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THE DISTRIBUTION OF SIGNAL AMPLITUDES IN RECORDED MUSIC

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INTRODUCTION

The story starts with the problems which beset any broadcaster who attempts to make the best of the available spectral space and dynamic range. Attention to these problems is accentuated by considerations, on the one hand, of the types of equipment used to carry the signal from the radio station to the transmitter, and on the other, by the apparent increase in the dynamic range and spectral content of current pop music recordings. Most of the discussions which result talk about the spectral density, signal probability, dynamic range and so on, but often without any data being presented. Where equipment intended to modify such parameters is proposed a practical selection might be made on the basis of some listening tests. However the technical arguments can only be well rehearsed when data is present. Indeed this data might suggest alternative directions in which attention might be focussed and it may well pose a few more queries than it attempts to answer.

Studies have, of course, been carried out in the past. D J Meares investigated the relationship between frequency and Sound Pressure Level's in sound control rooms [1] which have been updated by K E Randall [2]. Others have written on the statistics or the spectral content of sound signals [3,4,5]. More recently L G Moeller [6] has investigated the statistical amplitude differences between older and modern recordings.

Much more useful information can be gathered from the references but there still remains a gap where modern pop music and the radio broadcaster is concerned.

Amongst the developments in audio signal reproduction is the increasing acceptance of the Compact Disc (CD) medium. Amongst many attractions it offers a wide dynamic range and an ability to reproduce full amplitude signals up to 20kHz. It has been conjectured that its use within radio broadcast will increase and eventually it will supplant the conventional vinyl disc as the major music source. This is likely to have important consequences for the UK's Independent Local Radio (ILR) network most of which rely on pop music for the majority of their programming.

Modern pop music has been using synthesisers for some years. From the outset of its use fears have been aired because it has been thought that the ability that purely electronic instruments have to produce waveforms with frequency components at levels much greater than natural instruments would show up the limitations of prevalent reproduction equipment. For straight-forward record reproduction this does not seem to have happened. However it is far from clear that the conventional quality broadcast equipment chain may not suffer. The reasons for this lie in the need to provide pre-emphasis in the transmitter.

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This paper looks at the peak spectral response and amplitude distribution characteristics of some pop music. The effects of the standard 50us pre-emphasis with and without a limiter will be shown.

THE BROADCAST CHAIN

The usual signal path arrangements for the vhf transmitter of an ILR station are indicated in FIG 1. The signal from the studio centre will, in the main, comprise live microphone sources, cartridge tape sources and recorded music. It is usually the responsibility of the presenter to ensure that the level of these sources lies within sensible bounds. Guidelines have been laid down in terms of the signal level as monitored by a peak programme meter (ppm)*. For example, for uncompressed music, normal peaks in the range of ppm mark 4 to ppm mark 5 would be expected. The transmitters are usually lined up so that a stereo signal of 400Hz at 0dBu will cause a deviation of 21.3kHz, excluding pilot time. The maximum permissible deviation is of the main carrier 75kHz**.

In order to increase the received signal to noise ratio the vhf modulating signal is subjected to a 50us pre-emphasis curve FIG 2. Notice that the incoming audio signal is first passed to a limiter whose function is to prevent the over-deviation of the carrier. As a consequence of the main signal pre-emphasis the sidechain of the limiter is similarly subject to the same pre-emphasis characteristic.

The design of the broadcast limiter is a complex field, and one of the early works on the matter [7] remains largely valid today. However no IBA transmitter incorporates the delay line approach referred to and the current settings of IBA limiters at VHF transmitters are for an attack time of 1ms and an auto recovery time. In an auto recovery mode the recovery rate of the limiter is dependent on both the magnitude and the duration of any overdrive. Later work [8] anticipates a need to find ways of driving the transmitter harder without producing unacceptable gain reduction side effects due to the pre-emphasis.

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* The ppm is the standard level meter in use in UK broadcasting. It should meet the IEC 268-10 Type IIa specification. It is scaled in 6 approximately equal 4dB sections numbered 1 through 7, and calibrated such that ppm mark 4 is equal to 0dBu. This level is referred to as the operational level. The rise time should be 5ms, that is a 5ms tone burst will under read by 2dB.

** The threshold of the limiter at the transmitter is usually considered to be set at +10dBu, thus giving a 2dB grand-band as the studio sends a maximum audio level at +8dB (ppm mark 6) to the transmitter. The modulation levels are arranged to provide a 2dB guard band.

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MEASUREMENTS

The following recordings were chosen (Items 1 to 4):-

1	Dire Straits	Brothers in Arms	tracks 1 & 2	So Far Away, Money for Nothing	12:29mins
2	Phil Collins	No Jacket Required	track 1	Susudio	4:15mins
3	Eagles	Greatest Hits	track 3	Lying Eyes	6:20mins
4	Sarah Vaughan	The Divine	track 1	Perdido	2:10mins

Items 1 and 2 were chosen because:

1. They have been UK chart hits in the past year.
2. They have been recorded with C.D. in mind.
3. They appear to exploit the full dynamic range and were digitally mastered.

Item 3 was chosen as an example of "easy listening", where the track sounds well controlled in level.

Item 4 was chosen to represent a big band sound.

The CD edition of the above were chosen, for reproduction consistency, reliability and wide dynamic and frequency range.

The arrangement of equipment is shown in FIG 3. The peak signal level through the system can be accurately set by using a test CD with a set of maximum level tones. Maximum level was set to correspond to +12dBu (ppm7). It was found that all of the CD items registered reasonably close to the required guide lines referred to above and so no further adjustments to the system gain were made.

Photographs and notes of the analyser screen were taken for signals before and after 50us pre-emphasis and before and after the limiter. Both peak spectrum and amplitude probability were noted along with comments regarding the observed dynamics on the ppm. A large number of photographs was involved and a selection is presented here.

FIGS 4, 5 and 6 show results for Item 1. FIG 4 shows the peak spectrum and amplitude probability density (in two sensitivity ranges) along with any comments on the ppm readings prior to any processing. FIG 5 shows similar plots after 50us pre-emphasis and FIG 6 shows the situation after both 50us and limiting has been applied.

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The peak spectral density shows the maximum frequency component noted at any time during the music period. It gives some indication of what the worst spectrum required to be transmitted will be. Viewing it after the 50us pre-emphasis indicates how the spectrum has changed, for it will be this spectrum which is essentially applied to the limiter and which is required to be broadcast. So the peak spectrum emerging from the limiter ought to be quite different again.... but it can be seen that it is only in the bass region that there is any change. The usual settings of analyser bandwidth and trigger point were set to 12.8kHz and -40dB of input sensitivity. This allowed the analyser to operate almost in real time. The number of samples taken is important if extrapolations from the probability density curves are to be attempted***. Occasional photos were taken at the wider bandwidth of 25.6kHz simply to confirm that nothing extraordinary was taking place in the upper 12.8kHz of spectrum. The spectrum is shown linearly scaled because it shows a further two octaves of the bass end.

