The Circuit Designer's Companion: The safety earth and wiring/cables

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电路设计师指导手册(4)：安全地以及电线/电缆

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[Part 1 begins a look at grounding: when to consider it, how chassis materials affect it, and the problem of ground loops. Part 2 discusses power supply returns and I/O signal grounding. Part 3 covers inter-board interface signals, star grounding, and shielding.]

[第一部分开始讨论接地问题：何时考虑接地，机箱材料如何影响接地，以及接地环路问题。第二部分讨论电源回路和 I/O 信号接地。第三部分覆盖了板间接口信号、星形接地和屏蔽。]

1.1.12 The safety earth

A brief word is in order about the need to ensure a mains earth connection, since it is obvious from the preceding discussion that this requirement is frequently at odds with anti-interference grounding practice. Most countries now have electrical standards which require that equipment powered from dangerous voltages should have a means of protecting the user from the consequences of component failure. The main hazard is deemed to be inadvertent connection of the live mains voltage to parts of the equipment with which the user could come into contact directly, such as a metal case or a ground terminal.

1.1.12 安全地

确保市电地连接的安全需求非常迫切，因为从前面的讨论可以明显看出，这个需求与抗干扰接地措施经常发生冲突。大多数国家现在都有相关的电气标准，这些标准要求使用危险电压供电的设备在元器件发生故障时应该能够保护用户的安全。主要危害被认为是市电的火线电压被意外连接到用户可能直接接触的设备中的某些部分，如金属外壳或接地端子。

Imagine that the fault is such that it makes a short circuit between live and case, as shown in Figure 1.20. These are normally isolated and if no earth connection is made the equipment will continue to function normally

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but the user will be threatened with a lethal shock hazard without knowing it. If the safety earth conductor is connected then the protective mains

fuse will blow when the fault occurs, preventing the hazard and alerting the user to the fault.

想象一下这样的故障，即在火线和外壳之间发生了短路，如图 1.20 所示。火线和外壳正常情况下是隔离的，如果没有地连接，设备将继续正常工作，但用户将在不知情的条件下受到致命电击的威胁。如果连接了安全的地导体，那么起保护作用的市电熔丝将在故障发生时熔断，从而防止危害发生，还能提醒用户故障情况。

