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Recommendation G.165

ECHO CANCELLERS

(Geneva, 1980; amended at Malaga-Torremolinos, 1984

and at Melbourne, 1988)

1 General

1.1 Echo cancellers are voice operated devices placed in the 4-wire portion of a circuit (which may be an individual circuit path or a path carrying a multiplexed signal) and are used for reducing the echo by subtracting an estimated echo from the circuit echo. They may be characterized by whether the transmission path or the subtraction of the echo is by analogue or digital means (see Figures 1/G.165, 2/G.165 and 3/G.165).

1.2 This Recommendation is applicable to the design of echo cancellers using digital or analogue techniques, and intended for use in an international circuit. Echo cancellers designed to this Recommendation will be compatible with each other and with echo suppressors designed in accordance with Recommendations G.161 [1] and G.164. Compatibility is defined in Recommendation G.164, § 1.4. Freedom is permitted in design details not covered by the requirements.

Echo cancellers may be used for purposes other than network echo control on international circuits, e.g. in active 2-wire/4-wire hybrids or 2-wire repeaters, but this Recommendation does not apply to such echo cancellors.

Figure 1/G.165 p.

Figure 2/G.165 p.

Figure 3/G.165 p.

2 Definitions relating to echo cancellers

In the definition and text, *L* will refer to the relative power level of a signal, expressed in dBm0 and *A* will refer to the attenuation or loss of a signal path expressed in dB.

2.1 **echo canceller** (see Figure 4/G.165)

F: annuleur d'´echo

S: compensador de eco; cancelador de eco

A voice operated device placed in the 4-wire portion of a circuit and used for reducing near-end echo present on the send path by subtracting an estimation of that echo from the near-end echo.

These definitions assume that nonlinear processing, e.g. centre clipping, is not present in the send or receive paths unless otherwise specified and that the signal at S_{in} is purely echo.

Figure 4/G.165 p.

2.2 **echo loss (A_{ECHO} .PS 10)**

F: *affaiblissement d’´echo (A_{ECHO} .PS 10)*

S: *atenuaci´on del eco (A_{ECO} .PS 10)*

The attenuation of a signal from the receive-out port ($R_{o\du\dt}$) to the send-in port ($S_{i\dn}$) of an echo canceller, due to transmission and hybrid loss, i.e. the loss in the echo path.

Note — This definition does not strictly adhere to the echo loss definition given in Recommendation G.122, § 2.2 which applies to loss of the *a -t -b* path viewed from the virtual switching point of the international circuit. The echo canceller may be located closer to the echo reflection point.

2.3 **cancellation (A_{CANC} .PS 10)**

F: *annulation (A_{NL} .PS 10)*

S: *compensaci´on; cancelaci´on (A_{COMP} .PS 10)*

The attenuation of the echo signal as it passes through the send path of an echo canceller. This definition specifically excludes any nonlinear processing on the output of the canceller to provide for further attenuation.

2.4 **residual echo level (L_{RES} .PS 10)**

F: *niveau d’´echo r´esiduel (N_{RES} .PS 10)*

S: *nivel de eco residual (N_{RES} .PS 10)*

The level of the echo signal which remains at the send-out port of an operating echo canceller after imperfect cancellation of the circuit echo. It is related to the receive-in signal L_{Rin} by

$$L_{RES} = L_{Rin} - A_{ECHO} - A_{CANC}$$

Any nonlinear processing is not included.

2.5 **nonlinear processor (NLP)**

F: processeur non lin´eaire (PNL)

S: procesador no lineal (PNL)

A device having a defined suppression threshold level and in which:

a) signals having a level detected as being below the threshold are suppressed, and

b) signals having a level detected as being above the threshold are passed although the signal may be distorted.

Note 1 — The precise operation of a nonlinear processor depends upon the detection and control algorithm used.

Note 2 — An example of a nonlinear processor is an analogue centre clipper in which all signal levels below a defined threshold are forced to some minimum value.

2.6 **nonlinear processing loss (A_{NLP} .PS 10)**

F: affaiblissement par traitement non lin´eaire (A_{TNL})

S: atenuaci´on por procesamiento (o tratamiento) no lineal (A_{PNL})

Additional attenuation of residual echo level by a nonlinear processor placed in the send path of an echo canceller.

Note — Strictly, the attenuation of a nonlinear process cannot be characterized by a loss in dB. However, for purposes of illustration and discussion of echo canceller operation, the careful use of A_{NLP} is helpful.

2.7 **returned echo level (L_{RET} .PS 10)**

F: niveau de retour d'´echo (N_{RET})

S: nivel del eco devuelto (N_{DEV})

The level of the signal at the send-out port of an operating echo canceller which will be returned to the talker. The attenuation of a nonlinear processor is included, if one is normally present. L_{RET} is related to L_{Rin} by

$$L_{RET} = L_{Rin} - (A_{ECHO} + A_{CANC} + A_{NLP}).$$

If nonlinear processing is not present, note that $L_{RES} = L_{RET}$

2.8 **combined loss (A_{COM} .PS 10)**

F: affaiblissement combin´e (A_{COM})

S: *atenuación combinada (A_{COMB})*

The sum of echo loss, cancellation loss and nonlinear processing loss (if present). This loss relates L_{Rin} to L_{RET} by:

$$L_{RET} = L_{Rin} - A_{COM}, \text{ where } A_{COM} = A_{ECHO} + A_{CANC} + A_{NLP}$$

2.9 **convergence**

F: *convergence*

S: *convergencia*

The process of developing a model of the echo path which will be used in the echo estimator to produce the estimate of the circuit echo.

2.10 **convergence time**

F: *temps de convergence*

S: *tiempo de convergencia*

For a defined echo path, the interval between the instant a defined test signal is applied to the receive-in port of an echo canceller with the estimated echo path impulse response initially set to zero, and the instant the returned echo level at the send-out port reaches a defined level.

2.11 leak time

F: temps de fuite

S: tiempo de fuga

The interval between the instant a test signal is removed from the receive-in port of a fully-converged echo canceller and the instant the echo path model in the echo canceller changes such that, when a test signal is reapplied to R_{in} with the convergence circuitry inhibited, the returned echo is at a defined level.

This definition refers to echo cancellers employing, for example, leaky integrators in the convergence circuitry.

3 Characteristics of echo cancellers

3.1 *General*

This Recommendation is applicable to the design of echo cancellers. The echo cancellers are assumed to be ‘‘half’’ echo cancellers, i.e. those in which cancellation takes place only in the send path due to signals present in the receive path.

3.2 *Purpose, operation and environment*

Echo, in any 2-wire or combination 2- and 4-wire telephone circuit, is caused by impedance mismatches. An echo canceller can be used to reduce this echo to tolerable levels.

The echo present at the send-in port of an echo canceller is a distorted and delayed replica of the incoming speech from the far end, i.e. the echo is the incoming speech as modified by the echo path. The echo path is commonly described by its impulse response (see Figure 5/G.165). This response of a typical echo path shows a pure delay t_r, due to the delays inherent in the echo path transmission facilities, and a dispersed signal due to band limiting and multiple reflections. The sum of these is the echo path delay, t_d. The values of delay and dispersion will vary depending on the properties of the echo paths, e.g. they may vary for different national networks. It is assumed that the echo paths are basically linear and not continuously varying , e.g. have no phase roll (see

Recommendation G.164). In addition, the loss of the echo path in dB (see § 2.2 above) is likely to be such that the minimum loss from R_{out} to S_{in} of the echo canceller will be equal to the difference between relative levels at these two ports plus 6 dB. Echo cancellers designed to this Recommendation will perform properly for echo loss (A_{ECHO}) of 6 dB or greater. For (A_{ECHO}) less than 6 dB they may also work but with degraded performance. It is not possible to quantify this degraded performance.

