Acoustic breakthrough in record players

Measuring their susceptibility to sound feedback from loudspeakers

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In domestic audio equipment the phenomenon of acoustic interference with record reproducers from associated loudspeakers is well known, but very little effort has been made to measure the effect. This article describes a test procedure for quantifying the sensitivity of record players to acoustic breakthrough and presents the results as a range of measurements made under various operating conditions (dust cover up or down, different record support mats etc.). Next month the author suggests a simple test for acoustic breakthrough that can be done in the home without laboratory equipment.

IT HAS long been appreciated that a pickup/tone arm/turntable combination could be acoustically excited by the signal from a loudspeaker and under suitable conditions induce self-oscillation in a record reproducer system. Indeed this was one of the reasons for the demise of the radiogram. The use of a single enclosure to house all the components brought the turntable into close proximity to the loudspeaker and it became difficult to avoid self-oscillation due to acoustic and mechanical feedback. However as far as the writer is aware there were no efforts to quantify the sensitivity of turntables to acoustic pick-up until the publication of a *Hi Fi Choice* survey of turntables and cartridges in 1977.

Our laboratory recently became involved in some assessment tests on several record players and these necessitated an investigation of the relative susceptibility of the various designs to acoustic feedback. This in turn required an investigation of the test technique used to assess the susceptibility and to confirm that the results obtained were not influenced by conditions external to the equipment being assessed. The tests provided much information of sufficient interest to be worth wider discussion.

The assessment technique used for the *Hi Fi Choice* survey was not described in detail, but in outline it took the obvious form of exposing the turntable assembly to the pink noise acoustic output of a loudspeaker and plotting the amplifier output voltage as a function of the excitation frequency with the pickup stylus resting on a stationary record. It was shown that turntable designs vary widely in their sensitivity to acoustic pick-up and that some of the less satisfactory designs were as much as 20dB more sensitive to pick-up than the models where the designer had obviously given some considerable thought to the problem of isolating the pickup and turntable from the loudspeaker. A typical noise induced voltage/frequency response curve taken from the publication is reproduced in Fig. 1 as an indication of the results obtained.

The mechanism by which the noise-induced voltage becomes a problem is easy to follow. Any relative movement of pickup stylus and the record surface due to vibration will generate a noise voltage at the vibration frequency, and this after passing through the amplifier, will be radiated by the loudspeaker either as noise or vibration. Some fraction of this will reach the pickup stylus. If the acoustically excited voltage from the pickup, increased by the amplifier system gain and reduced by the signal attenuation between the loudspeaker and the pickup stylus, exceeds the initiating voltage, the system will burst into self-oscillation. This is the feedback amplifier stability equation in simple words. An amplifier having a gain of g with the feedback ratio of k will be on the verge of instability when gk in the simple gain equation:

$$\text{gain with feedback} = \frac{g}{1-gk}$$

exceeds unity

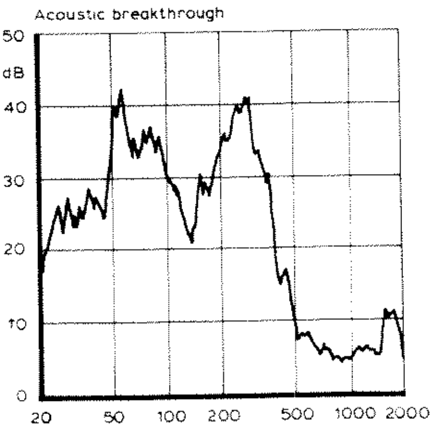


Fig. 1. *Acoustic breakthrough as illustrated in the Hi Fi Choice survey of turntables and cartridges in 1977. Turntable assembly was exposed to acoustic pink noise from a loudspeaker.*

The denominator is then zero and the gain rises to infinity.

The section of the signal loop providing the gain extends from the pickup through the amplifier and up to the current in the speaker voice coil. From that point onwards the signal is reduced by the inefficiency of the conversion from current variations in the voice coil to air pressure changes in the room and by the attenuation of the air path between loudspeaker and turntable. Mechanical vibration from the loudspeaker is attentuated along the parallel path for vibration through the speaker fixings into the speaker enclosure and from this through the supporting table and into the record player and hence up to the stylus tip.

