E MAC services

Cables and connectors

Section 8

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Outline

- **mode of propagation**
- **unscreened cables**
  - twisted pair
  - ribbon
- **screened cables**
  - screen operation
  - transfer impedance
  - the effect of the connector
- **cable installation**

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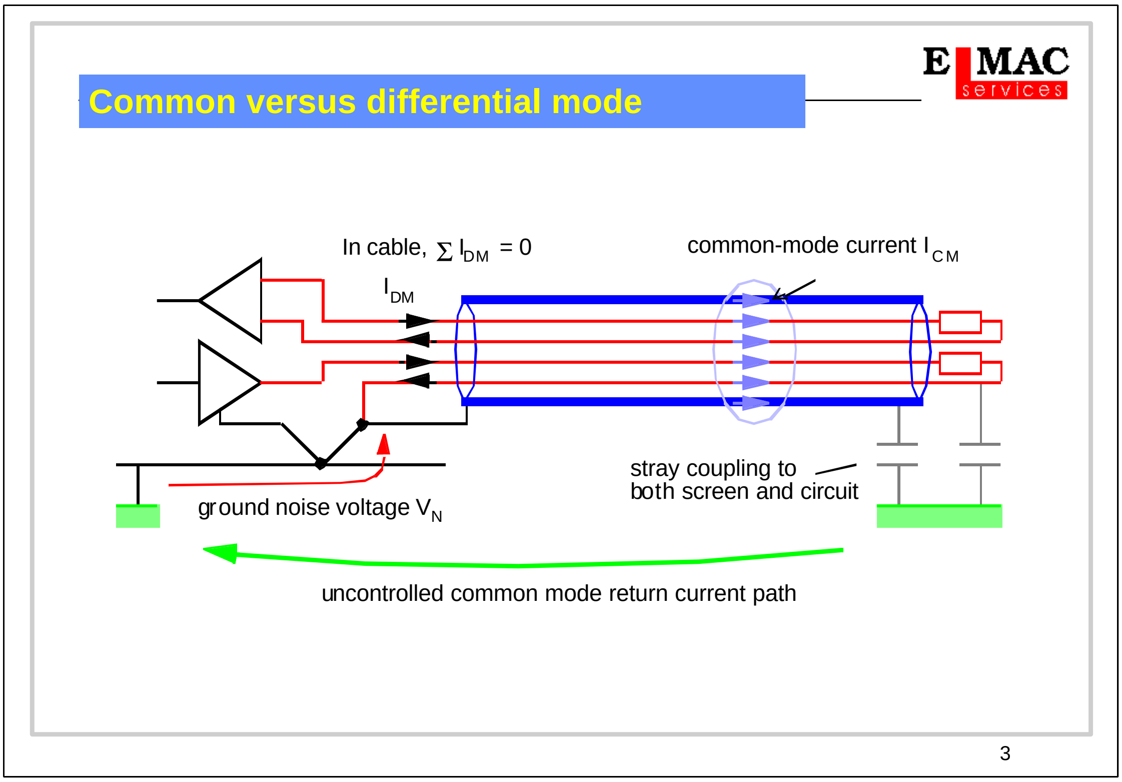


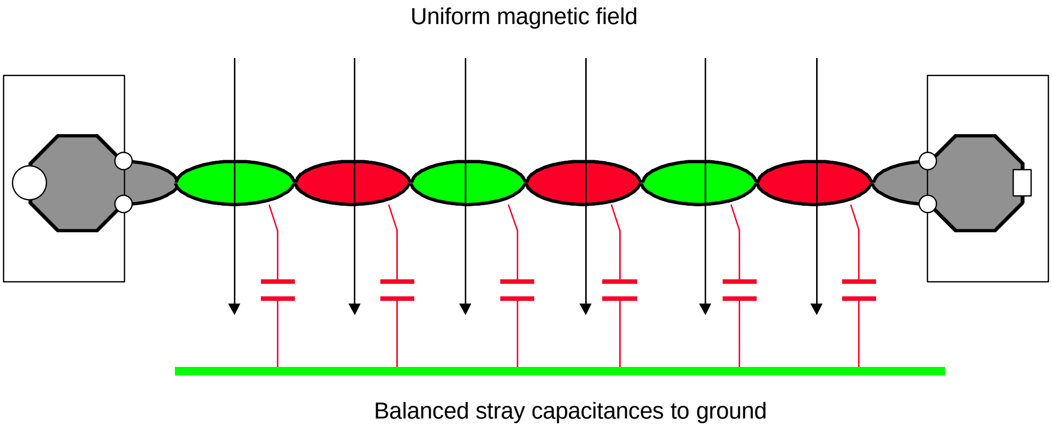
It is important to appreciate the difference between common-mode and differential-mode cable currents.

Differential-mode current, I_{DM}, is the current which flows in one direction along one cable conductor and in the reverse direction along another. It is normally equal to the signal or power current, and is not present on the shield. It contributes little to the net radiation because the total loop area formed by the two conductors is small; the two currents tend to cancel each other.

Common-mode current I_{CM} flows equally in the same direction along all conductors in the cable, potentially including the shield, and may or may not be related to the signal currents. That part of the signal current which does not return via the cable but leaks out through stray coupling, does appear as a common mode component. The other major source is the noise voltage developed within the circuit and referred between the point of connection of the cable, and the circuit's ground reference. This is why it is good practice to couple the circuit to ground at the interfaces.

I_{CM} returns via the associated ground network and therefore the radiating loop area is large and uncontrolled. As a result, even a small I_{CM} can result in large emitted signals.