Echo cancellers designed specifically for echo paths which are nonlinear and/or time variant are likely to be much more complex than those not so designed. It is felt that insufficient information exists to include such echo cancellers in this Recommendation. Echo cancellers conforming to this Recommendation are adaptive and will cope with slowly varying echo paths when only receive speech is present.

Figure 5/G.165 p.

An echo canceller must be able to synthesize a replica of the echo path impulse response using a sampled data representation, the sampling being at the Nyquist rate (8000 Hz). Such an echo canceller, to function properly, must have sufficient storage capacity for the required number of samples echo paths: too many storage locations will create undesirable additional noise due to the unused locations which, because of estimation noise, are generally not zero. It should be recognized that an echo canceller introduces an additional parallel echo path. If the impulse response of the echo path model is sufficiently different from the echo path impulse response, the total returned echo may be larger than that due to the echo path only.

The echo paths change as the echo canceller is used in successive connections. When speech first arrives at $R_{i\backslash dn}$, the echo canceller must adapt or converge to the new echo path, and it is desirable that this be fairly rapid, e.g. about one-half second. Also the residual echo should be small regardless of the level of the receive speech and the characteristics of the echo path. Some Administrations feel that a slightly higher residual echo level may be permitted provided it is further reduced using a small amount of nonlinear processing (see § 5).

When there is receive speech and the near party begins to double talk, an echo canceller may interpret the transmit signal as a new echo signal and attempt to adapt to it. This can seriously degrade the subjective quality of the connection. Not only is the echo cancellation reduced but distortion of the double talking speech may occur as the echo canceller dynamically attempts to adapt. Two common approaches are taken as a solution. The first is to use algorithm which causes slow adaptation during periods of double talk. The second is to employ a double talk detector , similar to that used in echo suppressors. The echo canceller double talk detector, however, generally should favour break-in at the expense of false operation on echo. This differs from the double talk detector in an echo suppressor.

Thus, echo cancellers have the following fundamental requirements:

1) rapid convergence;

2) subjective low returned echo level during single talk;

3) low divergence during double talk.

When echo cancellers are located on the subscriber side of the international signalling equipment, signalling tones do not pass through the cancellers so no special action is necessary. When cancellers are on the international side of the signalling equipment they are normally disabled by the switch during the active signalling exchange intervals in order to prevent distortion of the signalling tones by the echo canceller. When signalling tones simultaneously appear at the canceller receive and send ports (double talk) the receive signal will be processed through the echo path model contained in the canceller. The signal estimate produced by the canceller may sufficiently distort the send side signal so that it will not be properly recognized by the signalling receive unit (Note 1). An echo canceller must de disabled during the transmission of the CCITT No. 6 and No. 7 continuity check signal (Note 2).

If an echo canceller conforming to Recommendation G.165 is located on the international side of CCITT No. 5 signalling units an enabled canceller, it will interfere with the continuously compelled signalling exchange CCITT No. 5 unless additional special precautions are taken. See Recommendation Q.115 for details.

Note 1 — For some echo cancellers this problem may not occur when the send and receive frequencies are different.

Note 2 — CCITT Recommendation Q.271 on CCITT No. 6 and Recommendation Q.724 on CCITT No. 7 both include the following statement: ‘‘As the presence of active echo suppressors in the circuit would interfere with the continuity check, it is necessary to disable the suppressors during the check and to re-enable them, if required, after the check has been completed.’’

Echo cancellers having storage capacities of 16 ms to 40 ms have been successfully demonstrated. Maximum echo path delay t_d, in the network in which the canceller will be used will determine the required storage capacity.

3.3 *External enabling/disabling*

An option should be included in the echo canceller to provide for enabling or disabling by an externally derived ground (earth) from the trunk circuit. The enabler should function to permit or prevent normal echo canceller operation. Certain type C echo cancellers may be disabled directly by a digital signal. Some digital data signals may require Type C echo cancellers to provide 64 kbit/s bit sequence integrity in the externally disabled state.

3.4 *Tests and requirements for performance with inputs signals applied to the send and receive paths*

3.4.1 *Transmission performance*

The appropriate transmission performance requirements of Recommendation G.164 also apply to echo cancellers except as noted below.

3.4.1.1 *Delay distortion — Type A*

The delay distortion relative to the minimum delay shall not exceed the values given in Table 1/G.165.

H.T. [T1.165]

TABLE 1/G.165

Frequency band (Hz)	Delay distortion (μs)
500- 600	300
600-1000	150
1000-2600	50
2600-3000	250

Table [1/G.165] [T1.165], p.

3.4.1.2 *Attenuation distortion — Type A*

The attenuation distortion shall be such that if Q dB is the attenuation at 800 Hz (or 1000 Hz) the attenuation shall be within the range (Q + 0.5) dB to (Q — 0.2) dB at any frequency in the band 300-3400 Hz and at 200 Hz, within the range of (Q + 1.0) dB to (Q — 0.2) dB.

3.4.1.3 *Group delay — Type C*

The group delay in the send path should be kept to a minimum and should not exceed 1 ms. No significant delay should occur in the receive path.

Note — The creation of frame slips in the echo path can lead to an occasional degradation of the echo cancellation. If a delay is necessary to synchronize the digital send and receive paths, the global admissible delay on the send path, including the group delay mentioned above, must not exceed 1 ms and on the receive path 250 μs.

3.4.1.4 *Group delay — Type D*

The group delay in the send and receive paths shall meet the requirements of § 3.4.1.3 for Type C echo cancellers with the addition of the delay allowed for codecs as given in Recommendation G.712.

3.4.2 *Echo canceller performance*

The performance requirements which follow are for echo cancellers which include nonlinear processors (see Annex A for echo cancellers which do not include a nonlinear processor).

In the tests, it is assumed that the nonlinear processor can be disabled, that the echo path impulse response store (H register) can be cleared (set to zero) and that adaptation can be inhibited.

The requirements are described in terms of tests made by applying signals to $R_{i\backslash dn}$ and $S_{i\backslash dn}$ of an echo canceller, and measuring the $S_{o\backslash du\backslash dt}$ signals. The test set-up is as shown in Figure 6/G.165. The ports are assumed to be at equal relative level points. Band-limited noise is used as the receive input test signal. The echo loss is independent of frequency.

FIGURE 6/G.165 p.

The primary purpose of an echo canceller is to control the echo of a speech stimulus signal. This is done by synthesizing a replica of the echo path impulse response and using it to generate an estimate of the echo which is subtracted from the actual circuit echo. The synthesis must be accomplished using a speech input signal. Because of the difficulty of defining a speech test signal, the following tests are type tests and rely upon the use of a band-limited noise test signal primarily for measurement convenience and

repeatability. These tests should be performed on an echo canceller only after the design has been shown to properly synthesize a replica of the echo path impulse response from a speech input signal and its corresponding echo. Speech signals are not used in the tests in this section. Additionally, the nonlinear processor in the echo canceller should be designed to minimize and potentially avoid the perceptible effects of double-talk clipping and noise contrast [see Recommendation G.164, Table 1, Note a)]. Tests to ensure proper operation are under study.

3.4.2.1 *Test No. 1 — Steady state residual and returned echo level test*

This test is meant to ensure that the steady state cancellation (A_{CANC}) is sufficient to produce a residual echo level which is sufficiently low to permit the use of nonlinear processing without undue reliance on it.

The H register is initially cleared and a receive signal is applied for a sufficient time for the canceller to converge producing a steady state residual echo level.

Requirement (provisional)

With the H register initially set to zero, the nonlinear processor disabled for all values of receive input signal level such that L_{Rin} ≥" —30 dBm0 and —10 dBm0 and for all values of echo loss 6 dB and echo path delay, t_d Δ ms , the residual echo level should be less than or equal to that shown in Figure 7/G.165. When the nonlinear processor is enabled, the returned echo level must be less than —65 dBm0.

