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DIGITAL SYSTEMS AND NETWORKS

International telephone connections and circuits –
Apparatus associated with long-distance telephone circuits

**Interaction aspects of signal processing
network equipment**

ITU-T Recommendation G.161

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ITU-T Recommendation G.161

Interaction aspects of signal processing network equipment

Summary

The evolution towards interactive multimedia applications and the implementation of new signal processing devices both in terminals and communication networks means that a number of sophisticated signal processing algorithms will be deployed for echo control, noise reduction, level control, voice activity detection, speech coding, speech recognition and voice-band traffic technologies. These may interact with each one another in ways that could potentially affect the quality of speech and voice-band signals.

The purpose of this Recommendation is to describe interaction aspects and to provide requirements for the interoperability of Speech Processing Network Equipment (SPNE), between different SPNE, between SPNE and terminals and between SPNE and other devices in the General Switched Telephone Network including mobile networks.

Source

ITU-T Recommendation G.161 was prepared by ITU-T Study Group 15 (2001-2004) and approved under the WTSA Resolution 1 procedure on 13 June 2002.

FOREWORD

The International Telecommunication Union (ITU) is the United Nations specialized agency in the field of telecommunications. The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of ITU. ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

NOTE

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Interaction aspects of signal processing network equipment

1 Scope

The evolution towards interactive multimedia applications and the implementation of new signal processing devices both in terminals and communication networks means that a number of sophisticated signal processing algorithms will be deployed for echo control, noise reduction, level control, voice activity detection, speech coding, speech recognition and voice-band traffic technologies. These may interact with each one another in ways that could potentially affect the quality of speech and voice-band signals.

The purpose of this Recommendation is to describe interaction aspects and to provide requirements for the interoperability of Speech Processing Network Equipment (SPNE), between different SPNE, between SPNE and terminals and between SPNE and other devices in the General Switched Telephone Network including mobile networks.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; all users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published.

- ITU-T G.108 Recommendation (1999), *Application of the E-model: A planning guide.*
- ITU-T G.113 Recommendation (2001), *Transmission impairments due to speech processing.*
- ITU-T G.131 Recommendation (1996), *Control of talker echo.*
- ITU-T G.164 Recommendation (1988), *Echo suppressors.*
- ITU-T G.165 Recommendation (1993), *Echo cancellers.*
- ITU-T G.168 Recommendation (2002), *Digital network echo cancellers.*
- ITU-T G.169 Recommendation (1999), *Automatic level control devices.*
- ITU-T G.711 Recommendation (1988), *Pulse code modulation (PCM) of voice frequencies.*
- ITU-T G.712 Recommendation (2001), *Transmission performance characteristics of pulse code modulation channels.*
- ITU-T G.722 Recommendation (1988), *7 kHz audio-coding within 64 kbit/s.*
- ITU-T G.723.1 Recommendation (1996), *Speech coders: Dual rate speech coder for multimedia communications transmitting at 5.3 and 6.3 kbit/s.*
- ITU-T G.729 Recommendation (1996), *Coding of speech at 8 kbit/s using conjugate-structure algebraic-code-excited linear-prediction (CS-ACELP).*
- ITU-T G.763 Recommendation (1998), *Digital circuit multiplication equipment using G.726 ADPCM and digital speech interpolation.*
- ITU-T G.766 Recommendation (1996), *Facsimile demodulation/remodulation for digital circuit multiplication equipment.*

- ITU-T G.767 Recommendation (1998), *Digital circuit multiplication equipment using 16 kbit/s LD-CELP, digital speech interpolation and facsimile demodulation/remodulation.*
- ITU-T G.768 Recommendation (2001), *Digital circuit multiplication equipment using 8 kbit/s CS-ACELP*
- ITU-T P.340 Recommendation (2000), *Transmission characteristics and speech quality parameters of hands-free terminals.*
- ITU-T P.342 Recommendation (2000), *Transmission characteristics for telephone band (300-3400 Hz) digital loudspeaking and hands-free telephony terminals.*
- ITU-T Q.50.1 Recommendation (2001), *Signalling between International Switching Centres (ISC) and Digital Circuit Multiplication Equipment (DCME) including the control of compression/decompression.*
- ITU-T Q.115 Recommendation (1999), *Logic for the control of echo control devices.*
- ITU-T Q.761 Recommendation (1999), *Signalling System No. 7 – ISDN User Part functional description, plus Amendment 1 (2001).*
- ITU-T Q.764 Recommendation (1999), *Signalling System No. 7 – ISDN user part signalling procedures, plus Amendment 1 (2001).*
- ITU-T T.30 Recommendation (1999), *Procedures for document facsimile transmission in the general switched telephone network.*
- ITU-T V.17 Recommendation (1991), *A 2-wire modem for facsimile applications with rates up to 14 400 bit/s.*
- ITU-T V.18 Recommendation (2000), *Operational and interworking requirements for DCEs operating in the text telephone mode.*
- ITU-T V.21 Recommendation (1988), *300 bits per second duplex modem standardized for use in the general switched telephone network.*
- ITU-T V.23 Recommendation (1988), *600/1200-baud modem standardized for use in the general switched telephone network.*
- ITU-T V.26 Recommendation (1988), *2400 bits per second modem standardized for use on 4-wire leased telephone-type circuits.*
- ITU-T V.27 Recommendation (1988), *4800/2400 bits per second modem standardized for use in the general switched telephone network.*
- ITU-T V.29 Recommendation (1988), *9600 bits per second modem standardized for use on point-to-point 4-wire leased telephone-type circuits.*
- ITU-T V.32 Recommendation (1993), *A family of 2-wire, duplex modems operating at data signalling rates of up to 9600 bit/s for use on the general switched telephone network and on leased telephone-type circuits.*
- ITU-T V.34 Recommendation (1998), *A modem operating at data signalling rates of up to 33 600 bit/s for use on the general switched telephone network and on leased point-to-point 2-wire telephone-type circuits.*

3 Terms and definitions

This Recommendation defines the following terms:

3.1 acoustic echo: Acoustic echo is the reflected signal resulting from the acoustic path between the earphone/loudspeaker and microphone of a terminal, hand-held or hands-free mobile station.

3.2 cancelled end: The side of an echo canceller which contains the echo path on which this echo canceller is intended to operate. This includes all transmission facilities and equipment (including the hybrid and terminating telephone set) which is included in the echo path.

3.3 network echo suppressors: An network echo suppressor is a voice-operated device placed in the 4-wire portion of a circuit and used for inserting loss in the transmission path to suppress echo. The path in which the device operates may be an individual circuit path or a path carrying a multiplexed signal.

3.4 network echo canceller: An network echo canceller is a voice operated device placed in the 4-wire portion of a circuit and used for reducing the cancelled-end echo present on the send path by subtracting an estimation of that echo from the cancelled-end echo (see Figure 1).

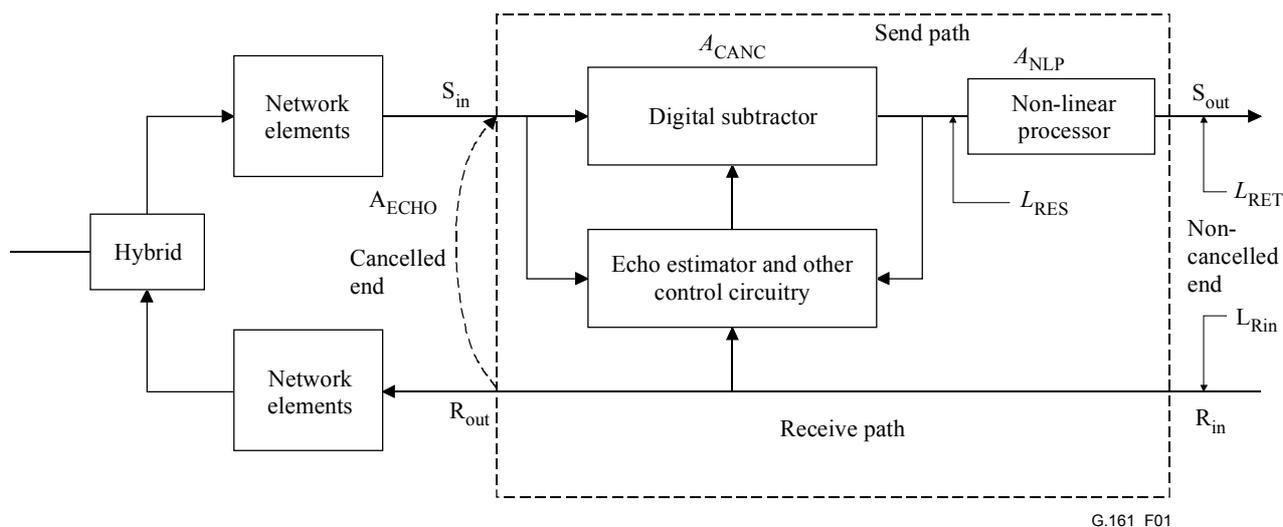
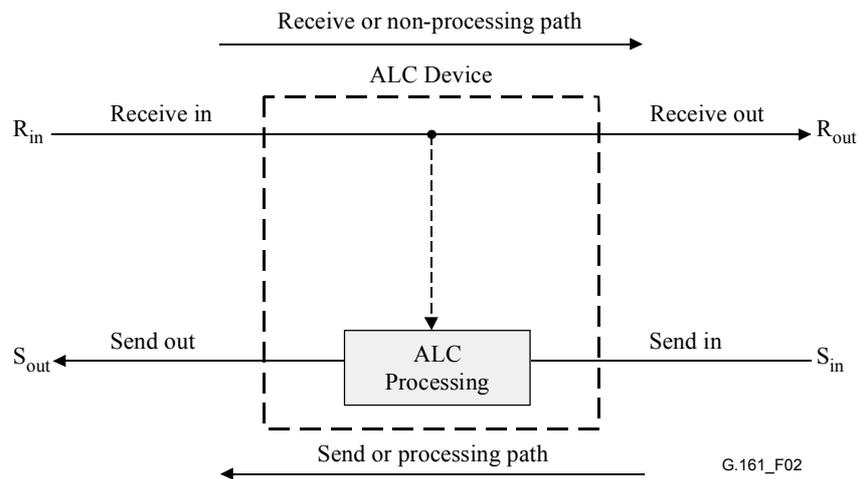


