

Electrical Evaluation of the Taser M-26 Stun Weapon Final Report

Submitted to: The Israel National Police, R&D Division

By: **Professor Shmuel (Sam) Ben-Yaakov**
Head, Power Electronics Laboratory
Department of Electrical and Computer Engineering
Ben-Gurion University of the Negev
Building 33, Room 313
P. O. Box 653
Beer-Sheva 84105
ISRAEL
Tel.: + (972) (8) 646-1561
FAX: + (972) (8) 647-2949
Elect. Mail: sby@ee.bgu.ac.il
Power Electronics Laboratory: <http://www.ee.bgu.ac.il/~pel>

Date: December 30. 2006



Signature: Shmuel Ben-Yaakov

Table of Contents

Section	Title	page
1	Background	3
2	Electrical Terminology	4
3	The Taser M26 Stun Weapon Electronic Technology	7
4	The construction of the Taser M26 Stunt Weapon	10
5	Measurements that were carried out	13
6	Experimental Setup	13
7	The manufacturer's specifications	20
8	Measurements results	22
9	Conclusions	31

Appendices

A	Statement of work and supplementary documents
B	"Taser Waveform and pulse rate procedure"
C	Specification sheet of M26 Stunt Weapon
D	Measurements results – Plots and Statistics
E	Raw data of measurements (Excel)

1. Background

This evaluation was commissioned by the Israel National Police (represented by Special Technologies Officer, Superintendent Tiberiu Roth) for the purpose of comparing the performance of the Taser M26 Stun Weapon to the specifications published by the manufacturer (Taser International Inc., Scottsdale, Arizona, USA). The motivation for this evaluation, as relayed to the writer of this report, is the fact that some previous tests have shown that the output of the M26 may include high amplitude spikes, inconsistent with the manufacturer's specifications. Although the conjecture was that the observed spikes are measurement artifacts, it was deemed necessary to verify this by an additional and independent set of tests.

This report is written by Professor Shmuel Ben-Yaakov (PhD, University of California, Los Angeles, USA, 1970) of Ben-Gurion University, Israel. I am well qualified to write this report being an electronic engineer, university professor, educator and industrial consultant with over 45 years of professional engineering experience. I head the Power Electronics Group of the Ben-Gurion University of the Negev, Israel, and serve as a consultant to a many companies worldwide. I have published over 250 technical papers in leading international journals and conference proceedings; I am an inventor of US and European patents, I currently hold about 20 patents (as an inventor).

The report is based on the results of a set of tests conducted at the Power Electronics Laboratory on four M26 units applying procedures and test equipment that are well suited for the task. The report includes: clarification of the electrical terminology used in this report, an Introduction to the Taser M26 technology, description of the experimental setup and measurement procedure, summary of results and conclusions.

Considering the fact that this report is meant to be read by both non-experts as well as experts in Electrical Engineering, attempt was made to keep the discussion general such that it will be understandable by the non expert. Electronics experts will notice that some definitions, explanations and discussions lack a theoretical rigor. This was sacrificed for the sake of clarity

considering that the majority of readers will be non experts in electrical engineering. It should be noted though, that all statements are based on precise and rigorous foundation.

2. Electrical Terminology

This section provides a short explanation of the electrical terminology used in this report to better understand the electrical parameters that are cited. It should be noted that the explanation below is meant for the non expert in the art who may not have the background needed for understanding of basic EE parameters. The definitions given below are thus not rigorous. Accurate definitions can be found in any basic EE textbook.

2.1 Voltage. This parameter represents the electrical tension that will cause an electrical current to flow. The units are Volts, the abbreviation is V and the symbol is V . If the value of the voltage is changing then the parameter: "peak voltage" (V_p) represents the highest value of voltage observed.

2.2 Current. This parameter is a measure of the flow of electricity caused by a voltage. The units are Amperes, the abbreviation is A and the denotation is I .

2.3 Resistance. This parameter is a measure of the ability of an element, component or substance such as human body tissue to limit the current when exposed to a voltage. The units are Ohms, abbreviated by the Greek symbol Ω (Omega) and the denotation is R .

2.4 Impedance. This parameter is similar to R (resistance), namely the ability of an element to limit (impede) the current when exposed to a voltage. The difference between impedance and resistance is the time dependent nature of the voltage (and resulting current). That is, resistance is specified for constant and time invariable voltage and current, while impedance is specified for time variable voltage and the associated time variable current. By time variable we

mean a non-constant value as a function of time, The units of impedance are also Ohms, the symbol is Z.

2.5 Ohms Law. Voltage, current and resistance (or impedance) are related by Ohm's law that states that the current, I, that will flow in an element of resistance R across which a voltage V is imposed will be the voltage divided by the resistance. Or in an equation form:

$$I = \frac{V}{R} \quad (1)$$

Conversely, the voltage that will develop on an element with a resistance R will be equal to the current flowing through it, multiplied by the resistance:

$$V = I * R \quad (2)$$

Extending equation (1) to the general case for voltages and currents that are not static but changing with time (time variable):

$$\tilde{I} = \frac{\tilde{V}}{Z} \quad (3)$$

And

$$\tilde{V} = \tilde{I} * Z \quad (4)$$

Where the symbol ~ denotes time variable parameters (voltage or current).

2.6 Electrical Load. This term refers to the element, substance or device that is the recipient of the electrical voltage or current. The electrical load will have a resistance (for fixed voltages and currents) and impedance (for time variable voltage and current)

2.7 Electrical Energy. This parameter is a measure of the amount of work that the electricity can do (e.g. heating, or mechanical movement in a case of electrometrical device). The units are Joules, abbreviated by J and the

denotation is E. Electrical energy that is delivered to a load is related to the voltage and current delivered to it. In particular, if a current I is flowing through a load of resistance R , the energy transferred to it will be proportional to the square of the current (I^2) multiplied by the resistance and proportional to the time that the current is flowing into the load.

2.8 Voltage Source. A device or system that produces a voltage at its output terminals (example: a battery or power line).

2.9 Current Source. A device or system that produces a current at its terminals and through the load connected to it. Current sources are created electronically or by a voltage source that has a large resistance (or impedance) connected between a voltage source and the load. This is shown pictorially in Fig. 1. If the serially connected Z is large then it will limit the current such that even if the impedance of the load is zero, the current will not be larger than the voltage of the source divided by the serially connected impedance (Ohms law).

2.10 Breakdown/Arcing/Sparking. These terms refer to a mechanism by which an element or substance that is exposed to a voltage starts to conduct even if its resistance at lower voltages is very high. For example, air has a very high resistance and when exposed to a voltage will not conduct. However, if two electrodes that have a certain voltage between them will be held in air, a spark or arch, will develop if the voltage between the electrodes exceeds a certain level (the breakdown voltage) depending on the distance between the electrodes. For dry air at atmospheric pressure the value is approximately 30,000V (30kV) per centimeter (cm). This value is for a stable voltage. In case of a time dependent voltage or special electrodes' shape (such as sharp points) the breakdown voltage may be lower.

2.11 Some Implications. Considering the above, one should bear in mind that for a given electrical load (such as a human body tissue) that has a given

resistance R , the relationship between the voltage across it and the current through it is maintained by Ohms law. That is, if a voltage V is imposed on the load, the current I will be according to equation (1) $I = V/R$. If a current I is flowing then the voltage will be according to equation (2) $V = I \cdot R$. And in particular, for a given load, there is no way to force both the current to a given value and the voltage to a given value because the ratio of the voltage to the current is set by R of the load.

Another implication of the above, relevant to this report, is that for a given current flowing through a load, the energy delivered to the load will be proportional to the square of the current (I^2), the resistance of the load and the duration of the current flow. Note that if the resistance is very small (say zero) the energy delivered will be zero even if the current is high. Conversely, if the resistance is large the energy delivered will be proportionally high.

3. The Taser M26 Stun Weapon Electronic Technology

Judging from Taser International Inc. publications including patents held by the company, from general knowledge in EE, based on professional experience and the results of the tests, conducted at the Power Electronics Laboratory of Ben-Gurion University, it is my opinion that the Taser M26 electronic design follows that of the classical two stage sparker. For the purpose of this report it would be sufficient to describe the electrical system of the M26 as an electrical energy source that has a very high voltage, a waveform shaper and impedance that is connected serially with the load. This is shown in a block diagram form in Fig. 2. "S" is a switch that when activated will connect the high voltage energy source to the rest of the circuit. The waveform shaper generates a signal that is referred to as a damped sinusoidal. By "damped sinusoidal" we mean a sinusoidal waveform with amplitude that decreases with time.

The pulses for one squeeze of the trigger are generated at a rate of about 20 pulses per second, lasting for about 5 seconds. Ideally, and assuming a given initial energy, the total energy delivered per pulse should be the same independent on the resistance of the load. However, the Taser M26 circuit, as

any practical circuit has internal losses. These are due to internal resistances and other energy absorbing elements. Consequently, some of the energy is lost within the M26. This loss will increase as the load resistance decreases (smaller Ohms values). This is because the ratio of internal energy loss to the one delivered to the load is dependent on the ratio of resistances (resistance of the load divided by the internal resistance). So when the load resistor is large one would expect that internal loss will be relatively small and most energy will be delivered to the load.

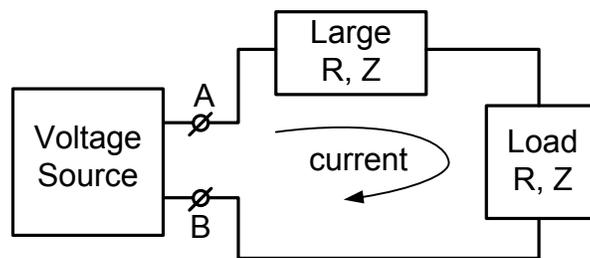


Fig. 1. A voltage source with terminals A, B connected to a load via a large R or Z to create a current source.

