Interfacing with Radio Systems

The Land Mobile Radio (LMR) devices are attached to the IP network using wired connection points on radio units to link to digital or analog voice ports on the routers. At a minimum, these wired connection points must be able to transmit audio from the LMR device to the voice port and to receive audio from the voice port. They may also pass signaling information to and from the LMR device. The signaling may be in-band in the form of special tones mixed with the audio stream or signaling bits for the digital T1 connections, or it may be out-of-band through the use of dedicated signaling leads for analog connections. In the following sections this chapter explores the mechanics of physically wiring the LMR device to the voice port on the router, and then addresses mechanisms for handling signaling between the two devices:

Cabling

The LMR signaling enhancements in Cisco IOS software are germane to the analog ear and mouth (E&M) interface and a digital interface provisioned for E&M LMR signaling only. For a description of how the leads on the analog E&M interface are implemented on Cisco IOS voice gateways, refer to *Understanding and Troubleshooting Analog E&M Interface Types and Wiring Arrangements*. We recommend reviewing this document before reading further.

Digital T1 Interface

Before an LMR device can be connected to a T1 interface on the router, either the LMR device needs to have its own T1 interface, or a device such as a channel bank needs to be connected between the LMR device and the router. The multiflex trunk (MFT) Voice/WAN Interface Cards (VWICs) listed in Table 2-2 use standard T1 cabling configurations as shown in Figure 3-1 and Table 3-1.

Figure 3-1 T1 Pinouts

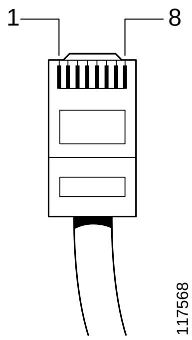


Table 3-1 Digital Voice Port Pinout (RJ-48C)

Pin	Signal
1	RX ring
2	RX tip
3	not used
4	TX ring
5	TX tip
6	not used
7	not used
8	not used

Note The RJ-48C receptacles on the MFT are pinned out as CPE, rather than as central office equipment. Use a T1/E1 crossover cable to connect to other CPE pinned out equipment, for example, PBXs.

The T1 interface on the router has multiple configuration options to match most common framing, line-code, line build-out, and other T1 configurations. From a Cisco IOS software perspective, each DS0 on the T1 is associated with a voice port through the use of the **ds0-group** statement. A signaling type is added to the statement to guide behavior based on the signaling bits for that particular channel. This is a typical LMR configuration:

```
controller T1 2/0
 framing esf
 linecode b8zs
 cablelength short 133
 ds0-group 0 timeslots 1 type e&m-lmr
```

Tip Although it is possible to assign all DS0s from the LMR device to voice ports using one **ds0-group** statement, it is not recommended because the mapping of DS0 to voice port is not deterministic. The only way to guarantee that a certain DS0 gets mapped to a certain voice port is to create a single **ds0-group** statement for each voice channel.

Analog E&M Interface

For analog connections, the E&M interface is the interface card type used to attach the leads from an LMR device. Of all the voice interfaces, only the E&M interfaces can accommodate the variety of different audio and signaling configurations present in the myriad of radio systems out in the field. The E&M port can be configured to transmit and receive audio information using one pair or two pairs of leads. It also has four different configurations for control of the signaling leads. Some radio systems may actually present an E&M interface for their wire-side connections, which obviously simplifies the connection process. However, many others systems will require planning for their connection.

E&M Interface Operation

This section describes the E&M interface leads and the signaling types used on E&M interfaces.

Leads

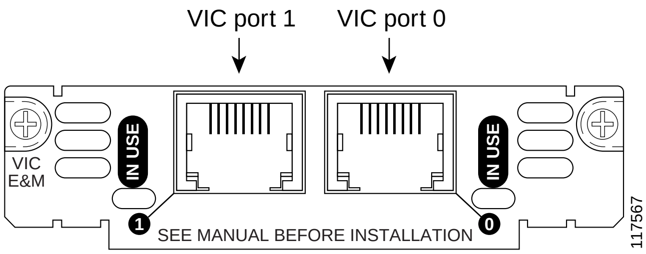
The E&M interface on the router has eight leads for use in connecting to the LMR systems. Four leads are available for the audio path. The other four are available for signaling. Table 3-2 describes the function of the various E&M leads and maps each lead to its corresponding pin on the E&M voice interface cards (VICs). Figure 3-2 shows the physical appearance of an E&M VIC, and Figure 3-1 shows the layout of the pins on a standard RJ-45 connector that would plug in to the receptacles on that VIC.

Table 3-2 E&M VIC Pinouts

Lead Name	Pin	Description
E (Ear or Earth)	Pin 7	Signal wire asserted by the router toward the connected device. Typically mapped to the push-to-talk (PTT) lead on the radio.
M (Mouth or Magnet)	Pin 2	Signal wire asserted by the connected device toward the router. Typically mapped to the Carrier Operated Relay (COR) lead on the radio.
SG (Signal Ground)	Pin 8	Used on E&M signaling Types II, III, and IV. Type IV is not supported on Cisco routers and gateways.
SB (Signal Battery)	Pin 1	Used on E&M signaling Types II, III, and IV. Type IV is not supported on Cisco routers and gateways.
Two-Wire Mode		
T1/R1 (Tip-1/Ring-1)	Pins 5 and 4	In two-wire operation, the T1/R1 leads carry the full-duplex audio path.
Four-Wire Mode		
T/R (Tip/Ring)	Pins 6 and 3	In a four-wire operation configuration, this pair of leads carries the audio in from the radio to the router and would typically be connected to the line out or speaker of the radio.
T1/R1 (Tip-1/Ring-1)	Pins 5 and 4	In a four-wire operation configuration, this pair of leads carries the audio out from the router to the radio and would normally be connected to the line in or microphone on the radio

See Table 3-3 for more information on E&M leads and VICs configured for E&M signaling Types I, II, III, and V.

Figure 3-2 E&M VIC Interface



Signaling Types

Five types of signaling configurations are defined for traditional E&M interfaces. The E&M port on a Cisco router supports four of those types: I, II, III, and V. These signaling types define different mechanisms for asserting signaling on the E-lead or recognizing signals asserted on the M-lead. In general, the Type II configuration is preferred for use with LMR because the absence of DC connectivity between the radio and the router ensures that no ground loops are created. Type V offers the option of connecting E&M ports back-to-back using a simple rollover cable, in 2-wire mode only. However, the devices carrying both E&M ports must be collocated and connected to the same ground or power system.

Figure 3, Figure 4, and Figure 5 illustrate the interface models for each of the E&M types which might be used to connect to an LMR system. Note that Type I is not displayed because that configuration is not conducive to interfacing with LMR system because it requires interconnection of the radio and router ground and power systems.

Note These are generic models. Additional electrical elements may be necessary to adjust the model to fit your specific application.