Note — Recommendation G.113 allows for up to 5 PCM codecs in the echo path. Meeting the requirement of Figure 7/G.165 under those conditions has not been verified. This is under study.

Figure 7/G.165, p.

3.4.2.2 *Test No. 2 — Convergence test*

This test is meant to ensure that the echo canceller converges rapidly for all combinations of input signal levels and echo paths and that the returned echo level is sufficiently low. The H register is initially cleared and adaption is inhibited. The double talk detector, if present, is put in the double talk mode by applying signals to $S_{i\dn}$ and $R_{i\dn}$. The signal at $S_{i\dn}$ is removed and simultaneously adaption is enabled. The degree of adaption, as measured by the returned echo level, will depend on the convergence characteristics of the echo canceller and the double talk detection hangover time.

Different echo cancellers may be designed to work satisfactorily for different echo path delays depending on their application in various networks. Thus Δ, whenever it appears in this Recommendation, represents the echo path delay, t_d, for which the echo canceller is designed.

The test procedure is to clear the H register and inhibit adaption. Signal N is applied at a level —10 dBm0 and a signal is applied at $R_{i\backslash dn}$. Then N is removed and simultaneously adaption is enabled (see Figure 8/G.165). After 500 ms inhibit adaption and measure the returned echo level. The nonlinear processor should be enabled.

Figure 8/G.165 p.

Requirement

With the H register initially set to zero, for all values L_{Rin} ≥" —30 dBm0 and —10 dBm0 and present for 500 ms and for all values of echo loss 6 dB and echo path delay, t_d Δ ms, the combined loss ($A_{COM} = A_{ECHO} + A_{CANC} + A_{NLP}$) should be ≥" 27 dB.

3.4.2.3 *Test No. 3 — Performance under conditions of double talk*

The two parts of this test are meant to test the performance of the canceller under various conditions of double talk. The tests make the assumption that, upon detection of double talk, measures are taken to prevent or slow adaption in order to avoid excessive reduction in cancellation.

3.4.2.3.1 Test No. 3 | is meant to ensure that the double talk detection is not so sensitive that echo and low level near-end speech falsely cause operation of the double talk detector to the extent that adaption does not occur. The test procedure is to clear the H register; then for some value of echo delay and echo loss, a signal is applied to $R_{i\backslash dn}$. Simultaneously (see Figure 9/G.165) an interfering signal which is sufficiently low in level to not seriously hamper the ability of the echo canceller to converge, is applied at $S_{i\backslash dn}$. This signal should not cause the double talk detector to be activated, and adaption and cancellation should occur. After 1 s the adaption is inhibited and the residual echo measured. The nonlinear process should be *disabled* .

figure 9/G.165 p.

Requirement

With the H register initially set to zero for all values of L_{Rin} ≥" —25 dBm0 and —10 dBm0, $N = L_{Rin}$ —15 dB, A_{ECHO} ≥" 6 dB and echo path delay, t_d Δ ms, convergence should occur within 1.0 s and L_{RES} should be N .

3.4.2.3.2 Test No. 3 | is meant to ensure that the double talk detector is sufficiently sensitive and operates fast enough to prevent large divergence during double talking.

The test procedure is to fully converge the echo canceller for a given echo path. A signal is then applied to $R_{i\backslash dn}$. Simultaneously (see Figure 10/G.165) a signal N is applied to $S_{i\backslash dn}$ which has a level at least that of $R_{i\backslash dn}$. This should cause the double talk detector to operate. After any arbitrary time, $\delta t > 0$, the adaption is inhibited and the residual echo measured. The nonlinear processor should be disabled.

figure 10/G.165 p.

Requirement

With the echo canceller initially in the fully converged state for all values of L_{Rin} ≥" —30 dBm0 and —10 dBm0, and for all values of N ≥" L_{Rin} and for all values of echo loss ≥" 6 dB and echo path delay t_d Δ ms, the residual echo level after the simultaneous application of L_{Rin} and N for any time period should not increase more than 10 dB over the steady state requirements of Test No. 1.

3.4.2.4 *Test No. 4 — Leak rate test*

This test is meant to ensure that the leak time is not too fast, i.e. that the contents of the H register do not go to zero too rapidly.

The test procedure is to fully converge the echo canceller for a given echo path and then to remove all signals from the echo canceller. After two minutes the contents of the H register are frozen, a signal applied to $R_{i\backslash dn}$ and the residual echo measured (see Figure 11/G.165). The nonlinear process is used in normal operation, it should be *disabled* .

figure 11/G.165 p.

Requirement

With the echo canceller initially in the fully converged state for all values of L_{Rin} ≥" —30 dBm0 and —10 dBm0, two minutes after the removal of the R_{in} signal, the residual echo level should not increase more than 10 dB over the steady state requirement of Test No. 1.

3.4.2.5 *Test No. 5 — Infinite return loss convergence test*

This test is meant to ensure that the echo canceller has some means to prevent the unwanted generation of echo. This may occur when the H register contains an echo path model, either from a previous connection or the current connection, and the echo path is opened (circuit echo vanishes) while a signal is present at $R_{i\backslash dn}$.

The test procedure is to fully converge the echo canceller for a given echo path. The echo path is then interrupted while a signal is applied to $R_{i\backslash dn}$. 500 ms after interrupting the echo path the returned echo signal at $S_{o\backslash du\backslash dt}$ should be measured (see Figure 12/G.165). The nonlinear processor should be *disabled* .

FIGURE 12/G.165, p.

Requirement (provisional)

With the echo canceller initially in the fully converged state for all values of echo loss ≥" 6 dB, and for all values of L_{Rin} ≥" —30 dBm0 and | (em10 dBm0, the returned echo level at S_{out}, 500 ms after the echo path is interrupted, should be | (em37 dBm0.

3.4.2.6 *Test No. 6 — Stability test*

Under study.

4 Characteristics of an echo canceller tone disabler

4.1 *General*

To ensure proper operation of all currently specified V-series modems, the echo cancellers covered by this Recommendation should be equipped with a tone detector that conforms to this section. This tone detector responds to a disabling signal which is different from that used to disable the echo suppressor as described in Recommendation G.164, § 5 and consists of a 2100 Hz tone with periodic phase reversals inserted in that tone. The tone disabler should respond only to the specified in-band signal. It should not respond to other in-band signals, e.g. speech, or a 2100 Hz tone without a phase reversal. The tone disabler should detect and respond to a disabling signal which may be present in either the send or the receive path.

The requirements for echo canceller disabling to ensure proper operation with ATME No. 2 equipment that transmits the 2100 Hz tone with phase reversals could be met by using either the tone disabler specified in this section, or the echo suppressor tone disabler specified in Recommendation G.164, § 5. However, use of the Recommendation G.164, § 5 disabler does not assure proper operation with all currently specified V-series modems.

The term disabled in this section refers to a condition in which the echo canceller is configured in such a way as to no longer modify the signals which pass through it in either direction. Under this condition, no echo estimate is subtracted from the send path, the non-linear processor is made transparent, and the delay through the echo canceller still meets the conditions specified in § 3.4.1. However, no relationship between the circuit conditions before and after disabling should be assumed. For one thing, the operation of echo cancellers with tonal inputs (such as the disabling tone) is unspecified. Additionally, the impulse response stored in the echo canceller prior to convergence (and prior to the disabling tone being sent) is arbitrary. This can lead to apparent additional echo paths which, in some echo canceller implementations, remain unchanged until the disabling tone is recognized. Also note that echo suppressors could be on the same circuit and there is no specified relationship between their delay in the enabled and disabled states. In spite of the above, it is possible, for example, to measure the round-trip delay of a circuit with the disabling tone but the trailing edge of the tone burst should be used and sufficient time for all devices to be disabled should be allotted before terminating the disabling tone and starting the timing.

