Definition of level and attenuation in telephone networks

- The purpose: definition of the measurement units used for signal level and circuit gain/attenuation in telephony; definition of the reference points employed in telephone networks;
- Digital exchanges are characterized by complex impedance at the interface with the subscriber line – the definitions are generalized for powers expressed in mVA instead of mW;

1. Attenuation/loss and gain (A)

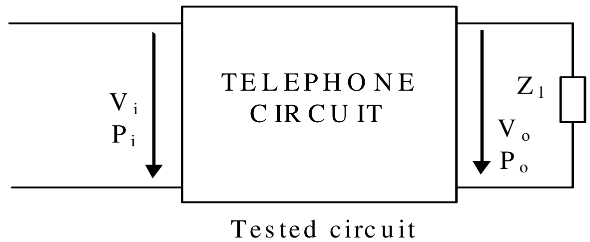

Fig. 1 Definition of attenuation

- Ratio of powers (real or apparent): $A = 10 \cdot \lg \frac{P_1}{P_2} [dB]$ (1) ; if A is positive, it is about power attenuation/loss ($P_2<P_1$) ; if A is negative, it is about a power gain ($P_2>P_1$).
- Voltage ratio: $A = 20 \cdot \lg \frac{V_1}{V_2} [dB]$ (2); if A is positive, it is about voltage attenuation/loss ($V_2<V_1$); if A is negative, it is about a voltage gain ($V_2>V_1$).

2. Return loss (A_r)

- The return loss expresses the degree of mismatch between two impedances Z_1 and Z_2 and it is given by the relation: $A_r = 20 \cdot \lg \left| \frac{Z_1 + Z_2}{Z_1 - Z_2} \right|$ (3); this formula represents the attenuation expressed in dB between an incident and the reflected signal, in an impedance mismatching point.

3. Apparent power attenuation/loss (A_a)

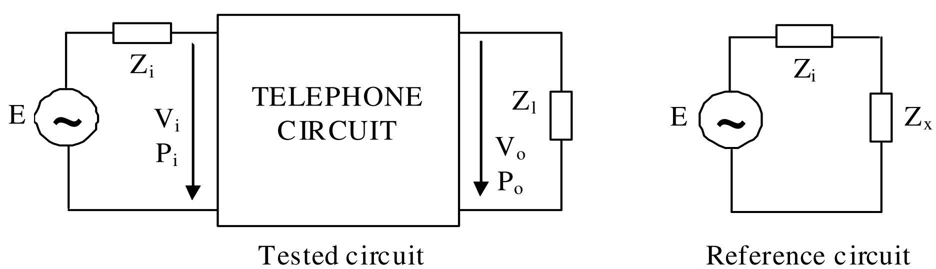

Fig. 2 Definition of apparent power attenuation

- The input apparent power P_i is defined as the power generated on a load impedance equal with the internal impedance Z_i of the generator; $P_i = \frac{E^2(f)}{4|Z_i(f_0)|}$ (4);
  - power P_o is the output apparent power on load impedance Z_l, that is: $P_o = \frac{V_o^2(f)}{|Z_l(f_0)|}$ (5)
  - apparent power attenuation is given by: $A_a(f) = 10 \cdot \lg \frac{P_i}{P_o} = 20 \cdot \lg \left(\frac{E(f)}{2V_o(f)} \cdot \sqrt{\frac{|Z_l(f_0)|}{|Z_i(f_0)|}} \right) [dB]$ (6)

- The general formula is applicable in the case of passive circuits – filters and passive reciprocal circuits; in this case the attenuation concept is based on the ratio between the input and output apparent power (identical definition in both directions – reciprocal character);
- If the impedances are resistive relation (6) can be applied; if we have a chain of amplifiers (for ex. amplifiers designed with operational amplifiers – see fig. 3) which are not influenced by the impedances Z_i and Z_l, condition $20 \cdot \lg \frac{E}{V_o} = ct$ is fulfilled and relation (6) must be modified (for maintaining the general concept of apparent power transfer):
  - The apparent power attenuation is computed at the reference frequency f_0=1020Hz:

$$A_a(f_0) = 20 \cdot \lg\left(\frac{E(f_0)}{2V_0(f_0)} \cdot \sqrt{\frac{|Z_l(f_0)|}{|Z_i(f_0)|}}\right)[dB] \quad (7)$$

  - The apparent power attenuation is expressed according to frequency as in (6). Because the ratio of impedances is independent of frequency, attenuation variation with the frequency depends only on the E/V_o ratio.

