

System layout and grounding

Section 4

Layout and grounding

E MAC
services

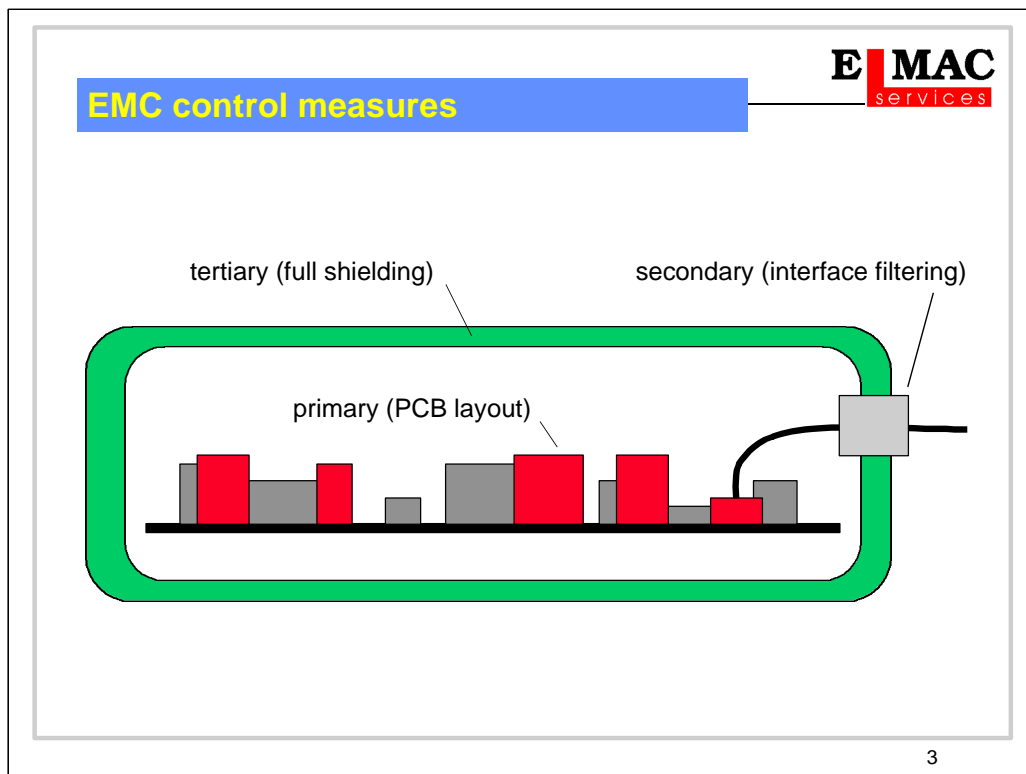
- **EMC control**
- **System partitioning**
- **Definitions of grounding**
- **Practical aspects of grounding**

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The most cost-effective way to design for EMC is to consider the equipment's layout and ground regime at the beginning. No unit cost is added by this approach. 90% of post-design EMC problems are due to inadequate layout or grounding: a well-designed layout and ground system can offer both improved immunity and protection against emissions, while a poorly designed one may well be a source of emissions and susceptibility.

The most important principles are

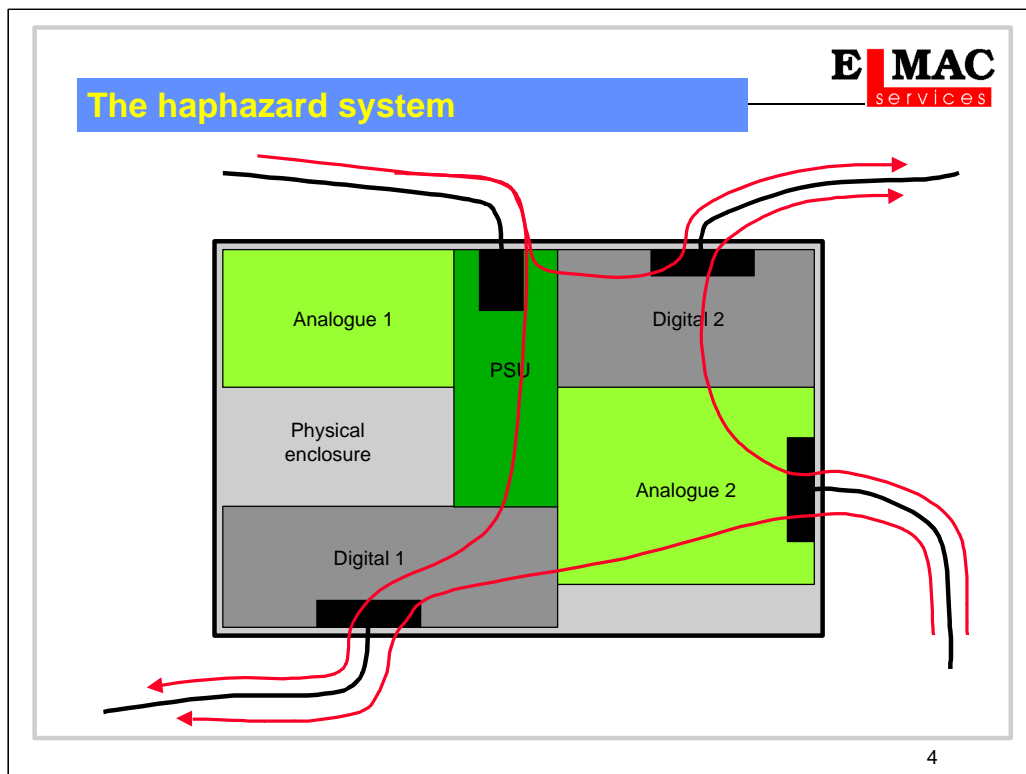
- partition the system to allow control of interference currents
- consider ground as a path for current flow, both of interference into the equipment and conducted out from it; this means
- careful placement of grounding points
- minimize ground impedance
- minimize radiated emissions from, and susceptibility of current loops by careful layout of high di/dt loop areas