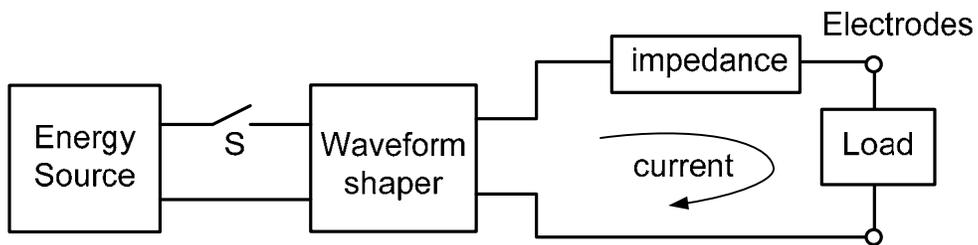


Fig. 2. Basic components of the M26 Taser relevant to output current pulse.

To demonstrate the operation of the circuit as understood by us, we have performed a computer simulation of the assumed circuit.

Fig. 3 shows the load current obtained by simulation for load resistances of Zero Ohms, 100 Ω , 1k Ω , 4k Ω , and 5k Ω . The duration of the pulse is about 10 microseconds (10 millionth of a second) for the positive part and same for the negative part. The total duration of the period of oscillation (positive plus negative) is about 20 microseconds, corresponding to a frequency of 50kHz (50 thousand cycles per second if run continuously). Fig. 4 summarized the results

by showing the value of the (positive) peak current I_p as a function of the resistance.

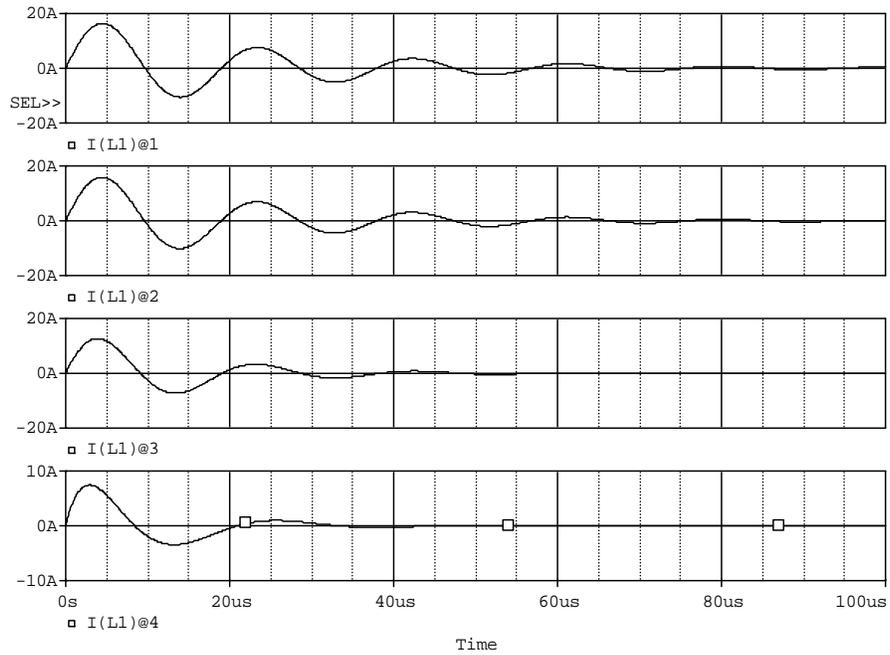


Figure 3. Computer simulation of Taser M26 output pulses. From top to bottom: shorted output, 100Ohm, 1kOhm, 4kOhm loads.

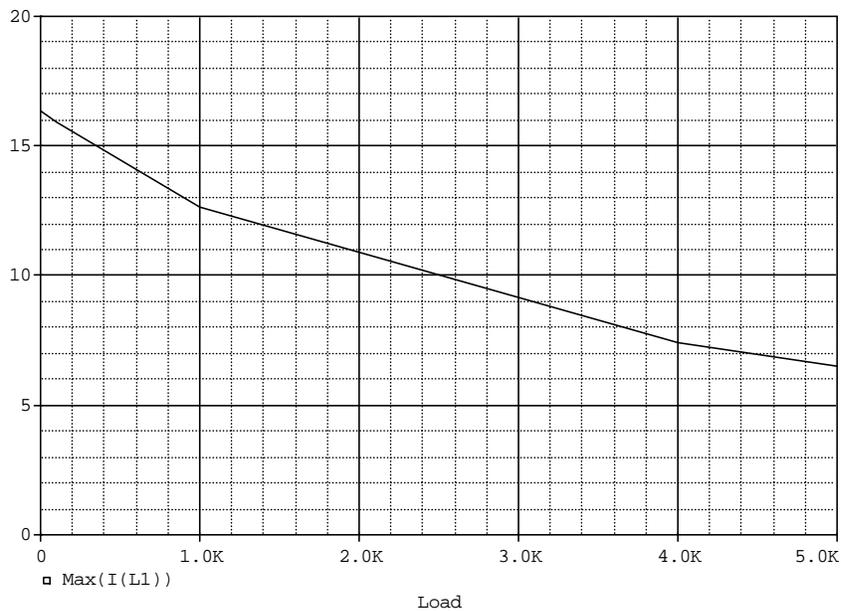


Figure 4. Simulated Peak Current (Fig. 3) as a function of the load resistance.

Implications: the implications of the simulation results depicted in Figs. 3, 4 are as follows:

- 3.1.1 The current waveform is a damped sinusoidal, the damping increases as the load resistance increases.
- 3.1.2 The circuit behaves approximately as a current source. For a 0 to 4k Ω resistance change the peak current changes by approximately a factor of two.
- 3.1.3 One would expect the energy delivered to the load to increase with load resistance.
- 3.1.4 The output voltage of the circuit (Ohms Law, current times resistance) may reach high values. For example with a 4k Ω resistor and 7.5A peak current (Fig. 3) the peak voltage will be $4,000\Omega \cdot 7.5A = 30,000V$ (30kV). With a lower load resistance the voltage will be proportionally lower.
- 3.1.5 If no load is connected to the M26 the output voltage may reach high values, limited by the design of the device.

4. The construction of the Taser M26 Stunt Weapon

The Taser M26 casing resembles a handgun. In normal operation mode a cartridge is attached to the front end of the weapon. The cartridge contains a folded wire, two mini arrows with hooks at their ends and the wires attached to the rear ends of the arrows and a means for firing the arrows. When fired, the mini arrows will be launched and if they hit a target, they will be attached to the target by the hooks while the wires carry the current from the weapon to the target. Figs. 5, 6 show the weapon, cartridge, and mini arrows. It should be pointed out that the connection between the weapon and the arrows is not continuous. There are air gaps between the contacts of the weapon and the contacts of the cartridge. Also, the wires are not connected electrically to the arrow. This can be seen clearly in Fig. 6 in which the end of the wire was pulled out from the hole in the arrow. It is clearly observed that the wire insulation is not

stripped down. This implies that the path of the current from the weapon to the target includes 4 non conducting gaps (2 air gaps at the front of the cartridge housing of the weapon and two wire insulations). Current will flow only after arcing occurs across these barriers. The mechanism is therefore as follow. At first the M26 sees a very high resistance (due to the very high resistance barriers) and will develop a high voltage at its front end. This high voltage will cause a breakdown of the gaps and current will start flowing towards the load. Then the voltage at the front end of the M26 will drop according to the resistance of the load (Ohms Law).



Figure. 5. Taser M26 with cartridge wires and arrows.

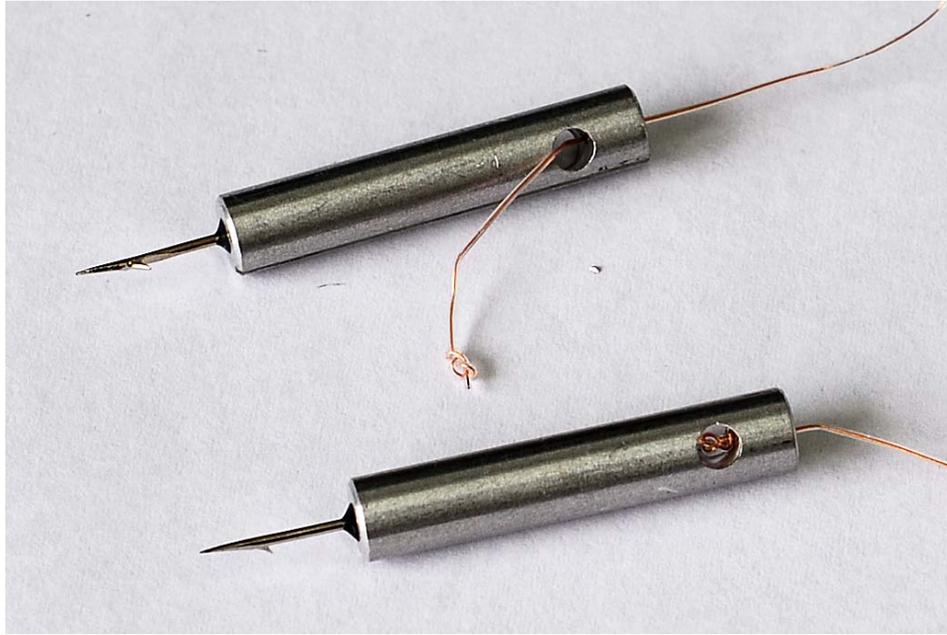


Figure 6. Arrows with one wire pulled out to show that the insulation is not stripped down.

If one of the arrows, or both, do not penetrate the skin of the target, current may still flow into the target. For example, if one of the arrows penetrates the skin while the other one is attached to the clothing, arcing may occur between the latter arrow and the body of the target closing the path for current flow.

In another mode of operation of the M26, the shocker mode, the weapon is operated without a cartridge. The weapon includes two contacts at its head separated by a distance of about 35 mm. When fired and without touching any target, arcing is observed. This implies that the voltage generated with no load (infinite resistance) is at least in the order of 100kV ($3.5 \times 30\text{kV/cm}$). This excludes the correction for the shape of contacts and the fact that the voltage is of short duration (high frequency). Both may reduce the breakdown voltage.