Figure 1/G.161 – Block diagram of an echo canceller (G.168)

3.5 terminal acoustic echo controller: Terminal acoustic echo controllers are voice operated devices installed in audio terminals on the customer premises, used for the purpose of eliminating acoustic echoes and protecting the communication from howling due to acoustic feedback from loudspeaker to microphone.

3.6 network acoustic echo controller: Network acoustic echo controllers are devices placed in the 4-wire portion of a circuit and used for reducing cancelled-end acoustic echo.

3.7 automatic level control device: An automatic level control device is a signal processing function located in the digital transmission path which automatically adjusts the level of a signal towards a predetermined value. Devices which modify the frequency response or spectral content of the signal in such a way as to affect the overall level of the signal are also defined as ALC devices for the purpose of this Recommendation. An ALC device is designed to process signals in one direction of transmission (see Figure 2).



G.161_F02

Figure 2/G.161 – Block diagram of an automatic level control device (G.161)

3.8 voice enhancement device: Voice enhancement devices are intended for use in digital network-based equipment for mobile applications. Voice enhancement functions include the control of acoustic echo generated by wireless handsets, noise reduction, and the recognition and accommodation of tandem free operation (TFO) and interworking function (IWF) signals.

3.9 circuit multiplication equipment: Circuit multiplication equipment is a general class of equipment which permits concentration of a number of 64 kbit/s PCM encoded input trunk channels on a reduced number of transmission channels.

3.10 voice gateways: A voice gateway is a subset of a gateway that deals with voice and voiceband traffic only, and not data or video traffic.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations:

A/D	Analogue-to-digital converter
ADPCM	Adaptive Differential Pulse Code Modulation
AEC	Acoustic Echo Controller
ALC	Automatic Level Control
BSC	Base Station Controller
BTS	Base Transmitter Station
CEST	Cancelled-end speech threshold
CME	Circuit Multiplication Equipment
CPE	Customer Premises Equipment
D/A	Digital-to-analogue converter
DCME	Digital Circuit Multiplication Equipment
DTDT	Double Talk Detection Threshold
EC	Echo Canceller
ERL	Echo return loss
ERLE	Echo Return Loss Enhancement
GSM	Global System for Mobile Communications

IP	Internet Protocol
IWF	InterWorking Function
L _{RET}	Returned Echo Level
MS	Mobile Station
MSC	Mobile Switching Center
NLP	Non-linear Processor
NR	Noise Reduction
PBX	Private Branch eXchange
PCM	Pulse Code Modulation
PSTN	Public Switched Telephone Network
SPNE	Signal Processing Network Equipment
TCE	Transcoder Equipment
TDMA	Time Division Multiple Access
TFO	Tandem Free Operation
VED	Voice Enhancement Device
VoIP	Voice over IP

5 Interaction aspects of signal processing network equipment

5.1 Interaction aspects of echo suppressors

The principle of echo suppressors is summarized as follows: When speech is detected on the receive path, a very high attenuation is inserted in the send path. When double talk is detected, the send path is closed and a receive loss is inserted in the receive path. Thus, during double talk, there is no echo suppression in the send path, but the echo is much more attenuated than the direct speech. Other refinements are possible, as indicated in ITU-T Rec. G.164. The following text relates to ITU-T Rec. G.164 echo suppressors.

Many problems can occur in the operation of echo suppressors; this is because the decision as to which end is talking and which is listening is based essentially on the transmission levels. If the level of the echo is high and the level of direct speech is low, speech could be mutilated and/or it could be difficult to distinguish between single talk and double talk. This could also be the case at the beginning or at the end of a speech burst.

The problems are compounded on long-delay transmission paths, because the pattern of conversation is usually changed. In addition, the cascading of echo suppressors is not recommended. In the case of voice-band data, a 2100 Hz tone is specified to permit disabling of the echo suppressor before the beginning of data transmission; this is for two reasons:

- to avoid insertion losses for modems with a secondary channel;
- to avoid delays due to hangover at turnarounds, thereby increasing the throughput.

Facsimile is a special case. Even if an echo suppressor is disabled by 2100 Hz tone, it may be re-enabled during a facsimile transmission. The tone disabler hangover time of an echo suppressor is specified as 250 ± 150 ms in 5.7/G.164. Therefore, periods of silence greater than 100 ms and less than 400 ms at the echo suppressor may allow the echo suppressor to remain disabled, while periods greater than 400 ms cause it to be re-enabled. During a facsimile call, there are a number of silent periods that may be long enough to permit the re-enabling of the echo suppressor. In addition, some facsimile manufacturers have chosen to exceed the signal separation intervals specified in ITU-T Rec. T.30; therefore, echo suppressors may be re-enabled.

Enabled echo suppressors may distort the facsimile signals. One type of distortion is the truncation of fast turnaround signals. Typically, the echo suppressor operates in a single-talk mode, so that when a signal arrives at the receive port, the suppression switch is activated and remains in that state until no signal arrives for a certain time. The recommended hangover time associated with each state transition is in the range of 24 to 36 ms, as specified in Table 4/G.164. The suppression hangover time guards against echo stored in the local echo path.

ITU-T Rec. T.30 specifies that the guard time between V.21 and V.29 transmission should be 75 ± 20 ms. If a return signal from the local facsimile machine (within a V.21 message-response sequence or a V.21/V.29 sequence such as a confirmation to receive (CFR) followed by training) reaches the echo suppressor transmit port within 24 to 36 ms of the termination of the signal at the receive port, the persistence of echo suppression insertion losses or open-circuit condition may introduce an attenuation. As a result, the echo suppressor mutilates the initial portion of that fast turnaround signal. When this signal is part of the training/training check signal, training might be disrupted and rate fallback ensues, or in a worse case, the call is terminated.

For certain combinations of propagation times and insertion losses, listener echo may cause the 2100 Hz tone to persist long enough to disable the echo suppressors. This echo may then contribute to the degradation of the image quality by reducing the signal-to-noise ratio during page transmission.

Similarly, an enabled echo suppressor may block a low-level secondary channel signal. If the level of that signal is high enough, the suppressor may enter the double talk mode, in which a receive loss is inserted. The result is a reduction in the levels of both the transmit and the receive signals, if echo suppressors are at both ends of the connection and are both in the double talk mode.

Enabled echo suppressors may cause errors in facsimile transmission and other low-speed modem transmission. However, it may be better to enable echo suppressors during facsimile transmission to protect against both talker and listener echoes and avoid their interference with facsimile at connection establishment and/or during image transmission.

5.2 Interaction aspects of echo cancellers

Echo cancellers are devices that use adaptive signal processing to reduce or eliminate echoes. Echo cancellers are placed in the 4-wire portion of a circuit, and reduce (or cancel) the echo by subtracting an estimate of the echo from the returned echo signal. Echo cancellers can be designed as "half" echo cancellers, i.e. those in which cancellation takes place only in the send path due to signals present in the receive path. A full echo canceller is possible consisting of two half echo cancellers, with each pointing in the opposite direction. The appropriate transmission performance requirements of echo cancellers are shown in ITU-T Recs G.165 and G.168.