When designing an amplifier with negative feedback the complex forms of both the gain and attenuation paths have to be considered in determining the stability margin, but where, as in the present example, the feedback path includes the room acoustics, the phase of the signal in the feedback path from loudspeaker to stylus tip cannot be controlled or predicted and oscillation is likely to ensue at any frequency at which the product of gain and attenuation approaches unity.

However, it is probable that the subjectively acceptable limit to the effect on sound quality of this feedback will be reached long before sustained oscillation actually occurs. The approach to continuous oscillation is marked by the appearance of a peak in the frequency response of the system and this colours the sound in exactly the way that the presence of any form of resonant circuit adds its own characteristic colour to a signal. This is nicely illustrated by the curves of Fig 2. The lower curve is the frequency response of an ordinary amplifier and it is seen to be flat within about ±1dB from 20Hz to 20,000Hz. The addition of sufficient positive feedback to bring it within about 5dB of sustained oscillation is seen to produce a peak of about 30dB in the frequency response at the frequency at which the amplifier would burst into oscillation if the feedback was further increased.

A system having such a small margin of stability that it is nearing continuous oscillation will have an overload performance that varies continuously with change in the programme spectrum. Each time there is a burst of programme

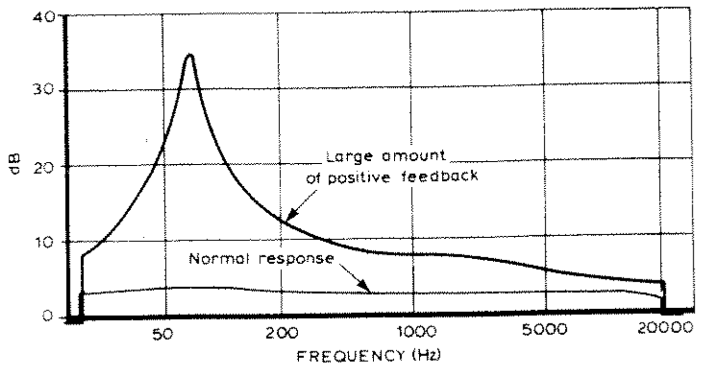


Fig. 2. *Frequency response of an amplifier with heavy positive feedback (upper curve) and without it (lower curve).*

energy in the vicinity of the peak in the frequency response, the amplifier may overload even though the signal amplitudes in other frequency regions are very far from overloading the amplifier. When the burst of programme energy around the peak frequency subsides the performance will revert to that of a system having a flat frequency response. The effects are broadly similar to those obtained when using an amplifier with a bass boost of 30dB. There is a subtle difference in that the bass boost obtained through feedback between the turntable and loudspeaker has a built-in time delay before it is operative. Thus a sound in the programme at the frequency of the peak will be followed by an echo delayed in time by an amount proportional to the spacing between loudspeaker and record player and to the amount by which the reproducer system fails to reach continuous oscillation. This time delay was clearly audible in the listening tests.

The 'noise' voltage that is induced into the pickup by the sound field of the loudspeaker, or by the transmission of vibration from the speaker to the pickup, is a function of the relative movement of stylus tip and record surface. It was initially thought reasonable to assume that the amplitude of movement of the record surface would greatly exceed that of the stylus tip, for the area of the record surface greatly exceeds the area of the tone arm and pickup assembly. To a first approximation the mechanical force exerted on any surface by the acoustic wave is directly proportional to the area of that surface. This neglects such factors as the shape of the surface and the variation in the phase of the incident acoustic wave over the turntable surface, but these are not really relevant in practice.

Acoustic excitation of the turntable and record occurs as a direct result of the mechanical forces exerted on the pickup and turntable enclosure by the sound wave from the loudspeaker, but there may be indirect effects due to acoustically excited vibration of the surface on which the record player stands. These surfaces, such as a table or set of shelves, will be excited into vibration by the incident acoustic wave or by direct mechanical transmission of vibration from the loudspeaker, and the resultant vibration of the table will be transmitted into the record player through the feet on which the unit stands. As the surface area of the shelf or table may greatly exceed the area of the record player the resultant vibration of the table surface transmitted into the player may exceed the amplitude of the vibration directly induced into the turntable by the same acoustic wave.