It should be noted that this condition does not necessarily fulfil the requirements for 64 kbit/s bit sequence integrity, for which case other means of disabling in line with Recommendation G.165, § 3.4 will apply.

A reference tone disabler is described in Annex B.

4.2 *Disabler characteristics*

The echo canceller tone disabler requires the detection of a 2100 Hz tone with phase reversals of that tone. The characteristics of the transmitted signal are defined in Recommendation V.25. Phase variations in the range of 180° ± | 5° must be detected while those in the range of 0° ± | 10° must not be detected.

The frequency characteristics of the tone detector are the same as the characteristics of the echo suppressor tone detector given in Recommendation G.164, § 5.2.

The dynamic range of this detector should be consistent with the input levels as specified in Recommendation V.2 and H.51 with allowances for variation introduced by the public switched telephone network.

4.3 *Guardband characteristics*

Similar to that defined in Recommendation G.164, § 5.3, consistent with the dynamic range given in § 4.2 above with the following exception. The detector should operate perfectly with white noise less than or equal to 11 dB below the level of the 2100 Hz signal. No definitive guidelines can be given for the range between 5 and 11 dB because of the variations in the test equipment used. In particular, performance may vary with the peak-to-average ratio of the noise generator used. As a general guideline, however, the percentage of correct operation (detection of phase variations of 180° ± | 5° and non-detection of phase variations of 0° ± | 10°) should fall by no more than 1% for each dB reduction in signal-to-noise below 11 dB. The Administration of the Federal Republic of Germany mentions the possibility of designing a detector capable of operating perfectly at 5 dB signal-to-noise ratio.

4.4 *Holding-band characteristics*

Same as defined in Recommendation G.164, § 5.4.

4.5 *Operate time*

The operate time must be sufficiently long to provide immunity from false operation due to voice signals, but not so long as to needlessly extend the time to disable. The tone disabler is required to operate within one second of the receipt of the disabling signal.

4.6 *False operation due to speech currents*

Same as in Recommendation G.164, § 5.6.

4.7 *False operation due to data signals*

It is desirable that the tone disabler should rarely operate falsely on data signals from data sets that would be adversely affected by disabling of the echo canceller. To this end, a reasonable objective is that, for an echo canceller installed on a working circuit, usual data signals from such data sets should not, on the average, cause more than 10 false operations during 100 hours of data transmissions.

4.8 *Release time*

Same as in Recommendation G.164, § 5.7.

4.9 *Other considerations*

Both the echo of the disabling tone and the echo of the calling tone may disturb the detection of the echo canceller disabling tone. As such, it is not recommended to add the receive and transmit signal inputs together to form an input to a single detector.

Careful attention should be given to the number of phase reversals required for detection of the disabling tone. Some Administrations favour relying on 1 to improve the probability of detection even in the presence of slips, impulse noise, and low signal-to-noise ratio. Other Administrations favour relying on 2 to improve the probability of correctly distinguishing between non-phase-reversed and phase-reversed 2100 Hz tones.

5 Nonlinear processors for use in echo cancellers

5.1 *Scope*

For the purpose of this Recommendation the term ‘‘nonlinear processor’’ is intended to mean only those devices which fall within the definition given in § 2.5 and which have been proven to be effective in echo cancellers. It is possible to implement such nonlinear processors in a number of ways (centre clippers being just one example), with fixed or adaptive

operating features, but no recommendation is made for any particular implementation. General principles and guidelines are given in § 5.2. More detailed and concrete information requires reference to specific implementations. This is done in Annex C for the particular case of a ‘‘reference nonlinear processor’’. The use of this term denotes an implementation given for guidance and illustration only. It does not exclude other implementations nor does it imply that the reference nonlinear processor is necessarily the most appropriate realization on any technical, operational or economic grounds.

5.2 *General principles and guidelines*

5.2.1 *Function*

5.2.1.1 *General*

The nonlinear processor is located in the send path between the output of the subtractor and the send-out port of the echo canceller. Conceptually, it is a device which blocks low level signals and passes high level signals. Its function is to further reduce the residual echo level (L_{RES} as defined in § 2.4) which remains after imperfect cancellation of the circuit echo so that the necessary low returned echo level (L_{RET} as defined in § 2.7) can be achieved.

5.2.1.2 *Network performance*

Imperfect cancellation can occur because echo cancellers which conform to this Recommendation may not be capable of adequately modelling echo paths which generate significant levels of nonlinear distortion (see § 3.2). Such distortion can occur, for example, in networks conforming to Recommendation G.113 in which up to five pairs of PCM codecs (conforming to Recommendation G.712) are permitted in an echo path. The accumulated quantization distortion from these codecs may prevent an echo canceller from achieving the necessary L_{RET} by using linear cancellation techniques alone. It is therefore recommended that all echo cancellers capable only of modelling the linear components of echo paths but intended for general network use should incorporate suitable nonlinear processors.

5.2.1.3 *Limitations*

This use of nonlinear processors represents a compromise in the circuit transparency which would be possible by an echo canceller which could achieve the necessary L_{RET} by using only modelling and cancellation techniques. Ideally, the non-linear processor should not cause distortion of near-end speech. In practical devices it may not be possible to sufficiently approach this ideal in this case it is recommended that nonlinear

processors should not be active under double talk or near-end single-talk conditions. From this it follows that excessive dependence must not be placed on the nonlinear processor and that L_{RES} must be low enough to prevent objectionable echo under double-talk conditions.

5.2.1.4 *Data transmission*

Nonlinear processors may affect the transmission of data through an enabled echo canceller. This is under study.

5.2.2 *Suppression threshold*

5.2.2.1 *General*

The suppression threshold level (T_{SUP}) of a nonlinear processor is expressed in dBm0 and is equal to the highest level of a sine-wave signal at a given moment that is just suppressed. Either fixed or adaptive suppression threshold levels may be used.

5.2.2.2 *Fixed suppression threshold*

With a fixed suppression threshold level the appropriate level to use will depend upon the cancellation achieved and the statistics of speech levels and line conditions found in the particular network in which the echo canceller is to be used. It is therefore recommended that the actual level should be field selectable to permit the user to adjust it for the actual network environment. Values of fixed suppression threshold levels to be used are under study — see Notes 1 and 2.

Note 1 — As an interim guide, it is suggested that the suppression threshold level should be set a few decibels above the level that would result in the *peaks* of L_{RES} for a ‘‘2σ-talker’’ and a ‘‘2σ-echo return loss’’ being suppressed.

Note 2 — Results of a field trial reported by one Administration indicated that a fixed suppression threshold level of —36 dBm0 gave a satisfactory performance. A theoretical study, by another Administration, of an echo path contianing five pairs of PCM codecs showed that for an L_R of —10 dBm0, the quantization noise could result in an L_{RES} of —38 dBm0.

5.2.2.3 *Adaptive suppression threshold*

A good compromise can be made between using a high T_{SUP} to prevent it being exceeded by loud talker residual echo and using a low T_{SUP} to reduce speech distortion on break-in by making T_{SUP} adaptive to the actual circuit conditions and speech levels. This may be achieved in a number of ways and no recommendation is made for any particular implementation. General guidelines applicable to the control algorithm and suppression threshold levels are under study.

5.2.3 *Control of nonlinear processor activation*

5.2.3.1 *General*

To conform to the recommendation made in § 5.2.1.3, it is necessary to control the activation of the nonlinear processor so that it is not active when near-end speech is likely to be present. When ‘‘active’’, the nonlinear processor should function as intended to reduce L_{RES} When ‘‘inactive’’, it should not perform any nonlinear processing on any signal passing through the echo canceller.

