Understanding Line Impairments

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Introduction

This document provides an explanation of the most common impairments that can be identified by examining the line shape parameter reported by the **show modem operational−status** command. This command is also discussed in the Overview of General Modem and NAS Line Quality, in the section Inspecting Individual Modems with the show modem operational−status Command.

Prerequisites

Requirements

There are no specific requirements for this document.

Components Used

This document is not restricted to specific software and hardware versions.

Conventions

For more information on document conventions, see the Cisco Technical Tips Conventions.

Line Impairments

Line impairments can be classified into three categories:

- Attenuation − loss of the original signal properties.
- Distortion − changes in the original signal properties.
- Noise − introduction of properties that do not belong to the original signal.

The table below describes these three impairments in more detail:

Impairment	Description

Attenuation	• Channel attenuation ♦ Frequency response ♦ Signal level ♦ Line quality • Loop attenuation • Digital attenuation • Load coils (usual for subscriber loops longer than 18000 feet)
Distortion	• Pulse code modulation (PCM) distortion: ♦ coding ♦ extra transcodings ♦ Robbed bit signaling (RBS) every sixth frame ♦ clock drift • Harmonic distortion • Intermodulation distortion • Extra conversions between analogue and digital • Adaptive Differential PCM (ADPCM) and other non−PCM modulations • Amplitude distortion ♦ Jitter ♦ Wander ♦ Gain hits ♦ Digital padding • Frequency distortion ♦ Offset ♦ Reflection loss (on some frequencies, especially from bridge taps) • Interference (on some frequencies) • Phase distortion ♦ Hits ♦ Jitter ♦ Wander • End−to−end delay (especially over satellite links) • Delay distortion • Echo ♦ Near end ♦ Far end ♦ Others • Fold−over distortion • Non−linear distortion
Noise (white and colored)	• Impulse • Background • Thermal • Quantization

	• Crosstalk (including other services and power) • Frequency (bad splitters) • Interference from CPU

It can be difficult to guess why the quality of a given line is poor based only on the aggregate values obtained by modems through end−to−end line probing. There are too many impairment sources, each with various permutations and superpositions. For example, the signal quality (SQ) parameter allows us to estimate the line bit error rate (BER) based on the signal level and average symbol error (such as decision error, equalizer error and trellis error), as shown in the table below:

SQ	BER
7 6 5 4 3 2 1 0	Not detectable Not detectable 10E−6 10E−6 10E−4 10E−2 10E−2 No connectivity

However, it does not allow us to identify where exactly along the call path the errors are introduced and what their nature is.

Line shape is simply another integral line quality parameter. It is a result of line probing performed by modems at both ends as part of phase 2 (after the phase 1 V.8 negotiation) of the initial trainup sequence. During line probing, the whole voiceband frequency range is tested with "loud" signals (6 dB above the normal level) in steps of 150 Hz. By the end of phase 2, modems at both ends have their own line shape map.

Most Common Line Shape Impairments

A long unloaded line and a long loaded line have different shapes. The unloaded line shows fade (attenuation gradually increasing with frequency) across the spectrum from < 1kHz up to 3750Hz. Adding a load coil to such a line imposes steep roll−off above a certain frequency (typically in the 3000−3400Hz range) but counteracts the fade below that point.

Let's illustrate this with some examples. First, let's look at the shape from a very short plain old telephone service (POTS) line.

Level	Frequency																									Atten
	150	300	450	600	750	900	1050	1200	1350	1500	1650	1800	1950	2100	2250	2400	2550	2700	2850	3000	3150	3300	3450	3600	3750	
-22	.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	.	.	
-24	x	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	x	.	
-26	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	x	
-28	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
-30	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	