It is illuminating to consider the multiplicity of resonant elements involved in the simplest situation where the turntable motor and arm are assembled on a single motor board resiliently isolated by springs or rubber from the body of the player unit, which in turn is resiliently isolated from the table or shelf on which the units stand. It is assumed that the system is energised by a pink noise signal from the loudspeaker.

The surface of the turntable and motor mounting board and the unit enclosure will be subject to a driving force due to the impact of the acoustic wave on the turntable surface and on the box in which the turntable system is mounted. We started by assuming that the energy spectrum of the sound field incident on the record player is that characterising pink noise, equal energy per octave band, but the spectrum of the resulting vibration at the stylus tip will almost certainly be widely different. Any mechanically reasonant element in the path along which vibration is being transmitted will colour the signal by tending to concentrate the vibrational energy into bands centred on each resonant mode. The degree to which the energy is concentrated is a function of the Q of each resonant mode, but it also depends upon the length of time that the excitation persists. Resonant elements with high values of Q will require relatively long times to achieve their final amplitude and equally long times for the amplitude to decay to its normal level when the excitation is removed. Each resonant element in the path between the voice coil current and the stylus tip will add its own characteristic colouration to the signal.

The turntable itself will exhibit the resonances inherent in a circular disc, each resonant peak having a Q determined by the construction adopted for the turntable. A single simple circular metal plate will have many resonances of very high Q but a turntable consisting of two separate pieces of metal clamped together will have higher internal frictional losses and a lower value for Q. The addition of a mat to the table may also damp the resonances in the disk, any advantage so gained being a function of the quality and thickness of the mat and the degree of its adhesion to the table surface. The amplitude and frequency of maximum vibration of the turntable surface is a function of the distance of the pickup from the centre pin, but in addition to the resonant modes characteristic of a metal disc there will be others due to the turntable being supported only at its centre and thus free to rock about the centre pin.

The board carrying the motor and turntable will have the series of resonances characteristic of a rectangular plate, modified by the attachment of the motor to the board at several points. At all frequencies except that of the lowest mode of resonance, the point on the motor board at which the tone arm is fixed will move in and out of phase with the centre of the spindle. Thus at any given instant the tone arm base may be moving upwards while the turntable spindle and record surface are moving downwards or sideways.

The tone arm and cartridge assembly provides another group of resonances. The long section of the arm will exhibit both longitudinal resonance and torsional resonance with the rear section of the arm having similar modes of resonance but at other frequencies. There are other modes due to the resonant combination of the vertical compliance of the pickup and arm assembly and the effective mass of the arm. In consequence the movement of the stylus tip is unlikely to mirror the movement of the tone arm base, or that of the motor board to which the tone arm is fixed. The presence of the tone arm and mounting pillar between the motor board and stylus radically alters the frequency spectrum of the vibration at the stylus.

The resilient feet used to isolate the turntable from the table or shelf on which it stands will introduce a prominent peak into the vibration transmission path at some low frequency determined by the compliance of the resilient feet and the mass of the whole turntable unit. As will be shown by the tests to be described, acoustically induced mechanical vibration in the table or shelf on which the player stands is often the major cause of serious colouration of the signal from the turntable unit. Finally there is the colouration introduced by the presence of the many acoustic air resonances that are characteristic of every room. In addition to the direct colouration of every sound in the room these acoustic resonances determine to a large extent the attenuation of the path between loudspeaker and record player and the frequency at which the maximum excitation of the record player occurs.

In addition to the basic modes of resonance outlined in the previous paragraphs there are interactions between many of the modes of movement and these interactions result in very complicated patterns of vibration and modulation of the basic modes. In total there may be several tens of resonances in the acoustical and mechanical path between the loudspeaker and the stylus tip.

