An introduction to hifi Pt.4

CARTRIDGES & STYLI EXPLAINED

For fifty years or more, phonograph records have been a vital part of domestic sound systems and, while their dominance is now threatened by the digital compact disc, they are likely to be around for quite a few years yet. In this chapter, and the one to follow, we examine the technology of conventional records and record players.

by NEVILLE WILLIAMS

In practical terms, the so-called "black disc" has a longer history than any other item in a domestic sound system. The basic principle dates back to pioneers like Edison, Berliner, Bell and Tainter, who were offering their phonographs, gramophones and graphophones for sale before the turn of the century.

"Graphophone", along with many other such names, has long since been forgotten but "phonograph" and "gramophone" are still with us as generic nouns signifying a record player. Of the two, "phonograph" — abbreviated to "phono" — is the one most commonly used in the context of domestic audio equipment.

However, while modern, high-performance phono decks have their roots in the past, they are nevertheless the end result of decades of dedicated research and development, topped off with a significant content of space-age precision and technology.

Before discussing the major components in a modern, quality phono deck, it may be helpful to look at the record groove itself — a source of wonderment to many: how can a groove in the surface of a disc capture and store sound, especially sound as complex as that of a symphony orchestra?

The record groove

The answer to that question follows on from the closing paragraphs of Part 1, dealing with sound waves. We pointed out there that multiple pressure waves from a sound source, whether simple or complex, add up to a single pressure resultant at any one instant at any given point in a sound field.

The resultant varies continuously, depending on the instantaneous sum of the individual components. In a soundfield, an eardrum, or a microphone diaphragm, vibrates in response to the constantly varying pressure resultant (or sound pressure "envelope") at that particular point.

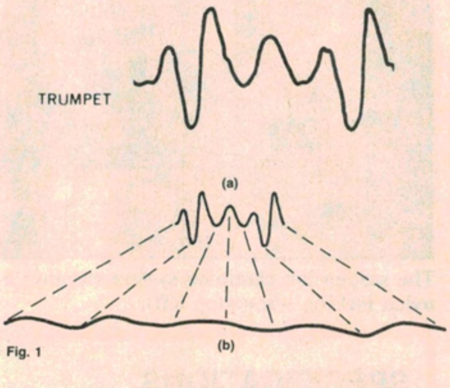


Fig.1: (a) represents a few cycles from the sound pressure envelope of a trumpet; (b) suggests how the same waveform might look as the segment of a groove in a laterally recorded disc.

Fig.1(a), reprinted from this earlier section, depicts a few cycles from the sound pressure envelope of a trumpet. Imagine this being picked up by a microphone and fed to a recording head inscribing a lateral (sideways modulated) groove in the surface of a master disc.

Fairly obviously, the groove deviations would be essentially proportional to those of the source signal but, to be physically traceable by a playback stylus, they need to be suitably adjusted in amplitude and elongated by virtue of groove speed, more or less as depicted in Fig.1(b).

When that same fragment of groove is replayed, the original signal (1a) will be recovered — hopefully along with the rest of the trumpet solo — to be fed to an amplifier and loudspeakers and enjoyed by all!

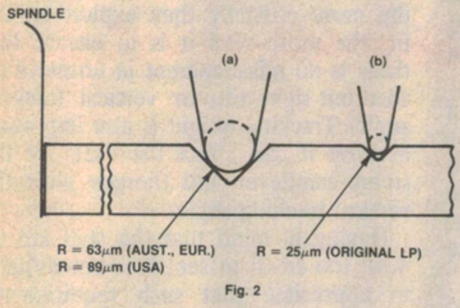
In short, a record groove can logically be regarded as a graph of a sound pressure envelope, not drawn on paper, but inscribed as a wriggly spiral, hundreds of metres long, in the surface of a disc. The more complex the source signal, the more complex the pattern of deviations in the groove, and therefore the more complex the sound pressure pattern ultimately radiated from the loudspeakers.

Groove size, shape

In the era of mechanical reproduction, the groove and "needle" geometry had to be sufficiently rugged to provide adequate drive for an acoustic diaphragm and horn system. However, with the widespread adoption of "electric" pickups and amplifiers in the '30s, a less cumbersome system became possible, although it did not actually emerge until after the war.

Fig.2 indicates the relative size of the "coarse groove" geometry (a) used in 78rpm shellac discs and (b) that adopted for "fine groove" LP vinyl records.

