This is an excerpt from The Needle-drop Handbook
by
Richard Brice

Published by Transform Media Ltd & Pspatial Audio

Machining noise - rumble in the grooves

Both McProud and Hirsch comment when measuring the best models in the tests above, that they suspected they had reached a baseline in their instrumentation and rumble was as low as they could measure with available test discs. The time was ripe to prove once and for all that the test records contained rumble which exceeded those of the best replay machines.

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[30] Turntables. Joseph F. Grado. Audio June, July, August, October 1977*. Joseph Grado was the president and founder of Grado Laboratories Inc. Now known for phono cartridges and headphones, in the 1960s Grado also produced some innovative tonearms and turntables.*

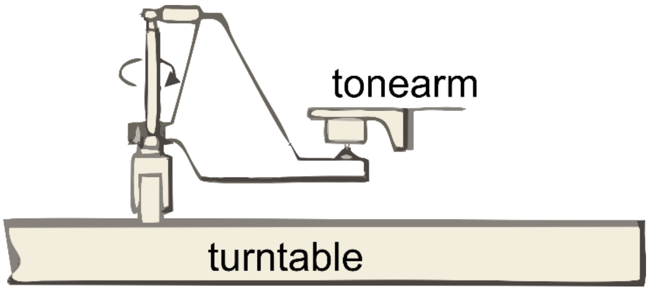
[31] Harrogate: the turntable war Wireless World, November 1977

An attempt was made by the turntable manufacturer Thorens (in fact, EMT-Gerätewerk in Lahr-Kuhbach) who invented a device named the *Rumpelmesskoppler* (*rumble measurement coupler* – illustrated right).

This rather whimsical contraption consists essentially of two elements: a central spindle; and a swivelling boom. Combined, they were conceived to sit on the rotating turntable instead of a test-record.

The Rumpelmesskoppler is used as follows.

The chuck and spindle of the central mandrel are tightened on the turntable centre-pin (with the knurled collet-chuck arrangement) and turn with the turntable. The boom is free to swivel around the spindle, as it is only coupled to the driven mandrel by a point-bearing at the apex of the boom and a half-sleeve-bearing on the shaft.



The reproducing stylus is placed on the tiny, black, PVC platform on the lower arm of the swivelling boom-frame (see diagram left).

By ensuring that the central axle has a very high degree of finish and by employing very low friction polymer bearings, the downforce of the cartridge stylus is enough to hold the boom platform stationary with the spindle rotating in the mandrel bearings.

These bearings are free enough from play[32] that they add little vibration of their own, but they couple any vibration of the turntable to the stylus. Used instead of a test record, rumble noise is measured as usual, but extraneous effects due to disc-recorded rumble are removed. (A test-record is still required, but only to set the alignment level against which the rumble-noise is calibrated.)

Thorens reported results of rumble tests using their Rumpelmesskoppler device which indicated that rumble-suppression in modern turntables greatly surpassed the performance of measurements taken using unmodulated test discs.[33] Their results are presented in Table 1.

[32] The bearings of the Rumpelmesskoppler are of self-lubricating plastic. The elastomeric qualities of the plastic allow a zero tolerance between the shaft and the bearing.

[33] Understanding Turntable Specifications. FELDMAN, L. Radio Electronics Feb 1980.

