Echo and stability in telephone networks

Telephony laboratory 2010-2011

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Introduction

- The echo is due to the use of a 2 wire subscriber – exchange duplex transmission and a 4 wire duplex transmission between exchanges (and in the switching process)
- The echo is generated by the reflected signals due to the impedance mismatching between different segments of a telephone circuit
  - The main source of echo is represented by the mismatch between the input impedance of the 2 wire subscriber lines and the balance impedance of the hybrid transformer.

1. Generation and effects of the echo

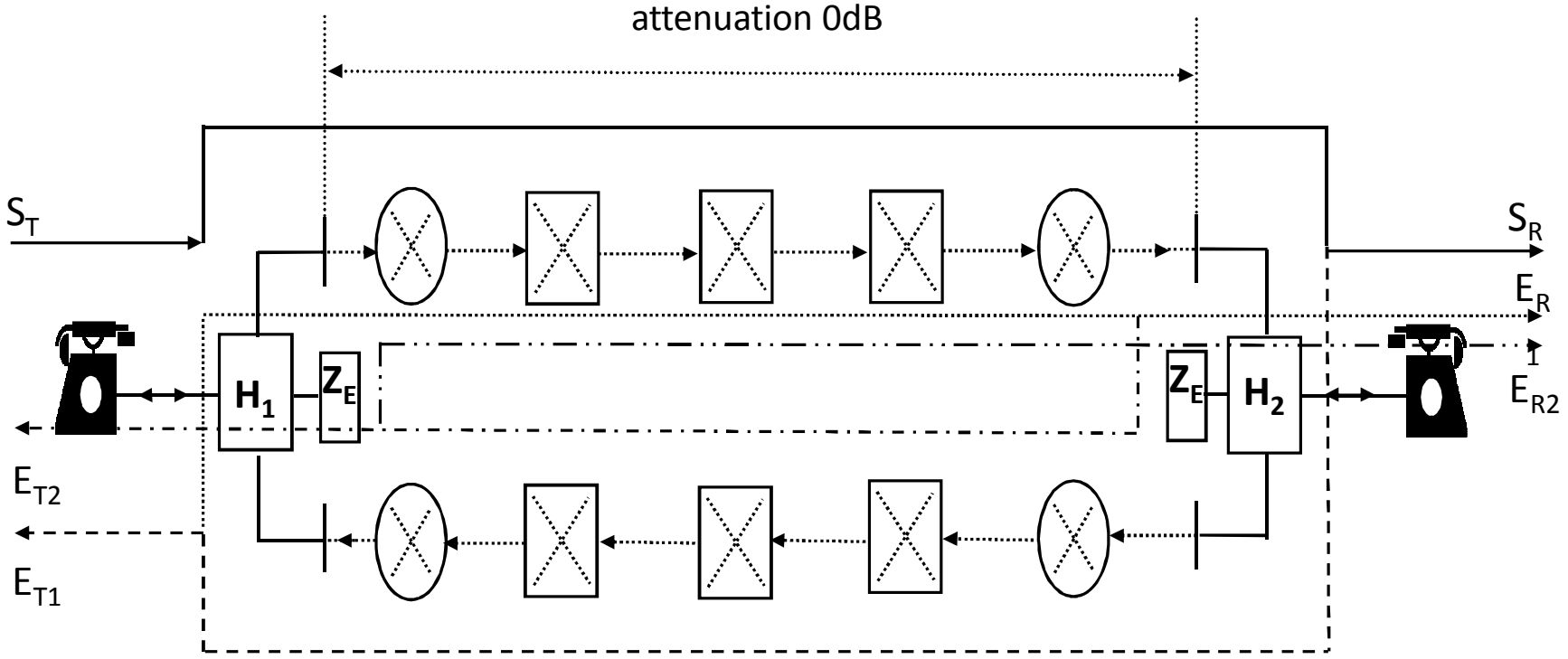


Fig. 1 Simplified schematic of a digital telephone connection and the associated echo signals

- The transmitted signal S_T is transferred from the 2 wire channel (subscriber loop), connecting the subscriber to the exchange, on the 4 wire channel by H_1, and transformer H_2 realizes the transfer from the 4 wire channel on the 2 wire channel of the called subscriber (subscriber loop);
- Due to the impedance mismatches at hybrid transformers H_1 and H_2 reflected signals appear and generate echo signals E_{T1} and E_{T2} at the transmission side and echo signals E_{R1} and E_{R2} at reception side.
- The most important echo signals are generated by the first reflections.

