TN003 ESD Simulator Calibration for IEC61000-4-2 & ISO10605

1. Calibration Objective

The objective of this report is to present calibration parameters required for ESD simulators, verify their performance, and compare the results to the requirements of the IEC 61000-4-2 or ISO10605 standard.

2. Requirements and Equipment

2.1 Tip voltage Verification

Both IEC61000-4-2:2008 and ISO10605:2008 specify that the tip voltage or the HV source of an ESD simulator must be verified with a high voltage meter or electrostatic voltmeter.

	IEC61000-4-2:2008	ISO10605:2008
Voltage calibration	Up to ± 15 kV	Up to ± 25 kV
Tolerance	< ± 5%	< ± 5%

Table 1 Simulator tip/HV source voltage tolerance.

When using a contact high voltage meter (>100 G Ohm input impedance) for calibration, the HV source will need to continuously charge the tip to maintain the voltage level, otherwise the meter will discharge the tip and the voltage reading will decrease gradually. **ES105-100 High-Impedance High-voltage Meter** from ESDEMC satisfies the requirements for HV calibration (>100 G Ohm input impedance and measures up to 100 kV with less than 2% tolerance).

Because the ESD simulator tip is sharp and small, the capacitive coupling between the tip and a non-contact electrostatic meter is weak, and therefore **<±** 5% accuracy may not be achievable. Further, most precision non-contact electrometers do not measure to ±25 kV. This would require a coupling factor for calibration between the discharge tip and the sensor of the non-contact electrometer. **ES102 Vibrating Capacitance Electrometer** from ESDEMC satisfies the requirements for the HV calibration (non-contact measurement with self-calibration up to 1 kV). With the coupling factor integrated with the externally calibrated HV source a measurement range of 200 V to 200 kV with less than 2% tolerance is obtained.

ESDEMC Technology LLC, 4000 Enterprise Dr, Suite 103, Rolla, MO, 65409, USA
www.esdemc.com Tel: (+1)-573-202-6411 Fax: (+1) 877-641-9358 Email: info@esdemc.com

2.2 Contact discharge mode current verification

Both IEC61000-4-2:2008 and ISO10605:2008 standards specify that the ESD contact mode discharge current waveform meet the requirements listed in Table 2.

Standards	IEC61000-4-2:2008	ISO10605:2008
RC Network	150 pF 330 Ohm	150 pF 330 Ohm 330 pF 2000 Ohm 150 pF 330 Ohm 330 pF 2000 Ohm
Voltage Range	CD 2 kV – 8 kV AD 2 kV – 15 kV	CD 2kV – 15 kV AD 2kV – 25 kV
First peak T_r	0.6 - 1.0 ns	0.7 - 1.0 ns
First Peak Tolerance I_p	3.75 A/kV < ± 15 %	3.75 A/kV < ± 10 % for 330 Ohm Res 0 ~+ 30 % for 2000 Ohm Res
Current at 40% RC I_1	2 A/kV < ± 30 %	2 A/kV, < ± 30 % for 330 Ohm Res 0.275 A/kV, < ± 30 % for 2000 Ohm Res
Current at 20% RC I_2	1 A/kV < ± 30 %	1 A/kV , < ± 30 % for 330 Ohm Res 0.15 A/kV , < ± 50 % for 2000 Ohm Res
Equipment	4 GHz Wideband ESD Current Target – Attenuator – Cable Chain < ± 0.5 dB DC - 1 GHz < ± 1.2 dB DC - 4 GHz > 1.2 x 1.2 meter reference plane Oscilloscope > 2 GHz analog Band	1 GHz Wideband ESD Current Target – Attenuator – Cable Chain < ± 0.5 dB DC - 1 GHz > 1.2 x 1.2 meter reference plane Oscilloscope > 1 GHz analog Band
Tolerance	Require ESD waveforms to be tested 5 times at each level and all waveforms should be within the standard specification	Require ESD waveforms to be tested 10 times at each level and calculated the average T_r, I_p, I_1, I_2, then the average parameters should be within the standard specification

Table 2 Contact mode discharge current waveform parameters.

ES613 ESD Simulator from ESDEMC satisfies the requirements for both **IEC61000-4-2:2008** and **ISO10605:2008** (**ES613-20** up to ±20 or **ES613-30** up ±30 kV).