Twisted pair



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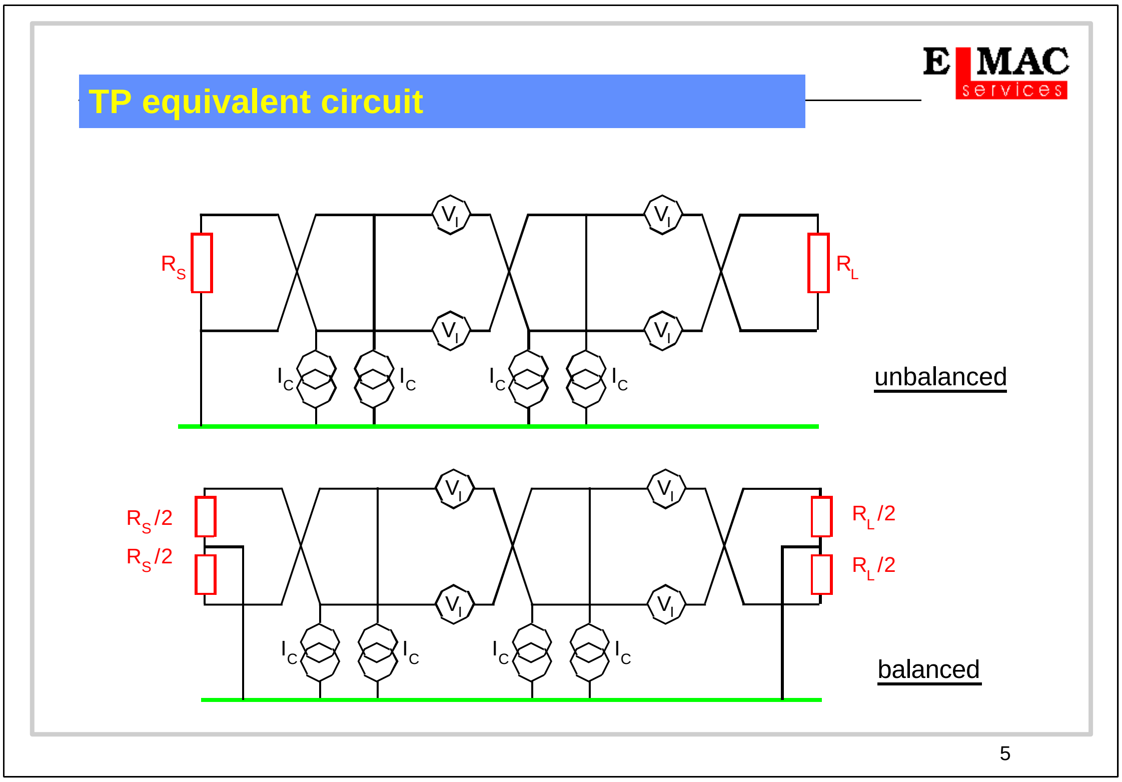
Twisted pair is a particularly effective and simple way of reducing both magnetic and capacitive interference pickup. Twisting the wires tends to ensure a uniform distribution of capacitances. Both capacitance to ground and to external sources are balanced. This means that common-mode capacitive coupling is also balanced, allowing high common-mode rejection.

Twisting is most useful in reducing low-frequency magnetic pickup because it reduces the magnetic loop area to almost zero. Each twist reverses the direction of induction so that two successive twists cancel the wires' interaction with the field. Effective loop pickup is now reduced to the small areas at each end of the pair, plus some residual interaction due to non-uniformity of the field and twist irregularity. If the termination area is included in the field, the number of twists per unit length is unimportant. If the field is localised along the cable, performance improves as the number of twists per unit length increases. Inter-pair magnetic crosstalk is reduced by randomizing the twist rate or twisting adjacent pairs in the opposite sense.

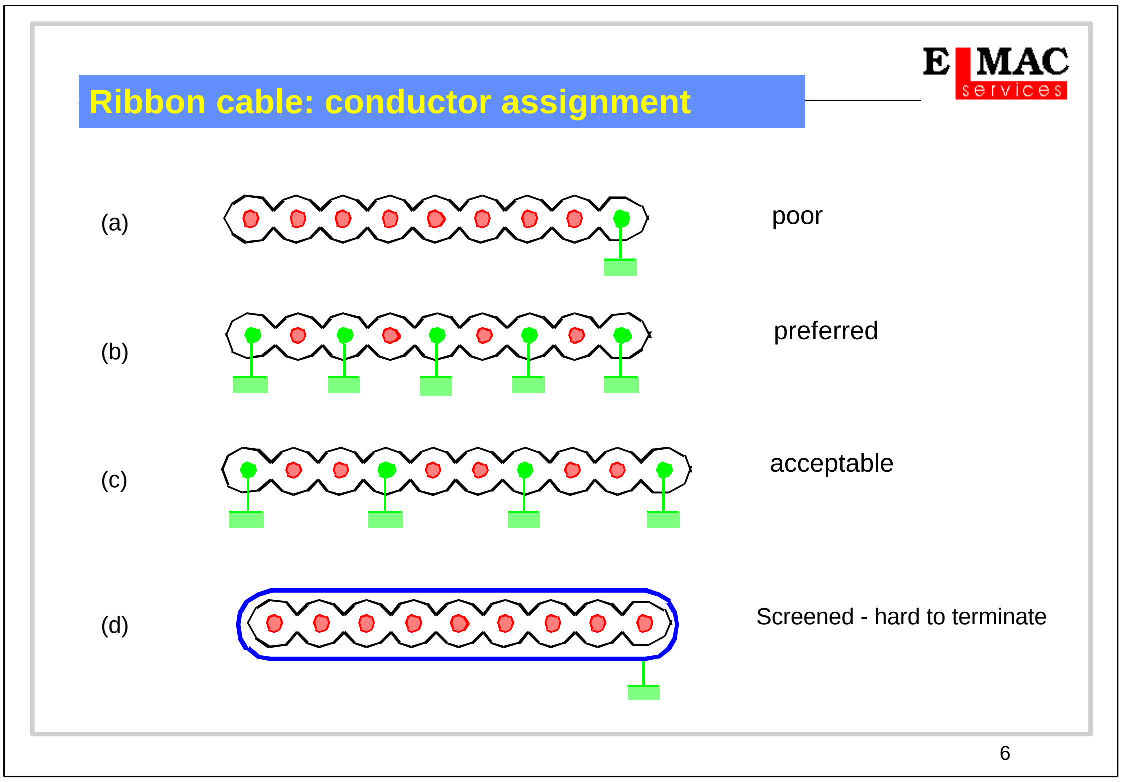


The crosstalk or external coupling to any cable, whether or not it is twisted pair, has both capacitive and inductive components. The equivalent circuit shows the capacitive coupling as a current source onto each conductor half-twist while the inductive coupling is a voltage source in series with each conductor, with an opposite sign at each half-twist.