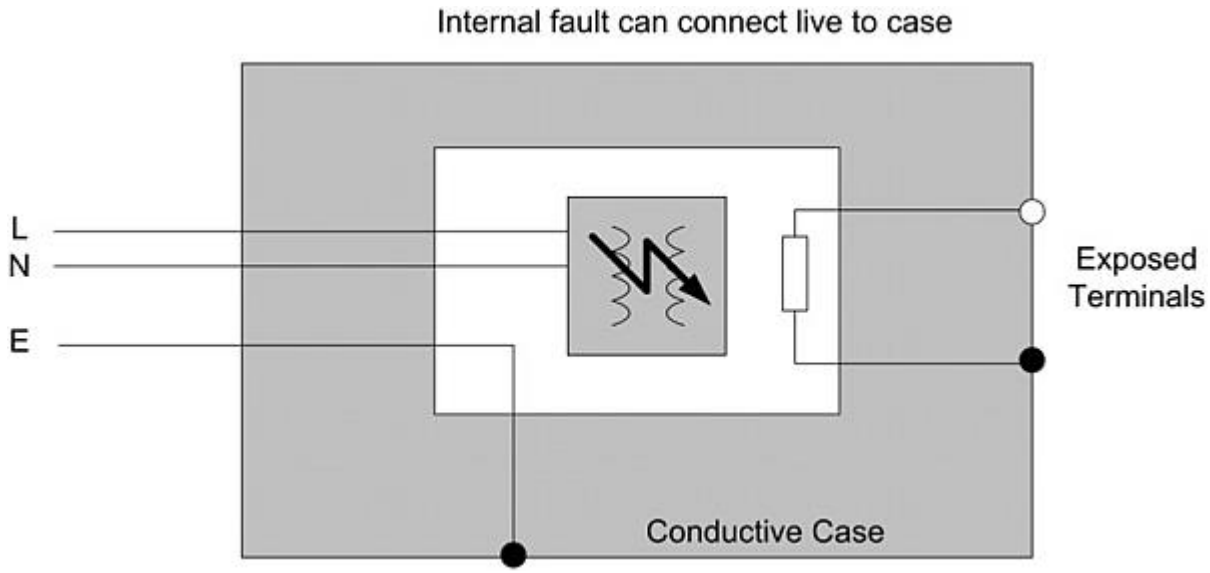

FIGURE 1.20 The need for a safety earth

图 1.20：需要一个安全地。

For this reason a safety earth conductor is mandatory for all equipment that is designed to use this type of protection, and does not rely on extra levels of insulation. The conductor must have an adequate cross-section to carry any prospective fault current, and all accessible conductive parts must be electrically bonded to it. The general requirements for earth continuity are:

基于这个理由，对所有设计使用这类保护措施的设备而言安全的地导体都是必须的，不能依赖于高度的绝缘等级。这种导体必须具有足够大的横截面以承载任何预期的故障电流，而且所有可接触到的导电部件都必须在电气上绑定到导体 。对地连续性的一般性要求是：

- The earth path should remain intact until the circuit protection has operated.
- The impedance should not significantly or unnecessarily restrict the fault current.

- 地路径应该保持完好无损，直到保护电路启动工作。
- 阻抗不应显著或不必要地限制故障电流。

As an example, EN 60065 requires a resistance of less than 0.5 Ω at 10 A for a minute. Design for safety is covered in greater detail in Section 9.1.

举例来说，EN 60065 要求在 10A、1 分钟的条件下保持导体电阻小于 0.5Ω。安全性设计在第 9.1 节有更详细的讨论。

1.2 WIRING AND CABLES

This section will look briefly at the major types of wire and cable that can be found within typical electronic equipment. There are so many varieties that it comes as something of a surprise to find that most applications can be satisfied from a small part of the range. First, a couple of definitions: *wires* are single-circuit conductors, insulated or not; *cables* are groups of individual conductors, separately insulated and mechanically contained within an overall sheath.

1.2 电线和电缆

本节将简要介绍在典型电子设备中经常见到的电线和电缆的主要类型。由于种类太多，因此发现大多数应用在局部范围内就能得到满足多少有点令人惊讶。首先，明确一些定义：*电线*是一些单独的电路导体，可以是绝缘的，也可以是非绝缘的。电缆是成组的单个导体，各导体单独绝缘，并且从结构上看包含在总的护套中。

1.2.1 Wire types

The simplest form of wire is tinned copper wire, available in various gauges depending on required current-carrying capacity. Component leads are almost invariably tinned copper, but the wire on its own is not used to a great extent in the electronics industry. Its main application was for links on printed circuit boards, but the increasing use of double-sided and multilayer plated-through-hole boards makes them redundant.

1.2.1 电线类型

最简单的一种电线是镀锡铜线，根据要求的电流承载能力的不同有很多种规格。元件引脚几乎总是不变的镀锡铜材，但电线本身在电子行业中并没有广泛使用。其主要应用是印刷电路板上的连接，但越来越多双面板和多层电镀通孔板的使用使得它们经常显得多余。

Tinned copper wire can also be used in rewirable fuselinks. Insulated copper wire is used principally in wound components such as inductors and transformers. The insulating coating is a polyurethane compound which has

self-fluxing properties when heated, which makes for ease of soldered connection, especially to thin wires.

镀锡铜线还可以用在可重新接线的熔丝连接中。绝缘式铜线主要用于绕线元件中，比如电感和变压器。其绝缘涂覆层是一种聚氨酯化合物，在加热时具有自熔特性，因此非常方便焊接，尤其是很薄的电线。

Table 1.2 compares dimensions, current capacity and other properties for various sizes of copper wire. In the UK the wires are specified under BS EN 13602 for tinned copper and BS EN 60182 (IEC 60182-1) for enamel insulated, and are sold in metric sizes. Two grades of insulation are available, Grade 1 being thinner; Grade 2 has roughly twice the breakdown voltage capability.

