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Recommendation

ITU-T P.810 (03/2023)

SERIES P: Telephone transmission quality, telephone installations, local line networks

Methods for objective and subjective assessment of speech and video quality

Modulated noise reference unit (MNRU)

ITU-T P-SERIES RECOMMENDATIONS

TELEPHONE TRANSMISSION QUALITY, TELEPHONE INSTALLATIONS, LOCAL LINE NETWORKS

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Recommendation ITU-T P.810

Modulated noise reference unit (MNRU)

Summary

Recommendation ITU-T P.810 describes the modulated noise reference unit (MNRU), a standalone unit for introducing controlled degradations to speech signals. The MNRU has been extensively used in subjective performance evaluations of digital processes as reference conditions.

Historically, MNRU was implemented in analogue hardware. The Recommendation was subsequently complemented with the description of digital implementations of the MNRU for narrowband and wideband signals.

This revision provides the extension of digital MNRU to fullband signals, which shapes the flat Gaussian noise used in the narrowband and wideband versions with an average speech power spectrum. The introduction of the shaped noise provides a more representative degradation for super-wideband and fullband speech as it reduces the energy of the noise towards high frequencies.

A reference implementation of the algorithms is provided in the software tool library (STL), Recommendation ITU-T G.191.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T P.70	1984-10-19		11.1002/1000/5923
2.0	ITU-T P.81	1988-11-25		11.1002/1000/1768
3.0	ITU-T P.81	1993-03-12	XII	11.1002/1000/1769
4.0	ITU-T P.810	1996-02-06	12	11.1002/1000/3301
5.0	ITU-T P.810	2023-03-01	12	11.1002/1000/15467

Keywords

Analogue MNRU, controlled degradation, digital MNRU, fullband MNRU, modulated noise reference unit (MNRU), P.50 MNRU, subjective performance evaluation.

* To access the Recommendation, type the URL http://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID. For example, http://handle.itu.int/11.1002/1000/11830-en.

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Introduction

The modulated noise reference unit (MNRU) was originally devised to produce distortion subjectively similar to that produced by logarithmically companded pulse code modulation (PCM) systems. This approach was based on the views:

1) that network planning would require extensive subjective tests to enable evaluation of the PCM system performance over a range of compandor characteristics, at various signal levels and in combination with various other transmission impairments (e.g., loss, idle circuit noise, etc.) at various levels; and

2) that it would be as reliable and easier to define a reference distortion system, itself providing distortion perceptually similar to that of the PCM systems, in terms of which the performance of PCM systems could be expressed. This requires extensive subjective evaluation of the reference system when inserted in one or more simulated telephone connections but leads to the possibility of a simplified subjective evaluation of new digital processing techniques.

Since its initial release, called ITU-T P.81, various organizations (Administrations, scientific / industrial organizations), as well as the ITU-T itself, have made extensive use of the MNRU concept for evaluating the subjective performance of digital processes. For example, MNRU was used as early as in the year 1988 for Recommendation [b-ITU-T G.722], and even before since 1981 for the 32 kbit/s adaptive differential pulse code modulation (ADPCM) algorithm of Recommendation initially called [b-ITU-T G.721], which was further redeveloped and revised in [b-ITU-T G.726]. The original narrowband version (100-3 400 Hz) was subsequently extended to a wideband bandwidth (70-7 000 Hz) and then fullband (up to 20 000 Hz); the MNRU is still widely used as a reference degradation in standardization efforts such as speech codecs selection and characterization or objective quality assessment models development [b-ITU-T P-Sup.800].

Fullband MNRU, also known as P.50 MNRU, was introduced in 2008 during the development of a super-wideband objective model [ITU-T P.863]. As the modulation of a super-wideband flat Gaussian noise (50-14 000 Hz) with speech produces unnatural distortions due to the energy of the noise being too prominent towards higher frequencies, the MNRU algorithm was supplemented with a filter that shapes the Gaussian noise to an average speech spectrum derived from ITU-T P.50 test signals [ITU-T P.50]. Since P.50 MNRU was adopted as a reference degradation in the design of super-wideband and fullband speech quality subjective assessments.

MNRU was originally constructed using analogue circuitry. However, it is nowadays implemented using digital circuitry or is simulated on computers. Further information on the effects of the MNRU parameters is given in [b-Law & Seymour].

The description of the narrowband and wideband analogue MNRU remains of interest and is retained in this revision, however fullband MNRU is described as a digital implementation only.

A reference implementation of the MNRU algorithms is provided in the software tool library (STL) [ITU-T G.191].

Recommendation ITU-T P.810

Modulated noise reference unit (MNRU)

1 Scope

The modulated noise reference unit (MNRU) is a standalone unit that is intended to introduce controlled degradations to speech signals. The purpose of this Recommendation is to describe MNRU as completely and in as much detail as possible to minimize implementation differences that may lead to subjective test results differences.

The need for systems that introduce controlled degradations to speech signals has proven critical for subjective testing, providing consistent reference points for comparison of subjective test results.

It is recommended:

1) that a narrow-band MNRU be used as the reference system in terms of which subjective performance of telephone bandwidth digital processes are expressed;

2) that a wideband MNRU be used as the reference system in terms of which subjective performance of wideband digital processes are expressed;

3) that a fullband MNRU be used as the reference system in terms of which subjective performance of super-wideband or higher digital processes are expressed.