The effectiveness of twisting a signal/return pair depends on the impedance and the balance or unbalance of the signal circuit.

For *unbalanced* circuits, capacitive coupling dominates at high impedances and there is little reduction in overall coupling by twisting. As the circuit impedance drops so capacitive coupling reduces and the inductive part becomes dominant, so that twisting becomes progressively more beneficial. Twisting together power conductors (circuit impedances of a few ohms) is therefore good practice.

Balancing the circuit eliminates (to a first order) the effect of capacitive coupling, and interaction with external fields is determined purely by residual inductive coupling. This will be sensitive to an odd or even number of half-twists, or more properly to the differences in voltages induced in the enclosed area at each termination.

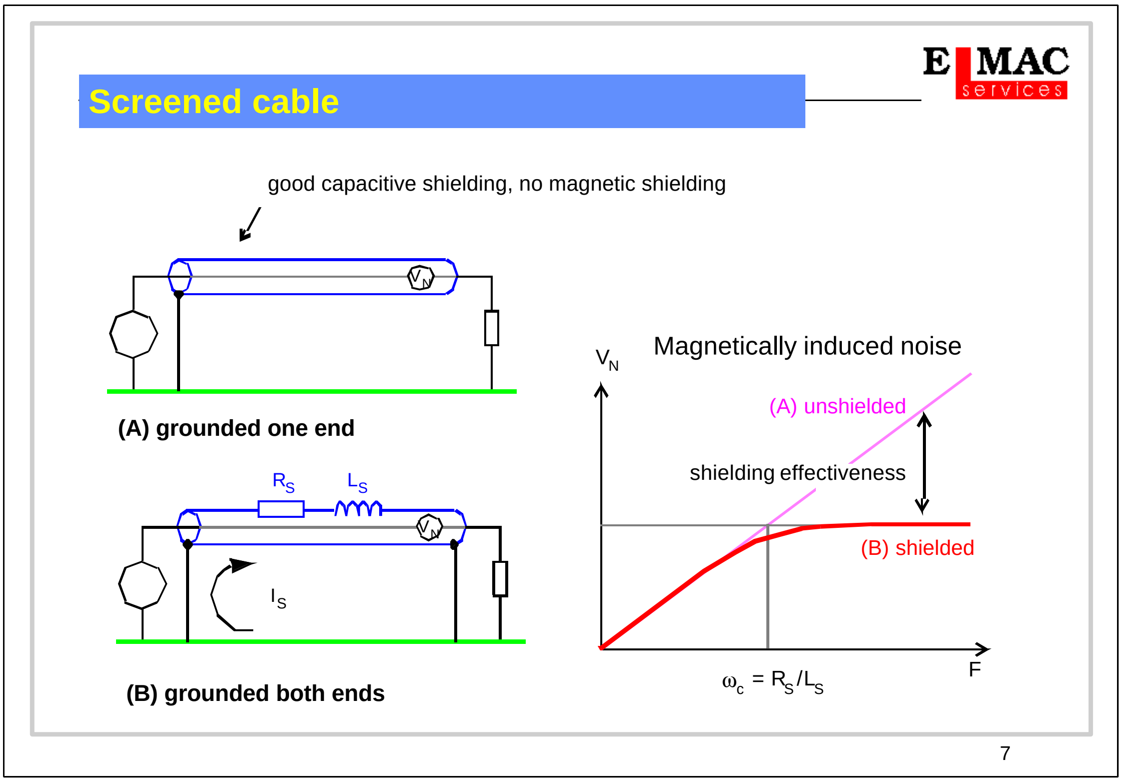


Ribbon is widely used for parallel data transmission within enclosures. It allows mass termination to the connector and is therefore economical. Like any other cable it should be shielded if it carries high frequency signals and is extended outside a screened enclosure, and within the enclosure should be routed near to the metallic structure and not across apertures or seams. Unfortunately, proper termination of the shield is usually incompatible with the use of a mass-termination connector.

The performance of ribbon cables carrying high frequency data is very susceptible to the configuration of the ground returns within the cable. The cheapest configuration is to use one ground conductor for the whole cable (a), but this creates a large inductive loop area for the signals on the opposite side of the cable, and hence crosstalk and ground impedance coupling between signal circuits.

The preferred configuration is a separate ground return for each signal (b). This gives almost as good performance as a properly terminated ground plane cable, and is easier to work with. Crosstalk and common impedance coupling is virtually eliminated. Its disadvantage is the extra size and cost of the ribbon and connectors.

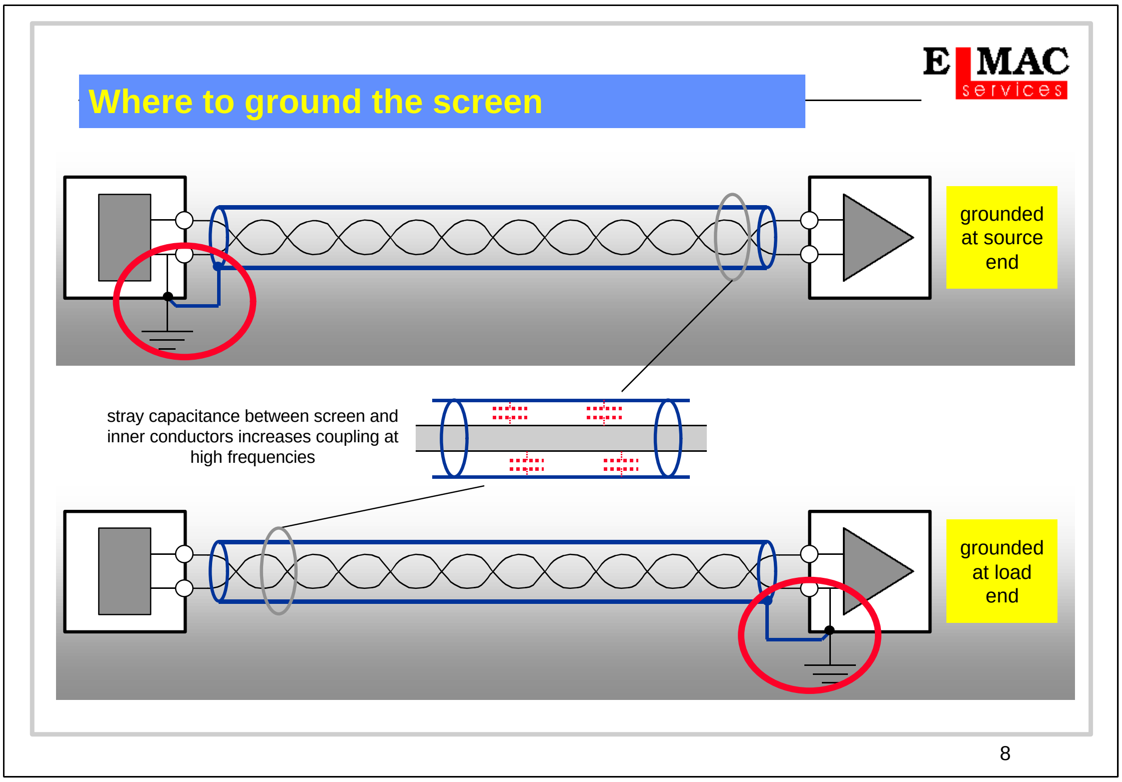
An acceptable alternative is configuration (c), two signal conductors per return. This improves cable utilization by 50% over (b) and maintains the small inductive loop area, at the expense of possible crosstalk and ground coupling problems between adjacent signals.



