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**SPECIFICATIONS FOR MEASURING EQUIPMENT
EQUIPMENT FOR THE MEASUREMENT
OF ANALOGUE PARAMETERS**

**PSOPHOMETER FOR USE
ON TELEPHONE-TYPE CIRCUITS**

ITU-T Recommendation O.41

(Previously "CCITT Recommendation")

FOREWORD

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NOTE

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ABSTRACT

Defines the basic requirements for an instrument to measure noise and other interfering signals on telephone circuits.

KEYWORDS

Complex impedances, measurement, noise measurement, psophometer, tester, weighting filter.

Recommendation O.41

PSOPHOMETER FOR USE ON TELEPHONE-TYPE CIRCUITS

(Published 1972; revised 1984, 1988, 1992, 1995)

1 Introduction

This Recommendation provides basic requirements for psophometers to be used for the measurement of noise and other interfering signals on international telephone circuits and circuit sections.

2 General

To accomplish the measurements as stated above, a psophometer should have the following significant characteristics:

- a) The relative sensitivity of the instrument, at various frequencies, should be as specified by the psophometric weighting characteristics. (See Note.)
- b) The reference point for the sensitivity of the instrument should be 0 dBm (one milliwatt) at 800 Hz.
- c) The r.m.s. (root mean square) value of the weighted noise signal should be detected and displayed. (See Note.)
- d) The dynamics of the detector and display device should meet requirements given in clause 3.
- e) The overall accuracy of the instrument when being used in its normal range and environmental conditions should be ± 1.0 dB or better. Specific tests for accuracy of various aspects of the instrument are given in clause 3.

NOTE – The characteristics of the weighting filter combined with an r.m.s. detector can be described by the formula (P_p means psophometric power):

$$P_p = \frac{1}{F_2 - F_1} \cdot \int_{F_1}^{F_2} \frac{V^2(f)}{10^{-3} \cdot |Z_n(F_0)|} \cdot 10^{W(f)/10} \cdot df \quad \text{mVA}$$

In this formula, $W(f)$ is the weighting filter of the psophometer with the limiting frequencies $F_1 = 16.66$ Hz and $F_2 = 6$ kHz as given in Table 1. $Z_n(F_0)$ is the input impedance of the instrument at the reference frequency F_0 . V is the unknown voltage to be measured. See also Annex A/G.100 [3].

Annex A provides a comparison of the ITU-T psophometric and North American (C-message) noise weighting currently in use.

3 Specific requirements

The following provides a minimum set of requirements that should be met by an instrument used as a psophometer.

3.1 Input impedance

All given impedances are for a balanced (earth free) input. The impedance to ground at 800 Hz shall be > 200 k Ω .

3.1.1 Terminating mode

When used in a terminating mode, the input impedance shall be 600 ohms with a return loss of ≥ 30 dB from 300 to 4000 Hz.

3.1.2 Bridging mode

When used in a bridging mode, the tapping loss across 300 ohms shall be ≤ 0.15 dB from 300 to 4000 Hz.

3.1.3 Complex input impedances

For measurements at interfaces with complex impedances, the instrument shall be equipped with corresponding input impedances. Examples for such impedances are given in Table 1/Q.552 [6].

For this application, the instrument shall be calibrated in accordance with A.3/G.100 [3], namely:

At the reference frequency of 1020 Hz, 0 dBm0 represents an absolute power level of 1 milliwatt measured at the transmission reference point (0 dBr point).

The voltage V of a 0 dBm0 tone at any voice band frequency is given by the expression:

$$V = \sqrt{1 \text{ W} \cdot 10^{-3} \cdot |Z_{1020}|}$$

where $|Z_{1020}|$ is the modulus of the nominal impedance, Z, at the reference frequency 1020 Hz. Z may be resistive or complex.

If the psophometer is not equipped with complex input impedances, measurements can be carried out using an appropriate impedance converter. (See e.g. Annex B/P.64. [7].) An impedance converter is a circuit that an input impedance equal to the applicable nominal complex impedance and an output impedance equal to 600 Ω . The output is decoupled from the input. The gain of the circuit is such that 0 dBm at the input equals 0 dBm at the output. This means that the level meter reads the level correctly in dBm.

When calibrating for weighted noise measurements at interfaces with complex impedances, the loss characteristic of the weighting filter at the two frequencies 800 Hz and 1020 Hz has to be taken into account. See Annex B.

