White Paper on Sage's Echo Sounder and Echo Generator

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1 Introduction

Sage Instruments Echo Sounder measures echoes in a telephone network. It provides complete information on multiple echoes in terms of echo level and echo delay. Echo Sounder also provides a reliable way of measuring round-trip delay, round-trip attenuation, and one-way delay and one-way attenuation.

Sage Instruments Echo Generator generates multiple echoes with programmable echo delay and echo level. When combined with Echo Sounder, Echo Generator facilitates the G.168-type [1] of echo canceller test and the measurements of round-trip delay and round-trip attenuation. When working alone, Echo Generator serves as a simple remotely-programmable loop-back.

The three most important parameters that affect voice quality in a phone network are voice clarity, echoes, and delay. Voice clarity depends on level, voice compression, noise, packet loss, jitter, and voice clipping etc. Along with Sage Instruments PVIT [2] (Packet-Voice-Impairments-Test that measures packet loss, jitter and voice clipping) and PSQM [3] (Perceptual-Speech-Quality-Measure that measures Mean-Opinion-Score (MOS) due to voice compression, voice level loss/gain and round-trip delay), Sage Instruments Echo Sounder and Echo Generator provide a complete set of test tools for characterizing the quality-of-service (QoS) of a telephone network.

2 Why Measure Echoes?

Echo is one of the most important factors that affect voice quality. The annoyance of echo is a common knowledge to every caller that bears no further explanation. Technically speaking, the annoyance of echo depends on both echo level and echo delay. Echo Sounder measures exactly these two parameters. The echo tolerance curve shown in Figure 1 graphically depicts the acceptable combination of echo level and echo delay. For example, based on Figure 1, an echo at -25 dB with less than 10 ms delay is probably not so objectionable to most people. It only adds some reverberant side-tones. But an echo of -30 dB at 100 ms delay will be very objectionable to almost every caller.

Echo will continue to be an inherent problem for telephone network as long as the analog 2-wire local loop exists. The primary source of echo is the impedance mismatch at the hybrid that links a 2-wire analog loop to a 4-wire trunk. Occasionally, acoustic feedback of certain phones also causes noticeable echos. No matter how well the hybrid is designed, there is no way to completely balance the 2-wire and 4-wire connection, because the 2-wire loop impedance (looking down from the 4-wire side) is unpredictable. The impedance varies depending on how long the loop is, how many phones

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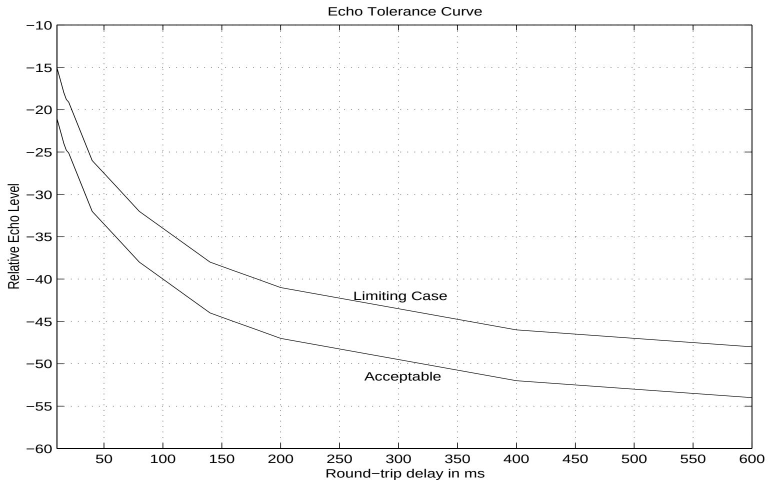

Figure 1: Echo tolerance curve adapted from ITU-T G.131 [4]. Vertical axis is the echo level in dB, and horizontal axis is the echo delay (round-trip) in ms. Any combination of echo level and delay must fall below the limiting case in order to meet the G.131 requirement.

and what kind of phones are connected, and whether or not there are load coils, etc. The perceived absence of echos during most phone conversations are largely due to the use of echo cancellers in the modern digital network [1].

In a VoIP (or more generally, in VoP, voice-over-packet) network, the echo problem is further exacerbated, not because the packet network creates additional echos (it may, of course), but because the extra delay introduced by the packet network makes the echo more annoying (see Figure 1). Furthermore, the long delay of packet network also makes the design and deployment of echo cancellers more challenging, as the long delay entails longer cancellation tail length.

3 Echo Sounder

3.1 Principles of Echo Sounder

Echo Sounder employs a Code-Domain-Reflectometry (CDR) technique to detect multiple echoes in a telephone network. Theoretical aspects of CDR and its superiority over conventional TDR (Time-Domain-Reflectometry) and FDR (Frequency-Domain-Reflectometry) are reported in [5]. Simply speaking, a CDR (on which Echo Sounder is based) achieves the TDR-equivalent reflection trace, but uses low peak level voice-like complex signal that is more suitable (than impulse or pulse used in a TDR, or tone(s) used in an FDR, for example) for a telephone network. More specifically, Echo Sounder transmits a carrier-modulated direct-sequence-spread-spectrum signal. The signal PSD (Power-Spectral-Density) is similar to that of an ERL (Echo-Return-Loss) filter. The echoes returned from the phone network are then measured by Echo Sounder after the demodulation and complex cross-correlation operations. With unique code sequence and proprietary bias-removing technique, Echo Sounder can reliably detect an echo with level even below -60 dB. Furthermore, the voice-like probing signal can go through numerous lossy voice processing devices (low-bit-rate vocoders, for example) without much degradation. The large processing gain associated with a CDR also enables Echo Sounder to have strong anti-interference capability. Theoretically, Echo Sounder can even be used for in-service testing (probing for echoes while the real conversation is on).

3.2 Operating Echo Sounder

On Sage's 93x, Echo Sounder is on option menu 28. Once in this menu, one will see two selections: "MEASURE" and "SETUP". If "MEASURE" is pressed, the test will immediately start. If "SETUP" is pressed, you will be guided to the selections of signal level and echo canceller disabling tone.