EMC control can be applied at three levels, primary, secondary and tertiary. Control at the primary level involves circuit design measures such as decoupling, balanced configurations, bandwidth and speed limitation, and also board layout and grounding. For some low-performance circuits, and especially those which have no connecting cables, such measures may be sufficient in themselves.

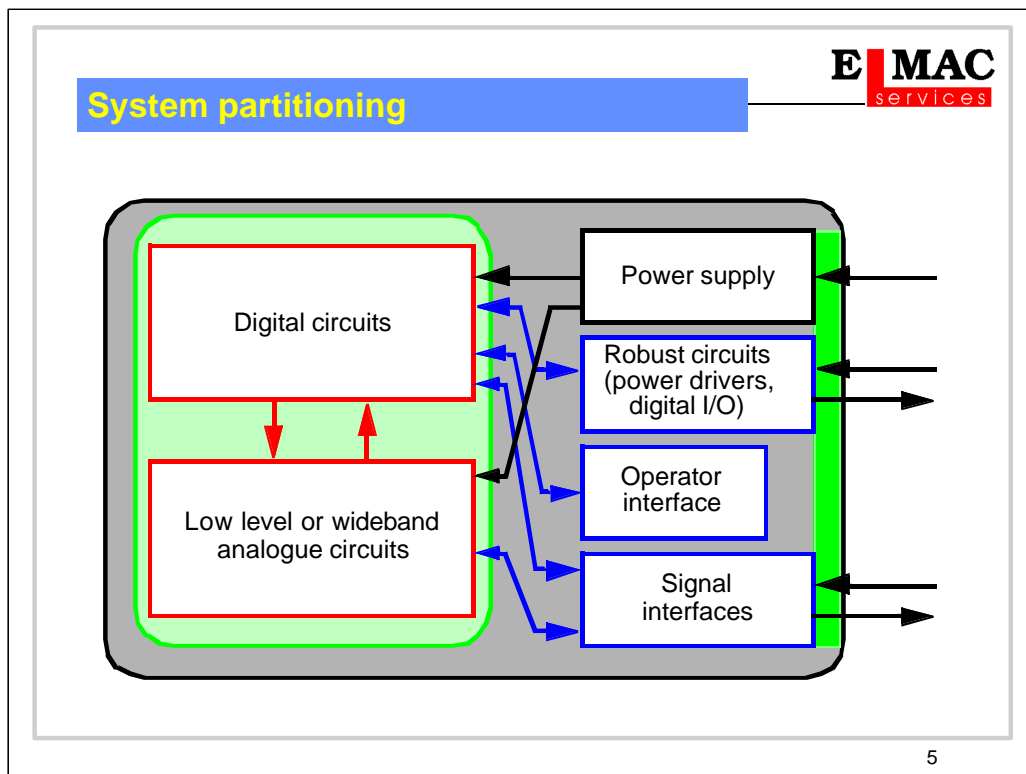
At the secondary level the interface between the internal circuitry and external cables is invariably a major route for interference in both directions, and for some products (particularly where the circuit design has been frozen) all the control may have to be applied by filtering at these interfaces. Choice and mounting of connectors forms an important part of this exercise.

Full shielding (the tertiary level) is an expensive choice to make and should only be chosen when all other measures have been applied. But since it is difficult to predict the effectiveness of primary measures in advance, it is wise to allow for the possibility of being forced to shield the enclosure.



The first design step is to partition the system. A poorly partitioned, or non-partitioned system may have its component sub-systems separated into different areas of the board or enclosure, but the interfaces between them will be ill-defined and the external ports will be dispersed around the periphery. This makes controlling the common-mode currents that will exist between the various external and internal interfaces very difficult. Dispersal of the ports means that the distances between ports on opposite sides of the system is large, leading to high induced ground voltages in the presence of incoming interference. Conversely, noise voltages generated within the system are coupled out efficiently by the inherent dipole mechanism, leading to high radiated emissions.

Usually the only way to control emissions from and immunity of such a system is by placing an overall shield around it and filtering each interface, which is a very expensive solution. In many cases it will be difficult or impossible to maintain integrity of the shield and still permit proper operation.