5. Measurements that were carried out

The measurements follow the specifications given in the Israel National Police order (see Appendix A). They included

- 5.1 Current measurements on five M26 units each fired four times when connected via the M26 arrows' wires to resistive loads of 100Ω , $1k\Omega$, and $4k\Omega$. Measurements included the current via loads, from which the various parameters were evaluated and calculated, e.g. peak current, energy, firing duration, pulses per second and others.
- 5.2 Voltage measurements on one M26 to estimate the voltage that it can develop with no load (shocker mode).
- 5.3 Duplication of measurements described in Taser International Inc. document "Taser Waveform and pulse rate procedure" (see Appendix B).

6. Experimental Setup

6.1 Current measurement procedure. Measurements were carried out by a LeCroy (Chestnut Ridge, NY) Waverunner Model LT264M oscilloscope equipped with a DC current probe model AP015. The resistive loads were built from strings of non inductive (carbon type) resistors in a construction (Figs. 7, 8 ,9) that will withstand the expected high voltage (especially with the $1k\Omega$ and $4k\Omega$ loads). To prepare the setup, a M26 cartridge was fired and the wire was wrapped on a block of Styrofoam (Fig. 10) such that the distance between individual wires was at least 3 cm. During experiments a M26 was attached to the fired (empty) cartridge and the resistive load was connected to the arrows at the end of the wires (Fig. 11). The current probe was clamped onto one of the resistor's wires. This wire was also grounded to earth potential using a jumper. Without this grounding arrangement, the potential of the wire inserted into the current probe is undefined and may reach high voltages dependent on parasitic resistive leakage paths of the various parts of the circuit. If a high potential develops between the

lead inside the probe and the probe electronics (which is internally grounded) mini sparks may develop which will cause the formation of erroneous spikes on the collected data. We have therefore followed the good engineering practice that calls for grounding the wire that is inserted into the current probe. As electronics professional would clearly verify, this connection does not change in any way the current flowing into the circuit except for eliminating the possibility of generating incorrect and irrelevant noise on the collected data.

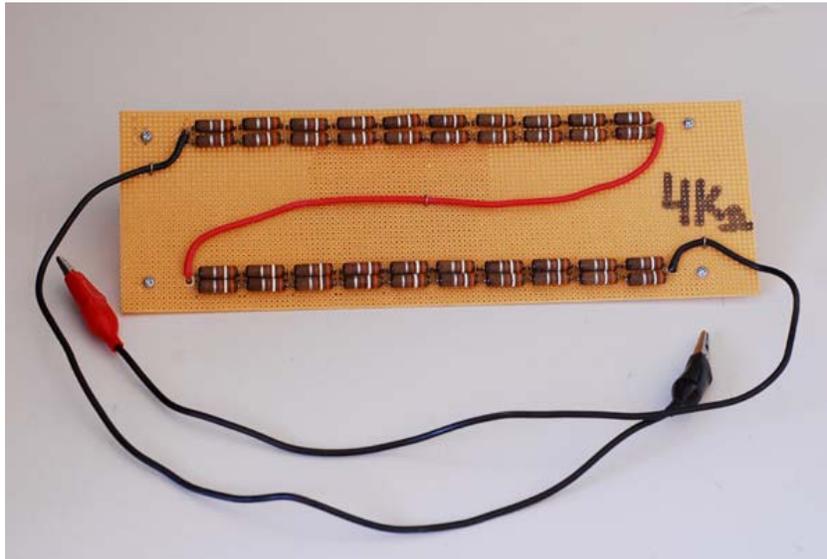


Figure 7. Construction of the 4kOhm load.

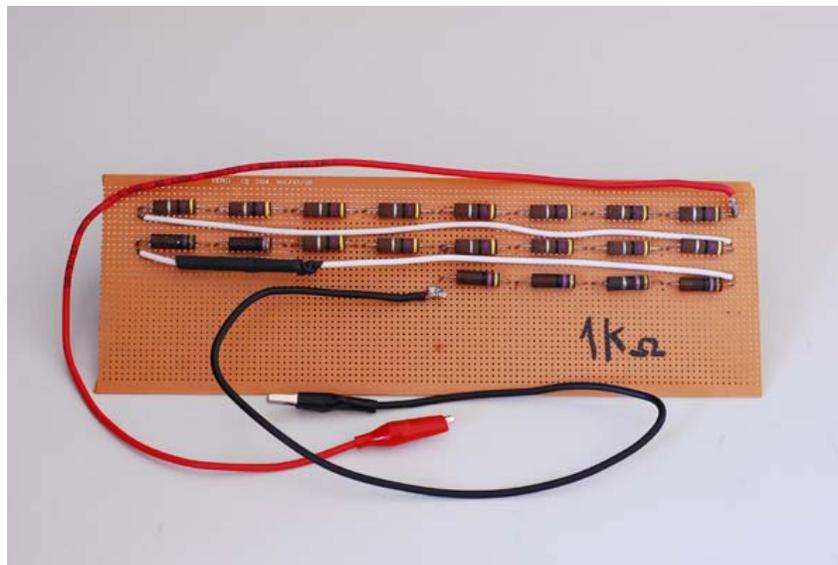


Figure 8. Construction of the 1kOhm load.

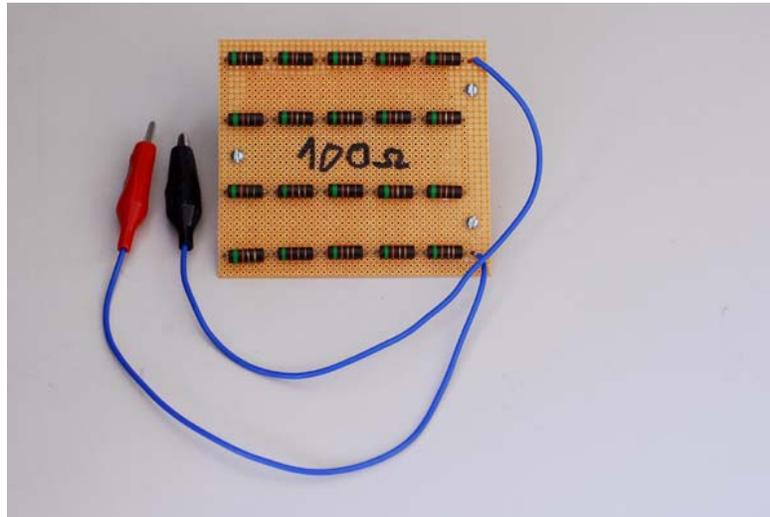


Figure 9. Construction of the 100Ohm load.



Figure 10. The M26 wires wrapped on a Styrofoam block

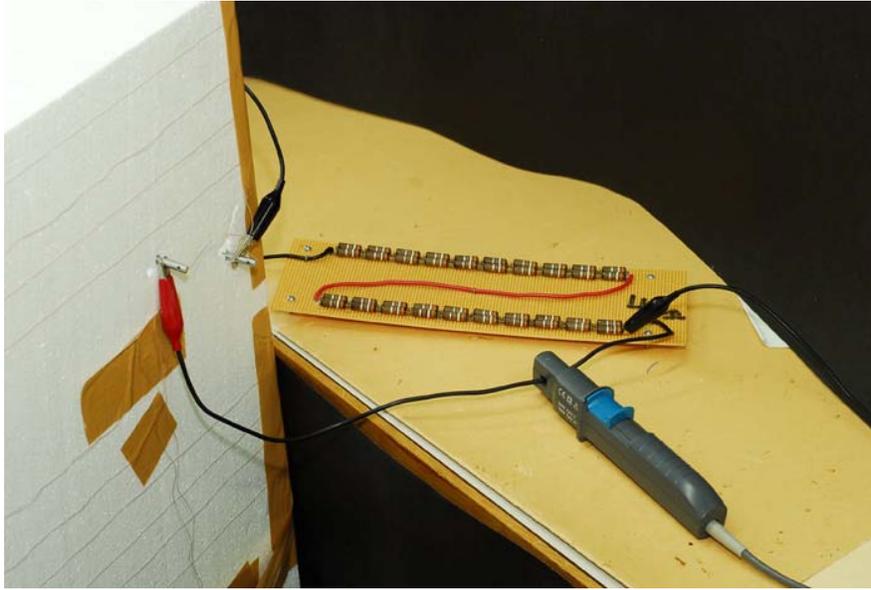


Figure 11. Experimental setup for current measurement

The data for each firing event was collected by using the "sequence" feature of the LT264M oscilloscope. In this mode the data for each pulse is registered while ignoring the time between pulses. The collected data was then transferred to a computer and processed using Microsoft Excel software.

6.2 Voltage measurements. The voltage measurements for estimating the open circuit (no load, shocker mode) voltage were carried out by a spark gap formed by two screws of approximately 4mm diameter with smooth ends. The spark gap was connected electrically to the M26 head by two wires soldered to the contacts on the head of weapon. The system was first calibrated by putting the 4kOhm load in parallel to the spark gap. By this, the voltage was limited to the voltage developed across this resistance. The set with 4kOhm connected in parallel is shown in Fig. 12. The gap was then increased until sparking was infrequent (not for every pulse). Then the parallel resistor was removed and the spark gap was increased to 30mm. The gun was fired and arcing was observed across the spark gap.

