Xflight Technologies LLC

XF-160GL3 Lightning Pulse Generator

Data sheet and User Guide

Version 1.2

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Xflighttech.com

XF-160GL3 Specifications

Item	Value	Unit
Unit length	220 (8.67)	mm (inch)
Unit width	150 (5.90)	mm (inch)
Unit height	64 (2.52)	mm (inch)
Unit weight	0.78 (1.85)	Kg (lbs)
Enclosure material	ABS plastic / FR-4 TG130	-
Battery requirement (Batteries not provided)	X6 1.2V (AA)	V
Current consumption (quiescent)	300	mA
Total power consumption (quiescent)	2.2	W
Battery polarity protection	Yes	
Safety cut-out switch	Yes (Optical)	
Output Pulse Terminals (material)	Brass	-
Output Pulse Terminals (type)	4mm Banana plugs	-
Max O/C peak voltage	400	V
Max S/C peak current	60	A
Current Measurement Bandwidth	400	KHz
Current Measurement Sensitivity	25	mV / Amp
O/C voltage rise time (@ 300V)	5.3 ± 10%	µs
O/C voltage fall time to half peak(@ 300V)	72 ± 10%	µs
S/C current rise time (@ 60A)	3.4 ± 10%	µs
S/C current fall time to half peak (@ 60A)	59 ± 10%	µs
Output Impedance	5	Ω
DO-160G WFs for current and voltage	1 and 4	-
DO-160G levels for voltage and current	1, 2 and 3	-
Unit protection against external voltages (TVS)	>567	V

A. Introduction

The XF-160GL3 produces a double exponential voltage / current pulse intended to give confidence that a design can pass **DO160G** and **MIL-STD-461G** conformance / Qualification tests. DO160G is the RTCA Inc. Environmental Conditions and Test Procedure for Airborne Equipment. It is a very important aviation industry specification and used throughout the industry to qualify any equipment prior to it being allowed to fly on commercial aircraft. Section 22 relates to **Lightning Induced Transient Susceptibility** testing. It defines certain waveforms that must be applied to any unit under test (UUT). Two types of application of simulated lighting energy are described.

(i) **Induced.** This is where the energy it transferred to the UUT via induction into cables connecting signals and power to the UUT. (The cabling to be as similar to a real installation as possible).

(ii) **Direct pin injection**. A test probe is connected, in turn, to each connector pin that allows any signal or power line to connect the unit to the aircraft.

Of the two cases above the direct pin injection is considered to be the worst case since all the energy is concentrated onto a single pin / signal. Furthermore, of the different types of waveform, the one considered to be the worst case is the double exponential (see appendix A(5)(b). The rise time and fall time of the pulse is important. This defines the pulse width and so the amount of energy that can be transferred to a UUT. For high impedance signals that effectively deflect the energy back to the source, the pulse width defines for how long a high voltage is present on the interface. The XF-160GL3 supports a waveform very similar to the DO-160G waveform 1 (WF1) and waveform 4 (WF4). WF1 is a current waveform for low impedance signals where it is not possible to meet the voltage requirement. WF4 is the voltage waveform.

DO160G defines different levels of energy (Level 1 being the weakest and level 5 the strongest). The level needed depends primarily on the equipment function (i.e. critical or not) and the installation location. (There is also a dependence on any electrical connections to other parts / equipment on the aircraft).

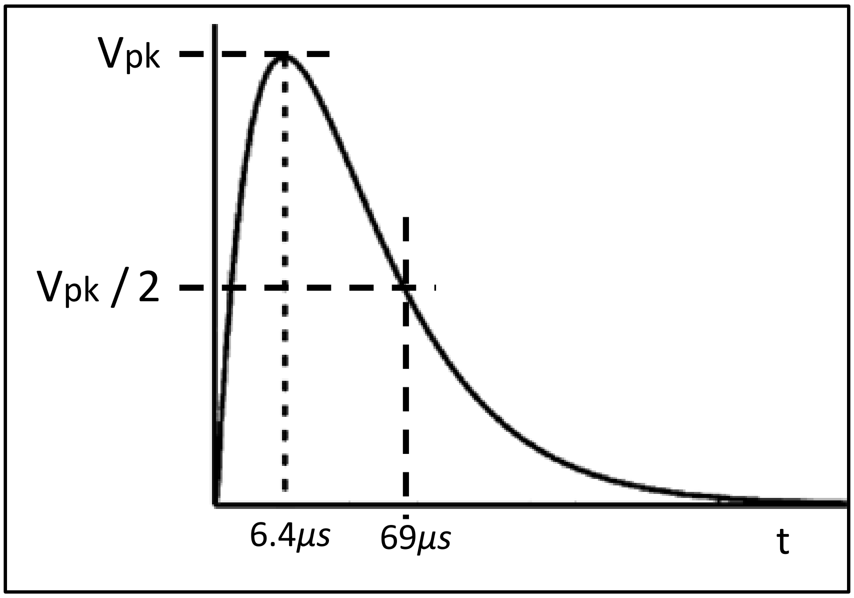
The XF-160GL3 allows for confidence testing of WF1/4 to level 3 as shown below.

Level	Voc / Isc for WF4/WF1 *	Comments
1	50 / 10	50V peak / or 10A peak
2	125 / 25	125V peak / or 25A peak
3	300 / 60	300V peak / or 60A peak

* *Voc is peak open circuit voltage. Isc is peak short circuit current.*

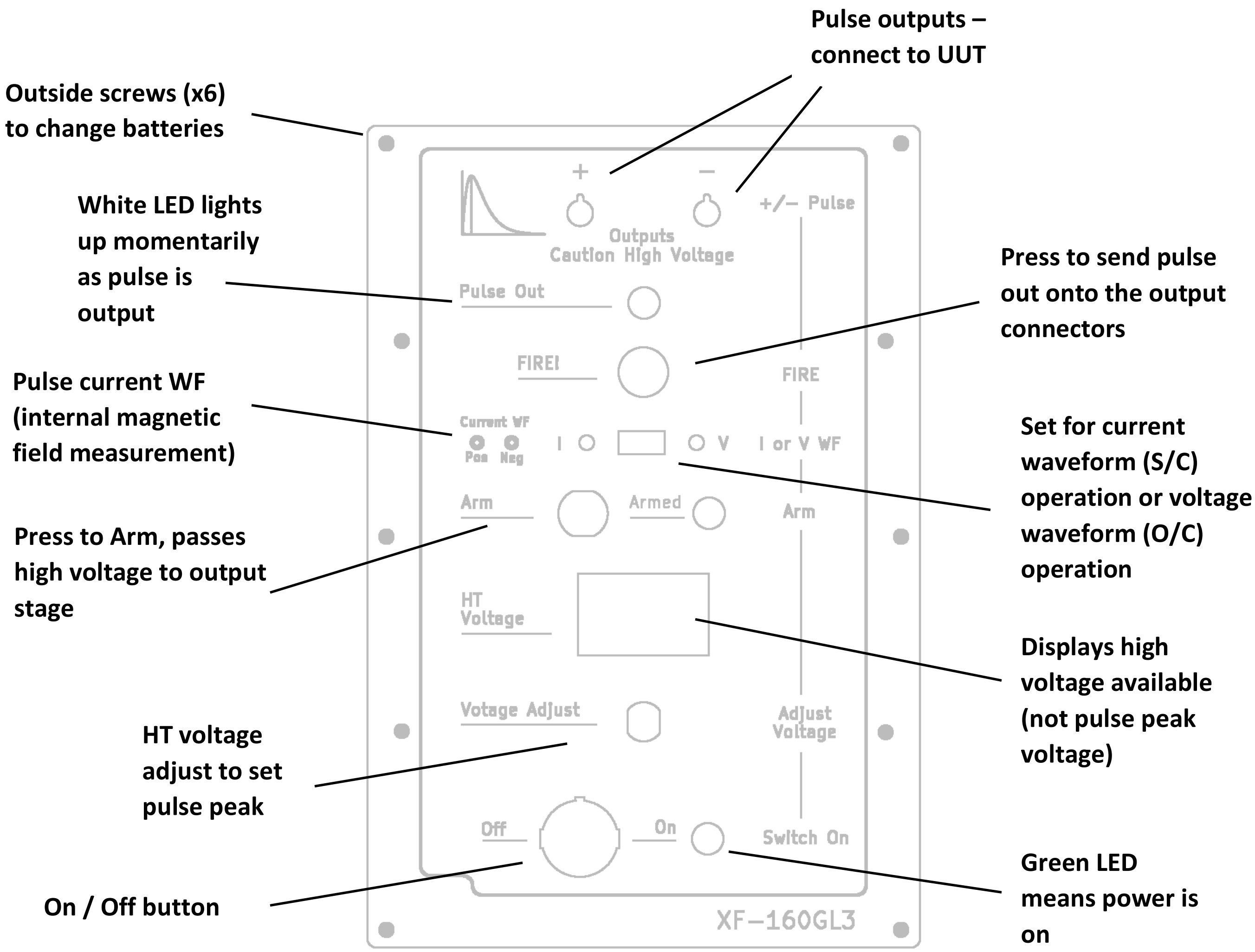
Level 3 waveforms and levels are generally for non-critical equipment inside the aircraft, such as in the Electronics bay.