表 1.2 对各种规格铜线的尺寸、电流能力和其它属性进行了比较。在英国，镀锡铜线要符合 BS EN 13602 标准，搪瓷绝缘型铜线要符合 BS EN 60182 (IEC 60182-1) 标准。这些电线出售时都用公制标注，共有两种绝缘等级，等级 1 的绝缘层比较薄，等级 2 的击穿电压能力基本上是等级 1 的两倍。

Table 1.2 Characteristics of Copper Wire

Wire size (mm diameter)	**1.6**	**1.25**	**0.71**	**0.56**	**0.315**	**0.2**
Approx. Standard Wire Gauge (SWG)	16	18	22	24	30	35
Approx. American Wire Gauge (AWG)	14	16	21	23	28	32
Current rating (amps)	22	12.2	3.5	2.5	0.9	0.33
Fusing current (amps)	70	45	25	17	9	5
Resistance/meter at 20°C (W)	0.0085	0.014	0.043	0.069	0.22	0.54
Inductance of 1 meter length (μH)	1.36	1.41	1.53	1.57	1.69	1.78

Wire inductance

We mentioned earlier that any length of wire has inductance as well as resistance. The approximate formula for the inductance (L) of a straight length of round section wire at high frequencies is

电线电感

我们以前曾提过，任何长度的电线都有电感和电阻。截面为圆形的一段直线在高频时的电感值近似计算公式是：

$$L = K \times l \times (2.3 \log_{10} (4l/d) - 1) \ \mu H$$

where: l and d are length and diameter respectively, $l >> d$ and K is 0.0051 for dimensions in inches or 0.002 for dimensions in cm.

其中：*l* 和 d 分别是长度和直径，而且 *l* >> d，尺寸单位为英寸时 K 等于 0.0051，为厘米时 K 等于 0.002。

This equation is used to derive the inductance of a 1 m length (note that this is not quite the same as inductance per meter) in Table 1.2 and you can see that inductance is only marginally affected by wire diameter. Low values of inductance are not easily obtained by adding cross-section and the reactive component of impedance dominates above a few kiloHertz whatever the size of the conductor.

这个公式可以用来算出表 1.2 中 1 米长度电线的电感(注意，这与每米电感值并不完全一样)，从表中可以看出，电感只受电线直径的少许影响。增加横截面获得较低的电感值并不容易，不管导体尺寸是多少，当频率大于几 kHz 时阻抗中的电抗成份就占主导地位。

A useful rule of thumb is that the inductance of a one inch length of ordinary equipment wire is around 20 nH and that of a one centimeter length is around 7 nH. This factor becomes important in high-speed digital and RF circuits where performance is limited by physical separation, and also in circuits where the rate-of-change of current (di/dt) is high.

一个有用的经验法则是，普通设备电线一英寸长度的电感约为 20nH，或者说一厘米长度的电感约为 7nH。在性能受物理分割限制的高速数字和射频电路中以及电流变化率(di/dt)很高的电路中，这个因素变得非常重要。

Equipment wire

Equipment wire is classified mainly according to its insulation. This determines the voltage rating and the environmental properties of the wire, particularly its operating temperature range and its resistance to chemical and solvent attack. The standard type of wire, and the most widely available, is PVC insulated to BS 4808 which has a maximum temperature rating of 85° C. As well as current ratings at 25° C you will find specifications at 70° C; these allow for a 15° C temperature rise, to the maximum rated temperature, at the specified current. Temperature ratings of 70° C for large conductor switchgear applications and 105° C to American and Canadian UL and CSA standards are also available in PVC. PTFE is used for wider temperature ranges, up to 200° C, but is harder to work with.

设备电线

设备电线主要根据其绝缘性能进行分类。绝缘性能决定了电线的额定电压和环境属性，特别是其工作温度范围以及对化学物品和溶剂侵袭的抵抗能力。应用范围最广的标准类型电线是 PVC，其绝缘性能符合 BS 4808，最大额定温度为 85℃。和 25℃时的额定电流一样，你可以找到 70℃时的电流值。在特定电流时允许高

出最大额定温度 15℃。PVC 还支持针对大型导体开关设备应用的 70℃额定温度以及美国和加拿大 UL 与 CSA 标准规定的 105℃额定温度。PTFE 用于更宽的温度范围，最高可达 200℃，但较难使用。

Other more specialized insulations include extra-flexible PVC for test leads and silicone rubber for high temperature (150° C) and harsh environments. Many wires carry military, telecom and safety authority approval and have to be specified on projects that are carried out for these customers.

