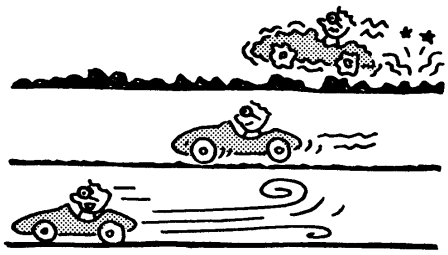
FURUTECH

The Appropriate Selection and Use of Audio Cables

Considerable interest has, in recent years, focused on the hitherto neglected, yet complex subject of high fidelity cables and interconnects.
Regrettably, conflicting claims from a plethora of producers has led to a great deal of confusion. As a result, it's extremely difficult to separate fact from fiction, which is naturally frustrating for the potential purchaser, particularly when it's obvious that cost effective sound quality improvements of a high order may be affected, simply by choosing as appropriate interconnect or cable.
In order that a precise interface between Hi Fi components may be successfully achieved, the specifications for the design of an interconnect dedicated to its specific purpose requires to be appreciated and whilst subjective assessment through listening is recommended, without the benefit of accurate specifications, subjective assessment alone will often result in an inappropriate purchase.
We sincerely trust that the following may introduce the reader to a meaningful correlation between cable design and sound quality, thereby assisting in the selection of appropriate cables and interconnects dedicated to their respective purposes.

There's More to Sound Quality Than Conductor Specifications

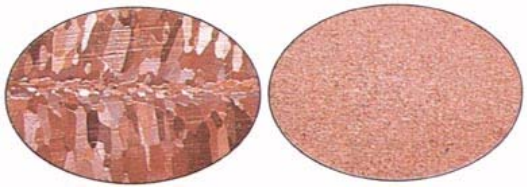
The following three types of cable are regularly employed in Hi Fi systems.
① A.C. power supply cables.
② Interconnect cables for the transmission of delicate audio signals.
③ Speaker cables for the transmission of signals from amplifiers to speakers.
Whilst A.C. power cables do influence quality, fundamental to the excellence of the system are the latter two, the interconnect and the speaker cables. In the design of these cables, three principal factors contribute to quality, these are:
① Conductor material specifications.
② Insulation material specifications.
③ Cable construction specifications.
The appropriate selection of quality conductor materials contribute to enhanced resolution, clear bass, image, height and depth, whilst the selection of insulation materials, together with construction methods, influence the accuracy of musical timbre and ambience.



TPC

OFC

PCOCC



TPC **PCOCC**

Conductor Types

TPC (Tough Pitch Copper)

TPC is a basic copper conductor widely employed for electric wires such as power leads and occasionally in inexpensive audio leads.
The electrolyzed electric copper is melted once and cooled into a conductor electric wire through repeated drawing into the desired size. The tough pitch copper which is melted and cooled in air contains about 300~500ppm of oxygen.

