DAB and CD quality — reality or illusion?

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This article reports on the results of an investigation carried out into whether the transmitted sound quality offered by Digital Radio (DAB) stations in Germany is superior to that of FM radio. The tests revealed that not all is as it should be, with many stations not conforming with the relevant ARD recommendations for DAB broadcasters.

When assessing the quality of audio codecs, especially for broadcasting, it cannot be presumed that the broadcast signal has endured just one coding process. The processing and distribution of broadcast signals can often include multiple coding/decoding processes. The so-called *cascading* or *concatenation* of audio codecs can generate perceivable impairments, depending on the number of coding processes and the bitrates used [1][2].

Because the coding history of the DAB signals we investigated was unknown, coding artefacts could not be completely excluded. However this study did not primarily focus on those coding artefacts. In order to do that, it would have been neccessary to apply other assessment methods than those presented here.

The main objective of the study was to determine whether broadcasters or programme providers really use the full potential of DAB to deliver radio programmes – with near-CD quality – to listeners, under optimal reception and listening conditions. In other words, our investigation was to determine if signal-processing systems – such as limiters, compressors and sound processors – are being used to maintain the original sound quality of the source, or whether these source signals are being altered adversely along the broadcast chain, resulting in diminished sound quality of the transmitted programmes.

When considering analogue (AM/FM) radio, or programmes that are mainly produced for in-car reception, dynamic compression seems to be useful (e.g. improvements in signal-to-noise ratio, adaptation of the programme dynamic range to the listening environment, etc.). However, in the case of Digital Radio – and presuming optimal reception and listening conditions at home – dynamic compression is unnecessary.

Certain broadcasters use dynamic compression and sound processing in Digital Radio to tailor the sound profile of individual programmes, in an attempt to differentiate them from other programmes or programme types. Naturally, such signal manipulation must be criticised if the quality of the transmitted programmes is substantially impaired by this kind of processing.

A brief history of DAB

The DAB system parameters were defined in 1992 and DAB was introduced as a European standard for digital radio broadcasting in 1995 [3].

The fundamental parameters of the system are:

- method of transmission — COFDM;
- two synchronized broadcasting networks — Band III (174 - 240 MHz) and L-Band (1452 - 1492 MHz);

- bandwidth — 1.536 MHz;
- usable data rate of the COFDM package — 1.8 Mbit/s;
- audio coding — MPEG-1 Layer 2 (Stereo 64 - 384 kbit/s); ARD recommendation is ≥ 192 kbit/s [4];
- Support for data transmission [PAD – together with Audio: NPAD – separate (stream or packet mode)].

The first pilot DAB projects were carried out in Germany in 1995. At that time, DAB had already beeen introduced in the United Kingdom and Sweden. Operational DAB services started in Germany in 1999.

At the time of writing (August 2003), more than 150 DAB stations were on-air in Germany [5] along with several additional services (e.g. radiotext, automatic and local interactive multimedia services). Approximately 65% of the population, and the land area, were covered by Digital Radio. Most of the 16 Federal States had launched DAB services. By 2005, some 88% of the land area and 90% of the German population will be covered. In other countries, large area coverage by DAB has also been established, notably in Belgium, Portugal, Switzerland, Norway, Italy, Canada and Singapore.

To date, some 350,000 receivers have been sold worldwide, with 30,000 being sold in Germany. In 2004, the receiver manufacturers plan to step up their sales rate in Germany to between 40 and 80 thousand receivers per year.

ARD's feelings about DAB are outlined in the accompanying yellow text box, which gives an extract from an ARD press release.

ARD press release, 29 January 2002

"**Implementing Digital Radio (DAB)** … attractive additional services should be developed to provide an inducement for listeners to switch to digital. Digital Radio offers opportunities for new programme innovations and the networking of existing programmes. ARD plans to increase its investment in Digital Radio by completely renovating its programme-making resources and its transmitter infrastructure to accommodate the new digital technique" [6].

Assessment of DAB sound quality – the concept

In order to evaluate the sound quality of DAB, 15-minute samples of actual German DAB programmes (from both public and private broadcasters) were recorded at different locations throughout Germany. From these samples, short clips of about 10 seconds duration were extracted, by fading in and out. Where possible, these clips (test sequences) included two examples of speech (female/male), a typical music sequence as well as a commercial – from each of the DAB broadcasts that had been recorded,

Table 1 (on the next page) shows the 88 test items from 33 DAB stations (48% public, 52% private) that were investigated. In the table, Ads = commercials and j stereo = joint stereo.

The evaluation of the sound quality was based on the following aspects:

- programme levels;
- loudness;
- sound quality;
- sound neutrality.

