PERFORMANCE ASPECTS
OF THE
BROADCAST CHAIN

RTS Report R88/36
TITLE : PERFORMANCE ASPECTS OF THE BROADCAST CHAIN

SUMMARY:

The noise floor of the transmission chain has been considerably lowered by replacing the Type D continuity desks (now 15 years old) with SSL 5000 types. For a live programme, the estimated noise floor at a quality receiver has decreased from -52dB to -57dB, an improvement of 5dB. However the tape noise of recorded programmes is now significant and degrades the potential noise level at the receiver by 9dB to -48dB.

The use of Dolby A noise reduction for serious music and drama could provide up to 10dB reduction in tape noise. Dolby SR is capable of giving an even greater improvement, but the additional advantage would be lost because of other noise levels in the chain.

In the long term, the widespread use of digital tape recorders with their inherently lower noise levels will eliminate noise due to tape. Further improvements will be possible with a fully digital transmission chain. However, neither of these situations applies at present.

Complaints about low average levels and poor audibility for Radio 3 have also been investigated. This is an old problem; it is due to Radio 3 specialising in material with a wide dynamic range. Measurements show that the loudest passages are reliably taken to PPM 6 (and sometimes over); the problem is that people listening in high ambient noise conditions (e.g. in a car) find the quiet passages inaudible. Various possible solutions are considered, all of which will cause dissatisfaction to some listeners. Some in-car listeners who find the MF service satisfactory (due to the 20dB of compression applied to Radio 3 MF) may find problems with the wider dynamic range of the FM service (which they will have to use if the MF service ceases).
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Appendix 4 - INCREASING PROGRAMME LOUDNESS - ANOTHER VIEW by Adrian Chinery, Radio Technical Services
1. INTRODUCTION

Acceptance tests on the new SSL 5000 continuity desks have shown that their noise and distortion levels are considerably lower than those of the 15 year old Type D desks which are being replaced. As a result, the noise and distortion produced by other elements in the programme chain has become more significant.

This report outlines the elements in the programme signal chain from the studio to the listener and considers the effect of the noise added at each stage.

At the same time, complaints are being received from listeners about differences in the perceived loudness of the various FM stations using Band II. In particular, Radio 3 is felt to be significantly quieter than the other networks. The conflict of interests between different listeners is also discussed.

2. TYPICAL PROGRAMME CHAIN

RES SK692A3 (Fig 1) shows a typical programme chain. Quoted noise levels are for each item or section of equipment. The studio and continuity desk noise levels are those for modern (SSL) equipment.

2.1 Studio Acoustics

The peak level of 100dBA shown on Figure 1 (RES SK692A3) is an arbitrary figure which will often be exceeded with close mixed musical instruments. The purpose in choosing this figure was to calculate the noise levels for sounds which are considerably louder than normal speech. The reduction of the spread between peak level and nominal line-up level from 20dB or more within the studio to 11dB at the desk output is part of the normal balancing process.

Acoustic noise in a studio is mainly confined to low frequencies. Because of the ear's ability to discriminate between sounds of different frequencies, low frequency acoustic noise will not necessarily mask or be masked by the higher frequency components of electronically generated noise.

Curves have been published for the maximum tolerable background noise level for various classes of studio. Around 1980 the maximum desirable level of background noise due to ventilation was reduced by about 10dBA. As alterations to the acoustic isolation of a studio require major building work, many BH studios only meet the old criteria. Also, where a refurbishment has been carried out, the desired improvements have not always been possible because floor loading considerations have prevented the building of the necessary mass walls.

The figure of 10-25dBA shown on Figure 1 as the noise level of the studio represents typical values for the new and the old criteria.

In time, as the re-equipping of BH proceeds, corrective action will be taken for the noisiest of the BH studios. However, a reduction in electronic noise levels due to the use of digital mixing and recording could bring the (lower) acoustic noise levels back into prominence when
monitored in a control cubicle. However, the point has already been reached where the background noise level in a listener's home (where 30dB is considered reasonably quiet) will often be the limiting factor.

2.2 Studio Mixing Desk

Sensitivity figures for an STC 4038 microphone have been used as these are considered typical of non-capacitor microphones. The noise due to the microphone and an SSL microphone amplifier is 7dB worse than the theoretical minimum (which is due to thermal agitation in the microphone output impedance).

Capacitor microphones are available which have a higher output level for a given sound pressure level. Less gain is therefore required in the desk microphone amplifier. As a result, despite the added noise of the head amplifier, some of these microphones can be quieter overall than the STC 4038.

In order for a 4038 microphone to generate an output equal to that of low-level tone (-70dBu), a sound level of 80dB (i.e. 80db above the reference of 20uPa or 2x10^-5N/m²) is required. This is about 6dB above the sound level produced by normal speech.²

(Figure 2 shows the relationship between overall system gain and typical unweighted noise levels. The sloping lines show the noise due to microphone and other pre-fader amplifiers; the horizontal lines show the fixed noise due to post-fader amplifiers.

(The figures for the AMC/S valve amplifier are included for historical comparison. It should be noted these figures include a significant allowance for hum and other low-frequency components.)

When the microphone faders are closed there is a residual level of noise due to the post-fader amplifiers, group mixing busbars etc. The horizontal lines on Figure 2 show the level of this residual noise due to individual items of equipment along the programme chain.