Echo Sounder is a single-ended manual test. A typical test configuration is shown in Figure 2.

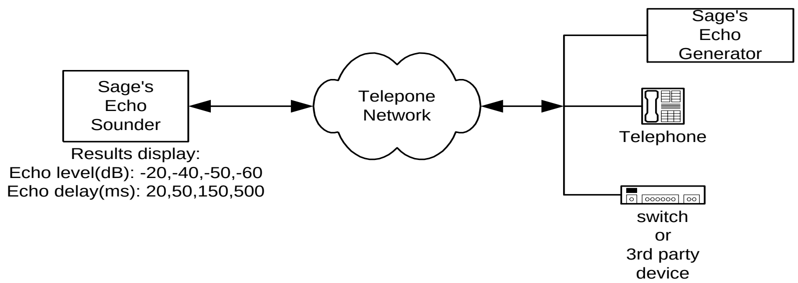

Figure 2: A typical test configuration for Echo Sounder. Typically, Echo Sounder originates or terminates a call. The other called or calling terminal can either be a Sage Echo Generator, a regular phone or a 3rd party device. Once a call is established, Echo Sounder measurement can then be started.

As shown in Figure 2, Echo Sounder is a single-ended test because both the transmitter and receiver are within a single test unit due to the nature of echo probing. The other end can be any "dummy" device as long as it can answer or originate a call. Once a call is established, Echo Sounder can then be started. Echo Sounder will continuously probe echoes and update results once every 5 to 7 seconds, until one stops it.

During the Echo Sounder test, one will hear the following signal sequence:

$$\underbrace{\text{EC Disabler Tone}}_{\text{1.8s,Optional}}, \underbrace{\text{Carrier-Modulated DSSS Signal}}_{\text{2s Actual Test Signal}}, \underbrace{\text{“Comfort tone”}}_{\text{3s 750Hz tone}}$$

Detailed explanations of the signal sequence are as follows:

The EC Disabler Tone: This is the 2100Hz, -12 dBm tone with phase reversal every 450 ms. Total duration of this tone is 1800 (4×450) ms. It has exactly 3 phase reversals. At the phase reversal point, the phase jump is guaranteed to be greater than 170 deg. The purpose of this tone is to disable the echo cancellers under test. This tone is only sent upon user request. At default mode, this tone is not sent (i.e., leave the echo canceller in enabled mode).

DSSS Signal: This is the actual echo-probing signal. It is a carrier-modulated and pulse-shaped Direct-Sequence-Spread-Spectrum (DSSS) signal. This noise-like signal has a center frequency of 1500 Hz, effective bandwidth of 1000Hz and peak-to-RMS ratio of 5 dB. Its level can be adjusted from 0 dBm down to -30dBm. The default level is -10 dBm. With 4-wire interface (analog or T1/E1), one should adjust the signal power to a higher level (to 0 dBm, for example) if the echo level falls below -35 dB. If the "echo" level is too high (above +10dB), the signal power level should be adjusted lower (to -20 dBm, for example) to avoid signal clipping. With 2-wire interface, there is no apparent performance gain by adjusting the signal power level. It is recommended that the signal power level be fixed at default -10 dBm.

Comfort Tone: The CDR technique used by Echo Sounder requires intensive computation for the complex cross-correlation operation. Sage's Echo Sounder first captures the echo signal, then performs "post-processing" to finish the cross-correlation computation. During this post-processing period (about 3 seconds), a comfort tone is continuously played to let the user know that the instrument is processing the data, and results will soon be available. This comfort signal is a 750Hz tone with level tied to the DSSS signal level.

3.3 Results presentation

Internally, after intensive computation, the DSP software will obtain a TDR-equivalent reflection trace as shown in Figure 3. The echo level and delay information is clearly shown in the graph. But the reflection trace shown in Figure 3 is not graphically presented to the user.

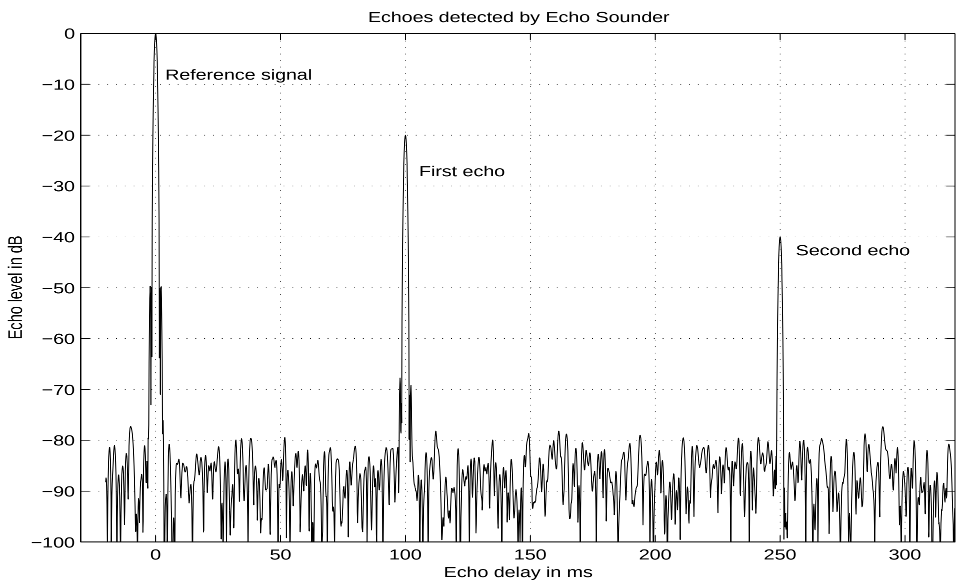

Figure 3: A simulated echo reflection trace obtained by Echo Sounder. Such reflection trace is obtained after the demodulation and cross-correlation operations. Two echoes are present, the first one at 100 ms with level of -20 dB; the second one at 250 ms with level of -40 dB. In this case, the Echo Sounder transmitting signal (reference signal) level is -10 dBm. 30 dBrn (-60 dBm) Gaussian noise is added into the simulation to make the reflection trace look "real" and "noisy". Otherwise, the background will be constant and way below -130 dB, instead of the -80 dB noise background as shown here.