Coarse grooves were originally played with steel "needles" designed to wear to the shape of the groove while playing. Towards the close of the era, they gave way to "permanent" styli with a hemi-



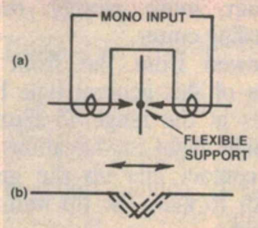


Fig.2: (a) depicts a "coarse" (78rpm) groove being played by a hemispherical jewel tipped stylus; (b) indicates the relative geometry of the groove and stylus adopted for the original LP discs.

Fig.3: In a mono recording, groove modulation is purely lateral, the depth of the groove remaining substantially constant. Compare this diagram with Fig.4f (below).

spherical jewel tip, as shown, commonly ground to a radius of 63μm (0.0025in).

By contrast, fine groove technology called for a tip radius of (initially) 25μm (0.001in) and a much lower tracking force (or weight) on the stylus — down from 30 grams or more to five grams or less.

Apart from the advantage of longer playing time and lower noise, the new standards encouraged progressive refinement of both recording and replay equipment, in terms of wider frequency response, lower distortion and greater dynamic range. Further impetus was provided by the subsequent introduction of stereo recording and playback.

45/45 stereo system

And that raises the question as to how it is possible to record two separate audio signals in the one groove, representing the left and right stereo channels.

Fig.3 depicts the situation with ordinary mono lateral recording. The cutting stylus is driven from side to side (a) by the incoming audio signal such that the groove (b) deviates to the left and right of its unmodulated path, the depth remaining substantially constant.

For mono playback, the head and arm must be free to follow slight undulations or eccentricities in the disc or turntable but the stylus system itself needs only to sense lateral groove deviation, generating a single, mono output signal as it does so.

By contrast, stereo LP recording and playback, introduced in the late '50s, uses the so-called "45/45" configuration. As indicated in Fig.4(a), it involves twin drive systems for the cutting stylus, each mounted at 45-degrees to the horizontal, and a complementary 45/45 mechanism in the playback head.

If signal drive is confined to the left channel (b) only the inner wall of the groove is modulated. Conversely, signal to the right channel only modulates the outer wall of the groove (c).

With different signals applied simultaneously to both channels, different modulation patterns appear on the respective walls. Depending on the instantaneous relationship of the drive signals, the stylus may move sideways, upwards or downwards, with the groove being modulated both laterally and vertically (d).

For stereo playback, the process is reversed, with the pickup stylus assembly responding to modulation on either or both walls and generating separate left-channel and right-channel signals.

Stereo-mono compatible

In practical recording situations, sound sources near the centre of the stereo sound field may produce similar signals in both channels, particularly at lower frequencies. Depending on the phase relationship of the cutter drive circuits, these "common mode" signals could cause the cutter to move either vertically (e) or horizontally (f).

Standard recording practice requires that "common mode" or "centre stage" signals produce lateral deflection of the cutter (f) equivalent to normal mono (Fig.3b). This ensures a basic compatibility such that a mono cartridge can play a stereo disc, and vice versa, the signal content being normal in each case, except for the absence of stereo information.

(Note that a mono cartridge, used to

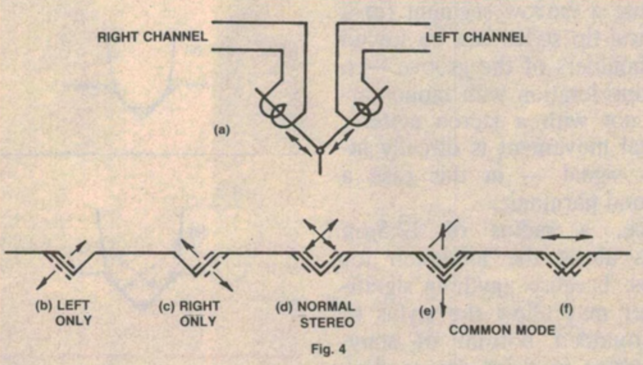


Fig.4: With a 45/45 stereo system (a), vertical as well as lateral modulation is evident in (b), (c) and (d). A special situation arises with identical signals in both channels, resulting in (e) and (f).