The waveform shape is shown below. The rise time is defined as the time to reach the peak voltage (or current). The decay time is defined as the time to fall back to half the peak voltage (or current).



6.4μs / 69μs DO160G pulse(WF4)

The XF-160GL3 main functions



B. Terms, Conditions and Warranty.

This product is only intended to be used for testing of electronic assemblies and units to gain confidence in the design prior to any formal conformance or qualification testing.

See Appendix D for details

C. Safety.

When switched on, this product generates high voltages internally and outputs a high voltage pulse. There are two areas where care should be taken. One is in normal operation when a pulse is output from the output terminals, the second is when the unit is opened to change the batteries. These cases will be detailed here in more detail.

Normal operation

In normal operation the output pulse width is less than 1ms in duration, however the voltage can be set to an output in excess of 300V. Hence **care should be taken not to touch the output connections when the pulse button is pressed**.

Changing the batteries

The internal electronics utilizes high voltage capacitors to store charge, hence it's very important not to open the unit while it is switched on. Before opening the unit it should be:

Set to a voltage of less than 50V.

Or it should be switched off and:

Left for at least one minute before opening it up.

Momentarily switching back on will confirm the voltage is at a safe level.

The following precautions have been designed into the XF-160GL3 Lightning Pulse Generator to mitigate any danger to an operator.

(i) A safety cut-out switch makes sure the power is cut to the unit when the internal assembly is lifted out of the box in order to change the batteries. This is a light activated cut-out.

(ii) When power is cut from the internal assembly printed circuit boards any high voltages still present will dissipate naturally to safe levels within 50 seconds.

(iii) Any high voltage areas within the internal assembly printed circuit boards are covered in protective insulating material to prevent conduction in case of accidental contact.

D. Description.

1. On / Off switch:	Powers up the XF-160GL3 ready for operation.
2. Power On LED:	The green LED shows that power is on.
3. Voltage adjust knob:	Allows the High Tension (HT) voltage to be set. This is not the peak output pulse voltage, but a voltage used to drive the pulse generation circuitry.
4. Volt Meter:	Allows the HT voltage to be set and so the final output peak pulse voltage can be estimated.
5. Arm Button:	Momentarily pressing this Arm button arms the pulse generator circuity. For safety reasons the pulse generator circuitry will start to lose this voltage with time and so the fire button needs to be pressed within seconds after arming to maintain the required peak pulse voltage.
6. Arm LED:	The orange Arm LED indicates that the XF-160GL3 has been armed and ready to fire.
7. WF Switch	The WF (Waveform) switch must be set to either I for the current waveform, or V for the voltage waveform, prior to either Switching on, Arming or Firing.
8. Fire Button:	The fire button generates the double exponential transient pulse. Once fired, the unit must be re-armed.
9. Fire LED:	The white Fire LED illuminates for the very short period the pulse is active.
10. Current WF	These test points are to monitor the current waveform. This is achieved by measuring the magnetic field as the pulse is generated and output. This gives a good indication of the current waveform, even if the connected UUT represents an inductive load. (The output is 25mV per Amp with 400KHz bandwidth).

Note on Calibration

The XF-160GL3 itself does not need calibration. If it is required to use the unit as part of a formal qualification procedure this can be done by measuring the output pulse with a calibrated oscilloscope (under known and measured ambient conditions, e.g. temperature, humidity and airflow).

E. Setup and Operation

Power Source

The XF-160GL3 requires x 6 AA 1.2V batteries. It is recommended that high mA rechargeable batteries are used; such as 2500mA. Typically the XF-160GL3 draws approximately 300mA, (about 2.2 Watts of power), this would then give approximately 50 hours of continual use.

It is important to ensure the XF-160GL3 is switched off prior to installing / changing the batteries. An internal, light activated, auto cut-out switch will remove power to the unit when the assembly printed circuit boards (PCBs) are removed. However it is recommended to switch off and wait at least one minute before opening up the unit.

Operation

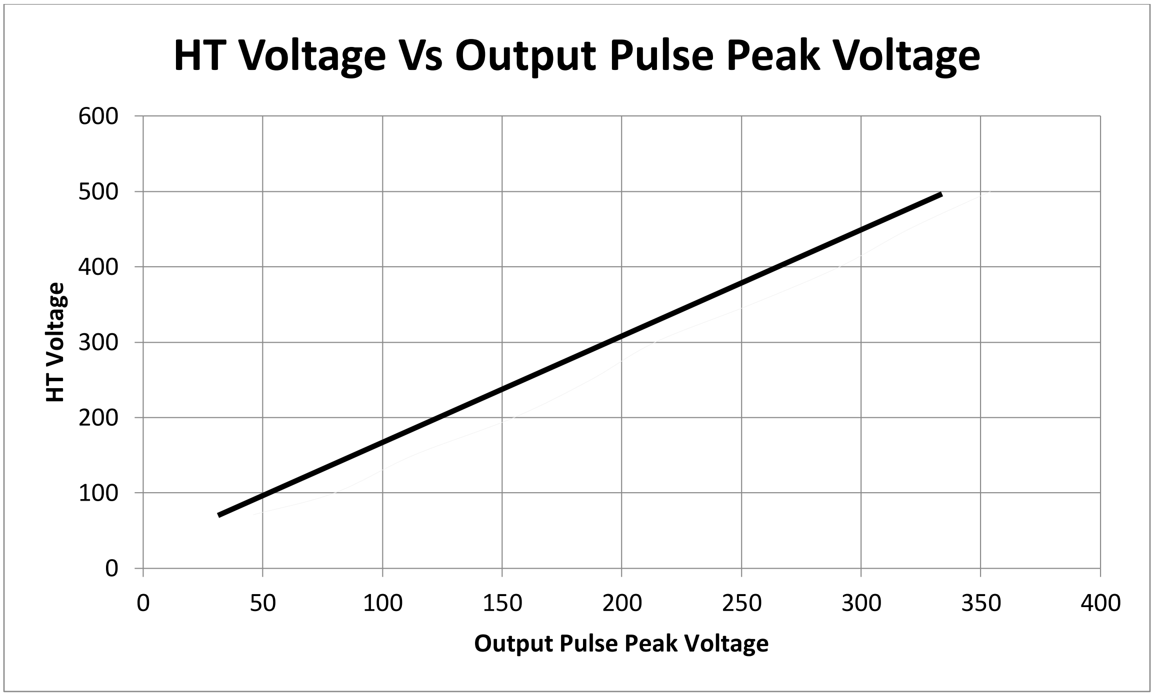
The XF-160GL3 is capable of providing both positive and negative going pulses. (It is a requirement of DO-160G to subject the UUT to both positive and negative pulses).