Figure 3-3 E&M Type II Interface Model

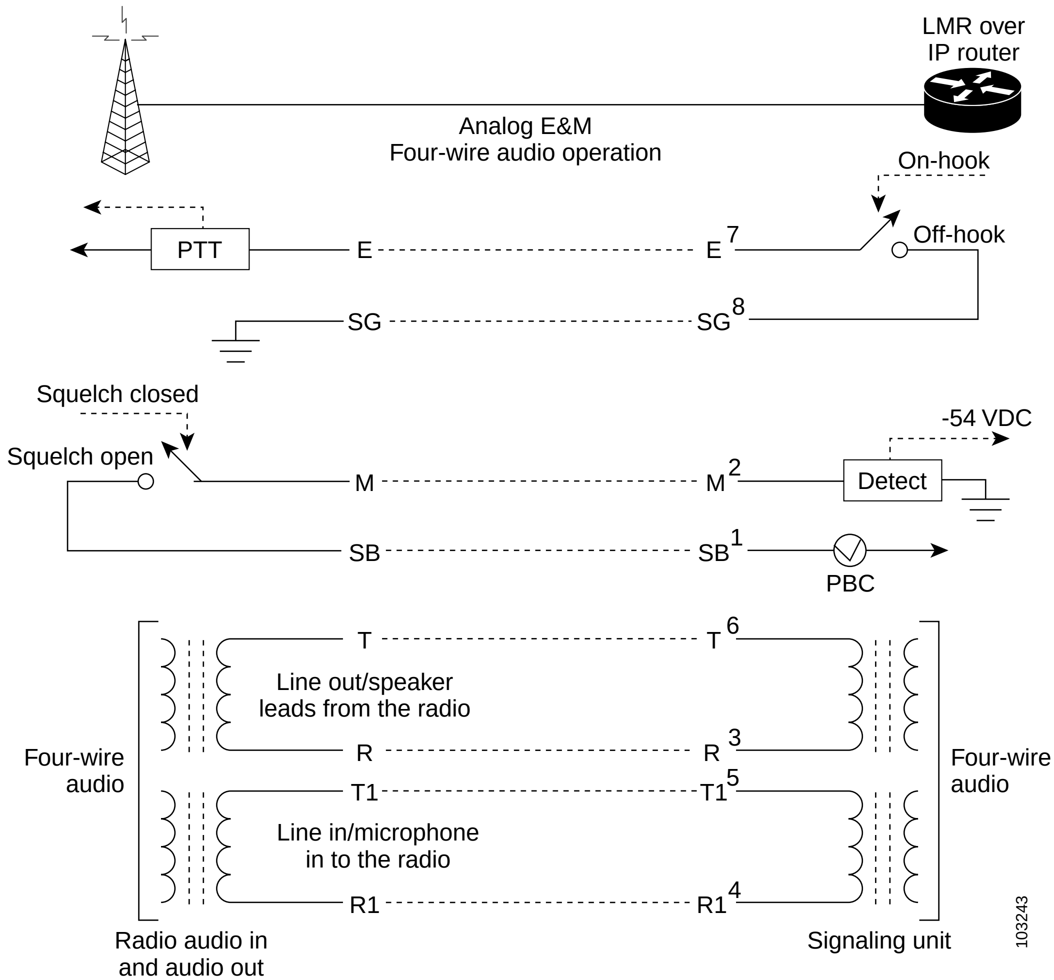


Figure 3-4 E&M Type III Interface Model

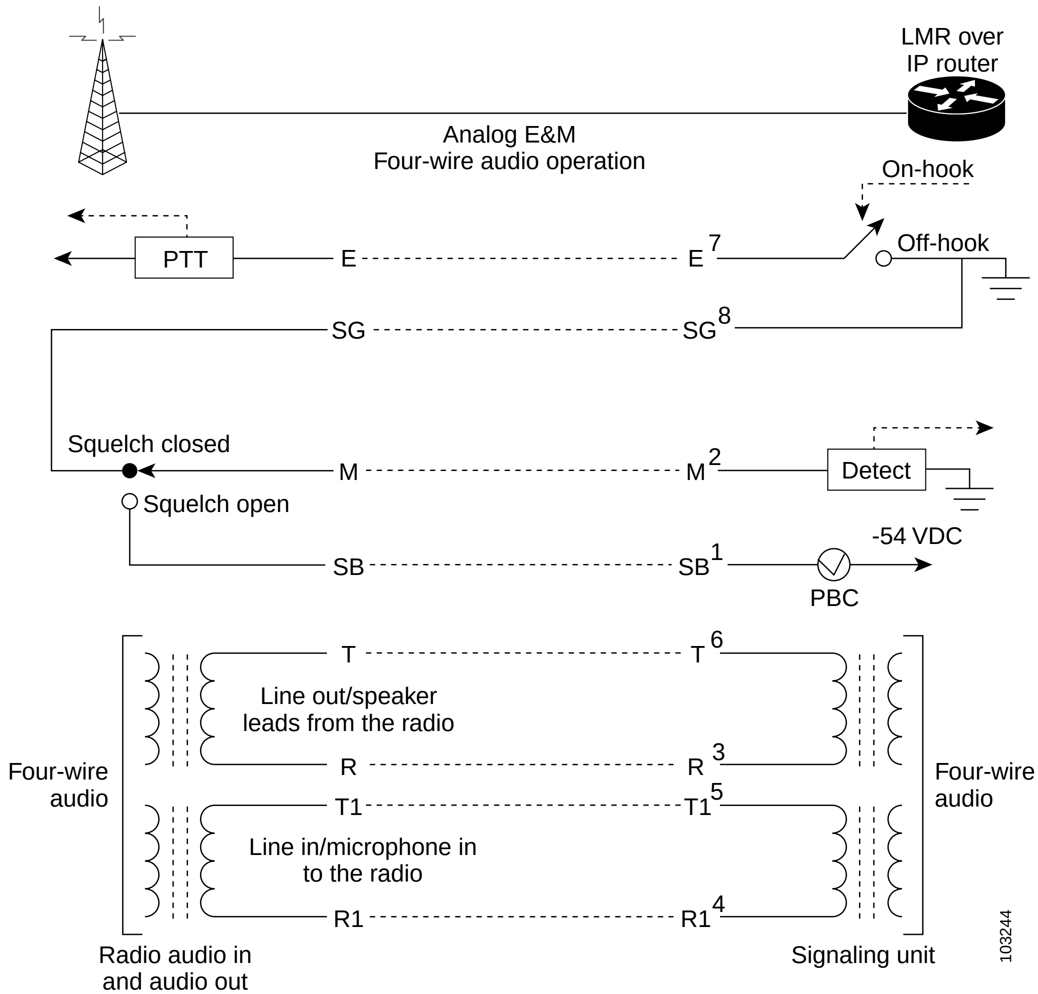
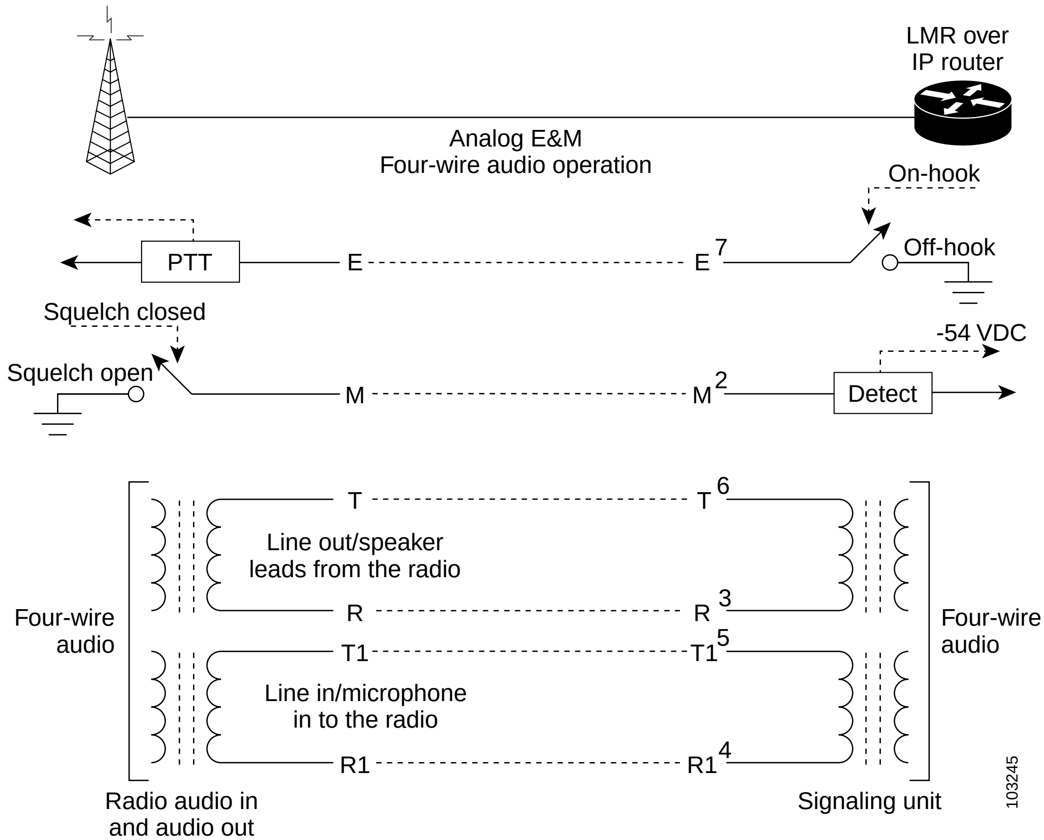


Figure 3-5 E&M Type V Interface Model



E&M Electrical Characteristics

The T1 E&M interface is compliant with the ANSI T1.403 and AT&T Publication 62411 standards for T1. The Analog E&M interface is described in the following section.