Cartridges & styli

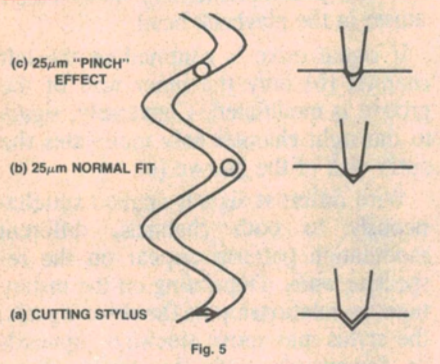


Fig.5: When a cutting stylus (a) is moving sideways, it cuts a narrower groove, forcing a spherical tipped stylus (b) towards the top of the groove as at (c) — described as "pinch" effect.

play a stereo record, should have sufficient vertical compliance in the stylus suspension to allow it to track the vertical modulation, and so avoid damage to the groove.)

Playback styli

In the '50s, the task of mass producing affordable, properly ground and polished jewelled styli, with a 25μm tip radius, was a daunting one but manufacturers learned to cope, first with sapphire and later with diamond, which is harder and more wear resistant.

With the introduction of stereo, and consequent closer attention to groove shape, it became desirable to use a tip radius smaller than 25μm, partly to ensure better tracking of fine (high frequency) groove modulation and partly in an effort to counteract "pinch effect", which can occur where the groove narrows, during lateral deviation of the wedge-shaped cutting stylus. (Fig.5a).

In traversing a narrow segment (c) a 25μm spherical-tip stylus can be forced up on the shoulders of the groove — a secondary consideration with mono cartridges but not with a stereo system, where vertical movement is directly interpreted as signal — in this case a spurious second harmonic.

In practice, a radius of 12.5μm (0.0005in) is about the minimum for spherical tips, because anything significantly smaller may allow the stylus to touch the rounded bottom of some grooves, resulting in noise due to debris, and/or distortion due to "skating" effects. Even 12.5μm is suitable only for cartridges able to operate with a very low tracking weight, because of accelerated tip wear and the risk of compressing fine groove serrations — described as "dynamic" distortion.

Nowadays, as a more forgiving figure for modestly priced spherical tips in modestly priced cartridges, most manufacturers favour a minimum radius of about 17.5μm (0.0007in).

Multi-radius styli

Seeking a more effective answer to both pinch effect and tracking problems, designers subsequently came up with the bi-radial or "elliptical" concept — the first step towards a 3-dimensional contour more closely resembling a recording cutter.

Viewed from the front (Fig.6a) a stylus of this general type has a major radius in the range 15-23μm, but with possible slight modifications to increase the contact line up the groove walls, and/or to keep the tip well clear of the bottom.

From above, the section within the groove is a slim oval (Fig.6b) with shoulder radii in the range 2.5-5μm, resulting in a stylus less prone to pinch effect and also better able to follow high frequency groove modulation — therefore exhibiting lower "tracing" distortion.

To take proper advantage of the elliptical contour, manufacturers adopted the practice of so arranging the stylus suspension that the axis of stylus movement and the alignment of the stylus shoulders was tilted forward relative to the vertical by a uniform 15 degrees — a figure later amended to 20 degrees. This is now an industry standard for the so-called "vertical tracking angle", observed by cartridge and record manufacturers alike.

The "Shibata" stylus, especially devised for the abortive 4-channel CD-4 system, pioneered the technology for a whole range of even more specialised styli, with small radius shoulders but a front profile intended to fit more snugly against the sides of the groove, as illustrated in Fig.6c.

High performance styli of this general type are variously described as "line contact", "lineal contact", "fine line", "contact line", &c, and they may be produced in diamond tipped form (Fig.6d) or as "nude" or "naked" (whole) diamonds (6e). But they have one thing in common:

The more specialised their shape and the more critically they exploit groove fit, the more vital it is to ensure that there is no misalignment in terms of either left-right tilt, or vertical tracking angle. Tracking weight is also important because it can affect the "set" of the stylus cantilever and thereby alter the vertical tracking angle.

Having in mind that the styli are almost too small to see, it is not difficult to appreciate that such requirements place extreme demands on the precision of the cartridge and playing arm, and on the operation of the mechanism as a whole. It is on this kind of precision that the performance of a top quality record player depends.