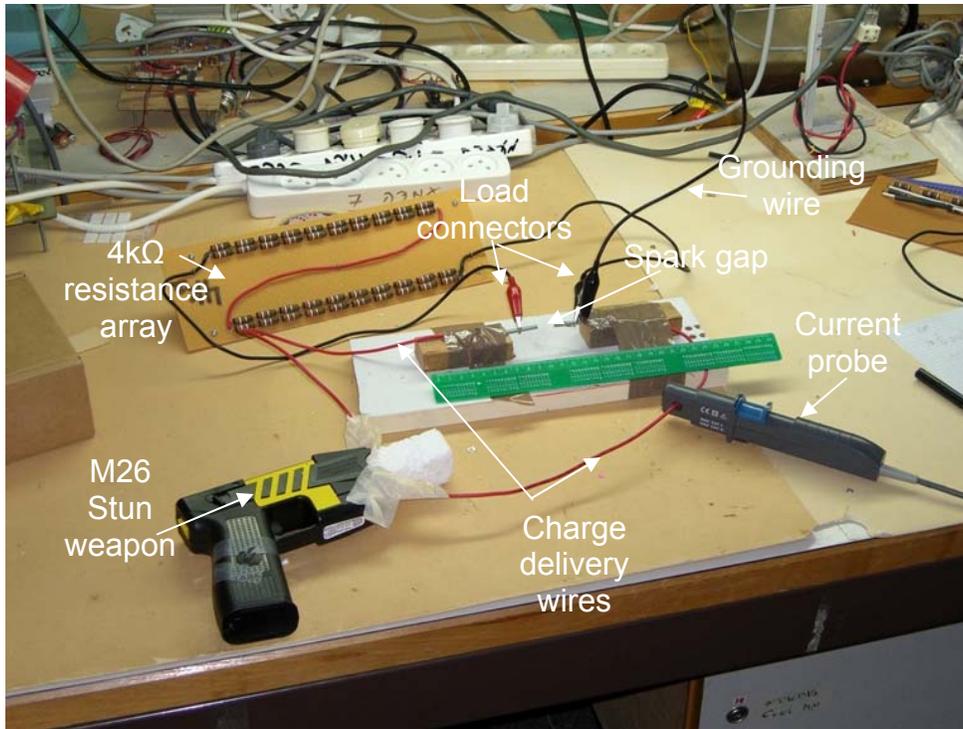


Figure 12. Spark gap experimental setup. Calibration with a 4kOhm resistor.

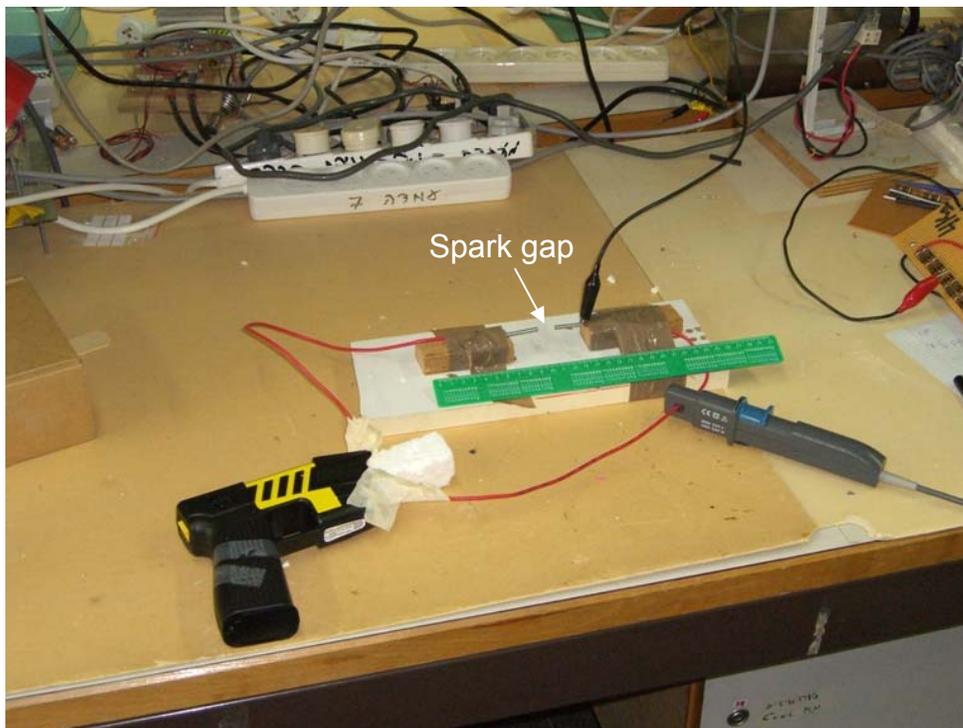
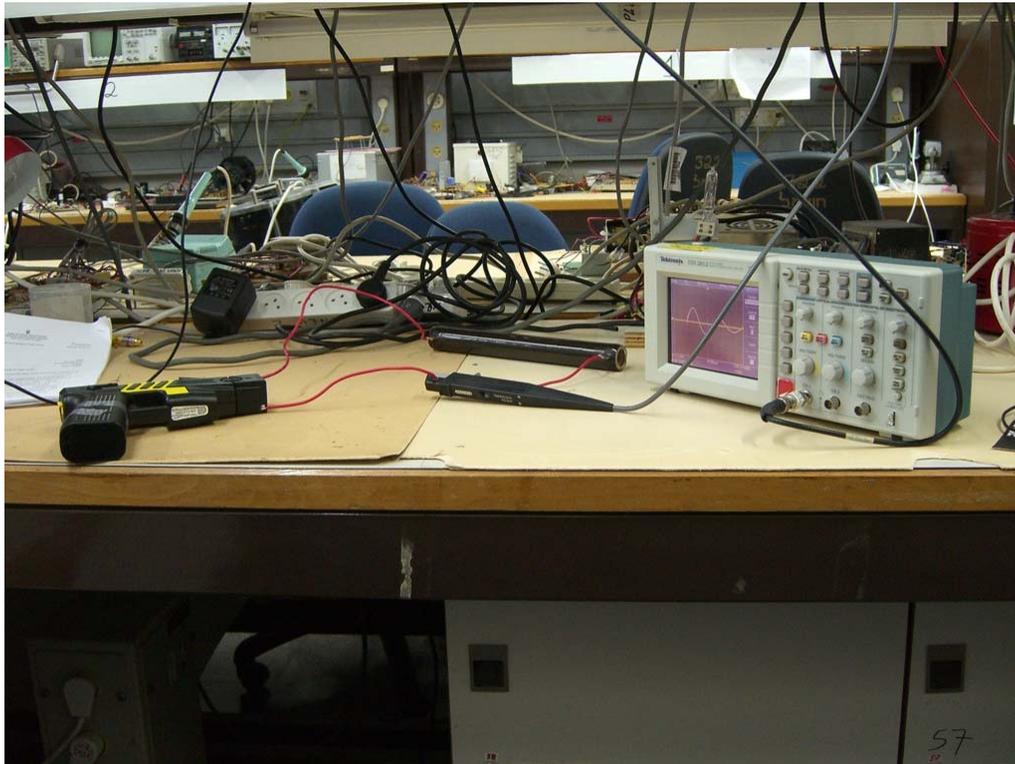


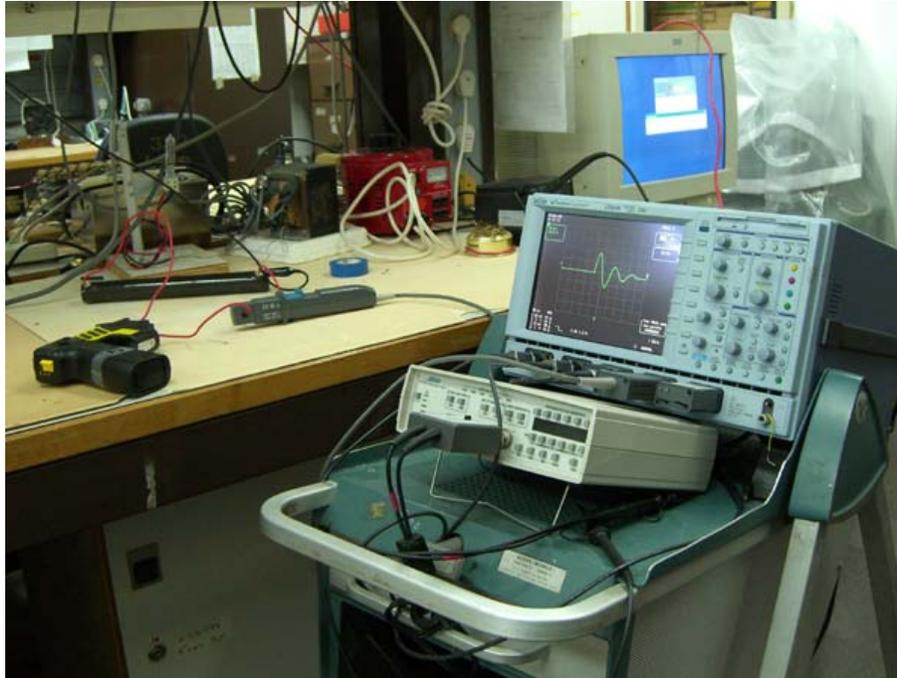
Figure 13. Spark gap experimental setup. 30mm Gap with no resistor in parallel.

6.3 Duplication of Manufacturer's Measurements procedure (Appendix B).

The procedure followed the one described in the document "Taser Waveform and pulse rate procedure" copied in Appendix B except for using a different current probe. The probe specified in the document is Tektronix Model TCP202 while we have used (due to the non availability of the TCP202) a Tektronix current probe Model A6302 and associated amplifier. The set up in this case is shown in the photograph of Fig. 14, the panel of Model AM503 amplifier is shown in Fig. 15. As would be clear to an electronics professional, the functionality of these two current probes is practically identical for the present M26 measurements.



(a)



(b)

Figure 14. Experimental setup for duplicating manufacturer's measurements. (a) The specified setup. (b) Repeating the measurement with LeCroy system.



Figure 15. Front panel of current probe amplifier.

Although we followed to the letter the procedure "Taser Waveform and pulse rate procedure" that is described by text and pictures (in an IKEA, do-it-yourself style), one should be aware that this procedure by Taser International Inc. is

highly questionable and certainly not recommended. This is for at least two reasons:

First, this procedure, at best, does not verify the specification given by the manufacturer. It measures the average wave shape of the current pulse (averaged over 16 pulses) and the time interval between pulses. So if spikes occur, they will be smeared. This procedure cannot verify the occurrence of high amplitude spikes.

Secondly, Taser International Inc. specified a wire wound resistor Ohmite Model L225J250 as a load. This resistor (due to its structure) has large inductance so the overall impedance Z is clearly different from the specified 250Ω resistance for DC or low frequency. Furthermore, this resistor is specified by Ohmite for DC or low frequency AC operation and not for pulse operation. Even worse, the specified safe operating voltage of this resistor (in DC or low frequency) is up to 3000VAC. It stands to reason that the breakdown for pulses will be at lower voltage. In the recommended test procedure the voltage across the L225J250 may reach voltages above 4000V. So there is a real danger that if high current pulses are formed the resistor will breakdown and suppress these voltages.