Partitioning separates the system into critical and non-critical sections from the point of view of EMC. Critical sections are those which contain radiating sources such as microprocessor logic or video circuitry, or which are particularly susceptible to imported interference: microprocessor circuitry and low-level analogue circuits. Non-critical sections are those whose signal levels, bandwidths and circuit functions are such that they are not susceptible to interference nor likely to cause it: non-clocked logic, linear power supplies, the operator interface and LF power amplifier stages are typical examples.

Critical sections can then be enclosed in a shielded enclosure into and out of which all external connections are carefully controlled. This enclosure may encase the whole product or only a portion of it, depending on the nature of the circuits: a major design goal should be to minimize the number of controlled interfaces, and to concentrate them physically close together. Note that the shield acts both as a barrier to radiated interference and as a reference point for ground return currents.

Ground definitions and purpose

- **Ground purposes**

- (1) Make interference voltages low compared to desired signal
- (2) Prevent adjacent but electrically separate circuits from floating
- (3) Guarantee personnel safety under fault conditions

- **Ground definitions**

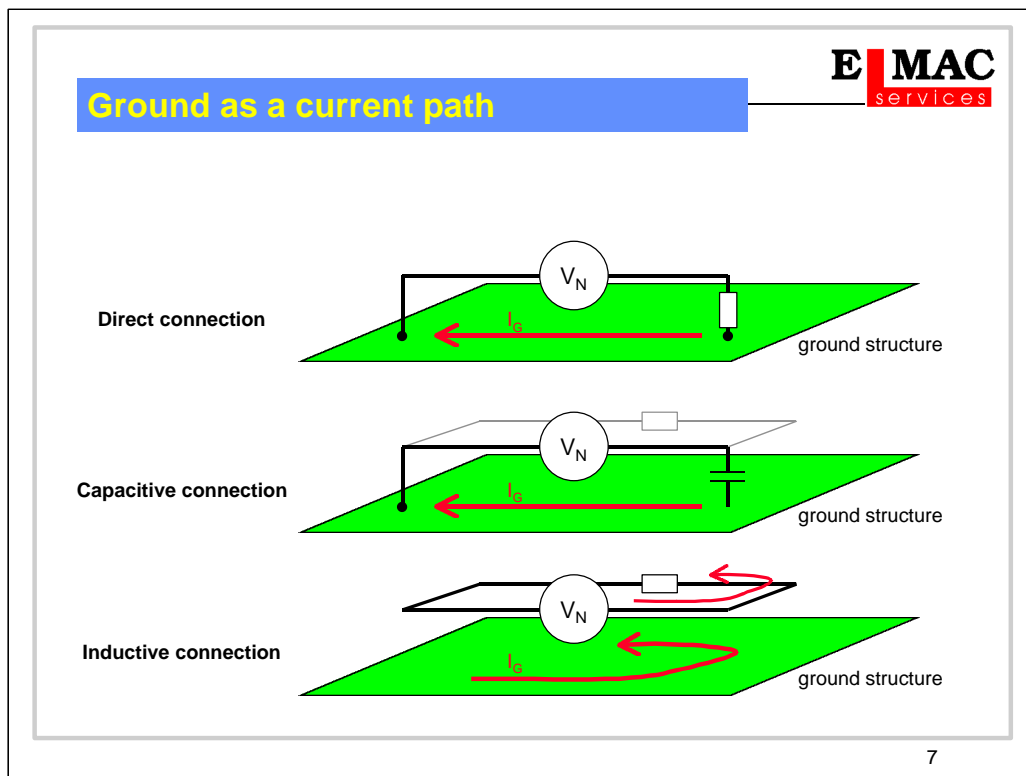
- (A) An **equipotential point or plane** used as a system reference
- (B) A **low impedance path** for currents to return to their source
- (C) A **low transfer impedance path** to prevent common mode currents converting to differential mode

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Once the system has been properly partitioned, it must then be properly grounded. For EMC we are concerned only with purpose (1). Providing safety paths and referencing adjacent circuits is operationally necessary, but does not guarantee low interference, and may even work against it.