While the parameters "programme levels" and "loudness" could be measured objectively, the assessment of "sound quality" and "sound neutrality" had to be carried out by means of psychoacoustic experiments. To avoid confusion between sound quality/neutrality and loudness, the loudness of all test items was adjusted with the help of the objective loudness measurements.

Abbreviations

AM	Amplitude Modulation
COFDM	Coded Orthogonal Frequency Division Multiplex
DAB	Digital Audio Broadcasting (Eureka-147)
dBFS	dB relative to Full-Scale reading
FM	Frequency Modulation
LSM	Loudness Meter
MPEG	Moving Picture Experts Group
NPAD	Not Programme-Associated Data
PAD	Programme-Associated Data
PPM	Peak Programme Meter

Table 1 – DAB test items

DAB station	Status	Speech male	Speech female	Ads	Pop/ Rock	Clas-sical	Ensemble	bitrate kbit/s	Mode
Bayern 2	public	+			+		Bayern	160	j stereo
Bayern 3	public	+	+	+	+		Bayern	160	j stereo
Bayern 5	public	+	+				Bayern	96	mono
Galaxy	comm.	+	+		+		Bayern	192	j stereo
RockAntenne	comm.	+	+	+	+		Bayern	192	j stereo
Antenne BB	public	+	+		+		BRBG 12	192	j stereo
BBRadio	comm.	+	+		+		BRBG 12	192	j stereo
DLR	public	+	+		+		BRBG 12	192	j stereo
ORB 1	public	+	+		+		BRBG 12	192	j stereo
RS2	comm.	+			+		BRBG 12	192	stereo
Energy	comm.		+		+		BRBG LE	192	j stereo
RTL	comm.	+	+	+	+		BRBG LE	192	stereo
BBRadio	comm.	+			+		BRBG LI	192	j stereo
Rock FM	comm.			+	+		BRBG LI	128	j stereo
RockIT Radio	comm.				+		BRBG LI	128	j stereo
SpreeRadio	comm.	+			+		BRBG LI	192	j stereo
BigFM	comm.	+	+		+		DAB BW	192	j stereo
DasDing	public	+	+		+		DAB BW	160	j stereo
HitRadio	comm.	+	+	+	+		DAB BW	192	j stereo
SWR 1	public	+	+		+		DAB BW	160	j stereo
SWR 2	public	+	+			+	DAB BW	192	j stereo
SWR 3	public		+		+		DAB BW	160	j stereo
DigMove	comm.				+		LSA-L	192	j stereo
DLF	public	+	+			+	Sachsen-Anhalt	192	j stereo
MDR Klassik	public	+				+	Sachsen-Anhalt		j stereo
Project	comm.	+			+		Sachsen-Anhalt	192	j stereo
Radio SAW	comm.	+	+	+	+		Sachsen-Anhalt		j stereo
Rockland S-A	comm.	+	+		+		Sachsen-Anhalt	192	j stereo
DW	public	+	+				SFB/DLR DAB K8C	64	mono
SFB Kultur	public	+	+			+	SFB/DLR DAB K8C	192	j stereo
SFB Multikulti	public	+	+		+		SFB/DLR DAB K8C	192	j stereo
SFB 88.8	public		+		+		SFB/DLR DAB K8C	192	j stereo
WDR2	public	+	+		+		SFB/DLR DAB K8C	192	j stereo

Measurements carried out

Programme and loudness levels

Measurement of the programme levels, the peak programme levels (PPM) and the quasi-peak programme levels (QPPM) were carried using ARD broadcast programme meters (ARD Pflichtenheft 3/6 with 0 ms and 10 ms integration time [7]).

Measurement of the loudness was carried out using loudness algorithms developed at the IRT [8][9]. The IRT loudness meter is based on the analysis of the display of QPPM with an integration time of 10 ms and a decay velocity of 20 dB/1.5 sec. The loudness level LSM is related to the median of QPPM levels over a defined time interval of, for example, 3 sec. The reading of the IRT loudness meter corresponds to 90% of the subjective loudness [8][9]. The IRT loudness meter is implemented as prototypes in two broadcast programme level meters (Pinguin and DAG2000) [10]. Both instruments are equivalent, meaning that identical readings of loudness levels are achieved with either, and both allow us to record the displayed levels vs time for further analysis. In the tests described here, the PC-based device (Pinguin) was used.

Figs. 1 and *2* illustrate how the measurement results were displayed, in this case for just eight test items (speech and music).

The corresponding maximum values PPM_{max}, $QPPM_{max}$ and the median of LSM were derived for each test item *(Fig. 1)* and presented as a stacked bar diagram *(Fig. 2)*. The three values in each stack describe the individual test item and define the characteristic level profiles which help us to compare different test items.