OBSERVATIONS

The limiter in the transmitter is sensitive to the programme envelope peaks. What ultimately matters is whether the signal is large enough, and for a short duration, such that it escapes any action by the limiter and causes over-deviation. A comparison between the probability density traces (FIGS 4 and 5) indicates that, in probability terms the effect of pre-emphasis appears to be similar to raising the overall gain by approximately 6dB. A glance at the spectral trace shows that this order of increase is found in the levels of frequencies which lie above the break point frequency implied by the 50us time constant. It is possible to see the effect of the limiter on the amplitude probability distribution as a narrower shaped main curve. In addition there is a skirt to this curve which comprises those peak signals which were not caught by the limiter. Readings made on the original screen show that the probability of the signal not being caught by the limiter and thus over-driving the transmitter by 4dB was around 7u% of the time for Item 1. It is arguable whether this is significant. What may be of more importance is whether the 50us pre-emphasis curve might not be improved upon. Although there is no possibility of altering the current vhf broadcast standard there is a thought that for programme links the J17 pre-emphasis curve might be more appropriate. The J17 curve is used in the NICAM system, for example, but it would seem unclear what benefits might accrue if it were used in a simple fm system.

*** The estimation of true probability requires knowledge of the total time occupied by the music, Tm, the total time represented by the number of samples, Ts, the class interval, dx and the reading taken from the graphs, Pv. The probability, P(x), (in per cent of the total music time) of the signal occupying the class interval at the selected voltage level is then:

$P(x) = Tm(Pv\ dx)/Ts$

where Ts is the number of samples times the sample window width. For the 12.8kHz bandwidth used here the window width is 62.5ms.

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Although the 50us time constant modifies the signal so that from the point of view of its amplitude density it looks similar to the un-emphasised signal but with about 6dB of gain, it is clear from the spectral density traces that it successfully fills the spectral space from around 2kHz upwards. There is however a bass rise of perhaps some 10dB still present. The J17 curve is likely to achieve an even denser peak spectrum but at the risk of producing a signal whose envelope peaks may be causing any protection limiter to work hard. This risk is reduced by the overall reduction in signal level although this will be accompanied by an increased susceptibility to channel noise at low frequencies. From the protection point of view this is as it should be but it does not bode well for the sound which might emerge at the receiving end. This sound will be very dependent on the particular audio qualities of the limiter and especially on its related attack and recovery profiles.

It suggests that the audio consequences of over-deviation can pass unnoticed while impairments due to limiting are noticed. Reducing the signal level entering the transmitter system by 6dB is likely to result in the emerged amplitude probability density much the same as that leaving the studio. This would be accompanied by an undesirable decrease in received signal to noise ratio.

There does not seem to be any outstanding difference between the current pop music items (Items 1 and 2) even with respect to Item 4 (recorded 1972) in terms of the spectral density. Thus there does not seem to be much reason for assuming that broadcast limiters work harder on account of the type of music fed to them. Although this could be simply due to the fact that the really different recordings were not sampled.

ACKNOWLEDGEMENTS

The Author wishes to thank the Director of Engineering of the Independent Broadcasting Authority for permission to publish this paper.

I would also like to acknowledge the assistance of Bruel and Kjaer Limited in the preparation of this work.

REFERENCES

[1] Statistics of typical programme sound pressure levels in sound studios and their control room D J Meares BBC RD 1973/37.

[2] An investigation into the spectral content of pop music, K E Randall BBC RD 1981/2.

[3] The Design Objectives for Audio Power amplifiers, D G Daugherty and R A Greiner, IEEE Transactions on Audio and Electroacoustics Vol AU-14 No 1.

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[5] R C Cabot, C R Genter and T Lucke, Sound Levels and Spectra of Rock Music, JAES April 1979 Vol 27 No 4.

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[7] The dynamic characteristics of limiters for sound programme circuits, D E L Shorter, W I Manson and D W Stebbings, BBC Engineering Monograph No 70 October 1967.

[8] Frequency Dependent Limiters for FM Broadcasting, W I Manson, BBC RD 1975/22.

THE DISTRIBUTION OF SIGNAL AMPLITUDES IN RECORDED MUSIC

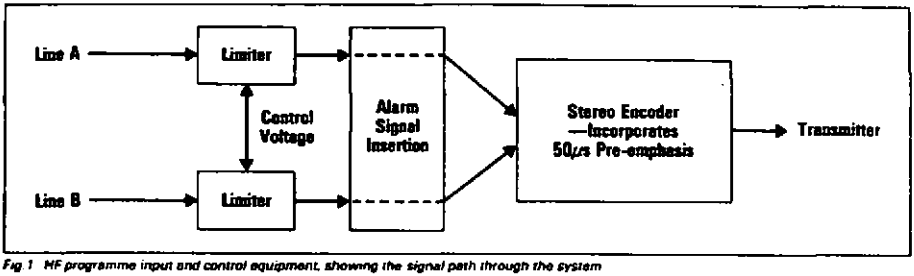

Fig.1 HF programme input and control equipment, showing the signal path through the system

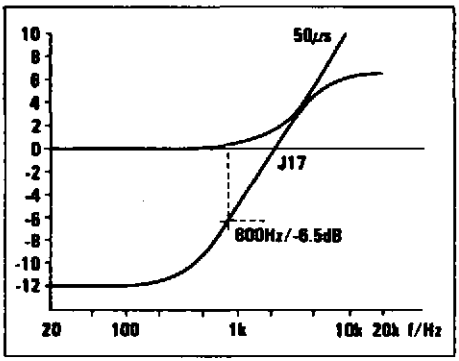

Fig.2 Pre-emphasis

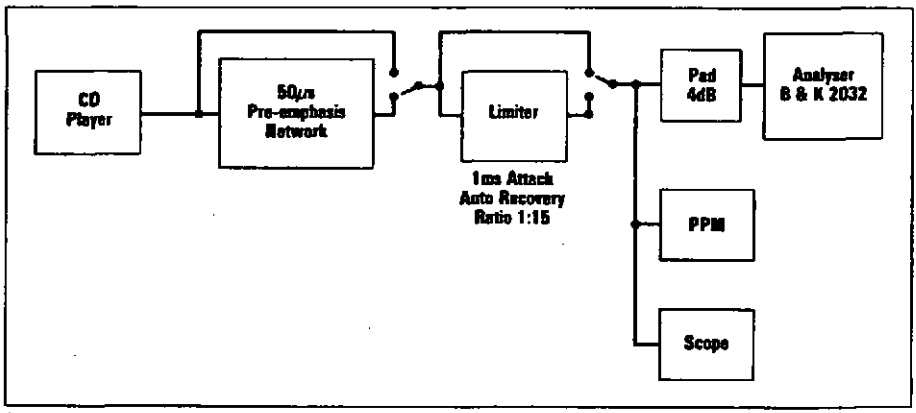

Fig.3 Equipment arrangements for the tests

The attenuating pad before the analyser was used to set the analyser so that the full use was made of the ±3v full scale sensitivity range