Frequency characteristic

In the recording process, the groove is normally inscribed in the surface of the master disc by a magnetic cutting head, as implied in Figs.3&4. The signal(s) to be recorded are fed to windings which are part of a magnetic circuit in the head and the resulting field, varying in response to the audio signal(s), causes the stylus to vibrate in sympathy,

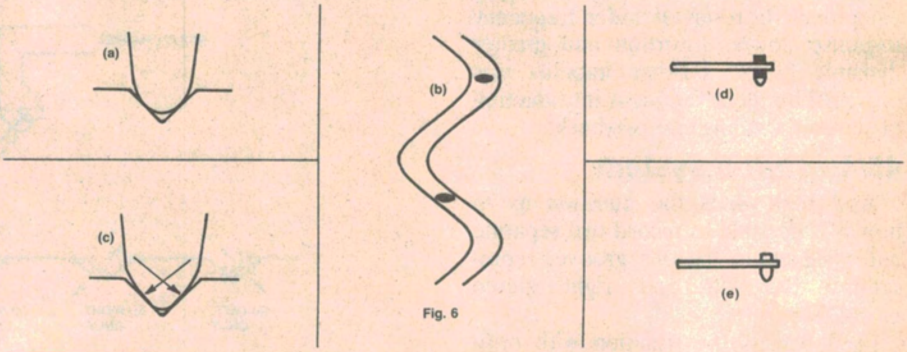


Fig.6: An elliptical stylus (a) largely overcomes pinch effect (b). Shibata or similar styli (c) provide a longer contact area with the groove walls. Styli may be jewel tipped only (d) or "nude" (i.e. whole) diamonds (e).

modulating the groove as it is inscribed.

By nature, a magnetic recording head exhibits what is termed a "constant velocity" characteristic, such that the amplitude of the groove modulation tends to vary inversely as the signal frequency. Double the frequency and the amplitude is halved; halve the frequency and the amplitude doubles.

Because this would lead to excessive amplitude at low frequencies and inadequate groove modulation at high frequencies, engineers normally modify the frequency response of the head drive amplifier(s) to counteract the constant velocity characteristic and so achieve a convenient level of modulation at all frequencies.

As a result all phono recordings have an intrinsic frequency characteristic which has to be taken into account in the replay system. A complete article could be devoted to the subject of recording characteristics used over the years but, fortunately, the vast majority of LP recordings conform to the "RIAA" (Record Industry Association of America) characteristic, either in its original or a slightly modified form.

In fact, a recording head compensated to the RIAA characteristic exhibits something fairly close to a "constant amplitude" response, producing a groove deviation which remains substantially constant with frequency. We shall be saying more about this later.

Phono cartridges

In the 78rpm era, the transducer components were often built into the actual pickup arm but, with the greater precision and higher expectations associated with fine groove records, the preferred approach was to mount them in a separate cartridge.

Over the years, phono cartridges have been designed around a variety of basic principles — Capacitor, FM, Magnetostriction, Optical, Semiconductor, Strain gauge, &c. but, while interesting in themselves, they attracted only limited support. Nowadays, the vast majority of cartridges fall into two main categories: piezo and magnetic.

Piezo cartridges

"Piezo", short for "piezoelectric", exploits the characteristic of certain (notably crystalline) substances to produce a voltage between opposite faces when subjected to pressure or stress. In a phono cartridge, the stress is provided by the stylus assembly, while the resultant voltages are sensed by tiny foils bonded to the relevant faces.

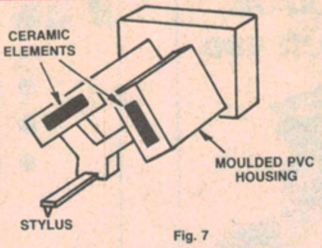


Fig.7: The physical construction of a typical ceramic cartridge — able to be mass produced reliably and cheaply but not well suited to true hifi requirements.

Early model piezo ("crystal") cartridges used tiny slabs of crystalline Rochelle salts. They were superseded by cartridges using specially processed barium titanate ceramic elements. While their output level was somewhat lower, they were much more durable, particularly at high levels of temperature and humidity.

Fig.7 illustrates one of many possible configurations for a stereo "ceramic" cartridge. A flexible suspension supports the stylus assembly, permitting the stylus to track the modulation while, at the same time, applying stress to the ceramic elements.

By nature, a piezoelectric cartridge exhibits a constant amplitude response, its output voltage being proportional to the amount of deflection, irrespective of frequency. Since, as noted earlier, an LP recording is recorded to a substantially constant amplitude characteristic, a ceramic cartridge will recover from it a substantially "flat" signal.