If the sound level at the microphone is high, the operator will need to reduce the overall system gain in order to control the peak levels. As a result, the noise on the output due to the microphone amplifier will be reduced. Under such circumstances, the noise due to the desk output stages and due to the recording processes will be the more significant.

If the sound level at the microphone is low, the operator will need to increase the overall system gain in order to achieve an adequate programme volume. Increasing the gain will increase the noise on the output due to the microphone amplifier and studio acoustics. These will then be the more significant sources of noise.

2.3 Source Multiple / NTP Switching Matrix

The acceptance test noise figures for the NTP switching matrix of -90dB are sufficiently low to be insignificant compared with other noise sources. Crosstalk between sources may be more significant but is not considered operationally to be a problem and no figures were available when this report was prepared.
2.4 Tape Noise

The overall (ie record/play) tape noise level of -48.5dBm for a machine with a wide guard-band replay head has been derived from measurements made in RTS Technical Investigations. After the Type D continuities are replaced, all the other items of post-studio equipment in the broadcast chain will have noise levels at least 10dB better.

Until digital recording becomes more widespread, the only practicable method of reducing the subjective effect of tape noise is to make more use of the currently available noise reduction equipment.

Dolby A noise reduction equipment offers the potential of a 10dB reduction in the tape noise level; this reduction is increased to 20dB with Dolby SR. The benefit of using Dolby A would be worthwhile; the extra benefit of using Dolby SR will be lost because of noise elsewhere in the broadcast chain.

2.5 Continuity

The figure of -62dBm for an SSL continuity desk was measured with a tape channel faded up at normal settings, but with the tape machine fader closed. The comparative figure for a Type D continuity desk is -52dBm.

2.6 Network Switching

The existing continuity and network switching is carried out by relay matrices with no active devices in the signal chain. Any crosstalk which does occur is considered to be so insignificant that no measurements have been taken. If the new network interchange has a comparable performance to the NTP source switching matrix, it will not contribute any significant noise.

2.7 Network Processing

Optimod FM processors are installed at the inputs to programme distributions to the Radio 1 and Radio 2 transmitters. The purpose of these processors is to increase the loudness and 'punch' of the programme material without allowing the transmitter to exceed the maximum permissible deviation. This is done by applying selective gain make-up. As far as can be ascertained, the settings of the Optimod FM processors take account of any increase in peak levels caused by the 50us pre-emphasis applied to FM transmissions.

At -59dBm, the noise level of an Optimod FM processor is marginal. However, because of the high average levels for Radio 1 and Radio 2, this noise is not considered to be a problem.

The FM network distributions for Radio 3 and Radio 4 are unprocessed. AM6/27 variable-emphasis limiters are installed at the input to the NICAM pcm bays to ensure the transmitter deviation limit is not exceeded. Because AM6/27 limiters reduce the applied pre-emphasis when
high levels of high frequency notes are present, they can cause a noticeable dulling at the receiver of, for example, top strings and brass instruments. This is discussed further in RTS Report 88/30*.

2.8 NICAM

In order to reduce the subjective effect of quantising noise, the NICAM system employs pre-emphasis to CCIR curve J17.

A noise measurement figure of -65dB4m was reported as being obtained at the output of a NICAM decoder at Sutton Coldfield when the input on the corresponding AM6/27 in London Control Room was terminated.

The ultimate performance of a digital system is defined primarily by the choice of the number of bits per sample and the sampling frequency. For the NICAM system, the choice of using the ten most significant bits out of fourteen was based in part on existing studio noise levels.

In the next five to ten years, quieter studios and electronics should be available. This will be aided by the more widespread use of digital mixing and recording. For the next generation of digital transmission equipment, thought should be given to increasing the number of bits per sample.

2.9 Stereo Coder, FM Transmitter and Receiver

Using a measuring check receiver at Sutton Coldfield, a noise measurement of -62dB4m was reported when the inputs to the Sutton Coldfield stereo multiplex coder were terminated. It is believed most of this noise was due to the check receiver; the figure obtained is better than the published spec for an RC1/17 (-60dB4).

Comparing BBC noise measurements with those quoted by receiver manufacturers, and those reported in popular press test reports etc., is not easy. Different methods of measurement, reference deviations, weighting curves etc. need to be taken into account.

Having examined the published specifications for a number of receivers, and having made a few comparative tests, it appears the best receivers on the market should be able to achieve a noise measurement of -60dB4m with an adequate (50-60dBuV) signal. With lower signal strengths the noise can rise rapidly.

Figure 3 shows how, for the RC1/12A and RC1/17 check receivers, changing the applied signal alters the expected noise level.

A mobile listener can suffer from particular problems. Firstly he is constrained to using an omnidirectional aerial. Secondly, reflections from buildings and other objects will cause standing waves to be set up with the result that he/she will be passing through a rapid series of signal peaks and troughs. These signal troughs can cause rapid bursts of noise (or signal muting), known as "fencepost multipath".

The specification for the RDS system was written so that the system would be able to help overcome the problem of fencepost multipath. Experience with the receivers now being produced shows that it is very
good in curing this problem.