Positive Voltage Pulse Operation

Follow the following procedure for injecting a positive voltage pulse:

Step 1: Confirm Operation of the XF-160GL3 in stand-alone mode

1. Connect an oscilloscope between the Positive (+) and the negative (-) output pulse terminals. Take care to ensure no damage to your oscilloscope with high voltages. (It is usually recommended to use the x10 probe settings to measure high voltages. Alternatively, construct a simple voltage divider with two resistors).
2. Turn the voltage adjustment knob fully anti-clockwise (i.e to the off position).
3. Slide the I/V selector switch to the V setting.
4. Switch the XF-160GL3 on, ensuring the green LED illuminates.
5. It will take some 30 seconds or so for the internal voltage to build up. After this time it will be possible to set up a voltage using the adjustment knob. Slowly adjust the voltage adjustment knob until the desired voltage is seen on the display, then wind back ¼ turn or so until the voltage is stable. Note that the HT voltage approximately relates to an output pulse peak voltage level as indicated in the chart below.



6. Momentarily press the Arm button and ensure the orange LED illuminates when this is done. Release this button after a very brief time of a second or so.
7. As soon as possible after releasing the Arm button press the Fire button. Note the pulse on the oscilloscope.
8. Repeat the above procedure until the voltage trace on the oscilloscope is what is required. Note, when adjusting the voltage knob, as soon as the desired voltage is approached, start to wind back the knob to stabilize the voltage. You now know what voltage to adjust next time, to produce the desired output pulse.

<u>Step 2:</u> Apply the XF-160GL3 pulse to the UUT

9. Connect short 4mm banana plug leads as follows
    a. <u>Negative</u> Pulse output to the UUT <u>ground</u>
    b. Positive Pulse output to the UUT signal to be tested
10. Switch the XF-160GL3 on, ensuring the green LED illuminates
11. Repeat the procedure of **Step1** above to output a pulse

Negative <u>Voltage</u> Pulse Operation

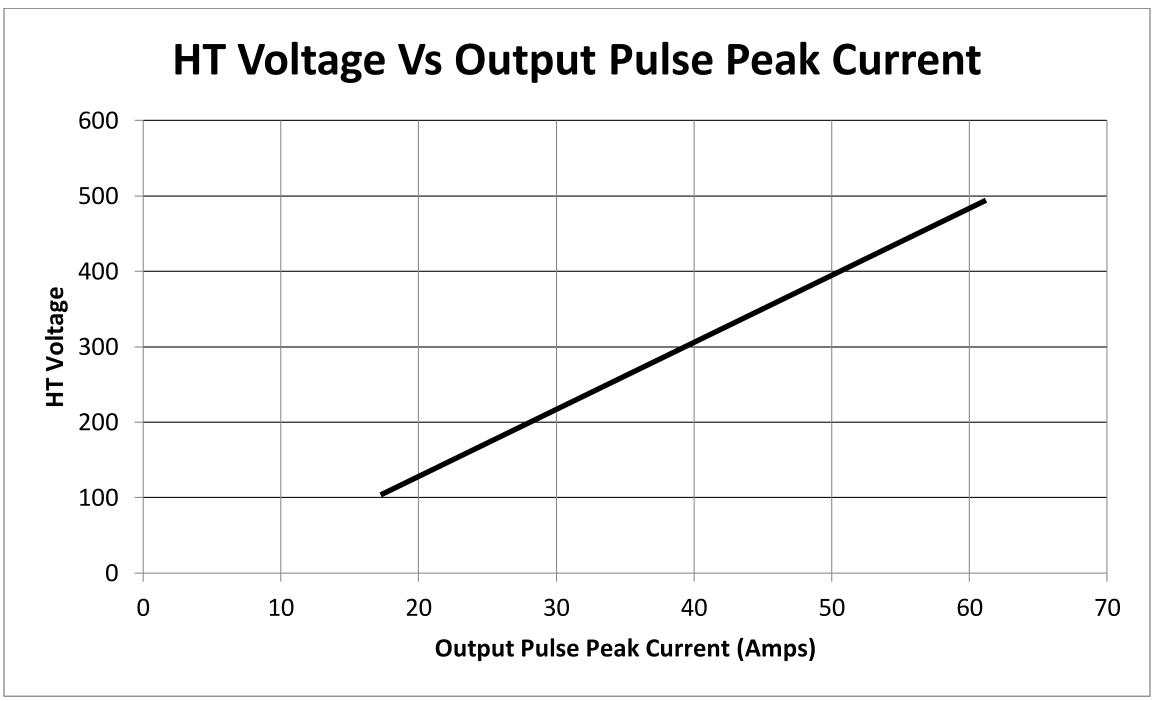
12. The procedure is exactly the same as above for the positive pulse with the connections being reversed, i.e.
13. Connect short 4mm banana plug leads as follows
    a. <u>Positive</u> Pulse output to the UUT <u>ground</u>
    b. Negative Pulse output to the UUT signal to be tested

Positive Current Pulse Operation

Follow the below procedure for injecting a positive current pulse:

Step 1: Confirm Operation of the XF-160GL3 in stand-alone mode

1. Short circuit the Positive (+) pulse and the negative (-) output pulse terminals with a wire of at least 18 AWG thickness.
2. Connect an oscilloscope between the Positive (Pos) Current WF test point and the negative (Neg) Current WF test point terminals.
3. Turn the voltage adjustment knob fully anti-clockwise (i.e to the off position).
4. Slide the I/V selector switch to the I setting
5. Switch the XF-160GL3 on, ensuring the green LED illuminates
6. It will take some 30 seconds or so for the voltage to build up. After this time it will be possible to set up a voltage using the adjustment knob. Slowly adjust the voltage adjustment knob until the desired voltage is seen on the display, then wind back ¼ turn or so until the voltage is stable. Note that the HT voltage approximately relates to an output pulse peak current level as indicated in the chart below.



7. Momentarily press the Arm button and ensure the orange LED illuminates when this is done. Release this button after a very brief time of a second or so.

8. As soon as possible after releasing the Arm button press the Fire button. Note the pulse wave shape on the oscilloscope. 25mV corresponds to a current of 1 Amp. If the current waveform is to be acquired with calibrated equipment, or simply to more accuracy, an external current clamp can be used. (This is preferable to a simple low inductance sense resistor for current measurement).
9. Repeat the above procedure until the current trace on the oscilloscope is what is required. Note, when adjusting the voltage knob, as soon as the desired voltage is approached, start to wind back the knob to stabilize the voltage. You now know what voltage to adjust next time, to produce the desired output pulse.

Step 2: Apply the XF-160GL3 pulse to the UUT

10. Remove any short circuit wire between the pulse outputs
11. Connect short 4mm banana plug leads as follows
    c. Negative Pulse output to the UUT ground
    d. Positive Pulse output to the UUT signal to be tested
12. Switch the XF-160GL3 on, ensuring the green LED illuminates
13. Repeat the procedure of **Step1** above to output a pulse

Negative Voltage Pulse Operation

14. The procedure is exactly the same as above for the positive pulse with the connections being reversed, i.e.
15. Connect short 4mm banana plug leads as follows
    a. Positive Pulse output to the UUT ground
    b. Negative Pulse output to the UUT signal to be tested

F. Maintenance

Changing the Batteries

If the unit is switched on, adjust the voltage to less than 50v. If the unit is off make sure it has been off for at least one minute.

Unscrew the six screws closest to the edge of the XF-160GL3 box. Slowly lift the board assembly up and out of the box, making sure not to unnecessarily poke fingers in-between the boards or touch any of the board electronic components.

Install the batteries making sure the positive and negative terminals are correctly aligned.

Install the printed circuit assembly back in the box, ensuring not to accidentally power on the unit.

Re-install the screws firmly, securing the top back onto the XF-160GL3 unit.

Power the unit on and note the green LED illuminates thus ensuring the batteries are correctly installed. (The unit will not be damaged if the batteries are incorrectly installed).

Long term storage

If storing for a long period of time ensure the batteries are first removed.

Appendix A

TVS Protection Application Notes

1. Testing generally tries to ensure any equipment can withstand two types of stress:
    a. A fast rise time to a high voltage followed by a more prolonged fall time from that voltage. This is a good test of **Insulation strength**.
    b. A high Current pulse is a good test for **current / fusing** withstanding capability.