Echo cancellers are designed to:

- cancel linear echo path signals, which means a routing consisting of only linear transforming elements in conjunction with a standard coding/decoding (see ITU-T Rec. G.711);
- refrain from cancelling the echo when requested to do so by an in-band disabling signal;

- return to an operational mode after being disabled when the in-band signal power level drops below a specified level for a specified period of time. This design allows some networks to transport voice-band data on the same speech channels. It also allows the echo canceller to re-enable during a voice call after it has been turned off erroneously (talkoff).

Echo cancellers have the following main advantages over echo suppressors:

- Send path transparency is improved;
- NLP hangover introduces fewer impairments;
- There is no receive insertion loss;
- Echo cancellation continues during double talk;
- Cascading is possible (for well designed echo cancellers).

Some echo cancellers are optioned to disable on the 2100 Hz tone specified in ITU-T G.164 for echo suppressors, and some are disabled with a 2100 Hz tone with periodic phase reversals of $180^\circ \pm 25^\circ$, as specified in ITU-T Recs G.165 and G.168 for echo cancellers. Use of the G.165/G.168 tone is intended to allow echo cancellers to be disabled independently of echo suppressors.

To improve the operation of the echo canceller for fax signals and low-speed voiceband data, it may be beneficial for some echo cancellers to disable the NLP for such calls. In this case, the echo canceller may optionally detect any 2100 Hz tone without phase reversals. If 2100 Hz tone without phase reversal is detected, the echo canceller shall remain enabled, and the NLP may optionally be disabled.

5.2.1 Interaction of echo cancellers with facsimile transmission

Although facsimile machines may transmit a G.164 disabling tone at the beginning of a call, there is no requirement to guarantee that the power of in-band signals will continue to hold echo canceller devices in the disabled state for the duration of the call. Echo cancellers conforming to ITU-T Recs G.165 and G.168 are designed to re-enable when the signal level drops below a predefined threshold for a predefined period of time, once the call is in progress. The reason for this is that echo cancellers conforming to ITU-T Recs G.165 and G.168 are designed to become re-enabled if no signal energy is present in both directions of signal transmission for a period greater than 100 ms (minimum) to 400 ms (maximum) (see 5.2 and 5.5/G.164 and 7.8/G.168).

The ITU-T Recs V.27 *ter* and V.17 modulation scheme employed by ITU-T Rec. T.30 are protected against the mutilation of the training sequence by echo suppressors (by using an unmodulated carrier prior to the training signal). In contrast, the V.29 modulation scheme is not protected. Some implementations are based on proprietary solutions to this problem (most notably the addition of an unmodulated carrier prior to V.29 transmissions of the same format as that used during V.27 *ter* and V.17 transmissions). Unfortunately, these schemes are not universally recognizable by terminals produced by different modem manufacturers.

The presence of echo can interfere with facsimile transmission in two ways:

- The echo could be misinterpreted as an T.30 protocol message and then interrupt the handshake between the two ends machines. This is particularly important if the facsimile machines are not protected against echo.
- The echo can reduce the S/N ratio necessary for the good transmission of images data.

Echo could be present for the following reasons:

- If echo cancellers are disabled according to the procedures of ITU-T Rec. G.164 (2100 Hz tone without phase reversal), then, depending on the propagation delay and the response time of the facsimile machines, echo could be present during the initial handshake. This could disrupt the establishment of the call. To ensure that the echo control device re-enables, a period of at least 400 ms is required during which no energy could flow in either direction. If these echo cancellers remain disabled, the echo of the V.21 signal may confuse the facsimile machine at the other end and/or confuse the facsimile demodulator of the network circuit multiplication equipment (CME). The image quality may be affected as well.

Other vulnerable instances during the connection are when handshakes are exchanged between pages. Disabled echo cancellers could allow echo at these instances; enabled echo cancellers, in contrast, control echo, including listener's echo.

Under some conditions, echo cancellers disabled using the G.164 procedures (2100 Hz) may affect the connection establishment or the quality of facsimile transmission because they may be disabled inadvertently by the called station identification (CED) tone; hence, echo control does not function as expected.

It should be noted that a number of echo cancellers already deployed in the PSTN are not able to eliminate completely short echo bursts that could occur while the canceller is reconverging after transitions between the narrow-band signals, such as the CED tone or the V.21 high-level data link control (HDLC) handshake, the wide band image signals (e.g. V.29 or V.27 *ter* signals), and again, narrow-band signals. In the future, it still will not be possible to guarantee that all echo cancellers will be able to avoid this problem.

Current Recommendations imply that echo cancellers should be enabled during facsimile transmission. The main conclusion is that it is better to use echo cancellers that are controlled according to the G.165/G.168 procedures in preference to G.164 procedures.

NOTE – This Recommendation does not discuss explicitly the case in which there is one echo canceller on one side of the connection and an echo suppressor on the other side.

5.2.2 Interaction of echo cancellers with modems

Most modem manufacturers feel that network echo cancellers should be disabled for modems with integrated echo cancellers (e.g. ITU-T Recs V.32 and V.34), because an active network echo canceller operating in conjunction with the integral echo canceller in the modem may cause undesirable phenomena under specific but unlikely circumstances. Some of these cases are:

- The echo canceller incorrectly identifies the cancelled-end signal as an echo and attempts to cancel it.
- When there is frequency offset in the echo path, the echo canceller injects bursts of reinforced echo interspersed with quiet periods.

Although neither case is likely, it was decided that the onus for making the decision to disable the network canceller should rest with the end users. Modem manufacturers had to rely on a unique technique to disable echo suppressors and echo cancellers.

Historically, manufacturers of modems with integrated echo cancellers have designed their modems to disable network-based echo cancellers (electrical echo cancellers). These modems disable network-based echo cancellers using the disabling tone specified in ITU-T Recs G.165 and G.168. Modem-based echo cancellers should accommodate three types of echoes simultaneously:

- 1) near-end echo;
- 2) far-end echo; and
- 3) any echo generated between the near-end and the far-end.

Because the range of echo path capacities needed for each case varies widely, three echo cancellers may be needed.

Prior to ITU-T Rec. V.32, most 2-wire modems used frequency division to provide duplex operation (i.e. different carrier frequencies were used for each direction of transmission). In the early 1980s, data showed that some echo cancellers did improve the operation (i.e. reduce or eliminate bit errors) for low-speed modems designed according to ITU-T Recs V.21, V.23, V.26 (alternative B), V.27 *ter* and V.29. Therefore, it was accepted that these modems benefited from an active echo canceller and a disabled echo suppressor. Accordingly, in 1984, ITU-T Rec. G.165 was modified to recommend that echo cancellers be disabled with a 2100 Hz tone with phase reversals.

Data have indicated that certain combinations of modems with different protocols and modulation schemes (ITU-T Recs V.18, V.21 and V.23, DTMF and some V.34 implementations) and some echo cancellers, in various simulated network configurations and in the network, exhibit degraded performance when the echo cancellers are enabled. Therefore it is strongly recommended to use the 2100 Hz Answer Tone with phase reversals as mandatory in any modem and protocol Recommendation where the presence of a network echo canceller is likely to affect the performance of the modem transmission.

Echo cancellers integrated in voice-band data modems e.g. full duplex echo canceller modem V.32 are not to be confused with the network echo cancellers that conform to ITU-T Recs G.165 and G.168, because the performance requirements for each are very different.

5.2.3 Interaction between echo cancellers (tandemed echo cancellers)

It is generally accepted that properly designed echo cancellers can be tandemed with little or no penalty in performance. In ITU-T Rec. G.131, clause "Rules for connections with echo control devices" indicates that circuits equipped with echo cancellers can be connected together in tandem without significant echo performance degradation. With the increasing use of dynamic routing and special features such as call forwarding, and because of the long delay introduced by low bit rate speech coders in cellular applications, it is very likely that some connections have more than one echo canceller.

Subjective tests on some echo cancellers verify that tandeming poses no problems under most conditions. However, reports have suggested that other echo cancellers cannot be tandemed without problems.

Test results showed that improper design of some of the auxiliary circuits, such as NLP's, could cause problems when the echo path delay for one of the echo cancellers in tandem exceeds its echo path capacity. For example, in some echo cancellers, the NLP may operate at inappropriate times during double talk. This occurs when the hangover time in the NLP circuit does not match the echo path delay characteristics.

To illustrate, assume that the NLP algorithm is designed to operate on the basis of the CEST/DTDT value (cancelled-end speech threshold (CEST)/double talk detection threshold (DTDT)). In the case where the echo path delay capacity of an echo canceller is exceeded, the echo arrives later than the "expected" time. As a result, the comparison is in effect between power levels of a later far-end speech burst and an unrelated near-end speech burst. Based on this scenario, clipping can occur.