3. LISTENER'S ACOUSTIC ENVIRONMENT

The acoustic noise level of the listener's environment is a factor which must be taken into consideration. Even in the quietest locations this is likely to be higher than in the noisiest of studios; a figure of 30dB is considered reasonably quiet.

For the background noise due to the broadcast chain to equal the acoustic noise of the listener's environment, the listener must increase the setting of his volume control so that peak listening levels exceed 95dB. This is reasonable for a concert but excessive for speech.

Many listeners are unable to enjoy such quiet background noise levels, either because their listening location has poor acoustic isolation or because they are also engaged in a noise producing activity (e.g. driving a car). They may also be restricted as to how loud they can reproduce the peak levels.

4. BROADCAST DYNAMIC RANGE

4.1 History

In order that quiet passages are not lost in the background noise, it is necessary to reduce the dynamic range from that occurring naturally (e.g. in a concert). A 1952 Engineering Training supplement stated:

"...transmission systems in general have a linear characteristic with well-defined maximum and minimum limits, the maximum being the power handling capacity and the minimum being the background noise inherent in the system. Unfortunately these limits usually delineate an intensity range which is much less than that normally experienced by the ear in every-day life. It is therefore necessary to compress the intensity range applied to the transmission system."

As the noise levels in the transmission system have reduced (by, for example, the introduction of FM broadcasting and NICAM sound distribution systems), the practical dynamic range available has increased.

The same 1952 supplement stated:

"...Normal practice in the BBC is to adjust quiet passages so that peaks below '2' do not persist for long."

By 1961, an Operational Instruction on Balance and Control was allowing music passages of approximately half a minute duration below PPM 1 without pre-warning control room. The same operational instruction also warned:

"...some programmes may well be directed to an audience the majority of whom will be listening under difficult circumstances, often with considerable background of extraneous noise, e.g. in the kitchen or on car radios. In such cases, the ratio of music to speech will have to be altered and sometimes reversed to ensure maximum intelligibility of
speech. The Home Service from opening until 0900 and the Light Programme from opening until 1830 should be treated in this way."

Recent measurements on Radio 3 with a recording PPM confirm that the period of time during which a PPM is allowed to stay below PPM 1 has increased. Even so, complaints are made by listeners who feel that increasing the level of the quiet parts of a concert spoils their enjoyment. The following extract is from a letter recently published in Hi-Fi News & Record Review:

"Even on a good day, the technical quality of the broadcast is unpredictable, as regular readers of 'Radio' will know. You'd have thought that the BBC would have got the main London concert halls perfected by now. Balance between announcers' voices and the music seems absurdly in favour of the former, witness Record Review on Saturday mornings. In that programme, if you want to listen to the musical examples at anything like a reasonable volume, the reviewer's voice blasts its way through the house. The BBC seems far too content to let bad old habits prevail...

What is needed is a more militant lobby, perhaps sponsored by HFM/RR, to keep the BBC up to the mark. We want better reception, wider frequency range, less squashed dynamics and less background hiss..."

Unfortunately for the above writer, the BBC has to take into account the needs of those who have to listen in less favourable environments.

4.2 Variations in loudness between BBC networks

As all networks control their peak levels to the same system maximum, it follows that a network with a narrow dynamic range (eg. Radio 1 which aims for a dynamic range of 4dB) will, on average, sound louder than a network which allows a wider dynamic range (eg. Radio 3).

In an attempt to compare the variations in loudness (as opposed to peak levels) between the four networks, a series of chart recordings were made. For these recordings an rms rectifier (to measure the power rather than the peak level) and a slow pen speed (to average out the peaks and troughs) were used.

Figure 4 reproduces a 50 minute section of the chart recording for each network. The overall height of each chart represents 50dB (1dB per small division). At the pen speed of 8dB/s, it takes the pen 6 seconds to go from the top to the bottom of a chart. On all the charts the point to which the pen would have been driven by 0dBu line-up tone is shown.

For Radio 1, the chart shows a tight control of loudness. The drop in the rms level during the speech item is because, for a constant peak level, the average energy in speech is lower than that in music. During these measurements a check was made with a TPM. This showed that the peak level was consistently being held to PPM 6.

The Radio 4 chart shows a couple of interesting points. At the end of the play there is a one minute dramatic pause before the closing credits. A listener in a noisy environment could think that his/her radio had gone faulty during this pause. Also, the contrast in levels between the end of "Kaleidoscope" and the beginning of the News is worthy of note.
Compared to the other three charts, the Radio 3 chart shows a much wider dynamic range. The loudest passages are as loud as the loudest parts of Radio 1, which shows the peaks were being taken up to the system maximum, but the quieter parts are allowed to persist for longer. By setting the introductory speech at a relatively low level the producer is probably indicating to the listeners how loud he intends the rest of the concert to be heard.

4.3 Other Work (on Broadcast Dynamic Range)

Before retirement, David Stripp (C. A. to G. M. Eng. R) produced a lengthy paper on the subject of programme loudness. Selected extracts are reproduced in Appendix 2. Two of his suggestions, namely that of providing automatic rebalancing of discs or CD's, and that of coding the appropriate control signal into the RDS data stream, are currently being investigated by the Baseband Systems section of Research Department.

As part of our investigation, Vaughan Reynolds looked into current operational practices for the control of level. His report is reproduced as Appendix 3.

