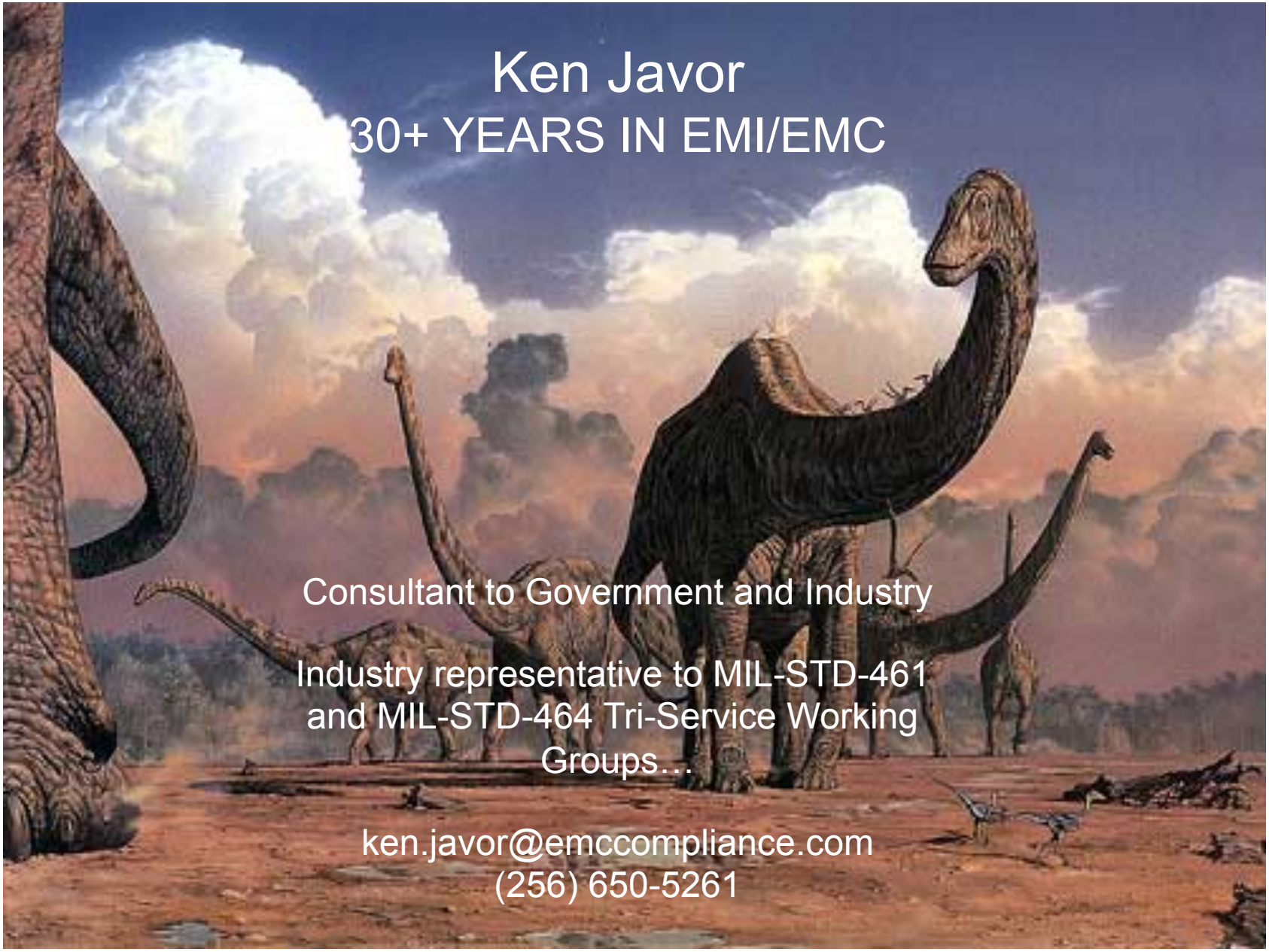
ROHDE&SCHWARZ

Trends in MIL-STD-461
1993 - 2014

Ken Javor
EMC Consultant



Ken Javor

30+ YEARS IN EMI/EMC

Consultant to Government and Industry

Industry representative to MIL-STD-461 and MIL-STD-464 Tri-Service Working Groups…

ken.javor@emccompliance.com
(256) 650-5261

PURPOSE OF STANDARD

Controls EMI characteristics of equipment/subsystems procured by DoD

GO/NO-GO or Pass/Fail Requirements*

Increases likelihood of compatibility in its EME

Easier to build EMC into equipments/ subsystems that to Band-Aid it in during system integration

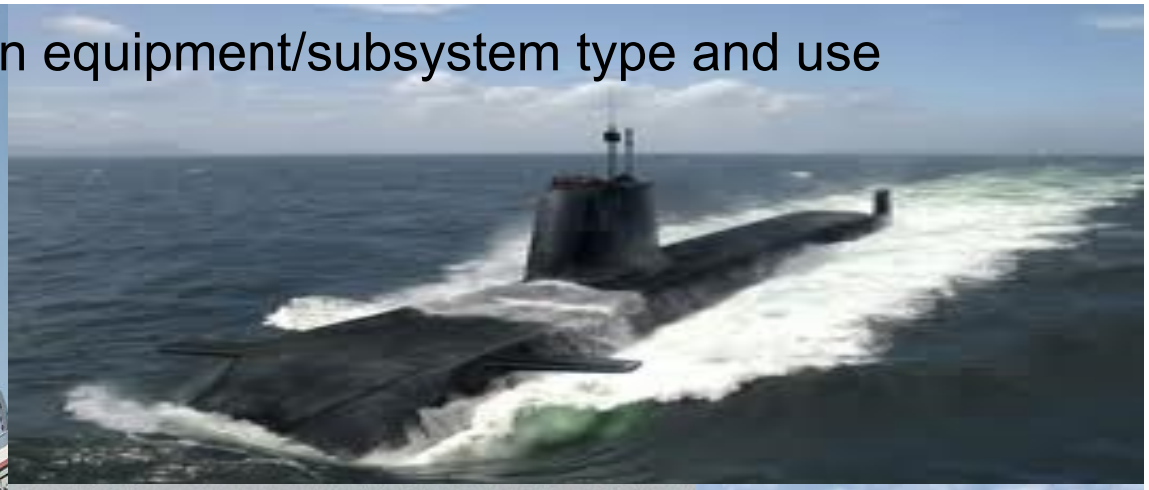
* Officially - actually, not so much…

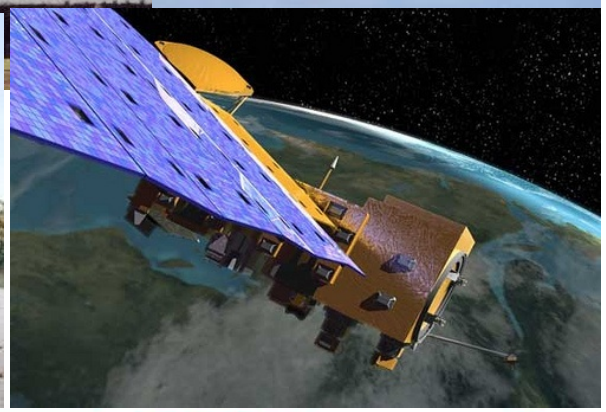
Key: black typeface applicable to all versions; red typeface was new in revision F, and green typeface is being discussed for revision G.

MIL-STD-461G schedule is a draft for industry review this fall and official release first or second quarter of 2015.

APPLICABILITY

Requirements depend on equipment/subsystem type and use





APPLICABILITY

Requirements and procedures may be tailored

Power Source Impedance

1967 - 1993	1993 - present	2007 - present
10 uF feedthrough capacitor	50 uH LISN	Added 5 uH LISN (tailored applicability)

4.3.8 EUT Test Configurations

4.3.8.6 Construction and Arrangement of EUT

MIL-STD-461F: primary power cables are never shielded

SUMMARY: TEST IT AS IT IS USED - “TEST AS YOU FLY”