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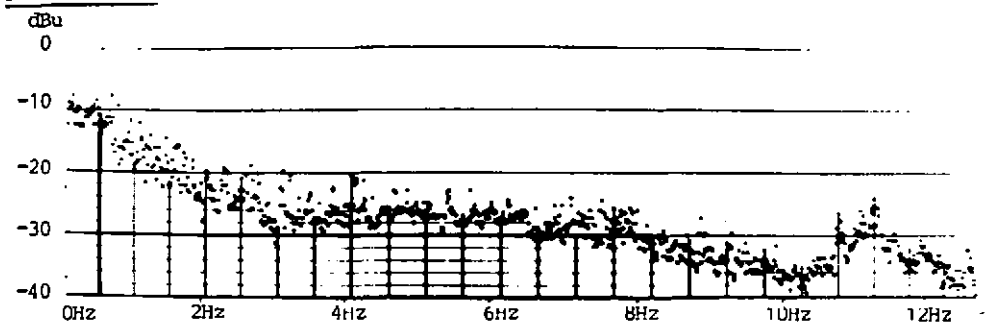
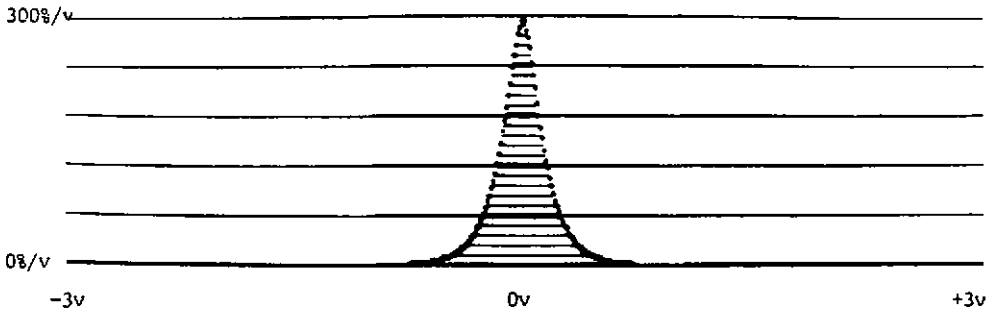
peak spectrum



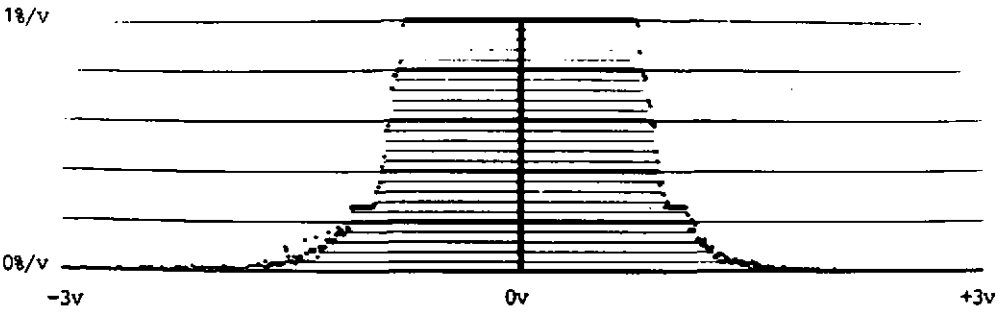
12.8kHz bandwidth, markers at 512Hz intervals

amplitude probability density



6641 samples, class interval 11.7mv

amplitude probability density



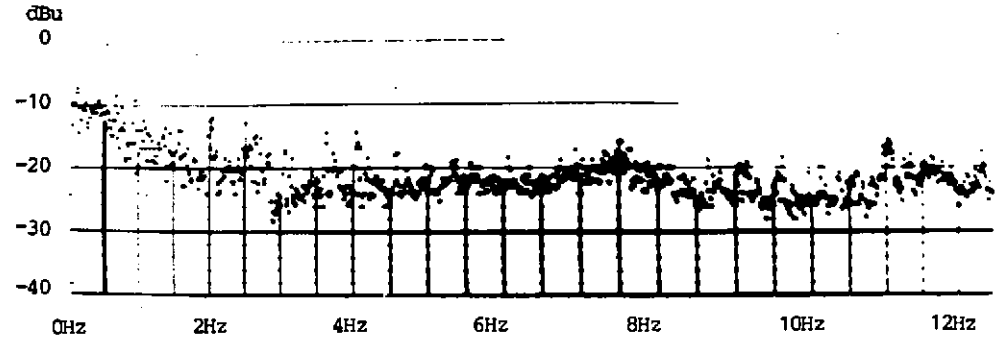
6641 samples, class interval 11.7mv

PPM notes: ppm mark 4 at peaks, noted that the true peaks must be under indicated by 12dB.

FIG 4: Traces for Item 1 without 50us or limiter in circuit.

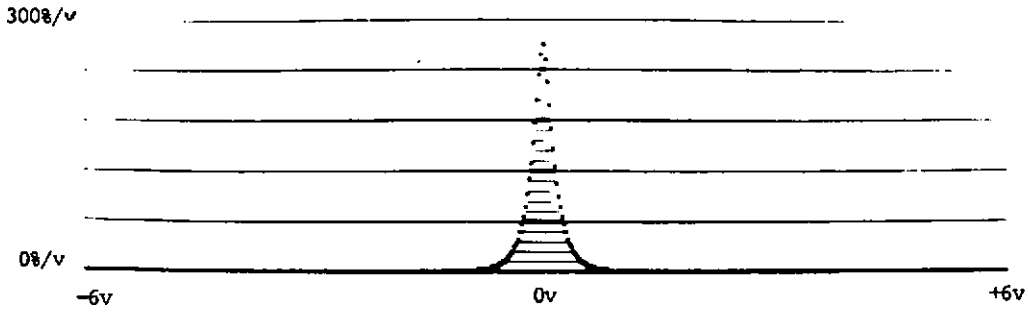
THE DISTRIBUTION OF SIGNAL AMPLITUDES IN RECORDED MUSIC

peak spectrum



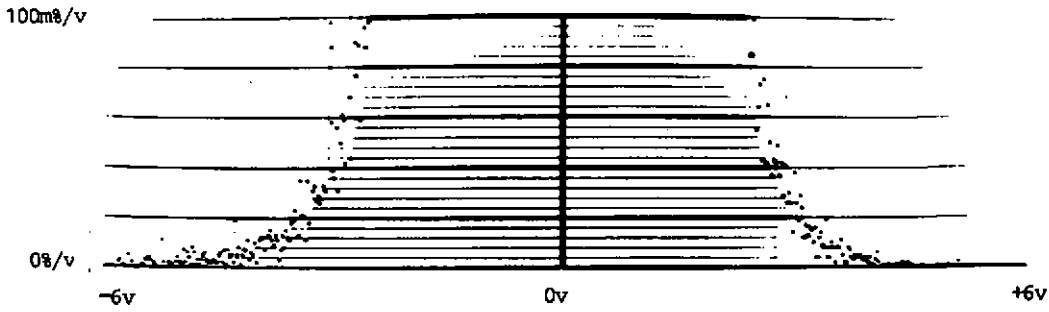
12.8kHz bandwidth, markers at 512Hz intervals

amplitude probability density



6641 samples, class interval 23.4mv

amplitude probability density



6641 samples, class interval 23.4mv

PPM notes: ppm mark 5½ (approximately +6dBu) is common peak level.