We can see a flat response from 450 through 3300Hz. We do not see any fade that would be characteristic of loop length. There is a small roll−off at 150Hz and a bigger one at 3450 through 3750Hz. The roll−offs at the edges are purely a characteristic of the lowpass filter applied to the POTS line in the analogue to digital logic before the codec. Let's look at some sample line shape output:

```
150    ..............................*
300    ................................*
450    .................................*
600    ................................*
750    ................................*
900    .................................*
1050   .................................*
1200   .................................*
```

```
1350   ................................*
1500   .................................*
1650   .................................*
1800   ................................*
1950   ................................*
2100   ................................*
2250   ................................*
2400   ................................*
2550   ................................*
2700   ................................*
2850   ................................*
3000   .................................*
3150   .................................*
3300   ................................*
3450   .................................*
3600   .................................*
3750   ...............................*
```

Long Subscriber Loop

Applying an unloaded three mile increases the fade. You might see −2dB of attenuation at 300Hz increasing gradually to −12dB at 3600Hz, resulting in a shape like this:

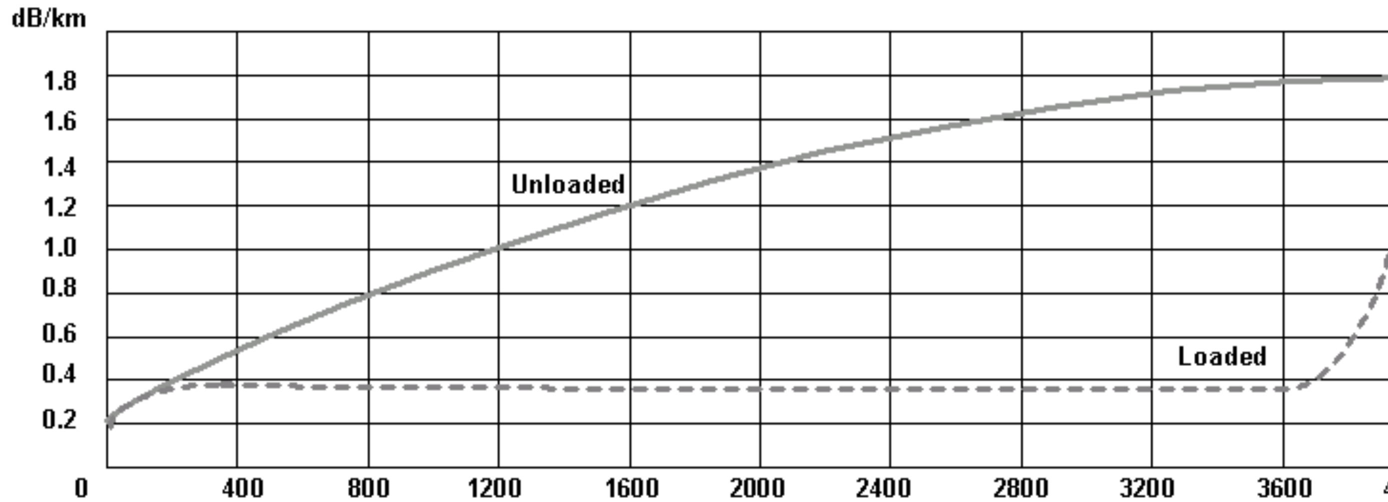
Level	Frequency																									Atten
	150	300	450	600	750	900	1050	1200	1350	1500	1650	1800	1950	2100	2250	2400	2550	2700	2850	3000	3150	3300	3450	3600	3750	
-22	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	
-24	.	x	x	x	x	x	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	
-26	x	X	X	X	X	X	X	x	x	x	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	
-28	X	X	X	X	X	X	X	X	X	X	X	X	x	x	x	.	.	.	.	.	.	.	.	.	.	
-30	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	x	x	x	x	.	.	.	.	.	
-32	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	x	x	x	.	.	
-34	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	.	.	
-36	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	x	.	
-38	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	.	
-40	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	x	

Some sample line shape output is shown here:

```
150    ...........................*
300    .................................*
450    .................................*
600    ................................*
750    ................................*
900    ...............................*
1050   ...............................*
1200   ..............................*
1350   ..............................*
1500   .............................*
1650   .............................*
1800   ............................*
1950   ............................*
2100   ...........................*
2250   ...........................*
2400   ..........................*
2550   ..........................*
2700   .........................*
2850   .........................*
3000   ........................*
3150   .......................*
3300   .......................*
3450   .....................*
3600   ..................*
3750   ............*
```

Load Coil

Load coils considerably improve line characteristics in voice frequency band at expense of higher frequencies.