The values of $QPPM_{max}$ and LSM were of specific interest because they show the relationship between modulation and loudness.

In accordance with ARD HFBL-K Recommendations 15-IRT *"Headroom for digital audio"* and 21-IRT *"Avoiding loudness differences in DAB/FM receivers"* [11][12], the maximum QPPM values in digital audio production and DAB broadcasting should not exceed –9 dBFS. That means using a level meter that accords with [7] and which has an integration time of 10 ms and a headroom reserve of 9 dB.

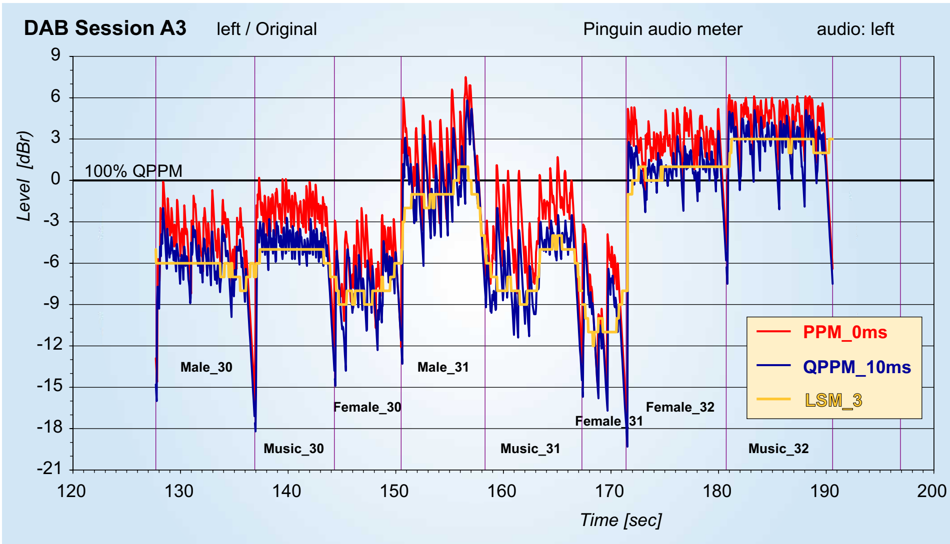

Figure 1
Measurement results for PPM, QPPM and LSM (versus time) with eight selected test items

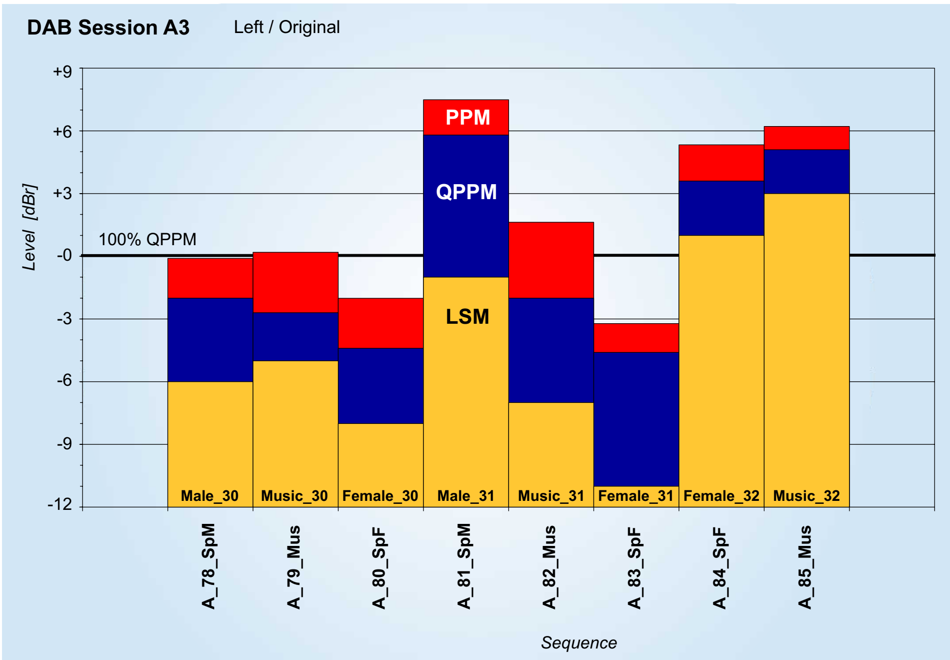

Figure 2
Individual test sequence parameters for PPM_{max}, $QPPM_{max}$ and LSM_{median}

In this context, it was interesting to observe how far these recommendations are also met by private DAB stations and, moreover, which individual loudness and QPPM profiles result from current modulation practice.