FIG 5: Traces with 50us only.

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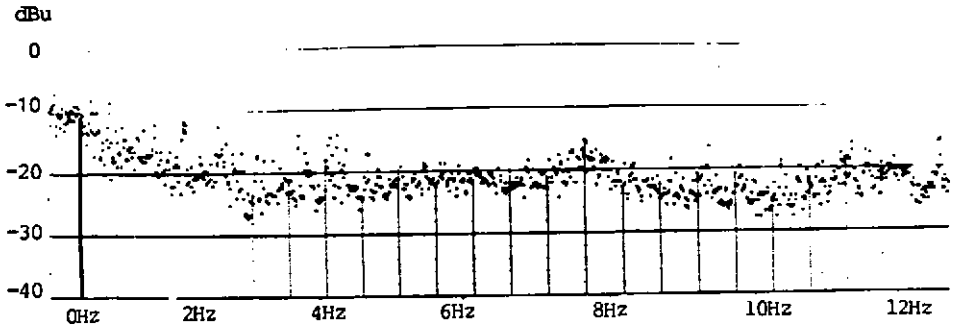
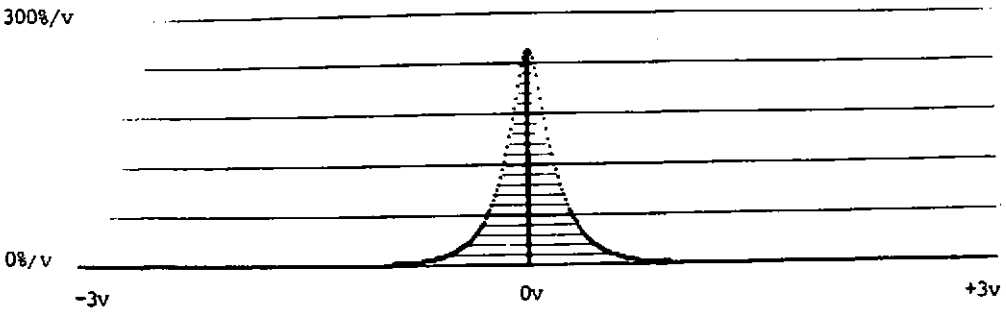
peak spectrum



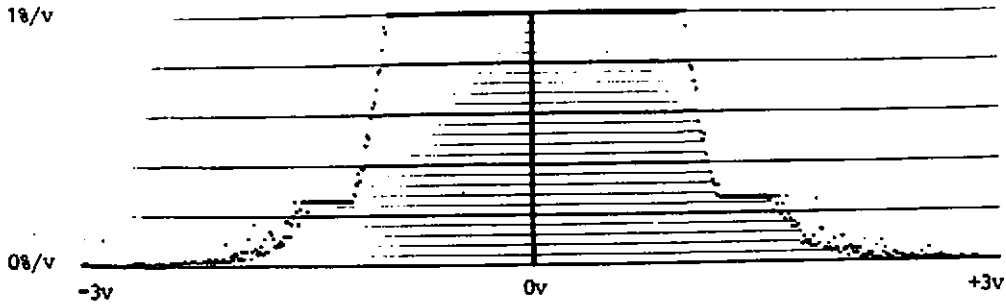
12.8kHz bandwidth, markers at 512Hz intervals

amplitude probability density



6776 samples, class interval 11.7mv

amplitude probability density



6776 samples, class interval 11.7mv

PPM notes: seldom exceeds ppm mark 5.

FIG 6: Traces with both 50us and limiter.

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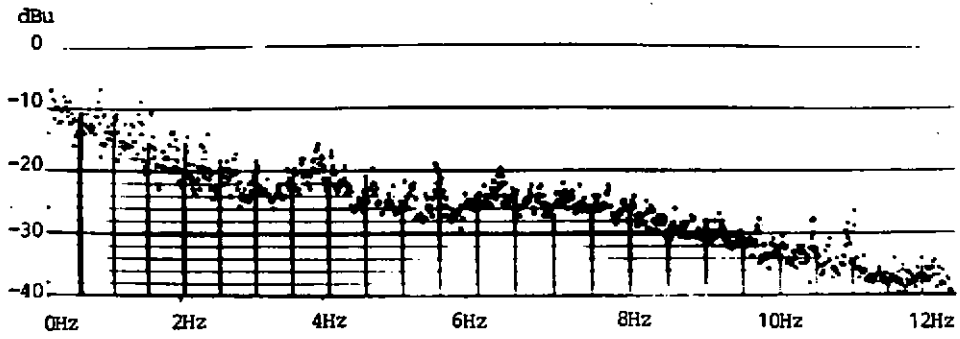
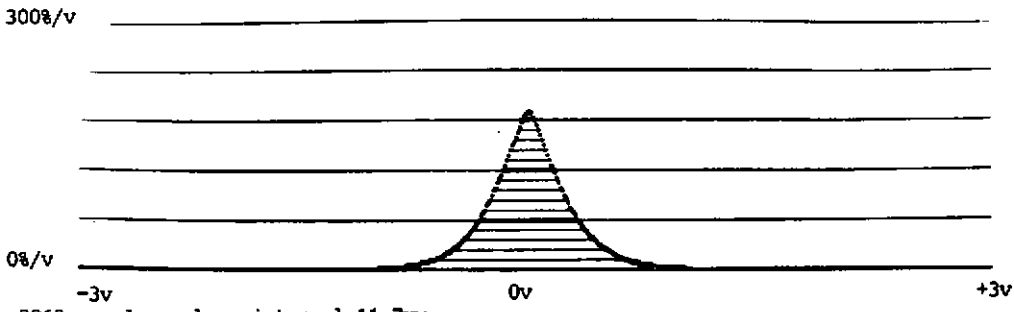
peak spectrum