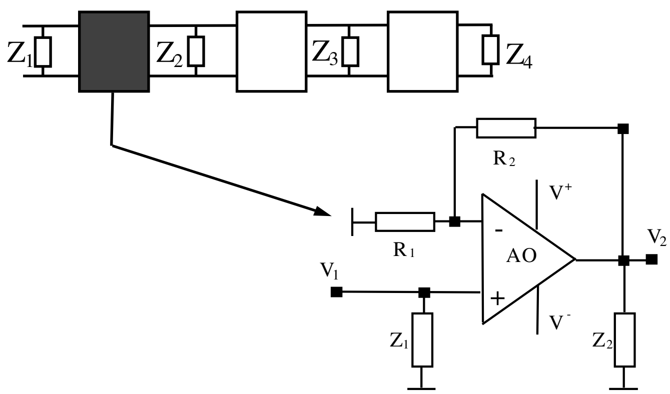

Fig. 3 Circuit composed of a chain of amplifiers

4. Insertion attenuation/loss (A_i)

- The input apparent power P_i is defined as the power generated on an impedance equal with the Z_l load impedance: $P_i = \frac{E^2(f) \cdot |Z_l(f)|^2}{|Z_i(f) + Z_l(f)|^2 \cdot |Z_l(f_0)|}$ (8);
  - power P_o is the output apparent power on the load impedance Z_l, that is: $P_o = \frac{V_o^2(f)}{|Z_l(f_0)|}$ (9)
  - the insertion attenuation is given by:

$$A_i(f) = 10 \cdot \lg\frac{P_i}{P_o} = 20 \cdot \lg\left(\frac{E(f)}{V_o(f)} \cdot \frac{|Z_l(f_0)|}{|Z_i(f_0) + Z_l(f_0)|}\right)[dB] \quad (10)$$

  - As in the case of the apparent power attenuation the general formula is applicable in the case of passive circuits – filters and passive reciprocal circuits; if we have a chain of amplifiers (for ex. amplifiers designed with operational amplifiers – see fig. 3) which are not influenced by the impedances Z_i and Z_l, condition $20 \cdot \lg \frac{E}{V_0} = ct$ is fulfilled and relation (10) must be modified (for maintaining the general concept of apparent power transfer):
    - Insertion attenuation/loss is computed at the reference frequency f_0=1020Hz:

$$A_i(f_0) = 10 \cdot \lg\frac{P_i}{P_o} = 20 \cdot \lg\left(\frac{E(f_0)}{V_o(f_0)} \cdot \frac{|Z_l(f_0)|}{|Z_i(f_0) + Z_l(f_0)|}\right)[dB] \quad (11)$$

- Insertion attenuation/loss is expressed according (10). Because the ratio of impedances is independent of frequency, attenuation variation with the frequency depends only on the E/V_0 ratio.

5. Absolute power level expressed in dBm for test tones

- Represents the apparent power level of a sine signal expressed in dB, relatively to a 1mVA apparent power: $L = 10 \cdot \lg \frac{P}{1mVA} = 10 \cdot \lg \left(\frac{\frac{V_0^2(f)}{|Z_n(f_0)|}}{1mVA} \right) [dBm]$ (12)
- In analog networks is usual the 1mW reference power; on the analog interfaces of the digital exchanges (two wire interfaces) complex impedances are used, as a rule it is necessary to use the apparent power; impedances are evaluated at the reference 1020Hz frequency.

6. Absolute power level of the real signals

- It is about the voice signals having a 300Hz-3400Hz frequency band; there are the following cases:
  - Systems with resistive impedances: the active power is computed as: $P = \int_{f_1}^{f_2} \frac{V_0^2(f)}{R} df\ [mW]$ (13)

    where R is the load resistance in Ω, $V^2(f)/R_0$ is the power spectral density in mW/Hz, f_1, f_2 – are the limit of the frequency band in Hz; the absolute power level in this case is: $L = 10 \cdot \lg \frac{P}{1mW} [dBm]$ (14)
  - Systems with complex impedances: the active power is computed as: $P = \int_{f_1}^{f_2} \frac{V_0^2(f)}{|Z(f_0)|} df\ [mVA]$ (15); the absolute power level this case is: $L = 10 \cdot \lg \frac{P}{1mVA} [dBm]$ (16); the variation of the power level with frequency is dependent only on the voltage.