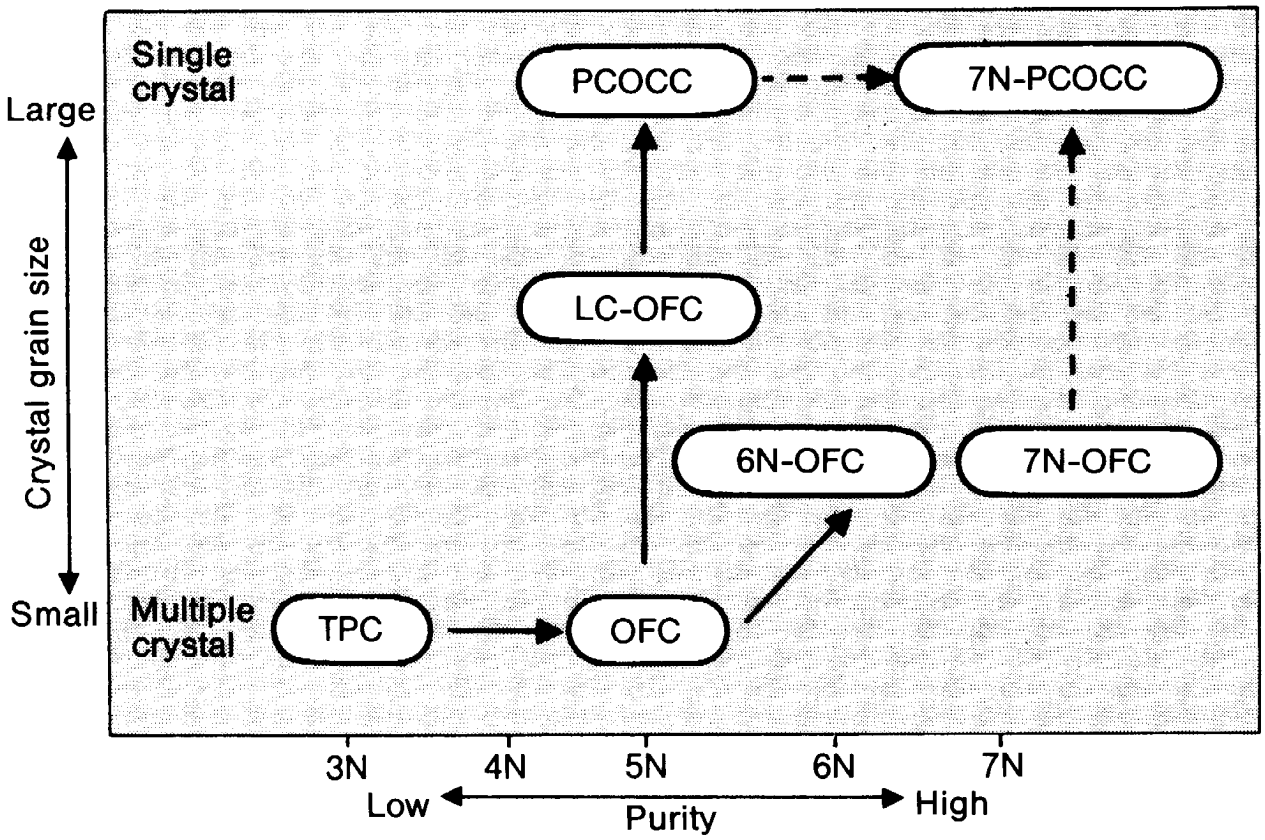
OFC (Oxygen Free Copper)

OFC is produced in an inert gas, oxygen free process and thus it's 10ppm represents a relatively low oxygen content. OFC's conductivity is of the order of 0.5% to 2% greater than that of TPC. OFC may be annealed in order to reduce the crystal grain structure.

PCOCC (Pure Copper by Ohno Continuous Casting Process)

PCOCC represents 'state of the art' in conductor material technology. PCOCC is produced from an exclusive and patented method of continuous casting, developed by Professor Ohno of The Chiba Institute of Technology. The PCOCC process involves the use of a heated mold, which produces a mono or single crystal ultra pure copper wire with insignificant oxygen and hydrogen inclusion. The copper material transformation has additional significant advantages, it reduces the ratio of stress to strain of the copper, therefore PCOCC has greater flexibility, PCOCC has a higher specific gravity and a higher "Q" therefore PCOCC's mechanical isolation or resistance to electromagnetically induced vibration within a conductor is excellent. PCOCC mono crystal copper wire has no crystal grain boundary in the signal transmission direction, consequently, PCOCC doesn't impede the extremely delicate audio signal and features the lowest distortion factor of any available conductor material. Since it's introduction in 1986, continued research and development into PCOCC has resulted in even greater purity. PCOCC with a purity of 99.99999% described as "7N" because of the seven "nine's", will, in future, be a feature of very superior cables.