Classification of echo

- 2 categories of echo:
  - Transmitter echo TE
  - Receiver echo RE
- The transmitter side (TE) – it is perceived by the person who is speaking as a delayed replica of his own signal; it has the suggestive name of talker echo.
- The receiver echo (RE) – it is perceived by the person who listens and has the suggestive name of listener echo;

Transmitter echo - TE

- It is due to the H_2 hybrid transformer located at the distant point (see fig. 1);
- The effect of this echo in telephony depends on:
  - The level of the echo – depends on the attenuation of the whole propagation path of the echo and especially on the trans-hybrid attenuation of the H_2 hybrid transformer, situated at the distant point.
  - The echo delay – depends on the structure of the circuit.
- This echo is more disturbing if the level and the delay are large.

Receiver echo - RE

- It is due to the unbalances of both hybrid transformers located at both ends of the communication channels.
- The listener echo is more disturbing if the signal/echo ratio is small and the delay is large.
- For small values of the echo delay (<3ms), the echo is perceived by the person who listens as a cave sound (hollowness) or barrel sound
  - This effects appears when the unbalances are more pronounced at low frequencies.

Conclusions

- The subscriber equipment impedance has a high influence on the echo generation (Z_{in} of the line seen by the hybrid depends on the terminal impedance).
- The echo attenuation on the 4 wire loop circuits is relatively low; the loop attenuation is due to the hybrid transformers and partially to the A/D and D/A converters.
- The digital switching inserts large delays and the echo is becoming more disturbing.

- The instability of the transmission systems appear if there are fulfilled conditions related to the gain and phase variation in the 4 wire loop.
- The oscillations appear usually at some frequencies where are fulfilled the conditions necessary for producing and maintaining the oscillations.
  - The phenomenon appears as a “whistle”.
- The instability makes the affected circuit unusable and can provoke crosstalk in the neighbor circuits.
- The side effect of the phone device do not has to suppressed completely.
  - The hybrid from the phone do not has to be very complex.

2. Parameters which characterize the echo, stability and the side effect

The return loss a_r

- Sources generating reflected signals:
  - impedance discontinuities in the junction points of cables with different diameters.
  - unused cable connected in parallel with the subscriber loops (bridged taps).
  - impedance discontinuities between the cables and the exchange, between the subscriber terminal and the cable.
- It is considered an ideal hybrid → perfect balance (see figure 2).
- The measurement signal s_m suffers a reflection in the junction point between the cable and the tested circuit.