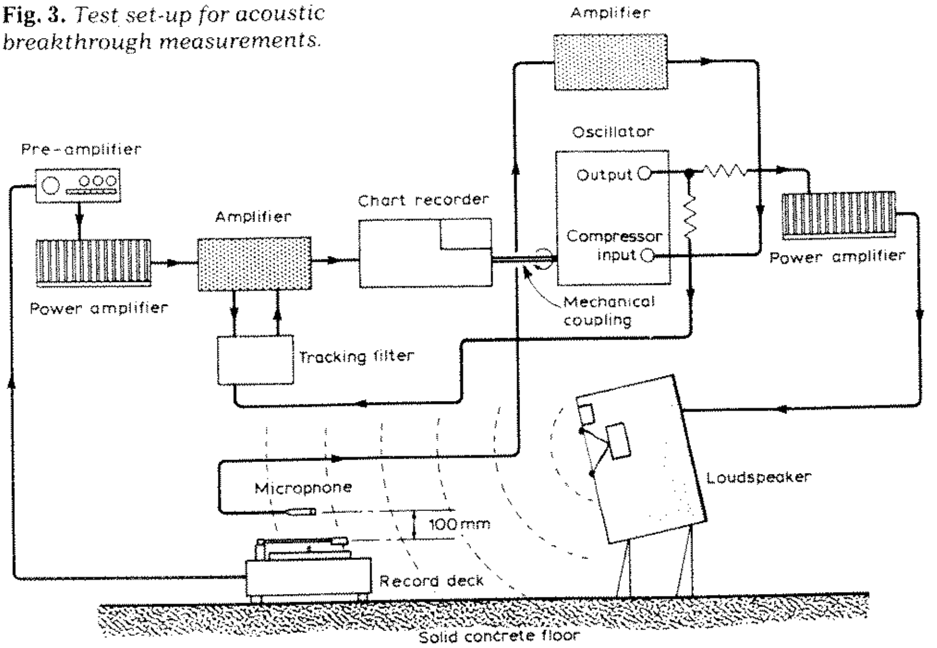
This all sounds very alarming and the question that springs to mind is: "Just how serious are the effects of all these parasitic vibrations on the sound output from the pickup?"

The experimental procedure adopted to provide objective data on the extent of the trouble was nominally straightforward. In the initial tests the turntable being investigated stood on a laboratory table, having a top 40 inches by 28 inches and incomparably stiffer and more rigid than any shelf system likely to be used in domestic conditions to support a record player unit. A wide range loudspeaker, an Eagle Type 7600 having a particularly flat frequency response, was used to provide acoustic excitation. This was driven by a Quad 405 amplifier from a B & K Type 1014 sine wave signal generator, but as it is necessary to ensure as far as possible that the acoustic signal has constant amplitude at the surface of the turntable, a feedback loop was installed to control the signal generator output, the control circuit microphone being supported at a point about 100mm above the turntable centre pin. This control loop takes out all the peaks and dips due to variations in the loudspeaker output and due to the standing waves that exist in any enclosed space.

The pickup output was amplified and given RIAA correction in a Quad pre-amplifier and then used to drive a B & K high speed chart recorder mechanically coupled to the 1014 signal generator that provided the drive signal for the loudspeaker. This combination of instruments provided printed charts of the acoustically induced voltages as a function of the exciting frequency. A block diagram of the test equipment is shown in Fig 3.

A typical acoustically induced response curve provided by this equipment is illustrated by Fig 4. The top of the chart (not shown) corresponds to 50dB on the vertical scale, and this corresponds to the signal output from a 5cm second recording of a 1kHz tone. The curves are those obtained when the sound pressure level was held by the control system at a level of 90dB at a point 100mm above the centre pin. However, it should be remembered that the ratio of signal-to-acoustically-induced-noise is independent of the level of the signal on the record that induces the "noise" voltage. A separate check showed that there were no significant amplitude dependent effects, the acoustically induced noise voltage from the pickup decreasing by 10dB each time the loudspeaker drive voltage was reduced by 10dB.