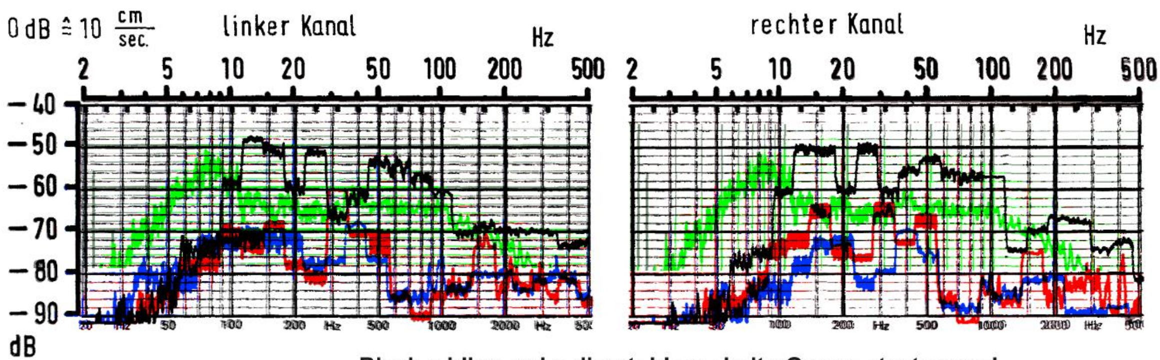
Table 1

Turntable	Test Record	Rumble Adaptor
High quality direct-drive	-48dB	-61dB
Thorens TD126 Mk III	-50dB	-72dB

Sadly, the *Radio Electronics* article, from which these results are taken, does not include a primary reference and only speaks of the information deriving from a “technical seminar at the Thorens’ works” (see January 1980 issue). The only other published work from Thorens regarding the Rumpelmesskoppler is in German.[34]

In truth, Thorens’ Rumpelmesskoppler results given at the marketing shindig reported in *Radio Electronics* were intended to demonstrate the superiority of their belt-drive turntables over the competitive direct-drive types which were slugging it out in the market at the time. Far removed from that squabble, which would continue for the rest of the life of the LP record as the principal carrier of commercial music, we can say that the figures indicate that the motor, torque-transmission and bearing noise of both direct-drive and the belt-drive type are five to ten times lower than the noise imprinted on the disc during master-acetate cutting. The rumble in either turntable type is indeed substantially lower than that imprinted on the test record.

The results of three turntable types tested by Ludvig Klapproth (using the Rumpelmesskoppler which he invented) are given below, along with the results from a test record.[35]



Black = idler; red = direct; blue = belt : Green = test record

And Klapproth says in the conclusion to this paper,

> *Dabei kennzeichnen die hier gezeigten Messdaten das hohe Qualitätsniveau der heute angebotenen Plattenspieler. Sie sind fast alle wesentlich besser als die zur Verfligung stehenden Schallplatten. (The measurement data shown here characterise the high-quality level of the turntables offered today. They are almost all of them much better than the available test records.)*

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[34] REIBRAD, RIEMEN, ZENTRALMOTOR - Eine Analyse von Plattenspielerantriebskonzepten anhand der Rumpelspektren (FRICTION WHEEL, BELT, CENTRAL MOTOR - An analysis of turntable drive concepts based on rumble spectra) Klapproth, L. Paper of the 47th Convention 1974-03-26/29 Copenhagen/Denmark.

[35] Op. cit. It was almost certainly Klapproth’s data which was presented at the Thorens’ seminar.

If, in normal use, the rumble noise limit is set by the medium itself, improvements in the replay system greatly beyond that limit are worthless; rather in the same way that improving preamplifier noise is pointless once it is substantially below the noise present on the source. To take a definition from the NARTB standard of 1953 where it says,

> *A record shall be considered rumble free if its rumble content is at least 8dB below that of the system being measured.*[36]

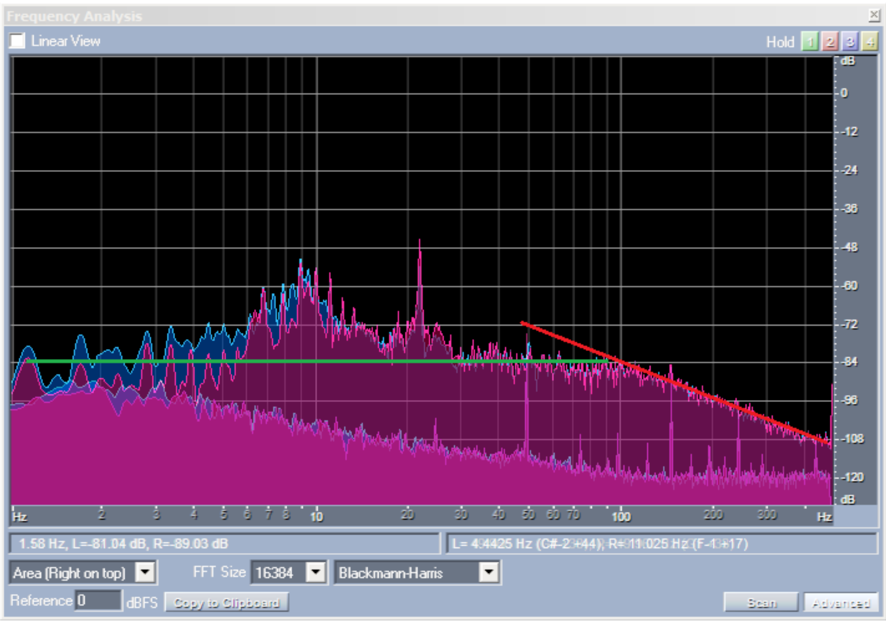
We can stand this on its head and say, *if the rumble content of a measurement system is at least 8dB below that of the record, the system may be considered rumble free*. This is the case for the belt- and direct-drive examples tested by Thorens.