This problem is mitigated since it only occurs during double talk, and most situations involving tandeming of echo cancellers do not include many cases in which the echo path capacity is greatly exceeded. Finally, with some adjustments to the time constants of the NLP, partial improvements can be made.

It has been observed that if an echo canceller converges too quickly, it can have annoying side effects if it is used in a situation where its echo path capacity is exceeded (such as sometimes occurs with tandem echo canceller operation). Therefore, the echo path capacity of an echo canceller should be 4 to 6 ms larger than the maximum expected network delay. This takes into account the

effect of dispersion. For example, to take into account a maximum pure delay of 58 ms, a 64-ms canceller could be selected.

Figure 3 shows three pairs of back-to-back ECs (EC_A , EC_B , EC_C), four delay generators (D_1 , D_2 , D_3 , D_4), and two hybrids (designated by return loss R_1 and R_2) in a reference connection for tandem ECs. The values of R_1 and R_2 should be appropriate for proper operation of the nearest canceller (e.g., at least 6 dB). By selectively disabling ECs (either singly or in pairs), and varying the delays, it is possible to capture the relevant attributes of telephone connections with ECs. Guidance on how to control echo cancellers can be found in ITU-T Rec. Q.115 and regarding Tandem Free Operation in Appendix I.

As an example (see Figure 4), 29 ms delay at D_1 50 ms at D_3 , 100 ms at D_2 , 80-110 ms at D_4 , and 4-wire termination in place of R_2 is a reasonable representation of an international call originating at an analogue station and terminating in a digital cellular network. In this case, EC_A and EC_B might be at opposite ends of the international facility, with EC_C in the cellular network (in which case, the right-facing canceller of the pair might be inoperative or absent). Alternatively (see Figure 5), EC_A might be in a national (land-based) network while EC_B and EC_C are at the ends of an international facility. In this case, D_1 , D_2 , and D_4 would be fairly short and D_3 would provide delay consistent with an international connection.

The sample configuration in Figure 5 can be extended easily if more pairs of ECs are required. In particular, inclusion of a fourth pair of ECs (and another delay generator) would capture the important features of an international connection with ECs in each national network as well as at the ends of the international facility.

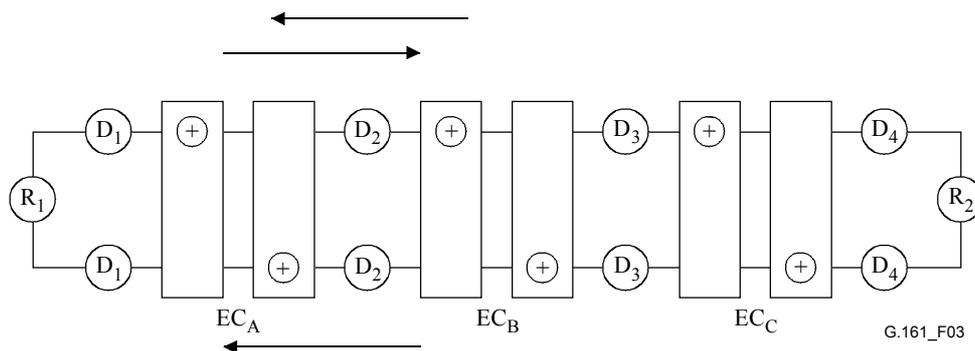


Figure 3/G.161 – Reference connection for tandem echo cancellers

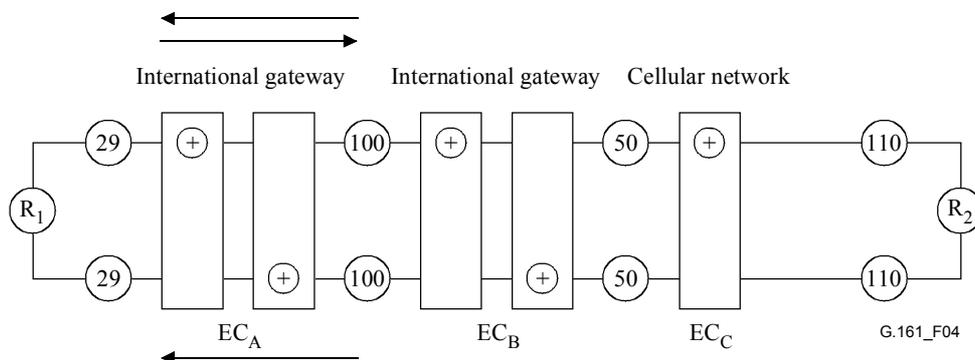


Figure 4/G.161 – Example of international connection originating at analogue station and terminating in a digital cellular network

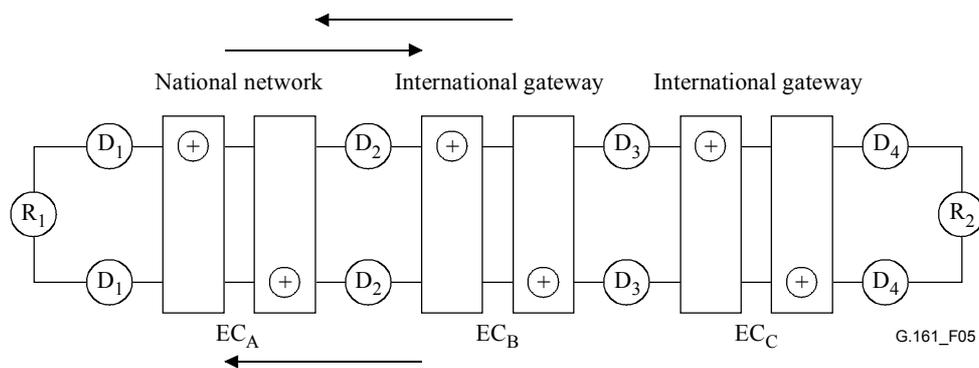


Figure 5/G.161 – Example of international connection

5.2.4 Interaction of echo cancellers with CME

Echo cancellers may be needed for CME, even for a short terrestrial circuit, because of the additional buffering delay in a CME. The appropriate transmission performance requirements of CME are shown in ITU-T Recs G.763, G.766, G.767 and G.768.

One possible interaction relates to the potential loading effect of the comfort noise injected by the echo canceller on a CME (see Figure 6). There are two known approaches for comfort noise. The first solution is to insert pseudo-random noise during the silent interval. The second solution is to allow some of the background or idle channel noise to pass through the NLP.

The operation of the echo canceller may modulate the near-end analogue noise injected into the S_{in} port of the echo canceller. This could cause the adaptive speech detector of the CME to falsely classify this change in noise level as the presence of speech. In this case, the CME transmits the noise spurt as if it were speech and thus increases the activity factor of the circuit. The consequence is a decrease in the compression gain, and in some systems, an increase in the occurrence of freeze-out. It also has a negative effect on the subjective quality.

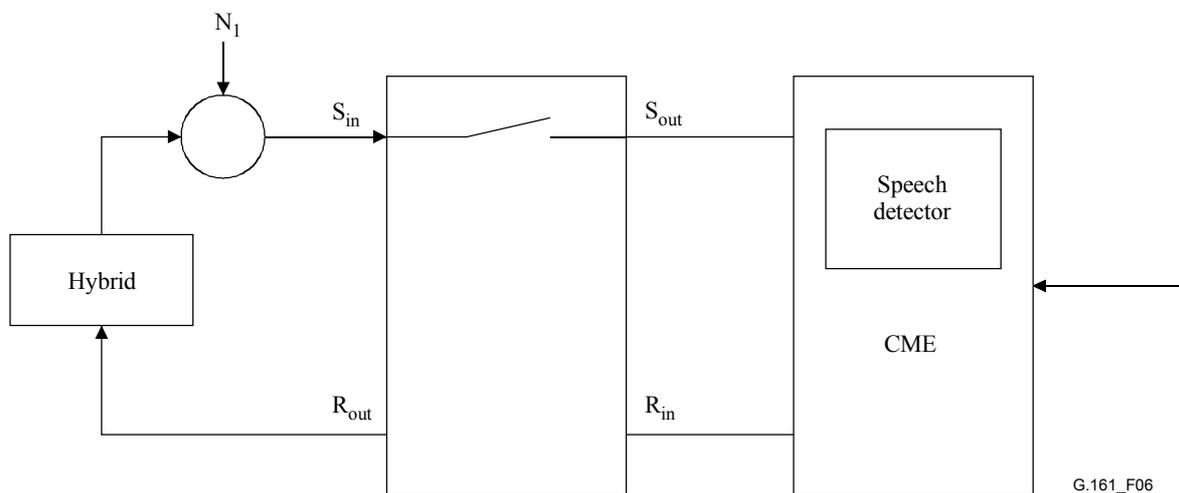


Figure 6/G.161 – Speech detector/echo control device interaction

5.2.4.1 Detailed interaction

This interaction occurs as follows:

- 1) Receive speech arrives at the receive input (R_{in}) port of the echo control unit.
- 2) The echo suppression switch or canceller NLP activates, stopping the echo or residual echo and attenuating the near-end-generated analogue terrestrial noise (N_1) present at the send input (S_{in}) port.
- 3) If very little noise is generated between the echo control send output (S_{out}) port and the CME speech detector input, the speech detector threshold adapts to its minimum level (typically, -50 dBm0).
- 4) When the receive speech stops, after a suitable echo control unit hangover time, the echo suppression switch or canceller NLP closes and the near-end-generated terrestrial noise (N_1), as seen by the CME speech detector, reappears as a step change in noise level.
- 5) The step change in noise level may exceed the speech detector threshold, causing the CME to transmit a noise spurt as if it were speech. The noise spurt duration is a function of the adaptation speed of the speech detector and the near-end-generated terrestrial noise level.