其它更专用的绝缘材料包括用于测试引线的超柔性 PVC 以及用于高温(150℃)和恶劣环境的硅橡胶。许多电线能满足军用、电信和安全权威认证要求，在这些客户部署的项目中必须对此有明确规定。

Table 1.3 is included here as a guide to the electrical characteristics of various commonly available PVC equipment wires. Note that the published current ratings of each wire are related to permitted temperature rise. Copper has a positive temperature coefficient of resistivity of 0.00393 per ° C, so that resistance rises with increasing current; using the room temperature resistance may be optimistic by several per cent if the actual ambient temperature is high or if significant self-heating occurs.

表 1.3 给出了各种常见 PVC 设备电线的电气特性。注意，每种电线公布的额定电流与允许的温升有关。铜具有每摄氏度 0.00393 电阻率的正温度系数，因此电阻随电流增加而增加。如果实际环境温度较高，或者自身发热严重，那么使用室温电阻值可能要比实际好几个百分点。

Table 1.3 Characteristics of BS 4808 Equipment Wire

Wire size (no. of strands/ mm diameter)	1/0.6	7/0.2	16/0.2	24/0.2	32/0.2	63/0.2
Resistance (Ω/1000 m at 20°C)	64	88	38	25.5	19.1	9.7
Current rating at 70°C (A)	1.8	1.4	3.0	4.5	6.0	11.0
Current rating at 25°C (A)	3.0	2.0	4.0	6.0	10.0	18.0
Voltage drop/meter at 25°C current (mV)	192	176	152	153	191	175
Voltage rating (KV)	1	1	1	1.5	1.5	1.5
Overall diameter (mm)	1.2	1.2	1.55	2.4	2.6	3.0
Near equivalent American Wire Gauge (not direct equivalent)	23	24	20	18	17	15

Wire-wrap wire

A further specialized type of wire is that used for wire-wrap construction. This is available primarily in two sizes, with two types of insulation: Kynar®, trademark of Pennwalt, and Tefzel®, trademark of Du Pont. Tefzel

is the more expensive but has a higher temperature rating and is easier to strip. Table 1.4 lists the properties of the four types.

绕线电线

另外一种专门类型的电线是绕线型电线，主要有两种尺寸和两种绝缘类型：Kynar®，商标是 Pennwalt，以及 Tefzel®，商标是 Du Pont。Tefzel 价格更高，但额定温度也更高，并且更容易剥皮。表 1.4 列出了 4 类电线的特性。

Table 1.4 Characteristics of Wire-wrap Wire

	Kynar: 30 AWG	26 AWG	Tefzel: 30 AWG	26 AWG
Conductor diameter (mm)	0.25	0.4	0.25	0.4
Maximum service temperature (°C)	105	105	155	155
Resistance/m at 20°C (W)	0.345	0.136	0.345	0.136
Voltage rating (V)	–	–	375	375
Current rating at 50°C (A)	–	–	2.6	4.5

Table 1.2 Characteristics of Copper Wire

表 1.2：铜线特性。

1.2.2 Cable types

Ignoring the more specialized types, cables can be divided loosely into three categories:

1.2.2 电缆类型

如果忽略比较专业的类型，电缆通常可以大致分成三大类：

- power;
- data and multicore;
- RF.

- 电源
- 数据和多芯
- 射频

1.2.3 Power cables

Because mains power cables are inherently meant to carry dangerous voltages they are subject to strict standards: in the UK the principal one is BS 6500. International ones are IEC 60227 for PVC insulated or IEC 60245 for rubber insulated. These standards have been harmonized

throughout the CENELEC countries in Europe so that any equipment which uses a cable with a harmonized code number will be acceptable throughout Europe.

1.2.3 电源电缆

由于市电电缆通常意味着承载危险电压，因此需要符合严格的标准：英国的主要标准是 BS 6500。国际标准方面，PVC 绝缘电缆是 IEC 60227，橡胶绝缘是 IEC 60245。这些标准在欧洲的所有欧洲电工标准化委员会国家中都已得到统一，因此使用带统一代码数字的电缆的任何设备在整个欧洲都是可接受的。

BS 6500 specifies a range of current ratings and allows a variety of sheath materials depending on application. The principal ones are rubber and PVC; rubber is about twice the price of PVC but is somewhat more flexible and therefore suitable for portable equipment, and can be obtained in a high-temperature HOFR (heat and oil resisting, flame retardant) grade. The current-carrying capacities and voltage drops for DC and single-phase AC, and supportable mass are shown in Table 1.5.