7. The manufacturer's specifications

The M26 datasheet (a copy in Appendix C) include "Power Output" specification which is the subject matter of this evaluation and report. It needs to be emphasized at the outset, that these manufacturer's specifications are confusing, ambiguous and from the theoretical point of view, incorrect. Furthermore, unlike the practice adopted by reputable manufacturers of electrical equipment the specification do not state if the numbers are "minimum" typical" or "maximum". This system of classification is used in the industry to set limits for specified parameters. The typical value is the most likely value, the maximum value is the upper limit and the minimum value is the lower limit of the parameters' value. Also, it is important to state under what condition was the parameter tested. For example, in the present case, when specifying the energy output one should state under what load conditions does this value hold and of course what are the

limits (min and max). Notwithstanding these deficiencies, attempt was made to interpret the meaning of the specified parameters.

The "Power Output" specifications include three parameters: peak voltage, average current, and energy. Each of these parameters is addressed and interpreted below.

7.1 Peak voltage. The specification states "peak voltage 50,000V". To the non professional this may sound as if the maximum output voltage of the M26 is 50kV. It is my opinion, this interpretation is wrong. To the best of my professional understanding and based on the operation of the M26 the interpretation should be: peak voltage: 50kV minimum under no load condition (shocker mode). First, to the meaning of peak voltage. The waveform of the currents and voltages generated by the M26 are damped sinusoids (Fig. 3). The peak voltage value is the highest voltage of this waveform. So "peak voltage" is the voltage measured at the peak of the waveform. For the M26 to work properly it has to be capable of developing high voltages for sparking the gaps (at the cartridge housing and arrows), and possibly to arc between an arrow attached to the skin of target and an arrow attached to the clothing of target, or between two arrows attached to the clothing. Hence the pertinent information is "what is the lowest voltage that the M26 can produce". We therefore interpret this parameter as stated above.

7.2 Average current. Being a bi-polar pulse (having a positive and a negative part), the average current, from the theoretical point of view, is close to zero (since the positive parts cancel the negative parts). Furthermore, since this parameter is related to questions of safety, negative currents are as important as positive currents. So my interpretation of this parameter is that it is: "the average of the absolute value of the current – typical value for some unspecified load resistance". It is also assumed that the averaging is over the complete (approximately 5 second) firing sequence and not within the pulse itself. In the latter case the values will be much higher than the one cited.

7.3 Energy. It is believed that this parameter is based on circuit design and in particular, the energy available in the M26 for each pulse. So my interpretation to this parameter is: " typical, for large resistance loads".

8. Measurements results

8.1 Current Measurements results. The detailed measurements' results are summarized in the graphs and tables given in Appendix D. (Figures and Tables in Appendix D are marked Fig. Dxx and Table Dxx). The raw data is given as Excel files and marked Appendix E. The main findings are that the current pulse waveforms are damped sinusoids with no spikes (Figs. 16-18). Evidently, the spikes observed by others are erroneous (test artifacts). The measured waveforms and the simulated waveform (Figs. 3) are in very good agreement. This verifies our conjecture concerning the way the M26 generates the pulses (Section 3). The implication is that the Taser M26 output can be categorized as a current source keeping the peak current in the range of about 20A for a shorted output to about 9A for a 4kΩ load (Fig. 19). Consequently, the calculated output voltage is about 2kV for a 100Ohm load and about 35kV for 4kOhm load (Fig. 20). Correspondingly, the calculated average (over the full firing sequence, about 5 seconds) of the absolute value of the current was found to range from 6mA to 1.5mA (Fig. 20). All the above are average values.

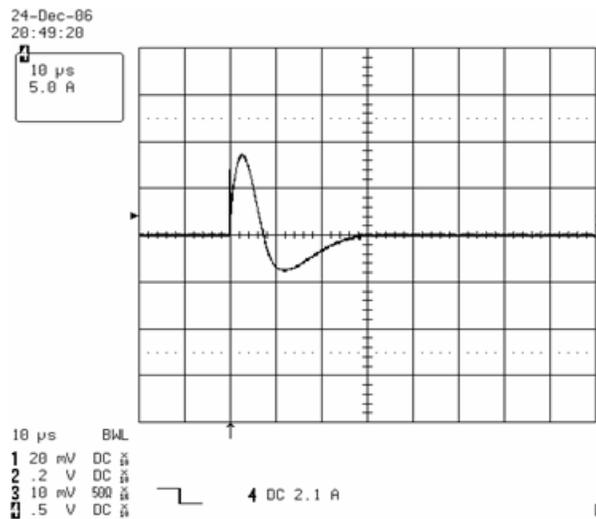


Figure 16. Typical output pulse current of the M26 as recorded during this evaluation. Load resistance 4kOhm.

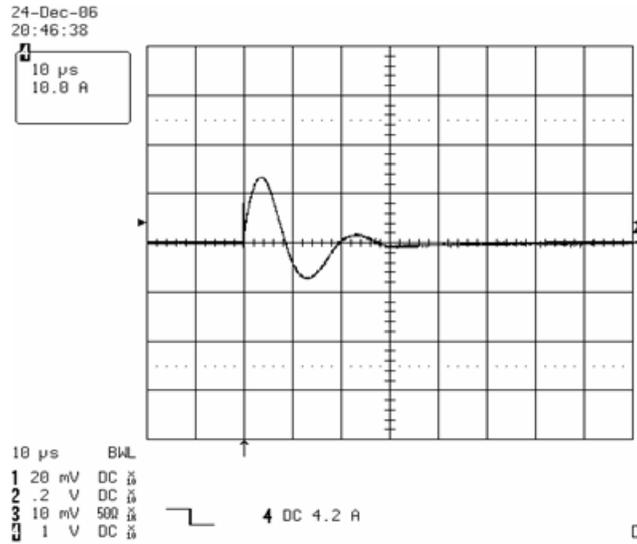


Fig 17. Typical output pulse current of the M26 as recorded during this evaluation. Load resistance 1kOhm.

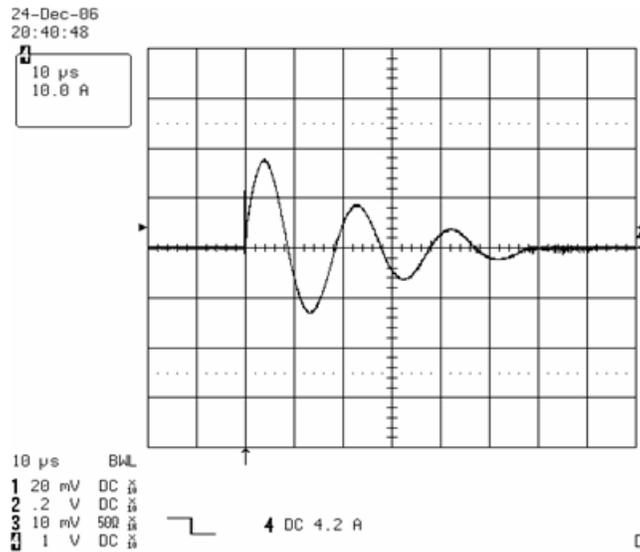


Figure 18. Typical output pulse current of the M26 as recorded during this evaluation. Load resistance 100 Ohm.

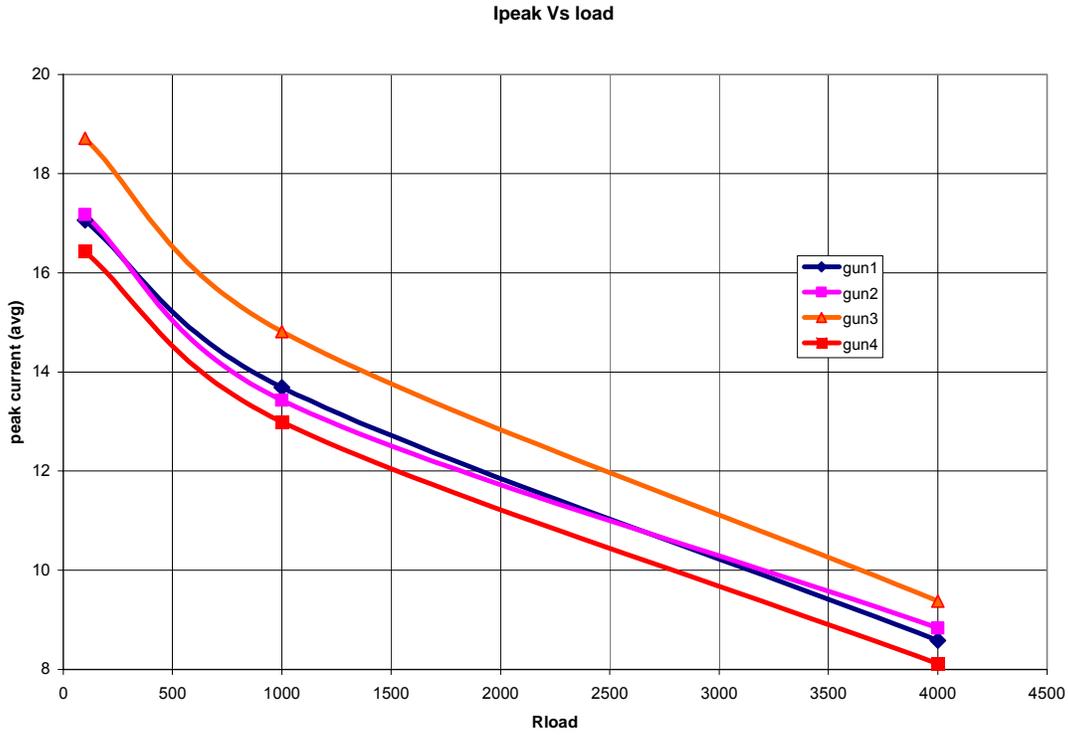


Figure. 19. Measured peak current versus load resistor for all M26 tested. Average values of 4 shots each.