Fig. 3. *Test set-up for acoustic breakthrough measurements.*

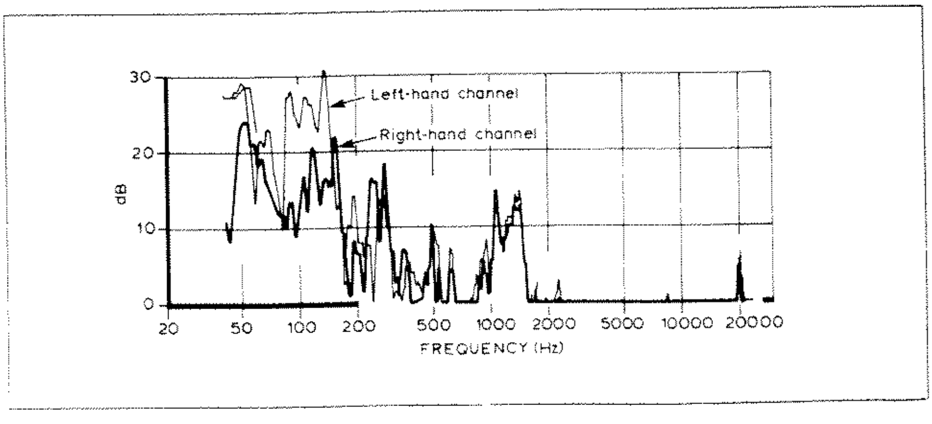


It will be seen from Fig. 4 that there are many prominent peaks in the induced noise voltage at frequencies up to about 300Hz with another group of resonances between 1000Hz and 1500Hz, the peak in the region of 50Hz being some 23dB below the level of the 1kHz reference signal. This chart, Fig 4, also illustrates another feature; in almost all the units tested the noise induced signal in the left hand channel was found to be greater than the signal induced into the right hand channel. Comparison of Fig 4 with Fig. 1 demonstrates the advantage of using sinusoidal tones rather than pink noise as acoustic excitation.

Figures 5 to 7 illustrate an interesting series of results taken while the test set-up was being verified. In Fig 5 the upper curve was obtained with the dust cover lid to the player in the 'up' position while the lower curve resulted when the lid was closed. It will be seen that closing the lid had little effect upon the breakthrough voltage at the lower frequencies, but effected a very significant reduction in the frequency band between 1 and 1.5kHz. This cover was one of the now almost universal Perspex type moulded lids and it is clearly too light in weight to exclude the low frequency components in the acoustic noise.

Fig. 6 compares the breakthrough with the turntable stationary and with it revolving normally, and it will be seen that there is no significant difference. An Audio Technica AT 12XE pickup

Fig. 4. *Example of acoustic breakthrough measurement on a record player made with the Fig. 3 set-up. The top of the chart (not shown) is at 50dB on the vertical scale, and this corresponds to a reference level of the signal output from a 5cm/s recording of a 1kHz tone. Note the difference in breakthrough between the left-hand and right-hand channels. The pickup is in the centre of the record.*



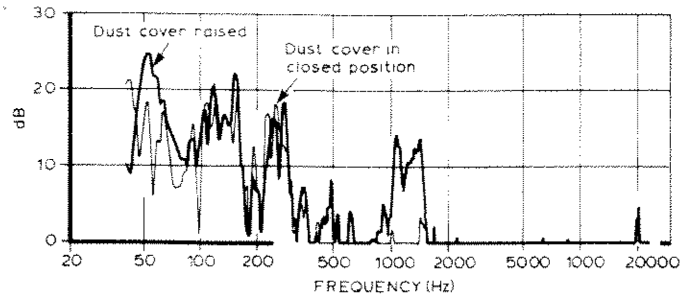


Fig. 5. *Breakthrough in the right-hand channel of a record player with the dust cover raised and in its closed position (50dB = ref. level of 5cm/s at 1kHz).*