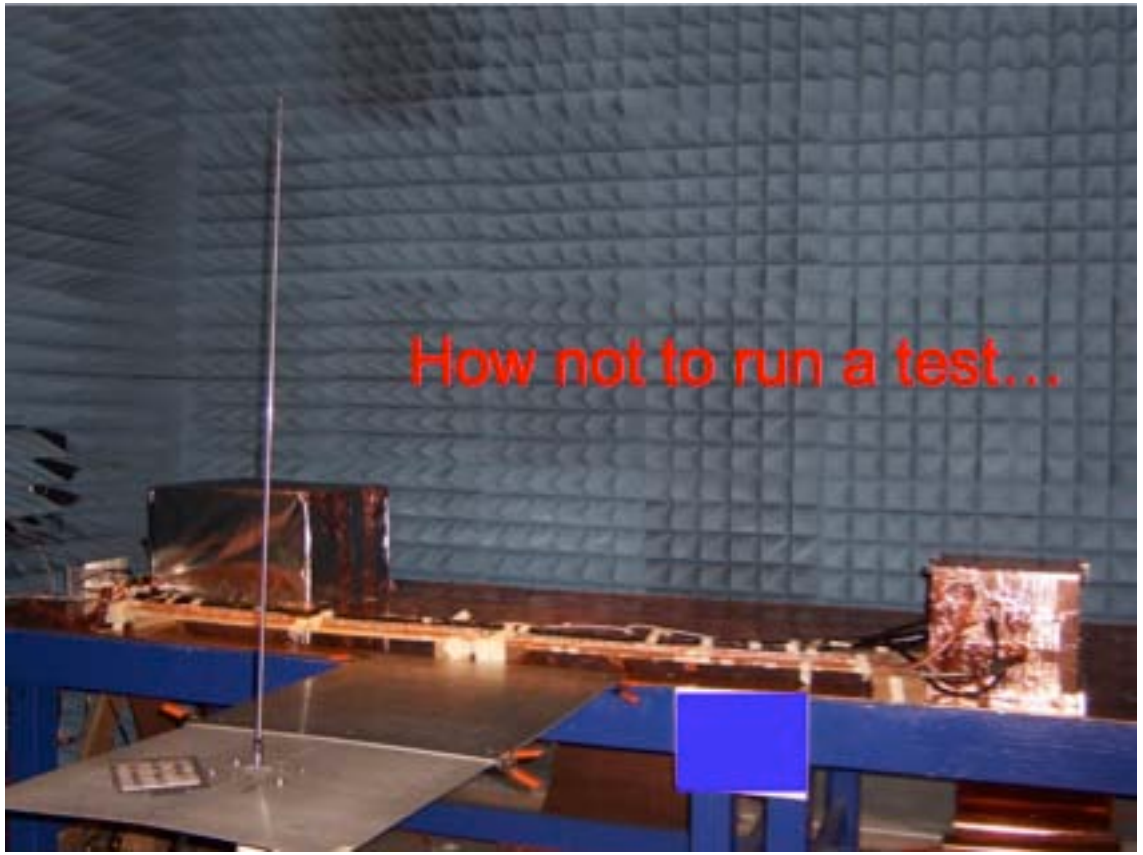


Table II - Emission Sweeps

Emission sweeps for broadband signals

Frequency Range Hz	Bandwidth Hz	Band sweep time (sec)	Band sweep time per Table II (sec)	# fast sweeps required
30 – 1000	10	20	30	1.5
1 k – 10 k	100	1.8	2.7	1.5
10 k – 150 k	1000	0.28	4.2	15
0.15 – 30 M	10 k	0.6	90	150
30 M – 1 G	100 k	0.194	290	1500
above 1 G	1 M	2 ms/GHz	30 s/ GHz	15,000

Time Domain sweeping is even better for broadband signals, but requires further instructions (-461G)

Table II - Emission Sweeps

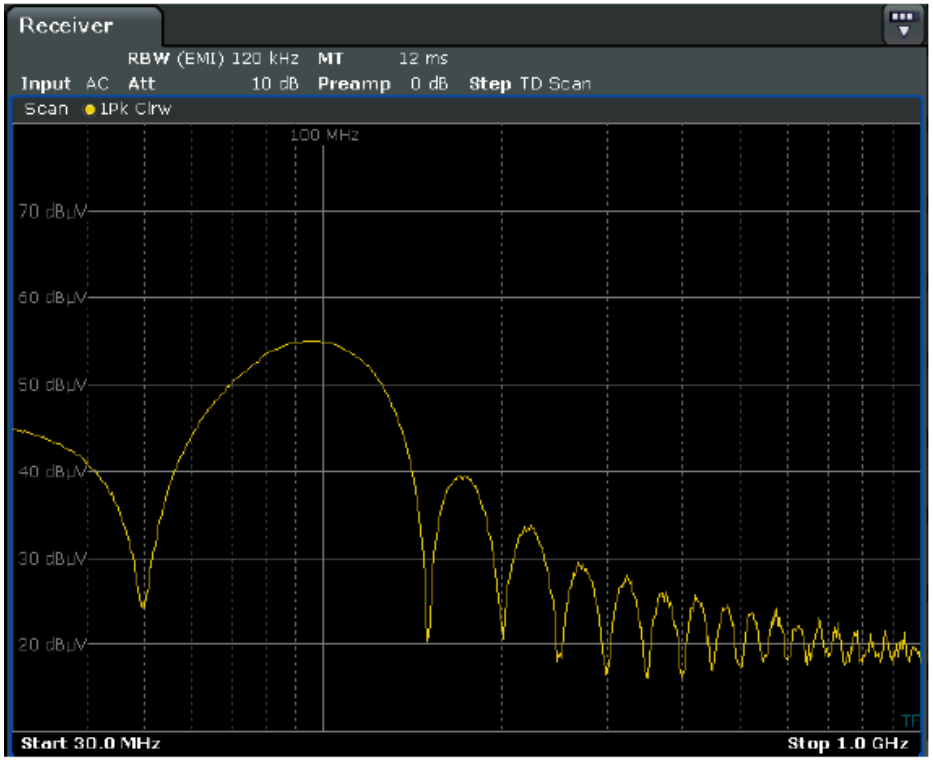


Fig. 20: Time domain scan with a measurement time of 12 ms, signal with a pulse period of 12 ms.

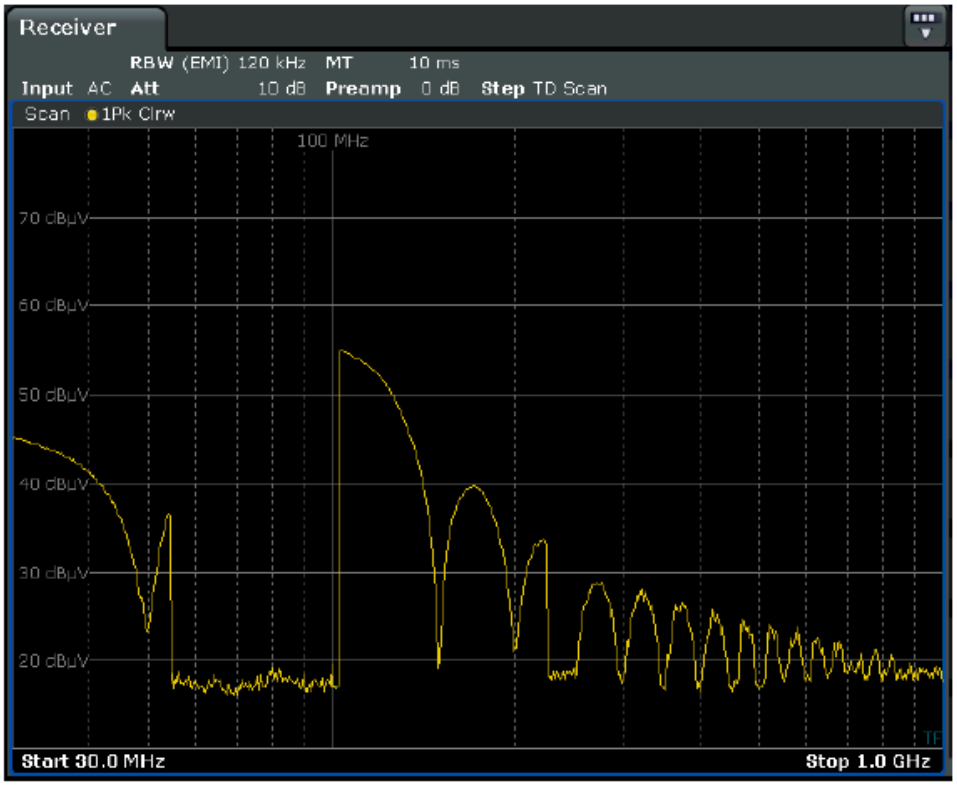


Fig. 21: The measurement time is shorter than the signal's pulse period.

(from R&S white paper: Comparison of Time Domain Scans and Stepped Frequency Scans in EMI Test Receivers, 2013)

Time Domain sweeping is even better for broadband signals, but requires further instructions (-461G)

Table III – Susceptibility Sweeps

Frequency Range	-461E step size	-461F step size	Relative sweep time F vs. E
30 Hz – 1 MHz	5%	5%	Same
1 – 30 MHz	1%	1%	Same
30 M – 1 GHz	0.5%	0.5%	Same
1 - 8 GHz	0.1%	0.25%	40% (250% faster)
above 8 GHz	0.05%	0.25%	20% (500% faster)

4.3.11 Suggested Change

Existing text:

4.3.11 Calibration of measuring equipment.
Test equipment and accessories required for measurement in accordance with this standard shall be calibrated in accordance with ANSI/NCSL Z540-1 or ISO 10012 or under an approved calibration program traceable to the National Institute for Standards and Technology. In particular, measurement antennas, current probes, field sensors, LISNs (see Figure 7 for required impedance), and other devices used in the measurement loop shall be calibrated at least every 2 years unless otherwise specified by the procuring activity, or when damage is apparent.