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A4001 ESD Current Target from ESDEMC satisfies the requirements for both **IEC61000-4-2:2008** and **ISO10605:2008** (up to ± 30 kV).

A4002 ESD Current Target Adapter Line from ESDEMC satisfies the requirements for both **IEC61000-4-2:2008** and **ISO10605:2008** to calibrate the frequency response of both ESD target and adapter line.

3. Test Setup:

The ESD current target should be mounted in the center of a 60” x 60” (1.2 m x 1.2 m) or larger vertical calibration plane. The plane can be one wall of a Faraday cage. The target is mounted to a 40 mm diameter hole centered in the plane and fastened by 8 screws and lock-washers. An oscilloscope, attenuators, and cabling are located inside the enclosure, or on the other side of the plane from the ESD simulator. Figure 1 illustrates a possible setup.

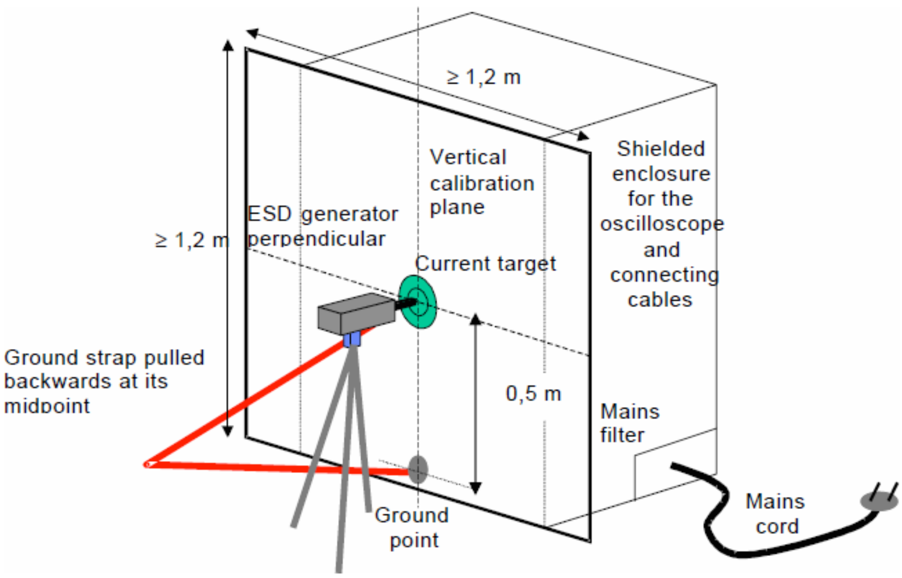

Figure 1 ESD Simulator Calibration setup.

Connect the attenuator directly to the ESD target output. If it is expected that the output voltage will exceed the oscilloscope input voltage rating additional attenuation may be used. Please refer to the Attenuation Calculation section below for details on selecting proper attenuation. Connect the ESD ground return cable to the target plane according to the standard. A simplified block diagram is shown in Figure

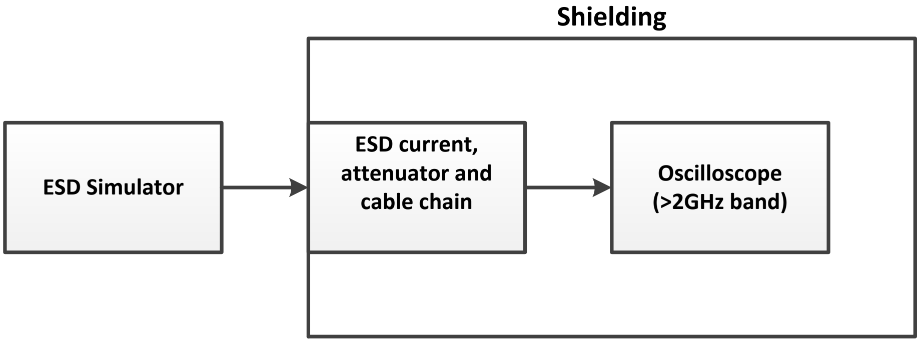

Figure 2:

Figure 2 Typical setup of ESD simulator measurement.

