Le88221/241

Dual Channel Auto Battery Switching (ABS) VoicePort™ Device

VE880 Series

APPLICATIONS

- **Voice enabled Cable and DSL Modems**
- **Voice over IP/ATM - Integrated Access Devices (IAD)**
- **Residential VoIP Gateways and Routers**
- **Media Terminal Adapters (MTA) Standalone & Embedded**
- **Fiber to the User/Premise/Home (FTTH/P/H), Fiber in the Loop (FITL) Optical Network Terminals (ONT)**
- **Wireless Local Loop (WLL), PBX, ISDN NT1/TA**
- **Set-Top Box, Home Side Box**

FEATURES

- **Complete BORSCHT function in a single VoicePort™ device for two channels**
  - — Battery Feed, Over-voltage support, integrated Ringing, line Supervision, Codec, Hybrid (2W/4W), Test
- **Integrated Power Management**
  - — Integrated high voltage switching regulator controllers
    - – Wide input voltage range (VSW =+3.3V to +35 V)
    - – Generates supplies for VBH, VBM & VBL
  - — Low power Idle and On-hook transmission states
- **Worldwide Programmability**
  - — Two-wire AC impedance, Balance Impedance, Gain
  - — DC feed voltage and current limit
  - — Ringing frequency, voltage and current limit
  - — 12 kHz and 16 kHz Metering
  - — Programmable loop closure and ring trip thresholds
- **Ringing**
  - — 5 REN with pin for pin compatible 100-V (Le88221) and 120-V (Le88241) devices
  - — Up to 110-Vpk internal balanced sinusoidal or trapezoidal ringing with programmable DC offset
  - — Unbalanced ringing for PBX trunk compatibility (Le88241 device only)
- **Powerful signal generator**
  - — Universal Caller ID generation
  - — Up to 4 simultaneous tones
  - — Automatic cadencing feature
- **Subscriber Loop Test/Self Test support**
  - — Comprehensive line sensing
  - — Integrated self test capabilities
  - — Line fault detection and reporting
    - – Loop supervision, AC/DC faults
  - — Test load switch (Le88241)
- **Pin selectable PCM/MPI or GCI interface**
- **G.711 µ-law, A-law, or 16 bit linear coding**
- **Integrated 150 mW 3-V or 5-V Relay Driver**
  - — Supports lifeline POTS in DSL IAD applications
- **Small footprint package - Exposed pad 80-pin LQFP**
- **Minimal external discrete components required**

ORDERING INFORMATION

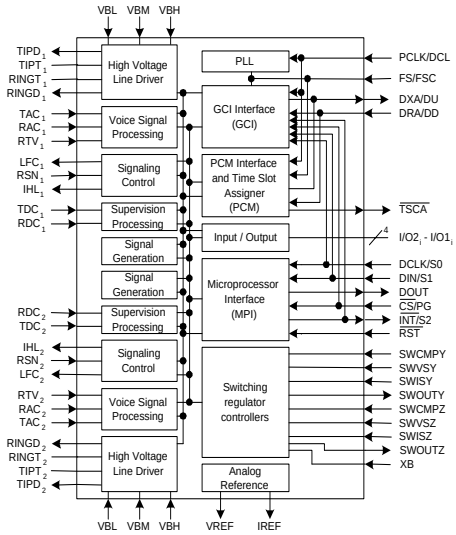
Device OPN	Package Type	Packing[2]
Le88221DLC	80-pin eLQFP (Green)[1]	Tray
Le88241DLC		Tray

1. *The green package meets RoHS Directive 2002/95/EC of the European Council to minimize the environmental impact of electrical equipment.*
2. *For delivery using a tape and reel packing system, add a "T" suffix to the OPN (Ordering Part Number) when placing an order.*

DESCRIPTION

Legerity's Le88221/241 Automatic Battery Switching (ABS) VoicePort™ device implements a dual-channel telephone line interface by providing all the necessary voice interface functions from the high voltage subscriber line to the µP/DSP digital interface. The ABS device can operate from external battery supplies, or from supplies generated by the on-chip switching regulator controllers. This device reduces system level cost, space, and power by achieving the highest level of voice integration possible. Designers benefit by having a simple, cost effective, low-power and dense, interface design without sacrificing features or functionality. The programmable, feature rich VoicePort devices provide a highly functional line interface which meets the requirements of short and medium loop (up to 1500 Ohms total at 1 REN) applications. Features include: high voltage switching regulator, self-test, line test capabilities, integrated ringing (up to 110-Vpk), worldwide software programmability, flexible signal generator with tone cadencing, caller ID generation and all BORSCHT functions. These VoicePort device features are crucial for designing cost-effective, full-featured Voice over Broadband solutions.