5.2.3.2 *Control guidelines*

It is recommended that the following two guidelines should govern control of the activation of a nonlinear processor. First, because they are intended to further reduce L_{RES}, *they should be active when* L_{RES} is at a significant level. Second, because they should not distort near-end speech, they should be inactive when near-end speech is present. Where these two guidelines conflict the control function should favour the second.

5.2.3.3 *Static characteristics*

A conceptual diagram showing the two operational states of a nonlinear processor is shown in Figure 13/G.165. The L_S L_R plane is divided into two regions, W and Z by the threshold WZ. In the W region the nonlinear processor is inactive while in the Z region it is active. Proper control of the nonlinear processor to ensure operation in the appropriate region requires recognition of the double-talk condition or the presence of near-end speech. Imperfect detection of double-talk combined with a high suppression threshold level will result in distortion of near-end speech. The echo canceller then exhibits some of the characteristics of an echo suppressor. A low suppression level will permit easy double-talking, even if a detection error is made because the near-end speech will suffer only a low level of non-linear distortion. If the suppression threshold level is too low then peaks of residual echo may be heard.

Figure 13/G.165, p.

5.2.3.4 *Dynamic characteristics*

The dynamic characteristics can be specified by stating the time that elapses when the signal conditions pass from a point in one area to a point in the other area before the state appropriate to the second area is established. Four such transitions are shown by arrows in Figure 13/G.165.

Transition No. 1 — W to Z, L

In this case the L_S signal occurred first and the L_R is increasing to a sufficiently high level to override the L_S signal in the control path and cause the nonlinear processor to change from the inactive to the active state. Since this will cause distortion of the L_S signal (near talker speech in this case) the action should not be initiated too quickly.

 R increasing

Transition No. 2 — Z to W, L

In this case the $L_R$signal has overriden the $L_S$signal in the control path and the nonlinear processor is in the active state. The $L_R$signal is now decreasing. The nonlinear processor should remain in the active state sufficiently long to prevent echo, which is stored in the echo path, from being hear by the far talker.

Transition No. 3 — Z to W, L

This transition is replicating the onset of double talk. As soon as possible after the $L_S$signal is detected the nonlinear processor should be switched to the inactive state in order to minimise any distortion of the near talker speech.

Transition No. 4 — W to Z, L

In this case $L_S$has been recognised but is decreasing. Any action which is taken should favour continuing to permit the $L_S$signal to pass. This implies there should be some delay in switching the nonlinear processor back to the active state.

5.2.4 *Frequency limits of control paths*

Under study.

Note — Depending on the particular implementation of the nonlinear processor, the considerations and frequency response limits given in Recommendation G.164, § 3.2.4.2 for the suppression and break-in control paths of echo suppressors may also be applicable to similar control paths used in nonlinear processors. These control paths may include the activation control and adaptive suppression threshold level control.

5.2.5 *Signal attenuation below threshold level*

The attenuation of signals having a level below that of the suppression threshold level of a nonlinear processor in the active state must be such that the requirements of § 3.4.2.1 are met.

5.2.6 *Testing of nonlinear processors*

The nonlinear processor may be considered as a special case of an echo suppressor which is limited to suppressing only low level signals. The types of test required to determine the nonlinear processor performance characteristics are very similar to the echo suppressor tests given in Recommendation G.164. However, depend ing on the specific implementation of a nonlinear processor, the transitions between areas W and Z of Figure 13/G.165 may not be as sharply defined as is the case for echo suppressors. Signals observed at the send-out port of the echo canceller may be distorted for short periods when transitions between the W and Z operating regions occur. Although Recommendation G.164 may be used as a guide to the testing of nonlinear processors it may be necessary to introduce unique test circuit modifications in order to make measurements on some specific nonlinear processor implementations. No recommendation can be given for a universal test circuit appropriate for all nonlinear processor implementations.

ANNEX A
(to Recommendation G.165)

Echo cancellers without nonlinear processing

It may be possible to implement echo cancellers without the inclusion of nonlinear processing. For these echo cancellers the total echo loss is provided by echo cancellation. The achievable echo cancellation is limited by the characteristics of the echo path and by the method of implementing the echo canceller. In particular, if one pair of codecs conforming to Recommendation G.712 is used in the echo path or in the echo canceller, the maximum echo cancellation (considering quantizing errors in the echo canceller and other impairments) is that shown by the solid line in Figure A-1/G.165.

Echo cancellers conforming to the solid line in Figure A-1/G.165 have been tested and found to provide acceptable performance in Japan. Other tests, however, suggest that the echo cancellation required in echo cancellers for general application is at least that shown by the broken line in Figure A-1/G.165. Further study is needed. Pending the results of that study, echo cancellers which do not include nonlinear processors are not yet recommended for general application.

All the provisions and tests in the body of Recommendation G.165 apply to these echo cancellers except as follows:

a) § 3.4.2.1: the residual echo level requirement is that shown by the solid line of Figure A-1/G.165.

b) For all other tests, any reference to non-linear processing should be ignored.

Figure A-1/G.165, p.

ANNEX B
(to Recommendation G.165)

**Description of an
echo canceller reference tone disabler**

B.1 *General*

This annex describes the characteristics of an echo canceller reference tone disabler. The use of the term *reference* denotes a disabling implementation given for guidance only. It does not exclude alternative implementations of a tone disabler which responds to the signal as defined in Recommendation V.25, and which also meets all of the criteria for reliability of operation and protection from false operation by speech signals.

B.2 *Disabler characteristics*

The echo canceller reference tone disabler described in this annex detects a 2100 Hz tone with periodic phase reversals which occur every 450 ± 25 ms. The characteristics of the transmitted signal are defined in Recommendation V.25.

B.2.1 *Tone detection*

The frequency characteristics of the tone detector used in this reference tone disabler are the same as the characteristics of the echo suppressor tone detector given in Recommendation G.164, § 5.2, except that the upper limit of the dynamic range is —6 dBm0.

B.2.2 *Phase reversal detection*

The reference tone disabler responds to a signal which contains phase reversals of 108° ± 10° at its source (as specified in Recommendation V.25) when this signal has been modified by allowable degradations caused by the network, e.g. noise, phase jitter, etc. This disabler is insensitive to phase jitter of ± 15° peak-to-peak in the frequency range of 0-120 Hz. This accommodates to the phase jitter permitted by Recommendations H.12 and G.229. In order to minimize the probability of false disabling of the echo canceller due to speech currents and network-induced phase changes, this reference tone disabler does not respond to single phase changes of the 2100 Hz tone in the range 0° ± 110° occurring in a one second period. This number has been chosen since it represents the approximate phase shift caused by a single frame slips in a PCM system.

B.3 *Guardband characteristics*

Meet requirements in Recommendation G.164, § 5.3.

Note — The possibility of interference during the phase reversal detection period has been taken into account. One potential source of interference is the presence of calling tone as specified in Recommendation V.25. If the calling tone interferes with the detection of the phase reversal, the entire disabling detection sequence is restarted, but only one time. Recommendation V.25 ensures at least one second of quiet time between calling tone burst.

B.4 *Holding-band characteristics*

Meet requirements in Recommendation G.164, § 5.4.

B.5 *Operate time*

The reference tone disabler operates within one second of the receipt, without interference, of the sustained 2100 Hz tone with periodic phase reversals, having the level in the range —6 to —31 dBm0. The one second operate time permits the detection of the 2100 Hz tone and ensures that two phase reversals will occur (unless a slip or impulse noise masks one of the phase reversals).

B.6 *False operation due to speech currents*

Meets requirements in Recommendation G.164, § 5.6.