The profiles analysed (PPM, QPPM and LSM) are naturally of interest when comparing different DAB radio station. However, they are also of interest when comparing different programme blocks from an individual DAB station. Complaints from listeners often concern extreme differences in loudness between programmes, particularly in the case of commercials. Thus different programme blocks which included commercials were also analysed.

Sound quality and neutrality

During the psychoacoustic assessments, the parameter *sound quality* was used when assessing music items while *sound neutrality* was used for speech items. The assessments were carried out using the following 6-point quality scale, well-known from German school grades.

1	2	3	4	5	6
very good	good	satisfactory	just adequate	poor	unacceptable

The test persons were instructed to concentrate particularly on negative effects such as:

- excessive emphasis within particular frequency ranges (bass, midrange, treble);
- excessive changes in modulation level ("pump effects") and other distortions;
- excessive compression of the dynamic range;
- excessive background noises e.g. unnatural breathing noises during speaking, studio ventilation noise.

In order to avoid confusion between "sound quality" assessment and "loudness", all the test items were adjusted in accordance with the results of the loudness measurements. The assessments were carried out under stereo studio listening conditions in accordance with [13]. Each test item was presented twice.

Results

PPM, QPPM and LSM profiles of programme blocks with commercials

The results analysed above (peak values of PPM, QPPM and the median value of LSM) are presented in *Fig. 3* for seven DAB programmes containing commercials. It can be seen that jumps in loudness (yellow bars) between programme blocks (speech/music) and commercials are not dramatic in the case of any single station.

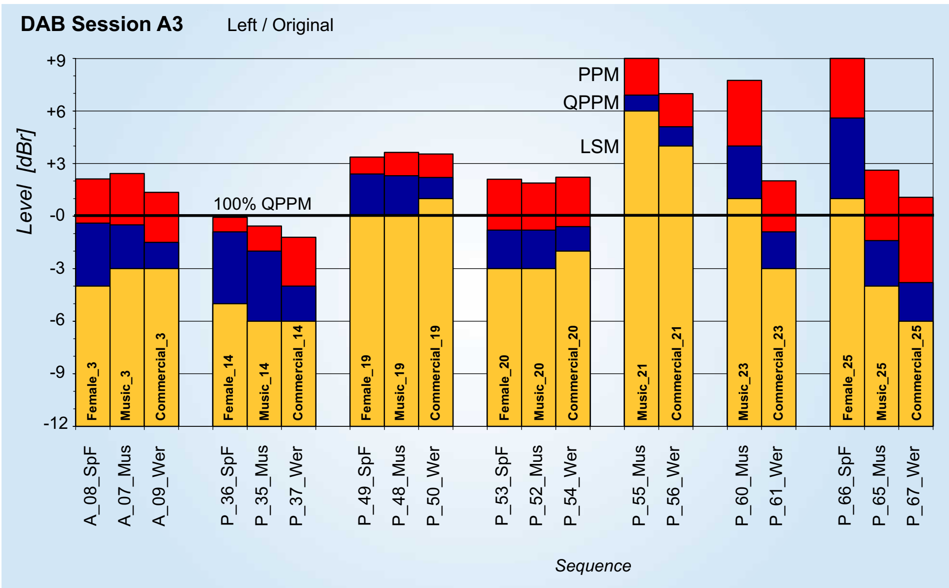

Figure 3
Measurement results for QPPM and LSM profiles, in combination with commercials

When noticeable jumps in loudness (>3 dB) occur (e.g. Programmes no. 23 and 25), they have to be interpreted as *positive* because the loudness of the commercials are *reduced* compared to the music or speech content.

Strong jumps in loudness (>10 dB) are indeed observed when comparing different DAB stations. However, these jumps are primarily caused by different modulation profiles, as the following results also show.

Comparison of public and private stations – PPM, QPPM and LSM profiles

Figs. 4a and *4b* show the original programme level situation of the public and private DAB stations under test. Comaparing the public stations (prefixed with "A_") with the private stations ("P_"), considerable level differences can be seen. In this context, the maximum $QPPM_{max}$ values (blue bars) are particularly interesting

