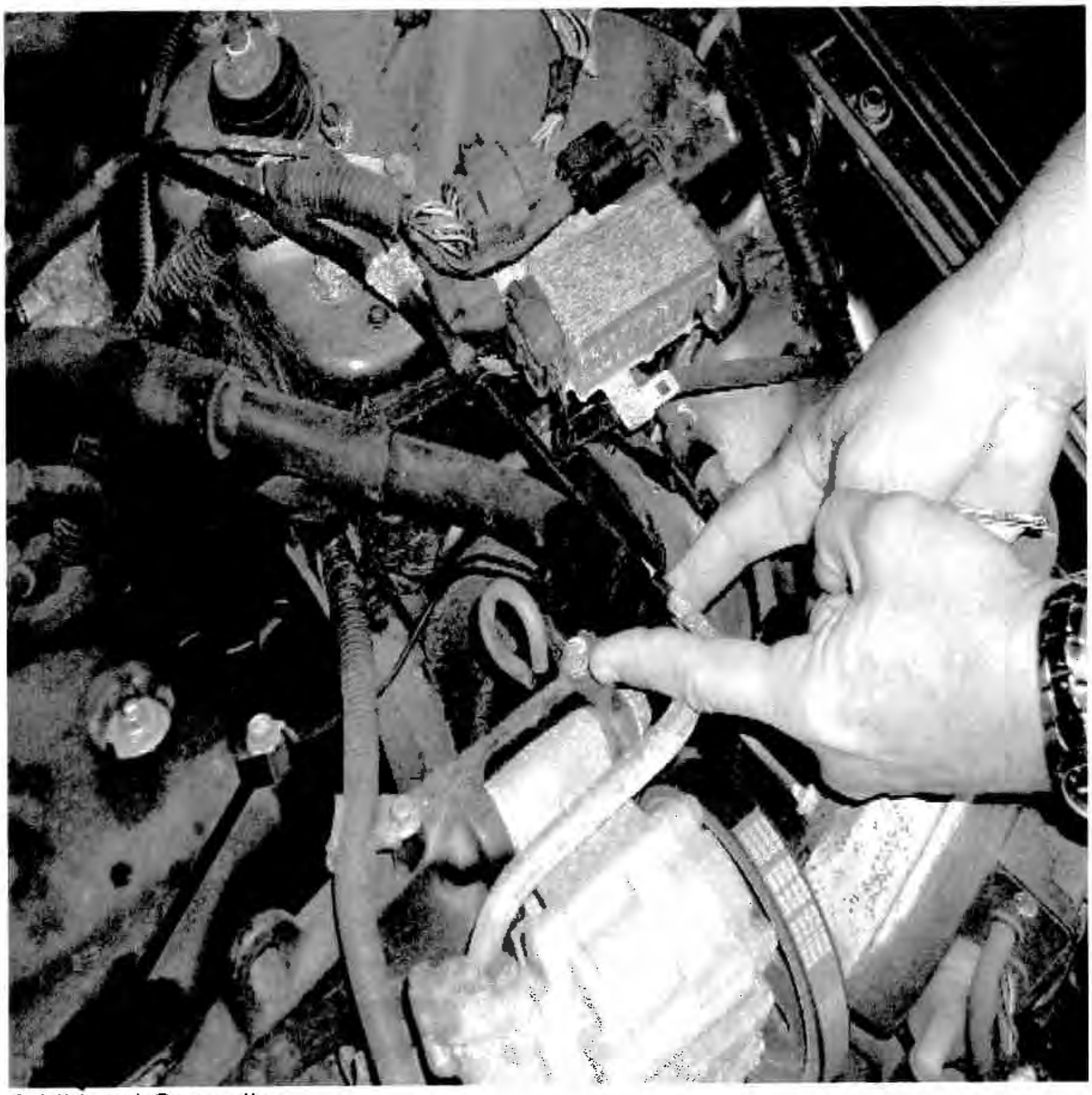
Honda 94 Disabled by Improved Road Sentry