3.2 Longitudinal losses

Input longitudinal interference loss and longitudinal conversion loss shall be ≥ 110 dB at 50 Hz. This requirement decreases 20 dB per decade to 5000 Hz. (The impressed longitudinal r.m.s. voltage shall not exceed 42 V.)

3.3 Measuring range

The usable measuring range of the instrument shall be -90 to 0 dBm.

3.4 Calibration accuracy at 800 Hz

The output indication shall be 0 dBm ± 0.2 dB with an input signal of 0 dBm at 800 Hz. For other levels over the usable measuring range of the instrument, the measurement error limits shall be as follows:

Range	Error limit
0 à -60 dBm	± 0.5 dB
-60 à -90 dBm	± 1.0 dB

3.5 Relative gain versus frequency (frequency weighting)

The required frequency weighting coefficients and accuracy limits at various frequencies are given in Table 1. In addition, the equivalent noise bandwidth of the weighting network shall be 1823 ± 87 Hz.

TABLE 1/O.41

Telephone circuit psophometer weighting coefficients and limits

Frequency (Hz)	Relative weight (dB)	Tolerance (\pm dB)
16.66	-85.0	-
50	-63.0	2
100	-41.0	2
200	-21.0	2
300	-10.6	1
400	-6.3	1
500	-3.6	1
600	-2.0	1
700	-0.9	1
800	0.0	0,0 (reference)
900	+0.6	1
1000	+1.0	1
1200	0.0	1
1400	-0.9	1
1600	-1.7	1
1800	-2.4	1
2000	-3.0	1
2500	-4.2	1
3000	-5.6	1
3500	-8.5	2
4000	-15.0	3
4500	-25.0	3
5000	-36.0	3
6000	-43.0	-

Also, the unit may be provided with the 1004 Hz to 1020 Hz test-signal reject filter, described in Table 1/O.132 [4], for use with the characteristics described in Table 1. In this case, the calibration of the measuring instrument shall include a correction factor of appropriate value to account for the loss in effective noise bandwidth due to the test-signal reject filter. The correction factor assumes a uniform distribution of distortion power over the frequency range involved and is of the following form:

$$\text{Correction} = 10 \log_{10} \frac{\text{Effective bandwidth of standard noise weighting}}{\text{Effective bandwidth of the measuring instrument}} \quad \text{dB}$$

3.5.1 Optional frequency characteristic

If desired, the unit may provide the optional frequency response characteristic for unweighted measurements given in Figure 1 in addition to the sponhometric weighting of Table 1.