● Transition of copper conductor



● The chemical and physical properties of copper ingot

		PCOCC	OFC	TPC
Purity		>99.997	>99.99	>99.9
Density	×	8.938	8.926	8.75
	max	8.940	8.932	8.88
Gas impurity	O_2(ppm)	<5	<10	200~500
	H_2 (ppm)	<0.25	<0.5	>0.3
Hydrogen embittrement		Absolutely none	No	Yes

● The properties of the elementary materials

	PCOCC		LC-OFC	TPC/OFC
Conductor diameter	5mmψ	15mmψ	1.6mmψ	0.9mmψ
The length of grain	>500mm	>50mm	<0.5mm	<0.05mm
The length of grain after drawn to 0.1mm¢	>1,125.00m		<13cm	<4mm
The number of grain in 2m length cable	1		>15	>400

Differences due to Conductor Construction

Cable employ in their construction either a solid or a stranded configuration of wires for their conductors, according to the application for which the cable is designed. Stranded wire is typically available in one of the following three configurations, each of which exhibits it's own characteristics.

① Bunch Stranded Conductor

The bunch stranded is a method of production whereby strands in the construction of the conductor are laid as a bunch in the same direction. Typically, cables provided for power cables and sometimes, proprietary Hi Fi and audio systems are produced from bunch stranded conductors. The cross-section of a stranded conductor is not perfectly circular, therefore, cables of such construction employed for signal transmission suffer from a reflection of the signal due to fluctuations of the characteristic impedance in the longitudinal direction of he cable, resulting in a deleterious sound quality.

② Concentric Lay Stranded Conductor

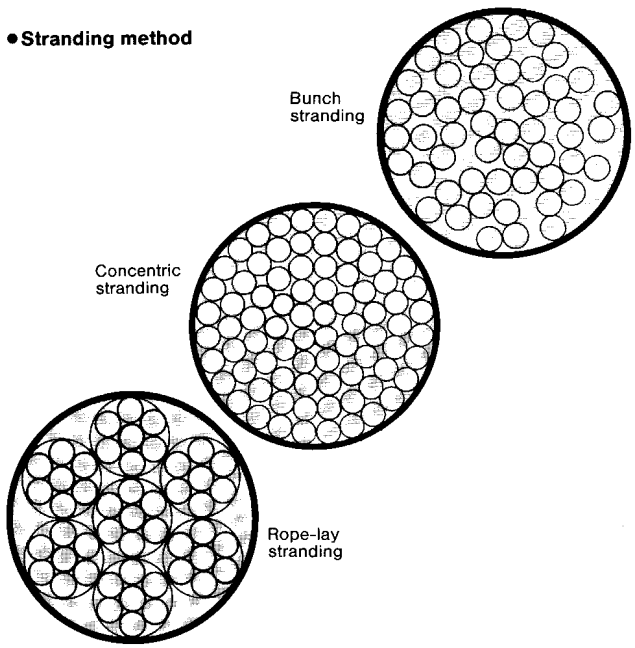
Concentric lay stranded consist usually, of multiple layer of concentric stranded wires. The center of the middle conductor coincides with the center of the diameter of the other layers. Adjacent strand layers within the conductors are usually laid in opposite directions. The uniform position relationship of the conductors in the longitudinal direction form a perfect circle through their section, suitable to signal transmission and contribute to a stabilisation of the characteristic impedance.

③ Rope Lay Stranded Conductor

Rope lay stranded is a kind of concentric lay stranded conductor having required members which are consist of bunch or concentric lay stranded wires. Rope lay stranding is usually a superior design employed in better quality speaker cables which require to having a large section yet remain flexible.

④ The Solid Conductor

The ultimate quality for conductors is achieved from a solid PCOCC conductor. It may be noted that all the compromises made in the design of the three forementioned methods of production are totally eliminated in a perfectly circular solid conductor, which may be produced in a variety of sizes according to the sectional area required. Such materials are Super PCOCC, which are "AS CAST" and are not reworked or drawn to size, FS-2T15S speaker cable and FA-11S interconnect cables are representative of "AS CAST" conductors, these are best conductors which Furutech manufacture and they feature in the finest quality cables.