Suggested change acknowledges that passive device calibration is quite different than calibrating an EMI receiver and cycle times and procedures are significantly different. SAE AIR for such passive device calibration is underway to support a change.

TABLE IV. Emission and susceptibility requirements

Requirement	Description
CE101	Conducted Emissions, Power Leads, 30 Hz to 10 kHz
CE102	Conducted Emissions, Power Leads, 10 kHz to 10 MHz
CE106	Conducted Emissions, Antenna Terminal, 10 kHz to 40 GHz
CS101	Conducted Susceptibility, Power Leads, 30 Hz to 150 kHz
CS103	Conducted Susceptibility, Antenna Port, Intermodulation, 15 kHz to 10 GHz
CS104	Conducted Susceptibility, Antenna Port, Rejection of Undesired Signals, 30 Hz to 20 GHz
CS105	Conducted Susceptibility, Antenna Port, Cross-Modulation, 30 Hz to 20 GHz
CS106	Conducted Susceptibility, Transients, Power Leads
CS109	Conducted Susceptibility, Structure Current, 60 Hz to 100 kHz
CS114	Conducted Susceptibility, Bulk Cable Injection, 10 kHz to 200 MHz
CS115	Conducted Susceptibility, Bulk Cable Injection, Impulse Excitation
CS116	Conducted Susceptibility, Damped Sinusoidal Transients, Cables and Power Leads, 10 kHz to 100 MHz
RE101	Radiated Emissions, Magnetic Field, 30 Hz to 100 kHz
RE102	Radiated Emissions, Electric Field, 10 kHz to 18 GHz
RE103	Radiated Emissions, Antenna Spurious and Harmonic Outputs, 10 kHz to 40 GHz
RS101	Radiated Susceptibility, Magnetic Field, 30 Hz to 100 kHz
RS103	Radiated Susceptibility, Electric Field, 2 MHz to 40 GHz
RS105	Radiated Susceptibility, Transient Electromagnetic Field

CS117 Indirect Lightning
ES101 (?) ESD

Table V. Requirements

Equipment and Subsystems Installed In, On, or Launched From the Following Platforms or Installations	Requirement Applicability																		Indirect Lightning Effects	ESD
	CE101	CE102	CE106	CS101	CS103	CS104	CS105	CS106	CS109	CS114	CS115	CS116	RE101	RE102	RE103	RS101	RS103	RS105		
Surface Ships	A	A	L	A	S	S	S	A	L	A	S	A	A	A	L	A	A	L	?	?
Submarines	A	A	L	A	S	S	S	A	L	A	S	L	A	A	L	L	A	L	?	?
Aircraft, Army, Including Flight Line	A	A	L	A	S	S	S			A	A	A	A	A	L	A	A	L	?	?
Aircraft, Navy	L	A	L	A	S	S	S			A	A	A	L	A	L	L	A	L	?	?
Aircraft, Air Force		A	L	A	S	S	S			A	A	A		A	L		A		?	?
Space Systems, Including Launch Vehicles		A	L	A	S	S	S			A	A	A		A	L		A		?	?
Ground, Army		A	L	A	S	S	S			A	A	A		A	L	L	A		?	?
Ground, Navy		A	L	A	S	S	S			A	A	A		A	L	A	A	L	?	?
Ground, Air Force		A	L	A	S	S	S			A	A	A		A	L		A		?	?

Legend:

A: Applicable
L: Limited as specified in the individual sections of this standard
S: Procuring activity must specify in procurement documentation

5.4 CE101

New in MIL-STD-461F (appendix)