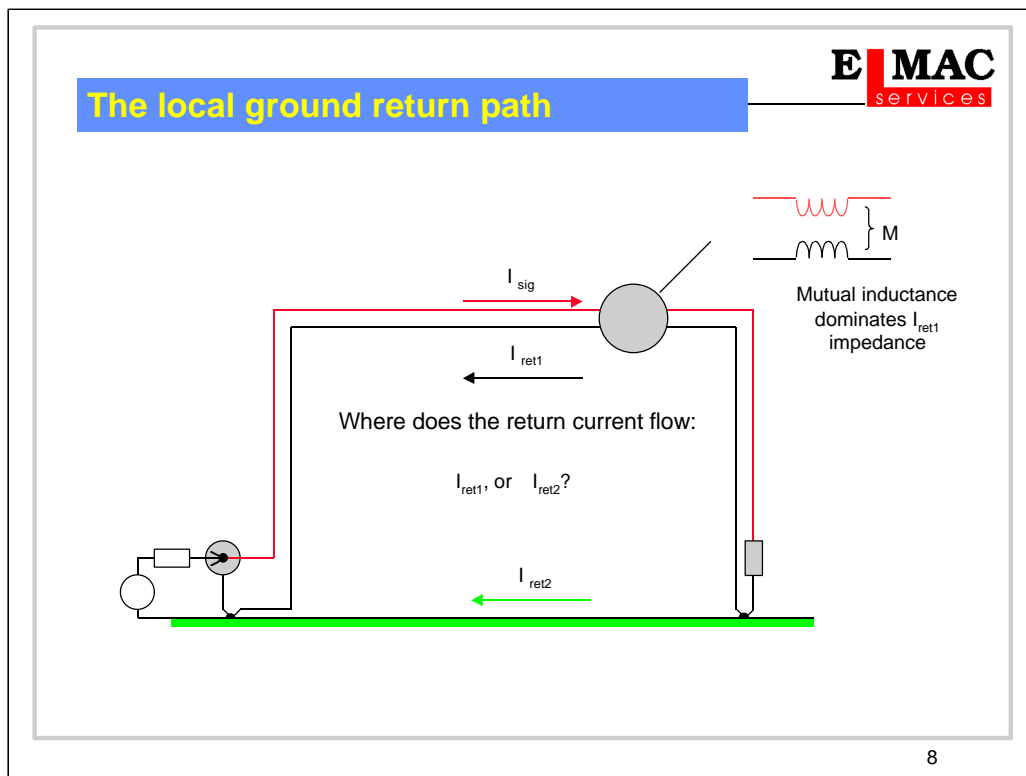
(A) is the classical definition of a ground network, but this is misleading in the presence of ground current flow. Especially as the frequency increases, finite impedance of conductors causes voltage differentials across supposedly equipotential regions. Even where signal currents are negligible, induced ground currents due to environmental magnetic or electric fields will cause shifts in ground potential.

Definition (A) takes no account of topology or geometry of the ground network; by contrast these factors are critical in (B) and even more so in (C). Ground currents always circulate as part of a loop. The task is to design the loop in such a way that induced voltages remain low enough at critical places, by ensuring that the ground circuit is as compact and as local as possible.



Various sources of ground current flow are shown above. Obviously it is possible to deduce a return path when the signal and load connections are known, although if there are several possible return paths the dominant one may not be intuitively clear. In general, return paths at frequencies above a few kiloHertz are decided by the inductance of the entire loop, so that when several loops are present the one with the least inductance (i.e. least enclosed area) takes the greatest current share.

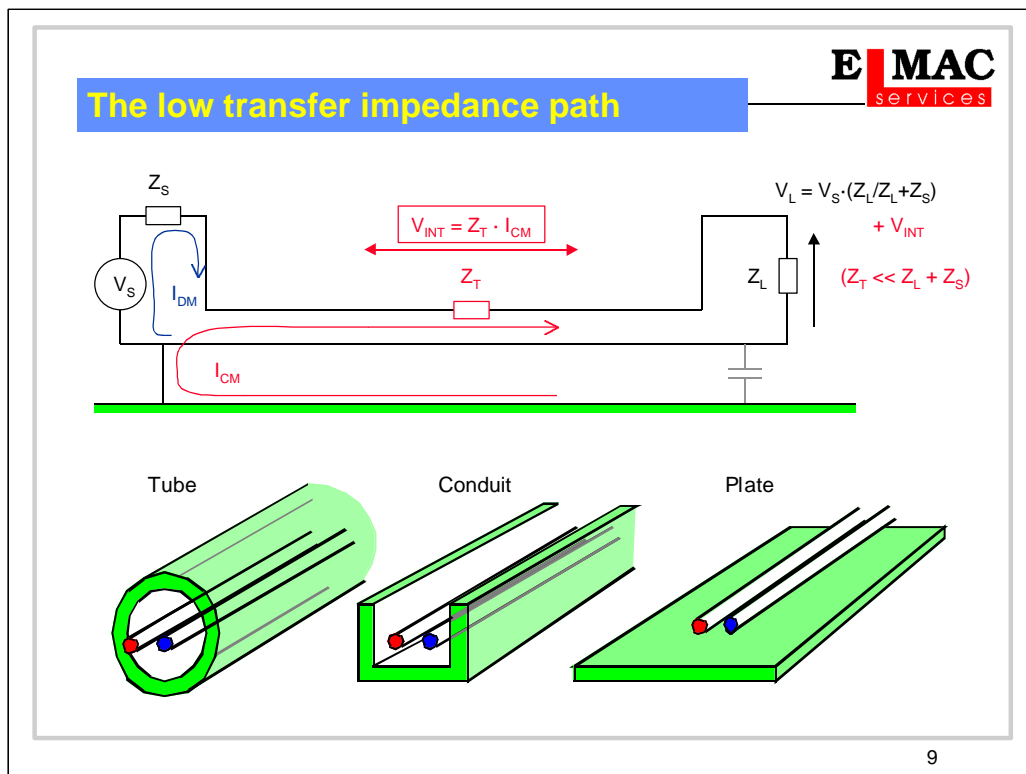
Capacitively- or inductively-coupled interference will create current flow in the ground network, and will also induce currents in other conductive structures even if there is no intended circuit current in them. Because the impedance of any conducting structure is not zero, these currents will create voltage differentials between different parts of the structure. For this reason the geometry of these structures relative to the wanted signal circuits is important: it must be chosen to minimize the transfer impedance between the structures and the circuit, so that differential currents are not induced into the circuit. This is the reason for configuring susceptible circuits, cables and wiring so that they are adjacent to large, unbroken metal planes, or enclosed in conduit or tubing.