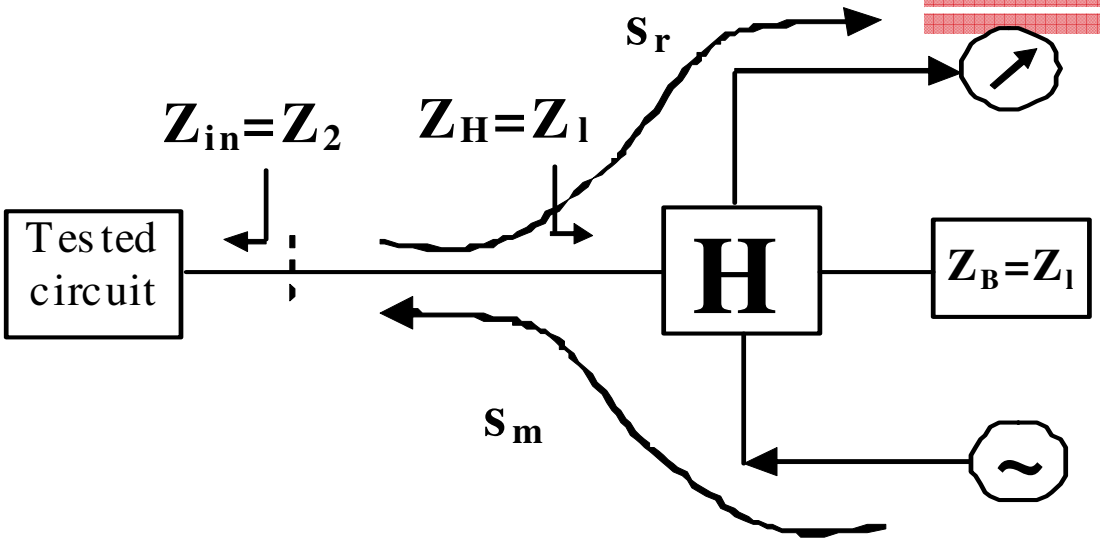


Fig. 2 Definition and measurement of the return loss parameter

- The return loss: $$a_r = 10 \lg \frac{P_{tr}}{P_{rec}} [dB]$$
- or: $$a_r = 20 \lg \left| \frac{Z_1 + Z_2}{Z_1 - Z_2} \right| = -20 \lg |r| [dB]$$

where the reflection coeficient is: $$r = \frac{Z_1 - Z_2}{Z_1 + Z_2}$$

The balance return loss a_{bal}

- Expresses the attenuation between the 4 wire input and output of the hybrid transformer;
- Expresses also the mismatching degree between the line impedance Z_l and the balance impedance Z_b :
- The balance return loss:

$$a_{bal} = 20\lg\left|\frac{Z_0 + Z_b}{2Z_0}\frac{Z_l + Z_0}{Z_l - Z_b}\right|[dB]$$

  - If Z_b=Z_o (Z_o = Z_{in} hybrid):

$$a_{bal} = 20\lg\left|\frac{Z_l + Z_b}{Z_l - Z_b}\right|[dB]$$

- The balance return loss depends on:
  - Characteristic impedance of the cable (subscriber loop)
  - Length of the cable
  - Cable parameters
  - Frequency
  - Impedance of the terminal equipment