Sage's test instrument internally sorts out up to 4 most significant echoes, and then numerically display the echo level and echo delay. In this case, the following results will be reported:

Echo Level: -20 dB, -40 dB; Echo Delay: 100 ms, 250 ms

The echoes are displayed in the descending order of level. Although the internal reflection trace has the capability of showing hundreds of echoes, only up to 4 echoes are displayed to users.

In reference to Figure 3, echo delay is defined as the delay corresponding to the reflection peak relative to the reference signal peak. Echo level is computed by integrating (summing) the total energy within 3 ms centered at the peak index (to account for dispersive echoes) and normalized by the reference signal energy (integrated within the same 3 ms window). For telephony application, only echo level (energy or power level) and echo delay are of interest. The echo phase (or polarity) and echo dispersion are not reported, although theoretically, the information are already available inside the DSP algorithm.

Also notice that the measured echo level is the echo source level minus the round-trip insertion loss at 1500Hz. For example, assume the echo at a "remote" hybrid under test generates an echo of -20 dB (or echo return loss of 20 dB), and the total round-trip attenuation from the hybrid to the test terminal (where Echo Sounder is connected) is 15 dB (at 1500Hz), then the echo level measured by Echo Sounder will be -35 dB. Likewise, the echo delay is the round-trip delay from the test terminal to hybrid and back to the test terminal. Figure 4 further graphically illustrates the echo level and echo delay interpretations.

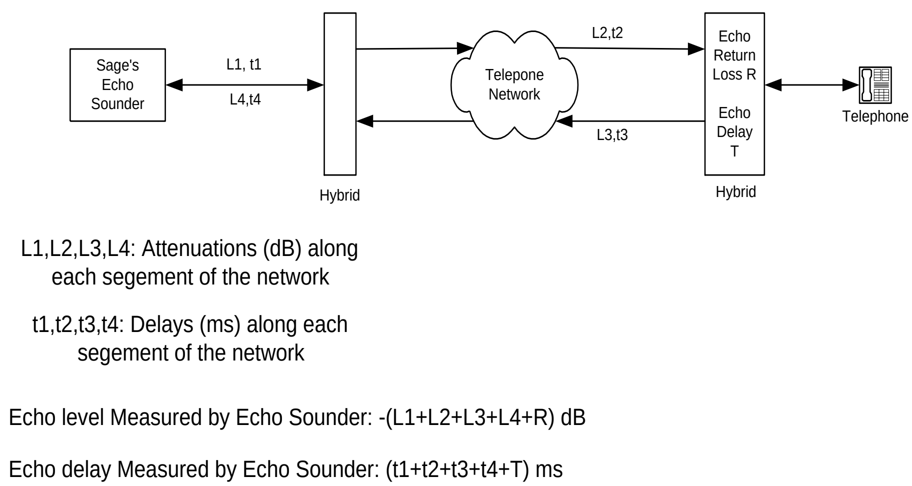

Figure 4: Interpretations of the echo level and echo delay measured by Echo Sounder.

3.4 Performance specifications

3.4.1 Measurement ranges and precisions

The measurement ranges and precisions of Echo Sounder are shown in Table 1. The echo delay ranges differ slightly with different interfaces.

Connection Interface	Echo Level Range/Precision	Echo Delay Range/Precision
2-Wire Analog	[-60,20]±1 dB	[7,900]±1ms
4-Wire Analog	[-60,20]±1 dB	[0,900]±1ms
T1/E1	[-60,20]±1 dB	[0,900]±1ms

Table 1: Echo Sounder measurement ranges and precisions

Notice that the Echo Sounder measurement ranges in Table 1 completely cover the whole range of interest shown in Figure 1. More explanations of the specifications are as follows:

Echo level: The minimum detectable echo level is -60 dB. Theoretically, there is no upper limit on echo level. But the hardware dynamic range will limit the maximum "echo" level to +20 dB. Technically speaking, an "echo" with positive gain (> 0 dB) is not an echo any more. But Echo Sounder can still detect such echoes. Echoes with level less than -60 dB are not reported, although the internal DSP algorithm may have detected them.

The echo level measurement accuracy is guaranteed to be within ±1 dB, although at echo level above -35 dB, the actual performance is much better.

Echo delay: On a 2-wire connection, the minimum detectable echo delay is 7 ms. This means, an echo with delay less than 7 ms is not reported. Practically, as shown in Figure 1, an echo with delay less than 10 ms is not an audible "echo". It only adds to the side-tone.

But on a 4-wire connection, Echo Sounder can measure an echo with delay as short as 0 ms. This allows Echo Sounder to be used to characterize the echo path seen by a network echo canceller. More details on this application are explained later.

The maximum detectable echo delay is 900 ms. For practical telephony applications, this delay range is wide enough. For echo with delay longer than 900 ms, the measurement accuracy will not be guaranteed. The echoes may or may not be measured, and results may or may not be accurate.

The delay measurement accuracy is guaranteed to be within ±1 ms, although for analog interface (ironically), the actual performance is much better.

3.4.2 Resolution on multiple echoes

When multiple echoes are present, the following two criteria will determine whether not the echoes will be reported:

Differential echo level requirement: The level difference between the primary echo and the secondary and tertiary echoes must be less than 40 dB for the secondary and tertiary echoes to be reported. For example, if 3 echoes are present, each with level of -10 dB, -30 dB and -40 dB, then all these 3 echoes will be reported. But if the echo levels are -10 dB, -30 dB and -55 dB, then only the first two echoes will be reported. But the primary echo (the strongest one) will always be reported as long as it is above -60 dB. The purpose of this criterion is to avoid reporting potential "phantom" echo's echoes caused by slightest impedance mismatch between the test instrument and the device under test, or caused by the correlative PCM quantization noise.