B.7 *False operation due to data signals*

Meets the requirement in Recommendation G.165, § 4.7. To this end, the tone disabler circuitry becomes inoperative if one second of clear (i.e. no phase reversals or other interference) 2100 Hz tone is detected. The detected circuit remains inoperative during the data transmission and only becomes operative again 250 ± 150 ms after a signal in the holding band falls at least 3 dB below the maximum holding sensitivity. Thus the possibility of inadvertent disabling of the echo canceller during data transmission is minimized.

B.8 *Release time*

Meets the requirements in Recommendation G.164, § 5.7.

ANNEX C

(to Recommendation G.165)

Description of a
reference nonlinear processor

C.1 *General*

This annex, which is for the purposes of illustration only and not intended as a detailed design (see § 5.1), describes a reference nonlinear processor based upon concepts that are as simple as possible but having included in it a sufficient number of features to give guidance for a wide range of possible implementations. To this end two variants of the reference nonlinear processor are included. Both are based on a centre clipper having either of the idealized transfer functions illustrated in Figure C-1/G.165. The suppression threshold level (determined, in this case by the clipping level) in the first variant is adaptive, adaptation being by reference to L_R. Activation control is by reference to the difference between L_R and L_S. In the second variant the suppression threshold is fixed.

It is assumed that the reference nonlinear processor is used in an echo canceller which can achieve a cancellation of the linear components of any returned echo of at least N dB. The value of N is under study.

Figure C-1/G.165, p.

C.2 *Suppression threshold* | $T_{\mathrm{S\backslash dU\backslash dP}}$)

Adaptive $T_{\mathrm{S\backslash dU\backslash dP}} = (L_R — x \pm 3)$ dBm0 for —30
L_R —10 dBm0

Fixed $T_{\mathrm{S\backslash dU\backslash dP}} = x$ ‘ dBm0

Note — Values of x and x ‘ are under study. Values of 18 for x and —36 for x ‘ have been suggested by confimation is required that these values are appropriate for use in all networks.

C.3 *Static characteristics of activation control*

$T_{\mathrm{W\backslash dZ}} = (L_R — y \pm 3)$ dBm0 for —30 L_R —10 dBm0

Note 1 — $T_{\mathrm{W\backslash dZ}}$ is as defined in § 5.2.3.3.

Note 2 — The value of y | ay be different for each variant, and this is under study. Values of x dB in the case of the adaptive $T_{\mathrm{S\backslash dU\backslash dP}}$ and ≥" 6 dB for y in the case of the fixed $T_{\mathrm{S\backslash dU\backslash dP}}$ seem reasonable.

C.4 *Dynamic characteristics of activation control*

Dynamic characteristics of the activation control are given in Table C-1/G.165 and C-2/G.165. Also see Figure 13/G.165.

C.5 *Frequency limits of control paths*

See Recommendation G.165, § 5.2.4.

C.6 *Testing*

Tables C-1/G.165 and C-2/G.165 indicate, by reference to Recommendation G.164 how the dynamic performance of nonlinear processor activation control may be checked using sine wave signals. Figures C-2/G.165 and C-3/G.165 show the traces obtained on an oscilloscope for these tests.

H.T. [T2.165]

lw(48p) | lw(24p) sw(30p) | lw(24p) sw(30p) | lw(30p) | lw(18p) | lw(42p) | lw(42p) | lw(42p) , ^ | l | l | l | l | ^ | ^ | ^ | ^ | ^ . cw(48p) | cw(24p) sw(30p) | cw(24p) sw(30p) | lw(30p) | lw(18p) | lw(42p) | lw(42p) | lw(42p) , ^ | c | c | c | l | ^ | ^ | ^ | ^ | ^ . Initial signal Send *L* S (dBm0) Send *L* S (dBm0) Receive *L* R (dBm0) Final signal { Receive *L* R (dBm0) Recommended value (ms) Test No. (Rec. G.164) Excursion (see Figure 13/G.165) Test circuit, Figure: Oscilloscope trace

} _ cw(18p) | cw(30p) | cw(24p) | cw(30p) | cw(24p) | cw(30p) | cw(30p) | lw(18p) | lw(42p) | lw(42p) | lw(42p) , ^ | c | c | c | c | c | l | ^ | ^ | ^ | ^ . Fixed —25 —10 —25 —30 15-64 Adaptive —55 —40 —30 —20 —15 — 5 —55 —40 —30 —40 —40 —30 { Δ[a] 5 Transition 2 14/G.164 Trace 1 and trace 2 of Figure C-3/G.165 (β) W/Z

} _ cw(18p) | cw(30p) | cw(24p) | cw(30p) | cw(24p) | cw(30p) | cw(30p) | lw(18p) | lw(42p) | lw(42p) | lw(42p) , ^ | c | c | c | c | c | l | ^ | ^ | ^ | ^ . Fixed —15 —25 —40 —25 16-120 Adaptive —40 —40 —25 —50 —30 —15 —55 —55 —40 —50 —30 —15 { 30-50 6 Transition 4 17/G.164 Trace 1 and trace 2 of Figure C-2/G.165 (β) [a] Δ is defined in § 3.4.2.1 [footnote [4]].

} _

TABLEAU C-1/G.165 [T2.165] à l'italienne, p.17

H.T. [T3.165]

lw(48p) | lw(24p) sw(30p) | lw(24p) sw(30p) | lw(30p) | lw(18p) | lw(42p) | lw(42p) | lw(42p) , ^ | l | l | l | l | ^ | ^ | ^ | ^ | ^ . cw(48p) | cw(24p) sw(30p) | cw(24p) sw(30p) | lw(30p) | lw(18p) | lw(42p) | lw(42p) | lw(42p) , ^ | c | c | c | l | ^ | ^ | ^ | ^ | ^ . Initial signal Send L S (dBm0) Send L S (dBm0) Receive L R (dBm0) Final signal { Receive L R (dBm0) Recommended value (ms) Test No. (Rec. G.164) Excursion (see Figure 13/G.165) Test circuit, Figure: Oscilloscope trace

} _ cw(18p) | cw(30p) | cw(24p) | cw(30p) | cw(24p) | cw(30p) | cw(30p) | lw(18p) | lw(42p) | lw(42p) | lw(42p) , ^ | c | c | c | c | c | l | ^ | ^ | ^ | ^ . Fixed —25 —30 —25 —10 16-120 Adaptive —55 —40 —30 —40 —40 —30 —55 —40 —30 —20 —15 — 5 { 15-75 4 Transition 1 14/G.164 Trace 2 of Figure C-3/G.165 (α) Z/W

} _ cw(18p) | cw(30p) | cw(24p) | cw(30p) | cw(24p) | cw(30p) | cw(30p) | lw(18p) | lw(42p) | lw(42p) | lw(42p) , ^ | c | c | c | c | c | l | ^ | ^ | ^ | ^ . Fixed —40 —25 —15 —25 | Adaptive —55 —55 —40 —50 —30 —15 —40 —40 —25 —50 —30 —15 {

| 6 Transition 3 17/G.164 Trace 2 of Figure C-2/G.165 (α)

} _

TABLEAU C-2/G.165 [T3.165] à l'italienne, p.18

FIGURE C-2/G.165, p.19

FIGURE C-3/G.165, p.20

Reference

[1] CCITT Recommendation — *Echo suppressors suitable for circuits having either short or long propagation time* , Orange Book, Volume III.1, Recommendation G.161, ITU, Geneva, 1977.

Recommendation G.166

CHARACTERISTICS OF SYLLABIC COMPANDORS

FOR TELEPHONY ON HIGH CAPACITY LONG DISTANCE SYSTEMS

(Malaga-Torremolinos, 1986; amended at Melbourne, 1988)

Compandors adhering to Recommendation G.162, *Yellow Book* , were intended for use in small capacity network systems and their use in large capacity network long-distance systems is not recommended. Compandors adhering to this Recommendation are intended for use in large capacity long-distance systems. Their use on small capacity network systems is optional. They are not intended for use in subscriber applications such as mobile communication systems.