General

Table 3-3 provides information about E, M, SG, and SB leads when the E&M VIC is configured for E&M signaling Types I, II, IV, and V.

Table 3-3 Signaling Lead Electrical Characteristics

Lead	Type I	Type II	Type III	Type V
E	Over current protected solid state relay contact to chassis ground	Over current protected solid state relay contact to SG	Over current protected solid state relay contact to chassis ground	Over current protected solid state relay contact to chassis ground
SG	Chassis ground via solid state relay	Over current protected solid state relay contact to E	Chassis ground via solid state relay	Chassis ground via solid state relay
M	Current limited opto coupler input to chassis ground	Current limited opto coupler input to chassis ground	Current limited opto coupler input to chassis ground	Current limited opto coupler input to –54 VDC
SB	Over current protected –54 VDC	Over current protected –54 VDC	Over current protected –54 VDC	Chassis ground

Unless interfacing requirements dictate otherwise, we recommend that you use Type II signaling when directly connecting to a radio to eliminate ground loops. Other signaling types in conjunction with external circuitry can also provide isolation of radio and LMR gateway chassis grounds. We recommend that any components used for external interface circuitry have appropriate agency approvals from Underwriters Laboratories Inc. (UL), Canadian Standards Association (CSA), Verband der Elektrotechnik, Elektronik und Informationstechnik or Association for Electrical, Electronic, and Information Technologies (VDE), British Standards Institution (BSI), or others.

Audio Interface

The E&M VIC presents four audio leads, T and R and T1 and R1, configurable for operation in either two- or four-wire mode. The leads are transformer-isolated with an impedance of 600 ohms across each pair, providing a 600 ohm transformer coupled audio appearance to radios. When the VIC-2E/M is used, these leads are DC blocked. When the VIC2-2E/M is used, these leads are DC over current protected. In two-wire operation, the T1 and R1 leads are used to carry the full-duplex audio. In four-wire operation, the T and R leads are the audio input to the router and the T1 and R1 leads are the audio output from the router.

PTT Interface (E-Lead)

The E&M VIC presents a solid state relay contact in series with a resettable circuit protection device between the E and SG leads when configured for Type II signaling. The built-in current limiting has a maximum of 270 milliamps (mA) or a typical value of 210 mA. In addition, there is a Positive Temperature Coefficient (PTC) device in series with the relay contact that will further limit and protect the circuit. Industry specification says that E-lead current should be limited to a maximum of approximately 250 mA, but with typical operating currents of about 50 mA or less. At currents between 5 mA and 30 mA, this interface exhibits an approximate resistance of 25 ohms. This information, in conjunction with detailed knowledge of radio PTT circuitry, should allow a technician to determine whether a direct connection between radio and VIC can be utilized or if external interface circuitry needs to be added.

E-Lead Operation During Router Reload

When the LMR gateway is reloaded, the VIC-2E/M and VIC2-2E/M interface cards will go off-hook, which will be interpreted as a PTT for those radio systems employing physical signaling. During this interval, the –52 volts from the SB lead is also removed. External circuitry that detects the absence of SB can be used to disable the PTT operation. Patriot Base Stations from Ritron and the Tactical Communications Bridge TCB-1 from Link Communications incorporate this circuitry.

COR Interface (M-Lead)

The E&M VIC presents the input side, that is, LED of an opto isolator in series with a current-limiting resistor and a transistor used to switch between the different E&M configuration types to the COR, also referred to as “squelch open,” output from a radio. Opto isolator input is also shunted with a resistor to control its sensitivity. When configured for Type II signaling, the radio COR needs to be able to source about 3 mA into a nominal 7400 ohm resistance with respect to the LMR gateway chassis ground to indicate a squelch open condition to the LMR gateway. This current can be sourced from the radio itself or from the SB lead of the LMR gateway. If the SB lead is used as a current source, the radio must be able to switch about 7 mA of current at an open circuit voltage of 54 V. Because most modern radios typically have an open collector or open drain output, additional external circuitry such as a solid state relay likely will be required between the radio and the E&M VIC.

E&M DC Characterization

This section describes the direct current (DC) characteristics of the E&M interface. Some typical voltages and currents were selected to characterize the E&M VIC DC operational parameters. The information is summarized in the following tables so that a radio technician can use this data in conjunction with knowledge of radio circuitry to perform the necessary integration.

The following testing methodology was used to populate the tables in this section:

- All testing was done in E&M Type II mode.
- Agilent model E3612A power supply was used for all tests in both constant voltage and constant current modes.
- All measurements were made at the end of one foot of 26 American Wire Gauge (AWG) stranded wire connected via an RJ-46 plug to the faceplate of a VIC.
- All E-lead on resistance measurements were made between the E-lead and the SG-lead and included resistance of internal protection device and solid state relay.
- All M-lead measurements were made between M-lead and the chassis ground and included internal M-lead type switching components and the control side of solid state relay.
- Voltages and currents were measured with Fluke Model 73 III VOM verified to have the current calibration sticker.
- All measurements were done at room temperature.
- Voltages of 5, 12, and 24 VDC were picked for testing because these were considered typical of what may be sourced by a radio.

Table 3-4 describes the E-lead (PTT) relay contact resistance for the VIC-2E/M for typical operating conditions.

Table 3-4 E-Lead (PTT) Relay Contact Resistance for VIC-2E/M

Voltage (VDC)	Current (mA)	Vdrop (VDC)	R(ON) ohms	Voltage (VDC)	Current (mA)	Vdrop (VDC)	R(ON) ohms	Voltage (VDC)	Current (mA)	Vdrop (VDC)	R(ON) ohms
5	1	0.033	33.0	12	1	0.030	30.0	24	1	0.030	30.0
5	2	0.054	27.0	12	2	0.055	27.5	24	2	0.060	30.0
5	3	0.081	27.0	12	3	0.076	25.3	24	3	0.081	27.0
5	4	0.097	24.3	12	4	0.104	26.0	24	4	0.102	25.5
5	5	0.130	26.0	12	5	0.128	25.6	24	5	0.127	25.4
5	10	0.264	26.4	12	10	0.245	24.5	24	10	0.261	26.1
5	20	0.504	25.2	12	20	0.503	25.2	24	20	0.495	24.8
5	30	0.740	24.7	12	30	0.747	24.9	24	30	0.747	24.9

Table 3-5 describes the E-lead (PTT) relay contact resistance for the VIC2-2E/M for typical operating conditions.

Table 3-5 E-Lead (PTT) Relay Contact Resistance for VIC2-2E/M

Voltage (VDC)	Current (mA)	Vdrop (VDC)	R(ON) ohms	Voltage (VDC)	Current (mA)	Vdrop (VDC)	R(ON) ohms	Voltage (VDC)	Current (mA)	Vdrop (VDC)	R(ON) ohms
5	1	0.032	32.0	12	1	0.037	37.0	24	1	0.046	46.0
5	2	0.067	33.5	12	2	0.072	36.0	24	2	0.062	31.0
5	3	0.090	30.0	12	3	0.094	31.3	24	3	0.094	31.3
5	4	0.120	30.0	12	4	0.126	31.5	24	4	0.132	33.0
5	5	0.159	31.8	12	5	0.155	31.0	24	5	0.155	31.0
5	10	0.321	32.1	12	10	0.305	30.5	24	10	0.315	31.5
5	20	0.619	31.0	12	20	0.629	31.5	24	20	0.612	30.6
5	30	0.923	30.8	12	30	0.921	30.7	24	30	0.941	31.4

Table 3-6 describes the M-lead detector (COR) detection thresholds for the VIC-2E/M.