BS 6500 标准规定了一系列额定电流，允许根据应用采用各种护套材料。主要材料是橡胶和 PVC。橡胶的价格大约是 PVC 的两倍，但柔韧性更好，非常适合便携式设备，并且能够达到高温 HOFR(耐热和油，阻燃)等级。直流和单相交流下的电流承载能力和压降以及可支撑重量见表 1.5。

Table 1.5 Characteristics of BS 6500 Mains Cables

Cross-sectional area (mm^2)	**0.5**	**0.75**	**1.0**	**1.25**	**1.5**	**2.5**
Current-carrying capacity (A)	3	6	10	13	16	25
Voltage drop per amp per metre (mV)	93	62	46	37	32	19
Maximum supportable mass (kg)	2	3	5	5	5	5
Correction factor (CF) for ambient temperature:						
60°C rubber and PVC cables:	Temp.	35°C	40°C	45°C	50°C	55°C
	CF	0.92	0.82	0.71	0.58	0.41
85°C HOFR rubber cables:	Temp.	35-50°C	55°C	60°C	65°C	70°C
	CF	1.0	0.96	0.83	0.67	0.47

Source: IEE Wiring Regulations *17th Edition.*

Unfortunately, American and Canadian mains cables also need to be approved, but the approvals authorities are different (UL and CSA). Cables manufactured to the European harmonized standards do not meet UL/CSA standards and vice versa. So, if you intend to export your mains-powered equipment both to Europe and North America you will need to supply it with two different cables. The easy way to do this is to use a CEE-22 6-amp connector on the equipment and supply a different cable set depending on the market. This practice has been adopted by virtually all of the

large-volume multi-national equipment suppliers with the result that the CEE-22 mains inlet is universally accepted. There are also several suppliers of readymade cable sets for the different countries!

遗憾的是，美国和加拿大的市电电缆也需要认证，但认证机构是不同的(UL 和 CSA)。根据欧洲统一标准制造的电缆并不符合 UL/CSA 标准，反之亦然。因此如果你想把市电供电的设备同时出口到欧洲和北美地区，你需要提供两种不同的电缆。最简单的方法是在设备上使用 CEE-22 6A 连接器，然后根据不同市场提供不同的电缆组件。这种方法实际上已被所有大批量跨国设备供货商所采用，结果是 CEE-22 市电插座得到了大量普及。当然，也有几家供货商为不同国家提供成品电缆组件。

The alternative, widely used for information technology and telecoms equipment, is to use a ″wall-wart″ plug top power supply and provide different ones for each market, so that the cable carries low-voltage DC and no approved mains cable is needed.

还有一种被信息技术和电信设备广泛使用的方法，即使用“壁瘤”顶插式电源，并为每个市场提供不同的产品，以便电缆承载低压直流，这样就不需要认证的市电电缆了。

1.2.4 Data and multicore cables

Multicore cables are used when you need to transport several signals between the same source and destination. They should never be used for mains power because of the hazards that could be created by a cable failure, nor should high-power and signal wires be run within the same cable because of the risks of interference. Conventional multicore is available with various numbers of conductors in 7/0.1 mm, 7/0.2 mm and 16/0.2 mm, with or without an overall braided screen.

1.2.4 数据和多芯电缆

当需要在相同的源与目标之间传输多个信号时就会用到多芯电缆。这种电缆永远不要用于提供市电，因为电缆故障可能引发危险。大功率线和信号线也不应存在于同一电缆中，因为可能发生干扰。传统多芯电缆有许多种导体，如 7/0.1mm、7/0.2mm 和 16/0.2mm，带或不带整体编织型屏蔽层。

As well as the usual characteristics of current and voltage ratings, which are less than the ratings for individual wires because the conductors are bunched together, inter-conductor capacitance is an important consideration, especially for calculating crosstalk (to which we return shortly). It is not normally specified for standard multicore, although nominal conductor-to-screen capacitances of 150 – 200 pF/m are sometimes quoted. For a more complete specification you need to use data cable.