7. Psophometric power level (dBmp)

- Physiological characteristics of the ear make the perception of the sound dependent on the frequency according to a weighting function W(f), the psophometric characteristic; the effect of the low frequency (for ex. 50Hz) or high frequency (3000Hz) components is lower than the effect due to the components included in the 800Hz – 2000Hz band; if we take into account this weighting characteristic the expression of the absolute and relative power becomes:

$$P_p = \int_{f_1}^{f_2} \frac{V^2(f)}{|Z(f_0)|} \cdot 10^{W(f)/10} df\ [mVA] \quad (17) \qquad L_p = 10 \cdot \lg \frac{P_p}{1mVA} [dBmp] \quad (18)$$

8. Relative power level (dBr)

- The relative level (in dB) in a point is given by: $L_r = 10 \cdot \lg \frac{P(1020Hz)}{P_0(1020Hz)} [dB]$ (19); P and P_0 are the apparent power in the considered point respectively in the reference point–TPR (Transmission Reference Point); in the case of some equipments, like PBX, it is usual also the term of LPR (Level Reference Point).
  - The relative level is numerically equal with the attenuation/loss or gain between the considered and the reference point at 1020Hz frequency; in the reference point the relative level is 0dBr;
  - The measurement signal applied in the transmission reference point (0dBr) has, as a rule, a value of -10dBm, to avoid the risk of systems overloading;
  - Significance of the relative level: it allows the characterization of some properties like: gain or attenuation between interfaces and of the capability of certain equipment to process the signals applied to an interface;
  - Can be used also in equipment designing and in performance tests.

9. Level expressed in dBm0

- Represents the absolute power level measured at 1020Hz reference frequency in the transmission reference point (0dBr); in a given point having the relative level L_r, a level L dBm0 generates an absolute value L_a: $L_a = L + L_r \ [dBm]$ (20)

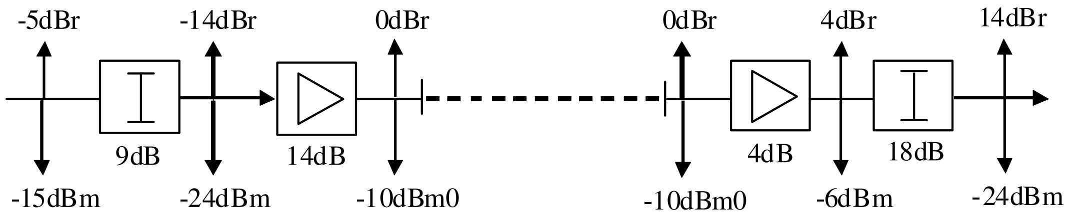

Fig. 4 Definition of absolute and relative levels

10. The use of the relative level (dBr) and of the dBm0 level in equipment designing and in performance tests – the case of PCM systems

- For the evaluation of the coders and decoders of the PCM systems the concept of digital reference sequence was introduced (Digital Reference Sequence – DRS); DRS is a possible PCM code sequence which, by decoding with an ideal decoder, generates a 0dBm0 signal.
  - Inversely, an analog signal with a 0dBm0 level applied at the input of an ideal coder will generate a reference digital sequence; the frequency of the signal (a sine signal) is chosen to be 1kHz (DRS represented by a sequence of 8 samples), but could be also selected a frequency which is not a sub-harmonic of the 8kHz sampling frequency – an appropriate value is 1020Hz, but in this case the DRS signal generation will be more complex;
  - DRS obtained from the reference sine signal has a peak value of 118; the maximum coding level in the case of an A law coder is 3,14dBm0 for a sine signal.
- The process of relative levels computation for the case of real coders and decoders, when the digital path doesn't include any digital processing (for ex. digital attenuation) it is depicted in fig. 5. By definition the relative level on such digital link is 0dBr.