Table 3-6 M-Lead Detector (COR) Detection Thresholds for VIC-2E/M

			Vdrop (VDC)	Equivalent Resistance (ohms)
M-Lead Positive	**M-Lead Off-Hook Detect (mA)**	2.10	15.5	7381
	M-Lead On-hook Detect (mA)	2.04	15.1	7402
M-Lead Negative	**M-Lead Off-Hook Detect (mA)**	2.08	15.6	7500
	M-Lead On-Hook Detect (mA)	2.06	15.2	7379
			Average	7415

The SB-lead open circuit voltage (VDC) is –53.4.

Table 3-7 describes the M-lead detector (COR) detection thresholds for the VIC2-2E/M.

Table 3-7 M-Lead Detector (COR) Detection Thresholds for VIC2-2E/M

			Vdrop (VDC)	Equivalent Resistance (ohms)
M-Lead Positive	**M-Lead Off-Hook Detect (mA)**	2.12	15.7	7406
	M-Lead On-Hook Detect (mA)	2.10	15.6	7429
M-Lead Negative	**M-Lead Off-Hook Detect (mA)**	2.30	16.9	7348
	M-Lead On-Hook Detect (mA)	2.28	16.8	7368
			Average	7388

The SB-lead open circuit voltage (VDC) is –53.1.

Audio Characteristics

This section describes the behavior of the voice ports on the router with respect to audio information passed through the interface. The tests used to obtain the data were performed according to standard voice testing methods for a telephony interface. The results describe how effectively the voice interface on the router can faithfully reproduce audio at different levels and frequencies.

Gain Tracking Characterization

Figure 3-6 and Figure 3-7 show the gain tracking error per Telcordia specification TR-NWT-000507. A 1004-Hz tone was presented to a digital T1 port configured for LMR on one router. The level of the tone was incrementally stepped through various levels starting at –60.0 dBm and proceeding to +3.0 dBm. A VoIP connection was made between the digital interface and an analog E&M interface configured for LMR on another router. The tone was measured at the receiving end and the level was recorded. The Telcordia specification places upper and lower limits for the difference between the level of the received tone and the level sent.

This testing was performed from a T1 interface on an NM-HDV module to an E&M port on an NM-2V module, and from a T1 interface on an NM-HD-2VE module to an E&M port on an NM-HD-2V module. The T1 interfaces were configured for extended superframe (ESF) framing and binary 8-zero substitution (B8ZS) line code and were configured to receive clocking from the attached tone generation device (Sage 930). The E&M interfaces were configured for E& M Type II, 4-wire operation at 600 ohm. Both the E&M and T1 voice ports had input gain and output attenuation set to 0 with echo cancellers disabled. The VoIP dial peers were configured to use the G.711 mu-law codec with voice activity detection (VAD) disabled.

Figure 3-6 Gain Tracking Error for NM-HDV to NM-2V

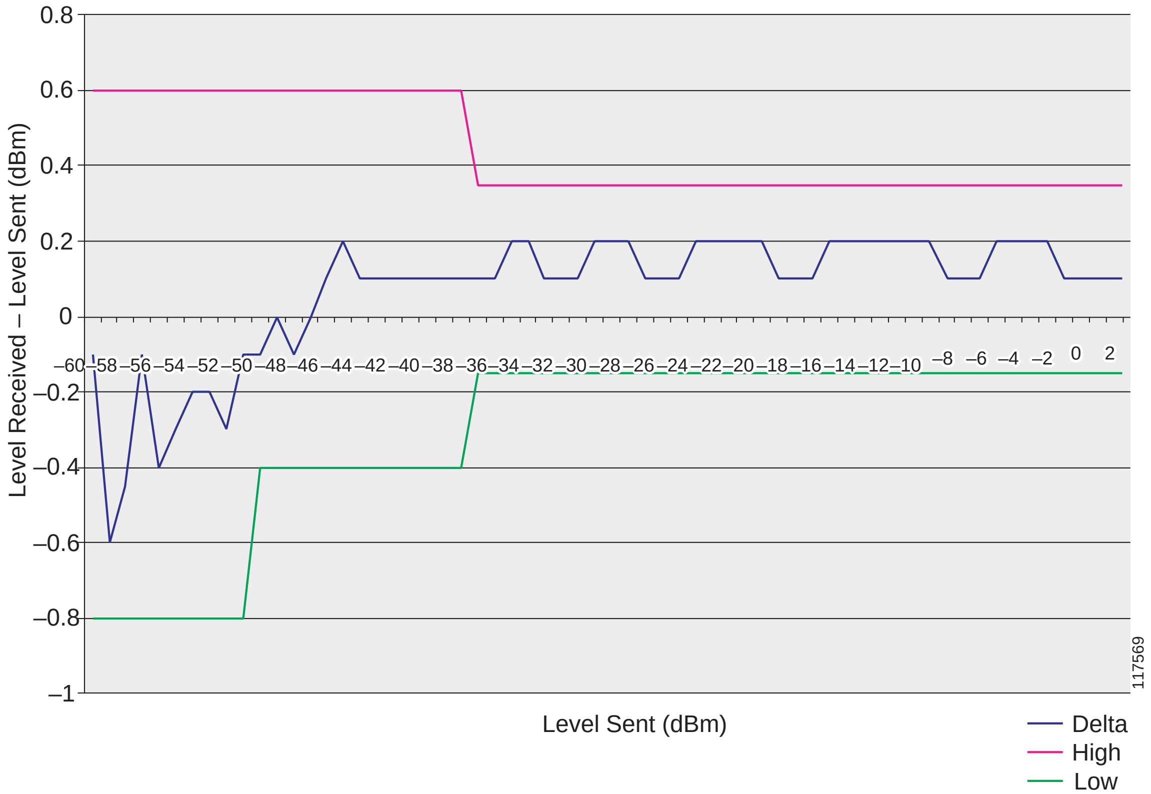
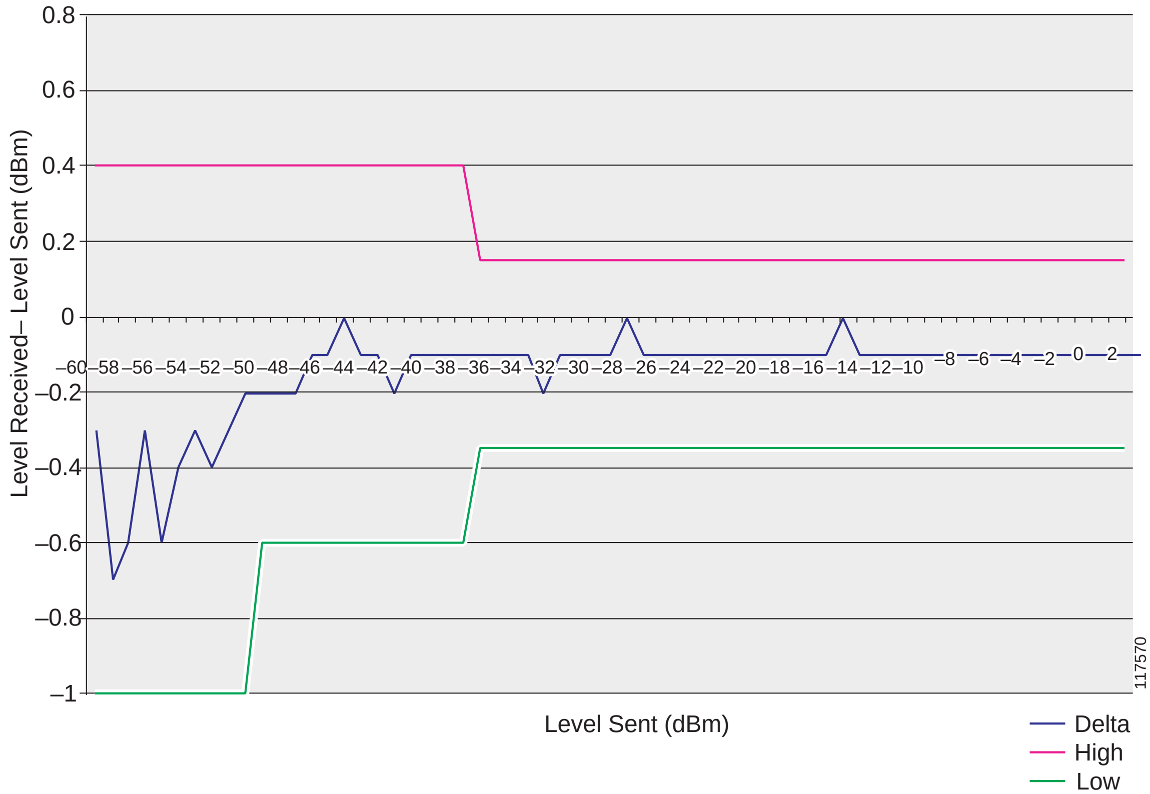