与通常的额定电流和额定电压特性一样，电缆也有这些特性，但它们的值要小于单根电线的额定值，因为导体捆绑在一起，导体间电容是一个重要的考虑因素，特别是在计算串扰时(不久还会提到这个问题)。虽然有时会引用 150-200pF/m 的标称导体至屏蔽层电容，但标准多芯电缆一般不规定电容这个参数。要想知道更完整的规格参数，你需要使用数据电缆。

Data communication cables

Data cables are really a special case of multicore, but with the explosion in data communications they now deserve a special category of their own. Transmitting digital data presents special problems, notably:

数据通信电缆

数据电缆是一种真正特殊的多芯电缆，但随着数据通信的爆炸式发展，它们现在已经有了自己的一个专门类别。传送数字化的数据有其特殊的问题，特别是：

- the need to communicate several parallel channels at once, usually over short distances, which has given rise to ribbon cable;
- the need to communicate a few channels of high-speed serial data over long distances with a high data integrity, which has given rise to cables with multiple individually screened conductor pairs in an overall sheath which may or may not be screened.

- 需要一次实现多个并行通道的通信，而且通常在短距离内，这就形成了带状电缆。
- 在长距离范围内实现多个通道的高速串行数据通信，这就形成了在一个(屏蔽或非屏蔽的)总护套内存在多个独立屏蔽导体对的电缆。

Inter-conductor capacitances and characteristic impedances (which we will discuss when we come to transmission lines) are important for digital data transmission and are quoted for most of these types. Table 1.6 summarizes the characteristics of the most common of them.

导体间电容和特征阻抗(在讨论传输线时会讨论到)对数字化的数据传输来说非常重要，也经常被这些类型的大多数电缆所引用。表 1.6 对大多数常见的这些电缆特性进行了总结。

Table 1.6 Characteristics of Data Transmission Cables

Cable type	Ribbon:		Round:	
	Straight	Twisted pair	Type A	Type B
Inter-conductor capacitance (pF/m)	50	72	40–115	41–98
Conductor-screen capacitance (pF/m)	–	–	66–213	72–180
Characteristic impedance (Ω)	105	105	–	50
Voltage rating (V)	300	300	300	30

Type A: multi-pair/multicore overall foil screened cable.
Type B: multi-pair individually foil screened cable.

Structured data cable

One particular cable application which forms an important aspect of data communications is so-called "structured" or "generic" cabling. This is general-purpose datacomms cable which is installed into the structure of a building or campus to enable later implementation of a variety of telecom and other networks: voice, data, text, image and video. In other words, the cable's actual application is not defined at the time of installation. To allow this, its characteristics, along with those of its connectors, performance requirements and the rules for acceptable routing configurations, are defined in ISO/IEC 11801 (the US TIA/EIA-568 covers the same ground).

结构化数据电缆

作为数据通信一个重要方面的特殊电缆应用是所谓的“结构化”或“通用”布线。这是通用型数据通信电缆，安装在建筑物或校园的基础设施中，方便以后实现各种电信及其它网络：语音、数据、文本、图像和视频。换句话说，这种电缆的实际应用在安装时是不确定的。为了达到这个目的，ISO/IEC 11801(美国的TIA/EIA-568 覆盖相同的范围)标准定义了这种电缆的特性以及连接器特性、性能要求和可接受的布线配置规则。

Equipment designers may not be too interested in the specifications of this cable until they come to design a LAN or telecom port interface; then the cable becomes important. The TIA/EIA-568 (both ISO/IEC 11801 and EN 50173 have similar specifications) parameters for the preferred 100 U quadpair cable are shown in Table 1.7. The standard allows for a series of categories with increasing bandwidth. Cat 5 and Cat 5e are popular and have been widely installed.