Echo spacing requirement: Two adjacent echoes must be separated at least 7 ms apart for both of them to be reported. If the echoes are spaced within 7 ms from each other, then only the dominant one is reported.

Maximum number of echoes: The maximum number of echoes that will be reported is 4, although the internal algorithm can theoretically detect hundreds of echoes.

3.4.3 Performance over impaired network

Echo Sounder is designed to work through highly-impaired voice network. But of course, the impairments will inevitably affect the measurement sensitivities and accuracies:

Attenuation distortion: Attenuation distortion does not affect Echo Sounder's measurement *per ce*. But keep in mind that the relative echo level measured by Echo Sounder includes the round-trip attenuation (loss). If there is too much attenuation, the effective echo level measured by Echo Sounder may be too low to be reported (below -60 dB).

Additive noise and interference signal: A beauty of the CDR technique used by Echo Sounder is that it can measure echoes even below the noise floor (i.e, working under negative SNR situation) due to its large processing gain. Simulation results with additive Gaussian noise indicate that, as long as the additive noise signal is less than 3 dB above the absolute echo level (i.e., SNR>-3 dB), the Echo Sounder will perform correctly. For example, assume the transmitted signal level is 0 dBm, and the echo level is -10 dB (so that the absolute echo signal level is -10 dBm) then Echo Sounder can tolerate a noise as high as -7 dBm (83 dBrn). If the interference signal is a narrow band signal outside the 750-2250Hz range, it will not have any effect. But if the interference signal is within the 750-2250Hz range, Echo Sounder can tolerate an interference tone level that is equal to the absolute echo level.

Delay: Echo Sounder's performance is in-sensitive to delay as long as the delay does not exceed 900 ms.

Vocoder compression: In wireless telephony and VoIP applications, the use of low-bit-rate vocoders are common. Echo Sounder is designed with vocoder compression in mind. It can work through all low-bit-rate (>5kbps) vocoders reliably, but the level sensitivity will of course be affected. Simulations through VSELP vocoder (a very sloppy vocoder used in TDMA phone) shows that, for every path through the vocoder, the low-level threshold (the correlated noise floor shown in Figure 3) will be raised by about 10 dB. That is to say, without Vocoder, Echo Sounder can detect an echo level as low as -60 dB. If one path has a vocoder, the lowest detectable echo level will be raised to -50 dB. If both paths have vocoders, then the lowest detectable echo level will be around -40 dB. As long as the echo is detected, the level and delay accuracies are always guaranteed.

Packet loss: Echo Sounder uses a long sequence (1 second) of test signal to extract out the echo information. It is very robust against packet loss. Theoretically, it can tolerate a packet loss as high as 50%. Of course, packet loss will affect the level measurement accuracy (because part of the echo signal is gone or replaced). But the echo will be detected (if there is any), and the echo delay will stay accurate no matter how bad the packet loss is.

Delay variations/Jitter/Packet slip: In a VoIP environment where a jitter buffer is used, the voice band signal may experience a sudden delay variation when the jitter buffer suddenly adjusts its buffer size. This normally only happens in silence period, therefore, it should never affect Echo Sounder. But if Echo Sounder is performed repeatedly (with silence gap in between for jitter), the measured echo delay may vary from time to time, depending on whether or not jitter has occurred. If jitter occurs in the middle of the active test signal, then its effect will be similar to packet loss. The level accuracy will be affected, and the echo delay may or may not reflect the delay variation, depending on which portion of the signal is jittered. But the echo will still be detected, if there is any.

Voice clipping: Leading-edge voice clipping caused by VAD (Voice-Activity-Detector for silence suppression) has no effect on Echo Sounder's performance.

4 Echo Generator

4.1 What Is Echo Generator?

As its name suggests, Echo Generator generates echoes. More specifically, it generates one or two echoes with precisely controllable levels and delays.

Echo Generator by itself does not perform any measurements. It is only a facilitator that facilitates various measurements at the other end. For example, Echo Generator can facilitate any measurement that requires remote loop back or any test equipment that has to do with echo probing, echo cancellation, return loss, VSWR (Voltage-Standing-Wave-Ratio), round-trip delay, and round-trip insertion loss etc.

4.2 Principles of Echo Generator

From signal processing point of view, what an Echo Generator does is to convolve the incoming signal $x(t)$ with an echo impulse response $h(t)$:

$$y(t) = x(t) \otimes h(t) = \int x(\tau)h(t-\tau)d\tau$$

and then "echoes" back signal $y(t)$. $y(t)$ is now an echo of the incident signal $x(t)$.

So, the determining factor of an echo is the echo impulse response $h(t)$. A hypothetical echo impulse response is shown in Figure 5. As shown in Figure 5, there are three key attributes

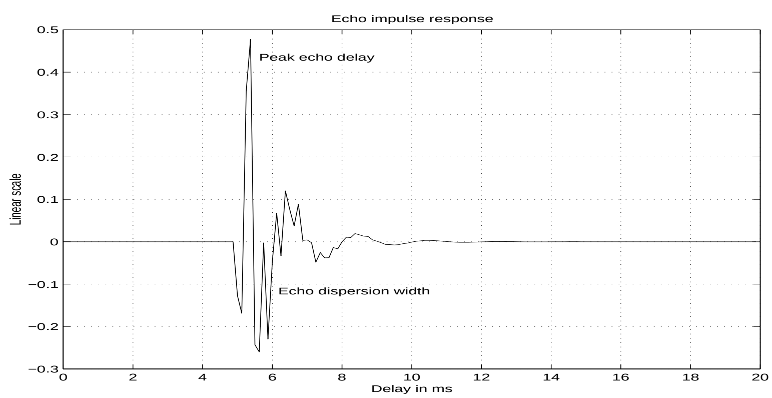

Figure 5: A hypothetical echo impulse response $h(t)$.

associated with the echo impulse response:

1. Peak echo delay: the delay of the peak echo energy. In Figure 5, the peak echo delay is 5.5 ms. This peak echo delay is the echo delay measured by the Echo Sounder.