VOICEPORT™ DEVICE BLOCK DIAGRAM



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PRODUCT DESCRIPTION

The Le88221/241 device implements a dual-channel universal telephone line interface. This enables the addition of a dual, low cost, high performance, software programmable line interface to DSL modems, cable modems, Integrated Access Devices, SMTA's or set top boxes for multiple country applications worldwide. The Le88221/241 device performs all necessary voice telephony functions from driving a high voltage subscriber telephone line to DSP codec functions in a single package for two lines. All AC, DC, and signaling parameters are fully programmable via microprocessor interfaces. The Le88221/241 device has integrated high voltage switching regulator controllers which can generate the high voltages needed for powering and ringing analog telephones. The high performance architecture permits high efficiency in all operating states and corresponding low power dissipation. Additionally, the Le88221/241 has self-test and line-test support to allow the system to resolve faults to the line or line circuit. The integrated digital access to important line information such as AC and DC line voltage on Tip or Ring and Metallic or Longitudinal currents is crucial for remote applications where dedicated test hardware is not cost effective.

The dual-channel Le88221/241 device is a highly functional voice-over-broadband system that meets the needs of short and medium loop customers. The Le88221/241 devices are targeted toward voice applications and provide all BORSCHT functions. The Le88221 device is a 92-Vpk internal ringing chip that has been optimized for short loop applications. The Le88241 device is a 110-Vpk internal ringing chip that has been optimized for short loop and medium loop applications, can operate in an unbalanced ringing mode, and offers an integrated test load switch.

The device selectively interfaces with a PCM or GCI backplane and can be controlled over the MPI or GCI interface.

The software programmed transmission filter coefficients and supervision data are easily calculated with the WinSLAC™ software. It allows the designer to enter a description of system requirements. WinSLAC then returns the necessary data and plots the predicted system results. This data is then compiled into the VoicePath™ software API to allow easy integration with system software and quickly enable implementation of the required product features.

DETAILED FEATURES OF THE LE88221/241 DEVICE

The Le88221/241 device supports the following features:

- Performs all Battery feed, Ringing, Signaling, Coding, Hybrid and Test (BORSCHT) functions
- Single chip solution provides high voltage line driving, digital signal processing, and high voltage power generation for two or more lines
- Exceeds GR-909 transmission requirements
- Single hardware design meets worldwide requirements through software programming of:
  - Ringing waveform, frequency and amplitude
  - DC loop-feed characteristics and current-limit
  - Loop-supervision detection thresholds
  - Off-hook debounce circuit
  - Ground-key and ring-trip filters
  - Two-wire AC impedance
  - Transhybrid balance impedance
  - Transmit and receive gains
  - Transmit and receive equalization
  - Digital I/O pins
  - A-law/µ-law and linear selection
  - Switching Power Supply
- Supports both loop-start and ground-start signaling
- On-hook transmission
- Power/service denial mode
- Smooth polarity reversal
- Supports wink function
- Neon lamp driving capability
- Metering generation with envelope shaping
  - Programmable metering duration
- Integrated test load switch (Le88241 device)
- Self-contained ringing generation and control
  - Programmable Ringing Cadencing
  - Internal battery-backed balanced or unbalanced, sine or trapezoidal ringing
  - Integrated ring-trip filter and software enabled manual or automatic ring-trip mode
- Flexible tone generation
  - Howler tone generation
  - Call progress tone generation
  - DTMF tone generation
  - Universal Caller ID generation
- Only 3.3 V logic and single battery supply needed
- Integrated switching regulator controller
  - Can generate the battery voltages for each line
  - Line-feed characteristics independent of battery voltage
- MPI, PCM or GCI interfaces
  - Supports most required PCM clock frequencies from 1.024 MHz to 8.192 MHz
- Compatible with inexpensive protection networks; Accommodates low-tolerance fuse resistors while maintaining longitudinal balance
- Monitors two-wire interface voltages and currents for subscriber line diagnostics
- Can monitor and/or drive Tip and Ring independently
- Built-in voice-path test modes
- Integrated self-test features
- Internal relay driver
- –40°C to 85°C operation
- Small physical size in 14 x 14 mm eLQFP