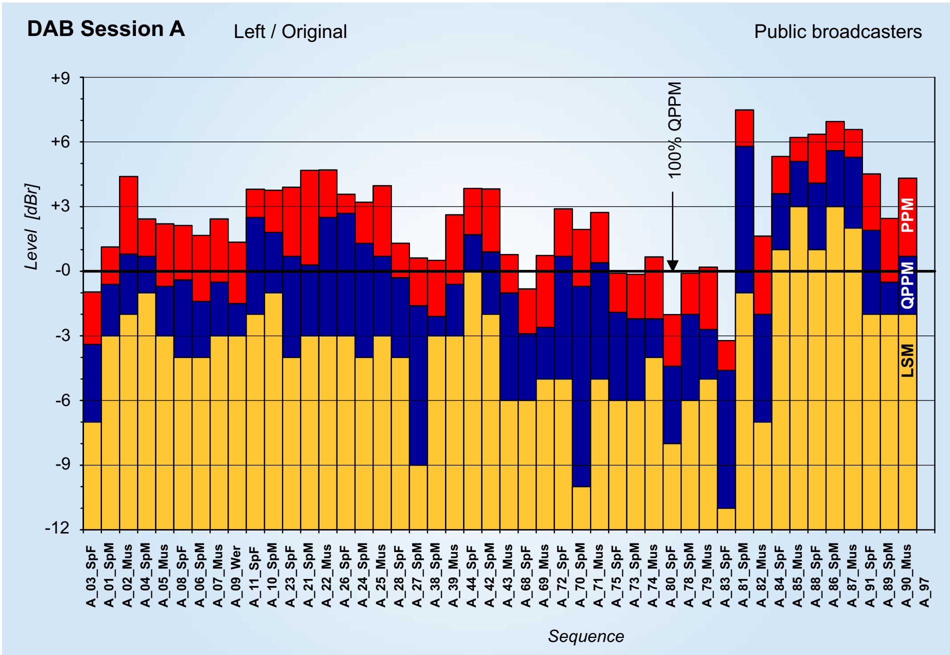

Figure 4a
PPM, QPPM and LSM profiles – music and speech sequences of public DAB stations (A_ stations)

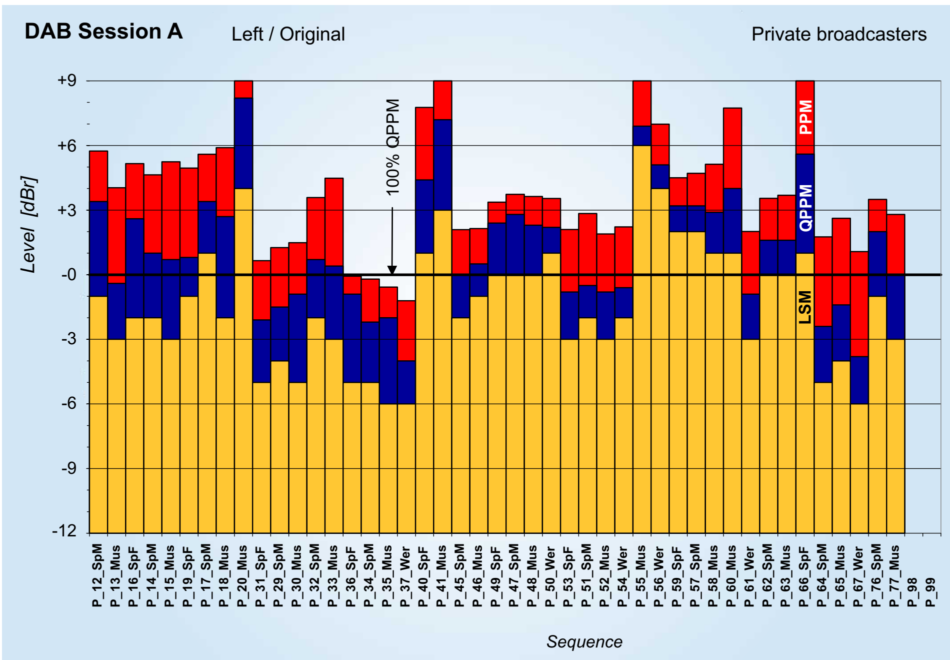

Figure 4b
PPM, QPPM and LSM profiles – music and speech sequences of private DAB stations (P_ stations)

because these values should meet with the corresponding ARD recommendations [11][12]. In these recommendations, the 100% modulation tag is defined as $QPPM_{max}$ = 0 dBr = –9 dBFS.

In *Figs. 4a* and *4b* “undermodulation” as well as “overmodulation” is noticeable. Only a few A_ and P_ stations meet the ARD recommendations. The main difference between A_ and P_ stations is obviously that a few programmes show full-range modulation: PPM_{max} = 0 dBFS = “clipping level” whereas the A_ stations maintain a certain headroom range.

Jumps in loudness of up to 13 dB (yellow bars) can be observed, caused by different levelling practices.