2. Echo dispersion width: the active period of the echo impulse response is dispersed across a period from 5 ms to 12 ms. So the dispersion width is 7 ms.

3. Total echo energy: the total echo energy is that integrated across the whole 7 ms dispersion period. The integrated energy corresponds to the echo level measured by the Echo Sounder.

By varying $h(t)$, Echo Generator can theoretically generate all kinds of echoes, dispersive or non-dispersive (time-domain characteristics), and flat or non-flat (frequency-domain characteristics).

Circuit Type	Level Range/Accuracy	Delay Range/Accuracy	Frequency Range
Analog 2-wire	[-40,9]±0.5 dB	[17,600]±0.5 ms	300 to 3300 Hz
Analog 4-wire	[-60,9]±0.2 dB	[17,600]±0.5 ms	300 to 3300 Hz
Digital T1/E1	[-60,9]±0.2 dB	[12,600]±1 ms	20 to 3900 Hz

Table 2: Echo Generator operation range and accuracy specifications

But how to determine $h(t)$ for practical implementation? There are literally infinite number of choices for $h(t)$.

Ideally, the user should determine the echo impulse response $h(n)$ ($h(t)$ sampled at 8000Hz) he/she wants, and then enter those information into the Echo Generator. But this can quickly become impractical if a user has to enter in a sequence of tens or hundreds of floating-point numbers.

Another solution is to pre-tabulate a set of "standard" echo impulse responses. But, so far, we have not found such standard echo impulse response published by any standard organizations.

So, this leaves us to take the simplest approach. Sage's Echo Generator uses an ideal $k\delta(t-t_0)$ function to generate an echo with delay t_0 and level of $20 \times \log 10(|k|)$ dB. More specifically, Sage's Echo Generator generates echoes according to the following equation:

$$y(t) = s_1 x(t-t_1) + s_2 x(t-t_2)$$

where t_1 and t_2 are the echo delays, and s_1 and s_2 control the echo levels:

$$EchoLevel_{dB} = 20 \times \log 10(|s_{1,2})|)$$

With PCM digital interface, the echoes thus generated are pure non-dispersive and flat echoes. But with an analog interface, the analog hardware will introduce certain amount of dispersion and frequency weighting on the echoes.

Notice that, with 2-wire interface, the Echo Generator contains an internal software hybrid (using echo cancellation technique) to separate the incoming and outgoing signals co-existing on a single pair of wire.

4.3 Performance specifications

The operation ranges and accuracies of Echo Generator are shown in Table 2: More explanations of the specifications are as follows:

Number of echoes: Echo Generator can generate 0, 1 or 2 echoes.

Echo level: With 4-wire interface (analog or digital T1/E1), the minimum allowable echo level is -60 dB, and the maximum allowable echo level is +9 dB. With 2-wire interface, the minimum allowable echo level is -40 dB. This is because, with 2-wire interface, the Echo Generator must use a software hybrid to separate the incoming and outgoing signals co-existing on a single pair of wire. This software hybrid only has finite separation depth (up to 45 dB). Therefore, this limits the lowest allowable echo level to -40 dB.

Echo delay: the minimum allowable echo delay is dictated by the instrument's inherent hardware and software delay. For analog interface, the minimum echo delay is 17 ms. For T1/E1 interface, the minimum delay is 12 ms. Theoretically, there is no upper limit on the echo delay. But 600 ms is long enough for telephony applications.

Frequency range: the frequency range means that, for any incoming signal within the specified frequency band, the signal will be echoed back with specified level and delay. But for signals outside the specified frequency band, the performance (especially echo level) is not guaranteed.

4.4 Operating the Echo Generator

On Sage's 93x, Echo Generator is on Option Menus 85 and 84.

4.4.1 In responder mode, Option Menu 85

When in Option Menu 85, Echo Generator works as a responder. It waits for call. After answering the call, it starts sending the following signal sequence:

$$\underbrace{\text{2225Hz TPT Tone}}_{\text{2s}}, \underbrace{\text{Noise-like training signal}}_{\text{1.5s, only for 2-wire}}$$

After sending the above signal, Echo Generator now enters the actual echo-generation mode with the following two default echoes:

1st echo: level: -3 dB, delay: 60 ms;

2nd echo: level: -6 dB, delay: 250 ms.

4.4.2 Remotely reprogram echo parameters via DTMF digits

At any time, one can remotely (from a phone or Sage 93x) reprogram the echo parameters via simple DTMF digits. To do this, one first presses the "⋆" key (digit), then waits for the 480 ms long prompt tones. After the prompt tones, one can start entering the numeric digits, followed by, in the end, a "#" key. If all the digits entered are valid, you'll hear a 480ms confirmation tones. The sequence of DTMF digits and interactive tones are shown below:

1. No echo:

$$D_\star, \ldots, \text{Prompt tones}, \ldots, D_\#, \ldots, \text{Confirm tones}, \ldots$$

2. One echo:

$$D_\star, \ldots, \text{Prompt tones}, \ldots, \underbrace{D_1, D_2}_{level}, \underbrace{D_3, D_4, D_5}_{delay}, D_\#, \ldots, \text{Confirm tones}, \ldots$$

3. Two echoes:

$$D_\star, \ldots, \text{Prompt tones}, \ldots, \underbrace{D_1, D_2}_{level1}, \underbrace{D_3, D_4, D_5}_{delay1}, \underbrace{D_6, D_7}_{level2}, \underbrace{D_8, D_9, D_{10}}_{delay2}, D_\#, \ldots, \text{Confirm tones}, \ldots$$

On the above sequences, D_x designates a DTMF digit that needs to be entered. More specifically, $D_\star$ designates the "⋆" digit; $D_\#$ designates the "#" digit, and $D_n, n = 1, 2, \ldots, 10$ designates any one of the 10 numeric digits (from 0 to 9 on the keypad). The prompt and confirm tones will be explained later.