The actual path taken by return currents is not always obvious. Consider a circuit consisting of a source and load, interconnected by a cable, each side of which is grounded. The return current in this case could flow either via the cable (I_{ret1}) or via the ground (I_{ret2}).

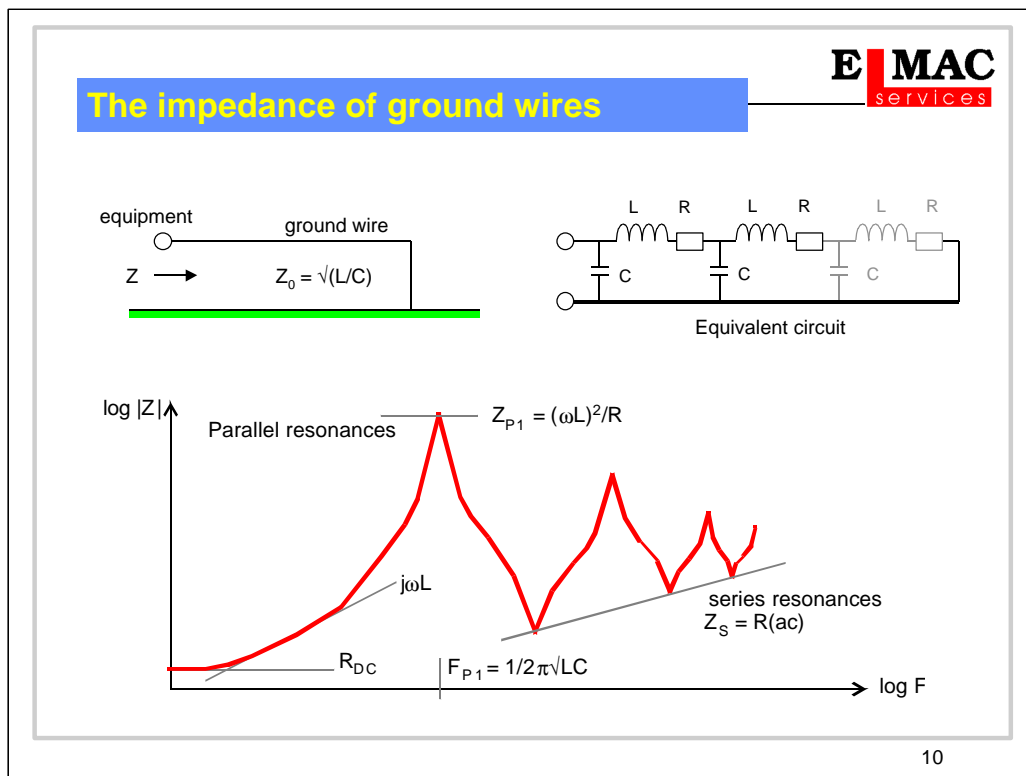
In practice the return currents will divide according to the relative impedances of the two paths. It might be thought that the ground path has the lower impedance, but in fact the cable path's impedance is dominated by the coupling due to mutual inductance with the signal path. The closer is this coupling, the lower is the effective impedance, because the field due to I_{sig} tends to cancel that due to I_{ret1} .

This effect is most pronounced with coaxial cable structures where the mutual coupling is almost unity, but it is readily observed even with ordinary cables. It dominates at frequencies where circuit inductive impedance is greater than resistance.



For EMC purposes, grounding provides a set of interconnected current paths, designed to have a low transfer impedance Z_T , in order to minimize interfering voltages at sensitive interfaces which may or may not be ground-referred. Depending on the interface under consideration, we reduce the transfer impedance of an appropriate part of the interconnected grounding paths. The result is a grounding structure, whose three-dimensional shape is designed for low Z_T .

The important quality of such a structure is that when a disturbance current I_{CM} flows in it, only a small interference voltage V_{INT} is generated differentially in the signal circuit. The dominant contribution to Z_T for external interference currents flowing in the ground is mutual inductance between common- and differential-mode circuits. This is minimized by a solid enclosing tube and is worst if the structure is a single parallel wire. Practical compromise structures are the conduit or the flat plate. The closer the differential mode circuit is to such a grounding structure, the less the Z_T , provided that the structure is unbroken in the direction of current flow.