This sequence is repeated for every speech spurt and produces a very annoying speech-correlated noise spurt heard by the far-end talkers every time they stop speaking.

This interaction is not limited to single echo control device network configurations. Figure 7 shows a possible network configuration, with multiple echo cancellers interacting with a CME speech detector. In this configuration, the CME speech detector may respond to unit step increases in noise power, which result from echo canceller center clipper activations in the send paths of echo cancellers 1 and 3 (The role of the NLP is to remove the residual echoes due to imperfect cancellation.). The CME speech detector first experiences a unit step increase in noise power from echo control device 3 switch activation, followed by a second step increase from echo canceller 1 switch activation. The extent to which the CME speech detector incorrectly responds to these step increases in noise power is a function of the noise power levels N_1 , N_2 , N_3 , and N_4 and the specific CME speech detector threshold adaptation algorithm. For example, the dual step increases in noise presented to the CME speech detector, which result from switch or center clipper activation at locations 1 and 3, are masked if the power level N_4 is excessively high. Likewise, high noise power levels at N_2 or N_3 may mask step increases in noise power caused by echo control unit 1.

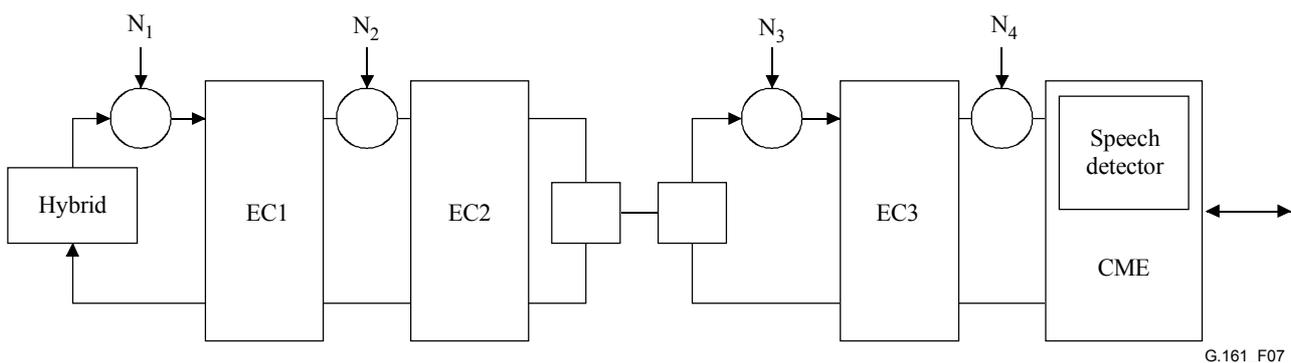


Figure 7/G.161 – Multiple echo control devices in a CME network configuration

5.2.4.2 Possible solutions

There are several methods for dealing with the interactions between the echo cancellers and the CME speech detector. In one approach, the echo canceller could be modified to monitor the terrestrial-generated noise at the send-input port. When the send transmission path is broken, noise at the proper level is injected into the send-output toward the CME, keeping the noise seen by the speech detector at a constant level (comfort noise) and avoiding speech detector activation. Not all echo cancellers may implement this approach, due to the number of different echo cancellers in use and the uniqueness of this application.

In a second approach, the speech detector adaptive threshold of the CME is frozen in the presence of speech on the corresponding receive channel.

A third approach is to specify an adaptive speech detector with a fast adaptation feature, which would track step changes in noise level and minimize the noise spurts.

The approaches described above may be unacceptable due to the number of different echo cancellers in use and the uniqueness of the proposed application. Further, the large base of echo cancellers prevents consideration of a fast phasing in of new echo cancellers.

This subject requires further study and may result in changes to ITU-T Rec. G.165 and/or ITU-T Rec. G.168 for new generation of echo cancellers. The main point of this clause is that the solution depends on the speech detection procedures of both the CME and the echo canceller.

5.2.5 Interaction with non-linearities and time variant signal processing techniques

5.2.5.1 Effects of a non-linear echo path

The theory of echo cancellation assumes that the echo path is linear and time-invariant. Therefore, it is critical that clipping and non-linear distortion not occur in the echo path between R_{out} and S_{in} of an echo canceller. If any clipping does occur, it is important that it be slight, infrequent, and that it occurs only during double talk conditions. Otherwise, the environment needs to be corrected, e.g. frequency offset removed or implementation of an acceptable transmission plan ensured.

One potential source of problems with high-level speech stems from the resultant non-linearities in the echo path. For optimal echo canceller performance, it is essential that the signal fed into the echo canceller's R_{in} port be linearly related to the signal at the echo canceller's S_{in} port. If any non-linear distortion of high-level speech occurs, the distortion should occur before it is used by the echo canceller so that the same clipped signal is sent to the R_{out} port. However, echo canceller performance may still degrade if the echo path is not linear.

Imperfect cancellation can occur, for example, in networks conforming to ITU-T Rec. G.108 in which quantization distortion units (qdu) (see Table 1/G.113) are added in an echo path. The accumulated quantization distortion from these codecs may prevent an echo canceller from achieving the necessary returned echo level (L_{RET}) by using linear cancellation techniques alone. It is therefore recommended that all echo cancellers capable only of modeling the linear components of echo paths but intended for general network use should incorporate suitable NLP's. In specific network environments with low delay or high echo return loss (ERL), it may be possible to disable the NLP in an echo canceller with a sufficiently high echo return loss enhancement (ERLE). This may result in higher overall speech quality, as NLP's sometimes cause speech degradation.

Some echo cancellers use the signal at R_{in} as its internal received signal R_{rcv} , and also pass R_{in} to the R_{out} port. This is acceptable provided that there is no clipping or other non-linear distortion of one signal leg that does not occur with the other. Otherwise, the echo path does not appear to be linear to the echo canceller and, consequently, performance suffers.

With the increased use of digital techniques in processing voice-band signals, digital insertion losses are being implemented increasingly in digital pads. Such digital padding typically occurs in PSTN End-Offices when they act as a host to a digital remote line module as well as in customer

premises equipment (CPE), such as private branch exchanges (PBXs). Improperly designed digital pads may add substantial non-linearities to the transmitted signal, including the returned echo signal, therefore degrading the canceller performance. The need to maintain linearity in digitally padded signals should be recognized.

Additionally, clipping or other non-linear distortion should not be "added" to the signal at the S_{in} port. This is most important when

- 1) echo is present only at the S_{in} port, or;
- 2) both echo and cancelled-end speech are present and the double talk detector has not been triggered, since clipping (distorting) one affects the other.

5.2.5.2 Voice compression in the echo path

With the increasing use of voice compression in the public and private voice networks, specifically 32 kbit/s adaptive differential pulse code modulation (ADPCM, see ITU-T Rec. G.726), the occurrence of a voice compression codec in the echo path becomes more likely. Measurements carried out with echo cancellers including an ADPCM circuit in the echo path have shown that the deterioration of the residual echo level may exceed 8 dB and the convergence speed decreases. If the NLP is enabled it may cause a reduced speech quality performance e.g. due to a disturbed echo signal caused by an unintentional switching of the NLP. An echo canceller may provide a certain amount of echo return loss enhancement.