4.4.3 Echo parameter DTMF-digits encoding scheme

In reference to the digit sequence shown above, each echo level parameter is encoded with 2 digits and each echo delay parameter is encoded with 3 digits. Choose the second sequence as an example, the level is encoded according to the following formula:

$$EchoLevel_{dB} = \begin{cases} -(D_1 \times 10 + D2), & \text{if } D_1 < 7 \\ D2, & \text{if } D_1 = 9 \end{cases}$$

and delay is encoded as:

$$Delay_{ms} = D_3 \times 100 + D_4 \times 10 + D_5$$

For example, if one wants to set an echo with level of -15 dB and delay of 164 ms, then the numeric digits (discounting the "⋆" and "#" digits) need to be entered are: "1,5,1,6,4". If one wants to set an "echo" with level of 4 dB and delay of 35 ms, the digit sequence should be: "9,4,0,3,5". If one wants to set two echoes with levels of 5 and -9 dB and delays of 64 and 128 ms, the digit sequence should be: "9,5,0,6,4,0,9,1,2,8". If one wants no echoes, then do not enter any numeric digits.

In reference to the operation ranges specified in Table 2 and in accordance with the encoding schemes outlined here, the following restrictions on the numeric digits apply:

1. The total number of numeric DTMF digits entered between the "⋆" and "#" keys must be either 0 (no echo), 5 (for single echo) or 10 (for dual echoes). If the termination "#" key is entered either prematurely (before 5 or 10 numeric digits are collected) or too late, an alerting tone pulses will be sent out by the Echo Generator.

2. If the entered digits represent a level or delay that falls beyond the specified ranges in Table 2, the entered digits will be deemed as invalid and the alerting tones will be heard.

3. If a non-numeric digit is mistakenly entered, it will be ignored and the alerting tone pulses will be heard.

4. One can correct or restart a new session of numeric digits any time by pressing the "⋆" digit, and waiting for the prompt tones. After terminating the digit sequence with the "#" key, one must hear the confirmation tones to make sure the settings are correctly placed. Otherwise, restart the sequence by pressing the "⋆" key again.

5. If a user requests two echoes with the same delay, the commands will still be accepted, but the result will be just a single echo with coherent in-phase addition of the two echoes. For example, if one requests two echoes with levels of -10 dB and -15 dB, and delays of 100 ms and 100 ms, then the actual echo generated by Echo Generator will be a single echo of $20 \times \log 10(10^{-10/20} + 10^{-15/20}) = -6.1\text{dB}$ and delay of 100 ms.

4.4.4 Various interactive tones

When remotely programming the Echo Generator, one will hear the following tones:

Prompt tones: this is a frequency-hopped 480 ms long, -6 dBm tones. It is called "prompt tones" because its role is to prompt the user to start entering the DTMF numeric digits. This "prompt tones" will be heard when one enters the "⋆" digit and the digit has been successfully received by the Echo Generator. After hearing this prompt tones, the Echo Generator suspends its echo generating functions, and goes into a DTMF digit receiving mode until all the digits are received and confirmed. The prompt tones consists of a sequence of 3 tones, each with frequency of 400 Hz, 800 Hz and 1200 Hz, and each individual tone has a level of -6 dBm and lasts 160 ms. When listening to it, the pitch will vary from low to high.

Confirmation tones: this is also a frequency-hopped 480 ms long, -6 dBm tones. It is called "confirmation tones" because its role is to confirm that all the digits have been successfully received and validated, and the Echo Generator now goes into the echo generation mode. This "confirmation tones" will be heard when one has finished entering the numeric DTMF digits and "#" digit. The confirmation tones is a mirror image of the prompt tones. It consists of a sequence of 3 tones, each with frequency of 1200 Hz, 800 Hz and 400 Hz, and each individual tone has a level of -6 dBm and lasts 160 ms. When listening to it, the pitch will vary from high to low.

Alert signal: this is a sequence of 3 tone pulses. Each pulse has ON-duration of 80 ms and OFF-duration of 80 ms, so the total duration of the whole sequence is 480 ms. The ON-period level is -6 dBm, and the frequency is 2225Hz. The tone pulses is deliberately designed to sound "annoying", because its goal is to alert the user that something is wrong. One will hear the alert signal under the following circumstances:

1. The circuit has over -30 dBm interfering signals or noise during the initial training period when in 2-wire mode. The alert signal will be continuously played until measures are taken to quiet down the circuit, and the training will then proceed.
2. In DTMF digit receiving mode (after hearing the prompt tones), whenever an invalid DTMF digit is entered, the alert signal will be played once, and the digit will be discarded.
3. When the terminating "#" key is entered prematurely (less than 5 or 10 numeric digits are received), the alert signal will be played once and the "#" key is ignored. If the "#" key is entered too late (meaning more than 10 numeric digits have been entered), the alert signal will be played every time an extra digit is entered. To correct the situation, simply enter "#" key to end the session, or enter "⋆" key to restart a new session.

4.4.5 Echo Generator manual mode, Option Menu 84

Echo Generator can also work in manual mode. Once a call is "manually" established, the echo delay and echo level parameters can be directly controlled through the user interface. The user interface is quite self-evident. So no further details are given here.

Even in manual mode, the Echo Generator can still accept remote DTMF digits command to reprogram the echo parameters.

5 Application Examples

Sage's Echo Sounder and Echo Generator can be used in as many ways as one's imagination can go. The primary use, of course, is to find out echo-related problems in a telephone network. The following application scenarios are just exemplary. They are by no means an exhaustive list.