1 General

1.1 Syllabic compandors are devices in which gain variations occur at a rate comparable to the syllabic rate of speech. A compandor consists of a combination of a compressor at one point in a communication path, for reducing the amplitude range of signals followed by an expander at another point for a complementary increase in the amplitude range. The compandor enhances the subjective speech performance primarily due to two actions. The compressor increases the average speech level of weaker signals prior to entering a communication path where increased noise is expected to be encountered. The expander, in returning the speech signal to its original dynamic range provides a subjective enhancement to the communication path by attenuating the noise perceived by the listening party during silences. For a further description of compandor operation see Annex A.

1.2 This Recommendation does not specify the detector characteristics, e.g., peak, r.m.s. or average.

The performance recommended may not be sufficient to ensure compatibility between compandors conforming to this Recommendation but which are of different design. Before using compressors and expanders of different design origins at opposite ends of the same circuit, Administrations should test them for compatibility. The tests should take account of the sensitivity of compandor performance to the characteristics of the test signal.

1.3 The use of a number of syllabic compandors on circuits carried on the same FDM carrier may result in a changed load being presented to the FDM system. The FDM system operating parameters could, therefore, require appropriate adjustment as a function of the load.

1.4 It should be noted that the subjective enhancement which occurs on speech, when syllabic compandors are used, does not apply to transmission of non-speech signals which may experience a signal-to-noise degradation on syllabic compandored circuits.

1.5 Some of the clauses given below specify the joint characteristics of a compressor and an expander in the same direction of transmission of a 4-wire circuit. The characteristics specified in this way can be obtained more easily if the compressors and expanders are of similar design; in certain cases close cooperation between Administrations may be necessary. Application rules for syllabic compandors address this issue.

2 Definitions

2.1 unaffected level

The unaffected level is the absolute level, at a point of zero relative level on the line between the compressor and the expander of a signal at 800 Hz, which remains unchanged whether the circuit is operated with the compressor or not. The unaffected level is defined in this way in order not to impose any particular values of relative level at the input to the compressor or the output of the expander.

To make allowances for the increase in mean power introduced by the compressor, and to avoid the risk of increasing the inter-modulation noise and the overload which might result, the unaffected level must be adjusted taking into account the capacity of the system. (See Reference [1], Chapter II, Annex 4, for detailed discussion of this adjustment.)

2.2 ratio of compression

The ratio of compression of a compressor is defined by the formula:

$$\alpha = \frac{L_{1C_{IN}} - L_{2C_{IN}}}{L_{1C_{OUT}} - L_{2C_{OUT}}}$$

where

$L_{1C_{IN}}$ and $L_{2C_{IN}}$ are any two different compressor input levels within the compressor operating range.

$L_{1C_{OUT}}$ and $L_{2C_{OUT}}$ are the compressor output levels corresponding to input levels $L_{1C_{IN}}$ and $L_{2C_{IN}}$ respectively.

2.3 ratio of expansion

The ratio of expansion of an expander is defined by the formula:

$$\beta = \frac{L_{1E_{OUT}} - L_{2E_{OUT}}}{L_{1E_{IN}} - L_{2E_{IN}}}$$

where

$L_{1E_{IN}}$ and $L_{2E_{IN}}$ are any two different expander input levels within the expander operating range.

$L_{1E_{OUT}}$ and $L_{2E_{OUT}}$ are the expander output levels corresponding to input levels $L_{1E_{IN}}$ and $L_{2E_{IN}}$ respectively.

3 Characteristics of syllabic compandors

3.1 *Unaffected level*

A nominal value of —10 dBm0 for the unaffected level is recommended for high capacity systems. However, Administrations are free to mutually negotiate a different unaffected level to allow optimal loading of their transmission systems. Such variation is expected to be in the range —10 to —24 dBm0. The loading effects of pilot tones should be considered.

3.2 *Ratio of compression* α

The compandor compression ration α should be 2 over the range of level specified in § 3.4 and over the temperatura range +10 °C to +40 °C. The difference between the measured level and the calculated level at the output of the compressor assuming a value of exactly 2 should not exceed ± .25 dB.

3.3 *Ratio of expansion* β

The compandor expansion ratio β should be 2 over the range of level specified in § 3.4 and over the temperature range +10 | (deC to +40 | (deC. The difference between the measured level and the calculated level at the output of the expander assuming a value of exactly 2 should not exceed ± | .4 dB.

3.4 *Range of level*

Under study

The range of level over which the recommended value of α and β should apply, should extend at least:

from +5 to —60 dBm0 at the input of the compressor, and

from +5 to —65 dBm0 at the nominal output of the expander.

3.5 *Variation of compressor gain*

The level at the output of the compressor, measured at 800 Hz, for an input level equal to the unaffected level, should not vary from its nominal value by more than ± | .25 dB for a temperature range of +10 | (deC to +40 | (deC and a deviation of the supply voltage of ± | % from its nominal value.

3.6 *Variation of expander gain*

The level at the output of the expander, measured at 800 Hz for an input level equal to the unaffected level, should not vary from its nominal value by more than ± | .5 dB for a temperature range of +10 | (deC to +40 | (deC and a deviation of the supply voltage of ± | % from its nominal value.

3.7 *Tolerances on the output levels of the combination of compressor and expander in the same direction of transmission of a 4-wire circuit*

The compressor and expander are connected in tandem. A loss (or gain) is inserted between the compressor output and expander input equal to the nominal loss (or gain) between these points in the actual circuit in which they will be used. Figure 1/G.166 shows, as a function of level of 800 Hz input signal to the compressor, the permissible limits of difference between expander output level and compressor input level. (Positive values indicate that the expander output level exceeds the compressor input level.)

The limits shall be observed at all combinations of temperature of compressor and temperature of expander in the range +10 | (deC to +40 | (deC. They shall also be observed when the test is repeated with the loss (or gain) between the compressor and expander increased or decreased by 2 dB and the measurement corrected by ± | .0 dB, assuming a β of 2.00.

FIGURE 1/G.166, p.

3.8 *Conditions for stability*

See descriptions given in § 2.6 of Recommendation G.162, Volume III of the *Yellow Book* , ITU, Geneva, 1981, § 2 of Recommendation G.143, *Red Book* , and Reference [1].

The limits shall be observed at all combinations of temperature of compressor and temperature of expander in the range +10 | (deC to +40 | (deC. They shall also be observed when the test is repeated with the loss (or gain) between the compressor and expander increased or decreased by 2 dB.

Note — The change of gain (or loss) of 2 dB mentioned in § 3.7 above is equal to twice the standard deviation of transmission loss recommended as an objective for international circuits routed on single group links in Recommendation G.151, § 3.

4 Impedances and return loss

The nominal value of the input and output impedances of both compressor and expander should be 600 ohms (nonreactive).

The return loss with respect to the nominal impedance of the input and the output of both the compressor and the expander should be no less than 20 dB over the frequency range 300 to 3400 Hz and for any measurement level between +5 and —60 dBm0 at the compressor input or the expander output.

5 Operating characteristics at various frequencies

5.1 *Frequency characteristic with control circuit clamped*

The control circuit is said to be clamped when the control current (or voltage) derived by rectification of the signal is replaced by a constant direct current (or voltage) supplied from an external source. For purposes here, the value of this current (or voltage) should be equal to the value of the control current (or voltage) obtained when the input signal is set to the unaffected level.

For the compressor and the expander taken separately, the variations of loss or gain with frequency should be contained within the limits of a diagram that can be deduced from Figure 1/G.132 by dividing the tolerance shown by 8, the measurement being made with a constant input level corresponding to the unaffected level.