Attenuation Calculation

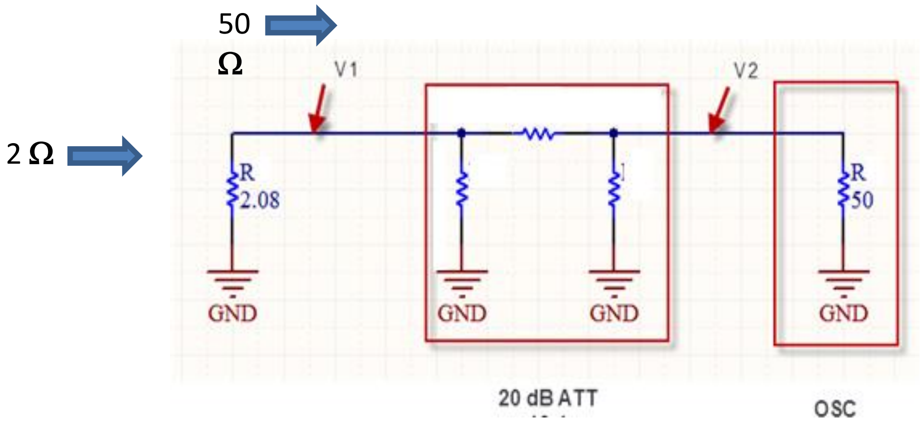

Figure 3 ESD Target with 20 dB attenuator configuration.

In the diagram above, a 20 dB attenuator is used in the measurement of an ESD discharge event, and an oscilloscope is represented as a 50 Ohm load. Because of the 20 dB attenuator the voltage seen at the input of the oscilloscope is 1/10 of the voltage incident at the target, or

$$V_2 = V_1/10.$$

Because the attenuator is terminated in 50 Ohm, the input impedance seen at port 1 is 2.08//50 Ohm = 2.00 Ohm, meaning

$$V_1 = I_{ESD} \times 2.00 \text{ Ohm}$$

Where, I_{ESD} is the current into port 1 during a discharge event. The 2.08 Ohm resistor is the specification for an ESDEMC factory calibrated A4001 Target. This may be different for other manufacture's targets. The ratio between ESD current and voltage present at the oscilloscope is then

$$I_{ESD} / V_2 = 5:1$$

This ratio is useful for determining how much attenuation is required for oscilloscope safe measurements because the currents for different high voltage set points are known. For example, during an 8 kV ESD test a discharge current, I_{ESD}, is expected to have a 30 A peak, corresponding to a peak voltage at the oscilloscope of 6 V. Additional attenuation should be added at the beginning of any new measurement setup to ensure safety of equipment until confidence in the setup is established.

An ESD Source Voltage versus Recommended Target Attenuator Size table is calculated below for reference. It is based on a 50 Ohm 5 Vrms real time oscilloscope measurement (a measurement range of 8 V with 1 V/div). The green zone is a safe operating area, and the numbers therein are the peak voltages seen at the oscilloscope. The yellow zone is a boarder-line area and should probably be avoided because when considering the ±15% peak current tolerance margin from standard, it might not be enough. A GHz high speed Oscilloscope has max voltage reading of 8V or 10 V at maximum scale:

ESD Source (kV)	Peak I (Amp)	First Peak Voltage in Oscilloscope (Volt)			
		Attenuation after ESD Target			
		20 dB	26 dB	30 dB	40 dB
4	15	3.0 V	1.5 V		
8	30	6.0 V	3.0 V		
15	56.25	11.25 V	5.62 V	3.56 V	1.13 V
25	93.75	18.75 V	9.38 V	5.93 V	1.88 V
30	112.50	22.5 V	11.25 V	7.12 V	2.25 V

Table 3 ESD Source voltage and Recommended Target Attenuation Setups.

Expected Waveform (for IEC standard)

The expected 4kV IEC 61000-4-2 standard waveform is shown in Figure 4.