5.1 Application examples of Echo Sounder

5.1.1 Measure voice network echoes

Figure 6 is an over-simplified voice network diagram showing where Echo Sounder can be applied. Basically, Echo Sounder can be used at any point of the network where echo may become a problem,

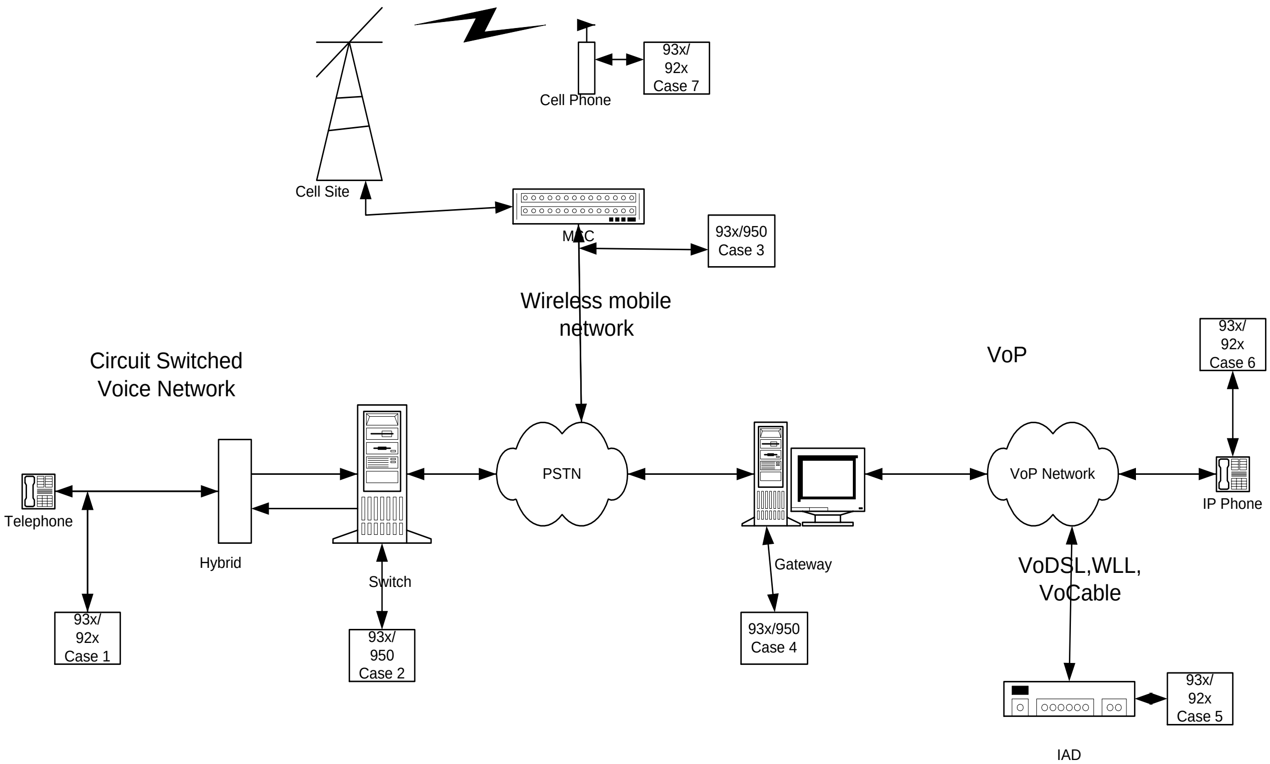

Figure 6: A simplified network diagram showing where Echo Sounder can be applied. Details of each case scenario are explained in the text.

and installation of echo canceller is being considered. In reference to Figure 6, we now examine each specific case in detail.

Case 1: calling from a 2-wire loop interface to any other points in the phone network, Echo Sounder can be used to find out all potential echoes that may impact the voice quality.

Case 2: by testing from a point (where network echo cancellers are installed) toward the hybrid, Echo Sounder can be used to characterize the echo path (echo delay and echo level). These information can then be used to configure or specify the performance requirements on a network echo canceller (in terms of cancellation tail length and cancellation depth, etc).

Case 3: When calling from a wireless mobile phone to a wireline phone on a local call, long delayed echo is commonly heard on a cellular phone because the PSTN wireline portion normally does not have a network echo canceller for local calls. By testing toward the PSTN network from the MSC (Mobile-Switch-Center), Echo Sounder can first determine whether or not an echo canceller is needed in MSC (are there any echoes?). If needed, Echo Sounder provides valuable information (echo delay and level) for the performance requirements on a to-be-installed echo canceller.

Case 4: A VoP network typically introduces significantly longer delay than a PSTN network. A minute amount of echo can be exacerbated by this long delay. Therefore, at the point where a voice gateway is installed, Echo Sounder should be used toward either the PSTN side or the VoP side to find out the minute amount of echoes from either side. The information provided by Echo Sounder can be used as justifications for installing echo cancellers at either side of the gateway, or as a way to locate the source of echo, and determine the responsible party.

Case 5: A non-attenuating digital loop (xDSL, Wireless Local Loop or Cable) linking an IAD (Integrated-Access-Device) to the VoP network also introduces long delayed echo if not for the embedded multi-channel echo canceller. With Echo Sounder, the performance of the embedded echo canceller can be verified, and voice quality can be guaranteed.

Case 6: With an analog audio signal adapter, Echo Sounder can also be connected to a digital phone to probe echoes.

Case 7: With adapter, Echo Sounder can also be connected to a wireless phone to detect potential echoes heard on a wireless call.

In all of the above scenarios, the echo canceller disabling tone can be turned on and off to qualitatively verify the performance of echo cancellers that are already installed in the network.