Adrian Chinery has contributed an alternative view based on his previous experience as Quality Monitor. This is reproduced as Appendix 4.

Both David Stripp and Vaughan Reynolds have come to the conclusion there is a particular problem of low average levels on Radio 3 when commercial discs or CDs are replayed in continuity. Part of the reason for this is because the RSAs who operate continuities are not trained score readers and can only alter the levels when the rules have already been broken.

The current merging of Radio Networks and Studio Operations gives the opportunity for music SM’s, with their ability to read a score, to be drafted into operating Radio 3 continuity. This would enable a more active rebalancing of commercial discs and CDs on transmission, especially if suitable music scores could be provided.

The alternative solution suggested by David Stripp, is to use equipment which can, prior to transmission, analyse the recorded level on a disc or CD. The information from this analysis is then used, on the subsequent transmission of that disc or CD, to drive an automatic ‘fader’. This is so that the overall dynamic range of the recording can be reduced while preserving the moment to moment dynamics. A further idea of David Stripp’s is that the fader control signal could be coded in a format which will allow its transmission within the RDS data stream. This would have the advantage that the attentive listener could restore the original dynamics of the recording, while a motorist or other background listener may choose to double the amount of compression.

There is no reason why this concept could not be carried further, and the RDS system used to carry data for all programmes on how loud a fully modulated signal should be reproduced.
5. CONCLUSIONS ON NOISE LEVELS

After the replacement of Type D continuity desks by SSL 5000 desks, the main sources of noise in the broadcast chain will be:

5.1 Acoustic noise in the studio

Improving the acoustic isolation of a studio requires heavy building work which is not practicable except when a major refurbishment/rebuild is in progress. Even then, floor loading restrictions in existing buildings mean that the current desired criteria cannot always be met. The White City development will be a major opportunity for a significant reduction in studio noise levels.

5.2 Microphone amplifier noise

The noise in modern (SSL) microphone amplifiers is within 7dB of the theoretical minimum, which is due to the thermal noise in the microphone output impedance. Some room for improvement may be possible with high-output capacitor microphones if the head amplifier noise can be kept low enough.

Studio and microphone amplifier noise is only significant for quiet sound sources. For a loud sound source, eg. a full orchestra, the noise due to the microphone amplifier and studio acoustics is pushed into insignificance. This is because of the reduction in system gain required to keep peak levels within system limits.

5.3 Tape noise

Tape hiss is the most significant source of noise between the studio control desk and the listener's receiver. It can cause up to 9dB of degradation in the signal to noise ratio as heard by the listener. For programmes which require wide dynamic contrasts, the use of a noise reduction system such as Dolby A would be an advantage and is recommended. No significant additional advantage is expected from using Dolby SR as the additional noise reduction would be masked by noises elsewhere in the broadcast chain.

5.4 Acoustic noise in the listener's environment

Acoustic noise in the listener's environment is outside the control of the BBC, but has to be taken into account when balancing programmes. As different listeners prefer different volumes and are subject to widely differing noise levels, the balance between the items of a programme is always a compromise. A particular balance for an orchestra may give rise to a complaint from an in-car listener that the quiet passages are lost under engine and road noise. At the same time, another listener sitting at home will complain that the balance has unnecessarily reduced the dynamics of the music.

This problem will get worse if Radio 3 loses its MF outlet. This is because, for reasons of obtaining the best out of the noisy MF broadcasting band, up to 20dB of compression is applied to the
Radio 3 MF transmitter distribution. This compression also improves the audibility for a listener in an acoustically noisy environment.

6. CONCLUSIONS ON PROGRAMME LOUDNESS

All networks control their peak levels to the same system maximum. A network with a narrow dynamic range (eg. Radio 1) will therefore sound louder than a network which allows a wider dynamic range (eg. Radio 3).

A limit on the maximum acceptable dynamic range is imposed by the noise levels in the broadcast chain and in the listener’s environment. BBC Studio Managers when balancing a programme are required to keep the dynamic range within acceptable broadcasting limits. This is to be done without losing the impact of the dynamic contrasts desired by the composer or author.

Problems of sustained low-level passages have arisen when commercial recordings (especially Compact Discs) are replayed in Continuity. One identified cause was that CD players were originally aligned so that a full modulation (all bits) sine-wave gave an output of +8dBu (PPM6). This was found to be insufficient in practice as wide variations in level were found between different Compact Disc recordings. Following further work the line-up level from CD players has been increased by 4dB.

Commercial recordings are often made with a dynamic range wider than is desirable for broadcasting. The Radio Sound Assistants (RSAs) who operate the Continuities are not able to ‘gain ride’ such recordings with a knowledge of the music being played. They are not trained score readers, neither is a score provided for their use. As a result, sustained quiet passages are allowed through uncorrected.

7. POSSIBLE SOLUTIONS TO IDENTIFIED PROBLEMS

The amalgamation of the operational part of Radio Networks with Studio Operations may make it practicable for trained score readers to operate Radio 3 Continuity. This would be an advantage when commercial music recordings with a wide dynamic range are being broadcast. Providing a suitable score is provided, it should then be possible for ‘on-air’ rebalancing of any such recordings.

Until digital recording becomes more widespread, the use of Dolby A noise reduction would help reduce the effect of tape hiss. This would be a particular advantage for serious music and drama.