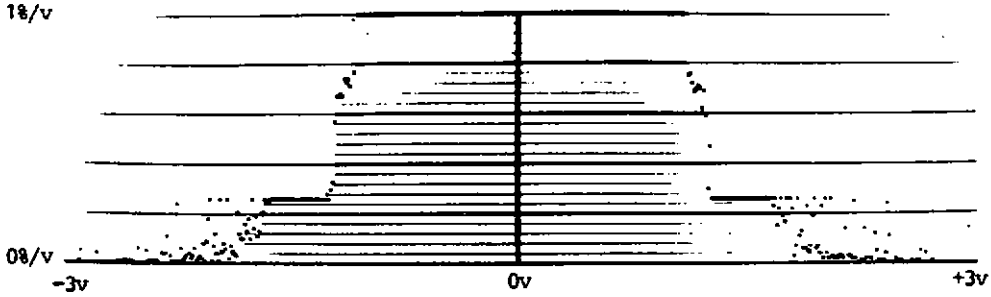
12.8kHz bandwidth, markers at 512Hz intervals

amplitude probability density



2263 samples, class interval 11.7mv

amplitude probability density



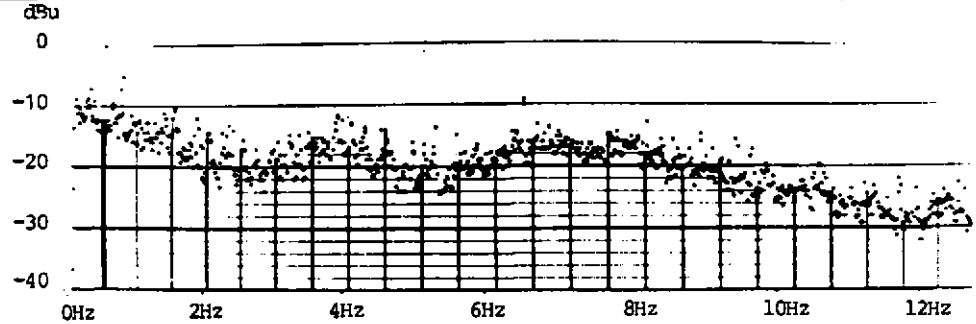
2263 samples, class interval 11.7mv

PPM notes: ppm mark 4 with occasional peaks at ppm mark 4½.

FIG 7: Traces for Item 2 without 50us or limiter in circuit.

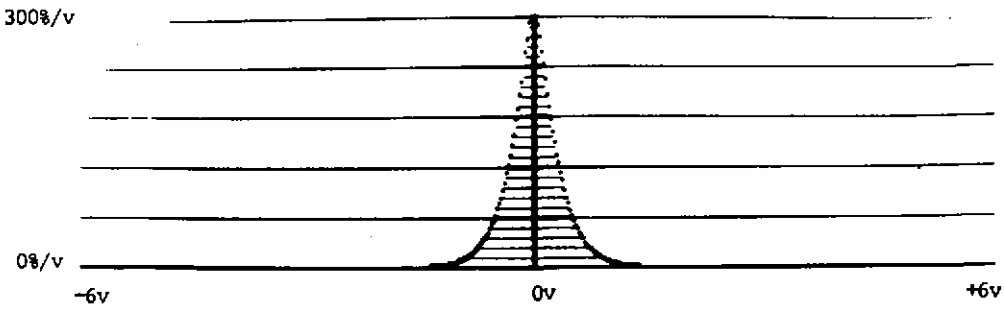
THE DISTRIBUTION OF SIGNAL AMPLITUDES IN RECORDED MUSIC

peak spectrum



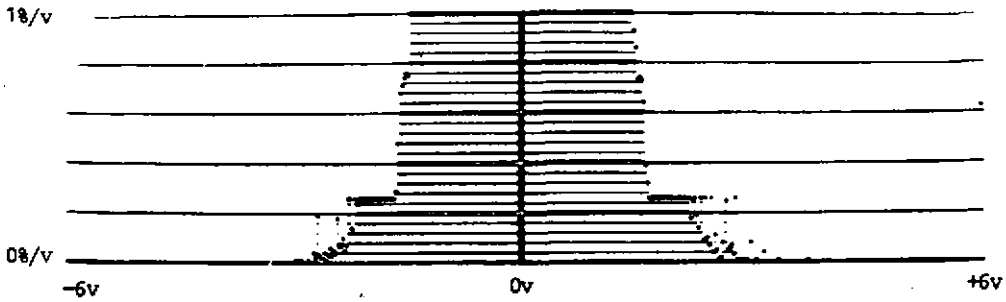
12.8kHz bandwidth, markers at 512Hz intervals

amplitude probability density



2263 samples, class interval 23.4mv

amplitude probability density



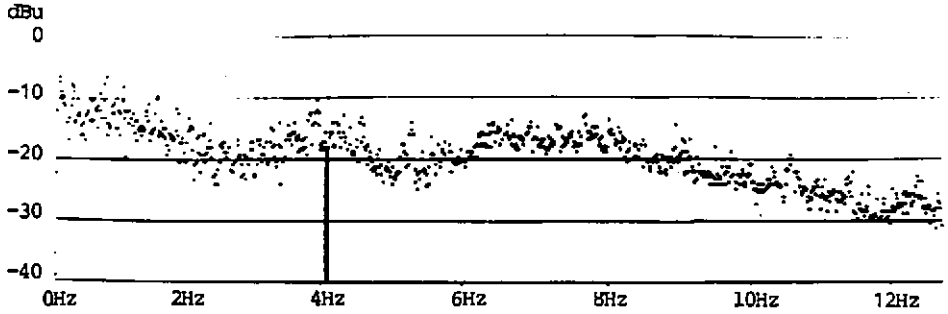
2263 samples, class interval 23.4mv

PPM notes: ppm mark 5½ usually seen with occasional peaks at ppm mark 6.

FIG 8: Traces with 50us only.

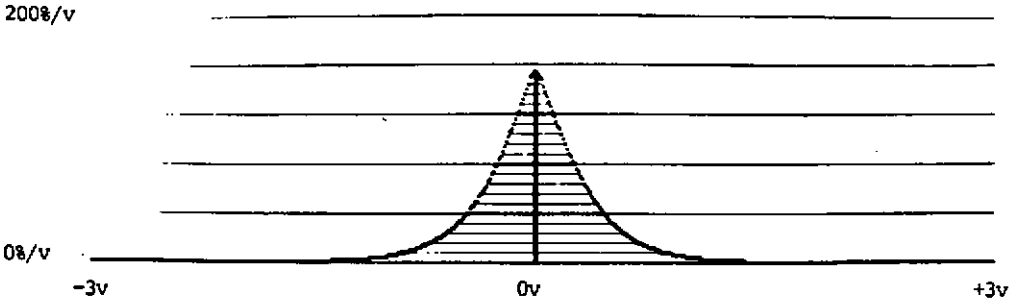
THE DISTRIBUTION OF SIGNAL AMPLITUDES IN RECORDED MUSIC

peak spectrum



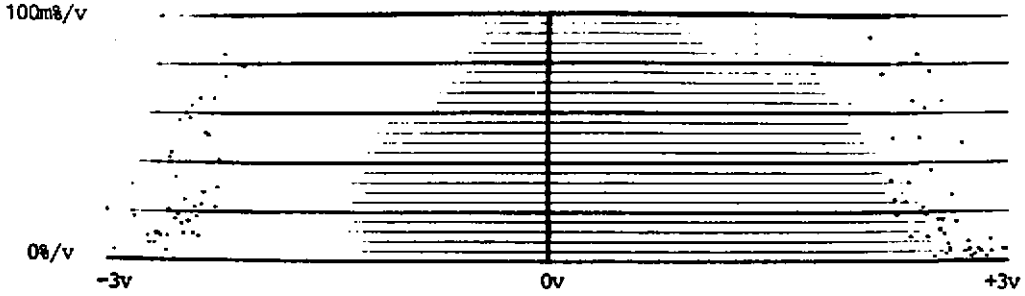
12.8kHz bandwidth, markers at 512Hz intervals

amplitude probability density



2392 samples, class interval 11.7mv

amplitude probability density



2392 samples, class interval 11.7mv

PPM notes: ppm shows peaks upto ppm mark 5½ only occasionally despite more than 4dB of limiting.