Various Characteristics of Conductors

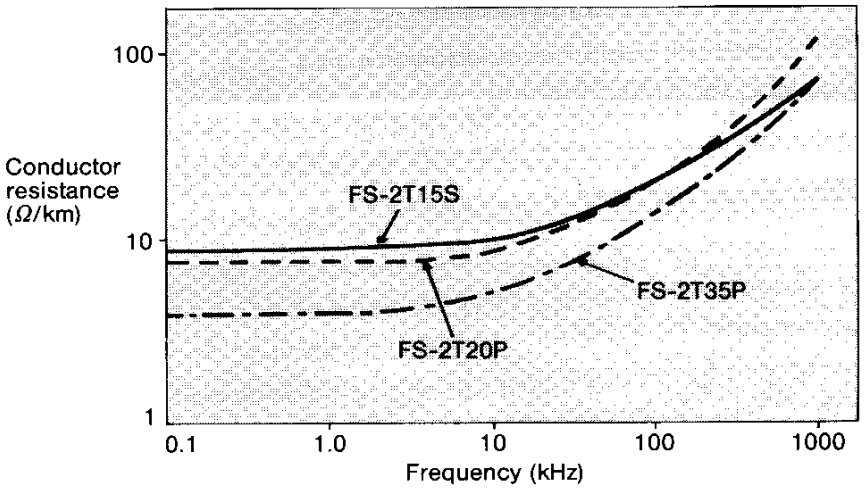
Conductor Resistance

Attenuation of the signal is directly proportional to conductor resistance. Attenuation represents the amount of energy consumed as the signal transmits along the cable, and the lower the attenuation and therefore conductor resistance, the better.

The foregoing is of paramount importance in the case of speaker cables where a high conductor resistance causes a decrease in the damping factor. The coil in a speaker generates it's own electromotive force which is fed back through a speaker cable and can, in extreme cases, damage the power amplifier.

D.C. resistance is in direct proportion to the conductor's sectional area and the material employed, the greater the diameter and the purer the material, the lower is D.C. resistance. When high frequencies are transmitted in A.C., a different set of values apply and conductor resistance increases due to skin effect, proximity effect and eddy current loss. Illustrated are the frequency characteristics of three Furutech speaker cables. FS-2T20P, FS-2T35P and FS-2T15S, the former two are stranded designs of 2 sq mm and 3.5 sq mm respectively and the third is a solid conductor of 1.5mm. It will be noted that in what is considered to be the audible spectrum, from 20Hz to 20kHz the frequency characteristics of all three remain relatively flat, however as the frequency increases from D.C. into A.C. the conductor resistance increases correspondingly. It may be argued that these frequencies are inaudible, but that's not the case, it's high frequencies which influence timbre and ambience and contribute to a clean, smear free treble, therefore thoughtfully designed cables produced from high quality materials and constructed with technical excellence together with an efficient insulation are a prerequisite to Hi Fi excellence.

● A.C. conductor resistance of speaker cables

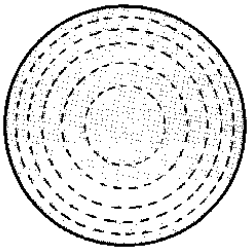


Skin Effect

Flowing current tends to favor the conductor surface as the frequency rises. The situation is considered to be due to the failure of the high frequency electromagnetic wave to enter the conductor metal or a reaction of current within the conductor.

In practice, when high frequencies are transmitted down the peripheral surface, they don't flow through the central portion of the conductor and the reduction in the effective sectional area results in an increase in conductor resistance, which causes an increase in attenuation and a resultant degradation in sound quality.

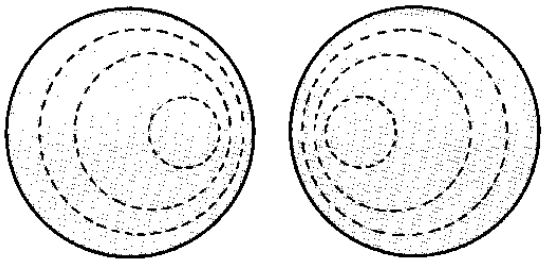
Skin effect



Proximity Effect

When conductors are positioned side by side and the high frequency current flows in each conductor, the currents tend to flow while keeping a distance if their flow direction is same. On the other hand, currents tend to flow while keeping proximity if the flow direction is opposite. In this way, the conductor resistance increases when the current flow is not uniform.