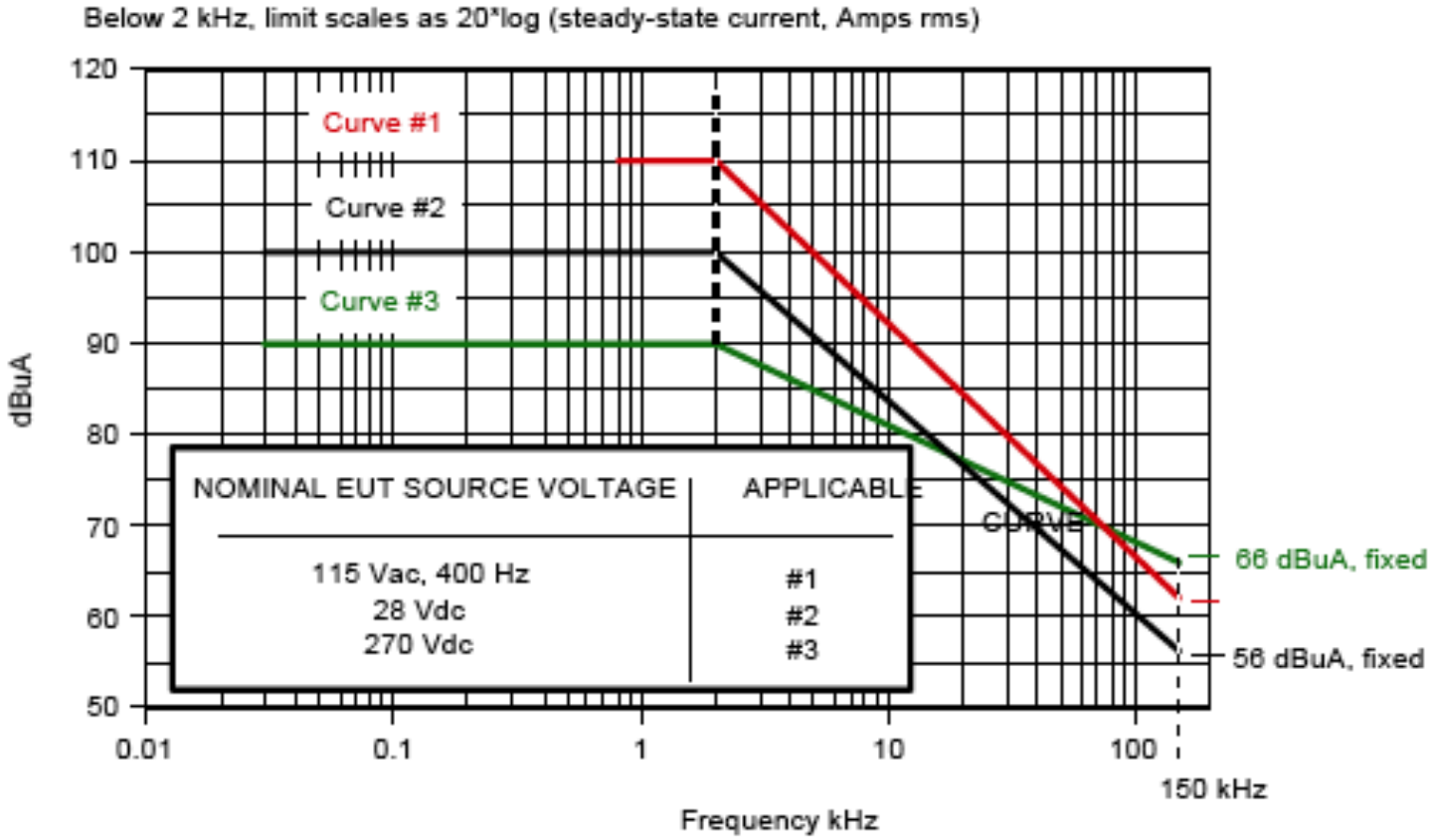
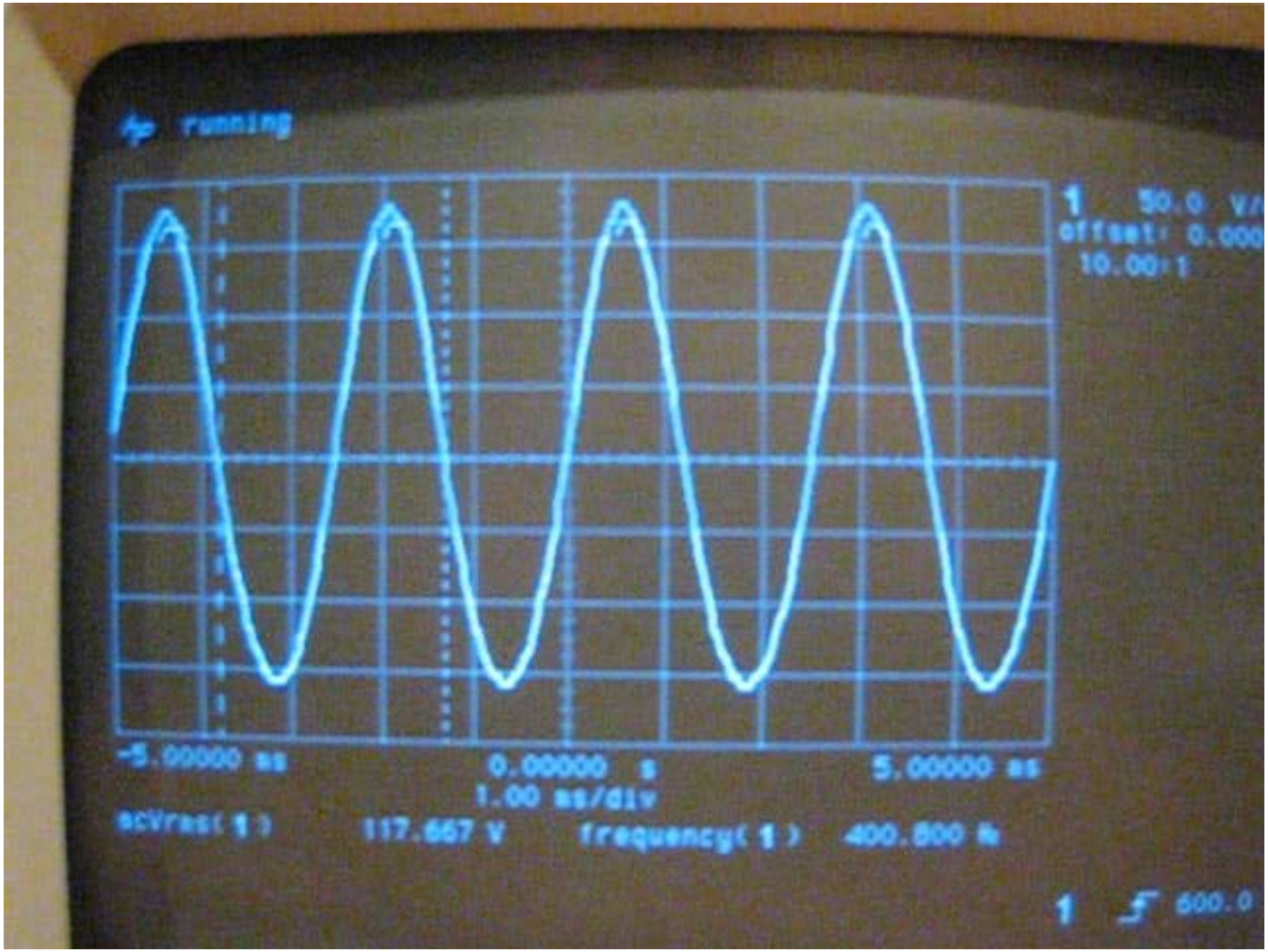
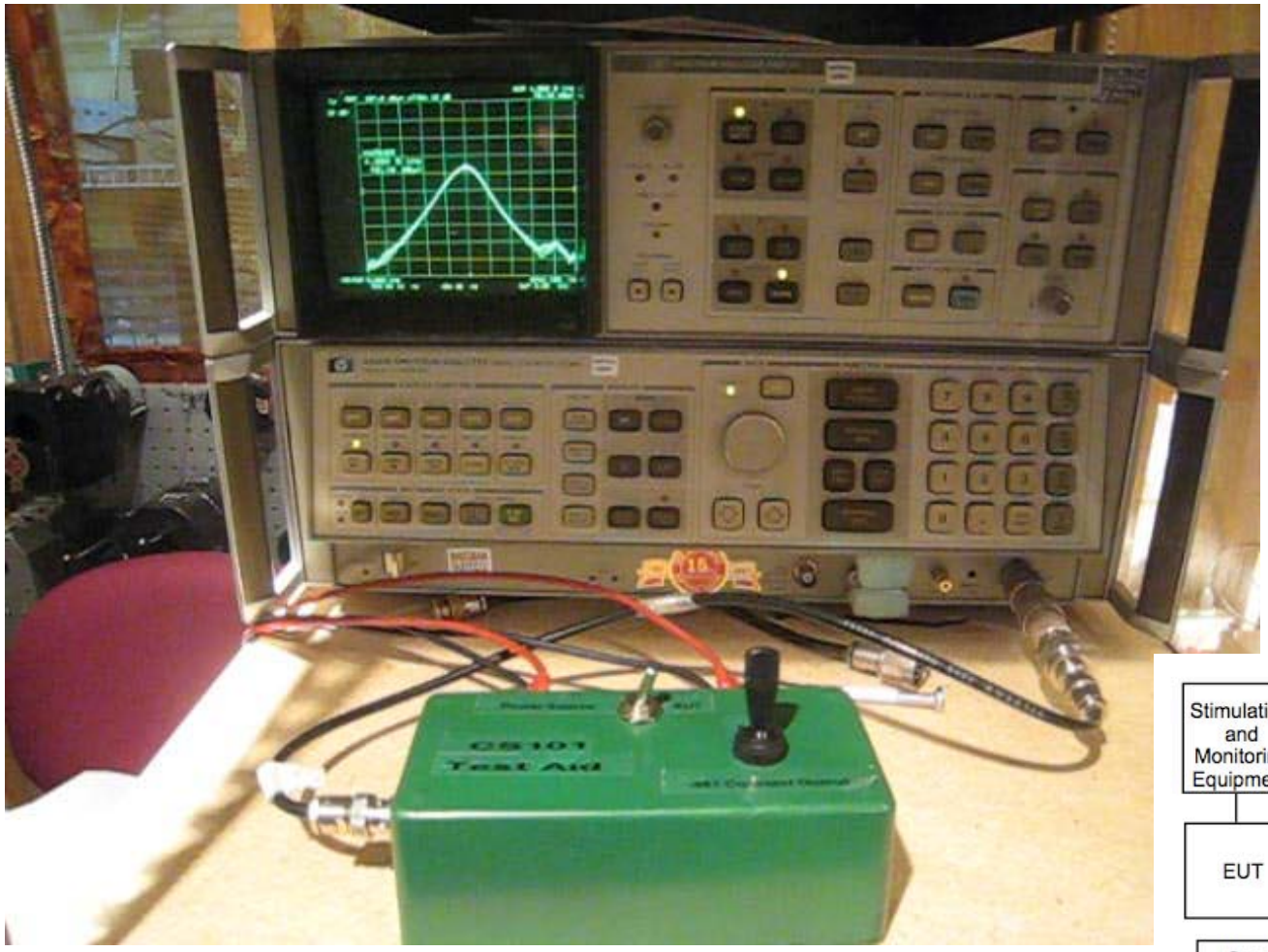


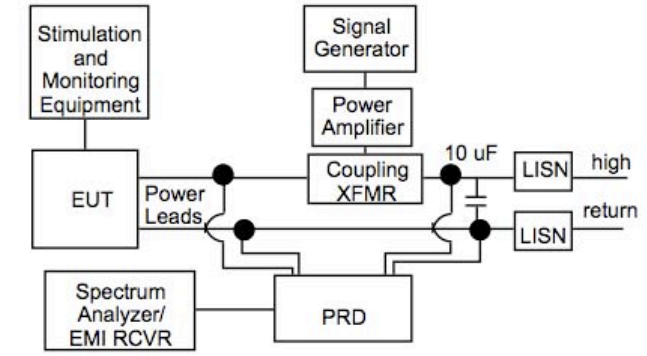
FIGURE A-6. CE101 limits for a 5 µH LISN.