2. Typical protection solutions include the addition of a TVS (Transient Voltage Suppression) diode. However care needs to be taken to select the most appropriate TVS and related components. This application note points out how these calculations are done under the two conditions of
    a. Low impedance UUT interface
    b. High impedance UUT interface

3. The first thing to know in detail is the signal requirements of a particular interface. The following questions will then need to be answered:
    a. Is the frequency of the signal so high that capacitive effects need to be considered?
    b. Can the interface cope with a series resistor to effectively reflect back as much of the pulse energy as possible? I.e. would a resistor unduly affect a signal's high / low switching thresholds, and put these out of spec.?
    c. What power and voltage levels should the TVS support?
    d. Is the TVS to be a uni-directional one or a bi-directional one?
    e. What type of technology and power / voltage levels should any series resistor have?
    f. What type of PCB layout should be considered?

4. The above is not an exhaustive list, but it does cover the most important issues. This application note will try to answer the above questions by giving guidance as to how to tackle the questions.

5. We'll start by going down the list from (a).

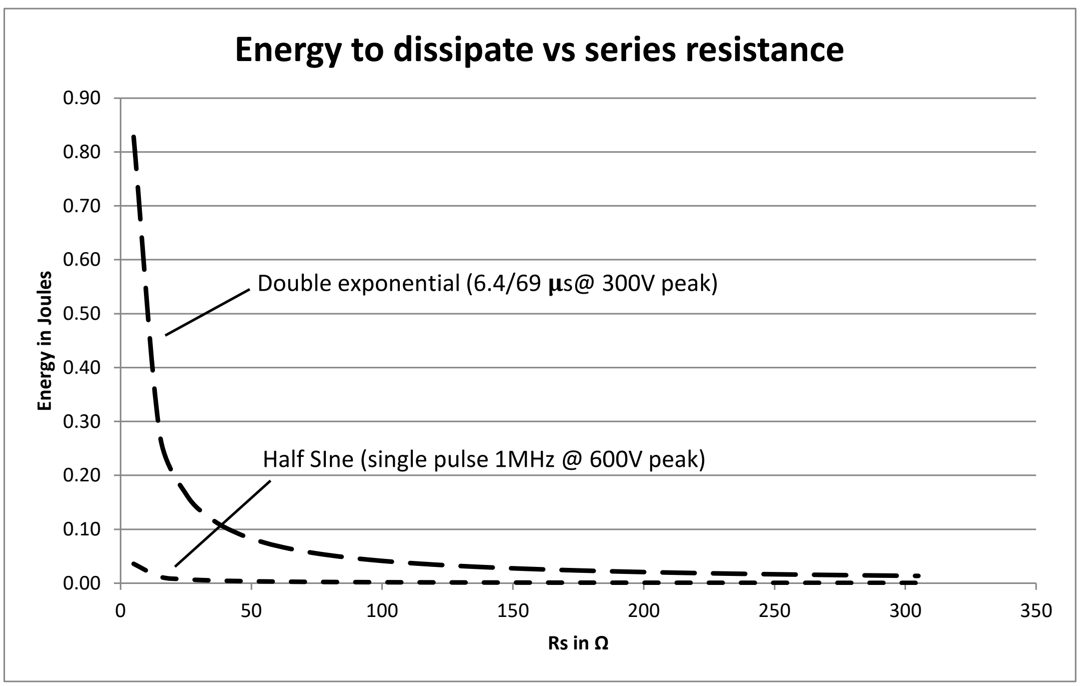
    a. Is the frequency of the signal so high that capacitive effects need to be considered?

    The signal needs to be considered. If the signal is simply a low speed clock, or a simple voltage level, high or low then capacitance is generally not a problem. A TVS has a certain intrinsic junction capacitance associated with it. It is also dependent on the reverse stand-off voltage and whether it is a uni or bi directional device. More details on the TVS later.

If the signal is a high speed Ethernet signal then the capacitance would more than likely kill the signal. In this case very low capacitance gas discharge tube (GDT) technology can be considered. However there may then be issues of longevity associated with such a design. GDT's tend to be specified for only a certain number of strikes / triggers before they start to degrade. For DO-160G Level 3 a good magnetics device ought to be fine.

b. Can the interface cope with a series resistor to effectively reflect back as much of the pulse energy as possible?

We will now consider only DC level or slow frequency signals. Any series resistor will act as a voltage divider with the impedance of the signal interface, be that an input or an output. As such any change in signal level will need to be calculated to make sure that a resistor will not put the triggering thresholds out of spec. Generally even a small resistor of say 100Ω will make a big difference to the type of TVS that can then be used. A resistor of some 100KΩ or so will be even more effective. The larger the resistor that can be added the better. The following chart shows the effect of the resistor.



The above chart shows the energy to dissipate by the UUT comparing the two pin injection cases at DO-160G level 3. At this level a double exponential pulse (long dashed line) must be applied with a peak voltage of 300V. And a 1MHz decaying Sine wave (short dashed line), at peak voltage of 600V. As can be seen above the double exponential contains much more energy: A factor of 23 more in fact! This is why we term the double exponential as the worst case. The equations used to calculate these pulse energies are detailed in Appendix B.

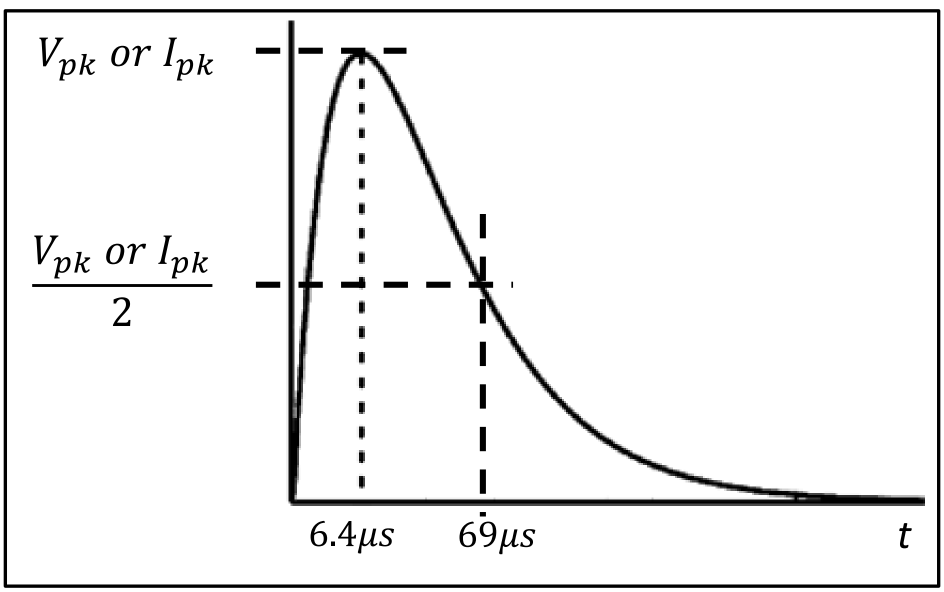
c. *What power and voltage levels should the TVS support?*

This is where things become interesting! The first thing to note is the DO-160G level to which the interface must adhere. The table below shows the possible levels for the 'worst case' waveforms WF4 and WF1:

Level	**Voltage WF 4 (O/C Volts)**	**Current WF 1 (S/C Amps)**
1	**50**	**10**
2	**125**	**25**
3	**300**	**60**
4	750	150
5	1600	320

Amplitude tolerances are +10%, -0%
Note the XF-160GL3 does not support levels 4 and 5.

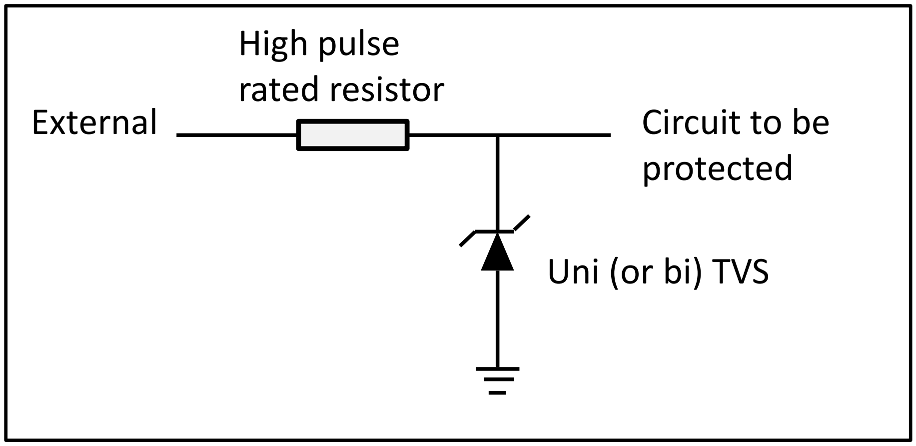
The double exponential pulses are defined as:



Temporal tolerances are +20%, -20%
Above is known as a 6.4/69μs pulse.