It has been suggested that to aid the listener in an acoustically noisy environment, receiver manufacturers should be encouraged to incorporate some form of simple compressor, which can be selected if desired by the listener.

It has also been suggested that a dynamic range control signal should be made available as RDS data. This would allow a HiFi purist to restore the original dynamics while an in-car or other background listener may choose to reduce further the dynamic range of the signal. The RDS
specification already includes a speech/music code. On a suitably
equipped receiver this would allow a listener to choose his/her own
balance between speech and music levels.

8. REFERENCES

1. Guide to Acoustic Practice; ACED; February 1980

2. Derived from Microphone Data Sheets introduction

3. RTS Report BB/30 "Considerations of the A, B, and M PPM
relationships in FM Broadcasting"; May 1988

4. Engineering Training Supplement & "Programme Meters"; ETD; 1952

5. Sound Services Engineering Operational Instruction 01.1.4; March 1961


7. The Relative Loudness of Radio Programmes; David Stripp; August 1987

8. DDTM 3.70.64 Noise in Low-Level Audio Frequency Amplifiers and
Associated Equipment; 1964

9. RTS Report BB/34 "Revision of the Line-up level for Compact Disc
Players"; June 1988

DGE
11/7/88
FIGURE 2  OUTPUT UNWEIGHTED NOISE LEVELS V SYSTEM GAIN FOR VARIOUS ITEMS OF EQUIPMENT

TYPE 200 TAPE

TYPE D CONTINUITY DESK

SSL DESK 1 GROUP, 24 CHANNELS

SSL DESK 1 GROUP, 8 CHANNELS

SSL DESK 1 GROUP, 1 CHANNEL

THERMAL NOISE FOR 3DBx AT 20°C, 20MHz BANDWIDTH

REPORT 88/36  SYSTEM GAIN dB  RADIO TECHNICAL SERVICES  FIGURE 2
Figure 3 Noise Level vs Signal Strength for RC1/12A & RC1/17 Receivers.
Theoretical minimum noise for a microphone

A noise voltage is developed across any impedance due to thermal agitation. For a microphone amplifier, the thermal noise developed across the microphone output impedance sets an irreducible minimum.

DDTM 3.70(64)* gives the thermal noise voltage for a 600 ohm resistor when measured at 20°C with a 10kHz bandwidth as -128dBu rms.

The thermal noise voltage is a function of the product of the resistance and the bandwidth. Therefore the -128dBu rms figure also applies to a 300 ohm resistance when measured with a 20kHz bandwidth.

Because of the peaky nature of 'white' noise, a TPM will give a reading 4dB higher than that given by a true rms meter. Also, for white noise, CCIR 468 weighting is found to increase the reading on a TPM by 6dB compared with the unweighted figure.

Therefore, the thermal noise due to a 300 ohm resistance at 20°C is -124dB or -118dB4W.

For an SSL desk, the equivalent input noise when terminated in 300 ohms is -117dB4, i.e. a noise factor of 7dB.

(Unweighted noise measurements are normally used on acceptance testing to ensure that any faults producing low-frequency noise eg. hum, are detected. A few spot checks are made to ensure a difference of 6dB is maintained between the weighted and the unweighted noise.)

"In many listening environments the apparent relative loudness is a function of absolute loudness. For example, taking a concert ending with a good loud orchestral climax peaking PPM 6, followed by a continuity announcement peaking PPM 4, 8dB lower. Listener A, in a block of flats, who has kept the music quiet enough to prevent his neighbour banging on the wall, will complain that he cannot hear the announcement above various local acoustic noises. Listener B, in a detached house, who has spent thousands of pounds on his audio equipment and has enjoyed the end of his favourite symphony at the perfectly reasonable realistic level of 100dB(A), will then receive the announcer's voice at about 92dB, which is ridiculously loud, about 30dB above realistic speech level. Customer C, who is perhaps not a listener in the strict, attentive sense of the other two, uses Radio 3 as background music in his car, will not hear the announcement above the engine noise any more than he could hear those parts of the music which Beethoven unwisely failed to score above mezzo-forte. Even if we classify the in-car customer as outside the Radio 3 target audience for that programme, it is obvious that it is impossible to satisfy simultaneously listeners A and B. We receive letters of complaint from both groups quite frequently, with listeners of the B group also complaining that we bring up the quiet passages of the music excessively."

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"Much of the music of Radio 1 and 2 is scored for multi-microphone techniques and increasingly features the use of electronic processing within the balance, so that the balance is defined at the output of the mixing console rather than acoustically in the studio. As noted earlier, both close microphones and appropriate electronic processing normally make music sound louder, for a given PPM reading, than music in a natural perspective. Moreover, the vast majority of musical numbers on Radio 1 and 2 last only for some three minutes and do not feature significant variations in loudness.