Meeting the corresponding ARD recommendations [11][12] as calculated and presented in *Figs 5a* and *5b*, it can be observed that jumps in loudness cannot completely be eliminated but could be reduced. Remarkable

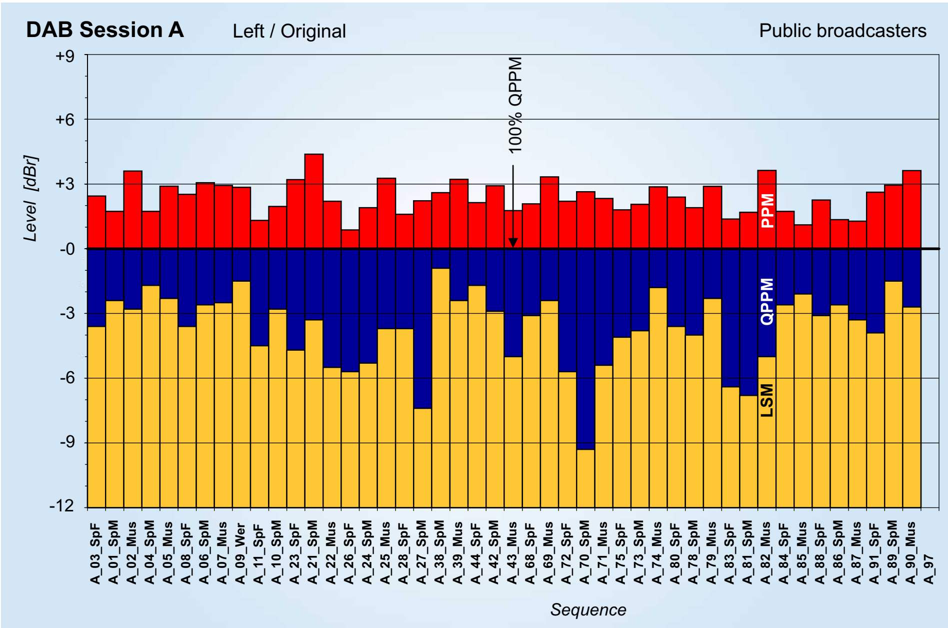

Figure 5a
Adjusted PPM, QPPM and LSM profiles – music and speech sequences of public (A_) DAB stations

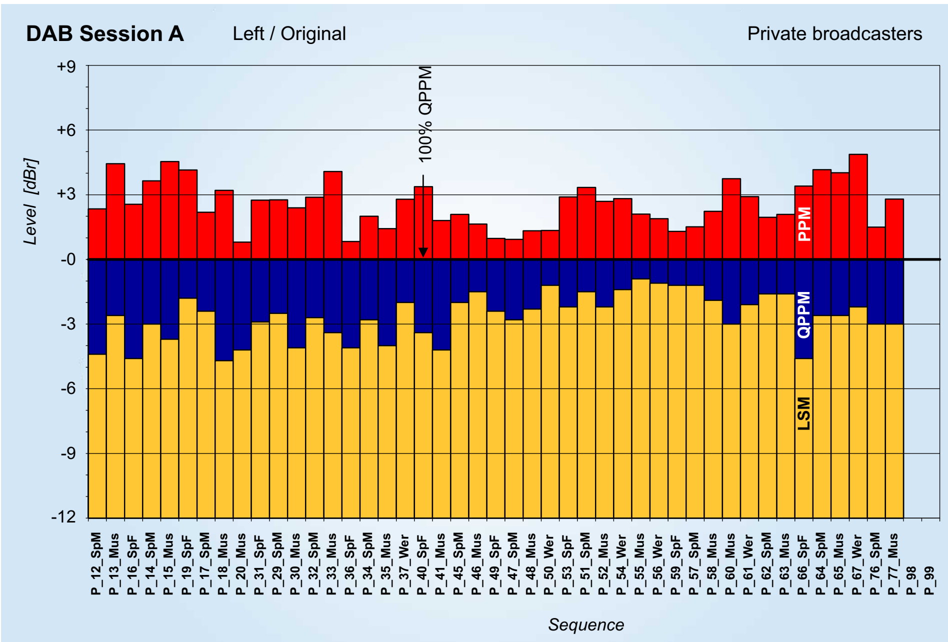

Figure 5b
Adjusted PPM, QPPM and LSM profiles – music and speech sequences of private (P_) DAB stations

jumps in loudness (>6 dB) only occur in a few cases.

A harmonization of loudness differences between DAB stations would be achieved by following the corresponding ARD recommendations [11][12]. In order to guarantee an optimal loudness balance between DAB programmes, the programme loudness should also be controlled in the broadcast studios. This means that, besides the programme level meters PPM and QPPM, a corresponding loudness meter would be helpful. The IRT loudness meter would be an appropriate choice for this purpose.