5.7 CS101 Problem

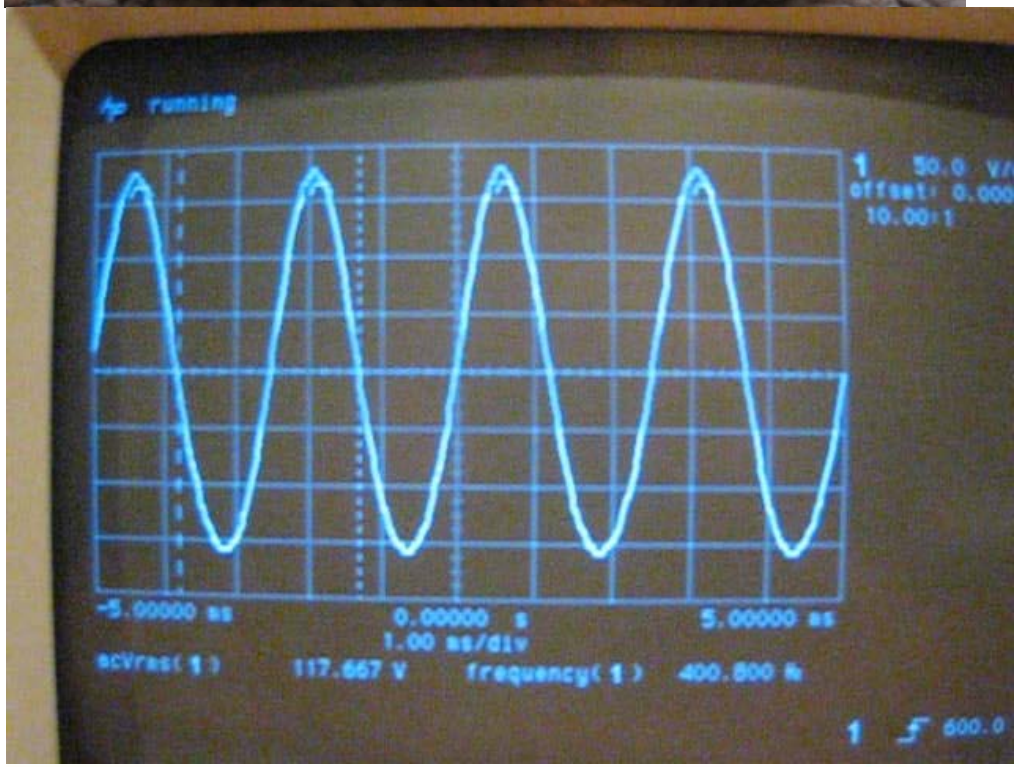


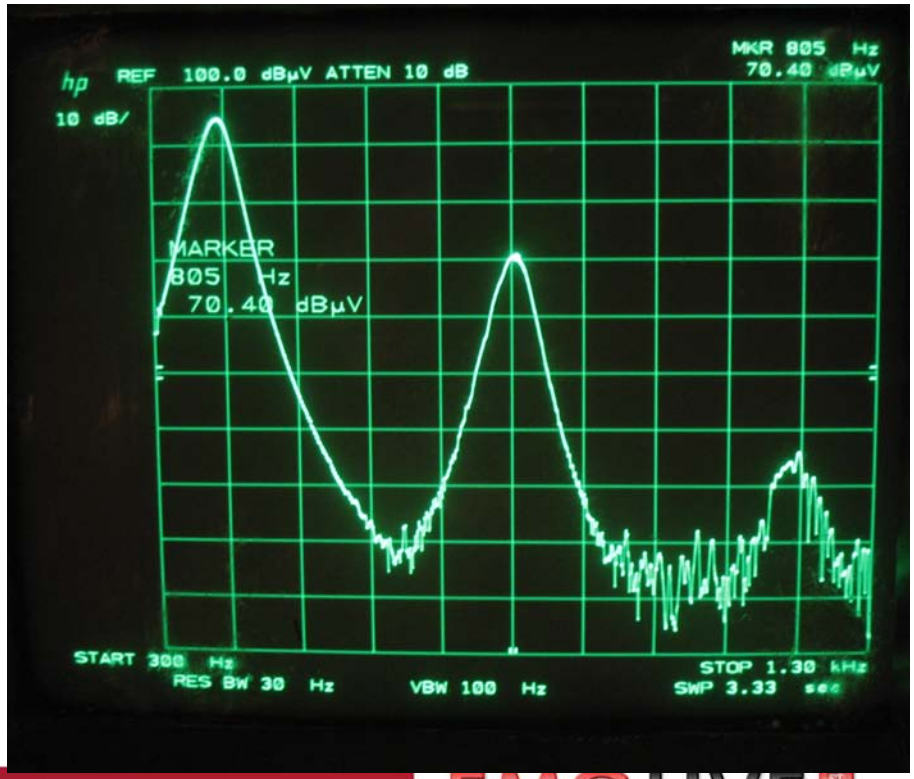
5.7 CS101 Solution





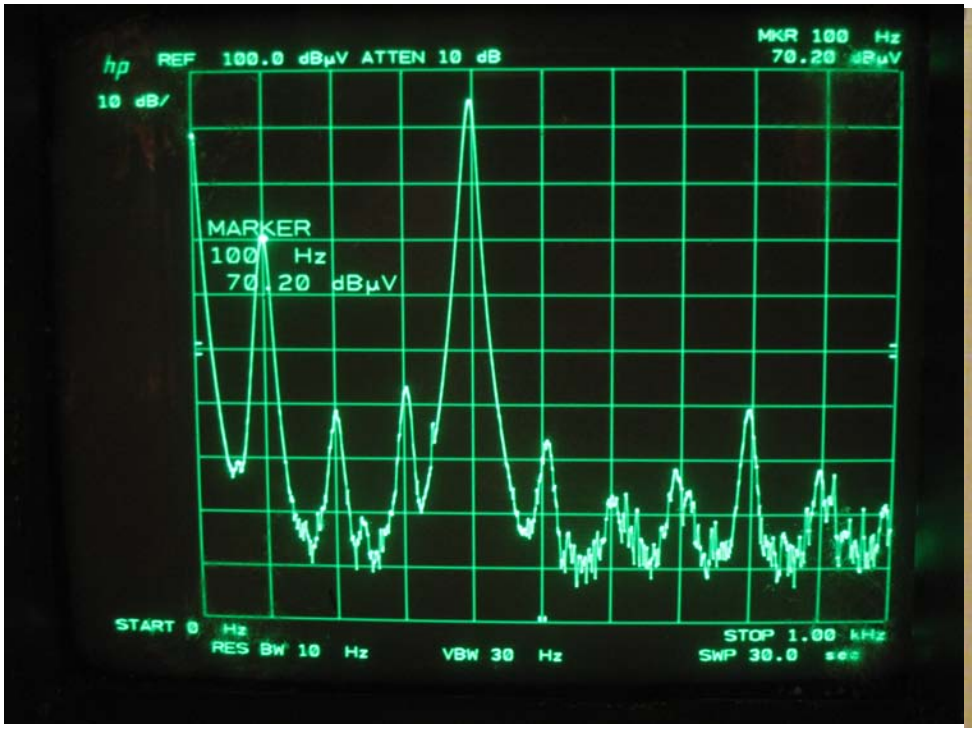
Performance Comparison 800 Hz CS101 Ripple

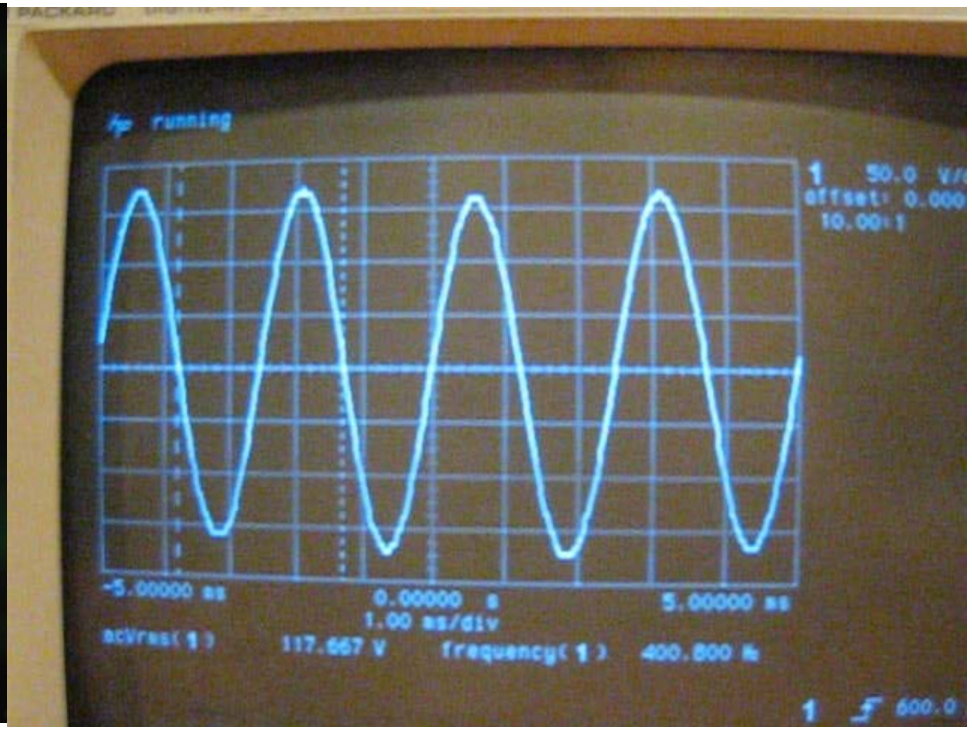




Performance Comparison 100 Hz CS101 Ripple

The Past Into the Future?