The music which forms the major part of Radio 3 is, in contrast, defined in the studio or concert hall with an internal instrumental balance. The relative loudness of the component parts of a symphony is controlled by the exertions of the performers and by the relative numbers of, say, violins to trombones in the orchestra as evolved over hundreds of years, to sound correct for a listener in the hall. The composer, conductor and performers contrive wide dynamic contrasts, sometimes a sudden change, sometimes a long, slow crescendo or diminuendo, as a vital part of the music. Such dynamics are expected by the listener either from the experience of attending concerts or from listening to gramophone records. The potential dynamic range of such music is reduced somewhat to fit the 20-30dB dynamic range (loudest peak to quietest peak, which is not the same as signal-to-noise ratio) of the FM system. This control has traditionally been achieved by a music S.M. studying a musical score so that loudness changes can be anticipated, preserving moment-to-moment dynamics as intended by the composer while keeping the overall range within the system limits. Since much of the nature of "serious" music demands these contrasts of loudness, the level will much..."
of the time be below the maximum; thus the average will inevitably be lower than that of the short, electronically processed music items of Radio 2.

The loudest peaks of Radio 3 can be no higher, in transmitter modulation terms, than those of Radio 2. ... There is, however, no general reason for controlling a musical climax to anything lower, but a large proportion of Radio 3 music is either broadcast live or recorded before an audience, so that re-takes are impossible. Rehearsals are often only a rough guide to the levels which will occur when the whole chorus is present or simply when the presence of the audience enhances the performers' adrenaline flow, so it is understandable that the S.M. may tend to err on the side of caution on the maximum peaks. Nevertheless, the majority of musical climaxes do reach the system maximum and the protective limiters are driven into limiting at such times.

...BBC balances should not be a serious source of low average levels; indeed the evidence of PPM chart recordings made by the Quality Monitor shows that our own balances are not commonly the problem. The remainder of Radio 3 is composed of commercial discs with smaller amounts of foreign recordings, talks and drama.

...There is some evidence that foreign tapes are often lower in peak and average level than the BBC balances; if further checking confirms this it can be dealt with by existing procedures for little extra effort.

The question of disc material is more difficult. First, to dispel a common misunderstanding, there is no evidence that compact discs are being recorded with a wider musical dynamic range than vinyl discs. Extensive studies in Quality Monitoring, comparing C.D.s to the directly equivalent vinyl issues, show no trend to expand the musical loudness range to exploit the better signal to noise ratio of the C.D. system. The C.D. does, of course, offer the advantage that quiet passages could be controlled up without the unpleasant exaggeration of surface noise produced by raising the quiet passages of a vinyl disc.

Unfortunately no one is in the position to provide appropriate control of discs because they are almost always played in Continuity. There is no rehearsal in the normal sense; the best hope is that the R.S.A may get a chance to preface on the loudest part of the disc if the music is well known to the presenter, but no musical score is provided and the R.S.A. is not qualified to read one in any case. Thus it is not surprising that disc programmes show up clearly on daily PPM charts as having a wide dynamic range with extended periods of low level.

Possible solutions include playing every disc from a studio where a Group 3 S.M. could rehearse and control levels to a score; this is not seen as a realistic proposal....

There is a possible solution, novel in concept, which is uniquely applicable to Radio 3. Virtually all discs for transmission in this network are checked before use by the Boxing Clerk, part of Radio 3 Music Department. This allows a faulty copy to be replaced in good time. We have recently installed for trial in this area a C.D. Checker, developed by the Quality Monitor.

I believe it should be possible to introduce equipment here to analyse record levels with an appropriate time resolution. Information derived
from this analysis could be recorded in a convenient format, probably on floppy disc experimentally but eventually in a form thereafter inseparable from the disc or at least its case or sleeve (the concept is applicable to vinyl discs as well as CDs) and would control a variable gain device in the continuity repro channel. The potential for one-man operation is obvious.

As envisaged so far the analysing equipment would not only derive data on the maximum peak level on the disc, or each band if musically appropriate, but could actually reduce the dynamic range "upwards" unobtrusively. It can adopt the slow fader movements and anticipation of changes used by a music S.M. and need give none of the instantaneous mangling of moment-to-moment dynamics inevitably caused by the attack and recovery time constants of a conventional compressor. I am discussing the possible implementation of the proposal with Sound Section of Research Department and am obtaining some hopefully relevant research reports from Germany. I have already recorded the fader movements used by a music S.M. to re-control a CD of the notoriously wide-range Mahler's 8th Symphony to fit within our normal (if unwritten) balance criteria, to study how clever the control algorithm needs to be.

(The work at Research Department is now being dealt with by the Baseband Systems section.)

...the information relating to the repro channel "fader" movements can, I hope, be coded in a format which will allow its transmission within the RDS data stream. Thus the attentive listener at home can choose to restore the originally recorded dynamics (incidentally reducing any transmission link noise in the process) while the motorist or other background listener may choose to double the amount of compression. Incidentally, extending this re-expansion/over-compression facility to BBC balances would be more difficult as it is not a single fader control...

In all the above considerations I have assumed that the prime target audience remains ... the intent listener in reasonably quiet surroundings. If Radio 3 feel that some programmes should be slanted more towards the background user (And why not? The title "Homeward Bound" led many of us to such expectations) then this must be understood and allowed for at the balancing stage, not bodged by some processor designed for pop music attached to the output of continuity.
OPERATIONAL PRACTICE FOR CONTROL OF LEVEL
by Vaughan Reynolds

1. According to Studio Operations Training, SMs balancing for serious music are supposed to try and keep the dynamic range within the window of PPM 1 to PPM 6, as far as possible. The dynamic range for popular music can be as little as 4dB i.e. PPM 5 to PPM 6.