This Recommendation describes narrowband (100-3 400 Hz) and wideband (70-7 000 Hz) MNRU in their analogue and digital forms. Fullband MNRU is specified in digital implementation only.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T G.191] Recommendation ITU-T G.191 (2023), *Software tools for speech and audio coding standardization.*

[ITU-T P.50] Recommendation ITU-T P.50 (1999), *Artificial voices.*

[ITU-T P.56] Recommendation ITU-T P.56 (2011), *Objective measurement of active speech level.*

[ITU-T P.863] Recommendation ITU-T P.863 (2018), *Perceptual objective listening quality prediction.*

3 Definitions

3.1 Terms defined elsewhere

None.

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 **combined path**: The combined signal and noise paths through the modulated noise reference unit.

3.2.2 **dBov**: dB relative to the overload of a digital system.

3.2.3 **noise path**: The path through the modulated noise reference unit that generates the modulated noise.

3.2.4 **Q**: The ratio, in dB, of speech power to modulated noise power. Q_N and Q_W may be used to refer to narrowband and wideband MNRU.

3.2.5 **signal path**: The path through the modulated noise reference unit that includes only the input signal.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

ADPCM Adaptive Differential Pulse Code Modulation

DC Direct Current

FIR Finite Pulse Response

IPR Infinite Pulse Response

MNRU Modulated Noise Reference Unit

PCM Pulse Code Modulation

RMS Root Mean Square

SNR Signal-to-Noise Ratio

5 Conventions

Implementations of the MNRU in analogue hardware and on digital hardware or in software are described in this Recommendation. Throughout this Recommendation, references will be made to analogue hardware and to digital implementations. Wherever the digital implementation is mentioned, it should be understood that the description is applicable either to software or to digital hardware.

6 General description

A simplified arrangement of the MNRU is shown in Figure 1 for the analogue narrowband and wideband versions, in Figure 2 for the narrowband and wideband digital versions, and in Figure 3 for the fullband digital.

It is recommended:

1) that a narrow-band MNRU be used as the reference system in terms of which subjective performance of telephone bandwidth digital processes are expressed;

2) that a wideband MNRU be used as the reference system in terms of which subjective performance of wideband digital processes are expressed;

3) that a fullband MNRU be used as the reference system in terms of which subjective performance of super-wideband or higher digital processes are expressed.

Speech signals entering from the left are split between two paths, a signal path and a noise path. The signal path provides an undistorted (except for bandpass filtering) speech signal at the output.

In the noise path, the speech signal instantaneously controls a multiplier with an applied Gaussian noise "carrier" that either has a uniform spectrum between the cut-off frequencies shown for the noise source for the narrowband and wideband versions, or the shape of an average speech power spectrum for the fullband version.

The output of the multiplier, consisting of the noise modulated by the speech signal, is then added to the speech signal to produce the distorted signal.

The attenuators and switches in the signal and noise paths allow independent adjustment of the speech and noise signal levels at the output. Typically, the system is so calibrated that the setting of the attenuator (in dB) in the noise path represents the ratio of the instantaneous speech power to noise power when both are measured at the output of the bandpass filter (terminal OT). Specifically, when both are set to 0 dB, the noise level measured at the terminal OT, with separate resistive terminations at the terminals T1 and T2 (unlinked), should be the same as the speech level measured at terminal OT, with separate resistive terminations at the terminals T5 and T6 (unlinked): as a check on this it should be established that the ratio of speech-plus-modulated-noise power (measured at terminal OT) to the power of the input speech (measured at terminal IT) is 3 dB (see clause 7.3.1).

For this Recommendation, the decibel representation of the ratio is called Q.

Digital implementations of the MNRU will be facilitated by noting that, when the signal path has unity gain, output speech-plus-modulated-noise generation can be expressed by:

$$y(i) = x(i)\left[1 + 10^{-Q/20} N(i)\right] \tag{6-1}$$

where $x(i)$ is the input speech, $N(i)$ is the random noise, Q is the ratio of speech power to modulated noise power in dB (determined by the noise path gain), and $y(i)$ is the output speech-plus-modulated-noise.