With a load coil, the three−mile loop discussed above reveals a roll−off point at around 3300 Hz only.

Level	Frequency																									Atter
	150	300	450	600	750	900	1050	1200	1350	1500	1650	1800	1950	2100	2250	2400	2550	2700	2850	3000	3150	3300	3450	3600	3750	
-22	.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	.	.	.	.	.	
-24	x	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	x	.	.	.	.	
-26	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	x	.	.	.	
-28	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	.	.	.	
-30	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	.	.	.	

The coil applies a signal level boost to frequencies proportionate to their fade below the coil's roll−off point, and extinguishes the frequencies above the roll−off point. Some sample line shape output is shown here:

```
150   ............................*
300   ................................*
450   .................................*
600   .................................*
750   ................................*
900   ................................*
1050  ................................*
1200  ................................*
1350  ................................*
1500  ................................*
1650  ................................*
1800  ................................*
1950  ...............................*
2100  ...............................*
2250  ...............................*
2400  ...............................*
2550  ...............................*
2700  ...............................*
2850  .............................*
3000  .........................*
3150  ........................*
3300  ....................*
3450  ..*
3600  .*
```

```
3750  .*
```

PCM Transcodings and non−PCM Modulations

A short loop with a dual codec can have a shape that looks very similar to a long loop with a load coil. One way to distinguish them is that the dual codec may show a deeper roll−off at 150Hz.

```
.....................*             150........................*
................................*  300................................*
.................................* 450.................................*
.................................* 600.................................*
................................*  750................................*
................................*  900................................*
................................*  1050.................................*
................................*  1200................................*
...............................*   1350................................*
...............................*   1500................................*
...............................*   1650.................................*
..............................*    1800................................*
..............................*    1950................................*
..............................*    2100................................*
.............................*     2250.................................*
.............................*     2400................................*
............................*      2550................................*
............................*      2700................................*
............................*      2850................................*
...........................*       3000................................*
...........................*       3150.................................*
..........................*        3300...............................*
........................*          3450.............................*
.................*                 3600....................*
....*                              3750...*
```

Unlike PCM modulation requiring a 64 Kbps data stream, ADPCM can work with only 32 or even 16 Kbps. The gain is based on the fact that during normal conversation human speech changes its properties gradually. By transmitting deltas instead of the the absolute values it becomes possible to pack multiple voice channels into the 64 Kbps stream. This fundamental assumption does not hold true for modem connectivity.

```
150   .....................*
300   ................................*
450   .................................*
600   .................................*
750   ................................*
900   ................................*
1050  .................................*
1200  ................................*
1350  ................................*
1500  ................................*
1650  ................................*
1800  ................................*
1950  ................................*
2100  ................................*
2250  ................................*
2400  ................................*
2550  ................................*
2700  ................................*
2850  ................................*
3000  ..............................*
3150  .........................*
3300  .................*
3450  ......*
3600  .*
3750  .*
```

Besides the deeper roll−off at 150 Hz and extinguished frequencies at the high end, it is also typical for ADPCM to expose a lower signal−to−noise ratio (SNR). Though it might still be possible for V.34 modems to use higher symbol rates, it is generally advisable to limit the rate to 2743 baud maximum.

More modern compression techniques fitting voice into a data stream of 8 Kbps or below have a worse impact on modem connectivity. It may still be possible for the modems to stay connected at, say, 2.4 Kbps or below. However, this does not mean they ever succeed in transmitting any user data over such a link.

Related Information

- **Understanding Transmit and Receive Levels on Modems**
- **Troubleshooting Modems**
- **Access−Dial Technology Support Page**
- **Technical Support − Cisco Systems**

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