Screened cables are used to reduce coupling of the inner cable conductors with the environment they pass through, but the screen functions differently at high frequencies and at low frequencies, and also has different effects as between electric field and magnetic field coupling.

For low frequencies an overall screen, grounded only at one end, provides good shielding from capacitively coupled interference but none at all from the magnetic fields, which induce a noise voltage in the loop formed when both source and load are grounded. To shield against a magnetic field, both ends of the screen must be grounded. This allows an induced current (I_S) to flow in the screen which will oppose the current induced in the centre conductor, effectively minimizing the loop area seen by the complete signal circuit. This effect begins to become apparent only above the cable cut-off frequency, which is a function of the screen inductance and resistance and is around 1 - 2kHz for braided screens or 7 - 10kHz for aluminium foil screens. Above about five times the cut-off frequency, the current induced in the centre conductor is constant with frequency.

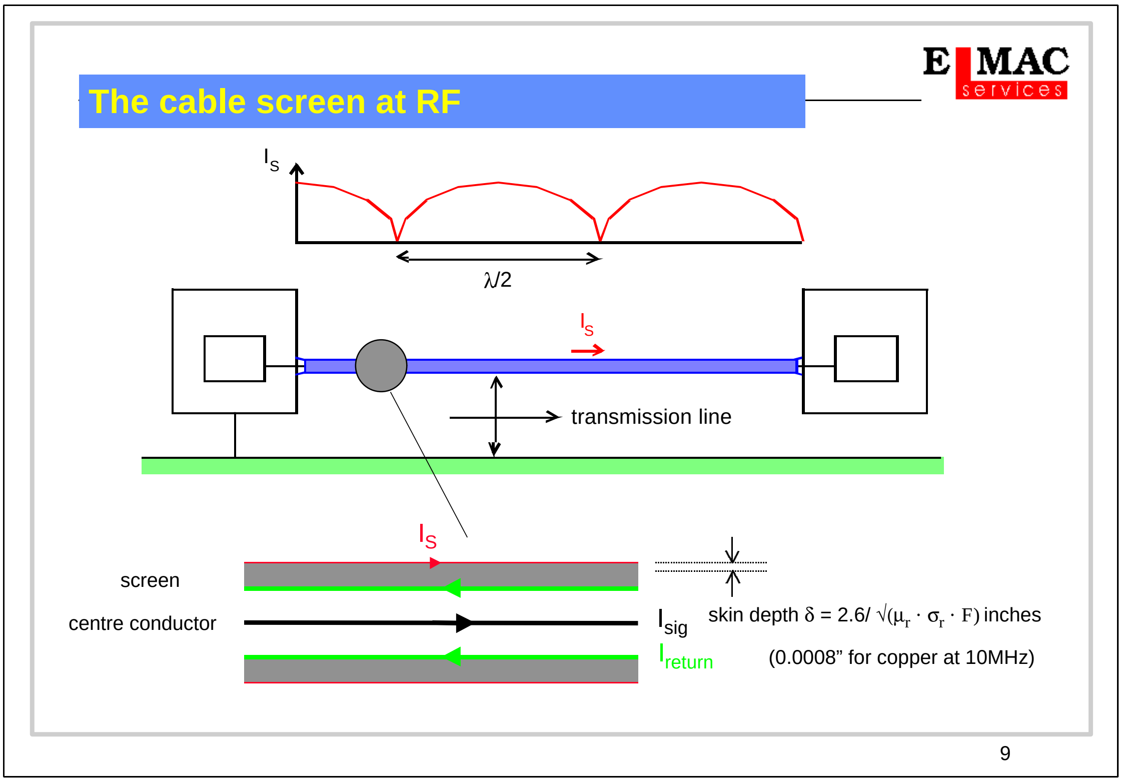
The same principle applies when shielding a conductor to prevent magnetic field emission. The return current must flow through the screen, and this will only occur (for a circuit which is grounded at both ends) at frequencies substantially above the shield cut-off frequency.



To minimize low frequency magnetic field pick-up, one end of the circuit should be isolated from ground, the circuit loop area should be small, and the screen should not form part of the circuit. You can best achieve this by using shielded twisted pair cable with the screen grounded at only one end. The twisting minimizes magnetic coupling, and the screen will reduce external capacitive coupling, but there is now the question of which end is best grounded.

Any voltage difference between the screen and the inner conductors will compromise the shielding since there is close capacitive coupling between them. Therefore the screen should be grounded at the same end as the circuit: for a circuit with an ungrounded source the screen should be grounded at the input common, whereas if the input is floating and the source is grounded then the screen should be grounded to the source common. But as the frequency increases, stray capacitance at the nominally ungrounded end reduces the efficiency of either arrangement by allowing undesired ground and screen currents to flow. This choice of screen grounding is really restricted oinly to low frequency circuits such as sensors and transducers in industrial environments.