In short, good belt-drive and direct-drive turntables are more than adequate to ensure their mechanical noise will not contribute significantly to the needle-drop noise. Both types face a common enemy: low-frequency noise imprinted in the record grooves themselves. How might we address this problem?

Mach ONE **– Machining noise reduction**

It's instructive to listen to the silent grooves of rumble test-records via various simple signal-processors.

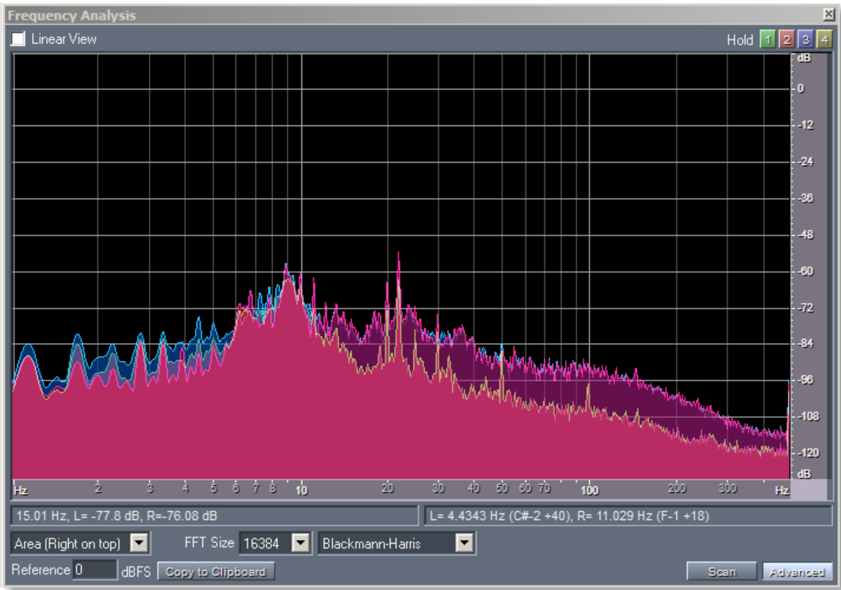
If an adjustable, sharp-cut high-pass filter is inserted, the first observation is that the "roar" with which we associate with turntable rumble disappears once the filter cut-off is above about 200Hz. The perceptible effects of rumble on discs are limited to a frequency-band from subsonic to about 200Hz.



36 NARTB Audio Recording and Reproducing Standards. Op. cit.

This is no illusion, if we look again at the recorded rumble from a test record (spectrogram above), we can see that, above 100Hz, the noise falls quickly – at 12dB/octave. Below 100Hz, the spectrum is more-or-less flat (ignoring the tonearm resonance effects around 10Hz and the recorded 22.5Hz spike). This is the region where most of the rumble-energy resides.