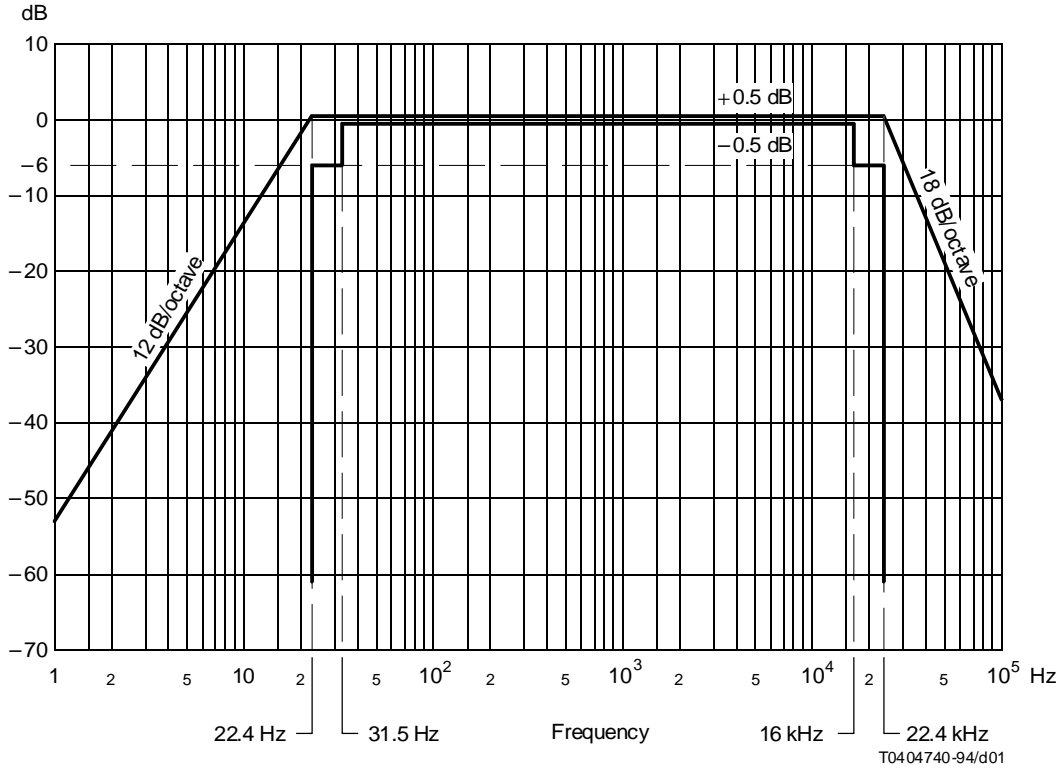


FIGURE 1/O.41
Frequency response characteristics for unweighted measurements

As an additional option, a flat filter with an equivalent noise bandwidth of 3.1 kHz (bandwidth of a telephone channel) is considered desirable for unweighted measurements. If provided, this filter shall have the characteristics of Table 2.

For the measurement of AC hum interference on telephone-type circuits an optional low pass filter with a cut-off frequency at approximately 250 Hz and an attenuation of ≥ 50 dB at 300 Hz may be provided.

3.6 Detector circuit characteristics

The detector circuit should measure the r.m.s. value of the noise input. An approximate, or full-wave “quasi” r.m.s. detector may be used if its output does not differ from a true r.m.s. detector by more than ± 0.5 dB for the following signal wave forms:

- Gaussian noise;
- sinusoidal signals;
- any periodic signal having a peak-to-r.m.s. ratio of 8 dB or less.

TABLE 2/O.41

**Characteristics of the optional flat filter with an equivalent noise bandwidth of 3.1 kHz
(bandwidth of a telephone channel)**

Frequency (Hz)	Attenuation	
< 300	Increasing	24 dB/octave (Note 1)
300	Approximately	3 dB (Note 2)
400-1020		$\leq \pm 0.25$ dB
1020		0 dB
1020-2600		$\leq \pm 0.25$ dB
3400	Approximately	3 dB (Note 2)
> 3400	Increasing	24 dB/octave (Note 1)

NOTES

1 Below 300 Hz and above 3400 Hz the attenuation shall increase at a slope not less than 24 dB/octave up to an attenuation of at least 50 dB.

2 The exact cut-off frequency shall be chosen to achieve an equivalent noise bandwidth of 3.1 kHz \pm 155 Hz.

3.6.1 Detector circuitry tests

The following test is recommended to assure that the detector circuitry is functioning as prescribed.

- a) Apply pulses of an 1800 Hz sine wave at a pulse rate of 80 Hz, with 20 percent of the cycle at full amplitude and 80 percent of the cycle 8.4 dB below full amplitude. The indicated r.m.s. value should be 5.0 ± 0.5 dB lower than the level of the ungated full amplitude sine wave.

Alternatively, psophometers manufactured to previous design specifications (see Annex A) shall meet the following test:

- b) Successively apply two sinusoidal signals of different frequencies, which are not harmonically related and which provide the same output level on the output indicator. Then apply both these signals at the same levels simultaneously. The increase on the output indicator should be $3 \text{ dB} \pm 0.25 \text{ dB}$ above the reading for the single frequency input. This condition should be fulfilled using different pairs of frequencies at different levels.

3.6.2 Turnover

Apply a rectangular wave form with a 20 percent duty cycle and a repetition rate of 600 pulses per second to the input of the instrument, and note the noise reading. Invert the input leads, the two readings shall agree within 1 dB. This test should be performed at several levels over the specified operating range of the set.

3.7 Detector and display dynamics (measurement averaging time)

The response time for the detector and indicating means shall meet one or both of the following requirements:

3.7.1 Instrumentation with continuous signal monitoring

The application of an 800 Hz sinusoidal signal with a duration of 150 to 250 ms should produce an output indication which is the same as that produced by the application of a continuous 800 Hz signal of the same amplitude. Applied signals of shorter duration should produce lower readings on the output indicator.

When performing this test the reading error shall be less than ± 0.2 dB.