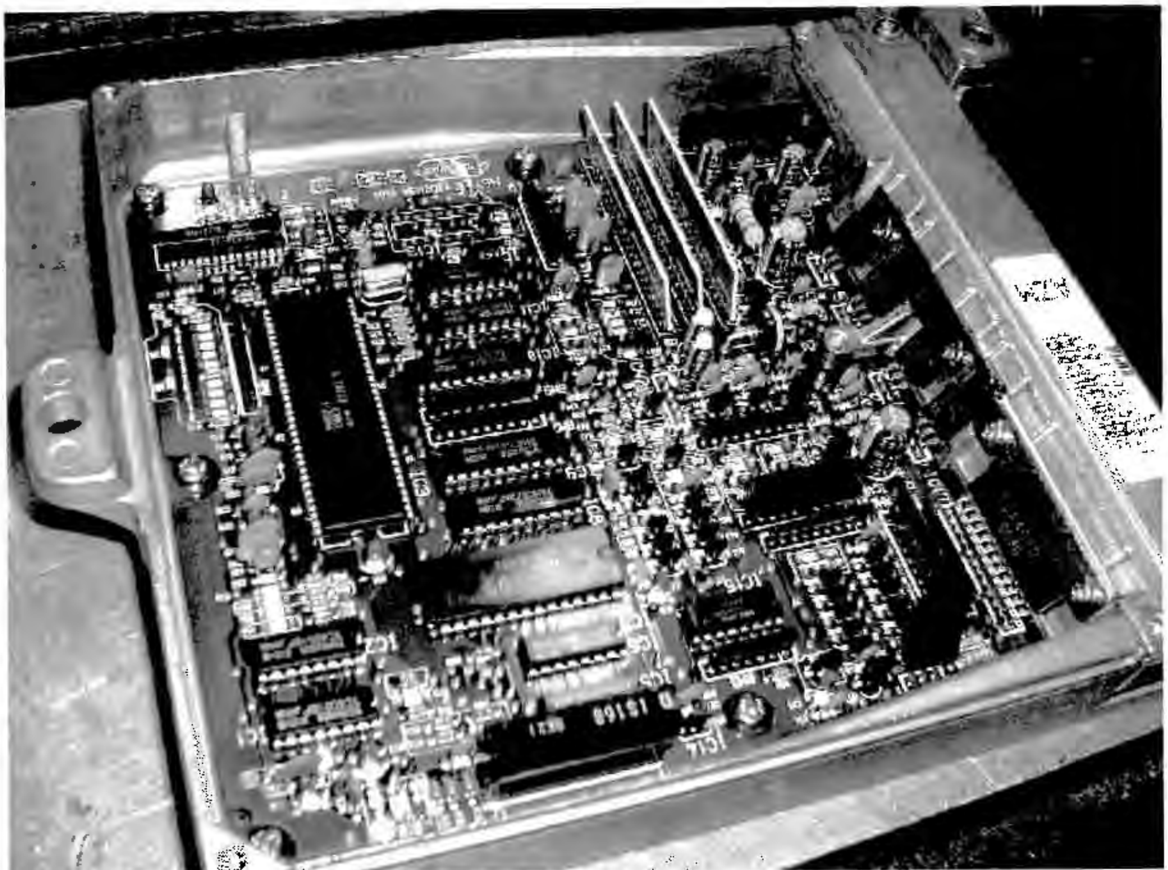
Engine Control Module mounted on firewall



Additional “short” ground straps make Honda hard to kill. High frequency resonance must be generated to over come this.



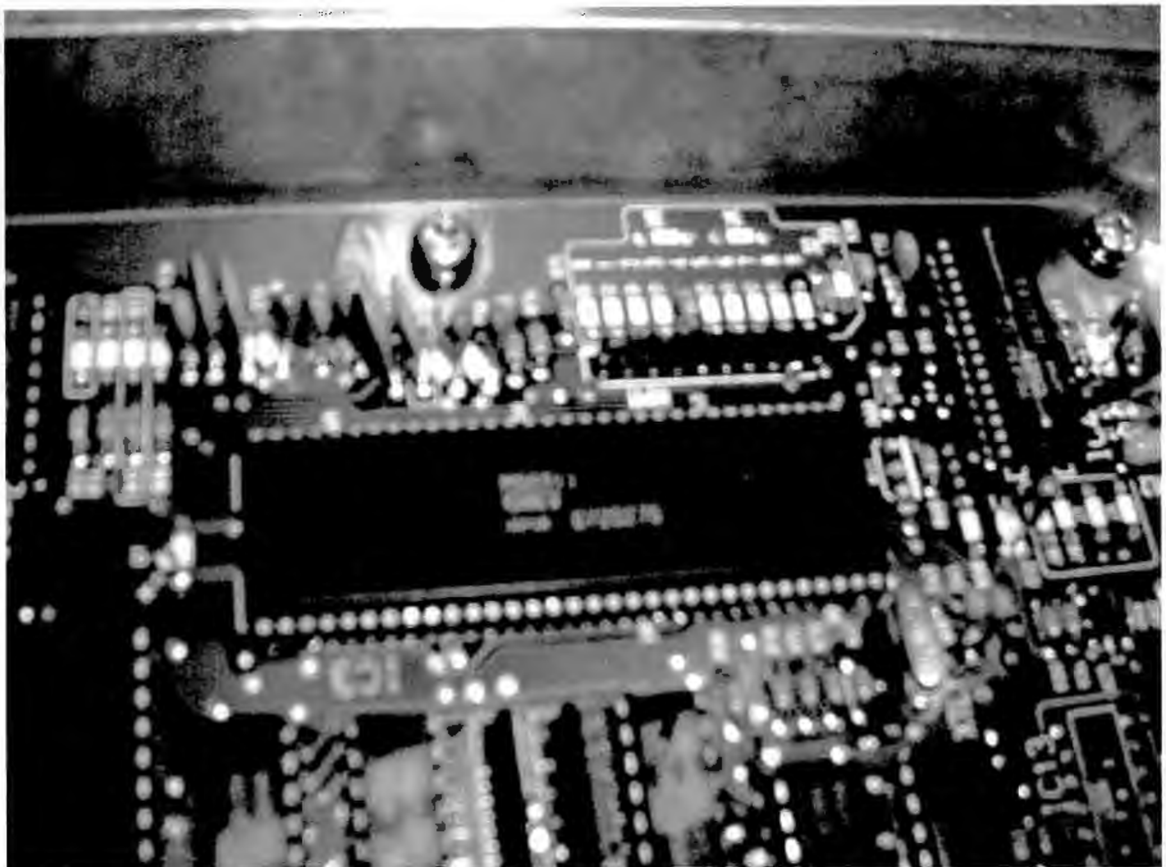
Additional Grounding



Module Cover removed to show top of Printed Wire Board Assembly

Honda EEC (electronic engine control) module with cover removed to reveal PWA. No physical damage was noted.

The printed wire board assembly was removed for inspection and testing. No shorts or opens were observed.



The microprocessor was found to be inoperable, no clocks or signals were present on board after Vcc and ground were applied. Preliminary conclusion was that internal damage to several major integrated circuits occurred.