emc STANDARDS

Another EMC resource
from EMC Standards

EM phenomena

Helping you solve your EMC problems

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EM phenomena – where they come from, how they can interfere

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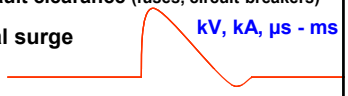
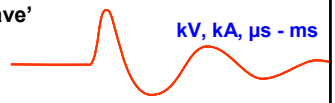
EM phenomena in long cables
(including mains cables, because they are long)

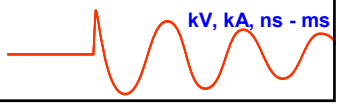
- **Transient over-voltage surges**
  e.g. due to thunderstorms; reactive load switching such as large motors or capacitor banks; fault clearance (fuses, circuit-breakers)
  - example of unidirectional surge



  - example of 'oscillatory wave'



  - example of 'ring wave'



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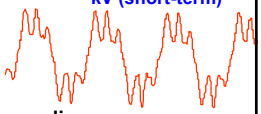
EM phenomena in long cables (inc. mains) continued…

- **Low-frequency induced voltages especially at the mains frequency**



  - differential-mode (transverse) and common-mode (longitudinal), both continuous and transient
  - a) caused by capacitive and inductive coupling
  - b) caused by potential differences between different parts of the earthing system due to current leakages and fault
  - c) caused by mains current flowing via insulation breakdown or spark arrestor operation after an overvoltage event

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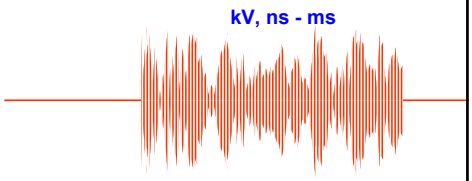
EM phenomena in long cables (inc. mains) continued…

- **Fast transient overvoltage bursts**



  - caused by arcs and sparks
  - e.g. switches, relays, contactors, commutator motors, poor connections, insulation breakdown, fault clearance (operation of fuses, circuit breakers, etc.)

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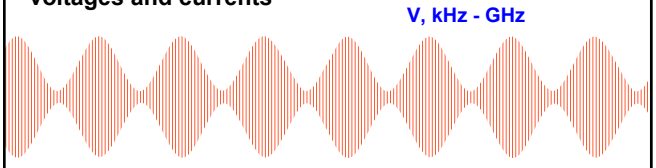
EM phenomena in *any* cables (inc. mains)

- **Continuous radio frequency (RF) voltages and currents**



  - often many frequencies present at the same time
  - usually modulated with different frequencies, using different modulation schemes (80% AM shown above)
  - the longer the cable, the lower the frequency range

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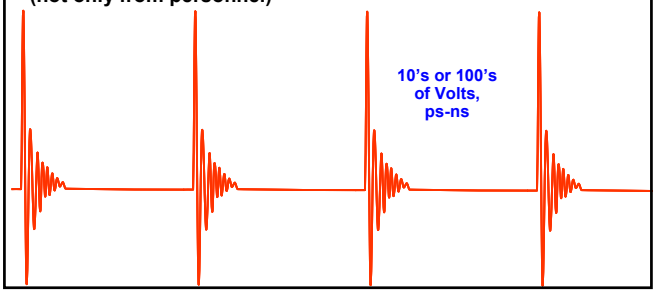
EM phenomena in *any* cables (inc. mains) continued…

- **Very fast transients**
  usually caused by electrostatic discharges (not only from personnel)



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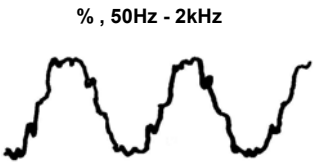
EM phenomena associated with electrical power supplies

- **AC waveform distortion**
  (this example is from Israel, in 2000)



  – **the distortion can be *harmonic***
  (mostly caused by rectifiers and fluorescent lamps)
  – **and/or *interharmonic***
  (mostly caused by frequency-changing power converters)

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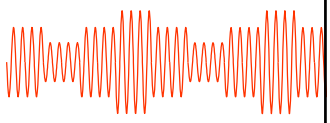
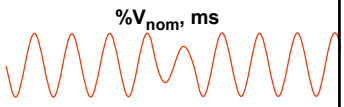
EM phenomena in electrical power supplies continued...