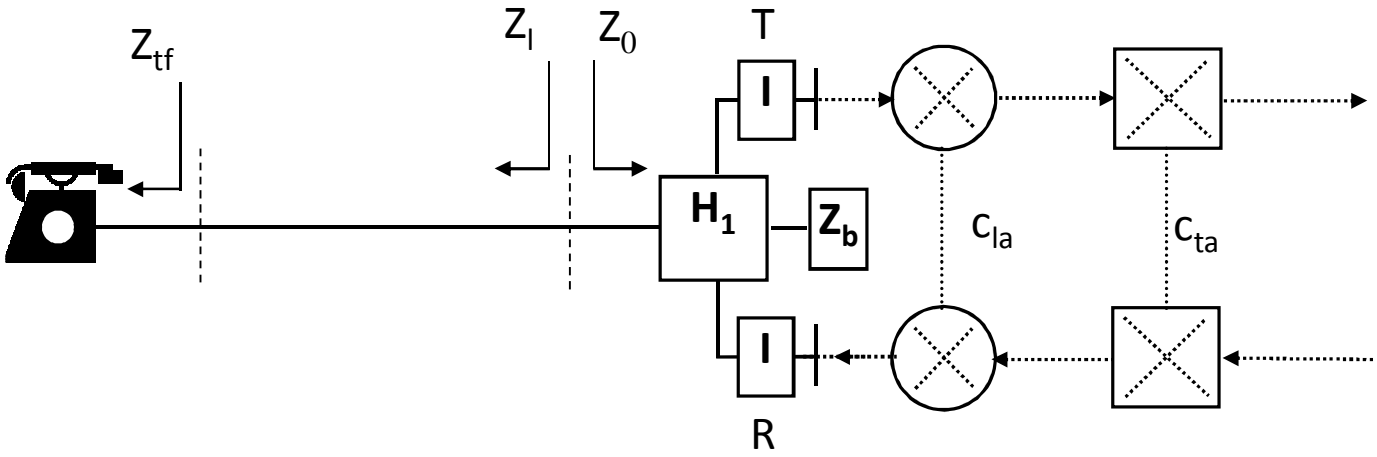


Fig. 3 Definition of the balance return loss and the parameters witch affect this attenuation

The test balance return loss (a_{balt})

- The line impedance is replaced with a particular impedance Z_t, which represents the impedance of a test circuit.
- Z_t is a characteristic of every national network.
- a_{balt} allows to verify in what extent the balance impedance from a digital exchange ensure an acceptable balance for the multitude of the subscriber loops from a given network.
- The test impedance represents the standardized balance impedance used in a national network.

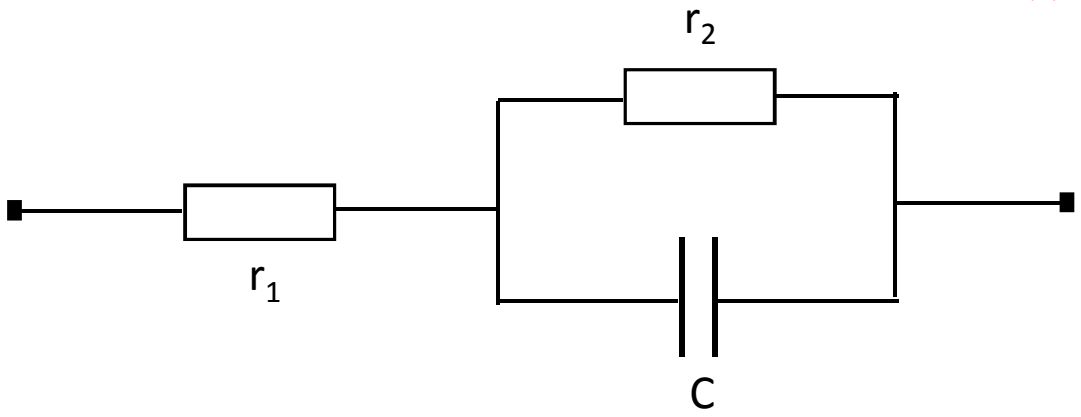


Fig. 4 Structure of the test and balance impedance (dipole)

Țara	Z_t		
	r_1 (Ω)	r_2 (Ω)	C (nF)
Germania/Austria	220	820	115
Marea Britanie	370	620	310
Italia	0	1100	33
Japonia	150	830	72
Noua Zeelandă	370	620	310

Tab. 1 Values of the test impedance (dipole) components used in different national networks.

- Different national network have different characteristics (parameters of the cables from the access network) and due to this are necessary different balance impedances for a better balancing of the hybrid transformers connected to the subscriber loops.
- The balance impedance represents the mean value of the input impedances of the subscriber loops from a national telephone network.

R and T analog pads

- The reduced attenuation of the digital telephone circuits generates high levels of the echo signal and a high oscillation probability of the 4 wire circuits.
- It is of interest the increase between some limits of the 4 wire circuits attenuation.
  - This attenuation increase can be achieved by inserting attenuators before the A/D converter and after the D/A converter – it is about attenuators T and R in fig. 3.
  - The attenuators usually insert a 7dB total attenuation; usually is preferred the insertion of a single attenuator, namely attenuator R, with a value of 7dB.

