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Terminology for loudness and level

dBTP, LU, and all that

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Abstract

This document describes briefly some of the terms and techniques that are used to describe and control the loudness and level of audio in broadcasting. Sometimes misunderstanding can occur because of loose or inaccurate use of terminology. The purpose of this document is to reduce that.

The kind of terms that are often used, are things like dB, dBFS, LUFS, LU, LKFS, dBu, dBm, V, alignment level, programme reference level, target level, dialogue level, loudness level, together with a range of “standard” numbers: 0.775, 0, -18, -20, -23, -24, -27, -31.

A description of dBFS, LU, LUFS, and related terms is given, together with an explanation of some of the common numerical values that are associated with measurements that use these units. Two methods of loudness normalisation using meta-data are briefly described and compared.

True-peaks of an audio signal can exceed the highest sample value (the sample peak) when the signal is processed, potentially leading to clipping. Proper metering and control of levels is therefore necessary.

Additional key words: MPEG 4, Dolby, dialnorm, RF mode, Line mode

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Introduction

This document describes briefly some of the terms and techniques that are used to describe and control the loudness and level of audio in broadcasting. Sometimes misunderstanding can occur because of loose or inaccurate use of terminology. The purpose of this document is to reduce that.

The kind of terms that are often used, are things like dB, dBFS, LUFS, LU, LKFS, dBu, dBm, V, alignment level, programme reference level, target level, dialogue level, loudness level, together with a range of "standard" numbers: 0.775, 0, -18, -20, -23, -24, -27, -31.

Let's start with a simple term, move on to its units, and then explore some of the more complicated terms.

Alignment level

Simply put, this is the agreed signal level that will be used when aligning equipment or circuits, which in this context means adjusting for an overall gain of unity. Figure 1 shows a simplified outside broadcast. To check the alignment of the contribution link the remote site sends tone at alignment level to the studio. Meters at both ends are used to check that the signal level is what it should be. Typically, alignment level for analogue circuits is "zero level", meaning 0dBu ($0.775V_{RMS}$) and for digital, -18dBFS. These units will be explained fully later.