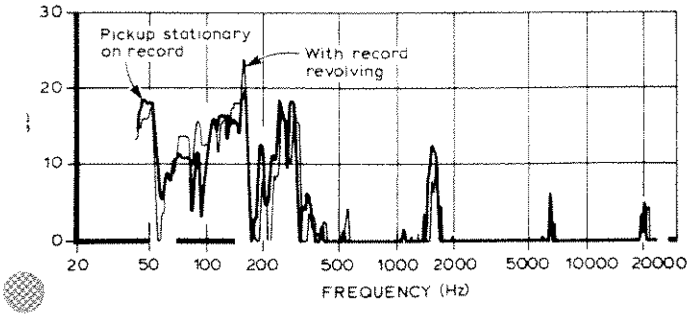


Fig. 6. *Measurements on right-hand channel comparing breakthrough with turntable revolving and breakthrough with turntable stationary (50dB = ref. level 5cm/s at 1kHz).*

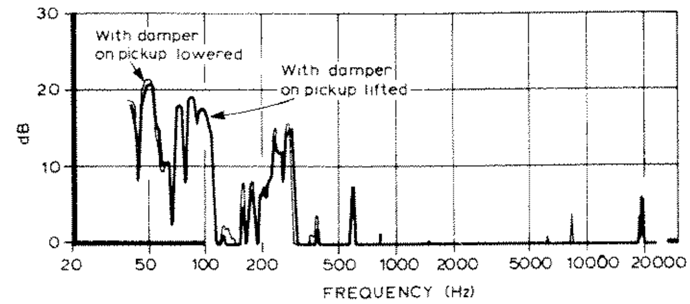


Fig. 7. *Breakthrough in right-hand channel with pickup damper lifted and damper lowered (50dB = ref. level 5cm/s at 1kHz).*

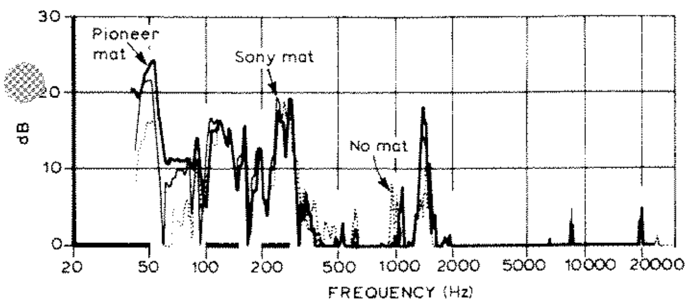


Fig. 8. *Effects of record support mats on breakthrough in right-hand channel (50dB = ref. level 5cm/s at 1kHz).*

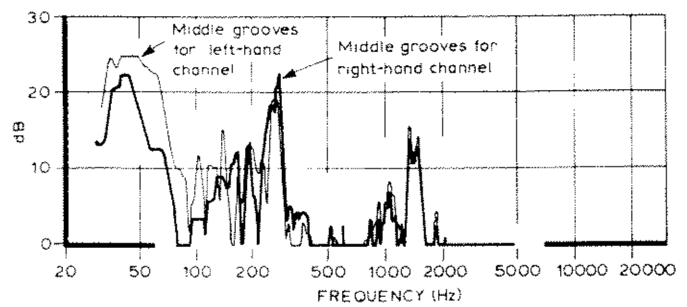


Fig. 9. *Breakthrough when turntable and loudspeaker are both mounted directly on a solid concrete floor. Results for right- and left-hand channel outputs with pickup on middle grooves (50dB = ref. level 5cm/s at 1kHz).*

was used for these preliminary tests, but to check the effect on the acoustic breakthrough of using a damper near the stylus tip a Shure V15 Mk4 pickup was substituted and charts taken with the brush in contact with the record surface and out of contact. It will be seen from Fig. 7 that the brush makes no significant difference to the acoustically induced voltage but Shure claim no advantage in this respect, the brush being added to reduce electrostatically induced charges and to reduce the amplitude of the low frequency arm resonance. It achieves both of these results.

In recent months there have been many claims to the advantages in terms of sound quality of using various types of special record mat, so as a matter of interest we tested about six different types of record support pad or mat that we happened to have available. These mats had many different rib patterns and included mats cut from pieces of soft foam and soft felt, but the differences were only of the order of those obtained by repeating the test on any one type of mat. It is reasonable to suggest that if the design, construction or material of a turntable mat does indeed produce significant differences in sound quality then it is unlikely to be due to their effect in reducing the amount of turntable vibration transmitted to the record surface. Fig 8 illustrates the differences between three of the types of mat we tested.