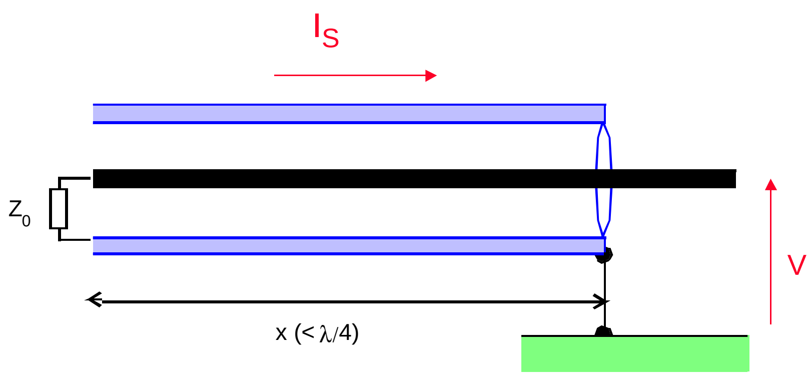
A frequent reason given for only grounding the screen at one end is that if there is a significant voltage difference between the earths at each end of the screen, current will flow in the screen if both ends are connected. This will be limited only by the impedance of the screen and the source impedances of the voltage differential; both of these could be very low, and the current that flows could be enough to damage the cable. Such voltage differentials are not unusual on large sites or between buildings. The preferred solution is to install the cable in a mesh-bonded ground network using parallel earth conductors (PECs), and certainly for new telecomm installations this approach should be insisted on. This type of installation prevents significant ground potential differences.



Once the cable length approaches a quarter wavelength at the frequency of interest, screen currents due to external fields become a fact of life. An open circuit at one end of the cable becomes transformed into a short circuit a quarter wavelength away, and screen currents flow in a standing wave pattern despite there being no external connection. The magnitude of the current is related to the characteristic impedance of the transmission line formed by the cable and the ground reference – a ground plane in an EMC test, but usually undefined in real life. Even below resonant frequencies, stray capacitance can allow screen currents to flow.

However at high frequencies the inner and outer of the screen are isolated by skin effect, which prevents currents on the surface from passing into the bulk of the conductor. Therefore signal currents on the inside of the screen do not couple with interference currents on the outside, and multiple grounding of the screen does not introduce interference voltages on the inside to the same extent as at LF. This desirable effect is compromised by a braided screen due to its incomplete optical coverage and because the strands are continuously woven from inside to out and back again. It is also more seriously compromised by the quality of the screen ground connection at either end.

Surface transfer impedance



Surface transfer impedance $Z_T = \dfrac{dV/dx}{I_S}$ Ω/m

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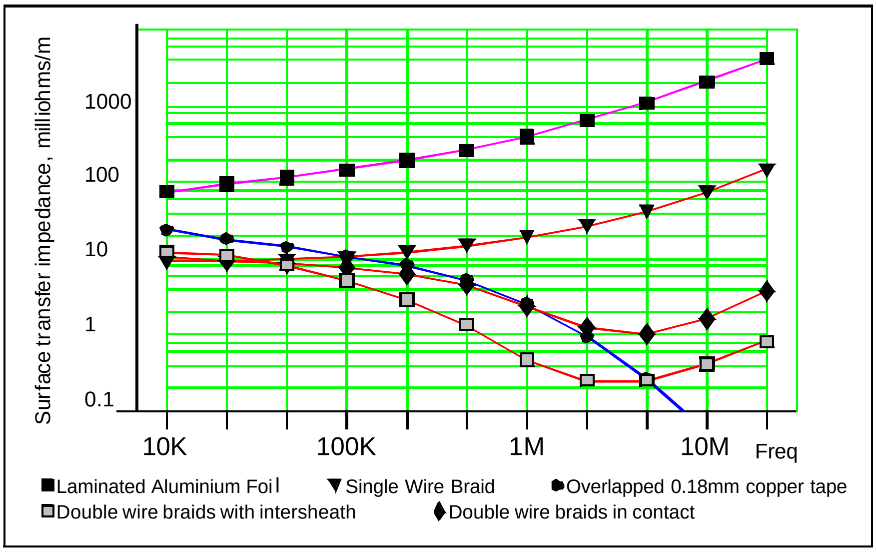
The screening performance of shielded cables is best expressed in terms of surface transfer impedance (STI). This is a measure of the voltage induced per unit length on the inner conductor(s) of the cable by an interference current flowing down the cable outer shield.

A perfect screen would not allow any voltage to be induced on the inner conductors and would have an STI of zero. Practical screens will couple some energy onto the inner. STI will vary with frequency and is normally expressed in milliohms per metre length. At low frequencies it is equal to the dc resistance of the screen, but at higher frequencies the STI is dominated by the effect of mutual coupling between the screen and the inner conductor. The parameters which affect the STI are

- mutual inductance - screen to inner
- mutual capacitance - screen to inner
- leakage capacitance - inner to external (“optical coverage”)
- skin effect and the compromising effect of braid weave