Figure 3-7 Gain Tracking Error for NM-HD-2VE to NM-HD-2V



Frequency Response Characterization

Table 3-8 shows the frequency response rolloff error per Telcordia specification TR-NWT-000507. A VoIP connection was made between a digital interface configured for LMR on one router and an analog E&M interface configured for LMR on another router. Initially, a 1004-Hz tone was presented to one of the ports at 0.0 dBm and the level received at the other end was recorded as a baseline measurement. Then, the frequency of the tone was stepped through various values starting at 60 Hz and ending at 3400 Hz, holding the level constant. The Telcordia specification places upper and lower limits for the level received based on the frequency sent using the 1004 Hz level as the baseline.

This testing was performed from a T1 interface on an NM-HDV module to an E&M port on an NM-2V module, and from a T1 interface on an NM-HD-2VE module to an E&M port on an NM-HD-2V module. The T1 interfaces were configured for ESF framing and B8ZS line code and were configured to receive clocking from the attached tone generation device (Sage 930). The E&M interfaces were configured for E& M Type II, four-wire operation at 600 ohms. Both the E&M and T1 voice ports had input gain and output attenuation set to 0 with echo cancellers disabled. The VoIP dial peers were configured to use the G.711 mu-law codec with VAD disabled.

Table 3-8 Frequency Response Characteristics for Voice Ports

Frequency (Hz)	Received Level (dBm)				
	Analog to Digital	Digital to Analog	Analog to Digital	Digital to Analog	Digital to Digital
	NM-2V to NM-HDV	NM-HDV to NM-2V	NM-HD-2V to NM-HD-2VE	NM-HD-2VE to NM-HD-2V	NM-HD-2VE to NM-HD-2VE
60	No Value	–2.6	No Value	–2.1	0.0
200	–0.5	–0.1	–0.6	–0.2	0.0
300	0.1	0.1	0.2	–0.1	0.0
400	0.0 to 0.2	0.1	0.1 to 0.4	–0.1	0.0
500	0.1	0.1	0.1 to 0.3	0.0	–0.1
600	0.1	0.2	0.2	–0.1	0.0
700	0.1	0.2	0.2	–0.1	0.0
800	–0.2 to +0.4	0.1	–0.1 to +0.4	–0.1	0.1
900	0.1	0.2	0.2	–0.1	0.0
1004	0.1	0.1	0.2	–0.1	0.0
1100	0.1	0.2	0.2	–0.1	0.0
1200	0.0 to 0.2	0.1	0.1 to 0.3	–0.1	0.0
1300	0.1	0.1	0.2	–0.1	–0.1
1400	0.1	0.2	0.2	–0.1	0.0
1500	0.1	0.1	0.1 to 0.3	–0.2	–0.1
1600	–0.2 to +0.3	–0.1 to +0.3	–0.1 to +0.4	–0.4 to +0.0	0.1
1700	0.1	0.1	0.2	0.0	0.0
1800	0.1	0.1	0.2	0.0	–0.1
1900	0.1	0.1	0.2	0.0	–0.1
2000	–2.0 to +1.1	–0.3 to +0.3	–1.9 to +1.3	–0.7 to –0.1	0.3
2100	0.1	0.1	0.2	0.0	–0.1
2200	0.1	0.1	0.2	0.0	0.0
2300	0.0	0.1	0.2	0.0	0.0
2400	–0.2 to +0.2	0.1	–0.1 to +0.4	0.0	0.1
2500	0.0	0.1	0.1 to 0.3	–0.1	0.0
2600	0.0	0.1	0.2	0.0	–0.1
2700	0.0	0.1	0.2	–0.1	0.0
2800	0.0	0.1	0.1 to 0.3	0.0	0.0
2900	0.0	0.1	0.2	0.0	0.0
3000	–0.4 to +0.2	0.0	–0.2 to +0.5	–0.2	–0.2
3400	–0.3	–0.3	–0.1	–0.4	–0.1

Signaling

LMR endpoints generally need some method to indicate to other endpoints on the wired network that they have received audio from their air interface that they will be sending onto the network. Similarly, the LMR device needs some method to understand these signals from the other devices on the wired network, so it can relay the received audio on its air interface. There are two basic methods to accomplish this task. First, the LMR endpoint can use physical signaling external to the audio stream to communicate its status. Second, the LMR endpoint can mix the signaling in with the audio stream using special tones or some other encoding system.

In addition to the LMR endpoint communicating its status, the gateway to which the LMR device is connected must receive the status, and then be able to effectively transport that status. With point-to-point connections, the signaling transport mechanisms are fairly straightforward. With multicast many-to-many connections, the mechanisms require some adjustments, which are described in the following sections:

Physical Signaling

On an analog E&M interface, physical signaling occurs though electrical changes on the various leads, primarily the E- and M-leads. For digital interfaces, T1 signaling bits are employed. The LMR gateways convert this received physical signaling to an internal representation, which looks strikingly similar to the T1 ABCD signaling bits. For unicast transport mechanisms, the signaling can be passed through the IP network using VoIP signaling packets. When the gateway on the other side of the connection receives these signaling packets, it translates the internal signaling representation back into physical signaling on its interface. In a multicast environment, it would be confusing to the gateway to receive conflicting signaling packets, so none are sent.

Let us consider a general example of this signaling method in operation across a unicast connection. An LMR endpoint recognizes audio on its air interface. It signals this state by applying voltage to its COR lead. The attached gateway interprets this state as a seize on its M-lead. The gateway sends this signal state across the network. The receiving gateway takes the signaling state and grounds its E-lead, indicating seizure. The LMR endpoint attached to the receiving gateway interprets this state as someone pressing the PTT button and transmits received audio on its air interface.

When implementing your LMR over IP network, consider these issues:

- Are the correct leads connected from the LMR endpoint to the E&M interface on the gateway?
- Does the signal state received from the other side of the connection map correctly to the signals the LMR system on this side expects to see?

Tone Signaling (In-Band)

If the LMR endpoint uses tone signaling mixed in the audio stream to communicate its activity states, from the gateway's standpoint, reception of the signaling consists of recognizing the existence of incoming audio information. The gateway accomplishes this function by passing audio samples of a sufficient dB level through its VAD algorithm. Note that reception of the signaling does not imply an understanding of the signaling. At this point, the gateway does not have the ability to examine the incoming voice stream to determine and characterize any tone signaling that may be present. Thus transport involves merely passing these voice samples untouched along the connection.

When implementing your LMR over IP network, consider whether the signaling will survive transcoding by means of lower bit-rate codecs such that it is recognizable when decoded at the receiver.

LMR Signaling

The previous examples of physical and tone signaling assumed homogenous systems. One LMR endpoint signals another LMR endpoint using substantially similar physical or tone signaling. Although this assumption may reflect the conditions in some installations, it clearly does not provide the interoperability needed in many other installations. The goal is to attach LMR endpoints to the IP network in such a fashion that regardless of whether the endpoint uses physical, tone, or no signaling at all, it can communicate with other LMR endpoints and traditional voice endpoints as well.

Table 3-9 describes the voice port configuration commands introduced to handle signaling differences in the various LMR systems that may be attached to the network. The M-lead options describe the ways in which the gateway can interpret signaling coming from the LMR systems. The E-lead options describe the ways in which the gateways can send signaling to the LMR systems. Although we find real E- and M-leads on analog interfaces only, these commands apply equally to the digital interfaces.