The first major reduction in the level of the acoustically induced noise appeared when the turntable under test and the exciting loudspeaker were mounted on separate supports, or were both mounted directly on a heavy concrete floor. Figs 4 and 9 illustrate the advantage. Not only did this reduce all the peaks by about 10dB but it substantially eliminated most of the minor peaks above 300Hz. If Fig. 9 is compared with Fig. 4 it will be seen that the improvement is radical, so much so that any method of assessing the amount of acoustic breakthrough must specify that the turntable and exciting loudspeaker are to be mounted on a solid concrete block, or on a solid concrete floor during the test. Standing the units on a timber floor greatly reduces the value of the data and may invalidate the conditions.

It is impossible to reproduce all the data obtained on the many turntables that were tested, but some general conclusions are interesting. In an early paragraph of this contribution it was pointed out that the induced noise voltage generated by the pickup was a function of the stylus velocity and that it should be the same whether the stylus vibrated against a stationary record or the record surface vibrated the stylus in a stationary pickup head. In all the turntables tested the pickup voltage appeared to result from vibration of the pickup against a relatively stationary record surface, vibration from the motor board being transmitted up the tone arm fixings and along the tone arm to the pickup. This is contrary to our first thoughts on the subject. It was earlier noted that wide changes in the softness of the turntable mat had relatively little effect on the noise induced voltage and this is one result to be expected if the pickup is moving with respect to the record surface.

As the evidence suggested that vibration of the tone arm was mainly responsible for the peaks in the acoustically excited frequency response, an attempt was made to separate the peakiness introduced by acoustic excitation of the record player enclosure from the peaks due to resonance in the tone arm. The arm was removed from the record player and mounted on a Goodmans vibration table driven by a separate amplifier and control loop system set to maintain constant the velocity amplitude at the base of the tone arm. The exciting frequency was then swept through the audio range and the RIAA corrected pickup output plotted by the B & K high speed chart recorder. This produced the chart of Fig. 10. It will be seen that this particular arm system introduced two major peaks in the response at frequencies around 60Hz and 250Hz plus a good deal of hash at all frequencies below about 100Hz.

It is interesting to compare this curve with that shown in Fig. 11, the acoustically excited response of the same tone arm system when mounted in the record player. The same two prominent peaks are present at 60Hz and 250Hz but with considerable extra noise produced by the acoustic excitation of the record player housing, particularly at frequencies above about 400Hz where there is little sign of trouble from the pickup arm alone.

Some of the undesirable effects on the sound quality of these acoustically excited peaks have been discussed earlier in the contribution but there are other effects that are equally undesirable. Prominent resonances in the tone arm when acoustically excited by the sounds from the loudspeaker are likely to result in modulation of the signal being reproduced from the record, for the contact of the stylus with the groove is being continually modified by resonant vibration of the arm. Thus any recorded signal is likely to be amplitude modulated at the frequency of these arm resonances. This suggestion was checked experimentally, the results being illustrated by Figs. 12 & 13. The first chart shows a spectrum analyser picture (narrow band analysis from 2kHz to 4kHz) of a 3kHz recording replayed without any signal being applied to the loudspeaker. Thus there can be no acoustically excited distortion and it will be seen that the general random noise is some 50dB below the peak signal. Fig. 13 is a repeat of the same recording when a 250Hz 95dB tone is reproduced by the loudspeaker. It will be seen that two sidebands have appeared having an amplitude about 25dB below the peak signal amplitude due to modulation of the recorded signal by the acoustically excited resonance in the tone arm.