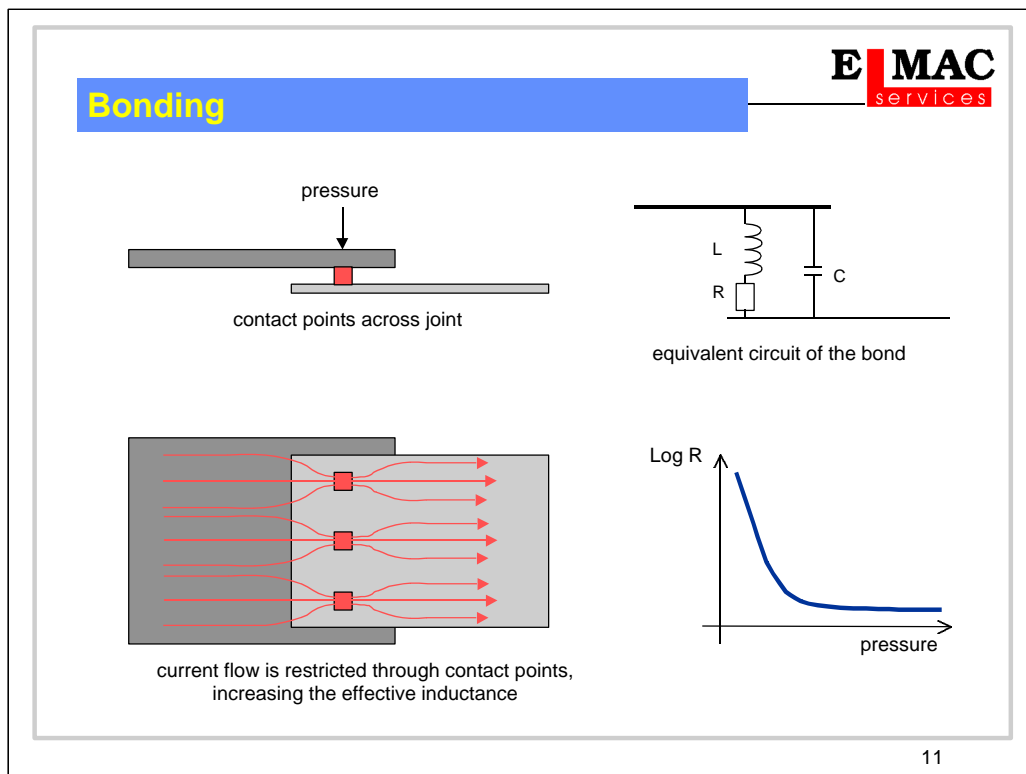


When a grounding wire is run for some distance alongside a ground plane or chassis before being connected to it, the result is a transmission line. This can be modelled as an LCR network with the L and C components determining the characteristic impedance Z_0 of the line. As the operating frequency rises, the inductive reactance exceeds the resistance of the wire and the impedance increases up to the first parallel resonant point. At this point the impedance seen at the end of the wire is high, typically hundreds of ohms (determined by the resistive loss in the circuit). After first resonance, the impedance for a lossless circuit follows the law

$$Z = Z_0 \cdot \tan(\omega \cdot x \cdot \sqrt{L/C})$$

where x is the distance along the wire to the short

and successive series (low-impedance) and parallel (high-impedance) resonant frequencies are found. As the losses rise due to skin effect, so the resonant peaks and nulls become less pronounced. To stay well below the first resonance and hence remain an effective conductor, the ground wire should be less than 1/20th of the shortest operating wavelength.




When two chassis or structural members are joined, the RF impedance across the joint determines the effectiveness of the chassis as an RF reference. Concentration of current at contact points gives a substantial increase in inductance across the joint, causing voltage differentials and external fields. To minimize this inductance, there must be no insulating material in the region of the joint, and the area of contact must be large. Paint or anodising must be completely removed around the contact.

A large contact area has the secondary effect of reducing contact resistance, and this parameter can easily be measured by installation technicians using proper test instrumentation. A high impedance bond can be identified from its contact resistance, a standard of $2\text{m}\Omega$ across each bond and $25\text{m}\Omega$ between any two points in the earth system being accepted in military situations.

Contact pressure also affects the impedance in a non-linear fashion. A reliable bond will have enough pressure to remain on the flat part of the resistance/pressure curve, so that there is little sensitivity to variations in pressure. Some surface preparations (for instance cadmium plating) need a higher contact pressure than others to maintain good conductivity.