Semi-loop loss and open loop loss a_{a-b}

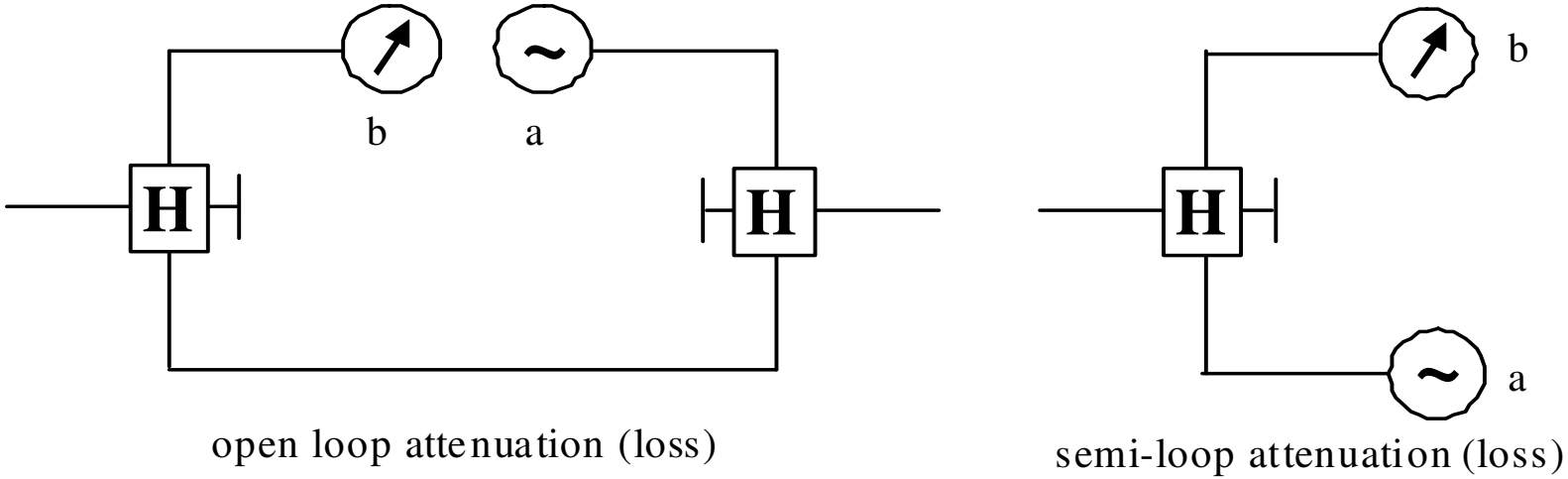


Fig. 5 Definition and measurement of open loop and half loop loss

- The semi loop attenuation includes only the return balance loss a_{bal} of one hybrid transformer of the 4 wire loop and can be used to characterize the transmission echo TE.

- The open loop attenuation a_{bal} includes the balance return loss of both hybrid transformers of the 4 wire loop and can be used to characterize the reception echo RE.
- The semi loop attenuation is used to characterize the national part of an international connection, the national part representing a semi loop.
- The characterization of the stability of a national connection is realized by the open loop attenuation.
  - In order to ensure the stability of the national connection there are imposed conditions to the open loop attenuation.