5.2 *Frequency characteristic with control circuit operating normally*

The limits given in § 5.1 should be observed for the compressor when the control circuit is operating normally, the measurement being made with a constant input level corresponding to the unaffected level.

For the expander, under the same conditions of measurement, the limits can be deduced from Figure 1/G.132 by dividing the tolerances shown by 4.

These limits should be observed over the temperature range +10 **|** (deC to +40 **|** (deC.

6 Nonlinear distortion

6.1 *Harmonic distortion*

The total harmonic distortion, measured with an 800 Hz sine wave at the unaffected level, should not exceed 0.5% for the compressor and the expander taken separately.

Note — Even in an ideal compressor, high output peaks will occur when the signal level is suddenly raised. The most severe case seems to be that of voice-frequency signalling, although the effect can also occur during speech. It may be desirable, in exceptional cases, to fit the compressor with an amplitude limiter to avoid disturbance due to transients during voice-frequency signalling.

6.2 *Intermodulation tests*

It is necessary to add a measurement of intermodulation to the measurements of harmonic distortion whenever compandors are intended for international circuits (regardless of the signalling system used), as well as in all cases where they are provided for national circuits over which multi-frequency signalling, or data transmission using similar types of signals, is envisaged.

The intermodulation products of concern to the operation of multi-frequency telephone signalling receivers are those of the third order, of type $(2f_1 - f_2)$ and $(2f_2 - f_1)$, where f_1 and f_2 are two signalling frequencies.

Two signals at frequencies 900 Hz and 1020 Hz are recommended for these tests.

Two test conditions should be considered: the first, where each of the signals at f_1 and f_2 is at a level of —5 dBm0 and the second, where they are each at a level of —15 dBm0. These levels are to be understood to be at the input to the compressor or at the output of the expander (uncompressed levels).

The limits for the intermodulation products are defined as the difference between the level of either of the signals at frequencies f_1 or f_2 and the level of either of the intermodulation products at frequencies $(2f_1 — f_2)$ or $(2f_2 — f_1)$.

A value for this difference which seems adequate for the requirements of multi-frequency telephone signalling (including end-to-end signalling over three circuits in tandem, each equipped with a compandor) is 32 dB for the compressor and the expander separately.

Note 1 — These values seem suitable for Signalling System No. 5, which will be used on some long international circuits.

Note 2 — It is inadvisable to make measurements on a compressor plus expander in tandem, because the individual intermodulation levels of the compressor and of the expander might be quite high, although much less intermodulation is given in tandem measurements since the characteristics of compressor and expander may be closely complementary. The compensation encountered in tandem measurements on compressor and expander may not be encountered in practice, either because there may be phase distortion in the line or because the compressor and expander at the two ends of the line may be less closely complementary than the compressor and expander measured in tandem.

Hence the measurements have to be performed separately for the compressor and the expander. The two signals at frequencies f_1 and f_2 must be applied simultaneously, and the levels at the output of the compressor or expander measured selectively.

7 Noise

The effective value of the sum of all noise referred to a zero

relative level point, the input and the output being terminated with resistances of 600 ohms, shall be less than or equal to the following values:

— at the output of the compressor: —45 dBm0p

— at the output of the expander: —80 dBm0p.

8 Transient response

The overall transient response of the combination of a compressor and expander which are to be used in the same direction of transmission of a 4-wire circuit fitted with compandors shall be checked as follows:

The compressor and expander are connected in tandem, the appropriate loss (or gain) being inserted between them as in § 3.7.

A 12-dB step signal at a frequency of 2000 Hz is applied to the input of the compressor, the actual values being a change from —16 to —4 dBm0 for attack, and from —4 to —16 dBm0 for recovery. The envelope of the expander output is observed. The overshoot (positive or negative), after an upward 12-dB step expressed as a percentage of the final steady-state voltage, is a

measure of the overall transient distortion of the compressor-expander combination for attack. The overshoot (positive or negative) after a downward 12-dB step, expressed as a percentage of the final steady-state voltage is a measure of the overall transient distortion of the compressor-expander combination for recovery. For both these quantities the permissible limits shall be ± | 0%. These limits shall be observed for the same conditions of temperature and of variation of loss (or gain) between compressor and expander as for the test in § 3.7.

In addition, the attack and recovery times of the compressor alone shall be measured as follows:

Using the same 12-dB steps as above for attack and recovery respectively, the attack time is defined as the time between the instant when the sudden change is applied and the instant when the output voltage envelope reaches a value equal to 1.5 times its steady-state value. The recovery time is defined as the time between the instant when the sudden change is applied and the instant when the output voltage envelope reaches a value equal to 0.75 times its steady-state value.

The permissible limits shall be:

— 3 ms minimum, 5 ms maximum for the attack time, and

— 13.5 ms minimum, 22.5 maximum for the recovery time.

ANNEX A

(to Recommendation G.166)

Compandor enhancement characteristics

The improvement which the compandor makes available is based on the fact that interference is most objectionable during quiet speech or pauses, but is masked by relatively loud speech. While it will not be necessary, therefore, to alter the performance of the system for speech signals at a high level, an improvement has to be provided when the signal level is

low. This noise reduction can be arranged by introducing loss at the receiving end of the circuit during periods when the signal is faint or absent. The loss so introduced will affect the noise or crosstalk which has crept in along the route, so that the interference is reduced by the amount of this loss. However, the desired signals are also affected, and in order that the speech level finally received shall be unchanged by the insertion of the compandor, an equal amount of gain has to be introduced at the sending end. The overall equivalent of the circuit is thereby kept constant, and also the low level signals are raised above the background of interference on the line.

The above-mentioned condition must not, however, be allowed to persist when high-level signals have to be transmitted, or overloading could occur in the line amplifiers along the route. The function of the compandors is to introduce the required amounts of gain and loss automatically in just such a way that the overall circuit equivalent remains unchanged irrespective of the speech level, while the signal-to-noise ratio is increased for low-level signals. This is shown schematically in the level diagram of Figure A-1/G.166. For one particular level, called the *unaffected* level *X* , the use of the compandor at no point introduces gain or loss, and the signal passes at an unchanged level throughout the system, as shown by (1), (2), (3).

Any given level of speech (4) would also normally (i.e. without compandors) pass at an unchanged level through the system as shown at (4), (5), (6). If we suppose that the level of interference on the system (noise, crosstalk, etc.) is that shown by (7), the signal/interference ratio is then given by *a* , and the interference level appearing at the output is that shown by (8), during both speech and pauses.

By the introduction of the compandor, however, the incoming speech level (4) is raised to (9), thereby giving a signal/interference ratio within the system of *b* . The level of the speech is restored to (6) at the receiving end, and the corresponding interference level *during speech* is shown at (10). However, as stated earlier, of even greater significance is the interference level during pauses, which is that shown at (11). Thus the effective ratio between speech signals and interference heard *during pauses* has the value shown by *c* .

The part of the compandor at the sending end is called the compressor, because the range of levels of the incoming speech signals is compressed. The unaffected level recommended by the CCITT for high capacity systems is —10 dBm0. However, Administrations may mutually negotiate a different unaffected level to permit optimal loading of their transmission systems. The unaffected level is expected to range from —10 to —24 dBm0. The selected unaffected level will affect the mean power per channel.

The part of the compandor at the receiving end is called the expander, and the same level remains unchanged.

It will be seen from the foregoing that, when compandors are required, one compandor has to be inserted at each end of the telephone circuit in the voice-frequency 4-wire path, with the compressor in the sending channel and the expander in the receiving channel.

Blanc

Figure A-1/G.166, p.22

Reference

[1] CCITT Manual *Transmission planning of switched telephone networks* , ITU, Geneva, 1976.

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