Transfer impedance examples



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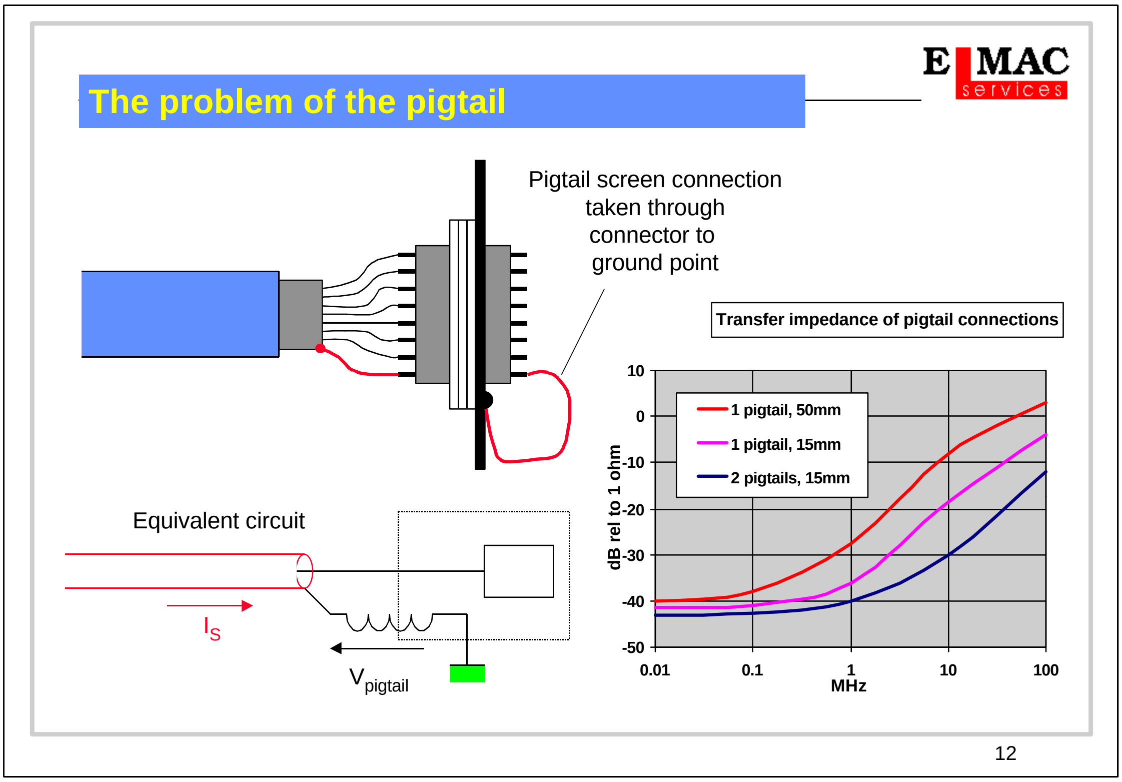
This graph compares STI versus frequency for various types of cable screen construction. The decrease in STI with frequency for the better performance screens is due to the skin effect separating signal currents on the inside of the screen from noise currents on the outside. The subsequent increase is due to field distortion by the holes and weave of the braid. A solid copper screen does not suffer from this, and its STI continues to reduce with increasing frequency.

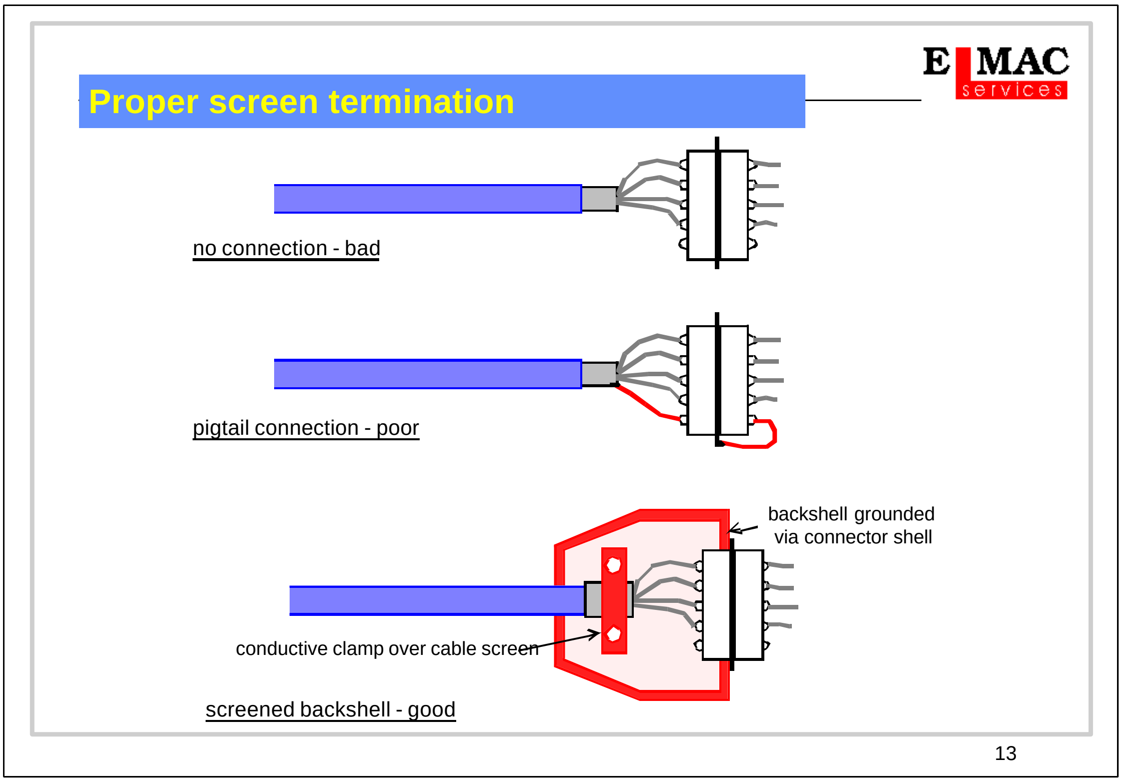
Note that most inexpensive types have a worsening STI with increasing frequency (a typical single wire braid is the popular RG58C/U coax). Once the frequency approaches cable resonance then STI figures become meaningless; figures are not normally quoted above 30MHz. The laminated foil screen is approximately 20dB worse than a single braid, due to its higher resistance and to the field distortion introduced by the drain wire, which carries the major part of the longitudinal screen current, but whose magnetic coupling with the inner conductors is much poorer than the coaxial part of the screen.



The actual surface transfer impedance of a cable-plus-connector system is often dominated by the STI due to the connector.

A pigtail connection is one where the screen is brought down to a single wire and extended through a connector pin to the ground point. Because of its ease of assembly it is very commonly used for connecting the screens of data cables. Unfortunately, it may be almost as bad as no connection at high frequencies because of the pigtail inductance, which appears in series with the cable screen and develops a voltage when interference currents flow down the screen to the ground connection. This voltage then couples readily from the end of the screen to the inner conductors. (This is a description of coupling *into* the system; the emissions coupling process is reciprocal.) The surface transfer impedance of such a connection rises rapidly with increasing frequency and effectively negates the value of a good HF screened cable.