Electrochemical compatibility

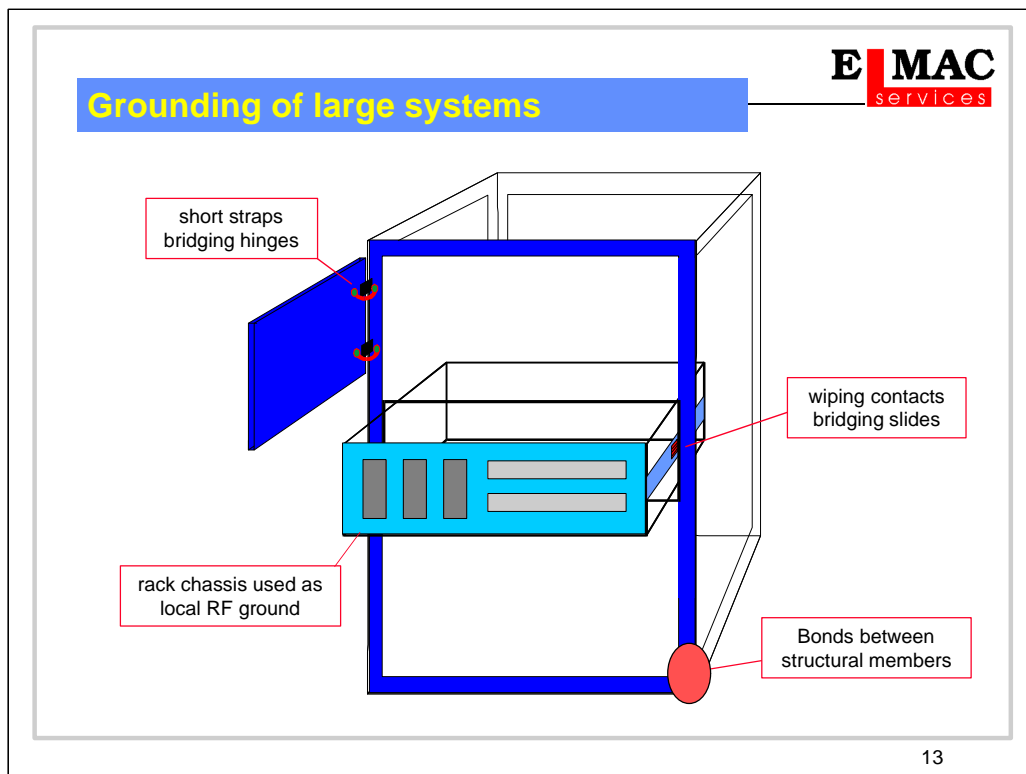


Metal	Group
Magnesium	I (most anodic)
Aluminium (+ alloys) Zinc Cadmium Galvanised Iron	II
Carbon Steel Iron Lead Tin + Tin/Lead Solders	III
Nickel Chromium Stainless Steel Brass	IV
Copper Silver Gold Platinum Titanium Bronze	V (most cathodic)

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Galvanic corrosion at mating surfaces occurs when two dissimilar metals are in contact in the presence of an electrolyte, such as water. Minimum corrosion occurs if the metals are in the same group in the electrochemical table above. The greater the separation, the more corrosion will occur. If dissimilar metals must be placed in contact, the joint should be protected, for example by painting, to exclude the presence of moisture.

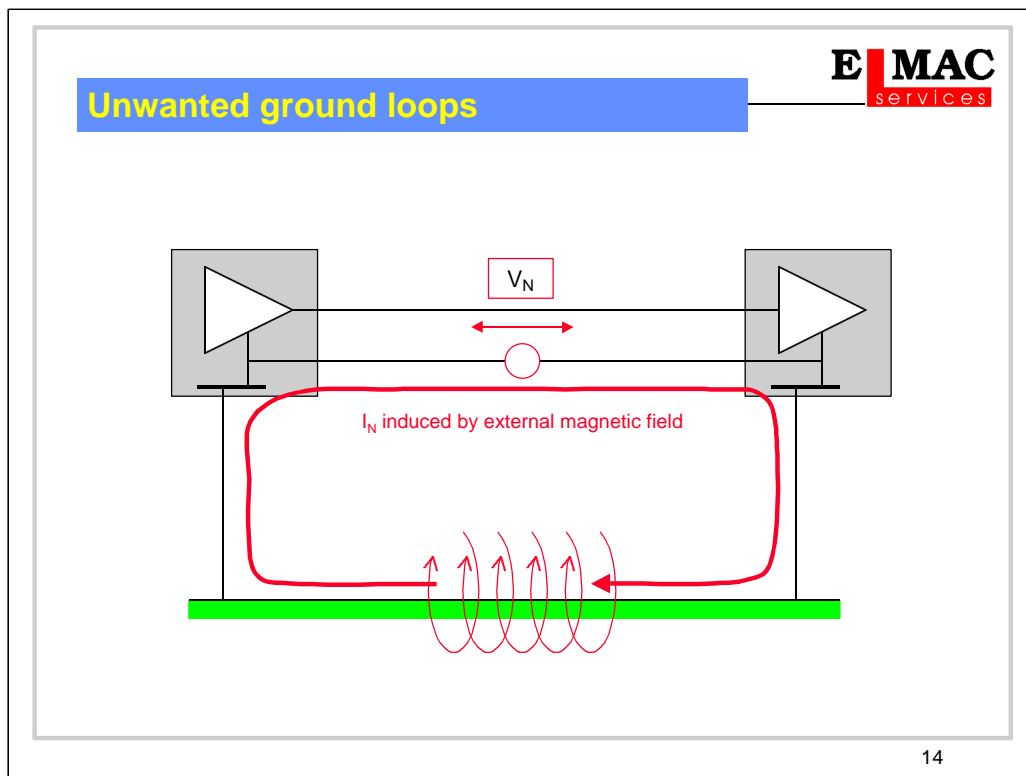
An alternative where such a joint must be frequently disturbed is to use a sacrificial washer between the two metals, which reduces the electrochemical potential at each surface. For instance if an aluminium (Group II) panel must be mated to stainless steel (Group IV) then a tin-plated washer (Group III) can be interposed between them. This will reduce the rate of corrosion and can also be replaced easily as part of a maintenance schedule.