Among other things, the measurements presented in *Figs 5a* and *5b* show that the recommended headroom of 9 dB (= –9 dBFS for QPPM) ensures sufficient reserve against signal clipping – even if no limiter is applied and unexpected "overmodulation" occurs.

Assessment of sound quality and sound neutrality

The listening set-up was based on absolute assessments of the recorded test items, without comparing them with the original programme material. Therefore, it could be expected that the test results for each item might be influenced by the preceding sound clips – resulting in a relatively wide dispersion of grades. However, even though we are all more familiar with human voices than with music recordings in general, it could not be shown that this dispersion effect was more apparent with music than with speech.

The results of the *subjective* assessments were presented as (rounded) means and 95% confidence intervals of the means. The 95% confidence intervals – applying an error probability of 5% – give a range of values around the mean where you would expect the "true" (population) mean to be located. Therefore, the 95% confidence intervals are appropriate for estimating the significance of any differences between different means. In other words, overlapping of the confidence intervals suggests no significant differences between the means under consideration. On the other hand, if the confidence intervals don't overlap, it can be assumed that any differences between the different mean gradings are significant.

Results for the music items are shown in *Fig. 6* and for the speech items in *Fig. 7*. In either diagram, different groups of items can be distinguished which belong to the same quality range. These groups differ significantly from other groups of items in the adjacent quality ranges.

Referring to *Fig. 6* (music), the mean assessments fell between < 2 = Good > and < 5 = Poor >. Fortunately, only 6% of the music sequences were assessed as < 5 = Poor > whereas 13% were assessed as < 2 = Good >.