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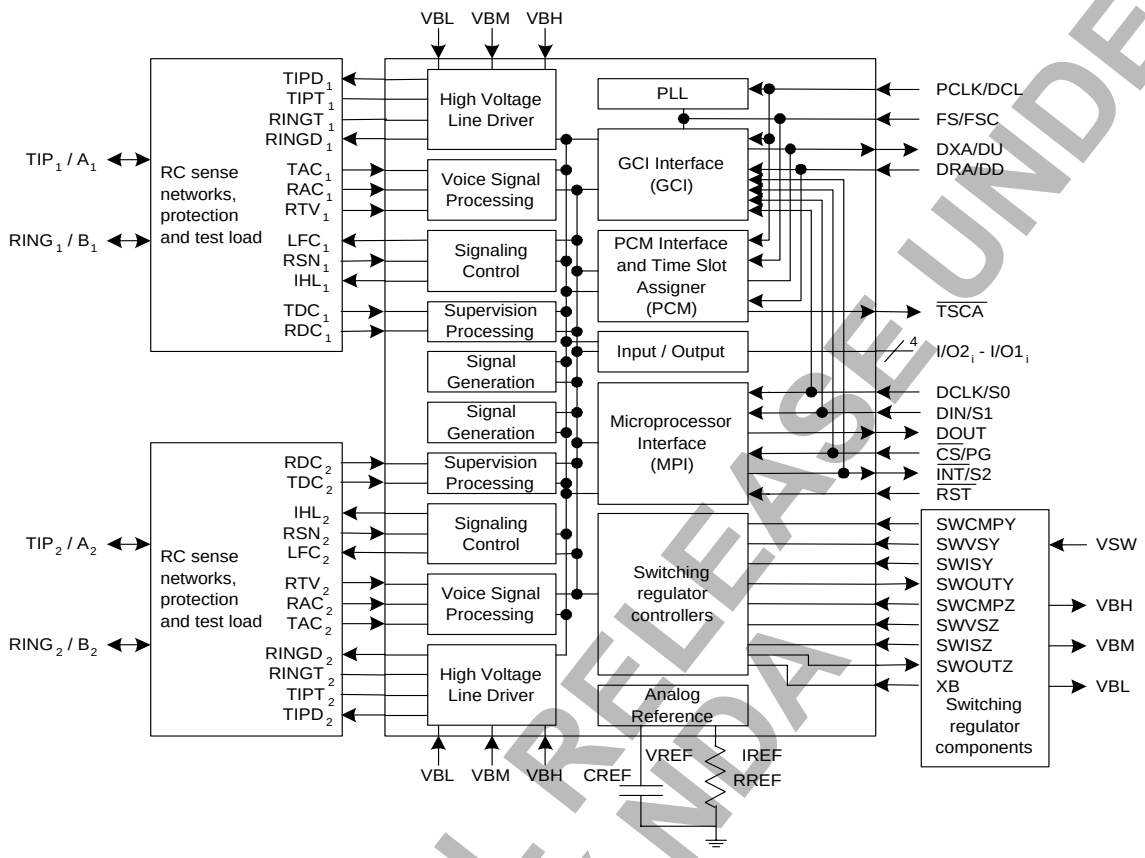
BLOCK DESCRIPTIONS

The Le88221/241 device provides a complete software-configurable solution to BORSCHT functions from digital interface to Tip and Ring for two channels.

The device includes a PLL to generate the necessary clocks for the internal processing functions, digital interfaces implemented in the PCM, MPI and GCI blocks, digital I/O, analog references, switching regulator controllers, voice signal processors, supervision, signalling and signal generation blocks as well as a high voltage line drivers.

Figure 1. Le88221/241 VoicePort™ Block Diagram



Digital Interfaces

The Le88221/241 device offers two digital interface options. The first is PCM/MPI mode, in which separate serial control and voice data interfaces are provided. Voice data is interfaced via a PCM highway with time slot assignment capability, and control information is communicated over the MicroProcessor Interface (MPI). The second is GCI mode, in which a single serial interface supports both voice data and control.