5.2.5.3 Voice compression between tandem cancellers

The use of voice compression as part of the voice transmission path could also affect connections that use tandem cancellers. Figure 8 shows a circuit in which tandem cancellers are in place, and voice compression is used only between the two cancellers. Although the canceller closer to the hybrid would not be affected, the canceller on the network side would see a non-linear or a time variant echo paths. The performance of the tandem still may be acceptable if the canceller closer to the network remains stable and maintains a return loss enhancement. Theoretically, the canceller on the network side would not see an echo because the canceller on the distant end has removed it. However, it is recommended that the cancellers on the network side should be removed effectively from the connection or disabled.

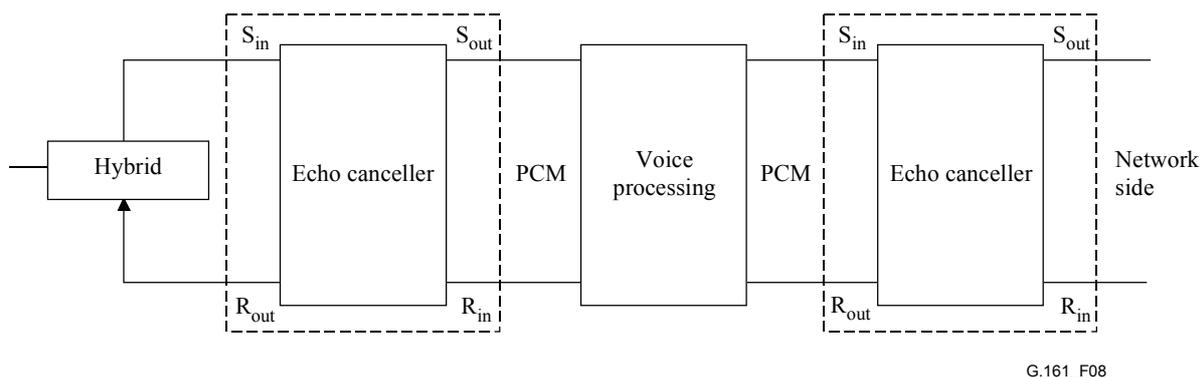


Figure 8/G.161 – Voice compression between tandem canceller

5.2.6 PCM offset

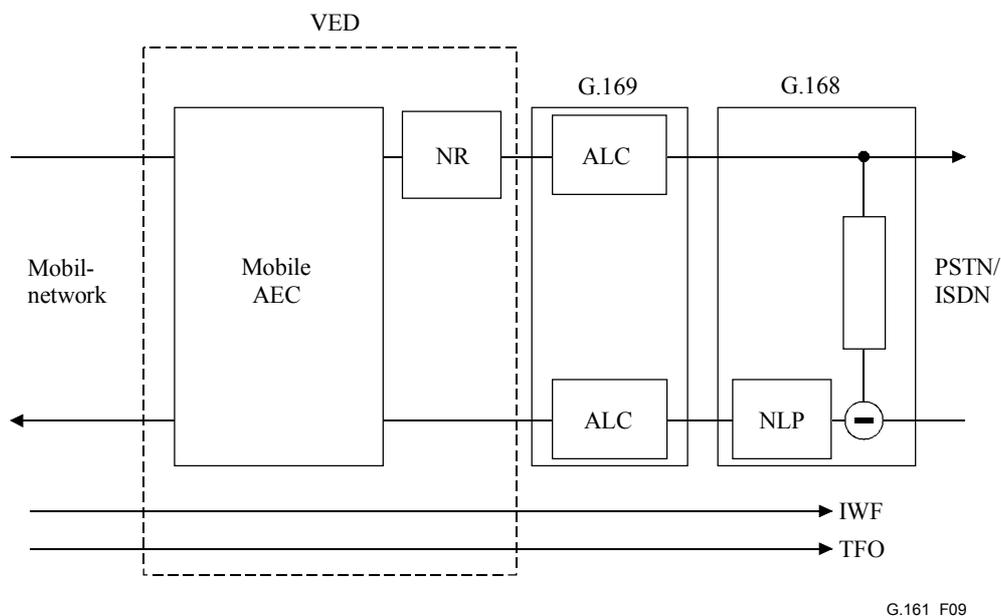
Distortion can occur in the presence of PCM offset. PCM offset is an unwanted, fixed DC signal level, caused by some analogue-to-digital converter or filter in the echo path, in the S_{in} signal relative to the R_{out} signal of an echo canceller. PCM offset can also happen in the R_{in} signal. This can result in degraded performance of an echo canceller and/or other SPNE ranging from reduced cancellation to unintentional speech clipping.

5.3 Interaction aspects of voice enhancement devices

5.3.1 Interaction aspects between Voice Enhancement Devices (VEDs), mobile applications and mobile networks

A VED is defined as any signal processing in the digital transmission path that performs voice enhancement functions on voiceband signals that traverse mobile networks (Figure 9).

Voice enhancement functions include the control of acoustic echo generated by wireless handsets, noise reduction, and the recognition and accommodation of tandem free operation (TFO) and interworking function (IWF) signals.



G.161_F09

Figure 9/G.161 – Network configuration of SPNEs including VEDs in a mobile network

When including VEDs in mobile networks the interworking between VEDs and the mobile network is mainly effected by the following points:

- the performance of the mobile terminal including:
 - the occurrence of acoustic echoes;
 - implemented echo cancellers in the terminal including additional level switching like NLPs or center clippers;
 - comfort noise injection;
 - noise reduction algorithm.
- the speech transcoder part including the effects of speech processing and radio transmission between the mobile handsets and the network connection point.

Consequently, this may lead to tandemed signal processing units like echo cancellers, NLP's, different kinds of comfort noise injection or noise reduction algorithms.

5.3.1.1 Interaction aspects between VEDs and acoustic echoes – Acoustic echo in digital mobile applications is typically time-variant

In the digital mobile network acoustic echo can affect the system. The microphone of mobile terminal receives locally generated signals like speech, multiple echoes caused by reflections and environmental noise.

The acoustic echo controller should take into account the reverberation time of the surroundings. Furthermore, the system is driven by signals such as periodic and aperiodic components with highly fluctuating magnitudes and pauses. This changes the characteristics of the acoustic echo continuously and the acoustic echo controller has to follow the changes in the impulse response.

The methodology for reducing acoustic echo in mobile networks correctly without appending side effects to the cancellation process is dependent on the acoustic echo controller's ability to characterize a signal as an acoustic echo. The correct determination is essential to a proper operation. Classification errors would be intensely harmful to the quality of the performance of VEDs.

5.3.1.2 Acoustic echo in digital mobile applications is non-linear

The speech from the far end (acoustic echo), injected into the mobile phone microphone, changes its characteristics by means of speech compression techniques. This causes non-linearities in these signals.

Loudspeakers and microphones in the terminals introduce non-linearities, especially if hands-free terminals are used. In this situation the typically small loudspeakers have to reproduce a sufficiently high signal level to playback the received speech signal. Typically, this leads to large non-linear distortions.

Another source of non-linearity might be radio interfaces in the echo path.

For optimal acoustic echo controller performance, it is important that the signal fed into the acoustic echo controller's R_{in} port should be linear related to the signal at the echo canceller's S_{in} port. Additionally, clipping or other non-linear distortion should not be "added" to the signal at the S_{in} port. This is most important when echo is present only at the S_{in} port, or both echo and cancelled-end speech are present and the double talk detector has not been triggered, since clipping (distorting) one affects the other.

5.3.1.3 Interaction aspects between echo cancellers/VEDs in tandem or noise reduction systems/algorithms in tandem

Acoustic echo controllers and noise reduction algorithms are increasingly implemented in both mobile handsets and hands-free terminals. Special care should be taken to consider and evaluate the possible interaction between tandemed AECs implemented in VEDs and in mobile terminals. This may lead to increased speech clipping introduced by tandemed NLP's or center clippers or the interaction between different kinds of comfort noise injection, resulting in an audible noise, switched between noise with different characteristics.

In addition, the influence of noise reduction algorithms in tandem on speech quality has to be considered.

5.4 Interaction aspects of automatic level control

Under study.

5.5 Interaction aspects of circuit multiplication equipment

5.5.1 Interaction aspects of circuit multiplication equipment related to speech quality effects

Analyses from subjective tests show that the voice quality of DCME depends basically on three parameters:

- the type of generated comfort noise;
- the total number of hops;
- the bearer load.

In conversational tests and expert listening, subjects were asked to note the characteristics of the eventual impairment (noise, cut, etc), which occurred during the conversation.

The voice degradations, which were noted, are of several types:

- cut during the communication;
- modification of voice timbre;
- variation of voice level;
- variation of comfort noise level.