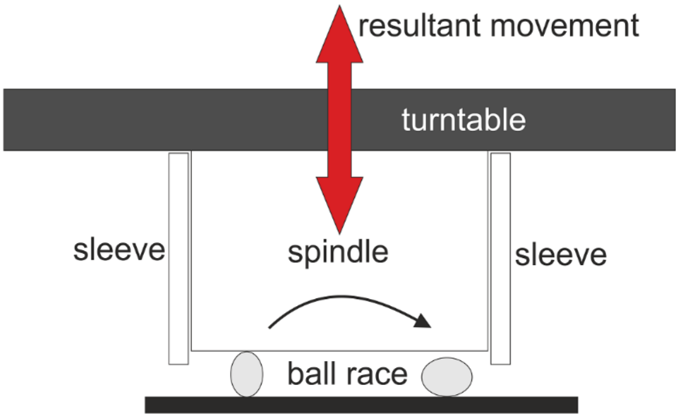
If we mix the channels, we discover that much of the recorded rumble is present on the *vertical* signal. If we mono the signal (and thereby listen to the *lateral* signal only), the perceptible rumble is greatly reduced. The same is not true if we listen the vertical, $[(L - R)/2]$ signal. This is clear in the spectrogram below in which the rear traces are of the raw rumble signal and the front trace is of the lateral signal only. There is a clear 12dB margin from the tonearm resonance to 200Hz.



From whence does this noise originate?

The wideband, vertical-component noise which is present on all test records (indeed, all records) is due to rumble in the bearings which carry the heavy platter of the recording lathe, see chapter six.

Necessarily massive and requiring substantial torque during the cutting operation, the lathe designer's job is very much more challenging than that of the turntable designer whose single bearing must only support a platter of a few kilograms and a torque sufficient to overcome the friction from a lightweight tonearm.



The basic turntable (the *headstock*) of a Neumann lathe weights 30kg**!** With a vertical bearing force of this magnitude, the simple, single ball-bearing (typical in a turntable) is not practical and a ball-*race* must be employed. It is impossible to impart on a race the same degree of finish possible with a single ball-bearing.[37]
The main bearing sleeve can be machined closely enough to constrain lateral movement of the turntable, so any unevenness in the ball-race will tend to resolve into vertical movement, as illustrated in the diagram above.

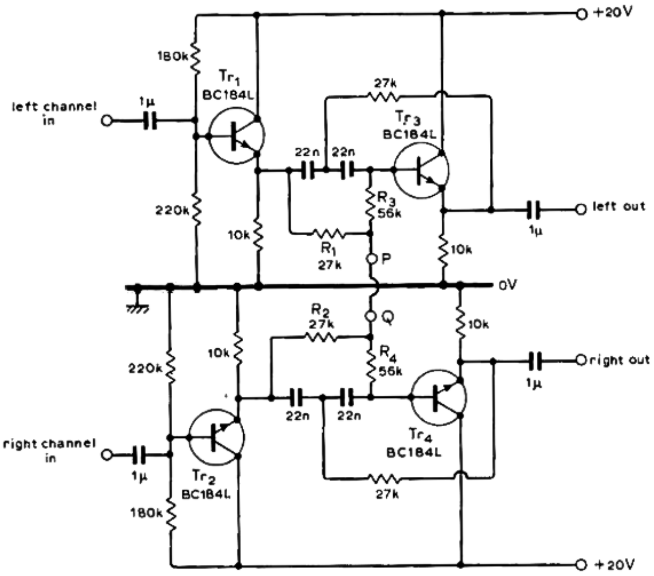
Additionally, because all lathes were conceived in the days of mono, lateral cut records[38], the vertical component of machining noise was long considered unimportant and the issue was never entirely addressed – even fully into the stereo era.

Accentuate the lateral: eliminate the vertical

Given the above, an approach to reducing the rumble noise of the recording lathe suggests itself. If we filter the vertical signal component recovered from a record, we can eliminate this element of the rumble noise.

Recalling that cutting an acetate is fundamentally an industrial machining job, we propose calling the vertical noise component extending from very low frequencies to around 200Hz, *machining noise* and name the noise reduction, *Machine Orthogonal Noise Elimination* or ***Mach ONE***.