The two modes are mutually exclusive and have different advantages and disadvantages. The PCM/MPI mode is most flexible and allows a wide range of DCLK (MPI data clock) and PCLK (PCM data clock) frequencies. PCM/MPI mode also allows use of the $\overline{\text{INT}}$ interrupt pin to signal pending interrupts to the external controller. GCI mode offers the advantage of using only four signals (FSC, DCL, DU, DD) to carry voice and control data. PCM/MPI mode uses twice as many signals (FS, PCLK, DXA, DRA for voice data and CSL, DCLK, DIN, DOUT for control data) to carry the same information. GCI mode has several disadvantages, however: only 2.048 MHz and 4.096 MHz DCL frequencies are allowed; the control interface is slow (250 µS/byte maximum throughput); and interrupt handling is more complex due to the lack of an interrupt pin. Multifunction pins are implemented to support these different modes while keeping the pin count low.

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PCM and GCI Mode Selection

The Le88221/241 device enters PCM/MPI or GCI modes based on the conditions outlined in Table 1.

The PCM / $\overline{GCI}$ select pin ($\overline{CS}$/PG) is used in combination with the DCLK pin to determine which mode the device is in on power up. If PG is held Low and DCLK is held static, GCI mode is entered 1 ms after power up or hardware reset and the application of valid DCLK and FSC signals. GCI mode will be exited at any time if PG is pulled high or a clock is detected on DCLK.

If PG is High then PCM/MPI mode is entered following power up. At this point, the mode can be changed to GCI if the GCI conditions are met. However, once a command is sent over the MPI interface, GCI mode cannot be entered without resetting the device.

Table 1. PCM/GCI Mode Selection

From mode	To mode	Requirement
Power On or Hardware Reset	PCM	$\overline{CS}$/PG = 1 *or* DCLK has ac clock present
Power On or Hardware Reset	GCI	$\overline{CS}$/PG = 0 *and* DCLK does not have ac clock present
GCI	PCM	$\overline{CS}$/PG = 1 *or* DCLK has ac clock present
PCM	GCI	No commands yet sent in PCM state *and* $\overline{CS}$/PG = 0 (for more than 2 FS) *and* DCLK does not have ac clock present

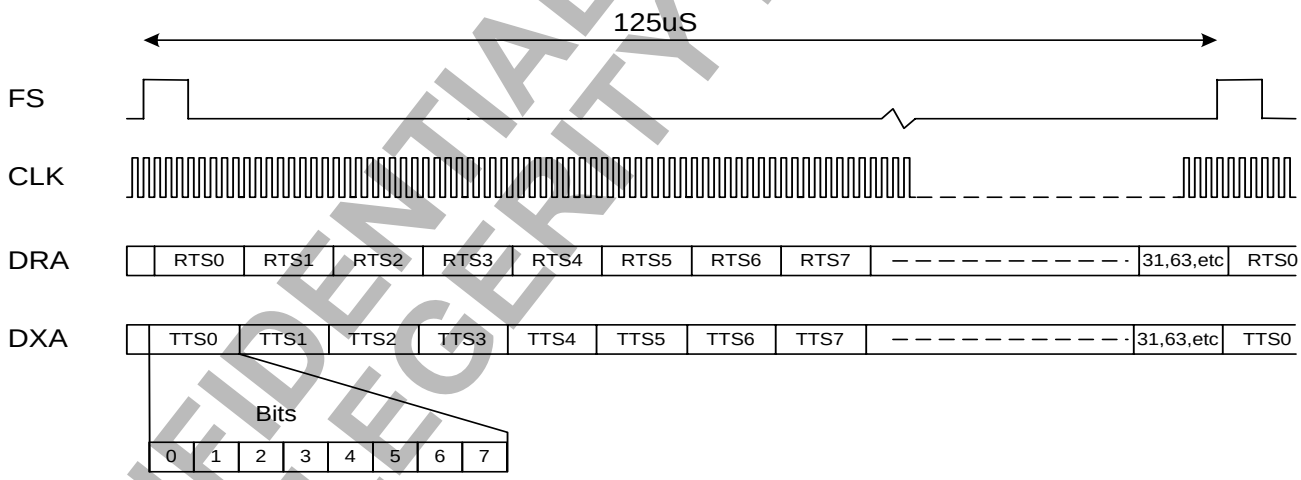
These methods are used to ensure the device operates in the desired mode at all times.