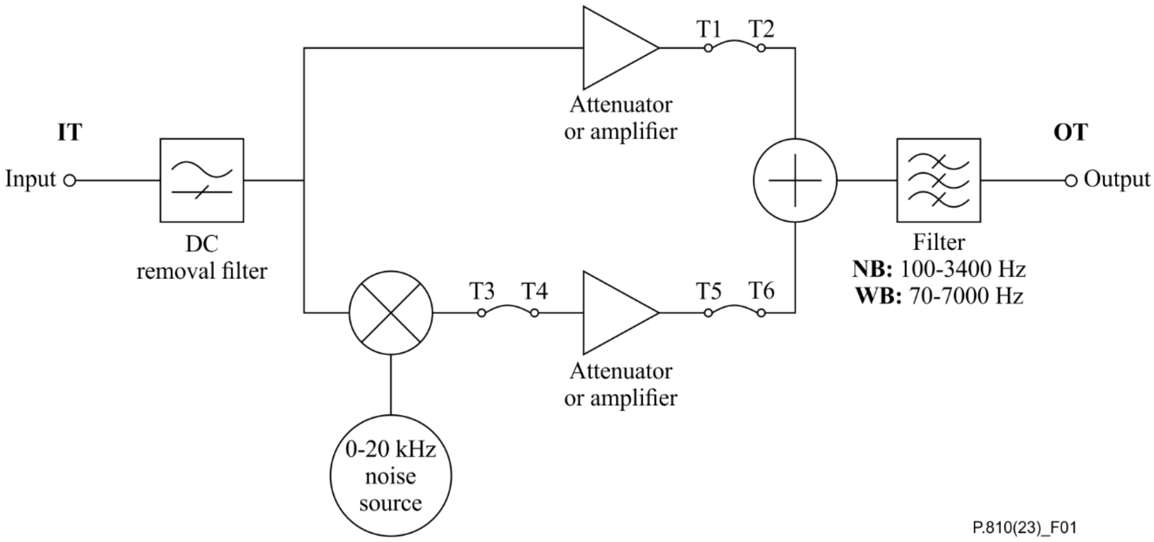

Figure 1 – Basic arrangement of analogue MNRU
The narrowband (NB) and wideband (WB) versions only differ in the output filter

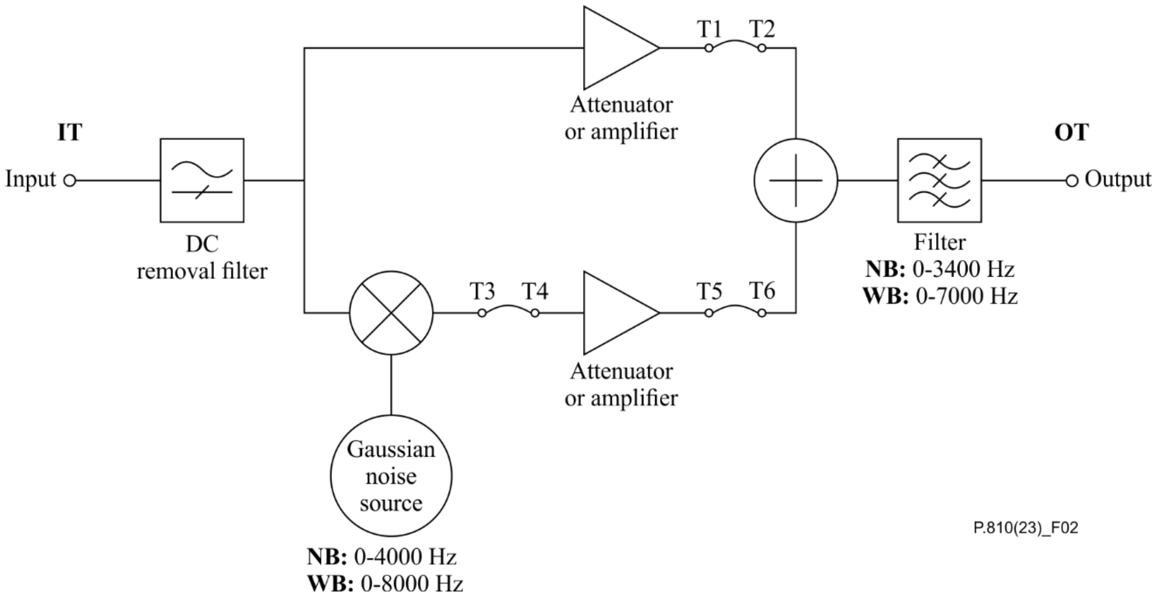

Figure 2 – Basic arrangement of narrowband and wideband digital MNRU
The narrowband (NB) and wideband (WB) versions differ in the noise source bandwidth and the output filter