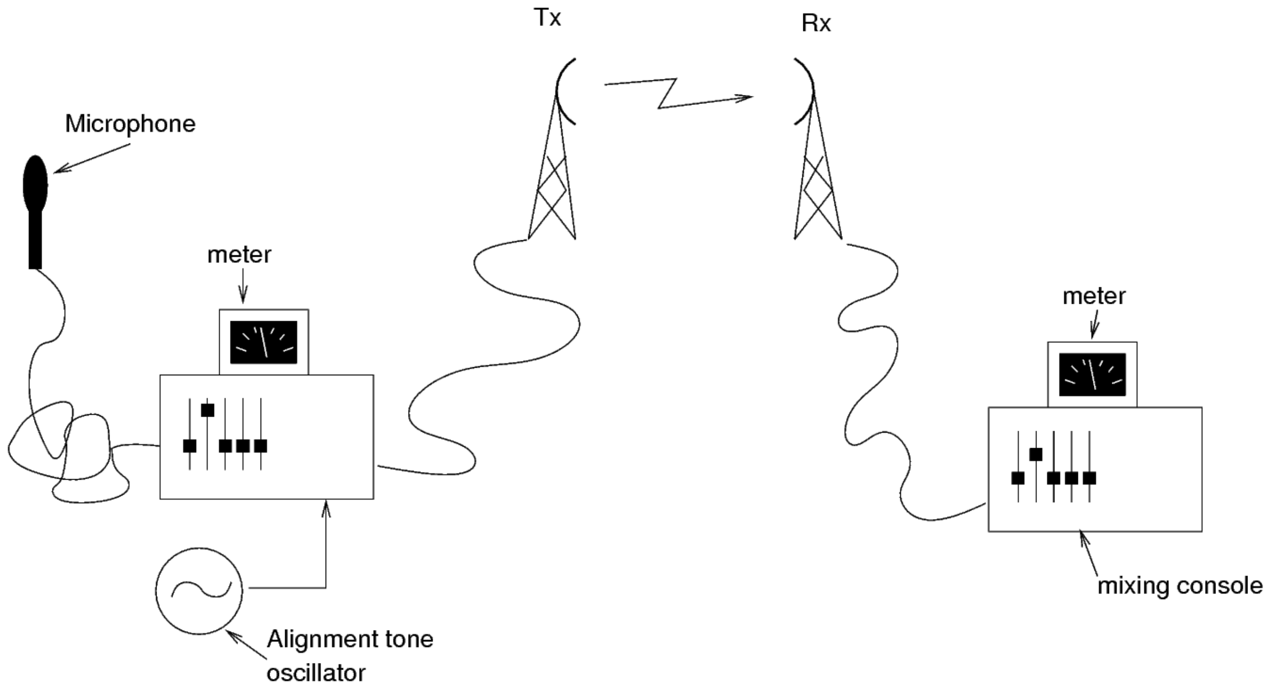

Figure 1: Alignment of contribution link

Alignment level is the signal level used during the process of alignment. It helps if we all agree to use the same level, so we use 0dBu, or -18dBFS, at 1kHz[1].

Units

dBu

The dB (decibel) is often used, and often used rather loosely. The dB is a *relative* measure of power. The value of a property of something is expressed *relative* to another value, as a ratio. Mathematically, if we want to express the value of P in dB, it's like this:

$$value = 10\log\left\{\frac{P}{P_{ref}}\right\} \ dB$$

Where P is the thing that we are measuring and P_{ref} is the thing relative to which we are going to express the result. We will be dealing with voltages, and so we will use "20 log" rather than "10 log" from here on[2].

So, if X is half of Y, expressed in dB, relative to Y, this is -6.02. If X is twice Y, it will be +6.02.

We might say, "X is +6 dB" and this would make sense if we knew that it was relative to the value of Y. We could say, "X is +6dB with respect to Y", or if Y is $0.775V_{RMS}$ we could say, "X is +6dB with respect to $0.775V_{RMS}$.". Why $0.775V_{RMS}$? Because that's the voltage that dissipates 1mW in 600Ω – a measure well-known in telecommunications.

This is rather long-winded, so units such as "dBu", are used. "dBu" is short for "dB with respect to $0.775V_{RMS}$".

So, "X = 0 dBu" means that $20\log\left\{\frac{X}{0.775V_{RMS}}\right\}$ is 0, so X is $0.775V_{RMS}$.

dBFS

In the digital domain, signal levels are usually expressed relative to the maximum possible signal level that can be represented in the numeric format being used. For example, in a 16 bit digital audio signal the usual "two's complement" representation would go up to 32767. So we would say that digital full scale is 32767 in a 16 bit system. A "0 dBFS sine wave" is one where the true peaks are at the maximum possible level that can be represented. A -18dBFS sine wave is one that peaks 18dB below the full scale value.

From dBu to dBFS

In converting a signal from analogue to digital, one must decide how many volts are going to equal how many digits. This is, in general, arbitrary, but for the sake of a simple life in broadcasting, it is much easier if we can agree on a single alignment of volts to digits. In Europe the alignment is such that 0dBu in the analogue domain is equivalent to -18 dBFS in the digital domain:

$$0dBu \leftrightarrow -18dBFS$$

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[1] Other frequencies are sometimes used, for example 997 Hz, or 1020 Hz.

[2] If the quantities X and Y are measures of power, a factor of 10 is used. Using a factor of 20 instead has the effect of squaring the quantities, which is appropriate if they are like voltage, where the power depends on the square of the voltage.

To summarise, “dB” is a relative term. “dBu” is relative to $0.775V_{RMS}$, “dBFS” is relative to maximum digital full scale. Use of “dB” on its own carries a risk unless it is completely, unambiguously, clear to what absolute value the value being described is relative.

Alignment level, again

As was stated earlier, alignment level is usually 0dBu or -18dBFS. This should now make complete sense, if it did not before. Note that this does not mean that 0 equals -18, nor that 0dB equals -18dB!

PPM – an aside

Commonly, you might see it written, or said, that maximum signal level should not exceed PPM 6 and that this is +8dBu. Whilst its origin is understandable, this kind of equivalence is false and has led to inappropriate setting of limiters and dynamics processors world-wide.

A 1kHz sine wave that reads 6 on the PPM[3], will indeed be +8dBu, but, a very peaky signal with short-duration spikes that do not cause the needle on the PPM to be deflected would have peaks higher than +8dBu. The choice of $0dBu \leftrightarrow -18dBFS$ took this into account, fully expecting that there would be transients above +8dBu, that this was normal, and absolutely fine, and the risk of clipping artefacts as a result was acceptably low. To set a digital brickwall limiter at -10dBFS, based on the limit of PPM 6 on an analogue meter is not logical. PPM 6 is not the same as +8dBu because one is a reading on a mechanical meter with finite rise and fall times, while the other is an electrical level. 6 does not equal +8. This is not just a change of units, but a completely different measurement technique.