PCM/MPI Interface and Time Slot Assigner (PCM)

This is a synchronized serial mode of communication between the system and the Le88221/241 device. In PCM mode, data can be transmitted/received on a serial PCM highway. This highway uses FS and PCLK as reference.

Data is transmitted out of the DXA pin and received on the DRA pin. The Le88221/241 device transmits/receives single 8-bit time slot (A-law/µ-law) compressed voice data or 16-bit two's complement linear voice data, occupying two conventional time slots. The PCLK is a data clock supplied to the device that determines the rate at which the data is shifted in/out of the PCM ports. The Frame Sync (FS) pulse identifies the beginning of a transmit/receive frame and all time slots are referenced to it. For the Le88221/241 device, the frequency of the FS signal is 8 kHz. The PCLK frequency can be a number of fixed frequencies as defined by command *46/47h Write/Read Device Configuration Register*, on page 65. For each channel, voice data compression and type of coding is selected by the C/L (Compressed/Linear) and A/µ-law bits in command *60/61h Write/Read Operating Functions*, on page 71.

Figure 2. PCM highway structure



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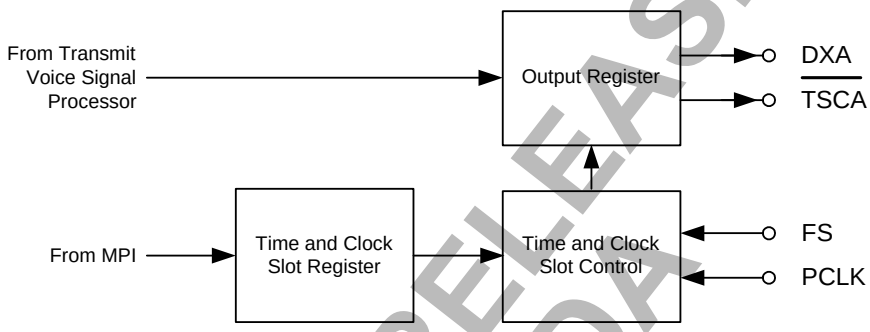
The Le88221/241 device command *44/45h Write/Read Transmit and Receive Clock Slot and Transmit Clock Edge*, on page 65 allows the time slots to be offset to eliminate any clock skew in the system. The Transmit Clock Slot and Receive Clock Slot fields are each three bits wide to offset the time slot assignment by 0 to 7 PCLK periods. The Transmit and Receive Clock Slot is a global command that is applied at the device level. Thus, for each channel, two time slots must be assigned—one for transmitting voice data and the other for receiving voice data. Figure 2 shows the PCM highway time slot structure.

Transmit PCM Interface

The Transmit PCM interface receives a code from the voice signal processor (compressor), which may be either 8 bit compressed code (A-law/µ-law) or a 16-bit two's complement linear code. The transmit PCM interface logic (Figure 3) controls the transmission of the data onto the PCM highway through the output port selection circuitry and the time and clock slot control block. The time slot control signal ($\overline{\text{TSCA}}$) is low whenever PCM data is transmitted on the DXA pin. This signal can be used for arbitration when there are multiple Le88221/241 devices on the PCM bus. The data can be transmitted on either edge of the PCLK. The clock edge on which the data is transmitted is selected by the XE bit in the Transmit and Receive Clock Slot Register (Command 44h/45h).

Command *40/41h Write/Read Transmit Time Slot*, on page 64 allows the time slot of the selected channel to be programmed. The Transmit Time Slot Register allows up to 128 8-bit time slots (using a PCLK of 8.192 MHz) in each frame. The PCLK frequency can be a number of fixed frequencies as defined by command *46/47h Write/Read Device Configuration Register*, on page 65; this means that for compressed data the number of 8-bit time slots can vary between 24 and 128, while linear mode supports between 12 and 64 pairs of time slots. Note that linear mode requires two back-to-back time slots to transmit one voice channel. The data is transmitted in bytes with the most significant bit first. Figure 5, on page 11 illustrates data flow on the PCM highway.