Large systems are difficult to deal with because distances are a significant fraction of a wavelength at lower frequencies. Ground connections made by wires of several tens of cm length, as we have seen, are not assured ground connections at high frequencies at all. This can be overcome by running cables within cabinets in shielded conduit or near to the metal chassis. The distributed capacitance that this offers allows the enclosure to act as a high frequency ground reference and to keep the impedance of unavoidable lengths of ground wire low. It also enables the ground connections themselves to be as short as possible, made to the nearest available chassis member.

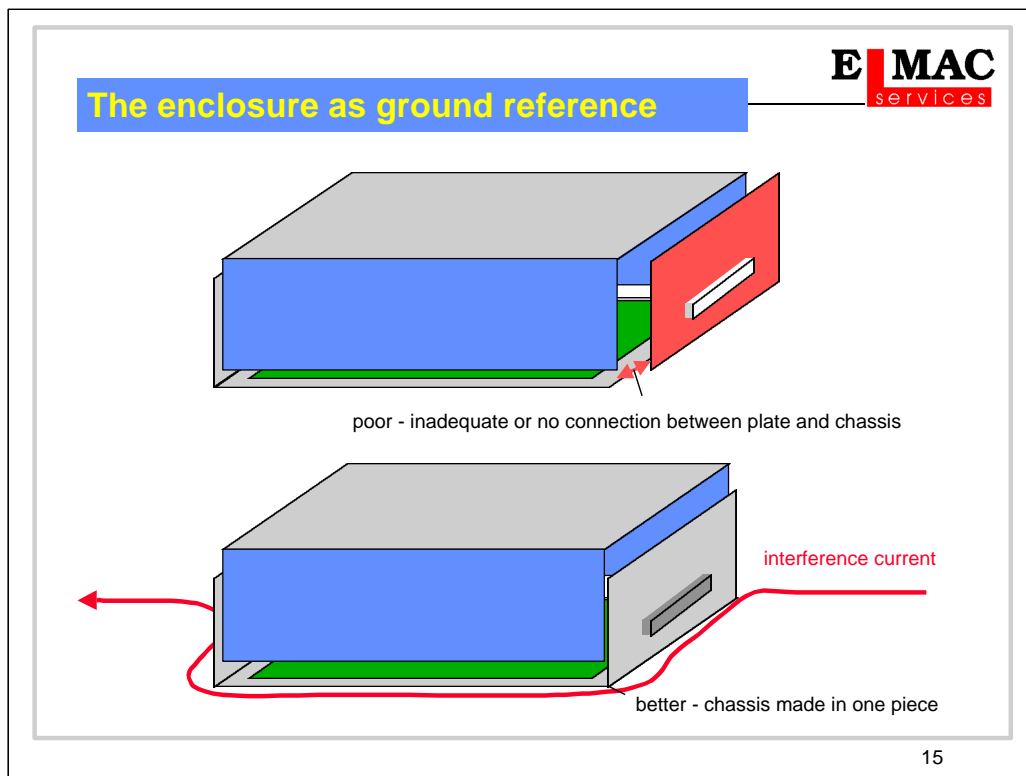
The chassis provides a good ground for safety purposes and for HF return currents, provided that all metalwork is solidly bonded together - it is not enough to rely on hinges or slides for ground continuity, unless the sliding or moving surfaces are deliberately designed for good low-impedance contact. A flexible strap can be placed across hinges, and spring finger contacts can be positioned to bridge sliding sections..

Provision of a separate signal ground, which if necessary can be subdivided further into "clean" and "dirty" ground returns for sensitive and noisy circuits, allows low frequency single-point grounding.



A ground loop is formed when there are two or more routes for ground current to flow between two circuits. Typically a ground loop will appear when two items of equipment are both supplied with a protective earth and there is also a signal ground return between them; in this case the ground loop is large and ill-defined, depending on cable layout. But strictly speaking, a ground loop can be formed by any such connection, even within a circuit, and is inherent in the multipoint ground schemes just discussed.

The danger of a ground loop is that any external magnetic field will induce a circulating current in the loop which in turn will result in a noise voltage V_N in the signal return conductor, that is injected in series with the signal. The amplitude of V_N will be proportional to the frequency of the interference and the area of the loop. Cures for ground loop interference include breaking the loop by signal isolation or by using earth line chokes or resistors (in which case V_N appears across the high impedance), using balanced signal circuits to improve common mode rejection, and where possible control of loop area and orientation.



In many cases a metallic enclosure can contribute to good EMC without necessarily being designed for proper shielding. This is particularly so where the enclosure is intended to act as the ground structure for the equipment. The structure must provide a low transfer impedance Z_T with respect to the internal circuits. If it does this, interference currents will be successfully diverted through the structure rather than through the circuit. Low Z_T means that the structure must maintain continuity in the direction of current flow.

In the example above, a poor form of construction has left an end plate inadequately connected to the L-shaped main chassis. Then interference currents induced on a cable which is terminated to this plate will be forced to flow through the circuit. If instead the chassis is formed in a single "U" shape then the continuity between the end plates is maintained and interference can avoid the circuit. In this design, the top cover plays little or no part in the process and need not be designed for good shielding.