Proximity effect (Current in each conductor flow opposite)



Type of Insulation

Materials

The materials most frequently utilised for electronic cables are PVC (Polyvinyl Chloride) and LDPE (Low Density Polyethylene). In commercial use, PVC is principally used for cables of low voltages typically 600 volts or less. LDPE, with its good dielectric characteristics, is often employed as an insulation material in communication cables for telephones etc. for high voltage power cables and for video and digital audio interconnect cables.
Superior materials include FEP (Teflon) and PP (Polypropylene). Teflon has excellent dielectric characteristics. Teflon is a heat resistant material as is evident from it's use as a surface material for pots and pans, which means the extrusion temperature for insulating a conductor requires to be of a high order, generally 400 to 500 degrees centigrade and at these high temperature the conductor surface will be oxidized.
Polypropylene is a pure, stable material with excellent insulation characteristics including dielectric constant. PP also exhibits better mechanical properties such as isolation to vibration and is the material favored for Furutech speaker cables and analogue interconnect cables.
Nowadays rubber insulated wire is rarely used for electronic equipment since flexible PVC (polyvinyl chloride) exhibits better characteristics for wear and resistance to various solvents etc. particularly for the outer sheaths of cables.

• Major insulation materials and their electrical characteristics

Material / Properties	Low Density Polyethylene (LDPE)	PVC	Polypropylene	FEP
The specific volume resistance (Ω·cm 20℃)	$>10^{17}$	10^{12}~10^{15}	6.5 X 10^{14}	$>10^{18}$
The dielectric constant (50~10^{6}Hz)	2.3	4~8	2.25	2.1
The dielectric loss tangent (50~10^{6}Hz%)	0.02~0.05	8~15	0.02~0.06	0.02~0.07

˙ Teflon is a trademark of Du Pont.

Electrical Characteristics of Insulation Materials

Insulation materials have four electrical characteristics, which are critical to cable design.
The specific volume resistance is the resistance per unit area for D.C. and is an index of insulation performance. The dielectric strength is the voltage at which insulation breaks down when voltage is applied to a material of 1 mm. The dielectric constant (described later) and the dielectric loss tangent are fundamental parameters in the design of audio cables.
The dielectric loss tangent is an guide line of the dielectric loss when an A.C. filed is a applied to the insulation material.

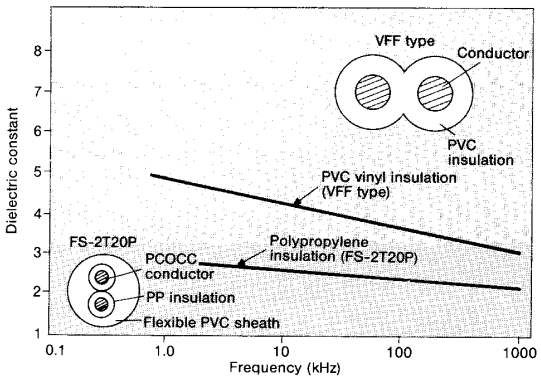
The Relative Dielectric Constant

The relative dielectric constant is probably the most important parameter in cable design. The relative dielectric constant (Es) is defined as the ratio between the electrostatic capacitance for parallel plate condensers in a vacuum (Co) and the electrostatic capacitance when an insulation material is interposed (C) and is expressed thus: Es=(C/Co). The relative dielectric constant may be interpreted, in other words, as the magnitude of polarisation for the vacuum (Es=1).
An insulation material containing a large volume of ions, for example PVC, polarises when an electrical voltage is applied. The altered structure of such an insulation surrounding the current carrying signal conductor causes dielectric loss, resulting in signal loss and a reduction in transmission velocity commensurate with the insulation's relative dielectric constant.
Figure 9 illustrates the frequency characteristics of relative dielectric constant (Es), between two cables, Furutech VVF, a power cable with a PVC insulation and Furutech FS-2T20P speaker cable, with a PP insulation and a PVC sheath.