5.1.2 Measure one-way delay

In a laboratory environment where a calling terminal and a called terminal are co-located, Echo Sounder also provides a reliable way of measuring one-way delay and one-way attenuation. This feature is only available on Sage's 93x, which can originate and terminate a call on a single unit. Figure 7 shows the test configuration. In reference to Figure 7, the test procedures are:

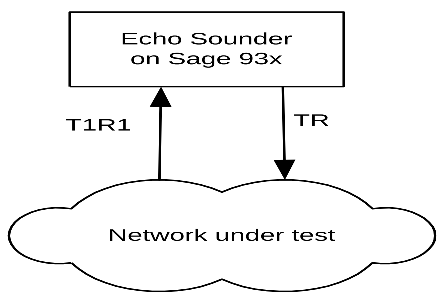

Figure 7: Test configuration for measuring one-way delay with Echo Sounder

1. Connect the calling terminal to 93x's TR interface, and connect the called terminal to 93x's T1R1 interface.

2. Select Option Menu 95 and put 93x in dry circuit 4-w (normally 600Ω) terminate mode.

3. Select Option Menu 97 to switch in the holding circuit of the TR terminal. One should hear dialing tone. After hearing dialing tone, go to the Dial/Ring option, and enter destination DTMF digits. Once the call goes through, one should hear the ringing tone at the T1R1 terminal. Go back to Option Menu 97, and switch in the T1R1 holding-circuit. The call is now established. To verify the connection, one can send a tone and then measure the tone. A tone should be measured with the same frequency as sent.

4. Now go to Option Menu 28 to start the Echo Sounder measurement. Echo Sounder will measure at least one echo. The shortest echo delay is the one-way delay from TR to T1R1, and the corresponding echo level is the one-way attenuation from TR to T1R1 at 1500Hz.

5. To measure the one-way delay on the return path, simply swap the connections of TR and T1R1, and repeat the above the procedures for the other direction.

Notice that only TR terminal can originate a call and send signal, and only T1R1 terminal can answer a call and measure signal.

5.1.3 Replace echo return loss measurement

On a 4-wire interface, Echo Sounder can completely replace the echo return loss measurement. The results from Echo Sounder are more useful as they contain echo delay information that return loss can not provide. Furthermore, Echo Sounder can resolve multiple echoes that return loss measurement has no clue of.

On a 2-wire interface, echo return loss uses an internal hardware bridge as hybrid. For "echo" with less than 7 ms delay, one has to keep using the echo return loss measurement.

5.1.4 Characterize the acoustic echo of special phones

As certain digital phones become smaller, the acoustic feedback from the speaker to the microphone can create an audible echo at the other end. Echo Sounder can be used to quantify such acoustic echo. Simply establish a call connection between Echo Sounder and the phone under test, and perform Echo Sounder test against it. All echoes measured are results of the acoustic coupling as well as electrical imbalance.

5.2 Application examples of Echo Generator

5.2.1 Facilitates echo canceller performance tests

When testing the performance of an echo canceller, one inevitably needs the source of echoes. Echo Generator provides multiple echoes with precisely-controlled echo level and echo delay to facilitate the performance test of an echo canceller. More on this topic later.

5.2.2 Provides remotely-programmable loop-back

In its simplest form (with just one echo), Echo Generator serves as a loop-back with remotely programmable level and delay. Echo Sounder can not only loop-back signal at 4-wire interface, it can also loop-back signal at 2-wire interface, thanks to its built-in software hybrid.

5.2.3 Impedance emulation

No doubt that Echo Generator can also be used to emulate an impedance mismatch to verify certain return loss or VSWR (Voltage-Standing-Wave-Ratio) type of measurements.

5.3 Combined applications of Echo Sounder and Echo Generator

When combined, Echo Sounder and Echo Generator form a powerful suite that can be used to measure anything that has to do with echoes and delays.

5.3.1 Echo canceller test

Echo Sounder and Echo Generator suite can be used to verify the performance of an echo canceller either in design lab or in the actual network. More specifically, Echo Sounder and Echo Generator can verify the following:

Cancellation depth: ITU G.168 [1] specifies requirements on echo cancellation depth with various echo levels. By stepping up and down the echo level inside the Echo Generator, Echo Sounder can then be used to measure the residual echo level after cancellation by the echo canceller.

Cancellation tail length: By stepping up and down the echo delay or by introducing multiple echoes with different delays, the echo canceller's tail length can be pin-pointed to within 1 ms.

Double talk: by commanding the Echo Generator to output a positively-gained echo (i.e., echo level > 0 dB), the Echo Sounder can then be used to verify the echo canceller's double-talk detection capability.

Response to disabler tone: by commanding the Echo Sounder to send the disabler tone before the test, Echo Sounder and Echo Generator can be used to verify if the echo canceller responds to it correctly by suspending the echo cancellation.

Delay introduced by the echo canceller: certain "poorly" implemented echo canceller tends to introduce significantly longer delay ($>$2 ms) when in enabled mode (than in the disabled mode). By comparing the echo delays measured by disabling and enabling the echo canceller, one can find out the "illegal" additional delay introduced by echo canceller. To guarantee that the Echo Sounder will measure echo when echo canceller is enabled, the Echo Level should be set as high as possible (to cause double talk situation) or echo delay as long as possible (so that the echo is beyond the EC's tail length).

5.3.2 Measure round-trip delay and round-trip attenuation

The Echo Sounder and Echo Generator suite provides a very reliable and convenient way of measuring round-trip delay and round-trip attenuation (at 1500Hz). By commanding the Echo Generator to generate a 0 dB echo with fixed known delay (100 ms, for example), the echo delay measured by Echo Sounder is the round-trip delay plus the additional echo delay introduced by the Echo Generator (100 ms), and the echo level is the round-trip attenuation. To ensure the echo will not be canceled by the echo cancellers, the echo canceller disabling tone should be turned on, or the echo delay should be set long enough (500 ms, for example) or the echo level is high enough so that the echo cancellers do not attempt to cancel the echo.

References

[1] "Digital network echo cancellers," *ITU-T Recommendation G.168*, April 1997.

[2] Renshou Dai, "A White Paper on Sage's PVIT, Packet-Voice-Impairments-Test", Sage Instruments white paper.

[3] Renshou Dai, "A Technical White Paper on Sage's PSQM Test", Sage Instruments white paper.

[4] "Control of talker echo," *ITU-T Recommendation P.131*, Aug., 1996.

[5] Renshou Dai, "Theory and Design of a Code-Domain-Reflectometer", Sage Instruments internal document, to-be published.