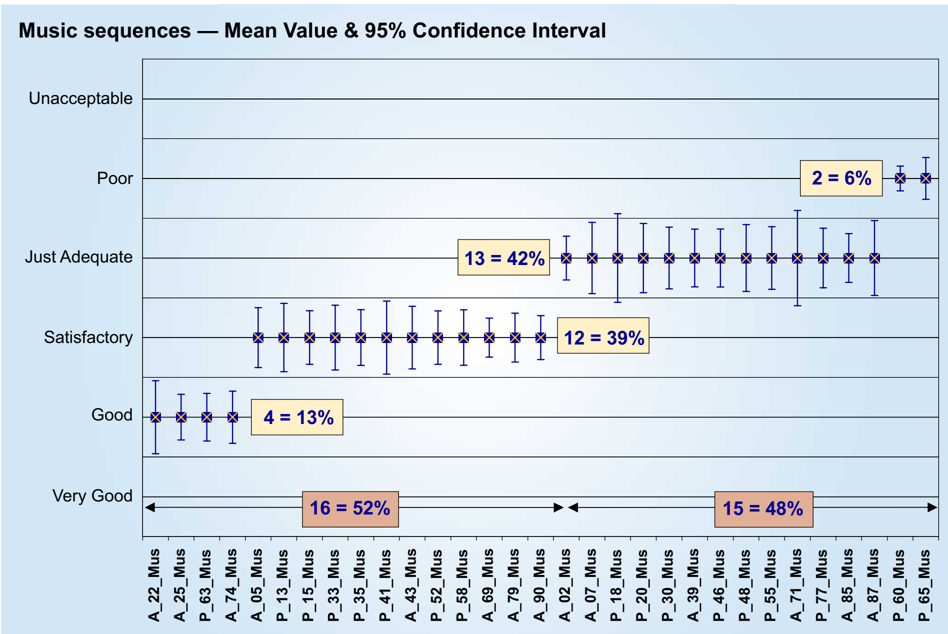

Figure 6
Sound quality – music sequences

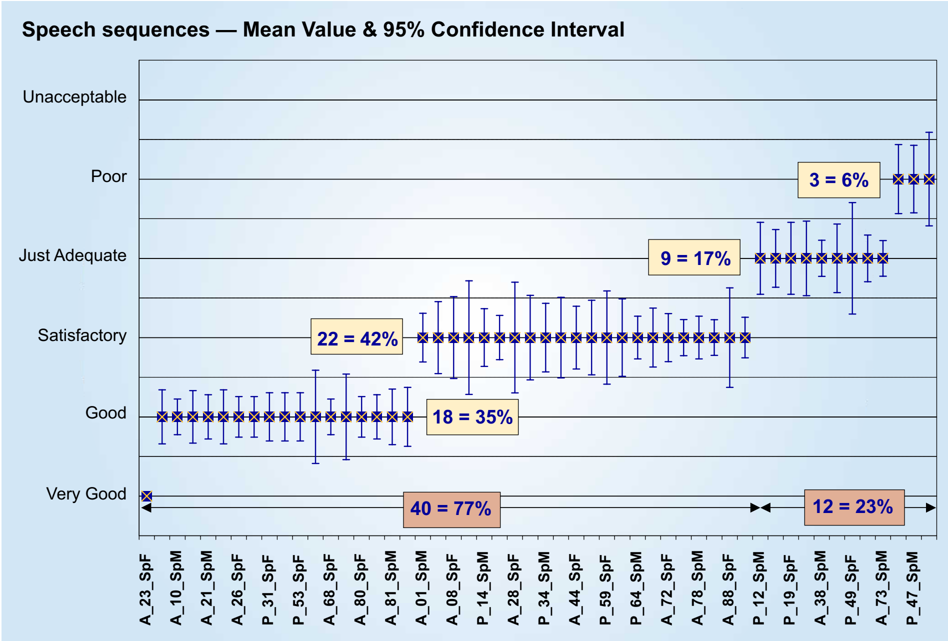

Figure 7
Sound quality – speech sequences

Of the other music sequences, 39% were assessed as < 3 = Satisfactory > and 42% as < 4 = Just Adequate >. If we define a more flat quality ranking of < 1 – 3 = rather good > and < 4 – 6 = rather poor >, 52% of the music items were assessed as “rather good” and 48% as “rather poor”.

Turning now to *Fig. 7* (speech), the quality distributions look slightly better. Only 6% of the items were assessed as < 5 = Poor > whereas 35% were assessed as < 2 = Good >. The other speech items were distributed between the quality ranges < 3 = Satisfactory > (42%) and < 4 = Just Adequate > (17%). When redefined in the flatter ranking scale introduced above, 77% were assessed as “rather good” and 23% as “rather poor”.

Conclusions

Altogether 86 short test items – recorded off-air from 33 German DAB stations – were analysed in the study described here. These items included male/female speech, music and commercials (ads). Besides the measurement of PPM and QPPM levels, the IRT loudness algorithm LSM was implemented in the PC-based level meter, Pinguin [10]. This meter allowed us to record the measured values versus time, for later analysis.

Starting on a positive note, the investigation found that the majority (67%) of German DAB stations use a data rate of 192 kbit/s which, in theory, should offer DAB listeners near-CD sound quality under favourable reception and listening conditions [4]. However, this was about the only positive point that emerged from the study.

Despite the existence of two current IRT recommendations for public broadcasters [11][12], diverging programme levels were observed on both public and private DAB stations. These diverging levels resulted in hugh jumps in loudness when switching between some stations. When considering different programme blocks (including commercials) from any one particular station, the jumps in loudness were in the main, quite tolerable.

If DAB stations were to follow the ARD recommendations (which define the maximum modulation of $QPPM_{max}$ = –9 dBFS), this would substantially reduce the loudness differences encountered between various stations. Even further improvements, in this respect, could be achieved if DAB stations used the IRT loudness meter.

The study also embraced the sound quality and neutrality provided by each station. As the evaluations were done without comparing the test material with a reference source, it cannot automatically be concluded from the results that the sound quality/neutrality was mainly being impaired by sound-processing equipment. We

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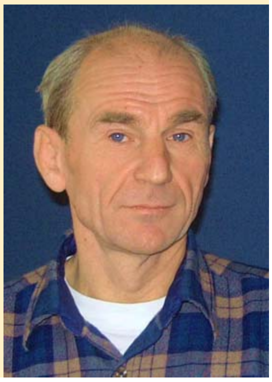

Siegfried Klar studied communications engineering at the academy of Giessen (Germany). Since 1978, he has been on the scientific staff of the Institut für Rundfunktechnik, Munich (IRT). After dealing with video measurement engineering, he changed to the radio broadcast department. In this new working field, he concentrated on problems addressing analogue and digital audio processing and the broadcasting of radio and TV signals.

Dipl.-Ing. Klar's current area of activity covers the analysis and optimization of digital audio broadcasting systems.

cannot exclude the possibility that the source material itself – the various male/female programme presenters, the position of the microphone etc. – were determining factors in the results that we obtained.

Among the music items tested, about 50% were evaluated as “rather poor” – this figure dropping to 23% in the case of the speech items. **Those DAB stations found to offer rather poor sound quality, particularly with music, are advised to apply sound processing in a more controlled manner!** This cannot be stressed too strongly. Even if sound processing (including compressors and limiters) is deemed to be necessary in broadcasting, the better controlled use of such devices could lead to significant improvements in the overall transmitted sound quality – so that DAB listeners at home could really benefit from the near-CD quality that the DAB channel has to offer them.

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