If a pigtail connection is unavoidable then it must be as short as possible, and preferably doubled and taken through two pins on opposite ends of the connector so that its inductance is halved. Note that the effective length of the pigtail extends from the end of the cable screen through the connector and up to the point of the ground plane or chassis connection. Cable screens must always be taken to a point at which there is the minimum noise with respect to the system's ground reference. If there is a conductive enclosure then the screen should be clamped to this.

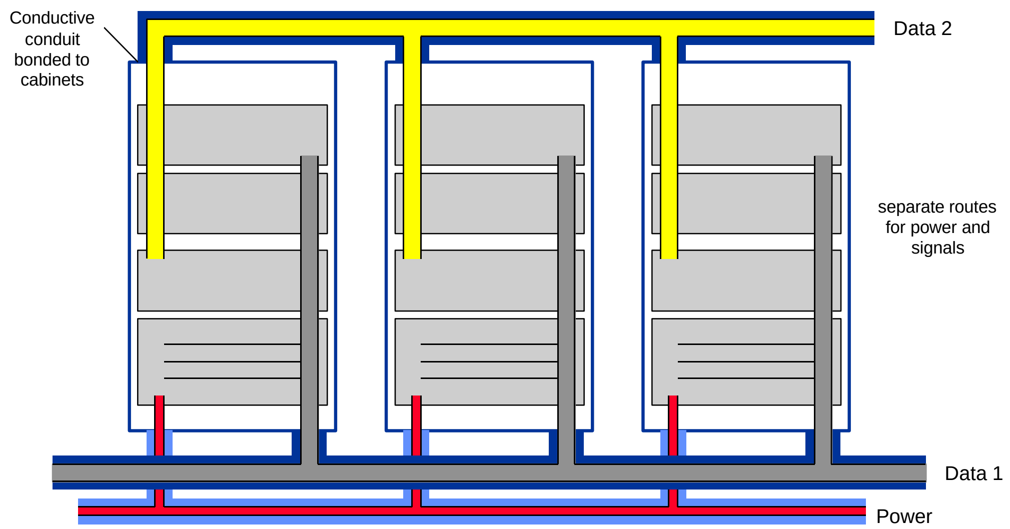


The overriding requirement for terminating a cable screen is a connection direct to the metal chassis or enclosure ground which exhibits the lowest possible impedance. This ensures that interference currents on the shield are routed to ground without passing through or coupling to other circuits.

The best connection in this respect is one in which the shield is extended up to and makes a solid 360° connection with the ground plane or chassis. This is best achieved with a hard-wired cable termination using a conductive gland and ferrule which clamps over the cable screen. Military-style connectors allow for this construction.

Of the readily available commercial connectors, only those with a connector shell that is designed to make positive 360° contact with its mate are suitable. Examples are the subminiature D range with dimpled tin-plated shells. The cable screen must make 360° contact with a screened, conductive backshell which must itself be positively connected to the connector shell.

Cable installation: segregation and routing



Cable segregation and routing between and within system cabinets

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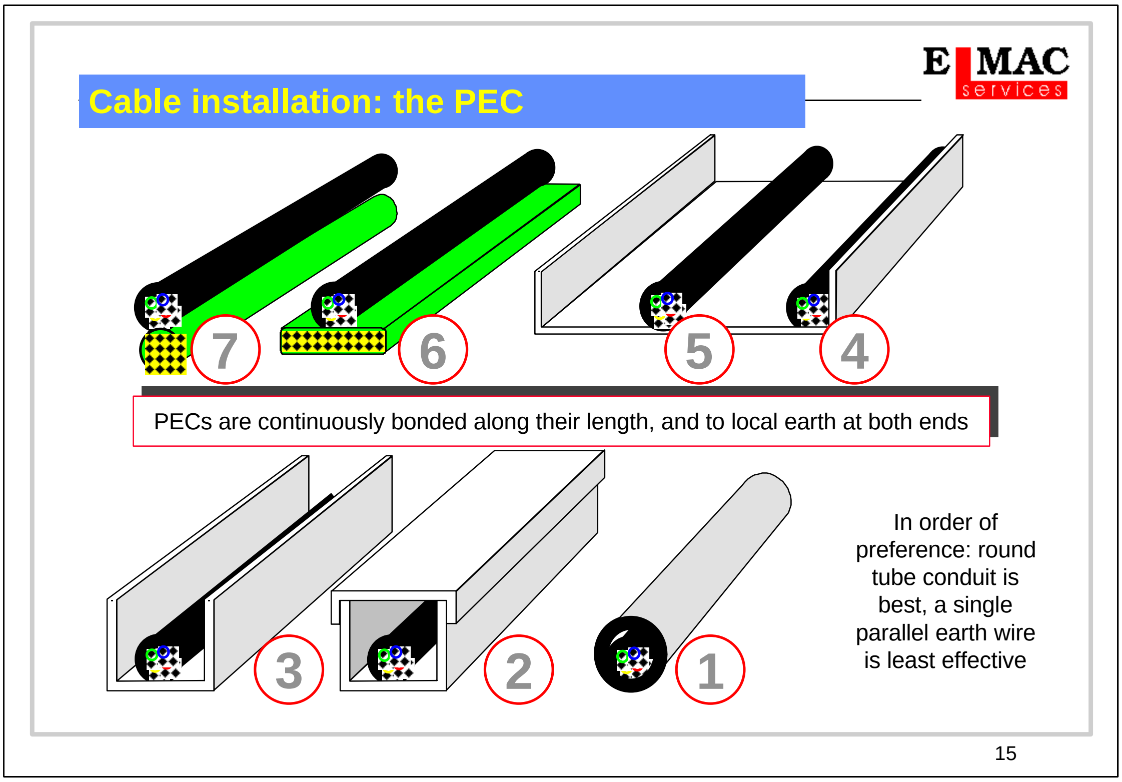
Cabling between equipment in a system should be segregated into classes, and all cables of each class should follow the same route within and between equipment. This route should be provided with a Parallel Earth Conductor (PEC) in the form of conduit or cable tray. Such a PEC should be bonded to the cabinet wherever the cables enter the cabinet. If all cables can be kept segregated within a single tray this is preferable, as there is then only need for one entry to each cabinet. Often though, it is necessary to make several entries, as shown above, and this both makes segregation easier but also puts greater stress on the cabinets, as interference currents will be encouraged to flow between entry points.