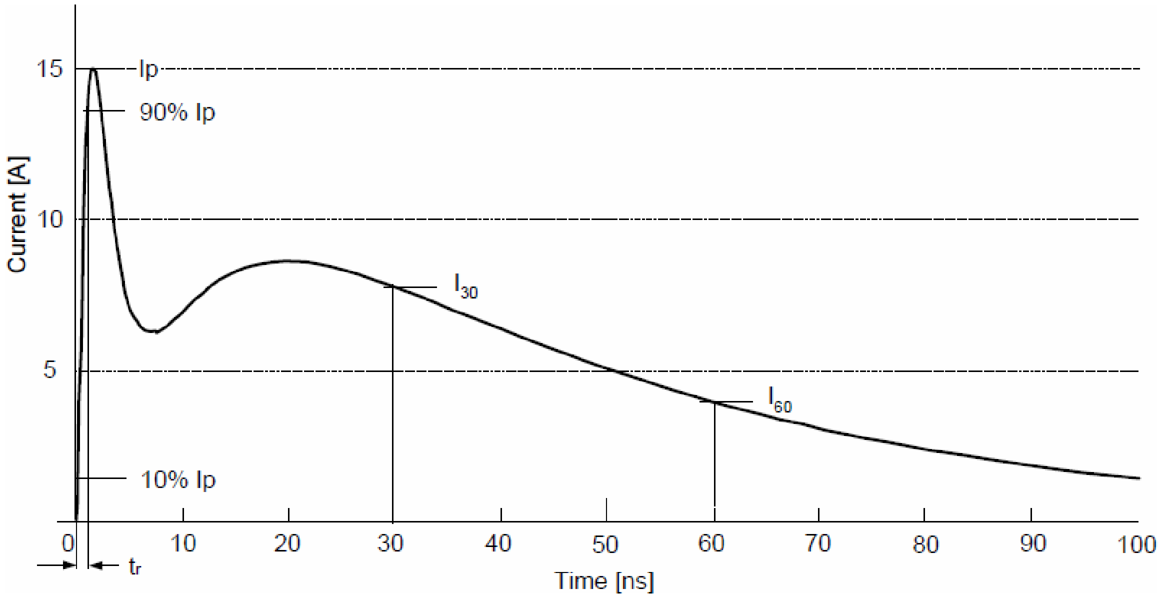

Figure 4: Ideal IEC 61000-4-2 ESD Simulator Waveform.

Measurement 8kV IEC Result

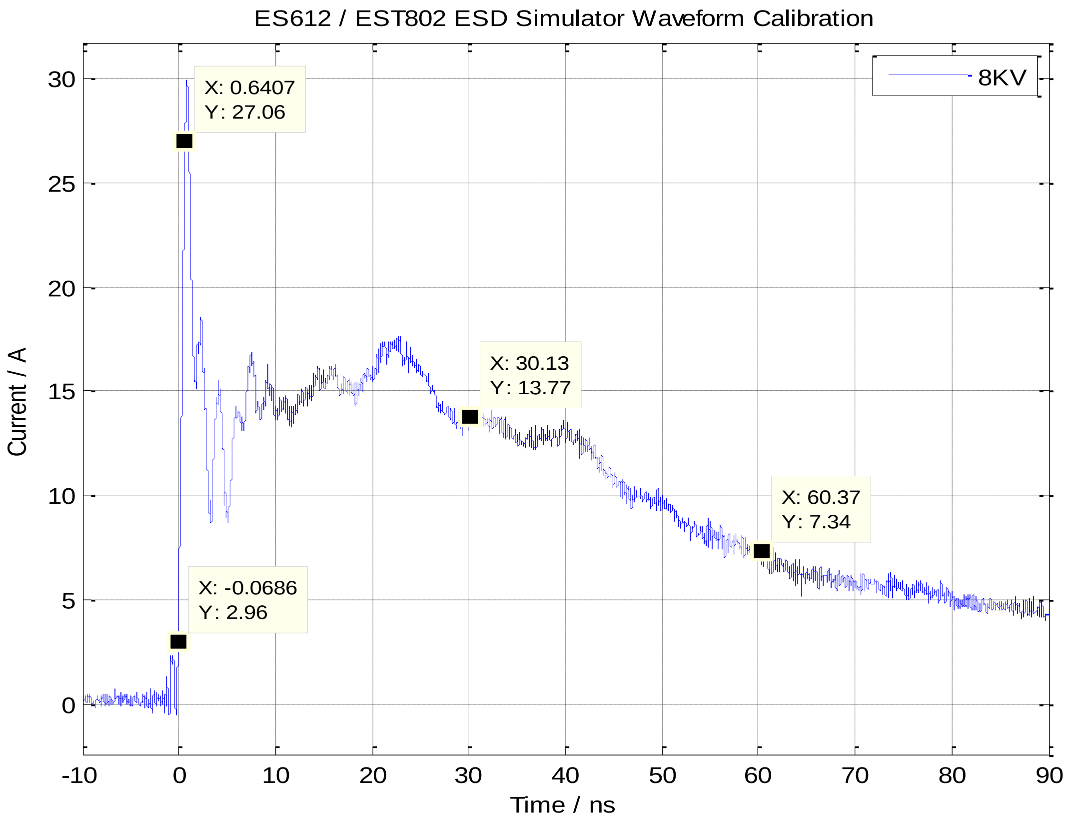

Figure 5 Measured IEC 61000-4-2 ESD Simulator Waveform.