The parameter which has the most determining influence on the speech quality degradation, is the number of hops, i.e. the number of successive coding/decoding. From 2 hops, the voice timbre seems different, less clear and there are in general some variations of voice level. The quality decreases very quickly with the number of hops. Therefore, it is recommended that tandeming of CME should be prevented. Two potential approaches are discussed with Tandem Avoidance of CME. One is by the control from a switching equipment through signalling interfaces, and the other is internal control between the CME. Procedures for control of Tandem CME Avoidance under the control of a switching equipment are contained in ITU-T Rec. Q.50.1, Amendment 1/Q.761 and Amendment 1/Q.764.

The other influential parameter is the bearer overload, which creates sometimes micro-cuts (freeze-outs). In this situation, the voice is often found distorted and metallic. Voice quality and overall quality are both degraded when the higher load level is applied on the system.

Concerning the comfort noise, it was observed, that the "adaptive" noise level is always preferred to the "fixed" noise: the overall quality of the communication is found better when the inserted noise level is adaptive. When set to "fixed", comfort noise is found disturbing (too high or too low level).

5.5.2 Synchronous reset in CME

In those DCME conforming to ITU-T Recs G.763, G.767 and G.768, limited numbers of encoders and decoders are pooled and assigned to the active speech channels utilizing external VAD/DTX/CNG schemes.

In such DCME, the speech encoders and corresponding decoders are not always connected to each other throughout the call, but only connected while the active speech signal exist on the channels. Especially in the case of DCME operating on multi-destination configuration, the codec pool is shared for the communication to multiple destinations, and the encoder is not always used with a specific decoder.

Because of these circumstances, the internal parameters of an encoder and corresponding decoder are not always the same at the beginning of a new voice spurt after silence elimination, which may result in the extension of convergence time and potential degradation of speech quality.

The Synchronous Reset between the encoder and decoder is the procedure to prevent such potential degradation in decoded speech quality, and it is preferable that the reset of internal parameters to a predetermined state takes place whenever the coder pair gets the new assignment after the silence period (see ITU-T Recs G.763 and G.768). The necessity of Synchronous Reset can be identified by the transition of internal assignment table in the DCME.

External Synchronous Reset is not necessary if silence suppression is supported according to the speech codec used, e.g. Annex B/G.729, or Annex A/G.723.1 and also if comfort noise generation is supported according to the speech codec used, e.g. Appendix II/G.711, Annex B/G.729, or Annex A/G.723.1.

5.6 Interaction aspects of acoustic echo controllers

5.6.1 Scope

The following specifications are the requirements for Acoustic Echo Controller(s) (AECs) which can be installed either in the terminal itself (terminal acoustic echo controller) or in remote places in the network (network acoustic echo controller) to interwork properly with other devices on the network side. They cover the applications for equipment with digital or analogue line interfaces for use in the following areas of telecommunications (denoted by applications):

- teleconferencing;
- loudspeaking (hands-free) telephones;
- videophone terminals;
- mobile and personal applications;
- interworking with speech codecs

There are two cases of interest here: speech coding on the R_{in} path and speech coding on the S_{out} path.

5.6.2 R_{in} path speech coding

5.6.2.1 Bit rate

The obvious item is that the bit rate at the edge of the processing unit including the AEC at R_{in} should match the incoming rate.

5.6.2.2 Bandwidth

The other consideration is that bandwidth of the AEC should, if at all possible, match the incoming bandwidth within a reasonable tolerance.

When activated, the processing in the AEC should maintain the bandwidth requirement which are given in ITU-T Rec. G.712 for telephone band speech and in ITU-T Rec. G.722 for wide-band speech.

If the AEC is not capable of equaling the incoming bandwidth, it should introduce compensating filters.

5.6.2.3 Tandem speech coding effects

If speech is re-encoded during processing within the AEC, the effects of tandeming with acceptable R_{in} speech codings should be considered. As a side note, the frequency shift method of howling control could be considered in this category. Also, any speech activity detection which results in processing of the R_{in} signal before being played out on R_{out} would be considered in this category. It is under study whether d.c. removal should also be in this category: current thinking is that it should not be. Overall, these tandem effects are considered to be less serious than those applying to the S_{in} to S_{out} path (5.6.3.3) since any effect in this section would be localized to the user of the AEC.

5.6.3 S_{out} path speech coding

5.6.3.1 Bit rate

The obvious item is that the bit rate at the edge of the processing unit including the AEC at S_{out} should match the outgoing line rate.

5.6.3.2 Bandwidth

The other consideration is that bandwidth of the AEC should, if at all possible, match the outgoing bandwidth within a reasonable tolerance.

When activated, the processing in the AEC should maintain the bandwidth requirements which are given in ITU-T Rec. G.712 for telephone band speech and in ITU-T Rec. G.722 for wide-band speech.

If the AEC is not capable of equaling the outgoing bandwidth, it should introduce compensating filters.

5.6.3.3 Tandem speech coding effects

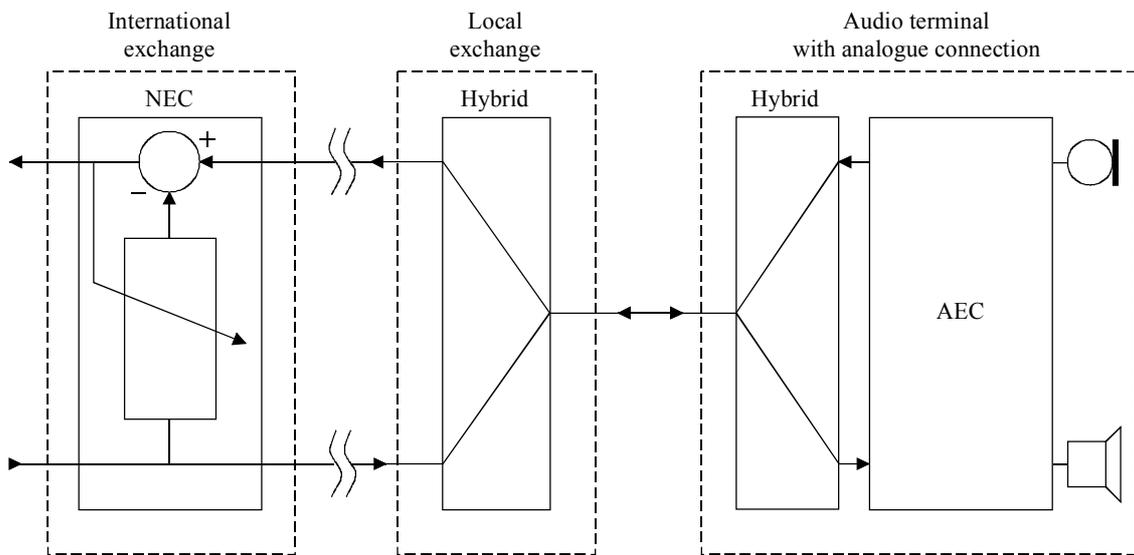
If speech is re-encoded during processing within the AEC, the effects of tandeming with acceptable S_{out} speech codings should be considered. The echo cancelling process itself is a form of speech coding in the sense of this clause and could have implications for the external speech coder on S_{out} . In general, processing which is representable as a linear filter would not pose a problem but processing which is non-linear might pose a problem. As a side note, the frequency shift method of howling control could be considered in this category. Also, any speech activity detection which results in modulating the S_{in} signal before being played out on S_{out} would be considered in this category. It is under study whether d.c. removal should also be in this category: current thinking is that it should not be. These tandem effects are considered to be more serious than the ones applying to the R_{in} to R_{out} path (5.6.2.3) since these effects are observable to the rest of the network and to the (possibly) non-AEC user. It is particularly important that the AEC does not negatively impact the performance of cascaded network equipment.

5.6.4 Interworking of AECs with network echo cancellers

Acoustic echo control is becoming an important issue due to the increase in hands-free telephone sets. Although there is some commonality between issues encountered for acoustic echo control and network echo cancellation, there are also many differences. The issues of level points, natural echo path loss (or gain), degree of loss-switching, as well as level and/or type of singing (howling) protection are all important to a study of acoustic echo cancellers. Hands-free telephones are responsible for controlling their own acoustic echo. If the network echo canceller is to reduce the acoustic echo due to terminal equipment, it must be noted that the processing window should be long enough to cover the round trip end-to-end delay between the canceller and the room in addition to the acoustical echo paths in the room itself. See ITU-T Rec. P.340 for more information on acoustical echo paths. In addition, it is important that an acoustic echo controller is capable of working in harmony with a network-based electric echo canceller.

Analogue hands-free telephones which allow real double talk may produce an acoustic echo signal. This echo signal is added to the electrical echo signal coming from the 4-wire/2-wire connection of the hybrid termination and cannot be reduced sufficiently if it is decorrelated. Analogue hands-free telephones including dynamic compression devices may amplify the ambient room noise during speech pauses and transfer it to the echo canceller input in the send path. Due to the signal dependent switching of hands-free telephones, the level of a double talk signal may be reduced at the echo canceller input in the send path. This may lead to increased clipping by the non-linear processor because the level of this double talk signal may fall below the threshold level.