Table 3-9 LMR Signaling Configuration Options

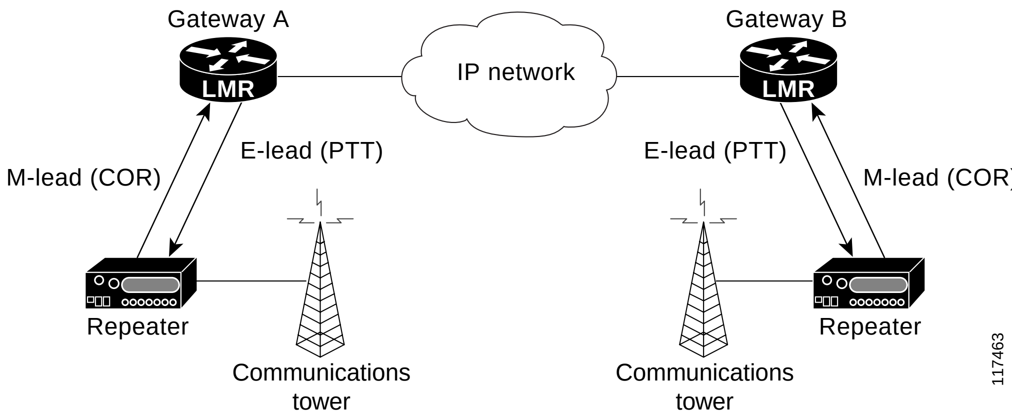
Voice Port Configuration Command	Behavior
lmr m-lead audio-gate-in	The gateway monitors the status of the M-lead. When it registers a seize condition for the M-lead, the incoming voice stream is passed to the digital signal processors (DSPs) for further processing. When the M-lead is idle, any audio arriving on the interface is ignored. If VAD is enabled for the connection, the received audio must still pass the VAD threshold in order for voice packets to appear on the network. Otherwise, voice packets will be constantly generated even if they contain just silence.
lmr m-lead dialin	The command operates exactly the same as the **audio-gate-in** option with the addition of a dial trigger. If the voice port is currently not engaged in a VoIP connection, a seize condition on the M-lead will trigger the voice port to dial a configured connection E.164 address. An idle condition on the M-lead does not by itself cause the connection to get torn down, but it does start the timer that is set with the **timeouts teardown lmr** command. The **lmr m-lead** command with the **dialin** option is designed for private line, automatic ringdown (PLAR) connections.

Table 3-9 LMR Signaling Configuration Options

Voice Port Configuration Command	Behavior
lmr m-lead inactive	The condition of the M-lead is ignored. The incoming audio stream is passed to the DSPs for processing. If VAD is enabled for the connection, the received audio must pass the VAD threshold in order for voice packets to appear on the network. Otherwise, voice packets will be constantly generated even if they contain just silence. Without VAD enabled, there is a great chance for problems with this option.
lmr e-lead seize	The gateway will place the E-lead in a seize or idle state depending on signaling state received on the connection. This command will be employed primarily in those situations where signaling packets can be expected from the other end of the connection, which for the most part means unicast connection trunk connections.
lmr e-lead voice	The gateway will place the E-lead in a seize or idle state depending on presence or absence of voice packets. Note that for this side of the connection, VAD is not triggering the E-lead. The E-lead is triggered by the presence of voice packets from the network. Of course, VAD may be responsible for the presence of the voice packets on the connection, but that is the business of the other side, over which this side has no control. This command is employed in those situations where signaling will not be forthcoming from the network, which generally means multicast connection trunk and connection PLAR connections.
lmr e-lead inactive	It might be supposed that with this command, the gateway would leave the E-lead in its default state. This is true, unless the gateway received signaling packets from the network, in which case it applies a state based on the contents of those packets. This behavior is seen in unicast connection trunk connections, and, this behavior is unavoidable. Therefore, the suggestion for these connections is to alter the way in which the voice port processes the seize and idle packets from the network, so that they both produce the same results. The process for accomplishing this task is described in the "Seize and Idle Bit Patterns" section.

Table 3-10, Table 3-11, and Table 3-12 present the behavior of the voice port E- and M-lead configuration options broken down by connection type, M-lead state, and the presence or absence of audio. The tables refer to Figure 3-8. The M-lead configuration option is what would be configured on the voice port of Gateway A, and the E-lead option is what would be configured on the voice port of Gateway B. The column headings present each of the four possible M-lead and audio permutations that can be expected from the LMR endpoint on Gateway A. The table entries are what the LMR endpoint on Gateway B can expect to see.

Figure 3-8 LMR Signaling from Gateway to Radio



For purposes of these tables, it is assumed that the default values for the voice port seize and idle bit patterns are used. In addition, it is assumed that VAD is enabled for the connection, unless otherwise stated.

Table 3-10 Unicast Connection Trunk

Voice Port Configuration Command		M-Lead Idle		M-Lead Seize	
Gateway A	**Gateway B**	**No Audio Supplied**	**Audio Supplied**	**No Audio Supplied**	**Audio Supplied**
lmr m-lead audio-gate-in	lmr e-lead seize	E-lead idle	E-lead idle	E-lead seize	E-lead seize
		No audio generated	No audio generated	No audio generated	Audio generated
	lmr e-lead inactive	E-lead idle	E-lead idle	E-lead seize	E-lead seize
		No audio generated	No audio generated	No audio generated	Audio generated
	lmr e-lead voice	E-lead idle	E-lead idle	E-lead idle	E-lead seize
		No audio generated	No audio generated	No audio generated	Audio generated
lmr m-lead dialin	lmr e-lead seize	E-lead idle	E-lead idle	E-lead seize	E-lead seize
		No audio generated	No audio generated	No audio generated	Audio generated
	lmr e-lead inactive	E-lead idle	E-lead idle	E-lead seize	E-lead seize
		No audio generated	No audio generated	No audio generated	Audio generated
	lmr e-lead voice	E-lead idle	E-lead idle	E-lead idle	E-lead seize
		No audio generated	No audio generated	No audio generated	Audio generated
lmr m-lead inactive	lmr e-lead seize	E-lead idle	E-lead idle	E-lead seize	E-lead seize
		No audio generated	Audio generated	No audio generated	Audio generated
	lmr e-lead inactive	E-lead idle	E-lead idle	E-lead seize	E-lead seize
		No audio generated	Audio generated	No audio generated	Audio generated
	lmr e-lead voice	E-lead idle	E-lead seize	E-lead idle	E-lead seize
		No audio generated	Audio generated	No audio generated	Audio generated

Table 3-11 Connection PLAR

Voice Port Configuration Command		M-Lead Idle		M-Lead Seize	
Gateway A	**Gateway B**	**No Audio Supplied**	**Audio Supplied**	**No Audio Supplied**	**Audio Supplied**
lmr m-lead audio-gate-in	lmr e-lead seize	No connection established	No connection established	No connection established	No connection established
		E-lead idle	E-lead idle	E-lead idle	E-lead idle
		No audio generated	No audio generated	No audio generated	Audio generated
	lmr e-lead inactive	No connection established	No connection established	No connection established	No connection established
		E-lead idle	E-lead idle	E-lead idle	E-lead idle
		No audio generated	No audio generated	No audio generated	Audio generated
	lmr e-lead voice	No connection established	No connection established	No connection established	No connection established
		E-lead idle	E-lead idle	E-lead idle	E-lead idle
		No audio generated	No audio generated	No audio generated	Audio generated
lmr m-lead dialin	lmr e-lead seize	No connection established	No connection established	Connection established	Connection established
		E-lead idle	E-lead idle	E-lead seized until connection torn down	E-lead seized until connection torn down
		No audio generated	No audio generated	No audio generated	Audio generated
	lmr e-lead inactive	No connection established	No connection established	Connection established	Connection established
		E-lead idle	E-lead idle	E-lead idle	E-lead idle
		No audio generated	No audio generated	No audio generated	Audio generated
	lmr e-lead voice	No connection established	No connection established	Connection established	Connection established
		E-lead idle	E-lead idle	E-lead idle	E-lead seize
		No audio generated	No audio generated	No audio generated	Audio generated
lmr m-lead inactive	lmr e-lead seize	No connection established	No connection established	No connection established	No connection established
		E-lead idle	E-lead idle	E-lead idle	E-lead idle
		No audio generated	No audio generated	No audio generated	Audio generated
	lmr e-lead inactive	No connection established	No connection established	No connection established	No connection established
		E-lead idle	E-lead idle	E-lead idle	E-lead idle
		No audio generated	No audio generated	No audio generated	Audio generated
	lmr e-lead voice	No connection established	No connection established	No connection established	No connection established
		E-lead idle	E-lead idle	E-lead idle	E-lead idle
		No audio generated	No audio generated	No audio generated	Audio generated