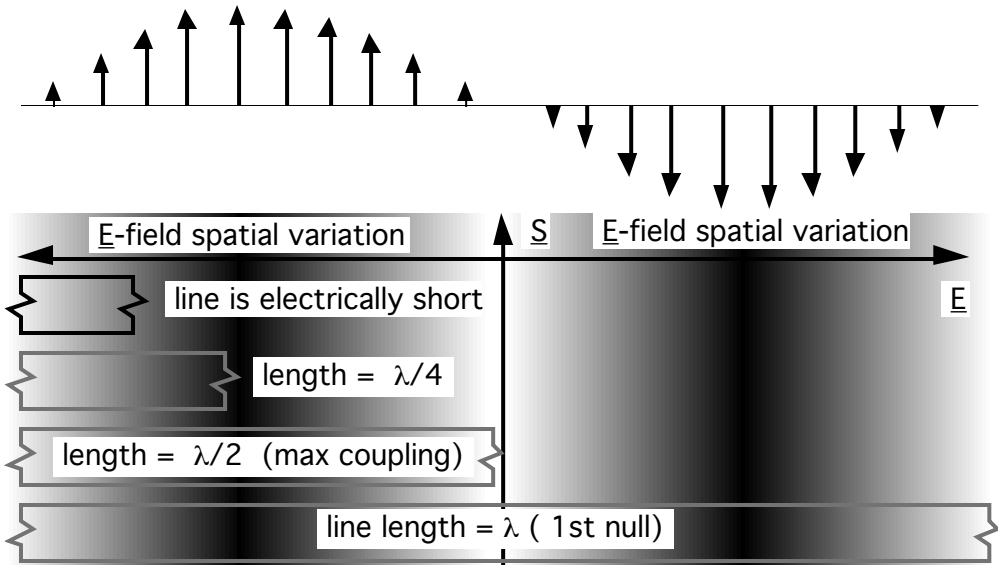


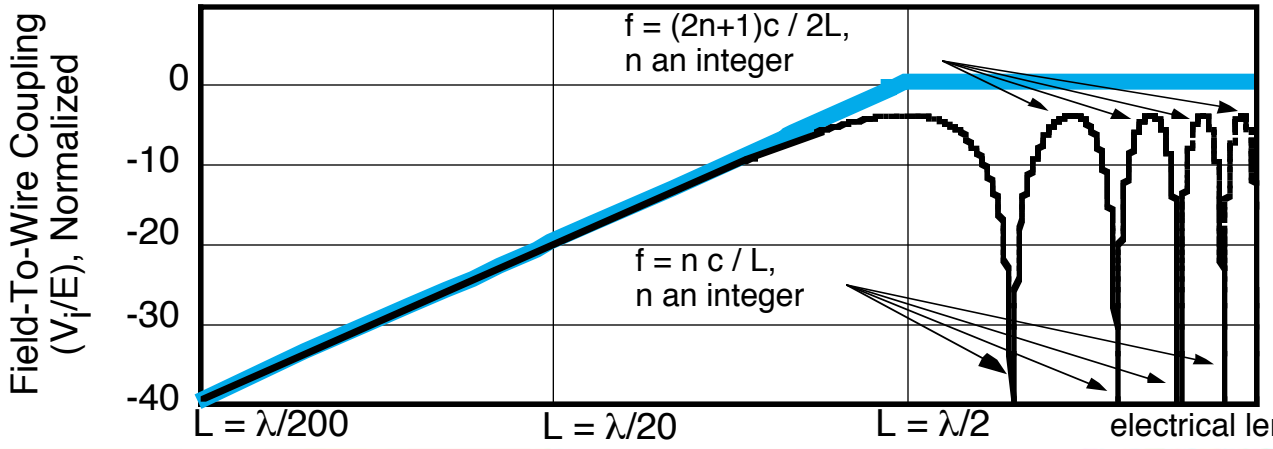
Testing at frequencies below the power frequency.

5.12 (5.13) CS114, Conducted Susceptibility, Bulk Cable Injection, 10 kHz to 200 MHz (continued)

coupling efficiency

$$\frac{V_i}{E_i} = 2h \sin(\pi l/\lambda)$$





5.12 (5.13) CS114 (continued)

FREQUENCY RANGE / PLATFORM		LIMIT CURVE NUMBERS SHOWN IN FIGURE CS-114-1 AND LIMITS							
		AIRCRFAFT (EXTERNAL OR SAFETY CRITICAL)	AIRCRAFT INTERNAL	ALL SHIPS (ABOVE DECKS) AND SUBMARINES (EXTERNAL)*	SHIPS (METALLIC) (BELOW DECKS)	SHIPS (NON-METALLIC) (BELOW DECK)**	SUBMARINE (INTERNAL)	GROUND	SPACE
4 kHz to 1MHz	N	-	-	77 dBµA	77 dBµA	77 dBµA	77 dBµA	-	-
10 kHz to 2 MHz	A	5	5	2	2	2	1	3	3
	N	5	3	2	2	2	1	2	3
	AF	5	3	-	-	-	-	2	3
2 MHz to 30 MHz	A	5	5	5	2	4	1	4	3
	N	5	5	5	2	4	1	2	3
	AF	5	3	-	-	-	-	2	3
30 MHz to 200 MHZ	A	5	5	5	2	2	2	4	3
	N	5	5	5	2	2	2	2	3
	AF	5	3	-	-	-	-	2	3

KEY: A = Army
N = Navy
AF = Air Force

* For equipment located external to the pressure hull of a submarine but within the superstructure, use SHIPS (METALLIC) (BELOW DECKS)

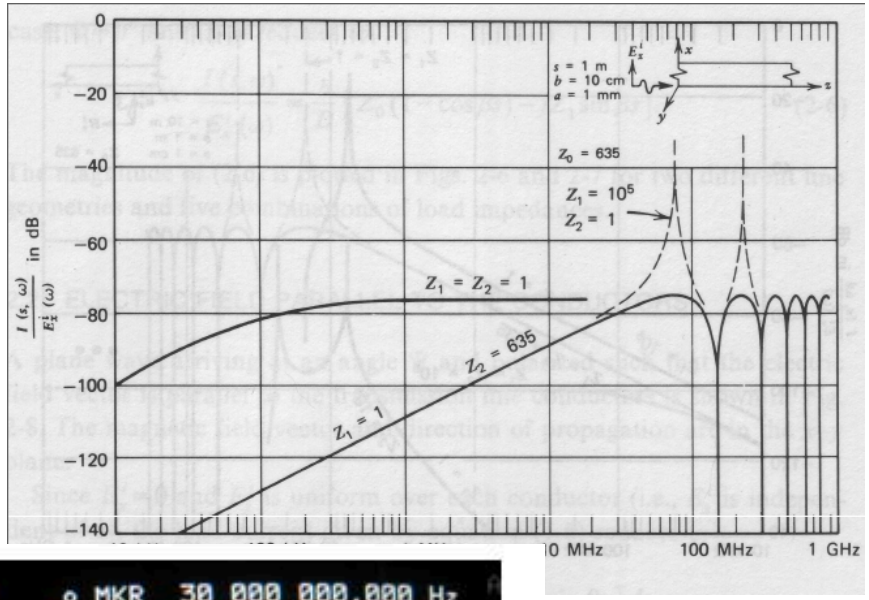
** For equipment located in the hanger deck of Aircraft Carriers

TABLE VI. CS114 limit curves

5.12 (5.13) CS114 (continued)

Level on current as present or on pre-calibrated forward power?

IN Compliance magazine, October 2014 issue



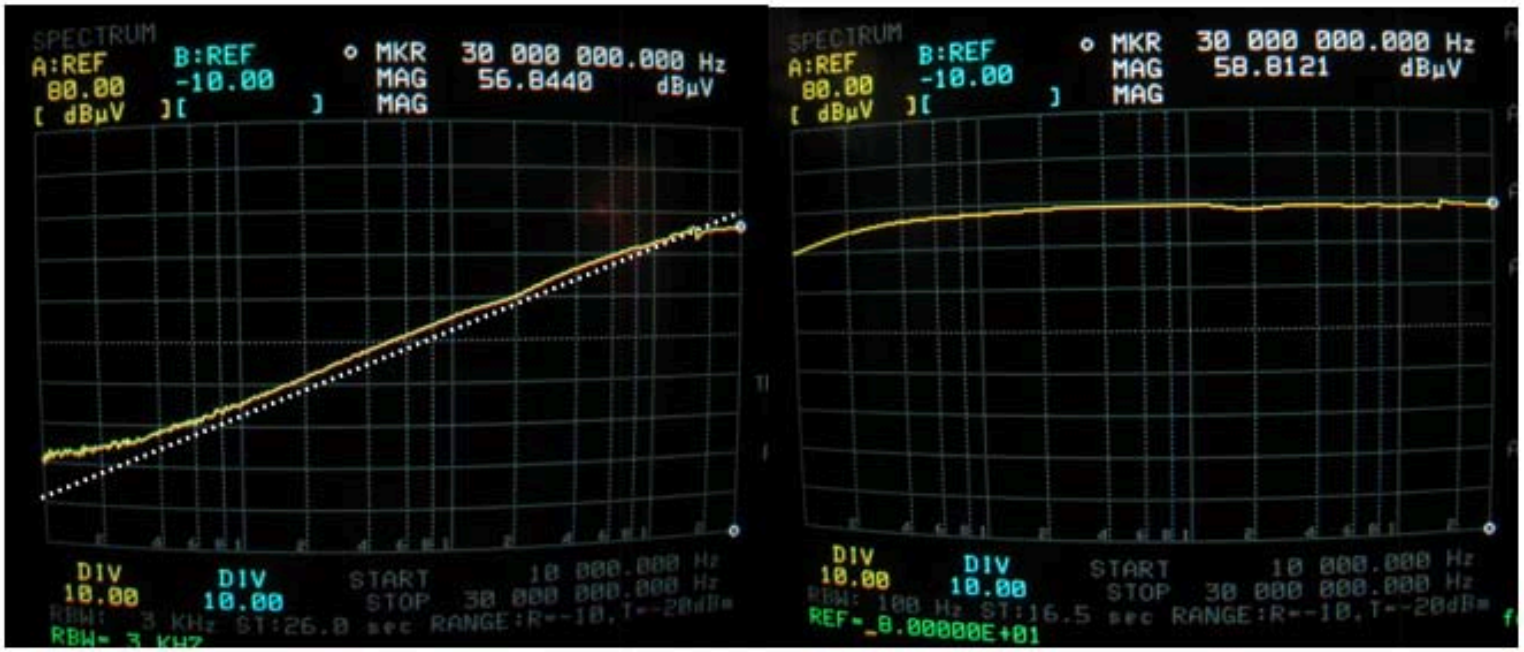


Figure 6a: Current coupled to XMSN line terminated in 50 Ohms from 10 kHz to 30 MHz. 4.6 V/m illumination. (white line is 20 dB/decade)