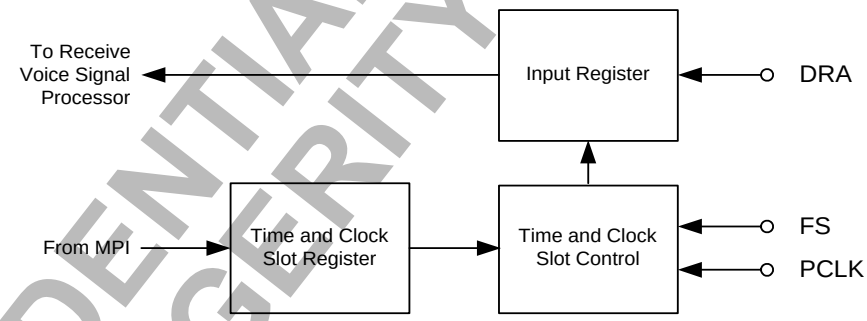
Figure 3. Transmit PCM interface



Receive PCM Interface

The receive PCM interface logic (Figure 4) controls the reception of data bytes from the PCM highway. 8-bit compressed (A-law/µ-law) or 16-bit two's complement linear data is formatted and passed to the voice signal processor (expander).

Figure 4. Receive PCM Interface



Command *42/43h Write/Read Receive Time Slot*, on page 65 allows the time slot of the selected channel to be programmed. The Receive Time Slot Register is 7 bits wide and allows up to 128 8-bit time slots (using a PCLK of 8.192 MHz) in each frame. The PCLK frequency can be a number of fixed frequencies as defined by command *46/47h Write/Read Device Configuration Register*, on page 65; this means that for compressed data the number of 8-bit time slots can vary between 24 and 128, while linear mode supports between 12 and 64 pairs of time slots. Note that linear mode requires two back-to-back time slots to transmit/receive one voice channel. The data is transmitted/received in bytes with the most significant bit first. Figure 5, on page 11 illustrates data flow on the PCM highway.

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Signaling on the PCM Highway

Signaling information can be sent on the PCM output if A- or µ-Law companding is selected and the SMODE bit in command *46/47h Write/Read Device Configuration Register*, on page 65 is set. In this case an extra time slot of signaling data is transmitted every frame immediately after the PCM voice data for the channel (see Figure 5, on page 11) and is transmitted whether or not the voice channel is active. The signaling data is defined in Table 2 and Table 3.

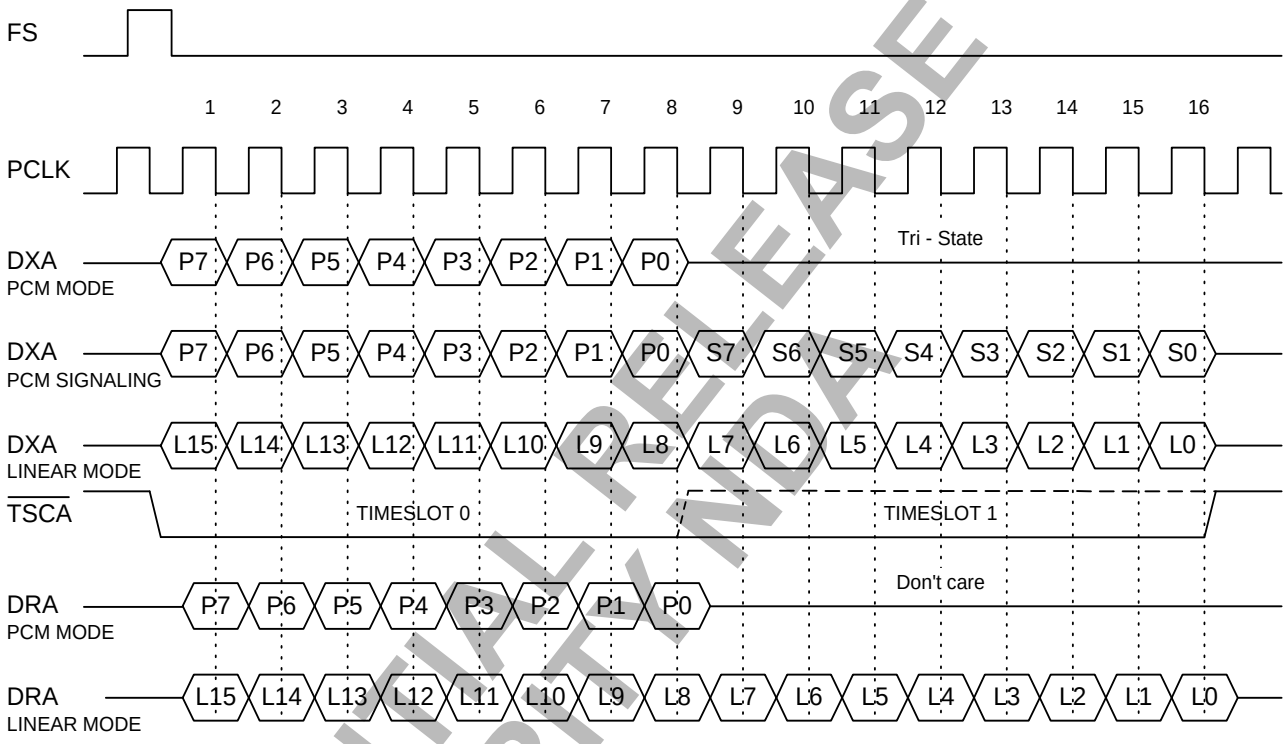
Table 2. PCM Highway Real Time Signaling Data Definition