3.7.2 Instrumentation with non-continuous signal monitoring

With the application of bursts of 800 Hz tone to the input of the psophometer, gated at a duty cycle of 50 percent, with half the cycle at full amplitude and the other half down 8.4 dB from full amplitude, the output device shall indicate a variation as shown in Table 3. The levels should be chosen to avoid autoranging points.

TABLE 3/O.41

Variation of the output indication with the application of specified bursts of 800 Hz at the input of the psophometer

Gating frequency (Hz)	Peak-to-Peak indicator variation (dB)
25	≤ 1
5	≥ 3

It is permissible to adjust the total input power with a 1 dB vernier control to a point where the display does not change so as to pass the less than 1 dB requirement.

3.7.3 Damped response

(Under study.)

3.8 Linearity

The following test is recommended to assure that excessive error is not caused by overload in the presence of signals which have a large peak-to-r.m.s. ratio.

Apply a signal at a frequency of approximately 1000 Hz in 5 ms pulses separated by 20 ms at an r.m.s. level corresponding to the highest value within any selected range of the instrument. When the level is decreased over a range of 10 dB the psophometer reading shall be proportional to the applied level decrease with a tolerance of ± 0.5 dB, for all ranges of the instrument.

3.9 Output indicator

If an analogue meter is used, the spacing of the meter markings shall be one dB or less over the normally used portion of the meter scale.

If a digital display is used, the noise reading shall be displayed to the nearest 0.1 dB. The result shall be rounded rather than truncated. The update rate for a digital display shall be at least once per second.

Optionally, instruments using digital displays may provide additional display characteristics to expand the application of the instrument. Such additional display characteristics shall be defined by the manufacturer to assist the user in interpreting the results.

3.10 Operating environment

The electrical performance requirements shall be met when operating at the climatic conditions as specified in 2.1/O.3 [5].

3.10.1 Immunity to electromagnetic fields

The unit should not be affected by the presence of electromagnetic fields (50 Hz). The test for this immunity is given below:

- a) With the instrument in the weighted measurement mode, an electromagnetic field strength of 16 A/m at 50 Hz shall cause an output indication of less than –85 dBm.
- b) With the instrument in an unweighted measurement mode (optional, see 3.5.1), an electromagnetic field strength of 0.8 A/m at 50 Hz shall cause an output indication of less than –85 dBm.

Annex A

Comparison of ITU-T and North American weightings

(This annex forms an integral part of this Recommendation)

Telephone circuit noise impairment is normally measured with “C-message” weighting within the North American domestic telephone networks [1], [2]. The frequency response of this weighting differs somewhat from the ITU-T psophometric weighting specified in this Recommendation. As a consequence, the relationship between measurements made with the North American noise meter and the ITU-T psophometer is dependent on the frequency spectrum of the noise being measured. In addition, it should be noted that measurements made with the North American noise meter are expressed in **dBm** (decibels referred to –90 dBm or decibels above a reference power of 10^{-12} watts). For example, if one milliwatt of white noise in the 300 to 3400 Hz band is applied to both an ITU-T psophometer and a North American noise meter, the following readings are obtained:

ITU-T psophometer (1951 weighting)	–2.5 dBm
North American noise meter (C-message weighting)	88.0 dBm

Recognizing that the relationship of the output readings of the differently weighted instruments will change for other noise spectra, the following rounded conversion formula is proposed for practical comparison purposes:

$$\text{Psophometer reading (in dBm)} = \text{C-message noise meter reading} - 90 \text{ (in dBm)}$$

This conversion includes the effect of the difference between the reference frequencies (800 Hz for psophometric weighting and 1000 Hz for C-message weighting) used in the two types of noise meters.

The C-message weighting coefficients and accuracy limits at various frequencies are given in Table A.1. A comparison between psophometric and C-message weighting is shown on Figure A.1.

Another weighting frequently used for measuring telephone circuit noise impairment within the North American domestic telephone networks is referred to as “3 kHz Flat” weighting [1]. This weighting is intended for the investigation of the presence of low-frequency noise (power induction, etc.) on the circuit under test. It is characterized as a 3 kHz low-pass weighting of Butterworth shape attenuating above 3 kHz at 12 dB per octave. The specification for this weighting is given in Table A.2.