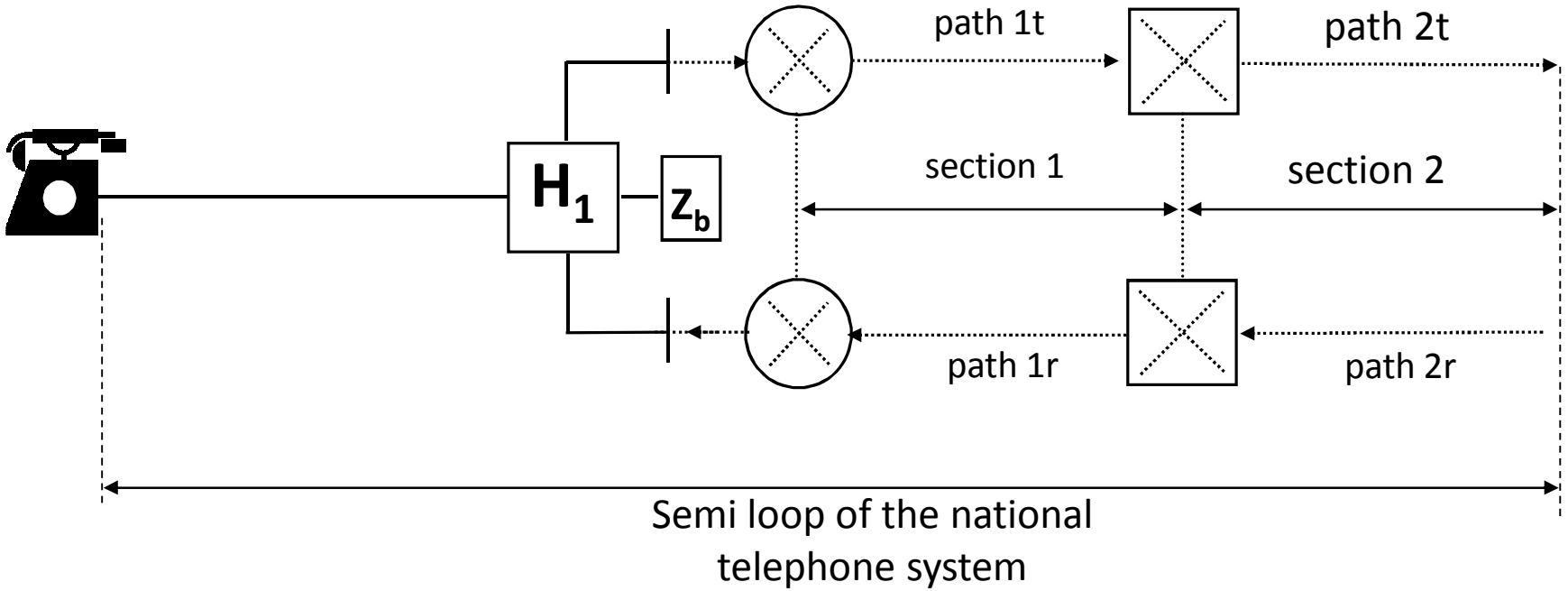


Fig. 6 Definition of the semi loop of a national telephone system

- The characterization of the stability of an international connection is realized by the attenuations inserted by the national semi loops (see fig. 6).
- In order to ensure the stability of the international connections conditions are imposed for the attenuations inserted by the national semi loops.

Stability loss a_s

- It represents the smallest value the semi loop or of the open loop attenuation in the 300Hz-3400Hz frequency band.
- It expresses practically the reserve up to the stability limit
  - It refers to the most disadvantageous conditions related to the stability of the circuits.
- a_s and the problem of the circuits stability in general must be considered in two different situations, namely:
  - The stability during the connection establishment and interruption phase.
  - The stability during the communication phase

- The input impedance of the user equipment (telephone or modem) affects the input impedance of the line, Z_{in} , seen by the hybrid, meaning that it affects more the stability of the hybrid if the line is shorter.
- If the line between the user equipment and the hybrid transformer is very short it can be considered that the input impedance of the line is equal with the input impedance of the user equipment, which can be zero (short-circuit) or infinite (interruption) in the establishment and interruption phase of the connection.

- In this phase (connection establishment or interruption) the hybrids a_{bal} is:

$$a_{bal-\text{int}erruption} = 20\lg\left|\frac{Z_0 + Z_b}{2Z_0}\right|[dB]; \quad a_{bal-short} = 20\lg\left|\frac{Z_0 + Z_b}{2Z_b}\right|[dB]$$

$$a_{bal-\text{int}erruption} = a_{bal-short} = 0dB \quad if \quad Z_0 = Z_b$$

- The semi loop attenuation of a digital connection could decrease up to the value R+T in the worst case characteristic the connection establishment or tear down.