Loudness measurement

The measurement of sound levels has been going on for years. Many will be familiar with terms such as “sound pressure level”, “A weighting” and so on. For broadcasting, there is one loudness measurement technique that we should know about. This has been relatively recently standardised by the ITU, and is known as Recommendation ITU-R BS.1770 [1]. Sound measurement for safety or nuisance assessment still uses things like “A”, or “C” weighting.

ITU-R BS.1770, or “1770” for short, is defined in the digital signal domain, and includes a frequency weighting called “K” weighting (because perceived loudness varies according to frequency), and a channel weighting (because sounds from channels at the rear seem louder than sounds from the front). There is also a “gating” function that is used to remove very quiet periods from the measurement, thus preventing misleadingly low average measurements for programmes which contain long pauses. The gated measurement can be thought of as measuring the loudness of the foreground (as opposed to background) sounds of the programme. The precise details of the algorithm do not concern us here.

The EBU has done considerable work, building on 1770 and has produced EBU R 128 and EBU Tech Docs 3341, 3342, 3343 and 3344[1,2,3,4]. The terminology in 1770 is a little loose in places, so, according to EBU terminology, we express the result of a loudness measurement like this:

$$loudness\ level\ ,\quad L_K \ = \ -\ 23\, LUFS$$

The measurement uses a “K” weighting, so we have the subscript “K” for the quantity “L”. The result is expressed in “LUFS” – **L**oudness **U**nits relative to **F**ull **S**cale. 1770 still refers to “LKFS”,

3 I refer to a “BBC” PPM, where the scale is from 1 to 7, alignment level is 4, and each increment corresponds to a gain of 4dB.

but the “K” belongs on the other side of the equation, not in the units. LKFS and LUFS are equivalent.

The 1770 algorithm is defined such that a stereo sine wave at 1kHz, at -18 dBFS, will have a loudness level, L_K, of -18 LUFS.

LUFS means “relative to full scale”. For differences between loudnesses, we use “LU”, so the difference between -23 LUFS and -21 LUFS is “2 LU”, not “2 LUFS”. Note that applying a gain of 1 dB to a signal will increase its loudness level by 1 LU. In that sense, 1 LU is equivalent to 1 dB.

Target level – the origin of “-23”

For the sake of a simple life, and reduced audience annoyance, EBU R 128 recommends that **all** programmes be normalised to an average foreground loudness level of **-23 LUFS**. The figure of -23 LUFS was chosen as the result of a careful study of broadcasting practice, dynamic range tolerance, and the capabilities of different transmission technologies. Note that this value assumes that gating is used in the measurement to prevent long pauses in a programme bringing down the average loudness. The ITU has a recommendation that uses -24 LUFS as a target level in specific circumstances, and, although recent revisions to 1770 suggest that this should be revised upwards slightly, resistance from a small number of administrations has prevented this. Of course, it should be borne in mind that, for practical purposes, the difference between -23 LUFS and -24 LUFS is slight.

In the EBU documents, the term “target level” refers to the desired average loudness of a programme, once normalised, as measured with an EBU mode ITU-R BS.1770 meter. The target level is -23 LUFS. It is accepted that in live operations one might miss the target by a small amount.

Meta-data to control loudness – the origin of “-31” and “-27”

Dolby Digital (AC-3) and Dolby E adopt a rather different method to try to ensure consistent loudness for the audience. Instead of requiring programme makers to make programmes to a specified target level, the programme can be mixed to any level, and the level is signalled by meta-data sent along with the audio. The meta-data is used in the receiver (digital TV set or set-top box) to normalise the programme output to a common level, and account for the different levels used in production.

Dolby call this technique “dialog normalisation” because their emphasis is on measurement and normalisation of the level of dialogue (speech). The meta-data value sent along with the audio to normalise the signal in the set-top box is called “dialnorm”, short for “dialog normalisation”. The vast majority of programmes also contain content that is not speech, and audience satisfaction requires that it too be measured. Therefore, in general, it is not dialogue loudness, but *programme* loudness, that should be used. Programme loudness should be measured with a 1770 loudness meter and that value used to set dialnorm. A measured loudness of -23 LUFS requires a dialnorm of 23.