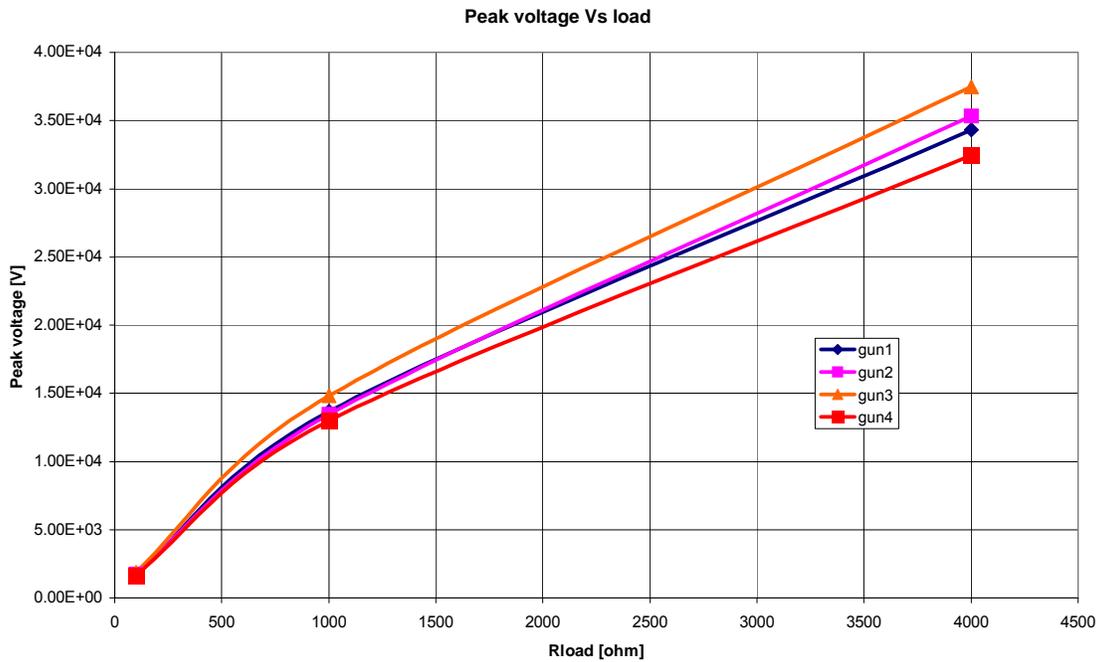


Figure 19. Peak voltage calculated from measured peak current versus load resistor for 4 M26 units. Average values of 4 shots each.

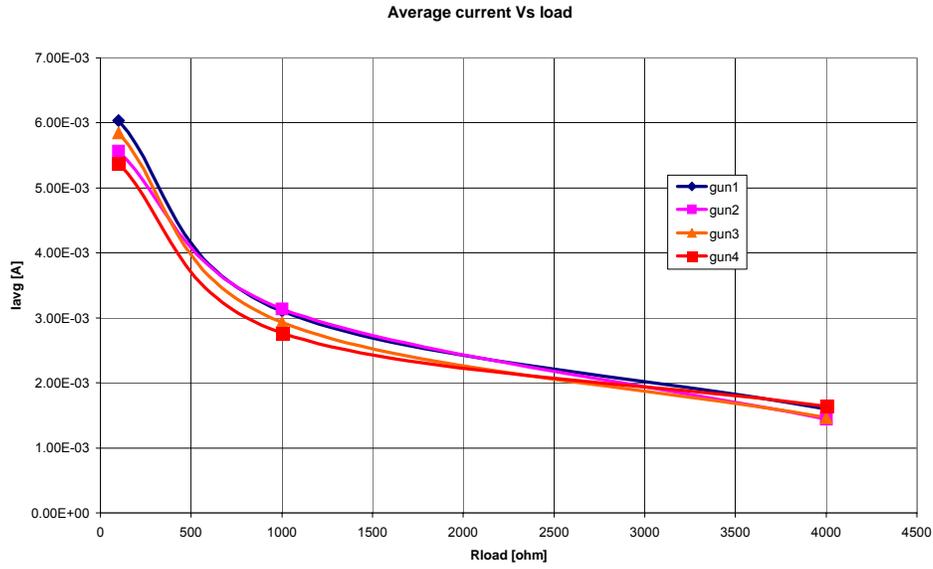


Figure 20. Average of absolute value of current, calculated from measured peak current, versus load resistor for 4 M26 units. Average values of 4 shots each.

The energy delivered to the load was found to be dependent on the load resistance (Fig. 21) as expected, ranging from about 0.2J to about 1.78J. It should be noted that all the above are average values.

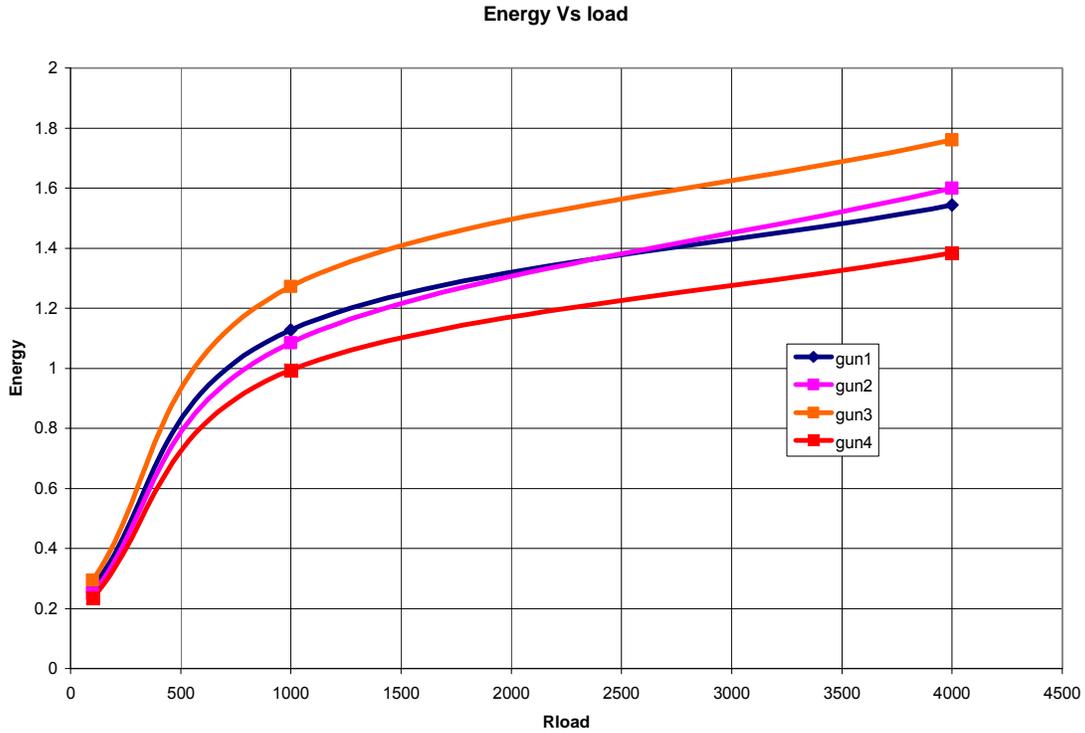


Figure 21. Average pulse energy, calculated from measured peak current, versus load resistor for all M26 tested. Average values of 4 shots each.

The repeatability of the M26 output was found to be good with only a small spread between the shots for a given unit and from weapon to weapon.

Table 1. Statistics of peak current [A]

peak-4kΩ	gun1	gun2	gun3	gun4
Max	9.21875	9.0625	10.1563	10
Min	7.96875	8.4375	8.90625	7.8125
Avg	8.579848	8.835943	9.373794	8.112305
stdev	0.386718	0.126001	0.173306	0.216767
peak-1kΩ	gun1	gun2	gun3	gun4
Max	14.0625	13.75	16.25	14.0625
Min	13.4375	12.8125	14.0625	12.6563
Avg	13.68827	13.43268	14.81418	12.99145
stdev	0.173325	0.213644	0.358813	0.137663
peak-100Ω	gun1	gun2	gun3	gun4
Max	18.4375	19.0625	19.6875	17.5
Min	16.5625	16.5625	18.125	15.9375
Avg	17.05826	17.17496	18.71142	16.42361
stdev	0.248675	0.268076	0.305512	0.283646

Table 2. Statistics – valley current [A]

valley-4kΩ	gun1	gun2	gun3	gun4
Max	-3.28125	-3.59375	-3.59375	-3.125
Min	-4.21875	-3.90625	-4.21875	-3.59375
Avg	-3.72955	-3.71844	-3.98883	-3.33643
stdev	0.28174	0.093552	0.109104	0.083595
valley-1kΩ	gun1	gun2	gun3	gun4
Max	-7.1875	-6.875	-7.1875	-6.40625
Min	-7.8125	-7.1875	-8.75	-7.34375
Avg	-7.41995	-7.07562	-7.69364	-6.5789
stdev	0.144766	0.150726	0.271076	0.095772
valley-100Ω	gun1	gun2	gun3	gun4
Max	-13.75	-11.875	-12.8125	-11.25
Min	-12.1875	-13.4375	-13.75	-12.5
Avg	-12.6784	-12.0544	-13.2649	-11.6821
stdev	0.205109	0.204784	0.217203	0.218749

Table 3. Statistics – energy [J]

energy-4kΩ	gun1	gun2	gun3	gun4
Max	1.804297	1.753633	1.908633	1.537187
Min	1.353125	1.492773	1.565547	1.280391
Avg	1.543665	1.59953	1.760044	1.384132
stdev	0.129963	0.039165	0.059181	0.044264
energy-1kΩ	gun1	gun2	gun3	gun4
Max	1.220352	1.139492	1.523867	1.182082
Min	1.065352	0.977188	1.157852	0.952465
Avg	1.127137	1.084856	1.271611	0.993684
stdev	0.021008	0.029281	0.058513	0.017193
energy-100Ω	gun1	gun2	gun3	gun4
Max	0.316074	0.298961	0.319934	0.258859
Min	0.255625	0.238734	0.276582	0.218609
Avg	0.270297	0.250283	0.294869	0.234949
stdev	0.007155	0.005809	0.008695	0.006879

8.2 Spark Gap Voltage measurements. Our spark gap output voltage measurements indicate that arcing still occurs at a gap of 30mm while the gap of 17mm was calibrated to correspond to 35kV peak. This implies that the M26 can produce voltages in excess of $30\text{mm} \times 35\text{kV} / 17\text{mm} = 60\text{kV}$ peak. Furthermore, considering that the distance between the contacts at the head of the M26 is 35mm and that sparking is observed with no load (Fig. 22), one can assume (by extrapolation) that the Taser M26 can develop voltages in excess of 70kV peak.