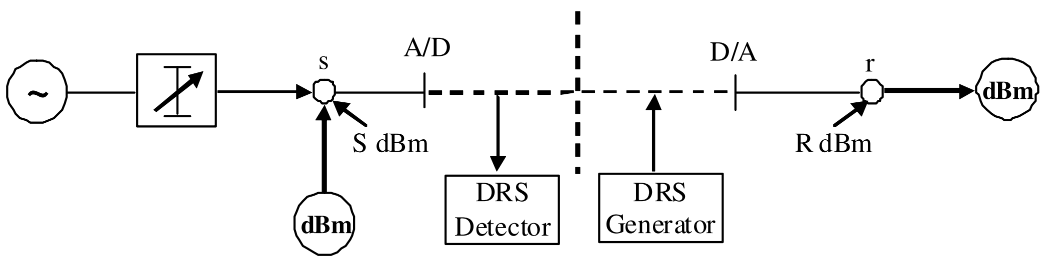

Fig. 5 Use of the DRS sequence for computation of the relative levels located in front of the PCM coder and behind the PCM decoders

  - The computation of relative levels in points „s" and „r" it is accomplished in the following ways: it is modified the level in point „s" until a device connected to the digital path identifies the DRS sequence corresponding to a level of 0dBm0; if the measured level is S dBm, results a relative level of S dBr=S dBm – 0 dBm0; similarly, in the case of the decoder, a DRS sequence is applied to the decoder and an R dBm level, numerically equal with the relative level expressed in dBr, is measured at the output of the decoder.

11. Other parameters expressed in units derived from dB – the voltage level

- By definition, the voltage level expressed in dBu is given by the relation: $L_u = 20 \cdot \lg \frac{U_x}{775mV} \ [dBu]$(21), where U_x is the effective value of the measured voltage; 775mV is the voltage which produces a power of 1mW on a 600Ω resistor; the voltage level is in general different of the power level; the difference appears if the load impedance is complex and the modulus is not equal with 600Ω, and we have: $L_p = L_u + 10 \cdot \lg \frac{600}{|Z|} \ [dBm]$ (22)

12. Virtual International Connecting Point – VICP

- The VICP points define the limits between the national and international part of a connection (see fig. 6); are used as reference points for the national and the international parts;