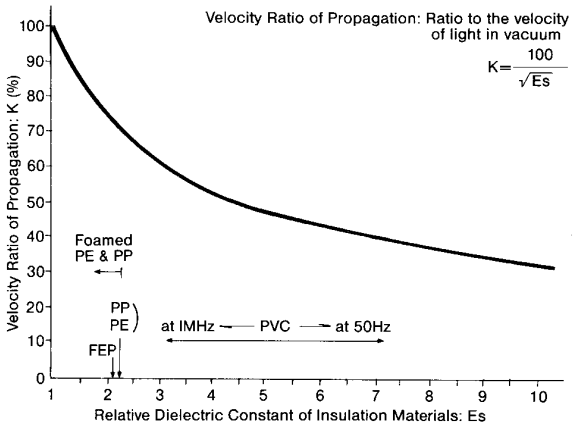
Capacitance

The electrostatic capacitance of a cable is determined by the position of two conductors and the dielectric constant of the insulation. Foamed polyethylene and polypropylene are employed in low capacitance cables such as Furutech FD-11, FV-11 and FA-21 where foaming reduces the dielectric constant, thereby stabilising the frequency characteristics. Within the audio range, the magnitude of capacitance together with conductor resistance, governs the level of attenuation and the lower the level of attenuation, the better the cable is.

● Frequency characteristic of dielectric constant



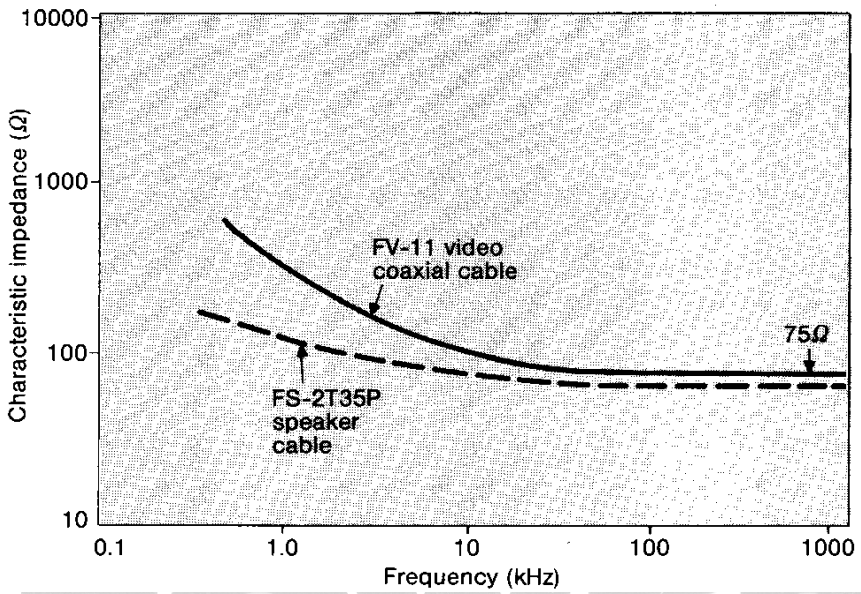
● Dielectric Constant vs Velocity Ratio of Propagation in Insulation



Characteristic Impedance

It is of fundamental importance for the transmission of high frequency signals such as those from video, or digital sources, that the transmitted signals match the characteristic impedance of the cable. The correct type of cable is a 75 ohm co-axial design and if an alternative is employed, then the signal will be partially reflected at a connection point such as an RCA type plug, and cannot be transmitted in a clear pattern, either the rise or the fall square wave form is deformed or the wave form is jittered, resulting in errors which cause a degradation of the sound quality.