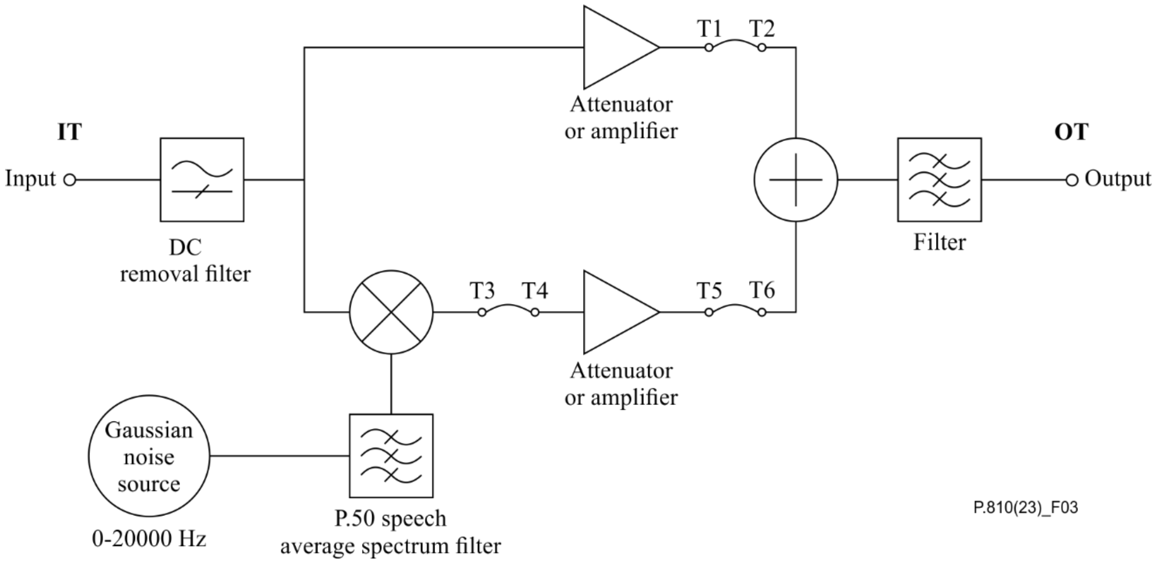

Figure 3 – Basic arrangement of fullband digital MNRU

7 Performance specifications

7.1 General

The specifications in this clause apply both to analogue hardware implementations and to digital implementations. Analogue MNRU hardware and digital implementations of the MNRU are described in parallel. Existing analogue hardware meeting the specifications in this Recommendation and digital implementations of the MNRU were tested extensively by ITU-T (Study Group 12) during the 1989-1992 study period. These implementations were found to be equivalent in their subjective effects. As the MNRU is intended only as a reference degradation for the subjective evaluation of digital processes, the ITU-T experts have deemed the subjective equivalence of MNRU implementations to be of paramount importance.

For practical implementations, the actual signal levels and noise levels may be increased or decreased to meet special needs. In such cases, the level requirements detailed below will have to be modified accordingly. In particular, the first digital MNRU implementations typically required speech material with a root mean square (RMS) level of −26.15 dBov (i.e., dB relative to the overload point of a digital A/D and D/A system); this value assured that the digital speech database (that was used for the ITU-T G.728 standardization) never suffered from 'clipping' due to any individual speech sample being 'cut' since being greater than the overload point. However, if the language used in the subjective testing has a peak-to-average level greater than 23 dB (the measured value for the whole speech database used for the ITU-T G.728 standardization), the RMS level of input speech should be reduced appropriately.

It can be shown that a direct current (DC) component in the input signal will generate an additive noise component on the output signal. This additive component of noise is not accounted for when one specifies a Q value. Thus, rather than having only a multiplicative noise at the output with signal-to-noise ratio (SNR) of Q, the output will have another additive noise component, this component increasing the overall noise in the output, and decreasing the total signal to (additive-plus-multiplicative) noise ratio. Thus, MNRU implementations should include (or provide external) high-pass filtering at the input.

NOTE – It was observed that the DC removal filter provided in the STL implementation [ITU-T G.191] may alter the perceived timbre of speech at high Q with fullband MNRU. It is therefore recommended to use a suitable DC filter in the fullband implementation.

7.2 Signal path

The requirements under this heading refer to the MNRU with infinite attenuation in the noise paths of Figures 1 to 3. For analogue hardware, separate resistive terminations at the terminals T5 and T6 (unlinked) will achieve this. Digital implementations may provide an option to disable the noise path, allowing a filtered version of the original signal to be produced as the output.

The frequency response of the signal path (i.e., between terminals IT and OT) of the analogue MNRU, as shown in Figure 1, should be within the limits of Figure 4 and Figure 5. The frequency response of the signal path of the digital MNRU shown in Figure 2 should be within the limits of Figure 6 for the narrowband and Figure 7 for the wideband implementation. The frequency responses of digital implementations have the same low-pass characteristic as the corresponding analogue hardware implementation.

For analogue hardware, the loss between terminals IT and OT for a 0 dBm, 1 kHz input sine wave should be 0 dB. Over the input level range +10 dBm to −50 dBm, the loss should be 0 dB ± 0.1 dB. Digital implementations should guarantee unity gain in the signal path.

Any harmonic component should be at least 50 dB below the fundamental at the system output (terminal OT in Figure 1) for any fundamental frequency between 125 Hz and 3 000 Hz in a narrow-band system, and 100 Hz and 6 000 Hz in a wideband system. Digital implementations, the output of which is delivered over high quality 16-bit digital-to-analogue converters, will readily meet these criteria.

The idle noise generated in the signal path must be less than −60 dBm, measured at terminal OT, in order to conform with clause 7.4.

It is recommended that the level of speech signals applied to the terminals IT of analogue hardware (Figure 1) should be less than −10 dBm (mean power while active, i.e., mean active level according to [ITU-T P.56]) in order to avoid amplifier peak-clippings of the signal, and be greater than –30 dBm to ensure sufficient speech signal-to-background-noise ratio. Digital speech materials used as input to digital implementations of the MNRU should be quantized with 16-bit linear quantization and have mean active levels that are, at most, −26.15 dB relative to the overload point of a 16-bit digital-to-analogue converter. Otherwise, speech may be clipped. As noted in clause 7.1, languages having peak-to-average ratios greater than 23 dB should adjust the levels appropriately. The software implementation of [ITU-T P.56], as found in [ITU-T G.191], should be used to determine the level for the purpose of meeting this requirement.