The common loudness level to which dialnorm should cause all programmes to be normalised in the receiver is -31 LUFS. The number “-31” forms part of the Dolby Digital decoder specification

Figure 2 shows how dialnorm works.

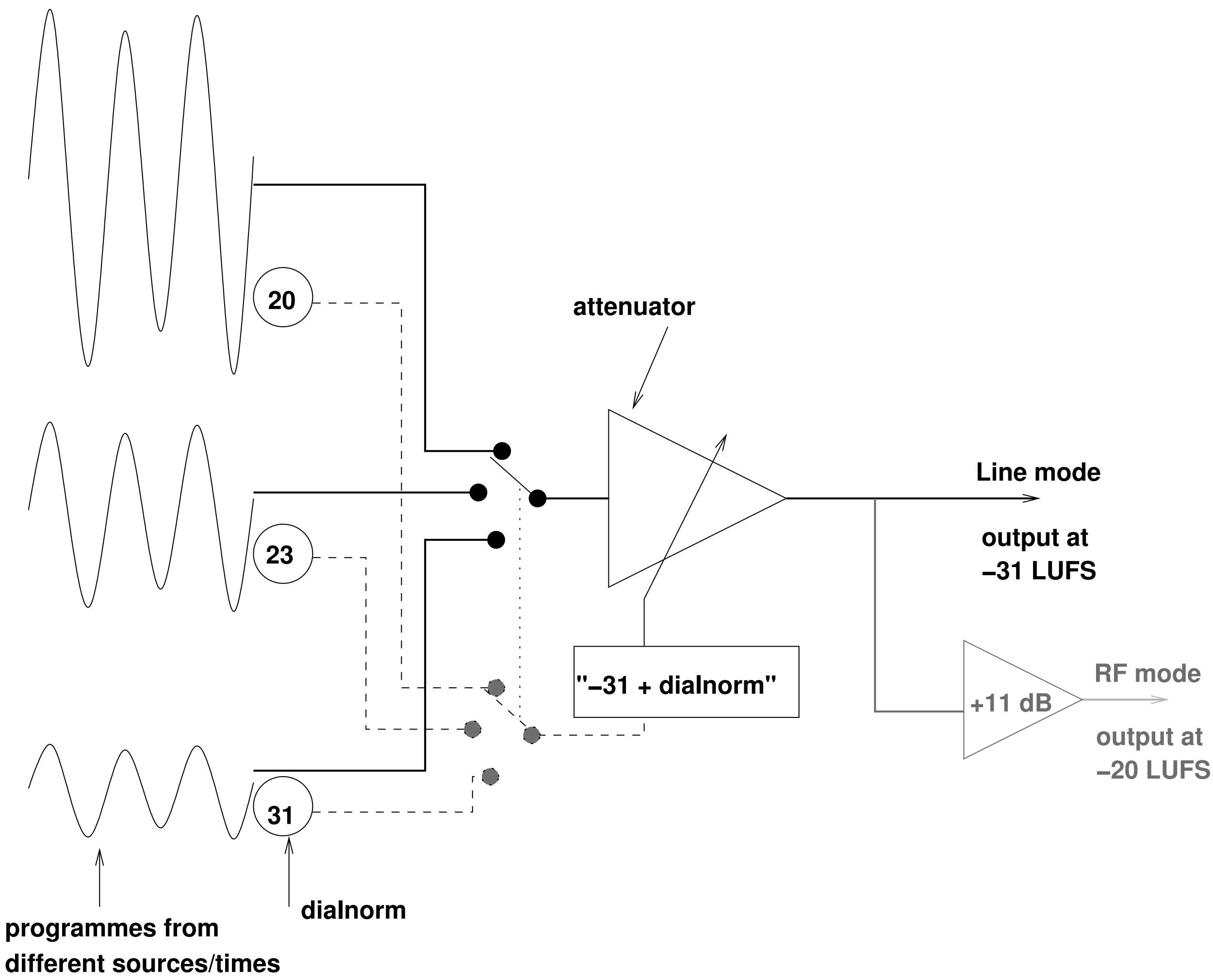

Figure 2: Use of “dialnorm” in Dolby Digital decoder to normalise to -31 LUFS

The attenuation applied in the receiver is equal to “-31 + dialnorm”. A programme sent with dialnorm of 27 will be attenuated by -4 dB, one sent with dialnorm of 23 will be attenuated by -8 dB.