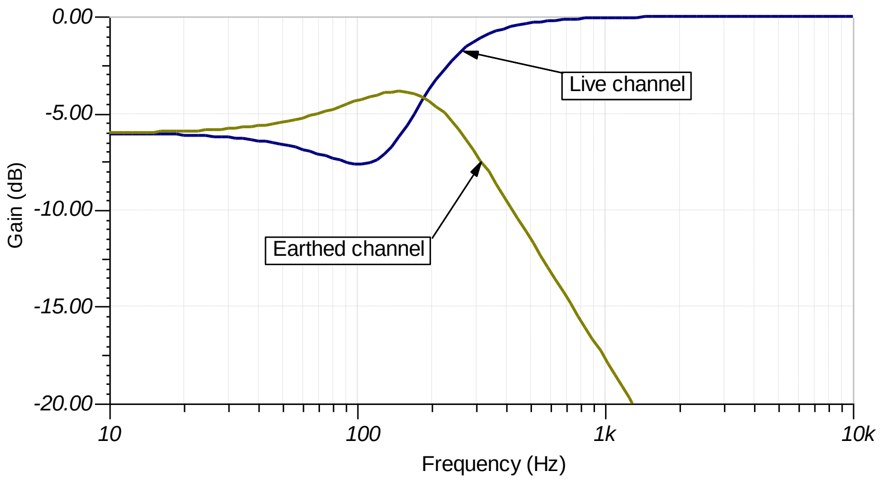
[37] In an interview with Larry Scully, the designer of the famous, American lathes which bore his name, he remembered that it was difficult to source a ball-race for the main, thrust spindle-bearing which produced little enough rumble that it did not leave a visible pattern on the disc itself. “A pattern produced by the vibrations. You could practically count the number of ball bearings by the pattern.” said Scully. Behind the Scenes. *Audio* November 1969.
[38] The fundamental mechanical design of the Neumann lathes (bed, main bearing etc.) remained substantially the same from the 1930s until the company stopped making lathes in the mid-1980s.



Of course, we are not the first to have considered this technique. The earliest reference we have is from Wireless World magazine *Circuit Ideas* from 1975; the very apogee of the vinyl record and firmly in the era of analogue electronics (shown left).[39]

Due to Oldfield, the circuit combines a pair of two-pole filters in such a way that the filtering action is applied to the instantaneous difference voltage between the left and right channel.

This circuit is representative of other analogue implementations and suffers from the limitation that – despite implementing two-pole filters – the practical filter responses are limited to 6dB/octave. Other authors have similarly failed to establish steeper filter responses or have resorted to considerable complexity to accomplish it.[40]



The transfer function to the two output ports is given in the graph (left). The inevitable non-constant group-delay response of this type of circuit leads to amplitude-response anomalies: in this case the 2dB "bump and dip" around 150Hz.

The baby and the bathwater

Don't we risk of losing wanted information along with the filtered noise when we filter the vertical component? Previous authors who have suggested cross-feed

[39] Stereo Rumble Filter. Oldfield, M. Wireless World October 1975.

[40] Non-intrusive Rumble Filtering by VLF Crossfeed with High Filter Slopes. Self, D. Presented at AES 140th Convention, Paris, France, 2016.

arrangements for rumble-reduction[41,42] have usually done so on the basis that nothing *important* is lost. For example, Oldfield argues,

> *Fortunately, as the human ear is not sensitive to directional information below about 400Hz, it is possible to remove the stereo (L -R) signal at low frequencies without losing stereo separation.*

We will not argue that here as *it is certainly incorrect*.[43] Instead, we will argue that, in the case of signal processing of gramophone records, the case need not be made, for the splendidly simple reason that little or no information is recorded in the vertical component of a record below about 200Hz anyway. Why? The answer lies in that most mysterious of circuits in lathe electronics rack: the *elliptical equaliser*.

Elliptical equaliser

Vertical modulation of the cutting stylus must be limited when cutting records because, if these modulations aren't carefully restricted, at the peaks of the wave the cutter chisel either digs so deep that it scrapes the aluminium substrate of the lacquer master disc or it produces a groove so shallow that the stylus slides out on playback. Out-of-phase information, or *excessive L-R information* is especially problematic because it causes these vertical movements of the cutter.