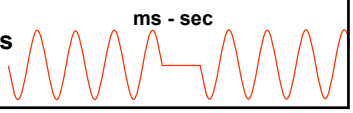
- **Rapid fluctuations of the supply voltage**
  caused by load fluctuations



- **Voltage dips and flicker**
  from network control and fault-clearance



- **Dropouts / interruptions**
  from network protection and fault-clearance



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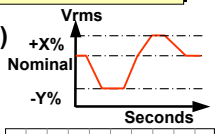
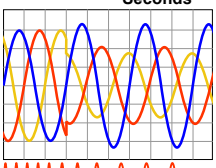
EM phenomena in electrical power supplies continued...

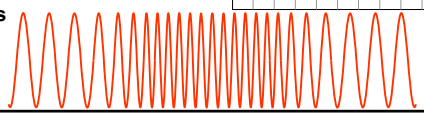
- **Slow variations (sags and swells)**
  caused by load variations



- **Three-phase voltage unbalance**
  caused by unbalanced loads, faults, etc.



- **Frequency variations**
  caused by significant load fluctuations on the generators



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EM phenomena in electrical power supplies continued...

- **All the above mains-power-related phenomena can be much worse where the mains distribution system is of poor quality**
  – **or when mobile or portable generators are used**
- **And don't forget that electrical supply cables tend to be long**
  – **so suffer from <u>all</u> of the EM phenomena in cables described earlier**
    ◆ **sometimes with higher levels and/or lower source impedances (especially fast transient bursts and surges)**

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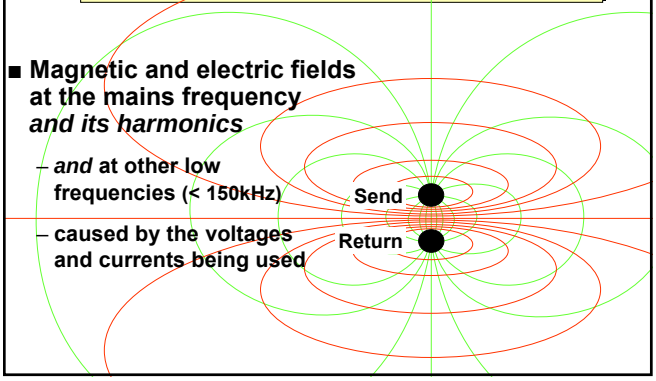
EM phenomena caused by electrical power *use*

- **Magnetic and electric fields at the mains frequency *and its harmonics***
  – ***and* at other low frequencies (< 150kHz)**
  – **caused by the voltages and currents being used**



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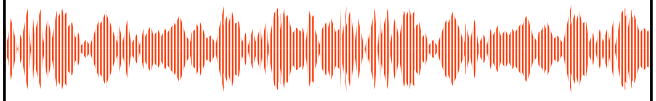
EM phenomena caused by electrical power *use* continued...

- **Electric and magnetic fields at random frequencies 0 - 400GHz from all arcs and sparks**
  – **from switches, relays, contactors, motor commutators, slip-rings, arc-welding, bad connections, insulation breakdown, fault clearance, etc.**



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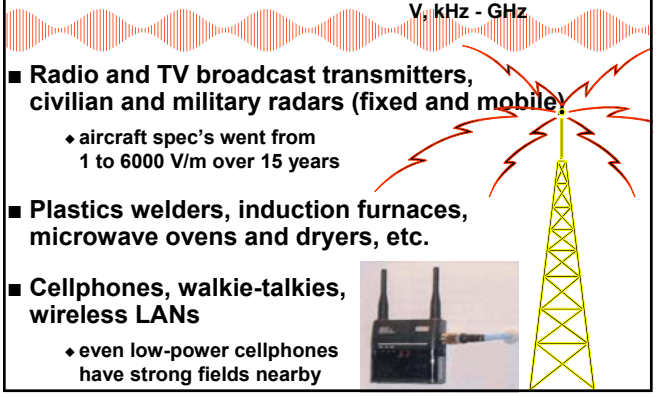
EM fields from *intentional* radiators