● Frequency characteristic of characteristic impedance



Shield

Cables for the purpose of interconnecting components are provided with a shield in order to protect the signal from external noise. There are two types of shield, one for the rejection of electrostatic ally induced noise and the other for the rejection of magnetically induced noise. For the rejection of electrostatic noise a metal with high conductivity such as copper wire or Aluminum foil is generally provided. Since the shield effect is in reverse proportion to the resistance of the shield, it is necessary to reduce the resistance of the shield in order to increases the current flow through the shield, which creates a barrier to external noise.
A ferrous material (iron, etc.) must be provided on the cable in case of shielding for the magnetic field. But, this type of shield is not used in the audio cable because the cable becomes thick and hard. Generally speaking, twisting of insulated conductors can have an effect to suppress the magnetic field. However, cable engineers do not call this the magnetic shield. The magnetic shield applies strictly to the case of providing the ferrous material.

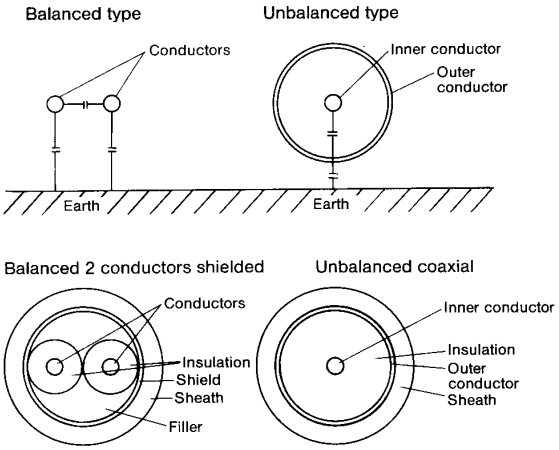
Appropriate Application of Interconnect Cables

Balanced and Unbalanced Interconnect Cables

Interconnect cables may be classified into two categories according to their construction and connection method, these are balanced and unbalanced.

The balance type has equivalent conductors with the same characteristics of capacitance, impedance and resistance, such as Furutech FA-11S and FA-21, which provide the going and return paths for the signal. Electrically these conductors are in equal relationship to earth (ground potential). These cables in addition to their conductors contain a separate shield, which may be introduced as a barrier to external noise, as necessary, by the connection of a flying lead attached to the shield. The flying lead should be connected to a ground or earth tag at the end of the cable, which is attached to the source of the signal. Such a configuration of wring for an interconnect is described as balanced.

The unbalanced type has a going and a returning line, which are not equivalent in terms of construction or electrical performance such as Furutech FV-11 and FD-11 cables. These are co-axial cables and the shield or screen is employed for the return path. In general the resistance of the shield is lower than that of the conductor.



Balanced and Unbalanced Signals

Signals used in audio equipment may be classified into two types, balanced and unbalanced. The voltage generated in a coil and piezo-electric element of a cartridge or microphone is a balanced signal electro-magnetically described as a modulated A.C. wave.

The pulse signal used in C.D. is an unbalanced high frequency signal, which is transmitted with reference to earth potential (0 volt).

The appropriate interface between the generated signal and the interconnect

For optimum transmission of the audio signal, the interconnect cable requires to be matched to the generated signal, a balanced interconnect for analogue signals and an unbalanced interconnect for digital signals.

Regrettably in practice totally inappropriate interconnects are often provided, yet as described above in the chapter dealing with characteristic impedance, it is essential that an interconnect dedicated to video or digital audio transmissions, designed for 75 ohms impedance, be employed for a digital or video device.

In order to reject external noise and E.M.I. induced noise from the extremely delicate analogue signal between amplifier and preamplifier, tape deck and preamplifier, turntable and preamplifier etc. a dedicated balanced cable requires to be employed.

Cable Selection

Check the cable currently in use or that, which is intended according to the following list:

① Conductor material

Conductor materials generally contribute to enhanced resolution; therefore check for purity of material, grain size and crystal length, single or multiple crystals PCOCC, LC-OFC or OFC are factors, which determine the grade of purity and therefore resolution.