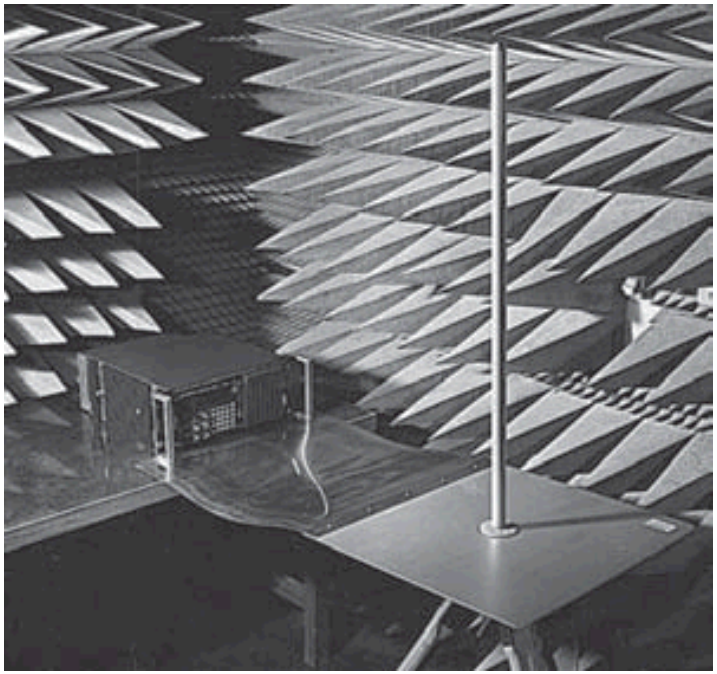
Figure 6b: Current coupled to short-circuited transmission line 10 kHz to 30 MHz. 4.6 V/m illumination.

5.16 (5.17) RE102

Issues under discussion for -461G (no guarantee of concrete action due to time constraints:

Rod antenna optimization
- Proper set-up
- Proper measurement system integrity check using correct capacitor value

Reverb



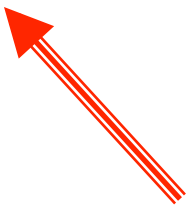
5.17 (5.18) RE103, Radiated Emissions, Antenna Spurious and Harmonic Outputs, 10 kHz to 40 GHz

5.17.1 (5.18.1) RE103 Applicability

This requirement may be used as an alternative for CE106 when testing transmitters with their intended antennas. CE106 is the preferred requirement unless the equipment or subsystem design characteristics preclude its use.

The requirement is not applicable within the EUT necessary bandwidth and within ±5 percent of the fundamental frequency.

This requirement is met if the emissions do not exceed the applicable RE102 limit



5.19 (5.20) RS103, Radiated Susceptibility, Electric Field, 2 MHz to 40 GHz

5.19.1 (5.20.1) RS103 Applicability

This requirement is applicable to equipment and subsystem enclosures and all interconnecting cables. The requirement is applicable as follows:

a. 2 MHz to 30 MHz	Army ships; Army aircraft, including flight line; Navy (except aircraft); and optional* for all others, **NAVAIR(!)**
b. 30 MHz to 1 GHz	all (except Navy aircraft) (may include Navy a/c again under G revision) **NAVAIR, again**
c. 100 MHz to 1 GHz	all
c/d. 1 GHz to 18 GHz	all
d/e. 18 GHz to 40 GHz	optional* for all

*Required only if specified in the procurement specification

The requirement at the tuned frequency of an antenna-connected receiver is 20 dB above the RE102 limit associated with the particular platform application

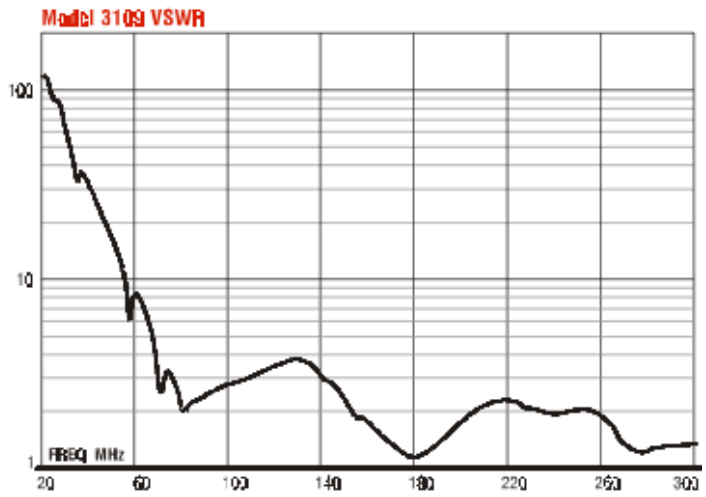
There is no requirement at the tuned frequency of antenna-connected receivers except for surface ships and submarines. (Surface ships and submarines get no relaxation at the tuned frequency.)

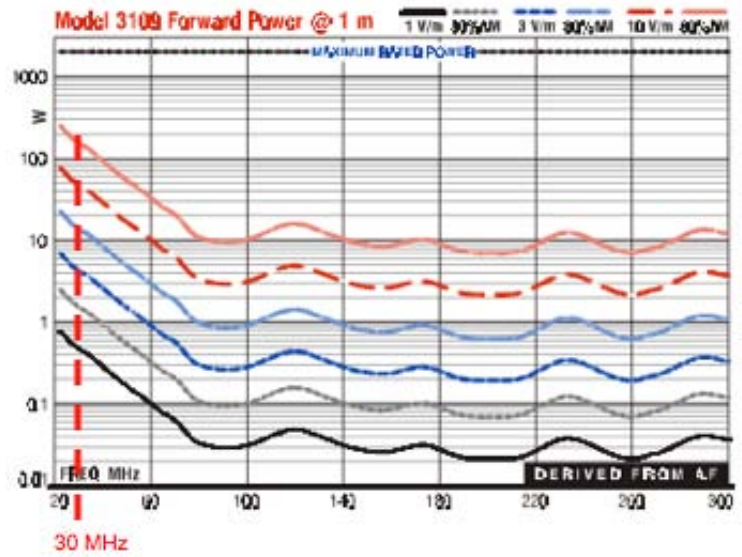
5.19 (5.20) RS103, Radiated Susceptibility, Electric Field, 2 MHz to 40 GHz

5.19.3 (5.20.3) RS103 Test Procedures

Under discussion: Applicability of grandfather clause allowing alternative pre-calibration of field in the absence of test sample and testing without a field strength monitor above 1 GHz.

Any suitable antenna may be used. MIL-STD-461F change: Ensure that the E-field sensor is indicating the field from the fundamental frequency and not from the harmonics."