If no series resistor where to be employed on the interface and if a TVS were to be specified as supporting the above waveform at the required voltage and current waveforms then there would be no problem (provided also that PCB space and component cost are not big issues). However, some data sheets show an adherence to a 10/1000µs pulse with certain peak current. Other devices such as resistors show the maximum power it can withstand. We need to find a good way to compare requirements vs component capabilities. Regarding a maximum voltage this is easy to do, but regarding the current waveform it is necessary to calculate how much energy is to be dissipated. It is the energy dissipation in a component that causes the damage.

For this discussion we are assuming a protection circuit of the form as shown below.



The first step is to calculate the amount of energy the interface needs to deal with. Power (in Watts) dissipated is Energy per unit time:

$$P = \frac{E}{t}$$

In purely electrical terms it is also current x voltage:

$$P = I.V$$

Hence:

$$E = I.V.t$$

Using Ohms law

$$I = \frac{V}{R}$$

The equation can be re-written as:

$$E = \frac{V^2}{R}.t \quad .....equation\ 1$$

The reason for writing like this is that R is a constant for the circuit and the voltage V will vary with time. This will become clearer later.

For the sake of this discussion let's assume we can employ a resistor of say 100Ω, and still maintain all signal transition specifications.

From equation 1 it is clear that the series resistance must be known before the energy can be calculated. With this in mind let's find out the energy associated with a double exponential pulse. There are two ways to do this. An accurate method is employed by Vishay, the well-known manufacturer of thick film resistors and TVS devices. The equation is given here:

$$E = \left(\frac{1}{3}\frac{V^2}{R_s}t_1\right) + \left(\left(\frac{V^2}{-2}\frac{\tau}{R_s}\right)\left(e^{\frac{2(t_3 - t_1)}{\tau}} - 1\right)\right)$$

Where:
t_1 is time to peak voltage (S)
t_2 is time to decay to half peak voltage (S)
t_3 is time the decay becomes negligible (nominally set to $20.t_2$) (S)
τ is the exponential rate of decay = - $(t_2 - t_1)/\ln(0.5)$ (S)
R_s is the total series resistance in Ohms. Note that this is the pulse generator output resistance plus the UUT series protection resistor.

Running through the calculation with a peak voltage of 300V and a protection resistor R = 100Ω (Hence total series resistance R_s of 100Ω + 5 Ω = 105Ω) gives an energy of 0.04053 Joules. However note the following:

The above equation can give a rather large value due to the elongated tail of the decaying exponential. In the example above a t_3 of 20 x the t_2 value is used. If a larger multiplication factor is used such a calculation can give the impression that a particular semiconductor device is specified to withstand the energy of a DO160G 6.4/69 µs pulse, but this is very much dependent on the calculation made. A design engineer needs to take care to use reasonable margin in the design to take care of component tolerances and to err very much on the side of caution. For simplicity we can try using a far simpler model of that pulse. The model I advocate is to treat the pulse as a simple triangular wave-shape.
To calculate the energy of any arbitrary wave-shape varying with time *equation 1* can be re-written in calculus form as:

$$E = \frac{1}{R_s}\int_0^{2.t_2} U(t).dt \quad \ldots\ldots equation\ 2$$

Where:
t_2 is time to decay to half peak voltage (S). We have used 2 x t_2 for our triangle model.

$U(t)$ is now the time varying voltage, in this case a straight line from the peak voltage at time = 0 to 0V at time = $2t_2$

Running through the derivation gives the following equation for the energy:

$$E = \frac{V_{pk}^2 2t_2}{3R_s} \quad \ldots\ldots equation\ 3$$

Details are given in appendix B.

The calculation with R=100Ω now gives a total energy of 0.0394 Joules.

Incidentally, using equation 2 to calculate the energy of a DO-160G Sine wave at level 3, i.e. a peak of 600V (A single Sine wave peak) with the example of 100Ω gives an energy of 0.0017 Joules. (23 times less than the double exponential just looked at). See appendix B for the derivation. The Sine wave is of course repeated at frequency so it is not entirely safe to assume it will not cause damage to a UUT if the double exponential pulse does not. Furthermore the higher voltage could damage an interface from a purely insulation strength point of view.

Given the energy, it is now a matter of finding a suitable resistors and TVS.

To summarize, we have said that a 100Ω resistor can be used. We have assumed that we wish to protect against a DO-160G level 3 lightning pulse. That means protecting against a 6.4/69 µs pulse. The testing will need to test against this pulse for both voltage and current and for both positive and negative pulses.

Furthermore we have said that we need to mitigate against an energy of 0.0394 Joules.

Let's now take our example a little further. Let's assume that our interface is a simple 12V logic level interface with low at 0V and high at 12V. Furthermore let's assume the interface can withstand an overvoltage up to 20V.

Let's take the Littelfuse TVS as a candidate protection TVS. The SMAJ12A looks like a good candidate device. It has the following features:

12V reverse stand-off voltage. This is the maximum voltage that does not put the diode into an avalanche breakdown mode. Although some current may be drawn.

13.3V minimum breakdown voltage. This is when the diode starts going into breakdown.

14.7V maximum breakdown voltage. This is the voltage at which the diode will definitely (if not before) be in breakdown.

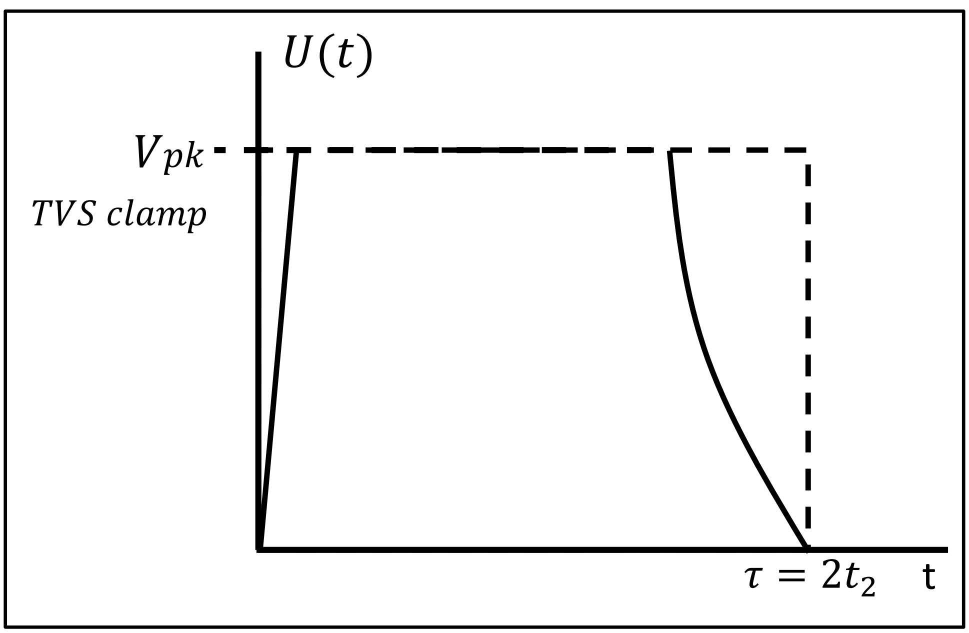
19.9V maximum clamping voltage. This is the voltage across the diode at maximum current.

Since we don't really want any conduction (and so no power loss) at normal operating voltage of 12V and we don't want any voltage greater than maximum 20V at the device to be protected, this diode would seem to be acceptable.

So we now need to look at its ability to cope with the 0.0394 Joules of energy.