- Radio and TV broadcast transmitters, civilian and military radars (fixed and mobile)
  - aircraft spec's went from 1 to 6000 V/m over 15 years
- Plastics welders, induction furnaces, microwave ovens and dryers, etc.
- Cellphones, walkie-talkies, wireless LANs
  - even low-power cellphones have strong fields nearby

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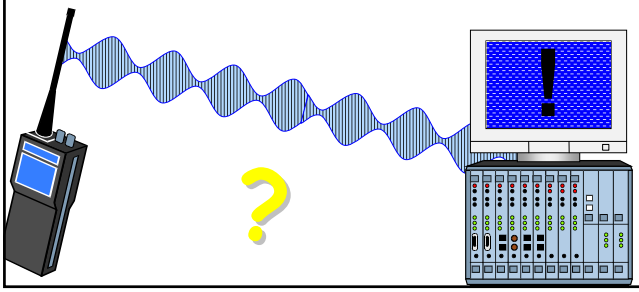
What distance from a 'hand-held' is equivalent to the immunity test levels under EMC and Medical Device Directives?



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Typical type of transmitter or radiator	For 3V/m Domestic, commercial and light industrial generic, and most medical equipment	For 10V/m Industrial generic, and medical life support equipment
Cellphone in strong signal area, 'intrinsically safe' walkie-talkie RF power = 0.8 Watts	1.7 metres (5½ feet)	0.5 metres (1½ feet)
Cellphone in weak signal area and standby mode RF power = 2 Watts	2.5 metres (8 feet)	0.76 metres (2½ feet)
Walkie-talkie handset RF power = 4 watts (emergency services can be 10W)	3.7 metres (12 feet)	1.1 metres (3½ feet)
Vehicle mobile (e.g. taxicab), Electro-Surgery RF power = 100 Watts (some ES are 400W or more)	18 metres (59 feet)	5.5 metres (18 feet)

Multiply distances by √2 for one constructive reflection from a metal surface, by √3 for two reflections, etc.

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EM fields caused by *unintentional* radiators

- Everything which uses electricity or electronics always 'leaks' and so emits some EM disturbances
  - the higher the rate of change of voltage or current, the worse the emissions tend to be
- Power and signals in devices, printed circuit board (PCB) traces, wires and cables leak EM waves
- Shielded enclosures leak EM waves from apertures, gaps and joints

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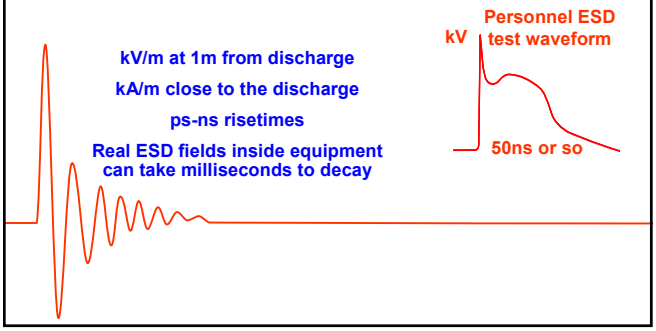
Electric and magnetic fields from electrostatic discharges

– caused by personnel, furniture, and mechanical motion



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EM Weapons (creating Intentional EM interference: IEMI)

- These were mostly designed for military use
  - but can be purchased for private use
  - or designed and constructed by any reasonably competent engineer
- Terrorists prefer bombs (they get more media attention)
  - but extortionists and people who want to create maximum financial damage might prefer EM weapons