To be continued

Fig. 10. *Vibration test on tone arm alone. Right- and left-hand channel outputs with pickup on solid object and constant velocity maintained at base of arm.*

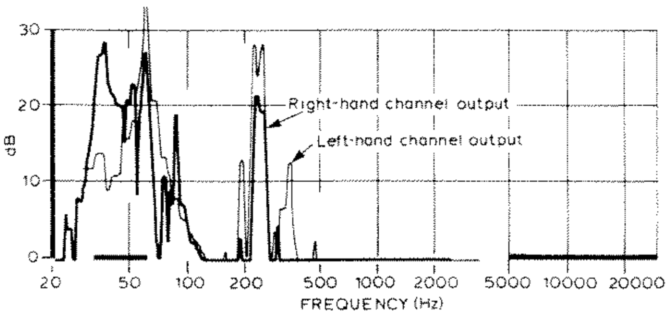
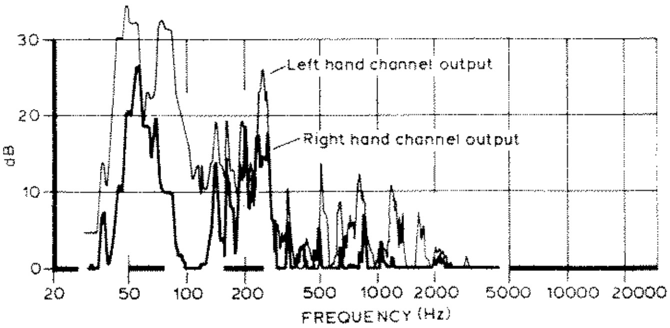


Fig. 11. *Breakthrough with same tone arm system as in Fig. 10 mounted in record player. Right- and left-hand channel outputs with pickup on middle grooves (50dB = ref. level 5cm/s at 1kHz).*



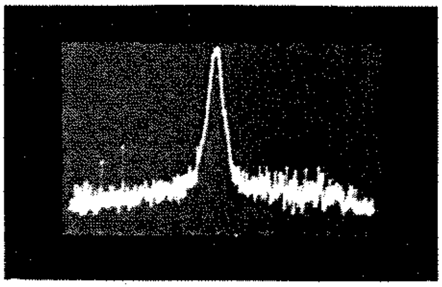


Fig. 12. *Spectrum analyser picture of 3kHz recording replayed without any signal being applied to test loudspeaker (30Hz bandwidth analysis 2kHz-4kHz).*

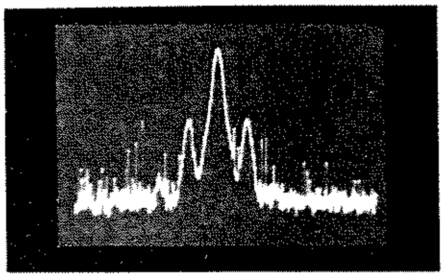


Fig. 13. *Same spectrum analyser test as in Fig 12 but with a 250Hz, 95dB tone coming from the test loudspeaker.*

References

Turntables & Cartridges. *Hi Fi Choice*, 1977.
Audible Effects of Mechanical Resonance in Turntables. Poal Ladegard of B & K. A.E.S. Convention Paper. 1977

Literature Received

V.h.f., u.h.f. and microwave (4GHz) **ceramic chip capacitors** made by Vitramon and specified in a leaflet, obtainable from Vitramon Ltd, Wycombe Lane, Wooburn Green, High Wycombe, Bucks HP10 0HH. WW 401

Data sheets on T and B Ansley **flat cables** and connectors, and associated components are distributed by Sasco, P.O. Box 2000, Crawley, Sussex RH10 2RU. WW 402

Switched-mode **power supplies** and regulators made by Lambda are described in two leaflets, LSS and LJ/LG, available from Lambda Electronics Co., Abbey Barn Road, High Wycombe, Bucks. WW 403

A leaflet on the Microdata M200 series of **data logging** equipment, designed for portable use, is available from Microdata Ltd, Monitor House, Station Road, Radlett, Herts WD7 8JX. WW 405

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The 1979 catalogue from Measurement Technology is available, containing information on **safety barriers** and intrinsically-safe power supplies, temperature transmitters and trip amplifiers, interface units and application papers. Sales Dept., Measurement Technology Ltd, Power Court, Luton, Beds LU1 3JJ. WW 407

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