~ 180 Watts x (200 V/m/20 V/m)^2 = 18 kW

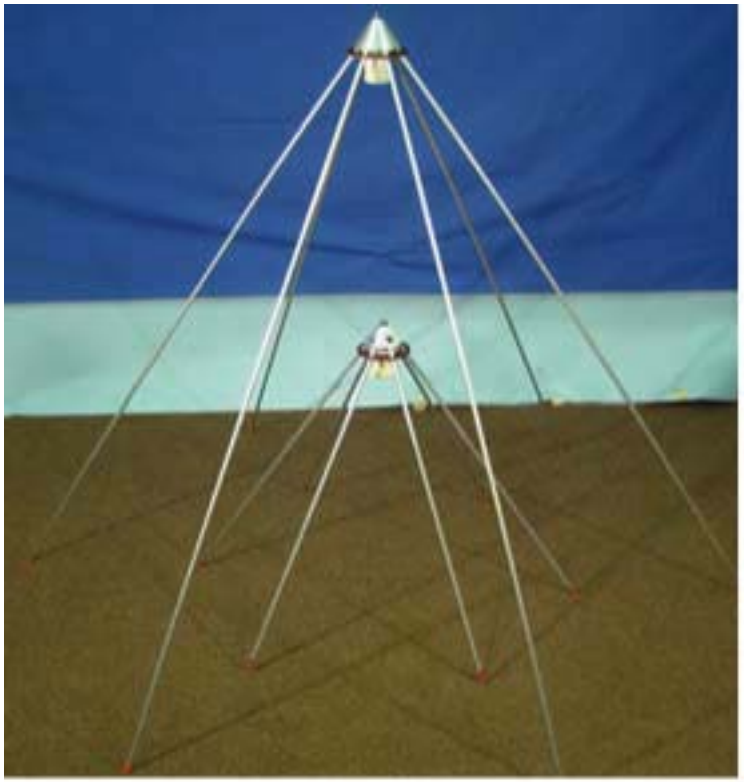
Max continuous power is 2 kW: not going to happen

RS103 Test Procedure (continued)

"Ensure that the E-field sensor is indicating the field from the fundamental frequency and not from the harmonics."

A major problem for higher field intensi

Possible solution, but major problem…



RS103 Test Procedure (continued)

"Ensure that the E-field sensor is indicating the field from the fundamental frequency and not from the harmonics."

A major problem for higher field intensities below 80 MHz…

The R&S®FSH8 with isotropic antennas.

R&S FSH outfitted with isotropic field sensors

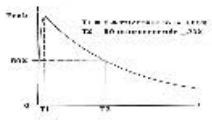
CS117 – Lightning Indirect Effects

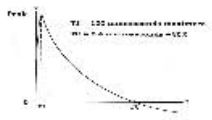
Borrowed from RTCA/DO-160G Section 22

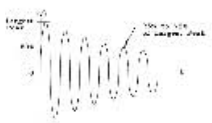
At present time, no pin injection.

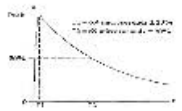
RTCA-DO160, and EUROCAE/ED-14:

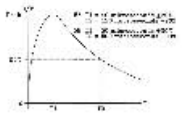
the basis for avionics testing by Boeing, Airbus, other avionics relevant standards

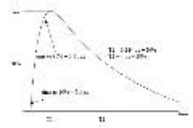








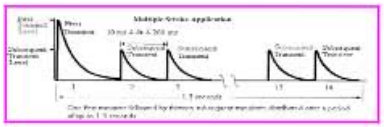




Waveform 1: Current

W1: Cable Bundle SS		
Level	Vlimit	Itest
1	50	100
2	125	250
3	300	600
4	750	1500
5	1600	3200

W1: Cable Bundle MS				
	First Stroke		Subsequent Stroke	
Level	Vlimit	Itest	Vlimit	Itest
1	50	50	25	25
2	125	125	62.5	62.5
3	300	300	150	150
4	750	750	375	375
5	1600	1600	800	800



Waveform 2: Voltage

W2: Cable Bundle SS		
Level	Vtest	Itest
1	50	100
2	125	250
3	300	600
4	750	1500
5	1600	3200

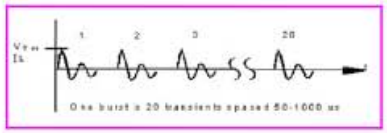
W2: Cable Bundle MS				
	First Stroke		Subsequent Stroke	
Level	Vtest	Itest	Vtest	Itest
1	50	50	25	25
2	125	125	62.5	62.5
3	300	300	150	150
4	750	750	375	375
5	1600	1600	800	800

Waveform 3: Voltage

W3: Pin Injection		
Level	Voc	Isc
1	100	4
2	250	10
3	600	24
4	1500	60
5	3200	128

W3: Cable Bundle SS		
Level	Vtest	Itest
1	100	20
2	250	50
3	600	120
4	1500	300
5	3200	640

W3: Cable Bundle MS				
	First Stroke		Subsequent Stroke	
Level	Vtest	Itest	Vtest	Itest
1	100	20	50	10
2	250	50	125	25
3	600	120	300	60
4	1500	300	750	150
5	3200	640	1600	320



Waveform 4: Voltage

W4: Pin Injection		
Level	Voc	Isc
1	50	10
2	125	25
3	300	60
4	750	150
5	1600	320

W4: Cable Bundle SS		
Level	Vtest	Itest
1	50	100
2	125	250
3	300	600
4	750	1500
5	1600	3200

W4: Cable Bundle MS				
	First Stroke		Subsequent Stroke	
Level	Vtest	Itest	Vtest	Itest
1	25	50	12.5	25
2	62.5	125	31.25	62.5
3	150	300	75	150
4	375	750	187.5	375
5	800	1600	400	800

Waveform 5: Current

W5A: Pin Injection		
Level	Vlimit	Itest
1	50	50
2	125	125
3	300	300
4	750	750
5	1600	1600
Boeing	2000	2000

W5A: Cable Bundle SS		
Level	Vlimit	Itest
1	50	150
2	125	400
3	300	1000
4	750	2000
5	1600	5000
X	3200	10000

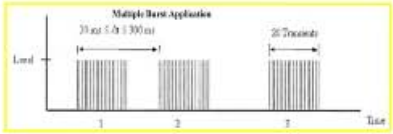
W5B: Cable Bundle SS		
Level	Vlimit	Itest
1	50	150
2	125	400
3	300	1000
4	750	2000
5	1600	5000

W5A & B: Cable Bundle MS				
	First Stroke		Subsequent Stroke	
Level	Vlimit	Itest	Vlimit	Itest
1	20	60	10	30
2	50	180	25	80
3	120	400	60	200
4	300	800	150	400
5	640	2000	320	1000

Waveform 3H & 6H: Current Multi Burst

Cable Bundle Multi burst				
Waveform	W3H		W6H	
Level	Vtest	Itest	Vlimit	Itest
1	60	1	70	5
2	150	2.5	180	12.5
3	360	6	430	30
4	900	15	1080	75
5	1920	32	2290	160

BOEING Multi burst W3		
Level	Vtest	Ilimit
A	50	10
B	150	30
C	300	60
D	1000	200



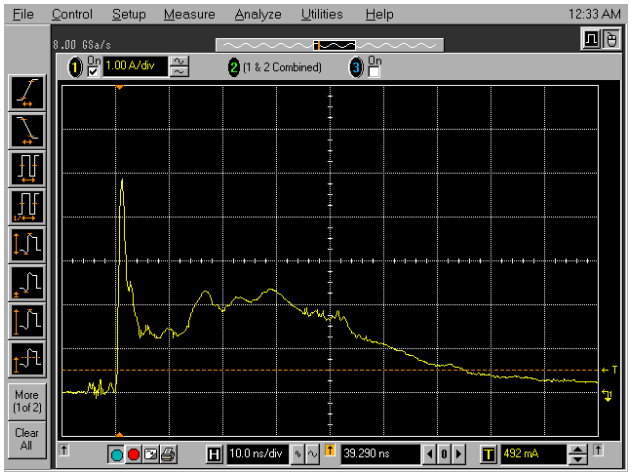
ES101(?) – ESD

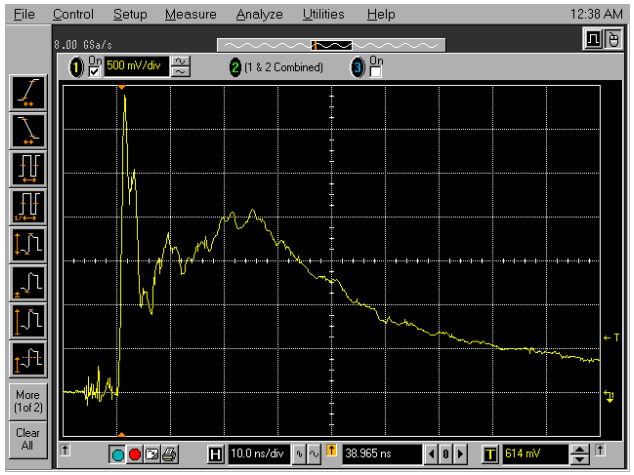
Personnel borne electrostatic discharge
Applicable to electrical, electronic, and electromechanical subsystems and equipment which does not interface with or control ordnance items
Leverage from Industry ESD standards
- RTCA/DO-160 section 25
- IEC 61000-4-2

ES101(?) – ESD

ESD requirements are specified as a certain potential
IEC 61000-4-2 specifies levels of 2, 4, 6, 8 and 15 kV for different applications.
All from a “gun” with 150 pF capacitance, and 330 Ohms resistance.

But effect operational electronics through di/dt





Data courtesy of Doug Smith at
http://emcesd.com/tt2010/tt120210.htm

Scale on this data
is 2x sensitivity.

FOR MORE INFORMATION VISIT
www.emclive2014.com