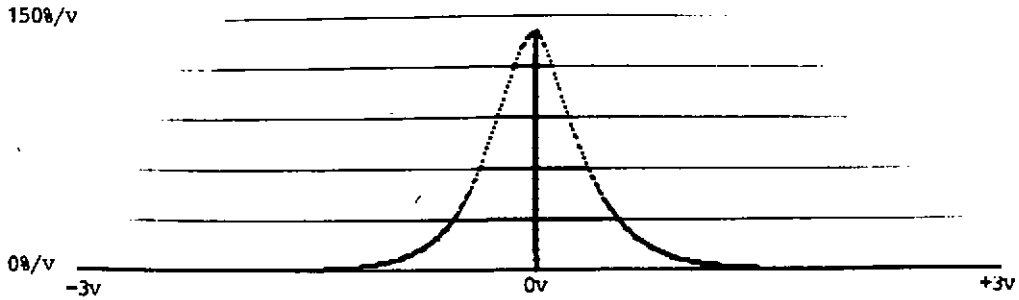
FIG 9: Traces with both 50us and limiter.

THE DISTRIBUTION OF SIGNAL AMPLITUDES IN RECORDED MUSIC

peak spectrum

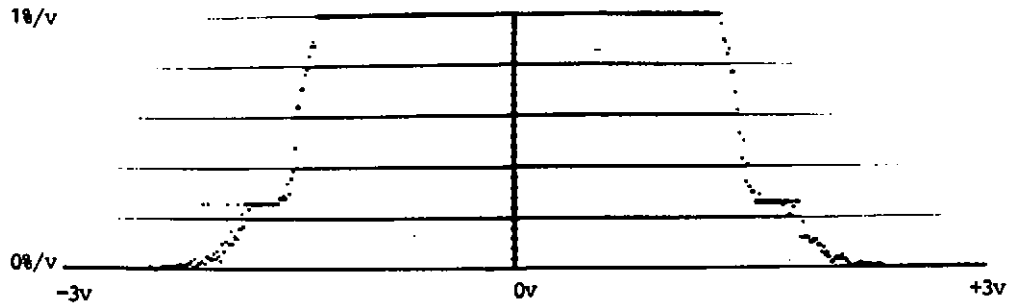
12.8kHz bandwidth, markers at 512Hz intervals

amplitude probability density



3376 samples, class interval 11.7mv

amplitude probability density



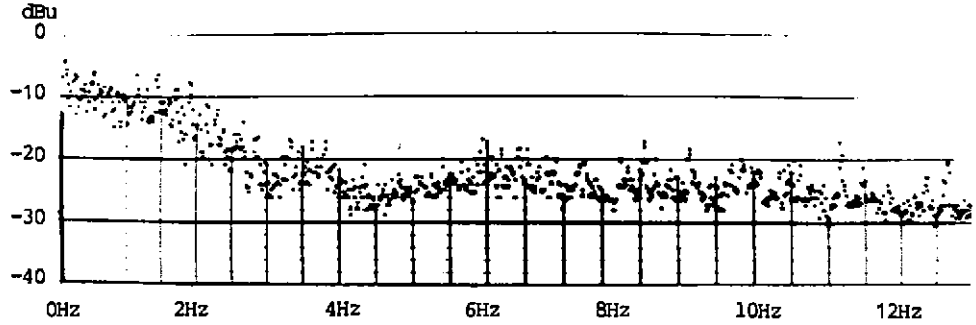
3376 samples, class interval 11.7mv

PPM notes: Usual peak level indicated at ppm mark 5.

FIG 10: Traces for Item 3 without 50us or limiter in circuit.

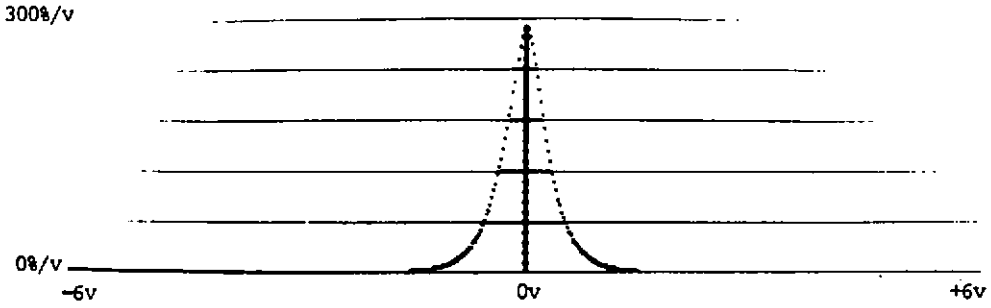
THE DISTRIBUTION OF SIGNAL AMPLITUDES IN RECORDED MUSIC

peak spectrum



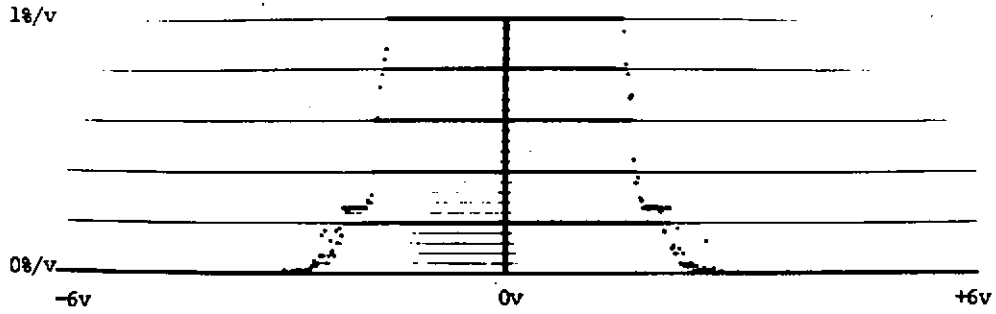
12.8kHz bandwidth, markers at 512Hz intervals

amplitude probability density



3376 samples, class interval 23.4mv

amplitude probability density



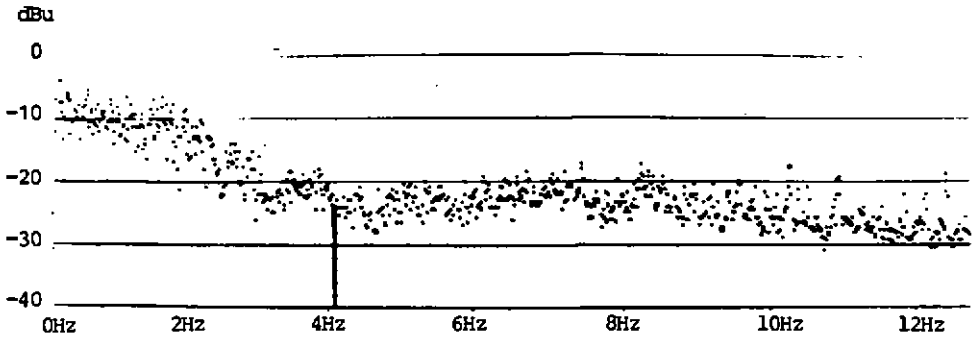
3376 samples, class interval 23.4mv

PPM notes: Usual peak level indicated at ppm mark 5½ only.