This makes it possible for a ceramic cartridge to be used without a frequency compensating preamplifier — but only in medium fidelity equipment. "Substantially" flat is not flat enough for a good quality system!

In addition, the need to perform "work" on the ceramic elements adds stiffness to the stylus movement, effectively reducing its "compliance". This calls for a fairly high playing weight to ensure that it tracks the groove and that, in turn, necessitates a more rugged stylus and assembly, leading to a higher effective tip mass, poorer transient response and the added likelihood of resonance effects in the passband.

Designers have made resolute attempts to compensate or otherwise upgrade crystal and ceramic cartridges to full hifi standards but without notable success. They remain a convenient medium-fi component although, even in that area, they are facing increased competition from mass produced magnetic types.

Magnetic cartridges

Essentially, magnetic cartridges involve a small permanent magnet, the components necessary to form a magnetic circuit, and the coils across which the signal voltages are developed.

Depending on the design, movement of the stylus may be transmitted to the magnet (MM, moving magnet system), to some element of the magnetic circuit (VR, variable reluctance) or to the coils (MC, moving coil). All have been used successfully in good quality cartridges.

All magnetic cartridges exhibit a constant velocity characteristic, such that the output signal voltage tends to vary

MM & VR magnetic phono cartridges — typical parameters

Weight of cartridge	3.5*-11gm
Equiv. stylus tip mass	0.3*-0.7mg
Rated frequency response	20Hz-20kHz/30kHz*
Freq. response tolerance	± 1dB*, ± 3dB.
Output, 1000Hz, 5cm/sec	2.0mV-5.0mV*
Channel separation, 1000Hz	20dB-30dB*
Channel balance, 1000Hz	1.5dB*-2.0dB
Dynamic compliance, 10Hz	20-40* μm/mN
Recommended tracking force+	10mN (1.0g)*-20mN
Load resistance+	47k-100k ohms
Total shunt capacitance+	200pF*-500pF

MC cartridges also, except for output impedance & voltage.
+ Follow manufacturer's recommendation.
* Denotes preferred end of quoted range.

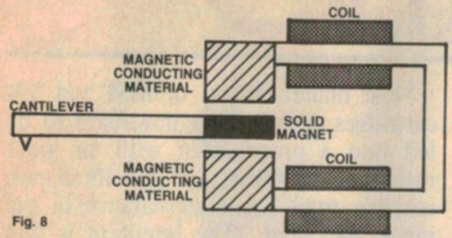


Fig. 8

Fig.8: Illustrating the moving magnet system. For simplicity, only one pair of coils, for one channel, is shown. The induced magnet system is an elaboration of this same principle.

directly with frequency: double the frequency and the output tends to double; halve the frequency and the output is likewise halved.

When playing an LP record, with its substantially constant amplitude characteristic, a magnetic cartridge will generate a signal with a rising treble and a falling bass response. Magnetic cartridges therefore need to be used with a compensated preamplifier — in fact, one exhibiting a response which is the converse of the RIAA recording characteristic. (See Fig.2b&c in the previous chapter).

Moving magnet system

Fig.8 depicts, in highly simplified form, the operation of an MM (moving magnet) type cartridge. A tiny magnet, mechanically coupled to the stylus cantilever, moves physically in the space between the pole faces, modulating the magnetic field and inducing signal voltage in the associated coils.

In a stereo cartridge, there are actually four pole faces and two magnetic circuits set at 90-degrees to each other and at 45-degrees with respect to the horizontal, respectively sensing modulation from the left and right groove walls.

The size of the moving magnet involves a compromise between output signal level, and the degree by which a more powerful (and heavier) magnet would increase the effective moving mass at the stylus tip. This could limit the response to transients and, as well, aggravate mechanical resonance effects.

The "induced magnet" concept offers a way around this difficulty by using a deliberately small or virtual moving magnet but supplementing its field with a powerful fixed magnet. While minimising the original problem, however, an extra magnet can add to the all-up weight of the cartridge, complicating arm resonance effects in the sub-bass region.

Variable reluctance

Fig.9 closely resembles Fig.8 but illustrates the variable reluctance approach, as expressed in Ortofon's VMS (variable magnetic shunt) type cartridge.