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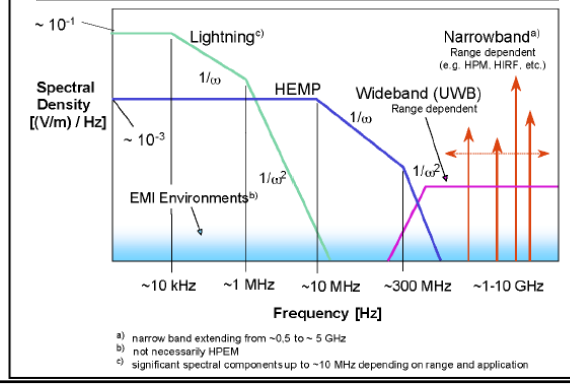
Spectra of EM weapons
(from IEC TR 61000-1-5)



a) narrow band extending from ~0.5 to ~ 5 GHz
b) not necessarily HPEM
c) significant spectral components up to ~10 MHz depending on range and application

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This EM weapon is available from Diehl Munitions Systeme for €150k

Suitcase sized, it will run off its batteries for 3 hours creating pulses of 120kV/m (at 1m)

It will prevent the operation of non-military hardened electronics for a radius of at least 20m

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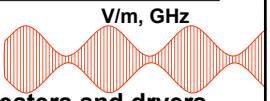
Most immunity standards only test up to 1GHz, so don't cover…

V/m, GHz



- **1.8GHz GSM, GPRS, 2GHz 3G cellphones and datacomms**
- **Microwave ovens, industrial heaters and dryers (usually 2.45 GHz, but can be 0.6 - 5GHz)**
- **Wireless LANs (1.8, 1.9, 2.45 and 5 GHz)**
- **Radars (airports and aircraft, harbours, ships, intelligent cruise control on cars) up to 77GHz**
- **IEMI above 1GHz**
- **Microwave communications (up to 60GHz) use narrow beams and low power – not usually a threat when off the beam's line**

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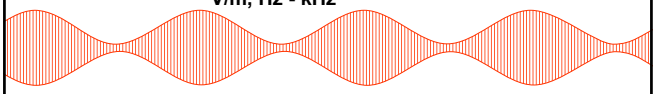
Most immunity standards only test down to 150kHz (and 50 or 60Hz) so don't cover…

V/m, Hz - kHz



- **Emissions from thyristor power control; motor drives (and other switch-mode or PWM power converters)**
  - **typically create strong disturbances 100Hz - 200kHz**
- **Article surveillance systems in shop doorways**
  - **can create very strong magnetic fields: 200Hz to 10MHz**
- **Emissions at harmonics of the mains supply**

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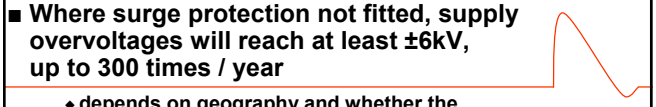
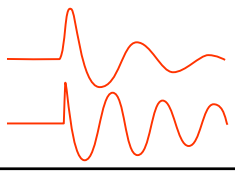
Most immunity standards only test with unidirectional surges up to ±2kV and 100J



- **Where surge protection not fitted, supply overvoltages will reach at least ±6kV, up to 300 times / year**
  - **depends on geography and whether the power lines are overhead or underground**



- **Superconducting magnet field collapse can create surges of up to 4 million Joules**
- **Oscillatory surges can occur, and these cause more stress**

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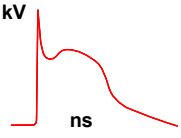
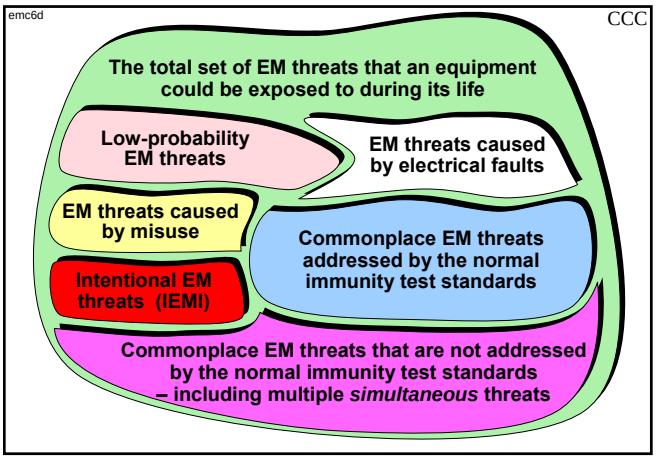
Most immunity standards test ESD with 0.7-1ns risetimes, up to ±8kV