We can now work out that, with a 6.4/69 µs pulse (square pulse model) the TVS is capable of mitigating an energy of 0.0829 Joules, so is acceptable. The calculation goes as follows:

Firstly we note that the TVS will clamp at a voltage maximum of 19.9V. This is far lower than the transient pulse we are considering and so it is reasonable (i.e. worst case) to model the clamped signal as shown here:



As such we will model it as a simple square pulse. See appendix B, where the energy is given as:

$$E_{sq} = P_{pk}\tau \quad \ldots.\,equation\ B9$$

So

$$V_{clamp}\ x\ I_{pk} = \ P_{pk}$$

$$P_{pk} x\ 2t_2 = 19.9V\ x\ 30.2A\ x\ 2\ x\ 69\mu s = 0.0829J$$

Hence, in our example $E_{sq} = 0.0829\ J$.

Since 0.0394 J < 0.0829 J, this TVS would seem to be ok.

Furthermore we can check on the Littelfuse data sheet by looking at the Peak Pulse Power rating chart. Reading on the horizontal axis it shows that a pulse of 0.1ms (100µs) means it can withstand a double exponential pulse with a peak pulse power of some 1.8kW.

Our incident pulse has peak power of:

$$\frac{V_{pk}^2}{R_s} = \frac{300^2}{105} = 857W$$

So again it will be ok. Note it is important when looking at such charts on manufacturers' data sheets to understand the pulse shape used. Some data sheets use square wave pulses.

Further, note the data sheet shows a maximum peak pulse current of 20.1A. Our peak current will be 19.9V / 105Ω = 0.198A, so also acceptable.

d. *Is the TVS to be a unidirectional one or a bidirectional one?*

This depends on two main signal parameters:

- Is the normal signal level only positive or positive and negative?
- Is the frequency of the signal such that capacitance is of utmost importance?

If the signal is a slow positive one then a uni-directional TVS is likely the best option since this will clip any unwanted signals more closely to the required signal range. However if capacitance is important then the bi-directional TVS has slightly lower capacitance and so would be fine provided any small negative pulse would not harm the UUT.

The unidirectional TVS will clip to the reverse stand-off voltage both negative and positive. The uni-directional one will clip to the positive reverse stand-off voltage and to the forward diode drop for negative signals.

e. What type of technology and power / voltage levels should any series resistor have?

The resistor is actually a very important aspect; possibly even more so than the TVS. The resistor after all will take the full brunt of the initial lightning pulse. The technology to be considered is therefore critical.

The first step is to consider a resistor that can withstand pulses, can handle the voltage from a point of view of dielectric strength and has a high enough peak power capability. On top of that it is also a good idea to reduce the inductance as much as possible especially on low impedance interfaces. If it is necessary to include only a very low value resistor then potentially a lot of current will be drawn into the UUT and must be conveyed to ground. A wire-wound resistor can have inductance up to some 56µH. This could cause issues as detailed below. Thick film is generally much more suitable.

Deciding on which resistor can cope is not so easy since resistors are specified in many different ways. Some specifications (e.g. IEC 60115-1) use 1.2µs/50µs and 10µs/700µs pulses. Others have a peak power vs pulse width chart. Some manufacturers don't quote inductance, while others don't quote the maximum voltage allowed. It is indeed very challenging to choose a suitable resistor. This highlights the importance of testing a candidate design prior to any formal compliance testing.

Let's take just one example and see what peak power the resistor needs to cope with. This is given by the following expression:

$$P_{pk} = \frac{{V_{pk}}^2}{R_s}$$

In our example of 100Ω series resistor and the DO-160G required 5Ω output impedance (supported by the XF-160GL3), the level 3 power, as before is:

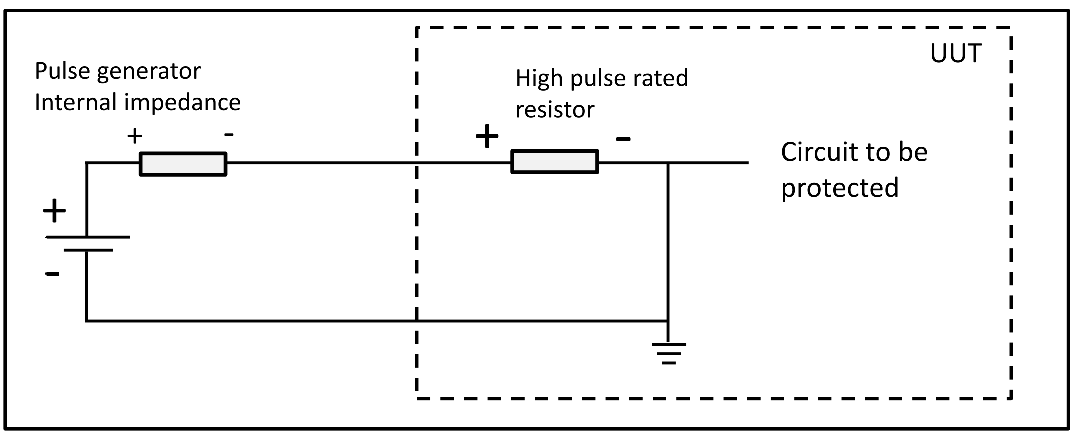
$$P_{pk} = \frac{V_{pk}^2}{R_s} = \frac{(300 - 19.9)^2}{105} = 747W$$

However note the peak voltage has been reduced to take into account the TVS clamping.

A resistor such as the Vishay CMB0207 series shows a peak pulse vs pulse duration chart. This reveals that resistor values of <1kΩ at 100µs pulse width can handle 600W. Hence this resistor would not be suitable. (If the resistor could be increased to 200Ω then it would be acceptable). How about the Vishay CRCW2512-HP? Taking a look at the peak power vs pulse width here reveals that it can handle approximately 700W at 100µs pulse width. Hence somewhat more at a smaller pulse width. Furthermore the maximum operating voltage is described as being 500V, so this device looks almost acceptable. A slightly better one would be recommended for reliable operation.

f. *What type of PCB layout should be considered?*

The in-line resistor and TVS must be placed as close to the external connector of the UUT as possible. This to reduce any PCB track (or connector wire) impedance and inductance.



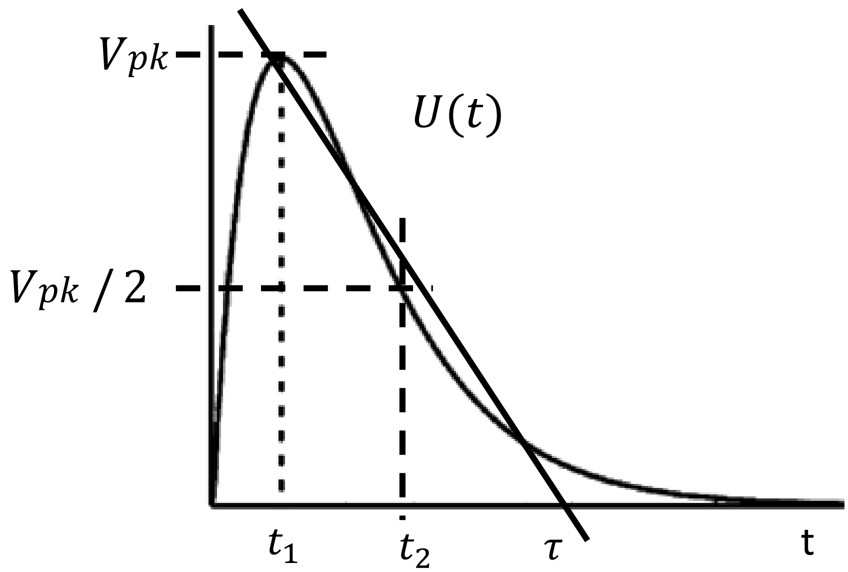
The above shows the problem if there is too much inductance at the UUT input. A high current pulse will cause the inductor to generate a voltage in such a way as to reduce the increasing current. Any inductance at the pulse generator (the XF-160GL3 has, by design, a very low inductance output) could generate a small negative voltage at the UUT. Any inductance at the UUT itself (or cables to it) could potentially generate a very high voltage at the input. This could cause damage to, or interference with, any nearby UUT electronics.

Regarding impedance, a high rise time exponential pulse contains many high frequency components; recall the Fourier transform theory. If the UUT tracks are long or the connection to ground is via unwieldy tracks or cables, everything may seem fine from a DC resistance point of view, but for impedance (i.e. resistance at frequency) certain frequencies may be impeded. This can cause reflection of energy and so unwanted interference and noise.