Echo attenuation a_e

- The echo attenuation represents the semi loop or open loop loss obtained by averaging the a(f) attenuation transfer characteristic of the circuit in the frequency domain.
- It can be calculated un-weighted or weighted according to the law 1/f, in the 300Hz - 3400Hz frequency band.
  - a_e un-weighted – used to evaluate the performances of data transmissions realized on telephone circuits.
  - a_e weighted – used to evaluate voice transmissions; the 1/f weighting law expresses the subjective effect of the human hearing.

- It is calculatd according to the following relations:

$$a_{e-unweighted} = 10\lg\left[\frac{1}{3100}\int_{300}^{3400} a(f)df\right][dB]$$

$$a_{e-weighted} = 10\lg\left[\frac{1}{3100}\int_{300}^{3400} \frac{a(f)}{f}df\right][dB]$$

$$a(f) = 10^{\frac{a_{a-b}(f)[dB]}{10}}$$

- Conditions imposed for the a_e of the national semi loop:

$$mean\ value > (15+n)dB; \quad s\tan dard\ deviation \le \sqrt{9+4n}$$

Where n is the number of 4 wire circuits.

3. Echo and stability performances of telephone circuits

Tolerance to echo in voice and data transmissions

- In data transmission the transmitter echo TE has practically no effects because:
  - If a modem realizes the separation of the transmission and reception path by dividing the telephone band in two sub-bands the echo is generated in the transmission band which is separated from the reception band.
  - If the modem transmits and receives on the same carrier (separation of the transmission paths by echo compensation) the echo compensators suppress not only the transmitted signal superposed on the received signal but also the received echo signal.

- In voice transmissions the transmitter echo is very disturbing, the speaker hearing his own voice.
- The factors which establish the echo tolerance to the transmission echo are:
  - the number of 2-4-2 loops which contribute to the echo generation.
  - the delays inserted by the previously mentioned loops.
  - total attenuation of the echo path (including the subscriber line).
  - echo tolerance obtained by laboratory tests.
- The echo tolerance is calculated for different delays and attenuations of the echo path and represents the percent of speakers which consider a transmission acceptable as quality for a given delay and attenuation inserted by the echo path.
- The echo path attenuation associated to a given echo tolerance can be characterized by a mean value and a standard deviation.

Mean propagation time in one transmission direction (ms)	Mean attenuation of the echo path (dB)	
	90 % satisfactory	99 % satisfactory
10	17,6	24,6
20	24,6	31,6
30	28,6	35,6
40	31,6	38,6
50	33,6	40,6
75	37,6	44,6
100	40,6	47,6
150	43,6	50,6
200	45,6	52,6