The current instruction is that the 'M' PPM should not exceed PPM 6 even if this means A & B are only 5 1/4, as they will be on coherent signals. This is rigidly adhered to.

Radio 3 Music SMs should be competent score-readers, and when balancing a programme, are trained to make intelligent use of the faders with reference to the musical score. Thus a sustained quiet passage can be gradually brought up in level, but level is reduced before a crescendo, both to avoid over-loud peaks, and to provide a realistic musical climax. This reduces the dynamic range, whilst maintaining the musical integrity of the work.

It is admitted, though, that because of the time lapse between SMs receiving their training and actually doing their own balances, many develop habits other than those taught, and larger dynamic range is often the result.

2. Measurements made of Radio 3 reveal that there is currently a good deal of programme where the dynamic range exceeds the 20dB recommended. This is particularly true when disc or CD is played in Continuity. Charts of the network outputs obtained in Network Supervisory Area show that the "average" level of Radio 3 is rather lower than Radio 2. This is no great surprise, since the peak-to-average ratio of drama and classical music is inevitably greater than that of popular music, even when techniques to reduce dynamic range have been applied. Radio 3 peak levels still reach PPM 6, or just over on occasions.

3. According to Radio Networks, RSAs who operate Continuities do not normally "gain ride" with a knowledge of the music being played. They are not score-readers, and if faders are used to increase levels of sustained quiet passages or reduce overload peaks, this is done according to the Technical Rules (O.I. 1.4 - Control and Modulation Range - March 1961). It is emphasized that RSAs only alter levels when the rules have been broken and they do not anticipate changes in level. Most vinyl LPs have similar peak levels due to the physics of the cutting/playback process. This means that, with experience, faders can be pre-set with reasonable certainty. However, some CDs have variations in peak levels of up to 10dB, making such pre-setting impossible. Unless the operator can read a score, there appears no easy solution to this other than playing the disc through first and providing a chart of the levels encountered throughout. The operator could use this to determine the correct balance. Another possibility is for a machine to provide the "chart" as data on a floppy disk. This data could be used to drive an automatic fader using an algorithm designed to compress dynamic range whilst still producing a musical result. Such a device would need much development effort, however. To make matters worse, some CDs are...
recorded at such a low level that there is insufficient gain available from the continuity desk to compensate.

[To correct for low level output from some CDs, the line-up level from continuity CD players was experimentally increased by 6dB (ie. so that a full modulation sine-wave gave an output of +14dBu). Further work shows an increase of +14dB (ie full modulation = +12dBu) to be sufficient.]

[Research department are working on a device to allow the automatic rebalancing of commercial discs and CDs.]

There is apparently a considerable variation in level control applied to both tapes and live OBs, especially between national regions. Some regions are well known to control to lower overall levels than others. Some tapes are supplied with line-up tone spliced onto the beginning which bears little relation to what follows it (some is even a different type of tape!). In a small sample of programme tapes, the tone varied by up to 2 dB between tapes from different sources.

[The tolerance of +1dB on record level could account for this difference]

RSAs will monitor the "H" PPM to ensure that it does not exceed PPM 6 even if this means that the A & B needles are only at PPM 5 1/4, as with a mono or centre-stage source. This potentially loses 3 dB of headroom in some situations.

[The question of the relationship between the A, B, and M levels is the subject of another report.]

Because of the way the "rules" have been written and interpreted, there is a greater tendency for RSAs to take down levels that are too high, than to bring up levels that are too low. While either action reduces dynamic range, the former causes a reduction in overall volume.

CONCLUSIONS

There is no "miracle" solution to the problem of audibility. Ultimately, the nature of the programmes being broadcast should determine the relative loudness of the various networks, unless artistic sacrifices are made. It is possible, however, to make careful changes in order to bring relative loudness of the networks closer together than they are at present.

It is obvious that different operators, balancers, etc. have their own idea of the dynamic range a particular piece of programme should have. If we are to go down the road of trying to increase the "loudness" of our programmes, we have to look closely at where in the chain dynamic range compression is applied. Current operational practices are placing much responsibility for level control and dynamics on RSAs in continuity, who are not trained for this task and are not recruited as score-readers etc. The alternative is the use of electronic equipment to compress signals prior to transmission.

[Organisational changes within Radio Networks and Studio Operations may make it practicable for trained score-readers to operate Radio 3

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continuity]

This brief study shows that there needs to be consultation throughout Programme Operations departments within Radio, to decide on a definite policy, to be applied universally as far as possible (if there is one already, it is not always being followed effectively). It need not restrict the freedoms of individual operators, but should make them aware of where their responsibilities lie. The final product should be consistent, and above all broadcastable, by the time it reaches continuity, if we are to achieve a louder sound without the wholesale use of electronic processing.

vr 20.4.88
INCREASING PROGRAMME LOUDNESS - ANOTHER VIEW
by Adrian P. Chinley

The following view is based upon my experiences as Quality Monitor, and a longstanding interest in audio. Many of the comments relate to R3 type material specifically.

Background

BBC Radio has endeavoured to provide a high technical quality service to its listeners in a cost effective way.