Table 3-12 Multicast Connection Trunk

Voice Port Configuration Command		M-Lead Idle		M-Lead Seize	
Gateway A	**Gateway B**	**No Audio Supplied**	**Audio Supplied**	**No Audio Supplied**	**Audio Supplied**
lmr m-lead audio-gate-in	lmr e-lead seize	E-lead idle	E-lead idle	E-lead idle	E-lead idle
		No audio generated	No audio generated	No audio generated	Audio generated
	lmr e-lead inactive	E-lead idle	E-lead idle	E-lead idle	E-lead idle
		No audio generated	No audio generated	No audio generated	Audio generated
	lmr e-lead voice	E-lead idle	E-lead idle	E-lead idle	E-lead seize
		No audio generated	No audio generated	No audio generated	Audio generated
lmr m-lead dialin	lmr e-lead seize	E-lead idle	E-lead idle	E-lead idle	E-lead idle
		No audio generated	No audio generated	No audio generated	Audio generated
	lmr e-lead inactive	E-lead idle	E-lead idle	E-lead idle	E-lead idle
		No audio generated	No audio generated	No audio generated	Audio generated
	lmr e-lead voice	E-lead idle	E-lead idle	E-lead idle	E-lead seize
		No audio generated	No audio generated	No audio generated	Audio generated
lmr m-lead inactive	lmr e-lead seize	E-lead idle	E-lead idle	E-lead idle	E-lead idle
		No audio generated	Audio generated	No audio generated	Audio generated
	lmr e-lead inactive	E-lead idle	E-lead idle	E-lead idle	E-lead idle
		No audio generated	Audio generated	No audio generated	Audio generated
	lmr e-lead voice	E-lead idle	E-lead seize	E-lead idle	E-lead seize
		No audio generated	Audio generated	No audio generated	Audio generated

Seize and Idle Bit Patterns

Generally, the LMR signaling behavior described in the previous section works well. However, in the vast domain of potential end systems, there may be those systems that need the E-lead open to indicate PTT or will ground the M-lead to indicate seizure on the COR lead, a sort of reverse polarity. Fortunately, Cisco IOS software has a mechanism to alter how the received signaling is represented internally and how the internal representation is mapped to the transmitted signaling. For example, if a gateway receives a seize signaling packet, it can map this packet to what the physical interface would interpret as an idle pattern. The interface would thus open the E-lead circuit, which would indicate to the device in this example that someone was pushing the PTT button.

Table 3-13 lists the bit conditioning commands that can be applied to a voice port interface and the general operation of the commands.

Table 3-13 Bit Pattern Options

Voice Port Configuration Command	Default Pattern	Behavior
define rx-bits seize ABCD (where ABCD = 0000 through 1111)	1111	Defines the bit pattern to send to the DSP upon receipt of a seize signal on the interface.
define rx-bits idle ABCD	0000	Bit pattern to send to the DSP upon the receipt of an idle signal on the interface.
define tx-bits seize ABCD	1111	Defines the bit pattern to send out the interface when a seize message is received from the network.
define tx-bits idle ABCD	0000	Defines the bit pattern to send out the interface when an idle message is received from the network.

Let us examine how the various bit pattern options operate in a little more detail. The behavior column references the voice port DSPs. The reason for this is twofold. First, conceptually there are three discrete interfaces in the process of converting physical signaling from the LMR endpoints to Real-Time Transport Protocol (RTP) signaling packets. We have the LMR endpoint to the gateway E&M interface, the E&M to the DSP interface and the DSP to the RTP signaling packets interface. Second, the signaling debug commands reference signaling going to and from the DSPs, so it is good to become familiar with that terminology now.

Table 3-14 and Table 3-15 outline the activities that occur on these interfaces. Table 3-14 describes the behavior when the gateway receives a seize or idle state on its M-lead from the LMR endpoint. Table 3-15 describes how the gateway generates a seize or idle state on its E-lead to the LMR endpoint. The signal translation tables referenced in the table are displayed in the **debug vpm signal** command output.

Table 3-14 Signaling from LMR Endpoint to Network

Action	LMR -> E&M	E&M -> DSP	DSP -> RTP
Seize	The LMR device either applies battery (for E&M signaling Types I, II, and III) or grounds (for Type V) the M-lead on the gateway's E&M interface indicating a squelch open (radio terminology) or off-hook (voice terminology) condition.	The E&M interface converts the seize signal to a digital ABCD bit representation of 1111 (0xF) and passes it the DSP.	The DSP looks up the signal state value at position 0xF in the transmit signal translation table. This state value is set with the **define rx-bits seize** command. The default seize bit pattern is 1111. The state value is placed in a signaling RTP packet for transmission across the network.
Idle	The LMR device either grounds the M-lead (for Type I and Type III) or opens the circuit (for Type II and Type V) on the gateway's E&M interface indicating a squelch closed or on-hook condition.	The E&M interface converts the seize signal to a digital ABCD bit representation of 0000 (0x0) and passes it the DSP.	The DSP looks up the signal state value at position 0x0 in the transmit signal translation table. This state value is set with the **define rx-bits idle** command. The default idle bit pattern is 0000. The state value is placed in a signaling RTP packet for transmission across the network.

Table 3-15 Signaling from Network to LMR Endpoint

Action	RTP -> DSP	DSP -> E&M	E&M -> LMR
Seize	When a signaling RTP packet is received from the network, it is passed to the DSP. The DSP looks up the appropriate ABCD bit pattern based on the received signaling state in the receive signal translation table. The ABCD bit pattern corresponds to the pattern set with the **define tx-bits seize** command. The default bit pattern is 1111.	The DSP passes the ABCD bit pattern to the E&M interface. For a seize, the bit pattern will be 1111.	The gateway grounds the E-lead on its E&M interface indicating to the LMR device that the PTT button is depressed (radio terminology), or we have gone off-hook (voice terminology).

Table 3-15 Signaling from Network to LMR Endpoint

Action	RTP -> DSP	DSP -> E&M	E&M -> LMR
Idle	When a signaling RTP packet is received from the network, it is passed to the DSP. The DSP looks up the appropriate ABCD bit pattern based on the received signaling state in the receive signal translation table. The ABCD bit pattern corresponds to the pattern set with the **define tx-bits idle** command. The default bit pattern is 0000.	The DSP passes the ABCD bit pattern to the E&M interface. For an idle, the bit pattern will be 0000.	The gateway opens the E-lead on its E&M interface indicating to the LMR device that the PTT button is released, or we have gone on-hook.

To take the guesswork out of configuring the bit patterns, Table 3-16 documents the gateway E&M interface behavior for all possible lead states and bit patterns. Table 3-16 applies to both digital and analog interfaces. The debug vpm signal command output columns show the output if the **debug vpm signal** command is enabled on the gateway. The default receive and transmit bit patterns, seize = 1111 and idle = 0000, are in bold.