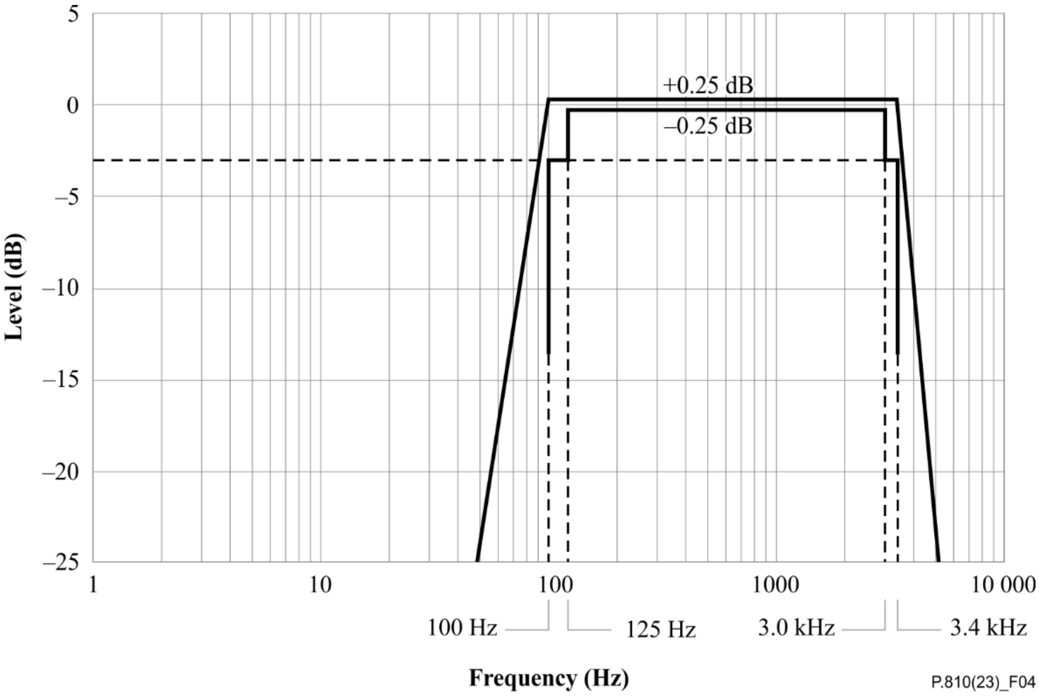

Figure 4 – Requirements for output filter of the narrowband analogue MNRU

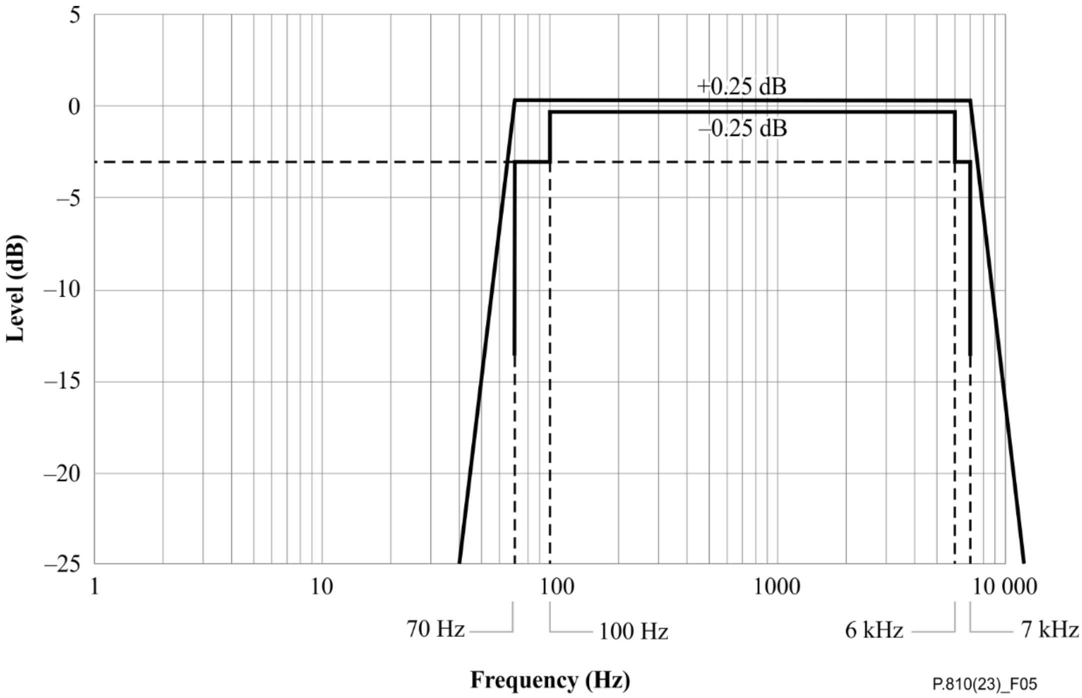

Figure 5 – Requirements for output filter of the wideband analogue MNRU

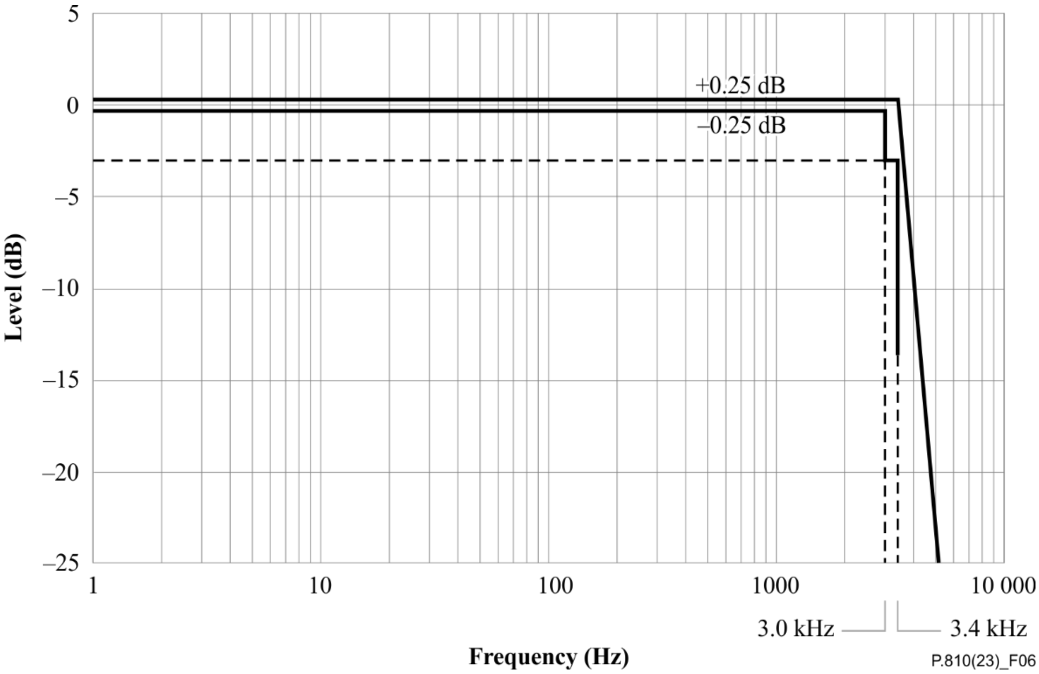

Figure 6 – Requirements for output filter of the narrowband digital MNRU

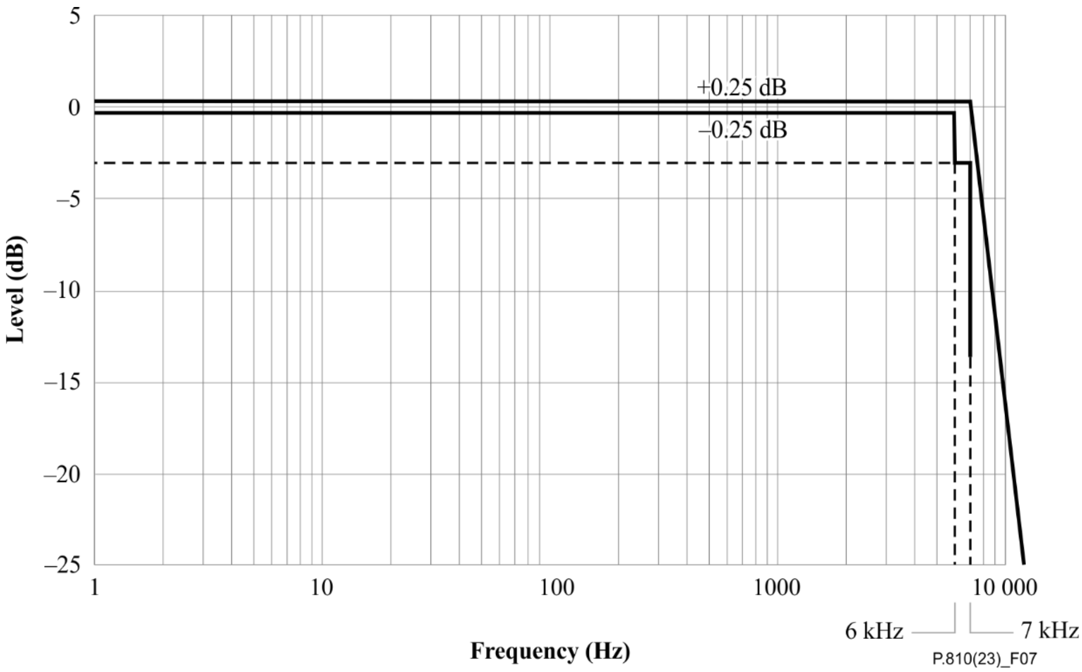

Figure 7 – Requirements for the output filter of the wideband digital MNRU

7.3 Noise path

The requirements under this heading refer to the MNRU with infinite attenuation in the signal paths of Figures 1 to 3. For analogue hardware, separate resistive terminations at the terminals T1 and T2 (unlinked) will achieve this. Digital implementations may provide an option to provide only the modulated noise as output.