kV



ns

- **Personnel ESD can be *much* faster than 0.7ns**
  - **– *or* can exceed ±24kV, when relative humidity falls below 25%**
- **ESD from processing machinery can be much faster, or have a much higher voltage, and can have also have much higher energy than personnel ESD**
  - **– e.g. due to tribocharging from webs of material**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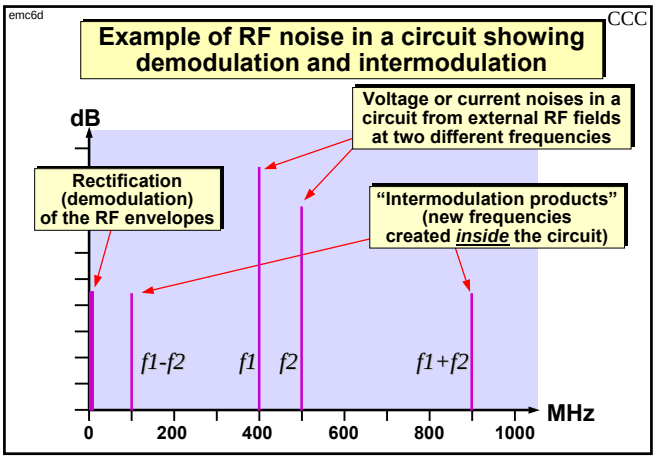
The total set of EM threats that an equipment could be exposed to during its life
Low-probability EM threats
EM threats caused by electrical faults
EM threats caused by misuse
Commonplace EM threats addressed by the normal immunity test standards
Intentional EM threats (IEMI)
Commonplace EM threats that are not addressed by the normal immunity test standards – including multiple simultaneous threats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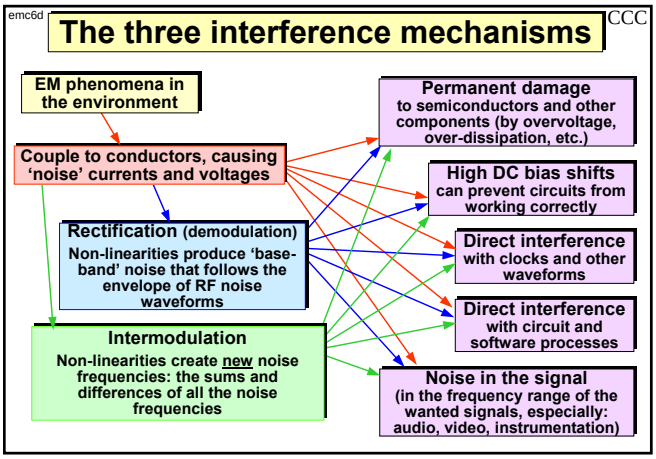
Example of RF noise in a circuit showing demodulation and intermodulation
Voltage or current noises in a circuit from external RF fields at two different frequencies
dB
Rectification (demodulation) of the RF envelopes
"Intermodulation products" (new frequencies created inside the circuit)
f1-f2
f1
f2
f1+f2
MHz
0
200
400
600
800
1000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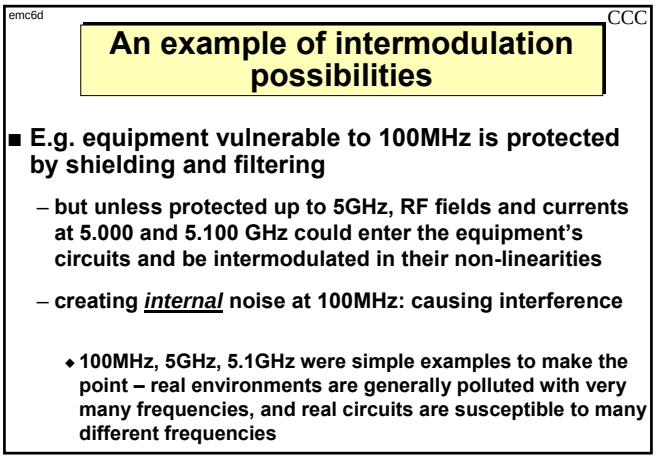
The three interference mechanisms
EM phenomena in the environment
Couple to conductors, causing 'noise' currents and voltages
Rectification (demodulation)
Non-linearities produce 'base-band' noise that follows the envelope of RF noise waveforms
Intermodulation
Non-linearities create new noise frequencies: the sums and differences of all the noise frequencies
Permanent damage to semiconductors and other components (by overvoltage, over-dissipation, etc.)
High DC bias shifts can prevent circuits from working correctly