Because the dialnorm parameter is set from a measurement using 1770, when working correctly, all programmes delivered using Dolby Digital, regardless of mix level, will be attenuated in the receiver to an average loudness of -31 LUFS. This value of -31 LUFS is sometimes referred to as a “reference level”. However, this term is poorly defined. “Target level” makes more sense.

If the actual loudness of the programme does not match its meta-data then this system does not work properly. The default setting of dialnorm in a Dolby Digital encoder is 27. This almost always needs to be changed to match local production style. A dialnorm signalled as 27 has often been found to be indicative of a failure somewhere.

RF mode and Line mode – the origin of “-20”

Also shown in Figure 2 is the “RF mode” output, a further complication of the Dolby Digital decoder. Loosely, “Line mode” is for Hi-Fi output, “RF mode” is aimed at less high quality, such as monophonic signals, RF modulated for input to analogue TV sets via the aerial socket. Line mode uses the -31 LUFS target level. RF mode, because it is aimed at lower fidelity output, adds 11 dB gain to the audio signal. This gives RF mode a target level of -20 LUFS (equal to the default of -31 LUFS, plus 11). The 11 dB of gain incurs a risk of digital clipping within the receiver, so RF mode includes an additional limiter.

MPEG 4 audio loudness meta-data

MPEG-4 audio, (ISO/IEC 14496-3) includes meta-data along the lines of Dolby's dialnorm. It too includes meta-data to describe the audio level, called “programme reference level”, or “prog_ref_level”, for short. It corresponds very closely to dialnorm, being a measurement of how far below full scale the signal is, and having a range from 0 to about -32.

MPEG-4 however has a major difference from Dolby Digital: MPEG-4 allows the user to set the target level. Instead of the fixed value of -31 specified in the Dolby Digital decoder, MPEG-4 allows the user to set the output level, and the receiver applies a gain adjustment equal to “target_level - prog_ref_level”. This allows the consumer to set the output level of MPEG-4 audio decoders to match other devices connected to the system (CD player, iPod, etc.). This is shown in Figure 3. Compare this with Figure 2.