7.3.1 Linearity as a function of input level

With a Q setting of 0 dB, the level of the modulated noise at the system output (terminal OT) should be numerically equal to the sine wave level at the input terminal (terminal IT). Correspondence within ±0.5 dB should be obtained for sine wave input levels from +5 dBm to −45 dBm, and for input frequencies from 125 Hz to 3 000 Hz in a narrow-band system, and 100 Hz to 6 000 Hz in a wideband system. Digital implementations calibrated for a given level (e.g., −26.15 dBov) will readily meet these criteria.

7.3.2 Gaussian noise spectrum

For a narrowband analogue system, when Q is set to 0 dB, input sine waves applied to the terminal IT in Figure 1 with levels from +5 to −45 dBm and frequencies from 125 Hz to 3 000 Hz should result in a flat noise system spectrum density at the output of the multiplication device (terminal T5 of Figure 1) within ±1 dB over the frequency range 75 Hz to 5 000 Hz. The spectrum density should be measured with a bandwidth resolution of a maximum of 50 Hz.

For a wideband analogue system, when Q is set to 0 dB, input sine waves applied to terminal IT in Figure 1 with levels from +5 to −45 dBm and frequencies from 100 Hz to 6 000 Hz should result in a flat noise system spectrum density at the output of the multiplication device (terminal T5 of Figure 1) within ±1 dB over the frequency range 75 Hz to 10 000 Hz. The spectrum density should be measured with a bandwidth resolution of a maximum of 50 Hz.

Digital implementations calibrated for a given level (e.g., −26.15 dBov) and where the noise source meets the requirements given in clause 7.3.3 will readily meet these criteria.

7.3.3 Gaussian noise amplitude distribution

The amplitude distribution of the noise at the system output should be approximately Gaussian.

NOTE 1 – For analogue hardware, a noise source consisting of a Gaussian noise generator followed by a peak clipper with a flat spectrum from near zero to 20 kHz will produce a satisfactory output noise at terminal OT.

NOTE 2 – To ensure sufficient linearity in digital implementations, a noise source consisting of a Gaussian random noise generator (followed by a peak clipper) with a flat spectrum from 50 Hz to the cut-off frequency of the low pass portion of the bandpass filter in Figure 2 and Figure 8 will produce a satisfactory output noise at terminal OT when the clipping level is at least 12 dB above the RMS noise level.

NOTE 3 – For digital implementations, noise that has an amplitude distribution that is approximately Gaussian may be generated by any of the several methods. If the noise is generated from uniformly distributed random numbers by appealing to the central limit theorem, then the number of such random numbers should be greater than 10.

7.3.3.1 Noise period

In digital implementations, the random noise should be generated using a Gaussian random number generator having a period longer than 2^{20} samples.

7.3.4 Noise shaping for fullband digital MNRU

In fullband MNRU, the output of the Gaussian noise generator is shaped following a long-term average spectrum of fullband speech. The filter response, shown in Figure 8, was derived from [ITU-T P.50]. This shape avoids higher amounts of perceived noise at high frequencies.

The noise shaping is implemented using two cascaded infinite pulse response (IIR) and finite pulse response (FIR) filters, where the IIR filter acts as a high pass filter with a cut-off frequency of 115 Hz, and the FIR is used as a lowpass and band-shaping filter.

The coefficients for both IIR and FIR filters are provided in Annex A.

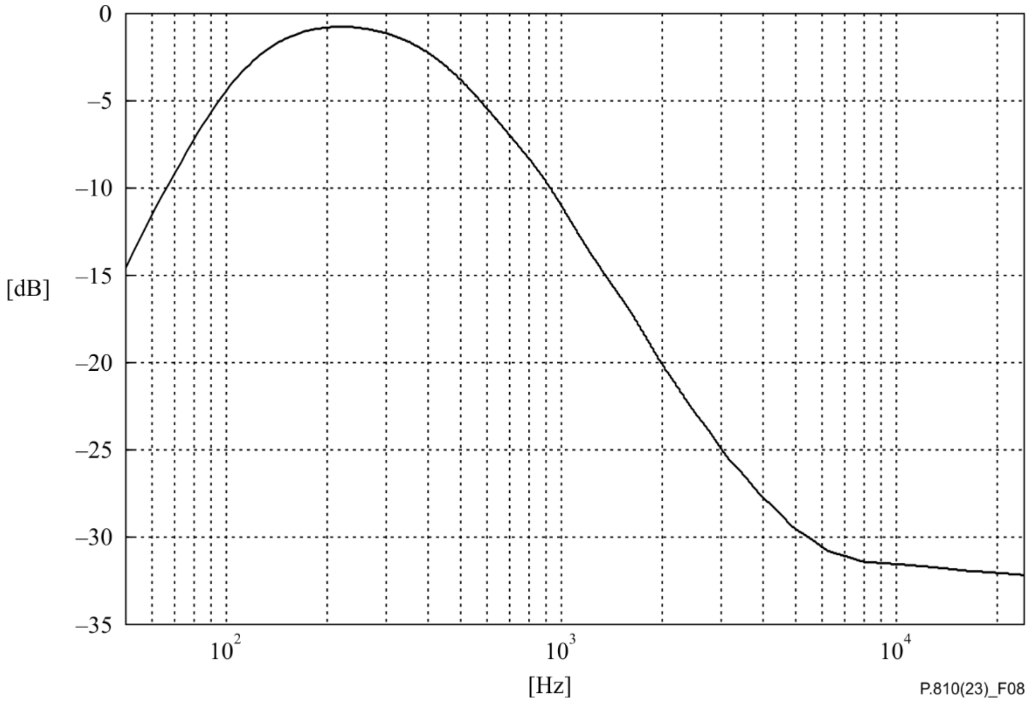

Figure 8 – Filter response for noise shaping in fullband MNRU

7.3.5 Noise attenuators

The loss of the noise attenuator(s), i.e., between terminals T4 and T5 in Figure 1, should be within ±0.1 dB of the nominal setting. The attenuator(s) should at least allow Q settings in the range −5 dB to 45 dB, i.e., a 50 dB range. Digital implementations will readily meet these criteria.