Direct interference with clocks and other waveforms
Direct interference with circuit and software processes
Noise in the signal (in the frequency range of the wanted signals, especially: audio, video, instrumentation)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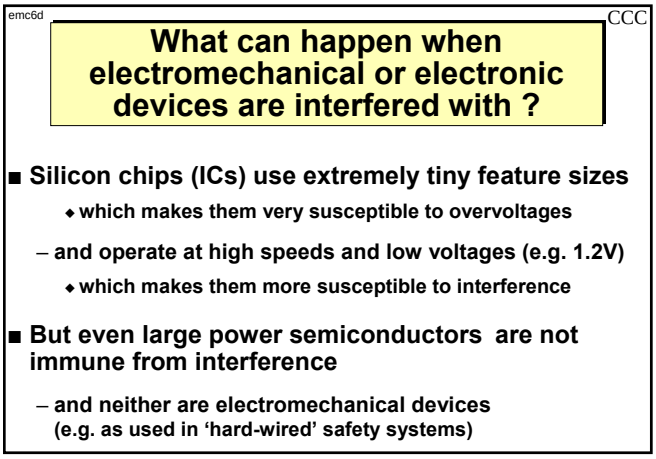
An example of intermodulation possibilities
■ E.g. equipment vulnerable to 100MHz is protected by shielding and filtering
– but unless protected up to 5GHz, RF fields and currents at 5.000 and 5.100 GHz could enter the equipment's circuits and be intermodulated in their non-linearities
– creating internal noise at 100MHz: causing interference
◆ 100MHz, 5GHz, 5.1GHz were simple examples to make the point – real environments are generally polluted with very many frequencies, and real circuits are susceptible to many different frequencies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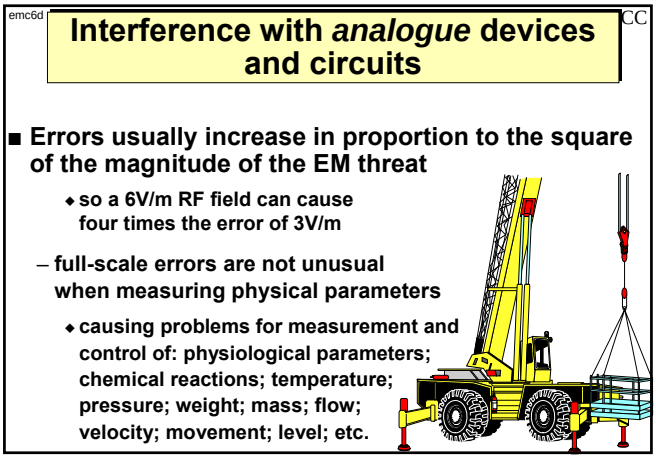
What can happen when electromechanical or electronic devices are interfered with ?
■ Silicon chips (ICs) use extremely tiny feature sizes
◆ which makes them very susceptible to overvoltages
– and operate at high speeds and low voltages (e.g. 1.2V)
◆ which makes them more susceptible to interference
■ But even large power semiconductors are not immune from interference
– and neither are electromechanical devices (e.g. as used in 'hard-wired' safety systems)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Interference with analogue devices and circuits
■ Errors usually increase in proportion to the square of the magnitude of the EM threat
◆ so a 6V/m RF field can cause four times the error of 3V/m
– full-scale errors are not unusual when measuring physical parameters
◆ causing problems for measurement and control of: physiological parameters; chemical reactions; temperature; pressure; weight; mass; flow; velocity; movement; level; etc.