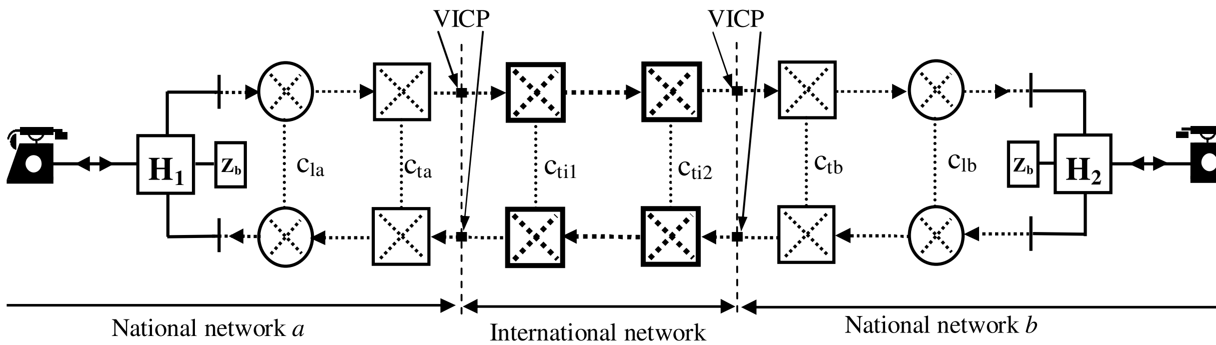

Fig. 6 Definition of the virtual international connection points

13. Loudness rating (LR)

- A telephone communication suppose the existence in the end points of two basic elements: one of them transmits the sound message (the mouth), the other receives the sound message (the ear) ;
  - a global telephone communication supposes an acoustic pressure at the both ends of the connection and an electric signal used to transmit the sound message along the connection;
  - the correct planning of the telecommunication networks requests the expression of the electro-acoustic attenuation between the acoustic source and the receiver; the specific attenuation (in dB), obtained by establishing equivalence between the attenuation of the two type of signals is the so called "loudness rating" (LR);
  - if the circuit is divided in several blocks, then the global rating for loudness is the sum of the individual values of LR.
- It is considered as reference for the national system the VICP point and the LR parameter is defined by the components:
  - Loudness rating at transmission (LRT) – represents the attenuation between the mouth of the subscriber who is speaking and the VICP point (or other reference point) – in this case the loudness rating represents the weighted mean (in dB) of the acoustic excitation pressure reported to the measured voltage (or power);
  - Loudness rating at reception (LRR) – represents the attenuation between the VICP point (or other reference point) and the ear of the subscriber who is listening – in this case the loudness rating is defined as the weighted mean (in dB) of the excitation voltage reported to the measured acoustic pressure (see fig. 7).

Remark: the loudness ratings LRT and LRR can be computed at any electrical interface of a telephone network.

- In fig. 7 it is presented the complete schematic of a telephone connection between the sound source and the receiver, composed of several interconnected parts; we have the following relations:

$$EFE = EFE(phone) + \sum_{i=1}^{n} EFC_i \; ; EFR = EFR(phone) + \sum_{i=1}^{n} EFC_i \; ; EFG = EFE + EFR \quad (23)$$

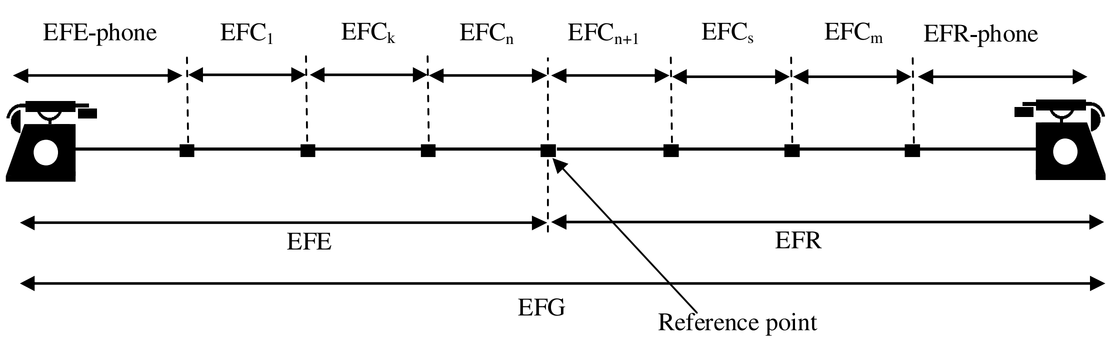

Fig. 7 Loudness ratings defined for a telephone connection

- The computation of the loudness ratings can be realized in subjective manner – low performances, or in objective manner – it is necessary a psycho-acoustic model which simulates the modality in which the brain translate the sonorous impressions;
- The loudness ratings of the telephone devices are obtained by using special equipments – it is not necessary a very precise measurement of the real loudness rating because this depends on the subscriber;
  - the loudness rating of a circuit is equal with the attenuation at 1020Hz if the attenuation is constant in the whole bandwidth, respectively the mean attenuation in the 300Hz-3400Hz band if there are important attenuation distortions;
  - the loudness rating for the subscriber circuits can be computed using the following relation: $EFC = K \cdot L \cdot \sqrt{R \cdot C}$ (24), where R is the cable resistance in Ω/km, C is the cable capacity in nF/km, L is the length in km, K is a constant that depends on the terminal impedance Z_0 of the cable (K=0.014 for Z_0=600Ω, K=0.015 for Z_0=900Ω, K=0.016 for Z_0-complex).
- In normal conditions of exploitation a global value of 10dB for the loudness rating is acceptable.

14. Data signal level on mixed circuits

- The power level of the signals transmitted and received by modems has a fundamental importance in the case of data transmissions performed on telephone circuits; the selection of a reasonable value of the data signal level is influenced by two opposite conditions:
  - values as high as possible necessary to ensure signal to noise ratio as high as possible at reception;
  - moderate values, appropriate for avoiding cross-talks risks and signals whose peaks can overrun the linearity threshold of the PCM converters;
- It is imposed a maximum power level of 0 dBm0 and a mean power level of -13dBm0;
  - for levels received by modems intended for good quality leased lines it is imposed -26dBm;
  - -28dBm for modems intended for medium quality leased lines;
  - -43dBm for modems intended for switched lines;

15. Evaluation of the noise parameters

There are used different weighting filters (characteristics) for different situations in order to evaluate the performances of telephone transmissions.