Appendix B

Pulse Derivations

1. **Triangular** Pulse Energy.



From the basic formula for a straight line we can write:

$$U(t) = -\frac{V_{pk}.t}{\tau} + V_{pk} \; .... equation\ B1$$

Where:
$U(t)$ is the variable voltage (vertical axis)
t is the time variable(horizontal axis)
V_{pk} is the peak voltage (a constant)
τ is the time for $U(t)$ to fall to 0

Given that power is energy per unit charge (or rate of change of power). We can write an equation for total energy as:

$$E = \int_{t=0}^{t=\tau} P(t)\, dt \;\; .... equation\ B2$$

Since:

$$P(t) = \frac{U(t)^2}{R_s}$$

And by substituting *equation B1* for $U(t)$, we can re-write *equation B2* as follows:

$$E_x = \frac{V_{pk}^2}{R_s} \int_{t=0}^{t=\tau} \left(\frac{-t}{\tau} + 1\right)\left(\frac{-t}{\tau} + 1\right)\, dt$$

Where E_x shows that the energy is for the exponential (x) pulse. Note also that R_s is the total series resistance.

$$= \frac{V_{pk}^2}{R_s} \int_{t=0}^{t=\tau} \left(\frac{t^2}{\tau^2} - \frac{2t}{\tau} + 1\right)\, dt$$

$$= \frac{V_{pk}^2}{R_s} \left[\frac{t^3}{3\tau^2} - \frac{t^2}{\tau} + t\right]_0^{\tau}$$

$$= \frac{V_{pk}^2}{R_s} \left(\frac{\tau^3}{3\tau^2} - \frac{\tau^2}{\tau} + \tau\right)$$

$$= \frac{V_{pk}^2}{R_s} \frac{\tau}{3}$$

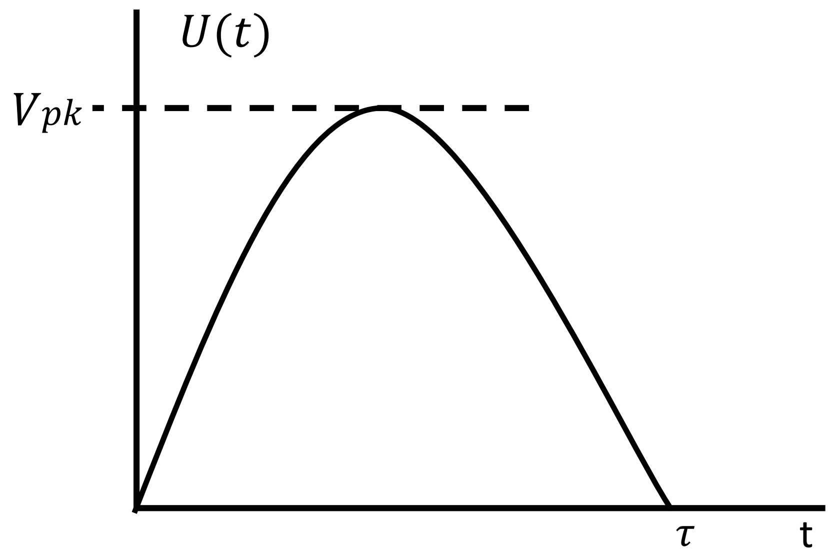
Now we can let $\tau = 2t_2$ (t_2 a constant) to end up with the energy equation:

$$\boxed{E_x = \frac{V_{pk}^2}{R_s} \frac{2t_2}{3} \quad \ldots.\, equation\ B3}$$

Or in terms of peak power:

$$\boxed{E_x = \frac{P_{pk}\, 2t_2}{3} \quad \ldots.\, equation\ B4}$$

2. Half Sine Pulse Energy.



We can write the time varying voltage as:

$$U(t) = V_{pk} sin\left(\frac{\pi t}{\tau}\right) \ldots . equation\ B5$$

Where:
$U(t)$ is the variable voltage (vertical axis)
t is the time variable(horizontal axis)
V_{pk} is the peak voltage (a constant)
τ is the time for $U(t)$ to fall to 0

$$E = \int_{t=0}^{t=\tau} P(t)\, dt \ \ldots . equation\ B2$$

Since:

$$P(t) = \frac{U(t)^2}{R_s}$$

Then:

$$E_s = \frac{1}{R_s} \int_{t=0}^{t=\tau} U(t)^2\, dt$$

And by substituting *equation B5* for $U(t)$, we can re-write *equation B2* as follows, where E_s denotes the energy for the half Sine (s) wave:

$$E_s = \frac{V_{pk}^2}{R_s} \int_{t=0}^{t=\tau} Sin^2\left(\frac{\pi t}{\tau}\right) dt$$

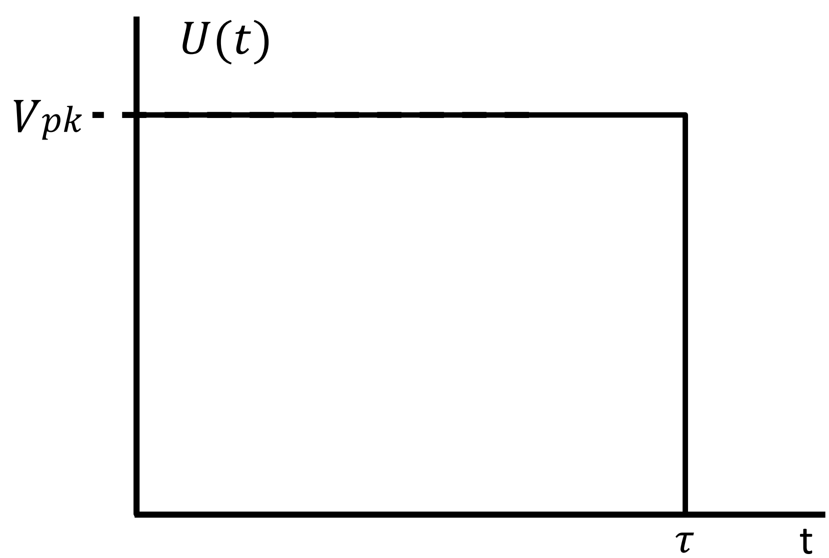
It can then be shown that this evaluates to the following simple expression:

$$\boxed{E_s = \frac{V_{pk}^2 \tau}{R_s\, 2} \quad \dots.equation\ B6}$$

Or:

$$\boxed{E_s = \frac{P_{pk} \tau}{2} \quad \dots.equation\ B7}$$

3. Square Pulse Energy.



We can write the time varying voltage as:

$$U(t) = V_{pk}t$$

Where:
$U(t)$ is the variable voltage (vertical axis)
t is the time variable(horizontal axis)
V_{pk} is the peak voltage (a constant)
τ is the time for $U(t)$ to fall to 0

$$E = \int_{t=0}^{t=\tau} P(t)\, dt \;\; \ldots.equation\ B2$$

Since:

$$P(t) = \frac{U(t)^2}{R_s}$$

Then:

$$E_{sq} = \frac{1}{R_s} \int_{t=0}^{t=\tau} V_{pk}^2\, dt$$

Since in this case V_{pk} is just a constant this just evaluates to the following simple expression:

$$\boxed{E_{sq} = \frac{V_{pk}^2 \tau}{R_s} \quad \ldots.equation\ B8}$$

Or:

$$\boxed{E_{sq} = P_{pk}\tau \quad \ldots.equation\ B9}$$

Appendix C

XF-160GL3 Specifications

Item	Value	Unit
Unit length	220 (8.67)	mm (inch)
Unit width	150 (5.90)	mm (inch)
Unit height	64 (2.52)	mm (inch)
Unit weight	0.78 (1.85)	Kg (lbs)
Enclosure material	ABS plastic / FR-4 TG130	-
Battery requirement (Batteries not provided)	X6 1.2V (AA)	V
Current consumption (quiescent)	300	mA
Total power consumption (quiescent)	2.2	W
Battery polarity protection	Yes	
Safety cut-out switch	Yes (Optical)	
Output Pulse Terminals (material)	Brass	-
Output Pulse Terminals (type)	4mm Banana plugs	-
Max O/C peak voltage	400	V
Max S/C peak current	60	A
Current Measurement Bandwidth	400	KHz
Current Measurement Sensitivity	25	mV / Amp
O/C voltage rise time (@ 300V)	5.3 ± 10%	µs
O/C voltage fall time to half peak(@ 300V)	72 ± 10%	µs
S/C current rise time (@ 60A)	3.4 ± 10%	µs
S/C current fall time to half peak (@ 60A)	59 ± 10%	µs
Output Impedance	5	Ω
DO-160G WFs for current and voltage	1 and 4	-
DO-160G levels for voltage and current	1, 2 and 3	-
Unit protection against external voltages (TVS)	>567	V

Appendix D

Xflight Technologies LLC Terms, Conditions and Warranty

4. **PARTIES.** This Contract represents the terms and conditions of sale of Xflight Technologies Products by and between Xflight Technologies LLC, of 1982 State Rd 44, New Smyrna Beach, Florida 32168, USA ("Seller"), and Buyer ("Buyer").