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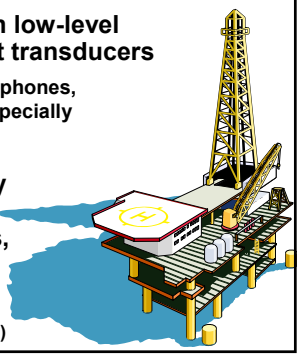
Interference with *analogue* devices and circuits continued...

- EMI errors are most likely in low-level signals, e.g. millivolt-output transducers
  - a common problem for microphones, strain gauge sensors, and especially for temperature sensors
- Analogue devices are easily destroyed by overvoltages from surges, fast transients, and ESD
  - and very high-power RF (mostly a military or security issue)



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Interference with *digital devices, circuits and software*

A Programmable Logic Controller (PLC) from Mitsubishi

- Functional performance errors tend only to occur when the EMI's magnitude passes a threshold
  - but then a variety of malfunctions can occur…

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Interference with *digital devices, circuits and software* continued...

- False key-presses, errors in communications, data and control
  - possibly changing operational mode
- Incorrect software operation, e.g...
  - continually repeating an inappropriate activity
  - changing operational mode (e.g. from crawl to full speed)

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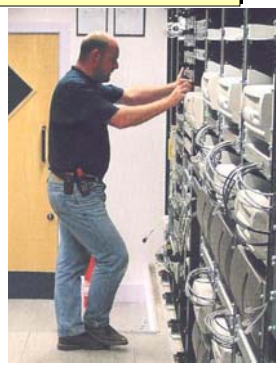
Interference with *digital devices, circuits and software* continued...

- Stopped operation (often called a 'freeze' or 'crash')
  - but this can cause the control outputs to assume random combinations of states
    - including those which can have undesirable or unsafe results for whatever is being controlled



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Interference with *digital devices, circuits and software* continued...

- All digital devices can easily be destroyed by overvoltages from surges, fast transients, and ESD
  - and by high-power RF (mostly a military and security issue)
    - with powerful microprocessors and their memory chips being the most vulnerable
- But some programmers forget that *all* software runs on physical devices
  - and when those devices are crashed or destroyed by high levels of EMI: ***software techniques cannot work***

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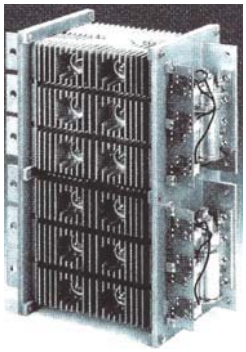
Interference with *power semiconductors*

- Permanent damage can be caused by overvoltages
  - surges, fast transients, ESD
  - and also by overcurrents
- Control terminals could be triggered at the wrong time
  - causing malfunction, and/or actuation of protective devices, and/or damage



A module-type 'stack' from Eupec

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Interference with *electromechanical devices*

- 'Hard-wired' circuits use electromechanical devices
  - which many designers seem to assume are totally immune to all EM threats

Some 'contactor relays' from Moeller

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Interference with *electromechanical devices* continued...

- But dips and dropouts in the AC supply can cause relays, contactors and solenoids to 'drop out'
  - individually – depending on type, age, and temperature
  - and if they are held-in by a normally-open contact, or operated on a reduced 'hold-in' voltage – they may not pull back in again afterwards
- Shock and vibration can make switch contacts 'chatter', causing sparking
  - which can interfere with electronic devices

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Interference with *electromechanical devices* continued...