7.4 Combined path

The requirements under this heading refer to the MNRU with both speech and noise paths simultaneously in operation.

With Q (as the case may be) set to zero and the input terminated by an equivalent resistance, the idle noise generated in the combined path should be less than −60 dBm when measured at the system output (terminal OT).

The frequency response of the combined signal should be within the limits of Figure 6 for the narrowband and Figure 7 for the wideband implementation. For ITU-T P.50 fullband MNRU, an appropriate filter should be used according to the desired frequency bandwidth of the subjective test.

Annex A

Filter coefficients for the fullband MNRU noise shaping

(This annex forms an integral part of this Recommendation.)

A.1 Fullband noise shaping FIR filter coefficients

The FIR filter for the noise shaping is composed of 257 taps:

```
P50_FIR = {
0.00000561594151,    0.00000461631277,    0.00000369040248,    0.00000288714003,    0.00000220437245,
0.00000165386346,    0.00000120840192,    0.00000083224186,    0.00000046748068,    0.00000005747181,
-0.00000050129696,   -0.00000126687031,   -0.00000231396361,   -0.00000370633341,   -0.00000552896875,
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0.01102477130725,    0.01019884047989,    0.00943823018108,    0.00872593434077,    0.00805912456826,
0.00743444501575,    0.00685475456398,    0.00631667908955,    0.00582060305648,    0.00535457213944,
0.00491436000282,    0.00449775366246,    0.00410899128504,    0.00375010692820,    0.00342465081991,
0.00312561257531,    0.00284723244767,    0.00258327728886,    0.00233244580560,    0.00209497467278,
0.00187569385651,    0.00167464135716,    0.00149232608655,    0.00132656642475,    0.00117529757454,
0.00103513843004,    0.00090552802572,    0.00078420624706,    0.00067179811803,    0.00056935695587,
0.00047887276380,    0.00040054225632,    0.00033455525832,    0.00027766777451,    0.00022715607456,
0.00018033113197,    0.00013597317515,    0.00009295421150,    0.00005158583940,    0.00001077862126,

-0.00002956458334,   -0.00006922412129,   -0.00010692262265,   -0.00014161753027,   -0.00017181527167,
-0.00019795237240,   -0.00022076836615,   -0.00024156582276,   -0.00026118256069,   -0.00028033106997,
-0.00029860210568,   -0.00031608554641,   -0.00033241468439,   -0.00034738516965,   -0.00036064371637,
-0.00037216508745,   -0.00038146039110,   -0.00038855510126,   -0.00039307523400,   -0.00039462134088,
-0.00039267719850,   -0.00038720380439,   -0.00037824818957,   -0.00036669189439,   -0.00035340702396,
-0.00033921161945,   -0.00032451611641,   -0.00030960831513,   -0.00029439881612,   -0.00027914669181,
-0.00026405976322,   -0.00024939976634,   -0.00023526572072,   -0.00022174930855,   -0.00020866596864,
-0.00019602992317,   -0.00018376863644,   -0.00017183171047,   -0.00016008465691,   -0.00014845162899,
-0.00013673010773,   -0.00012493396096,   -0.00011309584053,   -0.00010134784491,   -0.00008984393153,
-0.00007883102838,   -0.00006845406952,   -0.00005892474485,   -0.00005032274117,   -0.00004263429950,
-0.00003573851606,   -0.00002953892401,   -0.00002391218014,   -0.00001888716125,   -0.00001451287059,
-0.00001084303455,   -0.00000786307974,   -0.00000552896875,   -0.00000370633341,   -0.00000231396361,
-0.00000126687031,   -0.00000050129696,    0.00000005747181,    0.00000046748068,    0.00000083224186,
0.00000120840192,    0.00000165386346,    0.00000220437245,    0.00000288714003,    0.00000369040248,
0.00000461631277,    0.00000561594151 };
```

A.2 Fullband noise shaping IIR filter coefficients

The IIR filter can be expressed with the following equation:

$$y[n] = b_0 x[n] + b_1 x[n-1] + b_2 x[n-2] - a_1 y[n-1] - a_2 y[n-2]$$

where:

- $x[n]$ denotes the input signal
- $y[n]$ the output signal
- n the n^th sample in the signal
- a_i the feedback filter coefficients
- b_i the feedforward filter coefficients

And where:

		b_0	0.9894120426128
a_1	−1.9787119772419	b_1	−1.978824085
a_2	0.9789361932093	b_2	0.9894120426128

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