在真正设计 LAN 或电信端口接口之前，设备设计师可能对这种电缆的规范不是很感兴趣。但这种电缆的重要性越来越突出。表 1.7 给出了人们首选的 100U 四对电缆的 TIA/EIA-568 参数(ISO/IEC 11801 和 EN 50173 具有相似的规范) 。该标

准支持带宽越来越高的一系列分类。其中的 5 类和 5e 类电缆目前非常流行，得到了非常广泛的部署。

Table 1.7 Characteristics of TIA/EIA-568 (ISO/IEC 11801) 100 Ω Quad-Pair Cable

	Freq. (MHz)	Cat 3	Cat 5	Cat 5e	Cat 6
Bandwidth (MHz)		16	100	100	250
Characteristic impedance	0.1	75–150 Ω	75–150 Ω	N/A	N/A
	≥ 1	100 ± 15 Ω	100 ± 15 Ω	100 ± 15 Ω	100 ± 15 Ω
Attenuation dB/100 m	0.256	1.3	1.1	1.1	N/A
	1.0	2.6	2.1	2.1	2.0
	4.0	5.6	4.3	4.3	3.8
	10	9.8	6.6	6.6	6.0
	16	13.1	8.2	8.2	7.6
	31.25	N/A	11.8	11.8	10.7
	62.5	N/A	17.1	17.1	15.4
	100	N/A	22.0	22.0	19.8
	200	N/A	N/A	N/A	29.0
	250	N/A	N/A	N/A	32.8
Capacitance unbalance	1 kHz	3400 pF/km	3400 pF/km	330 pF/100 m	
DC loop resistance	N/A	|---------- 19.2 Ω/100 m, max. unbalance 3% ----------|			
Return loss dB at 100 m cable length	1–10	12	23	20 + 5log(f)	
	10–20	12–10log(f/10)	23	25	25
	20–100	N/A	23–10log(f/20)	25–7log(f/20)	
	200	N/A	N/A	N/A	18.0
	250	N/A	N/A	N/A	17.3

Other characteristics, particularly mechanical dimensions, crosstalk performance (extended for Cat 5e and 6), and propagation delay skew are also defined in the standard.

标准中还定义了其它一些特性，特别是机械尺寸、串扰性能(针对 5e 类和 6 类电缆进行了扩展)以及传播延时偏差等。

Shielding and microphony

Shielding of data and multicore falls into three categories:

屏蔽和颤噪效应

数据和多芯电缆的屏蔽分成三大类：

- copper braid. This offers a good general-purpose electrical shield but cannot give 100% shield coverage (80 – 95% is typical) and it increases the size and weight of the cable.
- tape or foil. The most common of these is aluminized Mylar. A drain wire is run in contact with the metallization to provide a terminating contact and to reduce the inductance of the shield when

it is helically wound. This provides a fairly mediocre degree of shielding but hardly affects the size, weight and flexibility of the cable at all.
- composite foil and braid. These provide excellent electrostatic shielding for demanding environments but are more expensive - about twice the price of foil types.

- 铜编织带。它能提供很好的通用电气屏蔽特性，但不能实现 100%的屏蔽覆盖(典型覆盖率是 80%－90%)，而且它增加了电缆的尺寸和重量。
- 带或箔。最常见的是镀铝的聚脂薄膜。加蔽线始终保持与金属接触，不仅提供终端接触，而且在螺旋状绕组时可减少屏蔽层的电感量。这种方法的屏蔽效果适中，但几乎不影响电缆的尺寸、重量和柔韧性。
- 组合式箔和编带。这种方法可以为要求严格的环境提供优异的静电屏蔽性能，但比较昂贵——约是箔类价格的两倍。

For small-signal applications, particularly low-noise audio work, another cable property is important - microphony due to triboelectric induction. Any insulator generates a static voltage when it is rubbed against a dissimilar material, and this effect results in a noise voltage between conductor and screen when the cable is moved or vibrated.

针对小信号应用，尤其是低噪声的音频应用，另外一种电缆属性也很重要——由摩擦电感应引起的颤噪效应。任何绝缘体在与异类材料摩擦时都会产生静电电压，当电缆在移动或振动时这种效应将在导体和屏蔽层之间形成噪声电压。

Special low-noise cable is available which minimizes this noise mechanism by including a layer of low-resistance dielectric material between braid and insulator to dissipate the static charge. When you are terminating this type of cable, make sure the low-resistance layer is stripped back to the braid, otherwise you run the risk of a near short circuit between inner and outer.

有种特殊的低噪声电缆可以最大程度地减轻这种噪声机制，它在编带和绝缘体之间加入了一层低阻电介材料用于释放静电荷。当你在终接这种电缆时，要确保上述低阻层被剥回编带，否则在内层和外层之间可能发生近似短路的风险。