5. **ITEMS PURCHASED**. Seller agrees to sell, and Buyer agrees to buy the following product (the "Goods") in accordance with the terms and conditions of this Contract:

Product
Xflight XF-160GL3 Lightning Pulse Generator

6. **INTELLECTUAL PROPERTY.** Intellectual property created, made, or originated by the officers, employees, or contractors of Seller shall remain the sole and exclusive property of Seller. Any intellectual property associated with Goods, specifically the electronics design, shall remain the property of Seller. Seller retains all rights to its pre-existing intellectual property and any intellectual property it creates in connection with the development and manufacturing of the Goods of this agreement. Parties agree that Seller will retain ownership of all rights in any invention and work product developed pursuant to the agreement and acknowledges that all materials created by the Seller pursuant to and related to the agreement belong to the Seller under United States intellectual property laws.

7. **WARRANTIES.** The Goods are sold on an "AS IS" basis. SELLER SHALL IN NO EVENT BE LIABLE FOR ANY INCIDENTAL, SPECIAL, OR CONSEQUENTIAL DAMAGES OF ANY NATURE, EVEN IF SELLER HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES. Seller's liability, if any, for defective Goods, is limited to replacement, repair or refund of the defective Goods, at Seller's option for up to 30 days from date of purchase.

8. **PERSONAL USE**. Buyer agrees to not develop or resell Goods, its components, or documentation to another party without Seller's written authorization.

9. **PRODUCT RISKS**. Buyer acknowledges that the ownership and operation of newly developed Lightning Pulse Generator, including the subject Goods contemplated by this contract, comes with many unforeseeable risks and potential hazards. Buyer has reviewed the risks, safety hazards and recommendations provided by Seller in the User Guide. Buyer has considered these risks and represents himself as a consumer with a sophisticated understanding of high voltage test equipment and safety protocols, and the concepts underlying the Goods' design. Buyer accepts all foreseeable and unforeseeable risks associated with the ownership and operation of the Goods, components, and related equipment.

10. **INDEMNIFICATION.** Buyer shall defend, indemnify, and hold harmless Seller, including its officers and agents, from any and all actual or alleged claims, demands, causes of action, liability, loss, damage and/or injury (to property or persons, including without limitation wrongful death), associated with the ownership and operation of the Goods of this contract. This indemnity shall apply in all actions, whether brought by an individual or other entity, or imposed by a court of law or by administrative action of any federal, state, or local governmental body or agency, arising out of or incident to any acts, omissions, negligence, or willful misconduct of Buyer, its personnel, employees, agents, contractors, or volunteers in connection with or arising out of Buyer's actions. This indemnification applies to and includes, without limitation, the payment of all penalties, fines, judgments, awards, decrees, attorneys' fees, and related costs or expenses, and any reimbursements to Seller for all legal expenses and costs incurred by it.

11. **REMEDIES ON DEFAULT.** In addition to any and all other rights a party may have available according to law, if a party defaults by failing to substantially perform any provision, term or condition of this Contract (including without limitation the failure to make a monetary payment when due), the other party may terminate the Contract by providing written notice to the defaulting party. This notice shall describe with sufficient detail the nature of the default. The party receiving such notice shall have 30 days from the effective date of such notice to cure the default(s). Unless waived by a party providing notice, the failure to cure the default(s) within such time period shall result in the automatic termination of this Contract.

12. **ARBITRATION**. Any controversies or disputes arising out of or relating to this Contract shall be resolved by binding arbitration in accordance with the then-current Commercial Arbitration Rules of the American Arbitration Association. The parties shall select a mutually acceptable arbitrator knowledgeable about issues relating to the subject matter of this Contract. In the event the parties are unable to agree to such a selection, each party will select an arbitrator and the two arbitrators in turn shall select a third arbitrator, all three of whom shall preside jointly over the matter. The arbitration shall take place at a location that is reasonably centrally located between the parties, or otherwise mutually agreed upon by the parties. All documents, materials, and information in the possession of each party that are in any way relevant to the dispute shall be made available to the other party for review and copying no later than 30 days after the notice of arbitration is served. The arbitrator(s) shall not have the authority to modify any provision of this Contract or to award punitive damages. The arbitrator(s) shall have the power to issue mandatory orders and restraint orders in connection with the arbitration. The decision rendered by the arbitrator(s) shall be final and binding on the parties, and judgment may be entered in conformity with the decision in any court having jurisdiction. The agreement to arbitration shall be specifically enforceable under the prevailing arbitration law. During the continuance of any arbitration proceeding, the

parties shall continue to perform their respective obligations under this Contract.

13. **NOTICE.** Any notice or communication required or permitted under this Contract shall be sufficiently given if delivered in person or by certified mail, return receipt requested, to the addresses listed above or to such other address as one party may have furnished to the other in writing. The notice shall be deemed received when delivered or signed for, or on the third day after mailing if not signed for.

14. **ASSIGNMENT.** Neither party may assign or transfer this Contract without prior written consent of the other party, which consent shall not be unreasonably withheld.

15. **ENTIRE CONTRACT.** This Contract contains the entire agreement of the parties regarding the subject matter of this Contract, and there are no other promises or conditions in any other agreement whether oral or written. This Contract supersedes any prior written or oral agreements between the parties.

16. **SEVERABILITY.** If any provision of this Contract shall be held to be invalid or unenforceable for any reason, the remaining provisions shall continue to be valid and enforceable. If a court finds that any provision of this Contract is invalid or unenforceable, but that by limiting such provision it would become valid and enforceable, then such provision shall be deemed to be written, construed, and enforced as so limited.

17. **WAIVER OF CONTRACTUAL RIGHT.** The failure of either party to enforce any provision of this Contract shall not be construed as a waiver or limitation of that party's right to subsequently enforce and compel strict compliance with every provision of this Contract.

18. **APPLICABLE LAW.** This Contract shall be governed by the laws of the State of Florida in the USA.

EXCHANGE OF GOODS

The following provisions relate to the physical exchange of Goods and payment forming the transaction of this agreement.

19. **TITLE/RISK OF LOSS.** Title to and risk of loss of goods shall pass to the buyer upon delivery F.O.B. at the seller's place of home or business to an agent of the buyer including a common carrier, notwithstanding any prepayment or allowance of freight by the seller.

20. **INSPECTION.** Buyer, upon receiving possession of Goods, shall have a reasonable opportunity to inspect the Goods to determine if the Goods conform to the requirements of this Contract. If Buyer, in good faith, determines that all or a portion of the Goods are non-conforming, Buyer may return the Goods to Seller at Buyer's expense. Buyer agrees to securely mail the goods back to buyer with electronic tracking to the address listed above.

21. **PAYMENT.** Payment due shall be made to Xflight Technologies LLC by cash, bank transfer, credit card or PayPal prior to shipment of Goods. If an invoice is not paid when due, seller will not ship Goods to Buyer. In addition to any other right or remedy provided by law, if Buyer fails to pay for the Goods when due or reverses credit card charges after shipment of Goods, Seller has the option to treat such failure to pay as a material breach of this Contract, and may cancel this Contract and/or seek legal remedies.

22. **PAYMENT OF TAXES.** Buyer agrees to pay all taxes of every description, country, federal, state, and municipal, that arise as a result of this sale, excluding income taxes.