Test Levels	Indicated Voltage	First Peak (±15%) T_{rise} = 0.8 ± 0.2 ns	Current @ 30 ns (±30%)	Current @ 60 ns (±30%)
Level 1	±2kV	7.5 A	4 A	2 A
Level 2	±4kV	15 A	8 A	4 A
Level 3	±6kV	22.5A	12 A	6 A
Level 4	±8kV	30 A	16 A	8 A

Voltage	Rise time (ns)		Peak Current [A]		Current at 30 ns [A]		Current at 60 ns [A]		Result
	IEC (±20%)	Cal Result	IEC (±15%)	Cal Result	IEC (±30%)	Cal Result	IEC (±30%)	Cal Result	
2 kV	0.8 (0.6~1.0)	0.905	7.5 (6.375~8.625)	**7.6**	4 (2.8~5.2)	**3.45**	2 (1.4~2.6)	**1.75**	PASS
4 kV		0.909	15 (12.75~17.25)	**15.15**	8 (5.6~10.4)	**7.6**	4 (2.8~5.2)	**3.3**	PASS
6 kV		0.914	22.5 (19.125~25.875)	**22.3**	12 (8.4~15.6)	**11.3**	6 (4.2~7.8)	**5**	PASS
8 kV		0.925	30 (25.5~34.5)	**30.6**	16 (11.8~20.8)	**15.5**	8 (5.6~10.4)	**6.5**	PASS

Table 4 IEC 61000-4-2 contact discharge current waveform parameters.

ESDEMC Technology LLC, 4000 Enterprise Dr, Suite 103, Rolla, MO, 65409, USA
www.esdemc.com Tel: (+1)-573-202-6411 Fax: (+1) 877-641-9358 Email: info@esdemc.com

4. FAQ Section

4.1 How do oscilloscope bandwidth / sampling rate affect calibration?

Some ESD events have been measured with a rise time <100 ps and the actual ESD waveform may be even faster. The bandwidth needed to resolve such a fast rise time is approximately $0.35/r_t$, or 3.5 GHz for a 100 ps rise time. Without enough bandwidth or sampling rate, the rise time will be down sampled and not adequately captured. A simplified comparison of the same rise time with not enough and enough sampling rate, respectively, is shown below,

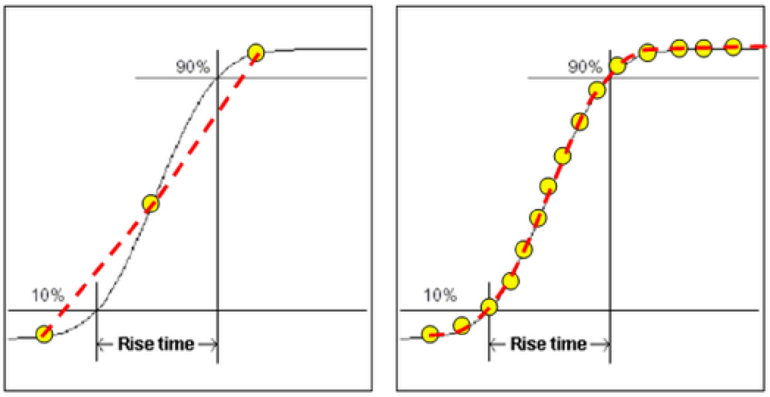

Figure 6 Rise-time comparison with and without enough sampling rate

In addition, the oscilloscope bandwidth / sampling rate could affect the measured first peak value as the first peak contains high frequency components. Even a waveform measured with the same oscilloscope with different sampling rates will show different results. This could lead to an ESD simulator appearing to have passed the standard with a slower sampling rate, but actually failing with a higher sampling rate. An example of this is shown below,