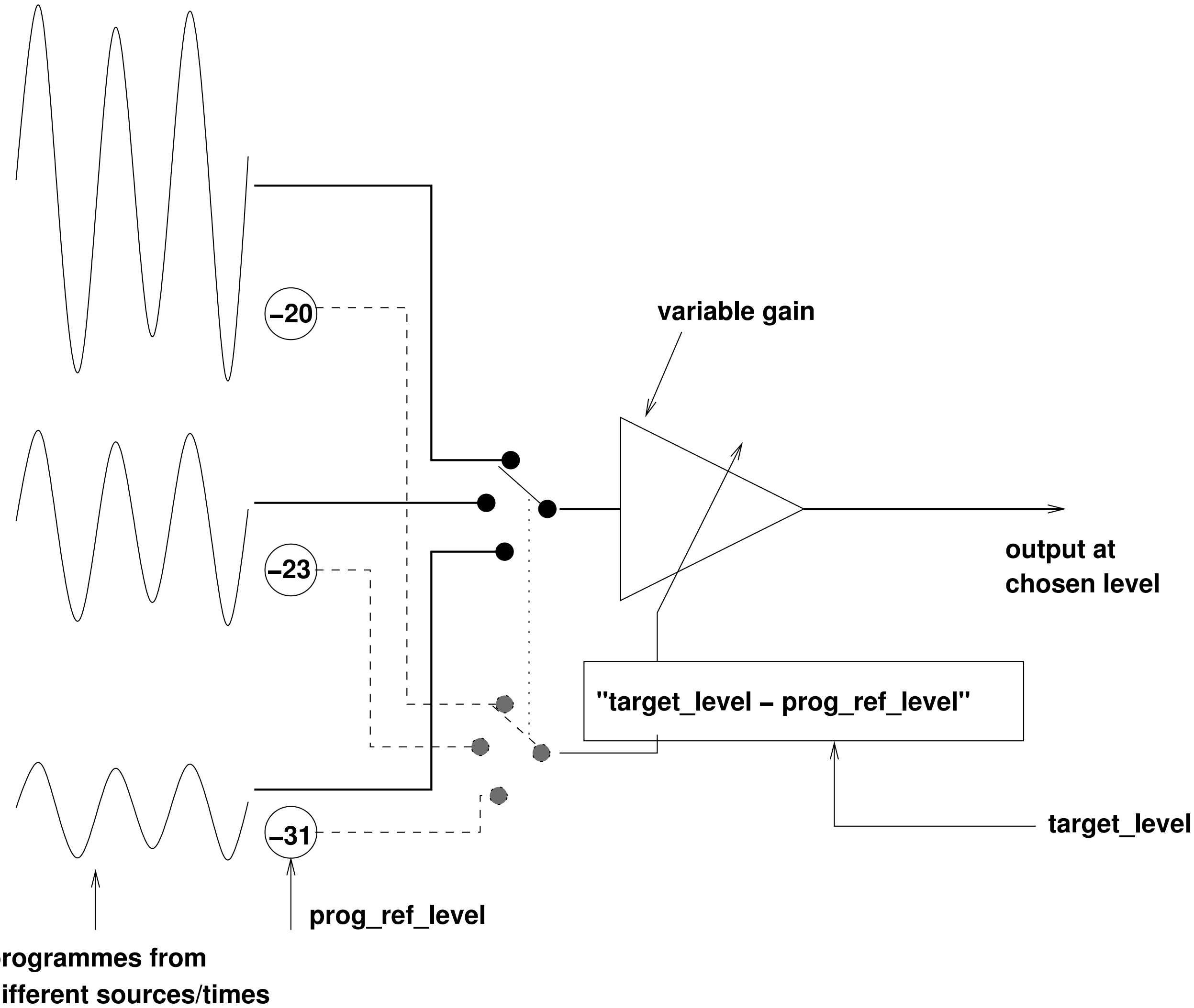

Figure 3: Use of MPEG 4 loudness metadata

-23 versus -31 versus -20

Traditional analogue broadcast TV networks (including those using NICAM-728 digital audio) and MPEG Layer II digital TV networks have endeavoured to be unity gain and have typically used a subjective loudness not far from the EBU R 128 recommended target level of -23 LUFS. The advent of broadcast platforms that include both unity gain MPEG Layer II services *and* Dolby Digital services led to audience complaints because of the level changes when switching from -23 LUFS normalised services to Dolby Digital services at -31 LUFS or -20 LUFS.

The Digital TV Group[4] "D Book", which sets out the detailed technical standards for digital terrestrial television in the UK, specifies that manufacturers should fix MPEG-4 audio target_level at -23, for stereo outputs to provide maximum compatibility of loudness with services working to EBU R 128 using unity gain codecs (existing Layer II services, and legacy analogue services).

Dolby has issued guidance to its licensed manufacturers, in the form of "***Dolby Technical Bulletin 11***", to try to reduce the audience annoyance caused by the introduction of services with substantially different loudnesses. The default behaviour should be to use "RF mode" for analogue outputs with its target level of -20 LUFS because this is rather closer to the norm of -23 LUFS than would be -31 LUFS.

The EBU PLOUD group has produced a set of documents on the subject of loudness measurement and control[1]: R 128 and Tech Docs 3341, 3342, 3343, and 3344. There is much, much, more information about loudness and level control during programme distribution in EBU Tech. Doc. 3344 - *"Practical guidelines for distribution systems in accordance with R 128",* which can be freely downloaded from the EBU using this link: http://tech.ebu.ch/docs/tech/tech3344.pdf

True Peak

The general shift away from quasi-peak metering towards loudness metering is complemented by a move towards **true peak** metering as well. There are three "peak" metering terms that it might be useful to clarify:

quasi-peak – not really peak at all. Historically measured with a mechanical meter with controlled rise and fall times, such as the well-known "PPM". Now done in software for digital applications using, for example, a 10ms integration time.

s*ample peak* – digital measurement of the highest sample value in the signal;

true peak – digital measurement, interpolating between the actual samples in order to take account of over-shoots that would occur later, with, for example, sampling rate conversion. Recommendation ITU-R BS.1770 includes an over-sampling true-peak meter.

Figure 4, below, shows the crest of two sine waves with the sample values that represent them.