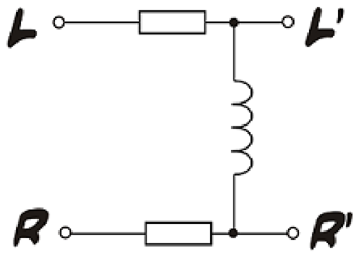
Mindful of the above, recording engineers are all taught not to plague their recordings with excessive energy in the channel-difference signal (bass and bass-drum are usually panned to the centre and so on). But large amounts of low-frequency channel-difference energy can arise due to operational oversights. For example, spaced microphones can respond to very low-frequency air-conditioning or traffic noise and, by dint of their physical spacing, result in excessive channel-difference information. The recording engineer, listening on small loudspeakers, may be completely unaware of the effect until the horror is unleased on the disc mastering team.

To contend with problems such as these, lathe electronics include a piece of equipment dedicated to eliminating vertical modulation below a certain frequency known as the *elliptical equaliser*.

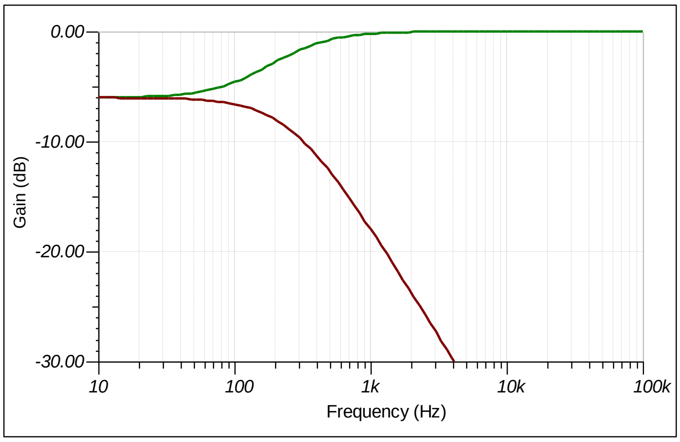
[41] Differential Rumble Filter. J P Macaulay, J.P. Circuit Ideas, Wireless World. Sept 1979

[42] Rumble Cancellation Filter. Langvad, J. Letters, Wireless World. Mar 1980

[43] Spatial Hearing. Blauert, J. MIT Press 1983. *There appears to be no lower frequency limit to hearing spatial lateralisation (headphone presentation). If a lower limit exists when the stimulus is presented over loudspeakers, it is due to reflections and standing-waves in the listening room - hardly a constant! Blauert provides data using loudspeaker presentation which certainly extends to 100Hz.*



This special equaliser (in Neumann' case, the EE66 or EE70) is a relatively simple device, at the heart of which are just three impedances (diagram above). The reactance of the cross-feed inductor is substantial at high-frequencies which ensures good channel separation. But, as the reactance of the inductor falls with reducing frequency, the channels separation is reduced until – at a theoretical zero-frequency, when the reactance of the inductor is zero – the resulting ***L'*** and ***R'*** signals are identical and no channel-difference information exits at all.



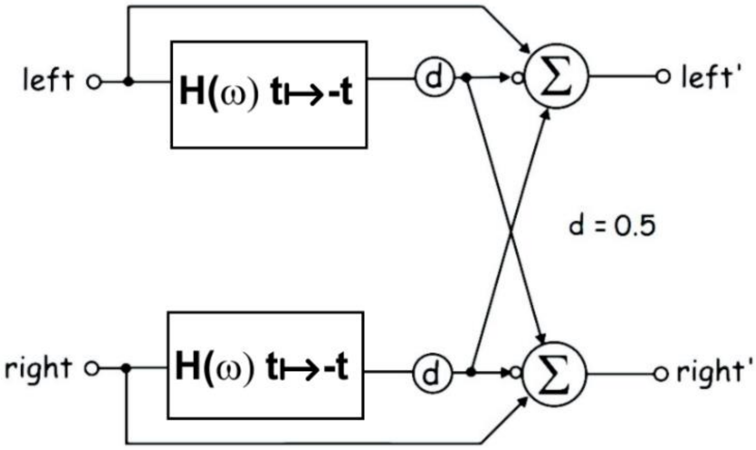
The default circuit values of the resistances and inductor in the Neumann equipment result in the transfer functions illustrated in the graph left (to both output ports, one input driven, the other grounded). They indicate the effect of the unit is not subtle.[44] The "live" channel is gradually attenuated below about 500Hz so that only a few dB of separation exists at 100Hz.