Segregated routing should be maintained as far as possible within each cabinet, though the PEC may be no more than a structural member or the backplate. As long as bonding continuity is maintained, this is sufficient.

Segregation is on the basis of signals within the cables:

- •class 1 – very sensitive signals: e.g. wideband data, video, analogue sensors
- •class 2 – slightly sensitive signals: e.g. ordinary analogue, slow digital
- •class 3 – slightly interfering signals: e.g. normal and suppressed power
- •class 4 – strongly interfering signals: e.g. heavy power, inverter drives

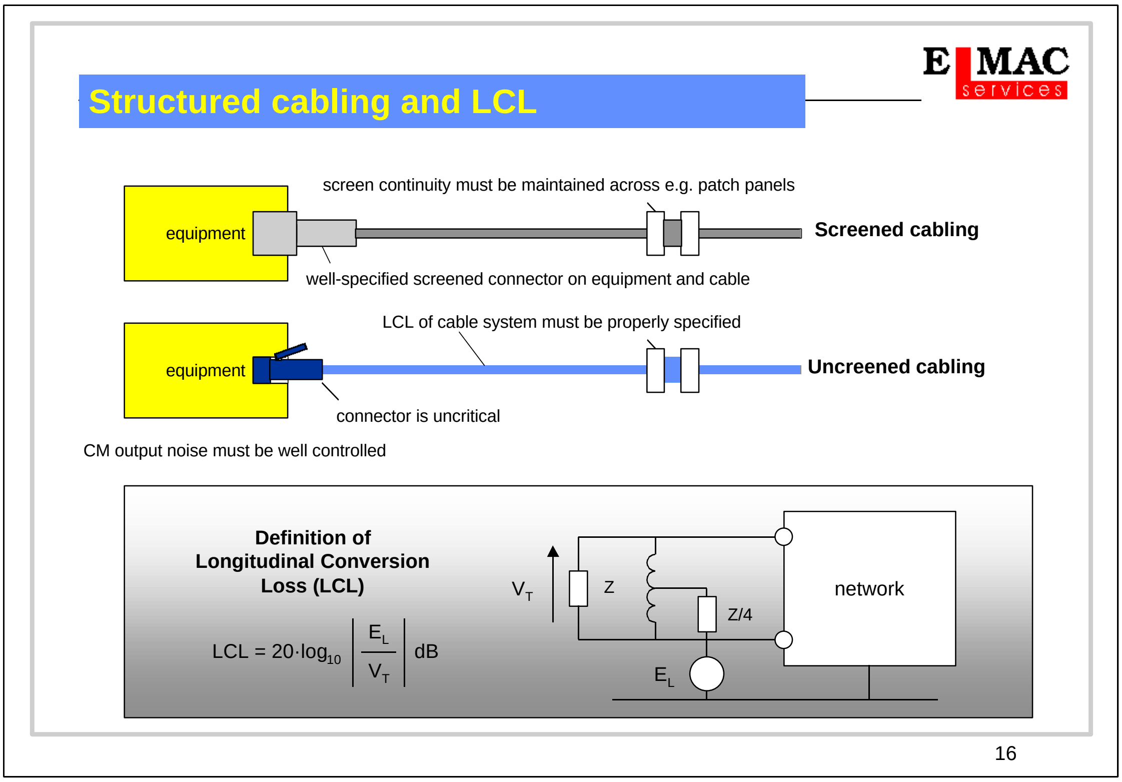
As a rule of thumb, cables should be grouped in classes and each class routed separately from the others, with a recommended minimum separation distance of 15cm between classes of adjacent levels and 50cm between classes differing by two levels. Short runs may be allowed to violate these recommendations where necessary.



The primary function of a Parallel Earth Conductor (PEC) is to divert high-level earth loop currents away from screened and unscreened cables. Since these currents are usually at 50/60Hz, and the related surges from lightning events have most of their energy below 10kHz, it is enough for this purpose that the PEC has low resistance and a sufficient current-carrying capacity. Most cable support systems have enough metallic cross-sectional area to provide this, especially on earth mesh bonded sites where earth currents can be expected to be low.

Any screen or earth conductor external to a cable should be regarded as a PEC and bonded to earth at both ends. Structural steelwork, for instance, is often suitable. Cable armouring should always be regarded as a PEC, and it is vital to ensure no breaks in the electrical continuity of any armour used for this purpose. Cable installers traditionally regard armour merely as mechanical strengthening or protection, and may not be used to bonding it at joints and to the local earth at each end.

For the PEC to be effective and to reduce magnetic field induction between the PEC and its cables, the cables must be run very close to their PEC throughout their length. PECs can also control induced interference at higher frequencies. The diagram above shows a variety of types of PEC, ranked by high frequency performance.



A common issue for equipment with data communication ports is how it will interface with cabling that has already been installed within a building, or "structured cabling". There is no clear preference as to whether the data cable should be shielded or unshielded. A good quality shielded cable can ensure minimum coupling with its environment, but only if it is properly terminated and if the shield is maintained unbroken along its length – not easy if it includes joints or patch panels. If this is not the case, then a well-specified UTP cable is likely to be better overall, as long as the equipment to which it is connected has good common mode rejection.

If you are designing a product with a LAN or telecom data interface then you will need to decide which type of cable to use. If shielded, then you must provide for a correctly terminated shielded connector, and ensure that the installation uses this connector with the proper cable in the right way. If unshielded, then the connector is less important, but the interface must have good common mode rejection, which will mean ensuring that the physical layout is balanced and, usually, incorporating a wideband common mode choke. It will also be necessary to specify the Longitudinal Conversion Loss (LCL) of allowable connected cables – typically by restricting them to one or other of the IEC 11801 categories (Cat 3, 5 or 6).

The LCL of a balanced cable system – or indeed any one- or two-port network – is a measure of the mode conversion exhibited by the system, that is the degree to which an inadequately balanced termination will develop an unwanted transverse (differential) signal when excited by a longitudinal (common mode) signal. It is measured as shown above. Although this diagram shows a differential mode signal generated by a common mode input, the principle is reciprocal and can be used to describe unwanted common mode signals developed by intended differential signals.

End of this section

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