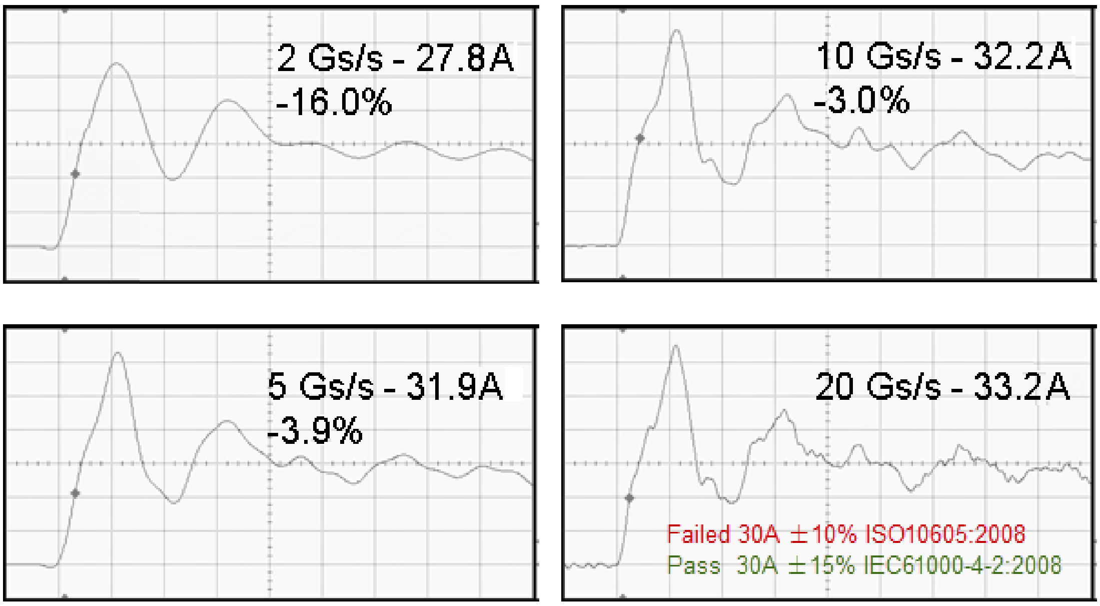

Figure 7 Effect of using different sampling rates with the same oscilloscope

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4.2 When buying an ESD Target, can I buy only the ESD target and use the cable and attenuators already in house for the calibration?

The standards require the ESD Target-Attenuator-Cable Chain (up to the connection to the oscilloscope) and the oscilloscope to be calibrated before the ESD simulator calibration test. If the ESD target is calibrated without the attenuator and cable, the ESD Target will have to be recalibrated with the new cable and attenuator. Or one should characterize the effects of their own cables and attenuators to compensate for them mathematically.

For cable selection, the standard requires the test cable to be well shielded and low loss. A RG400 cable no more than 1 meter long is preferred by the standard. RG 214 is 1/2 the loss and is commonly available, but may not be available with SMA connectors. Most high speed oscilloscopes use SMA or improved BNC connectors.

For attenuator selection, the frequency response needs to be flat up to 4 GHz to make the overall transfer impedance of Target-Attenuator-Cable Chain flat according to test standard. Also the attenuator needs to be able to handle a relatively large peak power rating.

4.3 How do the other setup parameters affect the waveform?

Parameters	Influence
Shielding	A 1.2 m x 1.2 m reference plane is required for the shielding against the direct coupling between oscilloscope and the ESD simulator. It is required by the standard. And the measurements observed by different oscilloscopes can be very different. Some oscilloscopes will show significant noise coupling (without the ESD target connection), and some will show very little.
Position of ground cable	The length and shape of the grounding wire, and thereby the effective inductance of the loop, will affect the secondary RC peak. This should be positioned correctly, but the effects on waveform are normally small.
Orientation of simulator	This typically has some effect on the test waveform but normally small.
Air Discharge	The approach speed and environmental factors greatly affect results making repeatability difficult.

Table 5 Parameters and their influence

ESDEMC Technology LLC, 4000 Enterprise Dr, Suite 103, Rolla, MO, 65409, USA
www.esdemc.com Tel: (+1)-573-202-6411 Fax: (+1) 877-641-9358 Email: info@esdemc.com