TABLE A.1/O.41

C-message weighting coefficients and accuracy limits

Frequency (Hz)	Relative weight (dB)	Tolerance (± dB)
60	-55.7	2
100	-42.5	2
200	-25.1	2
300	-16.3	2
400	-11.2	1
500	- 7.7	1
600	- 5.0	1
700	- 2.8	1
800	- 1.3	1
900	- 0.3	1
1000	0.0	0.0 (reference)
1200	- 0.4	1
1300	- 0.7	1
1500	- 1.2	1
1800	- 1.3	1
2000	- 1.1	1
2500	- 1.1	1
2800	- 2.0	1
3000	- 3.0	1
3300	- 5.1	2
3500	- 7.1	2
4000	-14.6	3
4500	-22.3	3
5000	-28.7	3

NOTE – The attenuation shall continue to increase above 5000 Hz at a rate of not less than 12 dB per octave until it reaches a value of -60 dB.

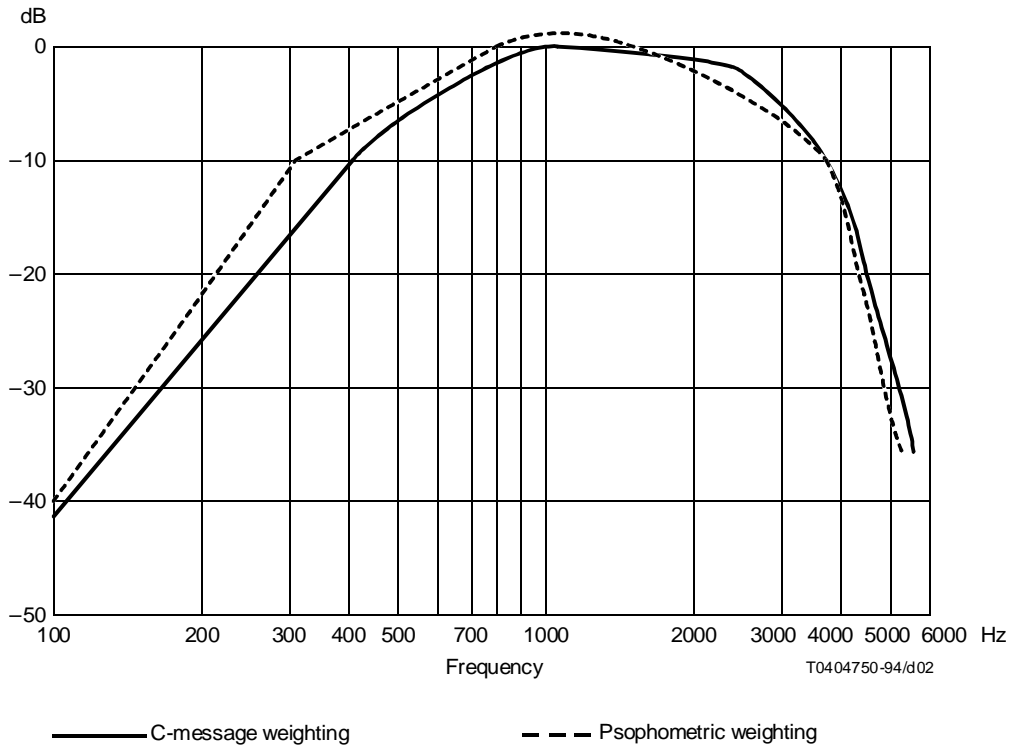


FIGURE A.1/O.41
Comparison between psophometric and C-message weighting

TABLE A.2/O.41
3 kHz flat weighting characteristic

Frequency (Hz)	30	60	400	1000	2000	3000	6000
Relative loss (dB)	0	0	0	0	0.8	3.0	12.3 ^{a)}
Tolerance (dB)	± 2.5	± 1.7	± 0.5	± 0.2	± 1.0	± 1.8	± 3.0

^{a)} The loss shall continue to increase above 6000 Hz at a rate of not less than 12 dB per octave until it reaches a value of 60 dB. The loss at higher frequencies shall be at least 60 dB.

Annex B

Level and noise measurements at interfaces with complex impedances

(This annex forms an integral part of this Recommendation)

B.1 Level measurements at interfaces with real impedance – General considerations

This annex provides background information concerning measurements at interfaces with complex impedances. It should be taken into account when calibrating level measuring equipment – especially psophometers – for measurements at such interfaces.