Figure 22. Sparking in shocker mode, capturing one two and a number of sparks. Distance between electrodes: approx. 35mm.

8.3 Results of measurements done according to the “Taser Waveform and pulse rate procedure”.

The results of the measurements according to the "Waveform and pulse rate procedure" were found consistent with the measurements made with non inductive loads. The small differences that were found are due to the fact that the resistor specified by Taser International Inc. for this procedure is a wire wound resistor. The main differences are: (1) The peak current (15.2A) was somewhat lower than expected for 250Ohm load. This is explained by the fact that the impedance Z of this inductive resistor is larger than 250Ohm. Results of LR (series inductance-resistance) measurements made at 50kHz (see Appendix D) on the resistors are given in Appendix D. (2) The measurement with the Ohmite L225J250 resistors show some oscillations at the onset of pulse (Fig. 23). These are absent from the measurement with the non inductive resistors (Fig. 17). In the latter, one also observes a small spike at the beginning of the pulse. All these are consistent with the fact that the Ohmite resistor is wire wound resistor with considerable inductance as well as intertwining capacitances.

The results of the pulse rate measurements according to the "procedure" (Fig. 24, 25) were of course identical to the ones carried out on the non inductive resistors.

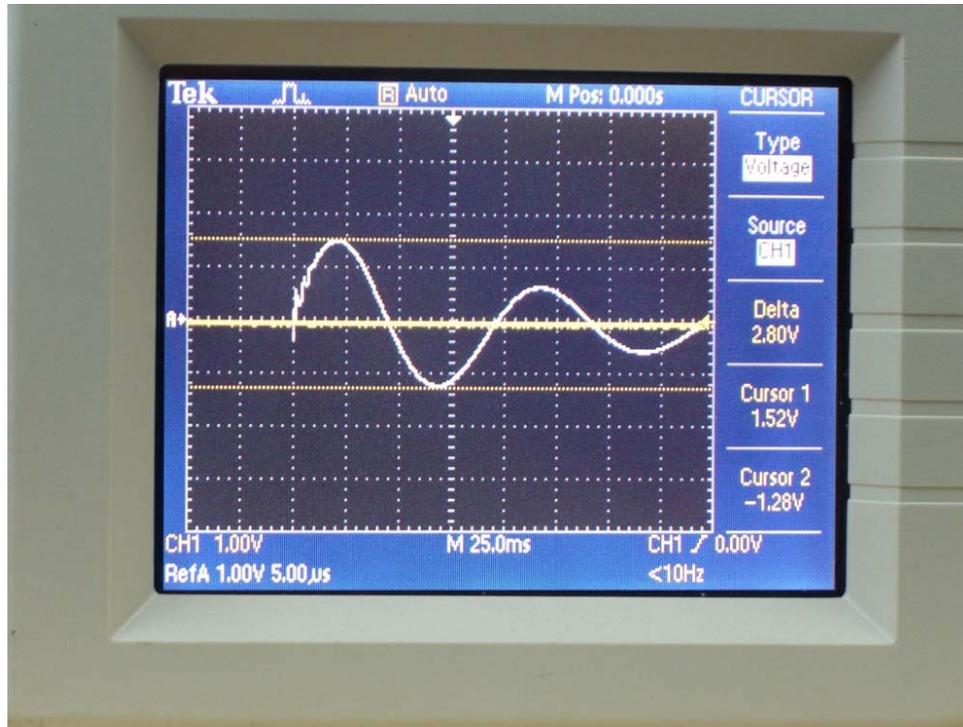


Figure. 23. Pulse shape measurement according to the "Taser Waveform and pulse rate procedure". Vertical scale 10A/div. Horizontal scale 5µs/div.

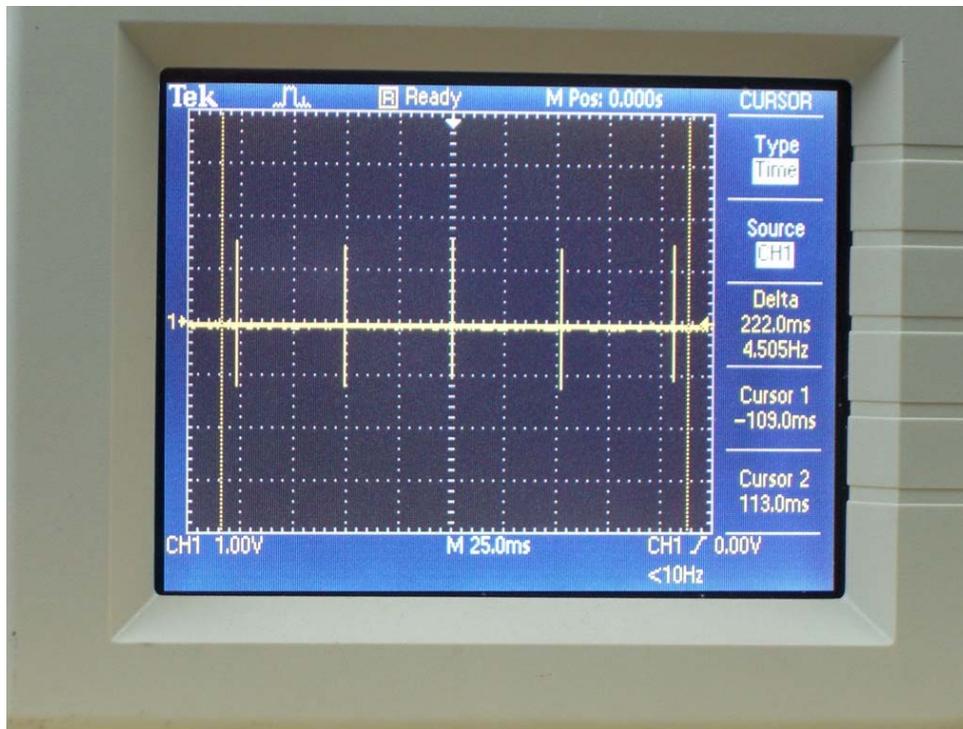


Figure. 24. Pulse rate measurement according to the "Taser Waveform and pulse rate procedure". Vertical scale 10A/div. Horizontal scale 5µs/div.

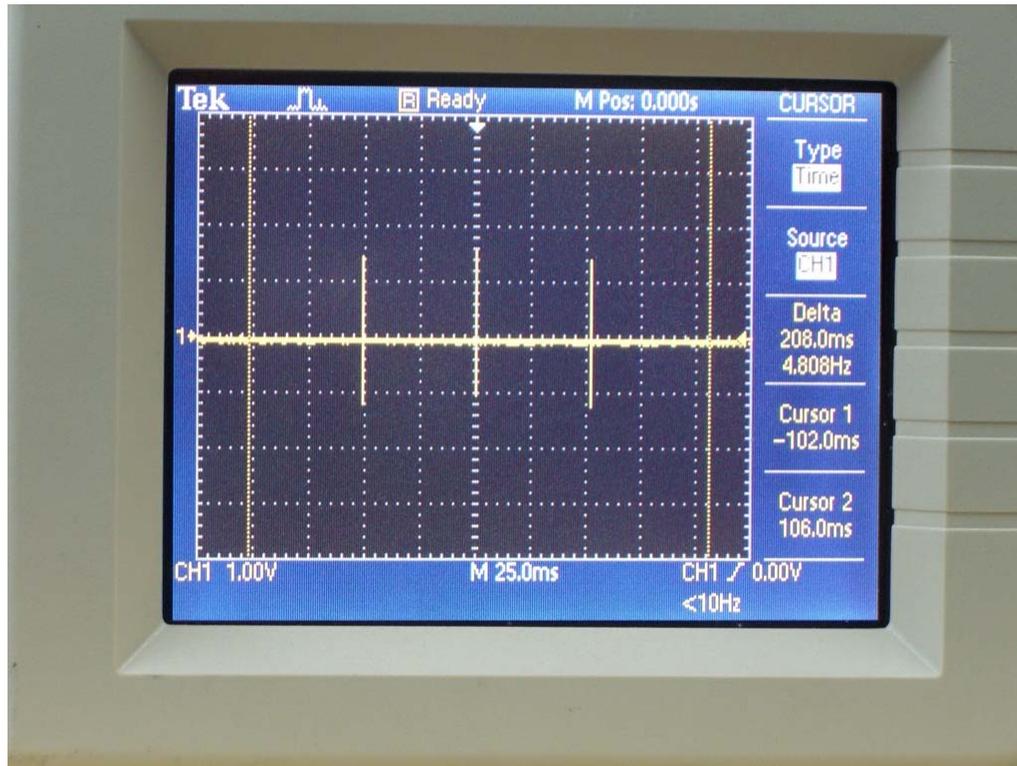


Figure. 25. Pulse rate measurement according to the "Taser Waveform and pulse rate procedure". Vertical scale 10A/div. Horizontal scale 5 μ s/div.