In broad terms, reluctance can be regarded as the equivalent in magnetic circuits of electrical resistance, limiting magnetic flux. An air gap in a magnetic circuit introduces considerable reluctance; modifying the air gap in a periodic fashion will vary the reluctance and

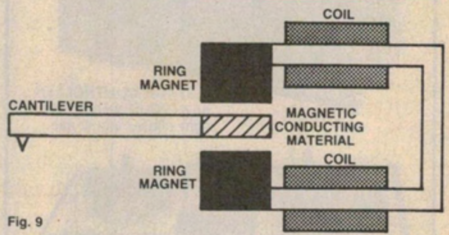


Fig. 9

Fig.9: In a variable reluctance cartridge, the magnet and coils are fixed but movement of part of the magnetic circuit modulates the magnetic flux, inducing a voltage across the coils.

therefore the flux, inducing voltages across the associated coils.

In the base of the VMS cartridge, a thin-walled armature of conducting material, attached to the cantilever, modifies the magnetic field created by a ring magnet, generating a signal voltage across the coils. Ortofon claim that their tiny tubular armature has less mass than a moving magnet, leading to improved high frequency and transient response.

Alternatively, in their MMC (Moving Micro Cross) variable reluctance cartridges, Bang & Olufsen (B&O) use a tiny flat armature attached at right angles to the end of the cantilever, and bridging the faces of four pole pieces on which are mounted the four coils.

Resonance, loading, &c

The natural resonance of the stylus system in moving magnet and variable reluctance cartridges is usually somewhere in the range of 15-25kHz. In terms of ultimate performance, the higher figure is to be preferred but it comes at a price: exotic (and more costly) technology, involving both the cartridge and the associated player, and increased vulnerability to misuse.

In most affordable quality cartridges, a resonance somewhat below 20kHz is tolerated, but subject to both mechanical and electrical damping. Mechanical damping has to do with the design of the cartridge; electrical damping with the coils and how they are terminated.

Because the coils in a moving magnet or variable reluctance cartridge are fixed, they can involve a relatively large number of turns, in the quest for adequate output signal voltage. However, with a coil inductance of typically 500 millihenries consideration has to be given to the capacitance of the pickup output leads and the input capacitance and resistance of the associated preamplifier.

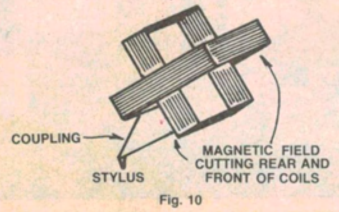


Fig.10: At the heart of a moving coil cartridge is a pair of coils driven by the stylus. In many MC cartridges, the stylus and cantilever are not user replaceable.

Most manufacturers of MM and VR cartridges design them nowadays to be fed into a preamplifier with an input resistance of 47kΩ, and specify a permissible total shunt capacitance in the range 200-500pF. The intention is that the electrical and mechanical characteristics should complement each other to produce an acceptably flat treble response.

Moving coil cartridges

At the heart of a moving coil cartridge is a pair of coils, as in Fig.10, to which is attached a cantilever and stylus. The coils are so positioned in a magnetic field that each one senses the modulation on a particular groove wall.

To minimise the moving mass, most MC cartridges use coils with a relatively small number of turns, resulting in low inductance, low impedance and only about one-tenth the output voltage of an MM or VR type cartridge.

With rare exceptions, MC cartridges cannot be fed successfully into the "Phono" sockets of a normal hifi amplifier. Early practice was to use them in conjunction with a special step-up transformer but the preferred method, nowadays, is to use a pre-preamplifier stage, either an outboard unit, or one built into the more deluxe amplifiers.

Over the years, MC cartridges have built up a virtual "cult" following, which credits them with a unique "sweetness" and "openess". In terms of published performance parameters, however, they differ little from the other types, except in respect to the output arrangements.

Magnetic fields

Last but not least, two matters should be mentioned which are common to all magnetic cartridges.

Since they involve magnetic circuits and coils, they are sensitive to stray external magnetic fields, especially those from unsuitable mains energised turntable drive motors. One mark of a well designed cartridge is effective internal shielding to isolate it, as far as possible, from external magnetic fields from any source.

The other point has to do with the field from the cartridge's own internal magnet. It is important that the cartridge does not interact with external ferrous components, if only because it can affect the playing weight when used with a ferrous turntable.