Figure B.1 shows a simple circuit consisting of a voltage source S with the source impedance R_{Source} which is connected to a load R_{Load} . The source produces a Voltage V_S , the voltage across the load is V_L .

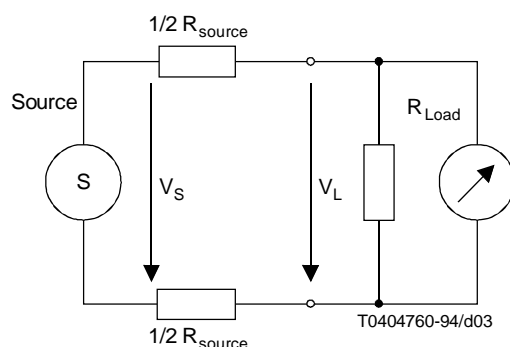


FIGURE B.1/O.41

The source may represent an unknown signal to be measured and the load may be the input impedance of a level meter. In spite of the fact that level meters mostly measure **voltages**, they may be calibrated for voltage level measurements in **dB** or power level measurements in **dBm**.

In case of power level calibration, the reading follows the formula:

$$\text{Resultat} = 10 \cdot \log (N_X / N_{\text{Ref}}) \quad \text{dBm} \quad (\text{B-1})$$

In this equation N_X is the unknown power level to be measured and N_{Ref} is the reference power level of 1 mW if the level meter is calibrated in dBm.

If the input impedance of the level meter (R_{Load} in Figure B.1) is 600Ω , the voltage V required to produce a power of 1 mW is

$$V = \sqrt{1 \cdot 10^{-3} \text{ W} \cdot 600 \Omega} = 774,597 \text{ mV} \quad (\text{B-2})$$

Per definition, this voltage is used as the reference voltage for voltage level calibration of level meters. Thus, the following formulae apply to voltage level readings (V_X is the unknown signal):

$$\text{Resultat} = 20 \cdot \log(V_X / 775 \text{ mV}) \quad \text{dB} \quad (\text{B-3})$$

and

$$0 \text{ dB} \triangleq 774,597 \text{ mV} \quad (\text{B-4})$$

Looking at equations (B-1) and (B-3), measurement results can be expressed as:

$$\text{Resultat} = 10 \cdot \log\left(\frac{V_X^2 / 600 \Omega}{775 \text{ mV}^2 / 600 \Omega}\right) = 20 \cdot \log\left(\frac{V_X}{775 \text{ mV}}\right) \quad \text{dBm or dB} \quad (\text{B-5})$$

and it can be seen that readings in **dBm or dB** are the same if the input impedance of the level meter is equal to 600Ω ! Because 600Ω was the most common reference impedance in the past, specifications could be given in **dB or dBm** without major difficulties.

It is obvious that these considerations do not apply if impedances Z different from 600Ω have to be taken into account. In this case, the voltage representing the $1 \text{ mW} / 0 \text{ dBm}$ reference point has to be calculated using the following formula:

$$V = \sqrt{1 \text{ W} \cdot 10^{-3} \cdot |Z|} \quad (\text{B-6})$$

Even if not strictly correct, **voltage level measurements** are sometimes performed at interface impedances different from 600Ω but still **maintaining the reference voltage of 775 mV**. It is clear that readings in dB would then be different from readings in dBm, because equation (B-6) provides the reference voltage in the latter (calibration in dBm) case.

B.2 Level measurements at interfaces with complex impedances

The situation becomes more difficult if the impedances in the Figure B.1 are **complex**. In this connection, the question may be raised whether complex impedances would disturb the weighting characteristic of the psophometer by introducing additional frequency-dependent loss or gain variations and thus influence noise measurements on telephone-type circuits. This question can be denied considering the following:

If the impedances in Figure B.1 would be equal, namely:

$$R_{\text{Source}} = R_{\text{Load}} = Z \quad (\text{B-7})$$

V_L would always be half of V_S regardless of the actual value of the impedances or whether they are real or complex. Even if these perfect matching conditions may not exist in practice, the requirements of equation (B-7) have to be observed because otherwise, e.g. frequency response errors would be introduced which would be a contradiction to the requirements as contained, e.g. in Recommendation G.712.