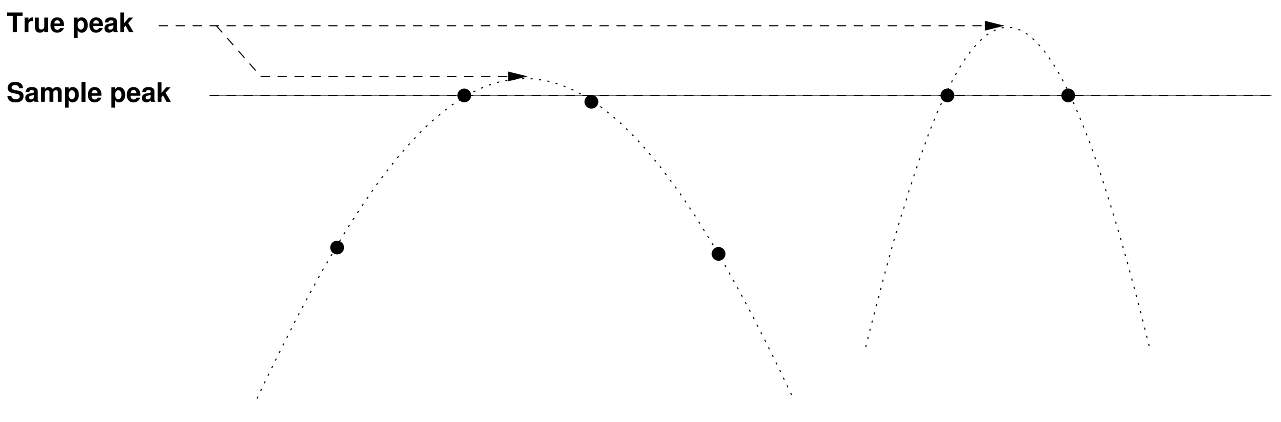

Figure 4: True peak and sample peak for crest of sine waves at different frequencies

4 The Digital TV Group (DTG) is the industry association for digital television in the UK. The Group publishes and maintains the technical specification for the UK's *Freeview* and *Freeview HD* platforms (the D-Book) and runs the digital television industry's test centre: DTG Testing.

As can be seen, the true peak of the sine wave reconstructed by interpolation (shown by the dotted curve) is higher than the value of any of the samples, including the “sample peak” that would be measured by a sample peak meter. Note also that the degree of over-shoot depends on the frequency of the sine wave: the crest on the right has a true peak significantly higher than that on the left, even though their sample peak values are identical.

Measurements of true peak level use the units “dBTP” and are referenced to the digital full scale value 0 dBFS. As can be seen from the figure, if the peak sample values are 0 dBFS, the true peak will be higher than 0 dBTP. A normal operation guideline could be to avoid true peaks above -1 dBTP, meaning that the highest sample values, the sample peaks, would be somewhat less than -1 dBFS.

Conclusions

The units dB, dBu, dBFS, dBTP, LUFS and LU need to be used, and need to be used accurately. The use of “dB” without extra qualification can lead to problems. Interchanging measurements made by a meter with simple electrical or digital levels has led to sub-optimal operational practices.

The terms “alignment level”, “loudness level”, “programme reference level”, “target level”, “dialnorm” have specific meanings, and, like the units that might be associated with them, need to be used accurately. The correct use of loudness control systems that include meta-data depends on an understanding of the terms that describe their operation.

The transition of working practices based on quasi-peak metering to those based on loudness level and true-peak metering will be made simpler if all parties involved have a shared understanding of the terms being used.

dB is a unit used for relative measurements;
dBFS is the unit for measurements of signal level relative to full scale;
dBTP is the unit for measurements of true peak audio level, relative to full scale;
LUFS is the unit for subjective loudness levels relative to full scale, measured using ITU-R BS.1770;
LU is the unit for subjective loudness differences (for example, relative to a specified target level such as -23 LUFS);
LKFS is equivalent to LUFS, but does not conform to international standard naming conventions;
Alignment level is an agreed signal level for making measurements on circuits;
Target level is an agreed subjective loudness level to which programmes should be normalised (-23 LUFS according to R 128);
Programme loudness is the average loudness level of a programme, measured according to ITU-R BS.1770;
Dialnorm and **programme reference level** are meta-data that are used to indicate programme loudness.

References

1) Recommendation ITU-R BS.1770, “Algorithms to measure audio programme loudness and true-peak audio level”, ITU, first published 2006, revised 2007, 2011

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5) EBU Tech 3343, “Practical guidelines for EBU R 128”, first published February 2011, http://tech.ebu.ch/loudness

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