- Overvoltages due to surges and fast transients can make open contacts spark-over
  - which is the same as closing them momentarily
    - applying power to circuits which should be off
- And surge currents can 'weld' contacts together
  - so that they won't open when required
    - a problem for switches, relays and contactors which don't use positively-guided or forced contacts
    - or where feedback of contact position is not used

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Many electromechanical devices should now be treated as electronic devices

- An increasing proportion of electromechanical devices are employing electronic devices to add functionality
  - e.g. 'safety relays', MCCs, motors
  - but these can suffer from all the interference problems that electronics are prone to
- The electronic content of any electromechanical device should always be asked about
  - and if it contains even one diode, transistor, hall sensor or IC – it should be treated as an *electronic device*

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The sorts of things that people do, that compromise EMC performance

- It is the responsibility of designers, users, and maintainers to take into account the real-life EM environment, including….
  - foreseeable proximity of portable radio transmitters…
  - and of fixed radio TV or radar transmitters
  - and of powerful RF-processing equipment, e.g…
    - induction heating, plastic sealing/welding, glue drying, medical diathermy, etc.
  - taking foreseeable future developments into account (e.g. expansion or other changes to the site or processes)

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The sorts of things that people do, that compromise EMC performance

- And it is also their responsibility also take account of the things that might happen over the lifetime…
  - that could affect the ability to resist the EM threats e.g…
- The foreseeable range of use: e.g. normal operation, start up, fault finding, maintenance, upgrade, etc.,
  - e.g. are doors or covers opened?
    - the reduced EM shielding might cause errors or malfunctions if the equipment is operated in this condition

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The sorts of things that compromise EMC performance continued…

- The foreseeable *use environment*, e.g….
  - static mechanical stresses causing bending or twisting
  - vibration, shock
  - temperature, exposure to liquids
  - mains supply voltage range
  - load range
  - human and vehicular traffic
  - cleaning regimes (especially if using abrasive materials)

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The sorts of things that compromise EMC performance continued…

- the *use environment* can compromise EMC, and over time can cause wear, corrosion, even damage, e.g….
  - filter performance can be reduced to 1/10th by high temperature + high supply voltage + high load current
  - filter ground connections can become high-resistance or break — making the filters ineffective
  - electrical bonds in the enclosure removed (e.g. lost fixings), broken or corroded — reducing shielding
  - shielding reduced by gaps or corrosion at gaskets around doors, covers, etc.
  - cable shielding reduced by damage from repetitive flexing, especially strain at connectors and glands

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The sorts of things that compromise EMC performance continued…

- Foreseeable misuse, e.g….
  - not following the manufacturer's installation instructions or good EMC installation practices, e.g….
    - use of incorrect types of cables or connectors
    - incorrect assembly of shielded connectors (very common!)
    - bad cable routing (e.g. power and signal bundled together)
    - inadequate earthing or bonding (e.g. using long green/yellow wires when short wires or metal-to-metal fixing is required)
  - unapproved modifications? (anything could happen!)

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The sorts of things that compromise EMC performance continued…

- Unless the ways in which the equipment could be used under these conditions over its lifecycle is thought through…
  - and appropriate steps taken in design, installation, and control of operation, cleaning, maintenance, modification, etc…
  - there is the potential for someone to do something that could either permanently or temporarily affect the EMC performance – and hence affect the level of safety provided by the equipment

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EM phenomena – where they come from, how they can interfere

the end

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Some useful references

- *Assessing an Electromagnetic Environment*
  Keith Armstrong, downloadable from the "Publications and Downloads" page at http://www.cherryclough.com
  - *Note:* this document was written to help with EMC Directive compliance, not for safety purposes
- *REO (UK) booklets on EMC*
  available via the "Publications and Downloads" page at http://www.cherryclough.com
  - as well as describing how to perform tests to the IEC/EN basic EMC test methods, these booklets describe the various types of EM disturbances, where they might occur, their possible magnitudes, and what effects they might have on electrical and electronic equipment