Given that this degree of vertical-signal filtering exists prior to disc recording, we are certainly justified in applying filtering on replay – especially so if we can make the replay filters steeper than those used on recording. In so doing, we eliminate the vertical noise component and do so *without jettisoning any recorded information*.

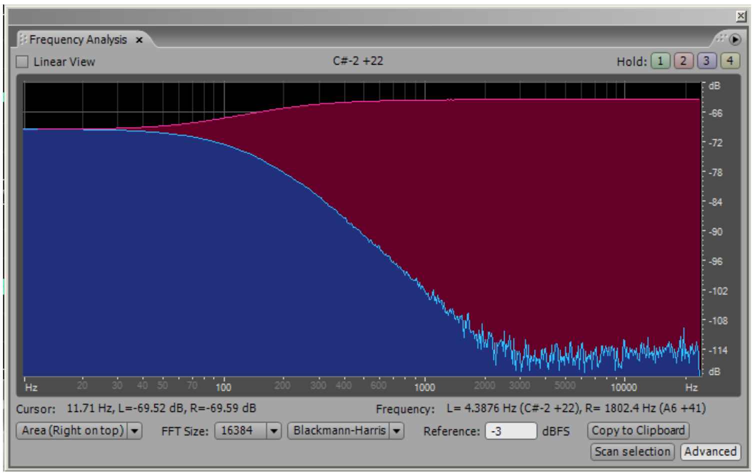
Time symmetrical

We benefit if the implementation of this noise-reduction is performed in the digital domain, because filtering duties may be made non-causal or phase linear. This is the approach we have taken in **Stereo Lab**. The structure of the noise reduction is illustrated below. The filters are two-pole (40dB/decade) types and are time symmetrical. The outputs of these filters are matrixed to produce the final left' and right' output.

[44] The Neumann elliptical equalisers do have a control whereby the series resistances may be reduced with switched relays so that the mono-ing effect of the equaliser commences at a lower frequency (150Hz). This less severe regime was selected when there was less troublesome low-frequency difference information in the source material.

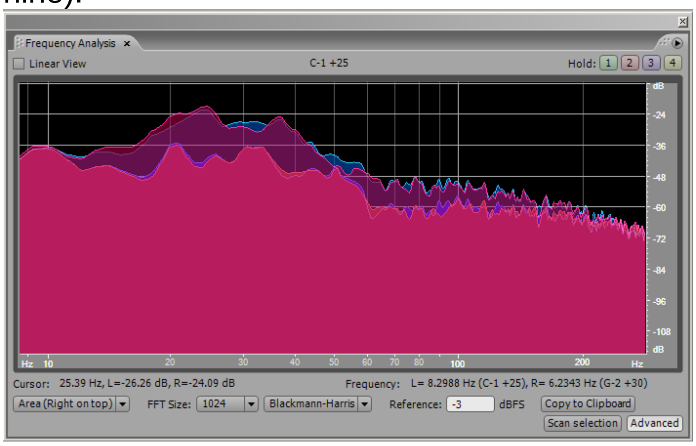


The transfer function of the **Mach ONE** process (live and non-driven channel outputs) is given (right). Not only is the filtering action clearly 40dB/decade (2-pole), but there are no frequency-response anomalies because the filters are linear-phase and their outputs may be matrixed with the original signals without complications.



Selecting Mach ONE

Mach ONE (**Mach**ine **O**rthogonal **N**oise **R**eduction) is configured by ticking the relevant option box in the phono settings dialogue. It is recommended as a default setting when processing raw needle-drop recordings for access copies (see chapter nine).



As the spectrogram left indicates, the **Mach ONE** process extends digital resolution by two bits (12dB) in the three-octave range between 20Hz to 160Hz. (The forward trace is with **Mach ONE** engaged.) Measuring the rumble performance according to DIN(A) or NAB, the unweighted rumble signal improves by 10dB to 18dB depending on the test disc employed.