The most important item, from the point of view of network echo cancellers, is that there be no signal (or signal component) on S_{out} which appears to be correlated with R_{in} (within the constraints of the tail delay of the network echo canceller) unless it is during an instance of obvious double-talk. For purposes of discussion, obvious double-talk is defined as having speech power at S_{out} greater than the power at R_{in} . In fact, this constraint is perhaps a bit generous since one might (incorrectly) read it to permit non-linear distortions in the echo path from R_{in} to S_{out} . A safer (but perhaps more strenuous than is required) condition would be to require that after initial convergence of the AEC the level at S_{out} be more than at least specified in ITU-T Rec. P.342, including non-linear processing, from the level at R_{in} unless double-talk is occurring. This latter condition protects the network echo canceller since there is no acoustic echo on which to adapt (see Figure 10).



G.161_F10

Figure 10/G.161 – Example of network configuration where disturbing interaction can occur between acoustic echo controllers and network echo cancellers

5.6.5 Interworking of AECs with CME

The constraints mentioned above for speech coding and network echo cancellers should largely satisfy the needs of CME equipment. One additional factor that is of interest is background noise effects. The AEC must keep the background noise level on S_{out} as constant and as low as possible. If the AEC includes a non-linear device like a center clipper or if it introduces a large amount of loss on the send path when there is speech on the receive side only, then appropriate comfort noise should be inserted by the AEC to avoid false activation of the CME speech detectors on modulated background noise which can result from non-linear processing or loss insertion.

5.7 Interaction aspects of voice gateways

5.7.1 Level offset

Under study.

5.7.2 Background noise

Under study.

5.7.3 Tandem signal coding

Under study.

5.7.4 Tandeming of voice gateways

Under study.

5.7.5 Low bit rate coding and other non-linear effects

Under study.

5.7.6 Voiceband data signals, signalling tones, facsimile traffic, call-processing tones, speech

Under study.

5.7.7 Interaction aspects of 3rd generation wireless networks related to speech quality effects

Under study.

Appendix I

Tandem-Free Operation (TFO)

I.1 Introduction

Speech coding is used extensively in telecommunication networks to reduce transmission bandwidth and increase capacity. High quality speech codecs operating at low to medium rates (4 to 16 kbit/s) have been a primary factor in making packet voice networks and, in particular, digital wireless systems feasible. Some popular low bit rate speech codecs developed by ITU-T are G.729 and G.723.1.

Despite the high quality of such codecs, they are lossy in the sense that the reconstruction of the speech signal is not perfect and the synthesized signal does not completely match the original speech in quality. Consequently, tandeming of codecs lead to further distortion of the processed signal. Depending on the quality/bit-rate of the codecs as well as the characteristics of the processed signal, the added degradation due to tandem codecs may be significant. Music and noisy speech signals are examples of cases where the additional degradation due to back-to-back codecs can be significant. In general, the lower the bit rate of a speech codec, the higher will be the degradation from tandeming. Tandeming codecs has been one of the technological hurdles in the way of the standardization of low bit-rate speech codecs.

The problem of codec tandems is often experienced in digital wireless telephony, where mobile-to-mobile calls involve two back-to-back codecs processing the signal in each direction. Figure I.1 shows such a situation, where the speech signal is assumed flowing from Mobile 1 to Mobile 2 for ease of illustration. Mobile 1 encodes the source speech signal and transmits the encoded speech data to Base Station 1. Base Station 1 decodes the speech data from Mobile 1 and produces $s(n)$. Because the call connection is mobile-to-mobile, Base Station 2 will encode the decoded speech signal $s(n)$ again and transmit the encoded data to Mobile 2. As a result, the signal from Mobile 1 to Mobile 2 is encoded twice and the speech quality will be degraded more than in single stage coding. Since the objective of digital Wireless telephony is to deliver service with quality comparable to that of landline telephony, it has been necessary to develop a remedy.

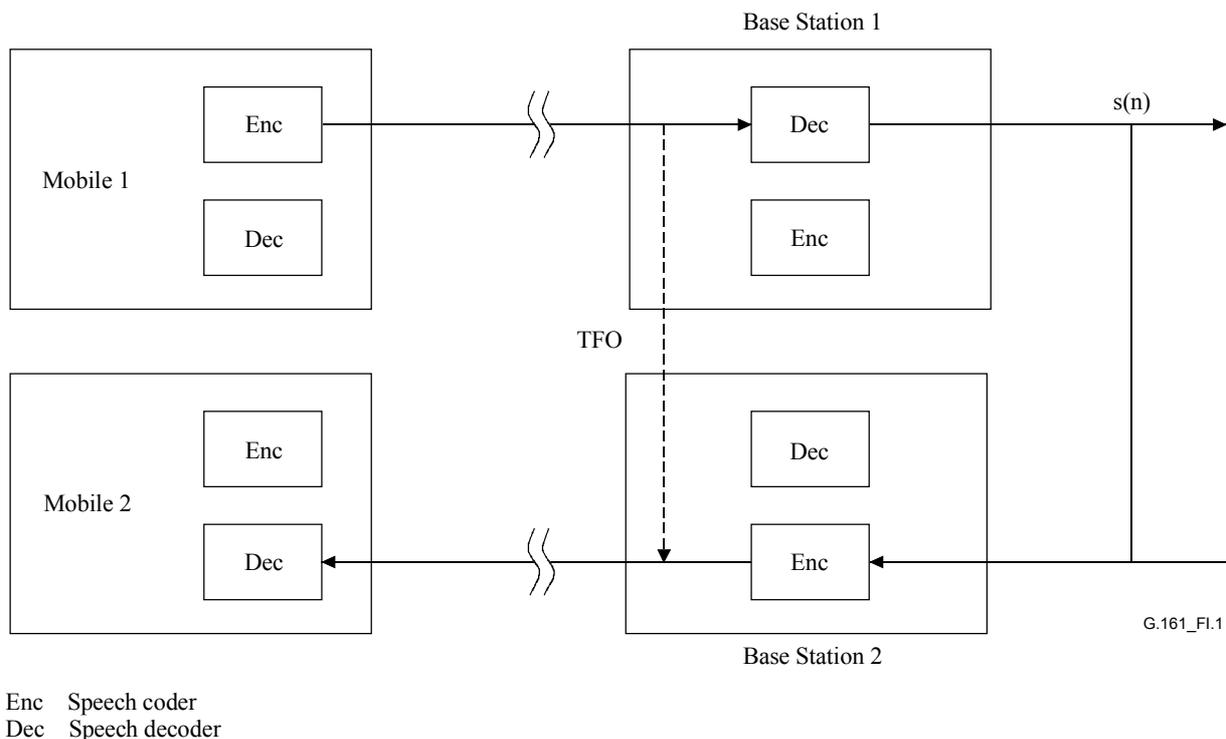


Figure I.1/G.161 – Tandem of speech codecs in a simple mobile-to-mobile-connection

I.2 Essence of the current standards

Generally speaking, TFO is implemented through an in-band signalling protocol that is designed to detect connections that flow through tandem codecs. Once such connections are identified and after it is established that the codecs are interoperable, the processing flow is altered to remove the extra coding/decoding stages in the base stations. In addition, in the case of terminal devices that support multiple codecs, provisions are put in place to allow negotiation towards the highest-quality codec supported by the two terminals.

The recent development of TFO standards has attempted to ensure tandem-free operation even across systems of different access technologies, e.g. GSM/TDMA, as long as the speech codecs on the two ends are interoperable.

Different TFO standards have been established over the years for various wireless access techniques. All of these TFO standards were based on the same approach, but adapted for use with the different speech codecs in different wireless access technologies. Existing TFO standards are [1]-[3]. The content of [2] and [3] are identical.

While the TFO standards were originally designed for wireless services, they were also intended to provide interoperability with wireline packet voice networks such as VoIP. The TFO standards can be easily applied to any packetized voice transmission. The TFO protocol is designed to work without requiring out-of-band signaling or intervention of higher layers of protocol allowing for simple implementation. An ultimate objective in the development of TFO is to have a universal standard that is interoperable with the existing standards, in order to provide for seamless operation across various networks and services.

Bibliography

- [1] TIA/EIA-895, *Tandem Free Operation*.
- [2] GSM 08.62, *Inband Tandem Free Operation (TFO) of Speech Codecs; Service Description; Stage 3*.
- [3] ETSI 3G TS 28.062, *Inband Tandem Free Operation (TFO) of Speech Codecs; Stage 3 – Service Description*.

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