The recent adoption of audio processing on R1 & R2 has brought this premise into question, and even R3 is likely to be compromised in an effort to cater for the in-car, or casual listener. The public expectations of technical quality have risen, particularly since the arrival of the Compact Disc, and eventually it will be possible to receive television programmes with NICAM digital sound. In comparison, judging by the correspondence in various Hi-Fi magazines, many people are not entirely happy with the quality of FM broadcasts. It is also unfortunate that the majority of the public do not consider the effort or expense of installing a proper aerial to be worthwhile. Even when this has been undertaken, it does not guarantee satisfactory reception; the proliferation of 'pirates', particularly in the London area, often results in insurmountable co-channel interference.

There is a conflict between the listener at home in quiet surroundings using high quality equipment, and the in-car listener. The former would probably prefer a wide dynamic range, possibly greater than that presently attainable, whilst the latter requires that the dynamic range be restricted to aid audibility in noisy surroundings. At present, programmes are balanced to cater primarily for the former, but there is an increasing need to improve matters for the in-car listener. Inevitably therefore, any compromise will result in a reduction in technical quality.

Increasing Loudness

Simply increasing the overall level will result in the protective limiters operating even more frequently than at present, which is undesirable. Even if the present limiters were to be replaced by less 'aggressive' devices, it is not advisable to use protective limiters as compressors. In order to increase loudness it makes more sense to leave the loud passages unaffected, and raise the level of the quieter passages. There are a number of ways in which this may be achieved:

1a. Train operational staff to increase the level of quiet passages. This is often done at present by music SH's using a copy of the score, and generally BBC recordings do not suffer from extended periods of very low modulation. Commercial recordings however may have a wide dynamic range, and since most of these are replayed in the continuity by musically untrained staff, it is not possible to manually control levels. In the future, suitable staff may be employed in these areas who could undertake this task; however, I believe the automatic level control as proposed by David Stripp to be a more elegant solution.
1b. The present PPM does not provide a very good indication of low level signals (PPM ‘1’ corresponding to just 20dB below peak level). Altering the law so that PPM ‘1’ corresponds to say 40dB below peak provides a better indication of low level signals. It is then possible to set a guideline that a programme should never drop below PPM ‘1’, which with the present PPM line-up is unrealistic. This would be easier to follow than a request that the programme should not drop below PPM ‘X’ for a period exceeding Y seconds. Whilst it would be difficult to modify the low end law of existing PPM’s, it should be reasonably easy with the new digital replacement.

I do not believe that any other alterations to PPM line-up or function are necessary or desirable.

2. Insertion of a signal processor prior to the transmission chain. Devices like those presently used on R1 & R2 are unlikely to be suitable for R3. Tests carried out in Quality Monitoring suggest that the optimum degree of compression with many audio processors is about 4dB. More than this and undesirable side-effects become noticeable on critical material, less and it is not worthwhile.

Probably the best type of processor for R3 is of the compressed side chain configuration. With this arrangement the input signal is heavily compressed (e.g. by 20dB) and added at a low level (e.g. -20dB) to the main signal. In this way the compressed side-chain contributes little when the signal level is high, but becomes increasingly significant at lower levels. By mildly tailoring the response of the side-chain component, the increase in background noise, which is inevitable with compression, may be largely avoided.

3. Encourage receiver manufacturers to fit user selectable compression. This should prove beneficial to the in-car listener, although where the incoming RF signal is weak it may only serve to make matters worse. With the possibility of the BBC marketing its own RDS receiver in the future, we may be in a position to influence manufacturers in this regard.

4. Although I think it unlikely to be adopted, there is one way of restricting the broadcast dynamic range to the benefit of both the home and in-car listeners. A simple compressor prior to the transmission chain, giving say 1:1.2 compression, would provide the in-car listener with a suitably narrow dynamic range. Many home listeners would also find this restricted range satisfactory. By adding a suitable expander, the serious listener could restore the full dynamic range, and also benefit from an overall improvement in signal/noise. Since the cost of providing the decoder is likely to be relatively small, many listeners would consider it worthwhile for the improvement offered.

As an alternative to a straight compander, Dolby B noise reduction could be employed. If this were coupled with a change in the pre-emphasis characteristic from 50uS to 25uS (or less), much of the excessive brightness of the un-decoded signal would be reduced (assuming 50uS de-emphasis in the receiver). An even better alternative would be Dolby SR since the un-decoded signal sounds less processed. However the high cost of suitable decoders would prove unpopular with listeners.

Overall, the straight compander is probably the best solution since it does not require careful level matching, provides wide-band compression,
and the un-decoded signal is more acceptable.

Programme Balance

A universal complaint from listeners is that the ratio of speech/music levels are wrong. Once again there is a conflict between the home and in-car listener, the former generally finds speech levels too high, whilst the latter complains that announcements are often inaudible. With the advent of RDS it should be possible to use a spare sub-code to identify programme content (e.g. speech or music) and enable suitably equipped receivers to set the volume for each programme type according to user selected settings.

The Future

The present FM broadcast system does not appear capable of satisfying all listeners, without radical change. This could either involve the adoption of a compander on the present service, or the use of an additional broadcast frequency carrying a compressed feed. Perhaps in future FM, with suitable compression, will be used for casual listening with the serious listener relying upon a digital DAB service.

Adrian P. Chinery, R.T.S. (Technical Investigations), May 1988