FIG 11: Traces with 50us only.

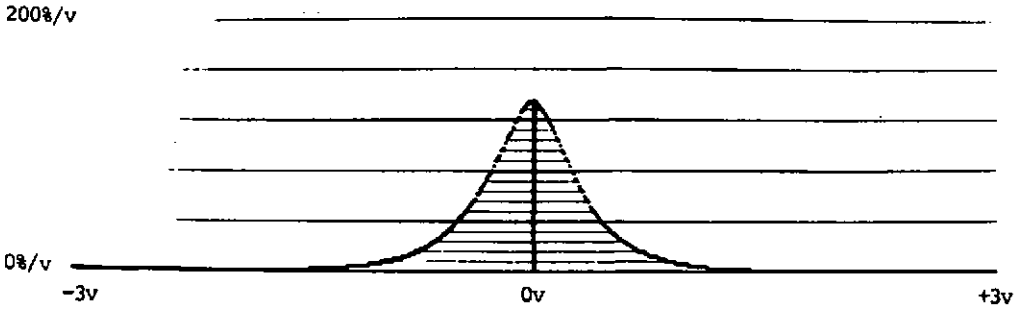
THE DISTRIBUTION OF SIGNAL AMPLITUDES IN RECORDED MUSIC

peak spectrum



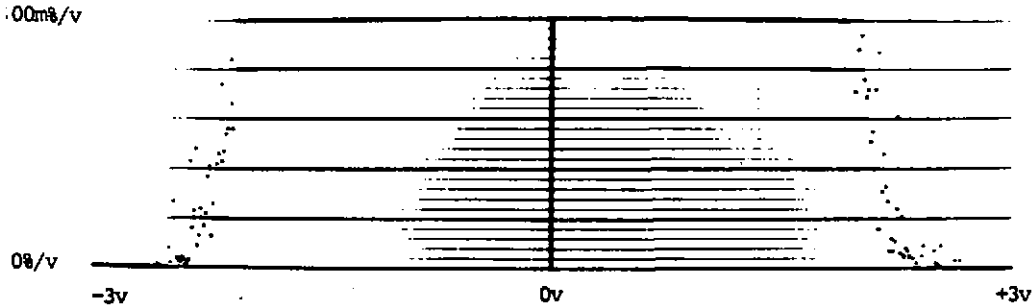
12.8kHz bandwidth, markers at 512Hz intervals

amplitude probability density



3397 samples, class interval 11.7mv

amplitude probability density



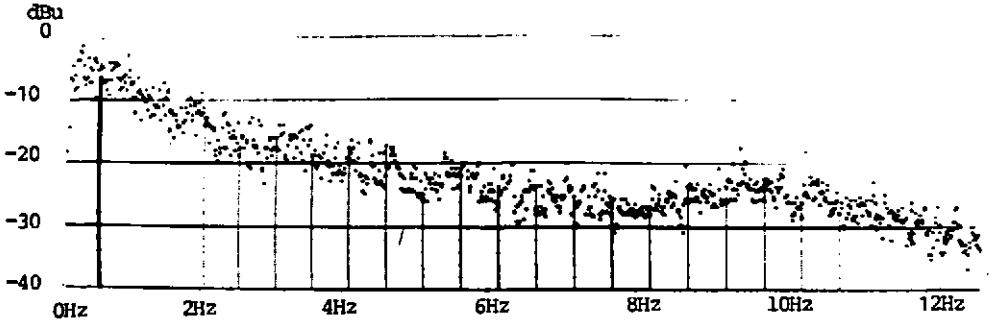
3397 samples, class interval 11.7mv

PPM notes: Fairly steady peak indication around ppm mark 5 with occasional amounts of gain reduction upto 4dB indicated on limiter.

FIG 12: Traces with both 50us and limiter.

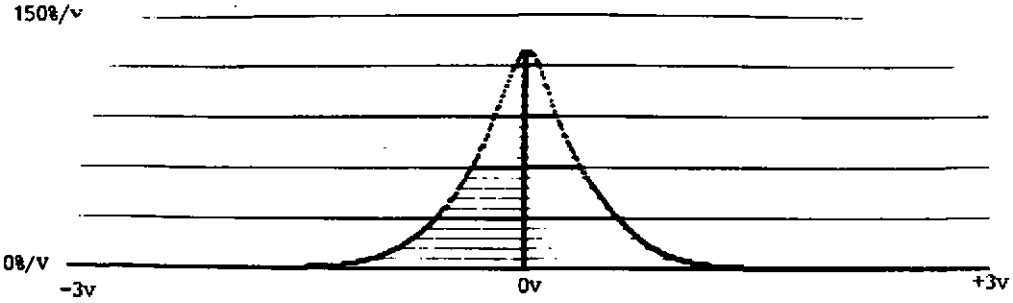
THE DISTRIBUTION OF SIGNAL AMPLITUDES IN RECORDED MUSIC

peak spectrum



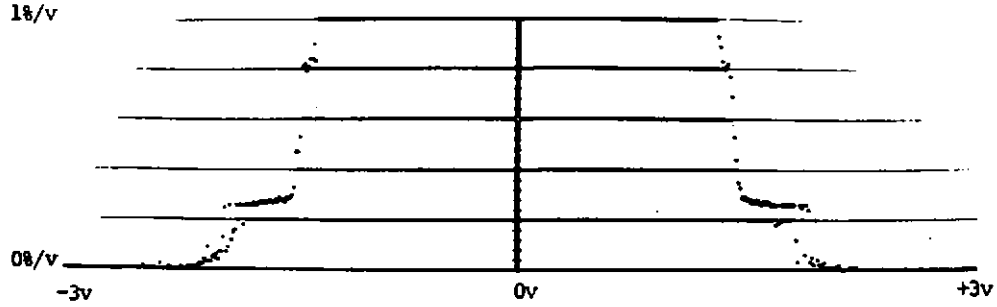
12.8kHz bandwidth, markers at 512Hz intervals

amplitude probability density



871 samples, class interval 11.7mv

amplitude probability density



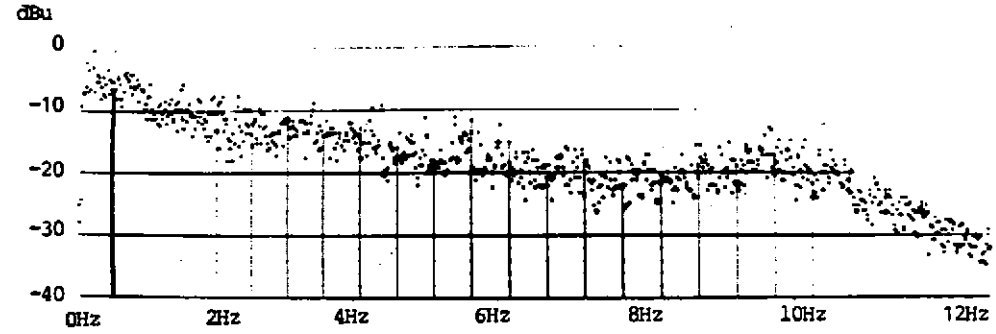
871 samples, class interval 11.7mv

PPM notes: Usual indication ppm mark 5 very occasional peaks above ppm mark 5½.