9. Conclusions

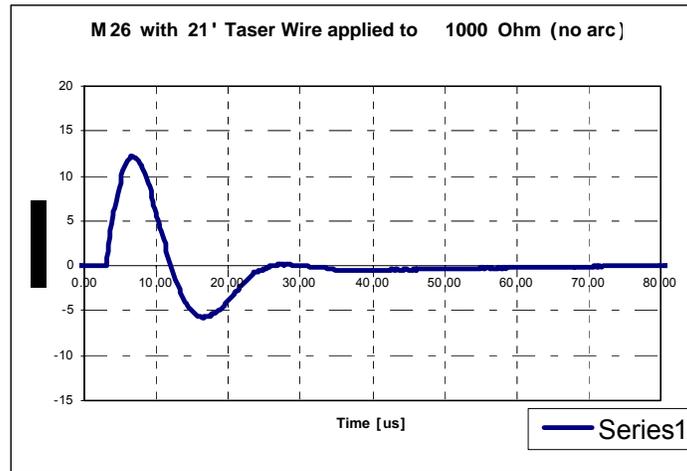
The primary conclusion of this report is that the findings of this evaluation are consistent with the Power Output specifications given in the Taser M26 data sheet, subject to the interpretation given in Section 7. I can thus confirm that the following were verified experimentally:

1. Peak voltage: 50kV (minimum) under no load condition (shocker mode).
2. Average of the absolute value of the current: 3mA (typical) for 1kOhm load.
3. Energy: 1.6J (typical) for a 4kOhm resistor.

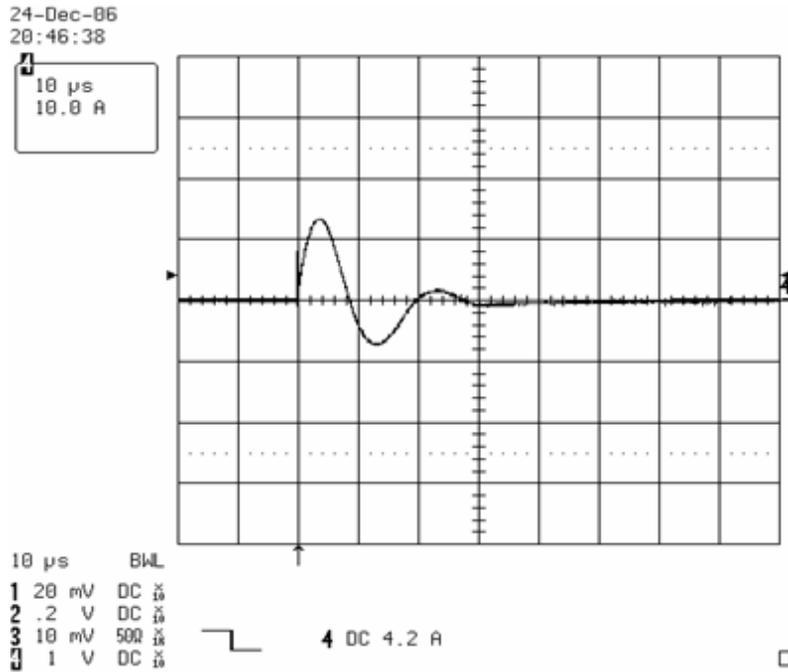
Comparing our results to the waveforms submitted by Taser International Inc. (see Excel file "M26 into various loads.xls" and "Proposal_Addendum.pdf" in Appendix A), we found one significant difference. To better explain this difference we copied below the Taser International results and ours. Fig. 26 is for the 1kOhm load, Fig. 27 is for the 100Ohm load. One discrepancy is the magnitude of the peak values. As one would notice our measured pulse shows a small spike at the beginning of the pulse (marked in Fig. 27b) while in the case of the Taser International data the pulse is smooth. Although Taser International does not provide description of the setup used by them, we believe that the explanation to the discrepancy is as follows.

First, we explain the reason for the spikes observed in our data. As discussed in Section 4, due to the air gaps at the head of the M26 and insulation at the end of the wires, an arcing process is needed before current can flow into the load. Once the sparking occurs, current will start to flow and due to the parasitic parallel capacitances in the head of the M26 and those of the (non-inductive) load one would expect to see a current spike considering the high voltage that needs to develop before the arcing occurs. In the Taser International data, this spike is missing. It is my conjecture that the reasons for that are: (1) that Taser International used wire wound resistor and hence inductive resistors and that the connection was different from the one described in the document "Taser waveform and pulse rate procedure". I suspect that the data given in "M26 into various loads.xls" was collected by a system that did not include the gaps, i.e. the load was connected directly by wires to the contacts on the M26 cartridge housing. In this case no arcing is expected and the resistor and its inductance become a continuous part of the inner electronics of the M26. I guess that this is the meaning of "no arc" at the head of the plots (marked in Fig. 27a). To verify this point, we have repeated the experiment with no arcing by connecting the wire wound resistor (Ohmite L225J250) directly to the head of the M26 by soldering the wires to the contacts. In this case (Fig. 28) the pulse was indeed smooth without a spike or oscillations at the beginning.

Considering the above I conclude, conditioned on the correct interpretation of the manufacturer's specifications (Appendix C), that no significant differences were found between the manufacturer's "output power" specifications as well as the measured data on the M26 Stunt Weapon (provided by the manufacturer), and the results of this evaluation. I further assert that the output current of the M26 does not include high magnitude spikes beyond the relatively small spikes, documented above, that are expected at onset of the current flow.

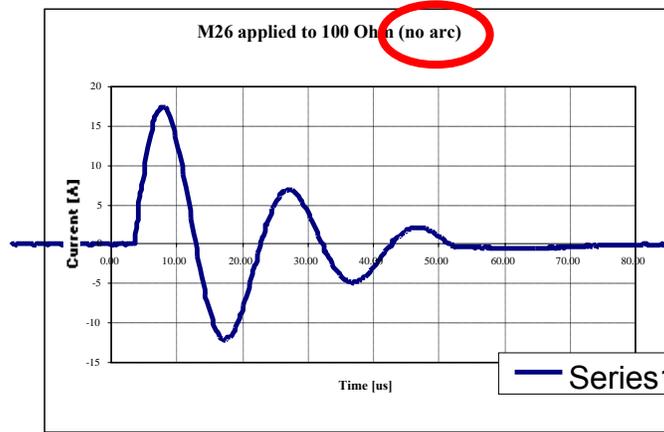


(a)

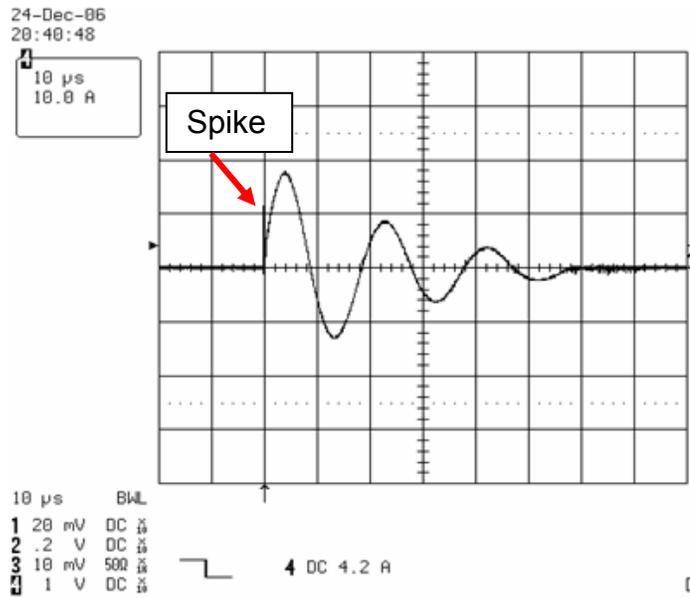


(b)

Figure 26. Measured current pulse with 1kOhm load. (a) Taser international Inc. data. (b). Data collected in this evaluation with a non inductive resistor.



(a)



(b)

Figure 27. Measured current pulse with 100Ohm load. (a) Taser international Inc. data. (b) Data collected in this evaluation with a non inductive resistor.

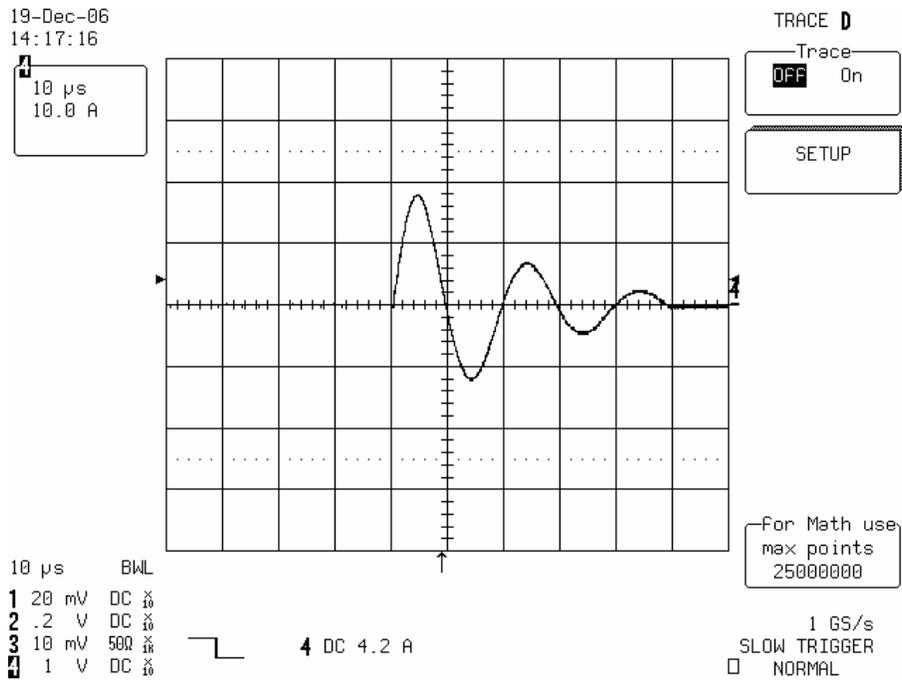


Figure 28. Measured current pulse with 250Ohm wire wound resistor (Ohmite) connected directly to the cartridge housing connections of the M26 (no gaps and therefore no arcing).

This Report includes the following Appendices submitted in attached files :

Appendix A. Statement of work and supplementary documents

Appendix B: "Taser Waveform and pulse rate procedure"

Appendix C: Specifications sheet M26 Stunt Weapon

Appendix D: Measurements results – Plots and Statistics

Appendix E: Raw data of measurements (Excel)