B.2.1 Level meters with complex input impedances

Complex impedances influence the calibration procedure of level meters. Taking into account Annex A/G.100, calibration to 0 dBm has to be performed at the reference frequency of 1020 Hz by applying a sinusoidal voltage V which produces an absolute power of 1 mW :

$$V = \sqrt{1 \text{ W} \cdot 10^{-3} \cdot |Z_{1020}|} \quad (\text{B-8})$$

where $|Z_{1020}|$ is the modulus of the nominal impedance, Z , at the reference frequency of 1020 Hz . Z may be resistive (real) or complex. This **voltage calibration** shall be maintained for any voice band frequency and shall result in a constant meter reading if a constant voltage is applied at any voice band frequency.

If Z is complex, the apparent power will vary at **different frequencies** when applying a **fixed voltage**.

This means that the reading in dBm will only be in accordance with the classical definition of power if measurements at interfaces with complex impedances are made at the reference frequency and using sinusoidal signals.

B.2.2 Psophometers with complex input impedances

The above findings are also applicable to psophometers which are basically level meters with a specific weighting filter and specific signal detectors.

Psophometers are normally calibrated at a frequency of 800 Hz. Nevertheless, equation (B-8) still applies which requires a calibration at 1020 Hz if a complex input impedance is to be used. The weighting filter has a gain of 1 dB at 1020 Hz referred to the reference point at 800 Hz. The calibration of the psophometer may be performed in several ways, two of which are described below, assuming the instrument is terminated in the applicable complex impedance.

Method 1 (in case the filter can be disabled):

- a) Disable the filter (flat weighting mode).
- b) Apply 1020 Hz, $V = \sqrt{1\text{W} \cdot 10^{-3} \cdot |Z_{1020}|}$
- c) Calibrate the meter to read 0 dB.
- d) Apply the filter.
- e) The meter should read + 1 dB at 1020 Hz and 0 dB at 800 Hz at the same voltage.

Method 2 (in case the filter cannot be disabled):

- a) Apply 800 Hz, $V = \sqrt{1\text{W} \cdot 10^{-3} \cdot |Z_{1020}|}$
- b) Calibrate the meter to read 0 dB.
- c) Apply 1020 Hz at the same Voltage as 800 Hz.
- d) The meter should read + 1 dB.

Instruments which are not equipped with the desired complex impedance can be calibrated to measure signal levels at voice band frequencies at interfaces with complex impedances as follows:

- a) Set the instrument to a high input impedance (bridging mode).
- b) Connect the applicable complex impedance across the input.
- c) Apply to the input a 1020 reference signal at a voltage $V = \sqrt{1\text{W} \cdot 10^{-3} \cdot |Z_{1020}|}$.
- d) The “dB” reading on the instrument represents “0 dBm” which is the new reference level.

B.3 Conclusion

The above findings have shown that measurements (including noise measurements using a psophometer) depend on the impedance present at the interface at which the measurement is performed.

In practice, circuits using the same cable may be terminated in resistive or complex impedances depending on the actual application. Under these conditions, interfering signals present on the different circuits will be generally the same. Whether measurement results obtained in these cases will differ, depends on the difference between the modulus of $|Z_{1020}|$ of the complex impedance and 600 Ω .

It is always possible, however, to calculate the voltage present at an interface using the following formula:

$$V = 10^{N_x/20} \cdot \sqrt{1\text{ W} \cdot 10^{-3} \cdot |Z_{1020}|} \quad (\text{B-9})$$

In this formula, N_x is the power level in dBm read from the level meter and $|Z_{1020}|$ the modulus of the input impedance of the meter at the reference frequency.

References

- [1] Recommendation G.123 (Annex A), *Noise allocation for a national system*.
- [2] *Noise Measuring Instruments for Telecommunication Circuits, CCITT Green Book*, Vol. IV.2, Supplement 3.2, ITU, Geneva, 1973.
- [3] Recommendation G.100 (A.3), *Definitions used in Recommendations on general characteristics of international telephone connection and circuits*.
- [4] Recommendation O.132, *Quantizing distortion measuring equipment using a sinusoidal test signal*.
- [5] Recommendation O.3, *Climatic conditions and relevant tests for measuring equipment*.
- [6] Recommendation Q.552, *Transmission characteristics at 2-wire analogue interfaces of digital exchanges*.
- [7] Recommendation P.64, *Determination of sensitivity/frequency characteristics of local telephone systems*.