FIG 13: Traces for Item 4 without 50us or limiter in circuit.

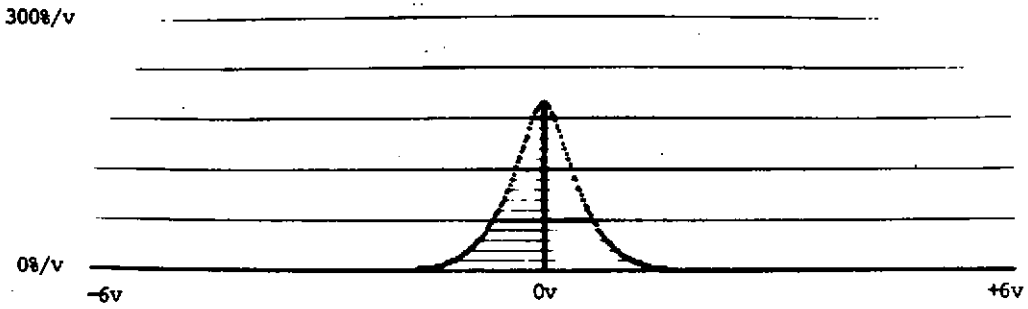
THE DISTRIBUTION OF SIGNAL AMPLITUDES IN RECORDED MUSIC

peak spectrum



12.8kHz bandwidth, markers at 512Hz intervals

amplitude probability density



871 samples, class interval 23.4mv

amplitude probability density

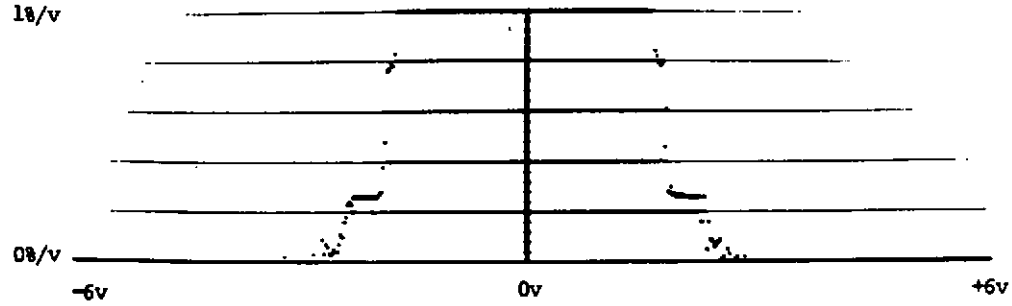
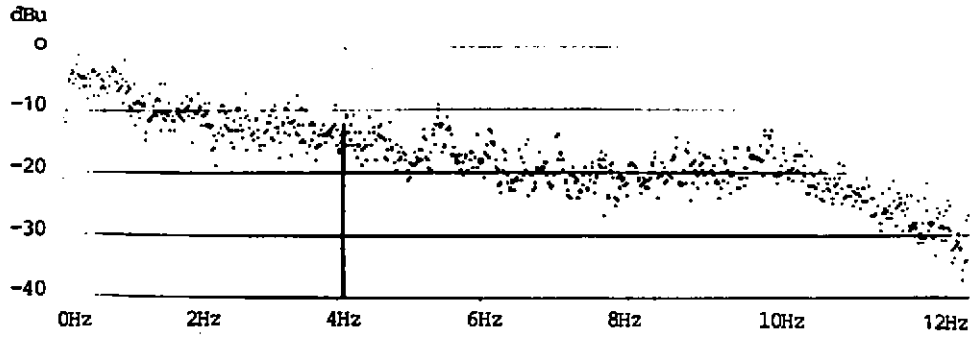


FIG 14: Traces with 50us only.

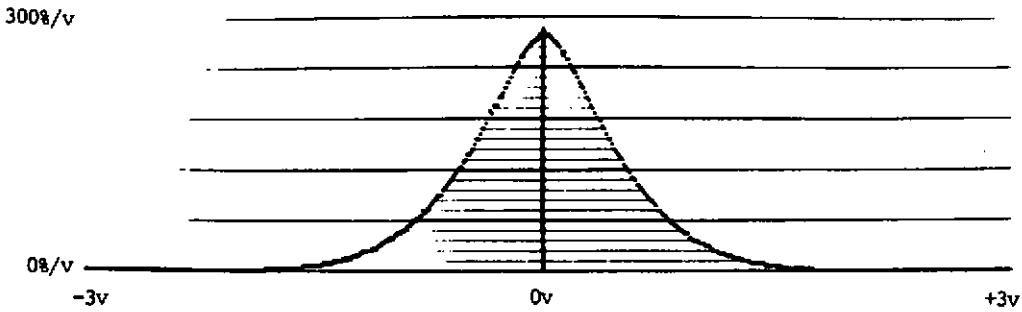
THE DISTRIBUTION OF SIGNAL AMPLITUDES IN RECORDED MUSIC

peak spectrum



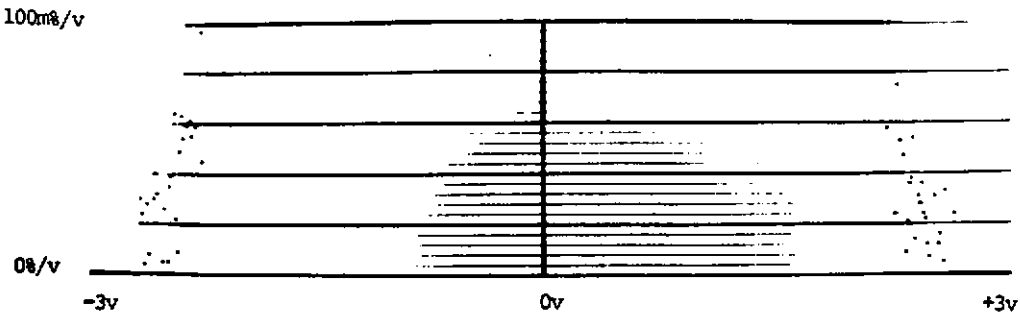
12.8kHz bandwidth, markers at 512Hz intervals

amplitude probability density



1169 samples, class interval 11.7mv

amplitude probability denstiy



PPM notes: Usual indication of ppm mark 5½ with peaks just reaching ppm mark 6 occasionally 4dB of gain reduction was shown by the limiter.

FIG 15: Traces with both 50us and limiter.