② Conductor construction

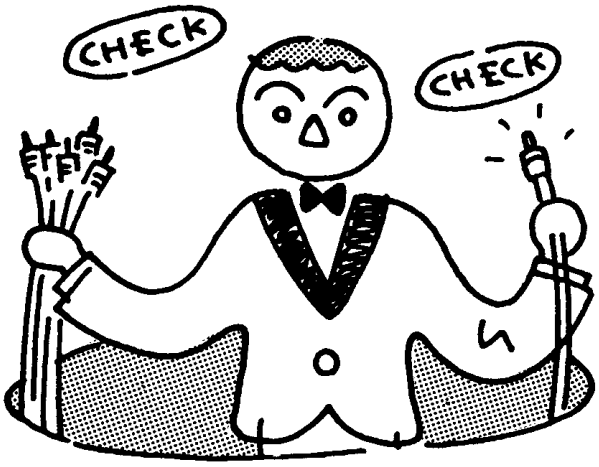
Where a stranded conductor is employed, particularly in speaker cables, check its cross section is a perfect circle. Where bunch stranded are laid in the longitudinal direction, they don't form a perfect circle, therefore the characteristic impedance for the cable may not be guaranteed and resultant reflections of the signal cause a deleterious sound quality.

③ Insulating material

Frequencies fluctuate according to the efficiency of the dielectric constant of the insulation the degree of which determines the signal transmission velocity. All Furutech cables exhibit a low dielectric loss and a stable frequency through the audio spectrum.

④ Sheath

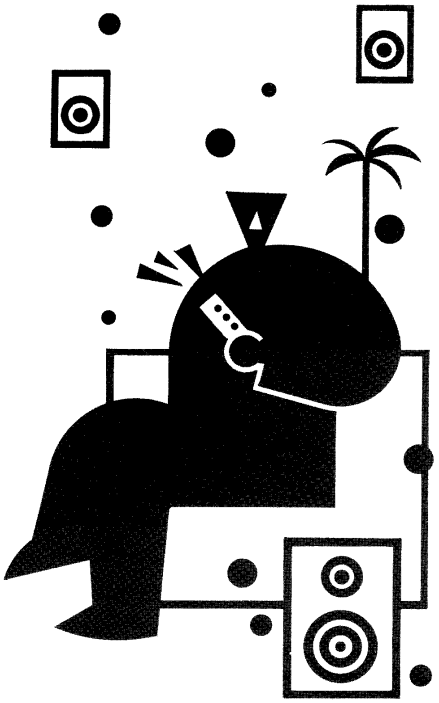
Outer sheaths require to absorb mechanical and electromagnetic ally induced vibration and bending with relative ease, therefore they should be soft and pliable.



Methods for Handling Audio Cables in Use

The audio cable consisting of it's conductor, insulation and construction is a delicate, scientifically designed product, therefore certain precautions require be taken in order that optimum performance may be realized.

- **Do not wind, bundle or bind.**
- **Do not stretch.**
- **Do not bend excessively.**
- **Do not place the audio cable in parallel with a power cable.**
- **Do not place the audio cable in parallel with ferrous constructions.**
- **Do not leave one end of any cable open, and do not allow the positive and negatives paths to short circuit.**
- **Disconnect unnecessary cables.**
- **Do not attempt to affect a joint in cables.**
- **Periodically clean any oxidation from contacts.**
- **Do not use in unnecessarily long.**



Improved Listening Pleasure

Appropriate cables, properly selected, dedicated to their respective purposes and interfaces within the Hi Fi system, will transmit without deletion, all the excitement contained in the original Hi Fi source and will make a significant and often cost effective contribution to the quality of listening pleasure.

Before any upgrade in the Hi Fi system is contemplated, a simple check on the improvements available through the existing components via good cables and interconnects is sincerely recommended.

Furutech appointed dealer's will be pleased to assist with an obligation free, home demonstration of the very considerable sonic improvements, which are possible.