- The non-weighted frequency characteristic (flat characteristic) – it is used for the evaluation of different equipment performances and for the evaluation of the data transmissions realized on telephone circuits.
- The non-weighted characteristic is a low pass characteristic with a 3kHz bandwidth; the characteristic is flat up the 50Hz frequency to be possible the evaluation of the effects of the power grid frequency on telecommunication lines.
- The narrow band frequency is used for the identification and evaluation of interfering signals with discrete frequencies (different tones).
- The psophometric characteristic (fig. 8) – it is a special weighting (filtering) characteristic used to the evaluation of the noise on the transmission of voice signals – it is considered the frequency characteristic of the ear.
  - Spectral components of the noise located in the 800Hz-2500Hz band are the most disturbing, the sensitivity of the ear being the highest in this frequency band.
  - The sensitivity of the ear decreases at frequencies located below 300Hz and above 4000Hz, the noise components located below and above these thresholds having a relatively reduced effect.
  - The absolute weighted power level (psophometric level) is expressed in dBmp.

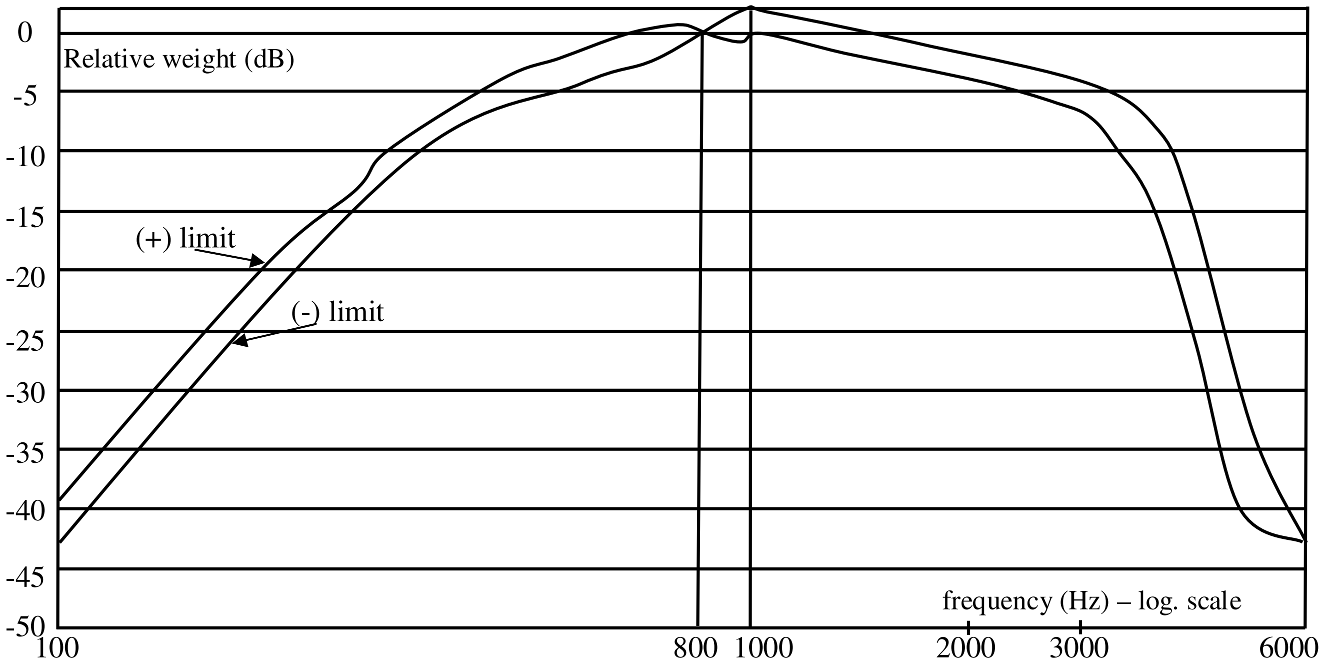

Fig. 8 Spectral mask of the psophometric weighting filter