Table 3-16 Interface Behavior for Lead State and Bit Pattern Combinations

M-Lead	rx-bits seize	rx-bits idle	debug vpm signal command output	tx-bits seize	tx-bits idle	debug vpm signal command output	E-Lead
Idle	**1111**	**0000**	`rcv from dsp sig DCBA state 0x0 encap 1`	**1111**	**0000**	`send RTP to dsp sig DCBA state 0x0`	Idle
Idle	**1111**	**0000**	`rcv from dsp sig DCBA state 0x0 encap 1`	1111	1111	`send RTP to dsp sig DCBA state 0x0`	Seize
Idle	**1111**	**0000**	`rcv from dsp sig DCBA state 0x0 encap 1`	0000	1111	`send RTP to dsp sig DCBA state 0x0`	Seize
Idle	**1111**	**0000**	`rcv from dsp sig DCBA state 0x0 encap 1`	0000	0000	`send RTP to dsp sig DCBA state 0x0`	Idle
Idle	**1111**	**1111**	**`rcv from dsp sig DCBA state 0x0 encap 1`**	**1111**	**0000**	`send RTP to dsp sig DCBA state 0x0`	Idle
Idle	**1111**	**1111**	**`rcv from dsp sig DCBA state 0x0 encap 1`**	1111	1111	`send RTP to dsp sig DCBA state 0x0`	Seize
Idle	**1111**	**1111**	**`rcv from dsp sig DCBA state 0x0 encap 1`**	0000	1111	`send RTP to dsp sig DCBA state 0x0`	Seize
Idle	**1111**	**1111**	**`rcv from dsp sig DCBA state 0x0 encap 1`**	0000	0000	`send RTP to dsp sig DCBA state 0x0`	Idle
Idle	0000	1111	`rcv from dsp sig DCBA state 0xF encap 1`	**1111**	**0000**	`send RTP to dsp sig DCBA state 0xF`	Seize
Idle	0000	1111	`rcv from dsp sig DCBA state 0xF encap 1`	1111	1111	`send RTP to dsp sig DCBA state 0xF`	Seize
Idle	0000	1111	`rcv from dsp sig DCBA state 0xF encap 1`	0000	1111	`send RTP to dsp sig DCBA state 0xF`	Idle
Idle	0000	1111	`rcv from dsp sig DCBA state 0xF encap 1`	0000	0000	`send RTP to dsp sig DCBA state 0xF`	Idle

Table 3-16 Interface Behavior for Lead State and Bit Pattern Combinations (continued)

M-Lead	rx-bits seize	rx-bits idle	debug vpm signal command output	tx-bits seize	tx-bits idle	debug vpm signal command output	E-Lead
Idle	0000	0000	rcv from dsp sig DCBA state 0x0 encap 1	**1111**	**0000**	send RTP to dsp sig DCBA state 0x0	Idle
Idle	0000	0000	rcv from dsp sig DCBA state 0x0 encap 1	1111	1111	send RTP to dsp sig DCBA state 0x0	Seize
Idle	0000	0000	rcv from dsp sig DCBA state 0x0 encap 1	0000	1111	send RTP to dsp sig DCBA state 0x0	Seize
Idle	0000	0000	rcv from dsp sig DCBA state 0x0 encap 1	0000	0000	send RTP to dsp sig DCBA state 0x0	Idle
Seize	**1111**	**0000**	**rcv from dsp sig DCBA state 0xF encap 1**	**1111**	**0000**	send RTP to dsp sig DCBA state 0xF	Seize
Seize	**1111**	**0000**	**rcv from dsp sig DCBA state 0xF encap 1**	1111	1111	send RTP to dsp sig DCBA state 0xF	Seize
Seize	**1111**	**0000**	**rcv from dsp sig DCBA state 0xF encap 1**	0000	1111	send RTP to dsp sig DCBA state 0xF	Idle
Seize	**1111**	**0000**	**rcv from dsp sig DCBA state 0xF encap 1**	0000	0000	send RTP to dsp sig DCBA state 0xF	Idle
Seize	**1111**	**1111**	rcv from dsp sig DCBA state 0x0 encap 1	**1111**	**0000**	send RTP to dsp sig DCBA state 0x0	Idle
Seize	**1111**	**1111**	rcv from dsp sig DCBA state 0x0 encap 1	1111	1111	send RTP to dsp sig DCBA state 0x0	Seize
Seize	**1111**	**1111**	rcv from dsp sig DCBA state 0x0 encap 1	0000	1111	send RTP to dsp sig DCBA state 0x0	Seize
Seize	**1111**	**1111**	rcv from dsp sig DCBA state 0x0 encap 1	0000	0000	send RTP to dsp sig DCBA state 0x0	Idle
Seize	0000	1111	rcv from dsp sig DCBA state 0x0 encap 1	**1111**	**0000**	send RTP to dsp sig DCBA state 0x0	Idle
Seize	0000	1111	rcv from dsp sig DCBA state 0x0 encap 1	1111	1111	send RTP to dsp sig DCBA state 0x0	Seize
Seize	0000	1111	rcv from dsp sig DCBA state 0x0 encap 1	0000	1111	send RTP to dsp sig DCBA state 0x0	Seize
Seize	0000	1111	rcv from dsp sig DCBA state 0x0 encap 1	0000	0000	send RTP to dsp sig DCBA state 0x0	Idle
Seize	0000	0000	**rcv from dsp sig DCBA state 0x0 encap 1**	**1111**	**0000**	send RTP to dsp sig DCBA state 0x0	Idle
Seize	0000	0000	**rcv from dsp sig DCBA state 0x0 encap 1**	1111	1111	send RTP to dsp sig DCBA state 0x0	Seize
Seize	0000	0000	**rcv from dsp sig DCBA state 0x0 encap 1**	0000	1111	send RTP to dsp sig DCBA state 0x0	Seize
Seize	0000	0000	**rcv from dsp sig DCBA state 0x0 encap 1**	0000	0000	send RTP to dsp sig DCBA state 0x0	Idle

The rx-bits patterns where both the seize and idle patterns are set to 1111 are in bold also. The behavior for these permutations differs from what you may expect and represents a departure from normal bit conditioning for LMR interfaces only. As outlined previously, if the M-lead registers an idle state, the rx-bits idle pattern is used as the internal state. So, if the M-lead is idle and the rx-bits idle pattern is 0000, the state is 0x0. When the rx-bits idle pattern is 1111, the state is 0xF. However, for the rx-bits patterns where both the seize and idle patterns are set to 1111, the rx-bits idle pattern is 1111, but the state is 0x0.

This behavior was instituted for the unicast connection trunk configurations. With unicast connection trunks, the signaling packets serve a dual purpose as a way to transmit signaling information and as a keepalive mechanism to monitor the health of the connection. So, even if there is no signaling transition on an interface, we will see a signaling packet from each side of the trunk every five seconds, unless the keepalive timer is changed. See the "Connection Initialization" section on page 4-4 for instructions for changing the keepalive timer. The recipient of these keepalive packets will set the E-lead state based on this signaling, even if the E-lead status is set to inactive on the voice port. If one side of the unicast trunk connection is using physical signaling and the other side is not, then to ensure that the lead states do not change, you can either turn off keepalives, which is not recommended, or alter the bit patterns so that idle is always played out on that other side. So, if both the seize and idle rx-bits patterns have the same value (either both 0000 or both 1111), then idle signaling packets are always sent to the other side. The transmitting gateway can then set the tx-bits patterns to either always play a seize or an idle, depending on what is appropriate.

You can determine current bit patterns for the interface with the **show voice port** command as shown in the following example:

```
lmr-3725e# show voice port 1/0/0 | inc ABCD

Rx Seize ABCD bits = 1111 Default pattern
 Rx Idle ABCD bits = 0000 Default pattern
 Tx Seize ABCD bits = 1111 Default pattern
 Tx Idle ABCD bits = 0000 Default pattern
 Ignored Rx ABCD bits = BCD
```

Codec Selection

Cisco VoIP gateways use coder-decoders (codecs), which are integrated circuit devices that typically use pulse code modulation (PCM) to transform analog signals into a digital bit stream and digital signals back into analog signals.

Some codec compression techniques require more processing power than others. Codec complexity is broken into two categories, medium and high complexity. The difference between medium and high complexity codecs is the amount of CPU utilization necessary to process the codec algorithm, and therefore, the number of voice channels that can be supported by a single DSP. Medium complexity codecs support four channels per DSP. High complexity codecs support two channels per DSP. For this reason, all the medium complexity codecs can also be run in high complexity mode, but fewer (usually half) of the channels are available per DSP.

Connections that require the transport of in-band tones for radio control, modem tones, or dual tone multifrequency (DTMF), should use full rate codecs, like G.711. If transcoding is required, it is recommended that transcoding be done only once for any end-to-end connection to minimize impacts to speech quality. Low bit rate codecs can be used if DTMF transmission is required, provided both ends of the connection support compatible out-of-band schemes like DTMF relay using H.245.