Tab. 2 Mean echo attenuation necessary for satisfactory echo performances

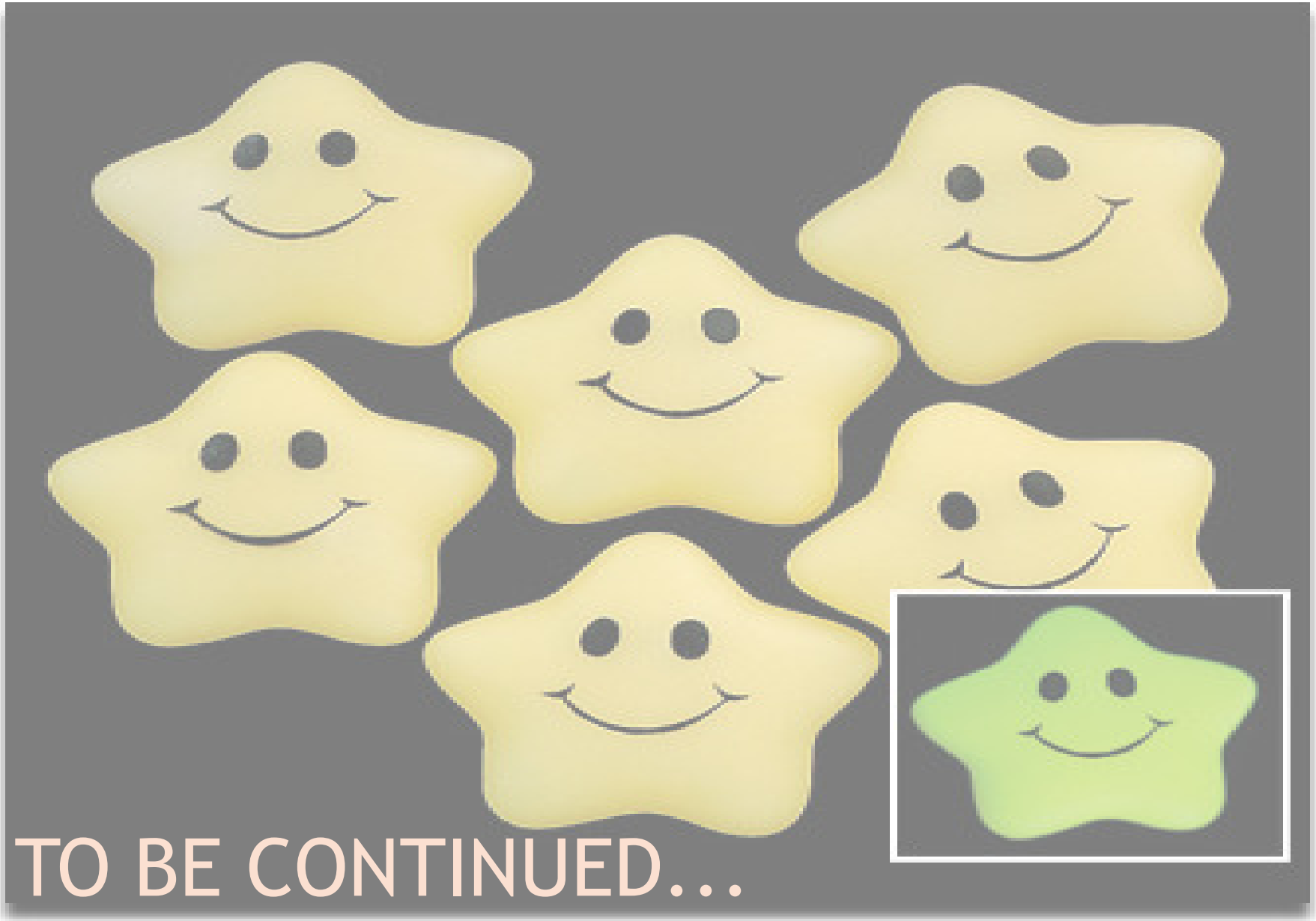
Tolerance to reception echo in voice and data transmissions

- The reception echo has a more reduced effect on voice transmissions, the effects of this echo being neglected if the open loop attenuation is larger then 8 – 10dB and the echo delay is smaller than 10ms.
- In the case of smaller delays, 3-4ms, the so called cave sound could appear in telephony, meaning that the voice signal is distorted similarly with the echo of a room.
- In this case it is not defined a satisfactory performances function of the delay and attenuation inserted by the echo path.

- In the situation of data transmission, the reception echo has very pronounced effects on the performances, due to apparition of ripples in the frequency transfer characteristic of the channel (both the attenuation and group delay characteristic presents ripples).
  - Such a frequency transfer characteristic is generated by the vector addition of the spectral components with their delayed and attenuated replicas.
  - Even if the delay is the same at each frequency, the phase difference between the spectral components and their delayed variants is changing with the frequency.

Stability performances of telephone circuits affected by echo

- The stability performances of circuits refer to two probabilities:
  - the oscillation probability of the circuits.
  - the probability to ensure a stability parameter for the circuit.
- The stability of a 4 wire telephone circuit is defined as the maximum gain, S, which can be inserted in each transmission direction without losing the stability, meaning without generating oscillations.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