	S7	S6	S5	S4	S3	S2	S1	S0
Channel 1	CFAIL	$OCALMY_1$	$TEMPA_1$	$IO2_1$	CAD_1	CID_1	GNK_1	$HOOK_1$
Channel 2	DAT	$OCALMZ_2$	$TEMPA_2$	$IO2_2$	CAD_2	CID_2	GNK_2	$HOOK_2$

Default settings, of consecutive time slots for Channel 2, cannot be used with PCM signaling. Also, the monitor A-->D converter output on the PCM highway is in linear mode which conflicts with PCM signaling.

Masking or unmasking of the interrupts in the interrupt mask register does not affect the real time signaling data. See command *4D/4Fh Read Signaling Register*, on page 67 for bit definitions.

Figure 5. PCM Interface Timing for XE = 0 (Transmit Data On Negative PCLK Edge)



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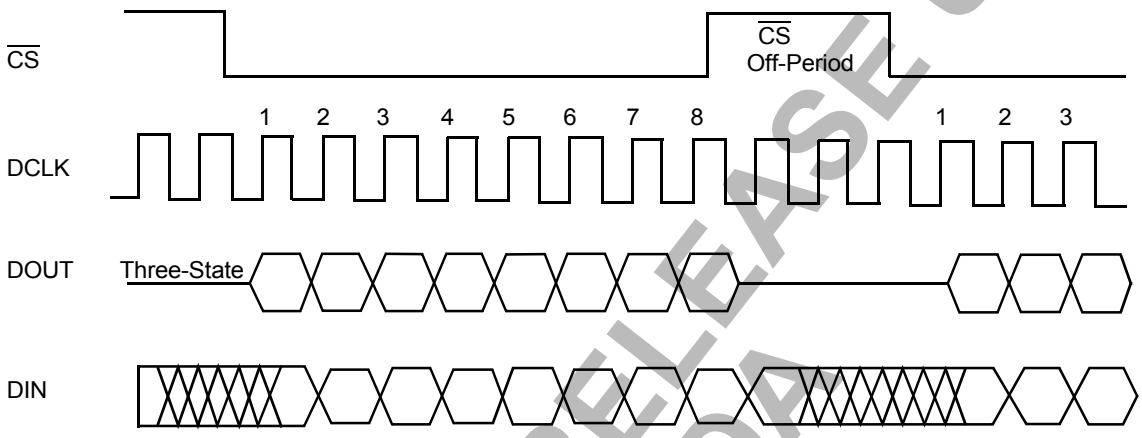
MICROPROCESSOR INTERFACE (MPI)

The microprocessor interface (MPI) block communicates with the external host microprocessor over a serial interface. It passes user control information to the other blocks, and it passes status information back to the external host.

The MPI physically consists of a serial data input (DIN) serial data output (DOUT), a data clock (DCLK), a chip select ($\overline{CS}$) and an interrupt signal ($\overline{INT}$) (see Figure 6, on page 12). The serial input consists of 8-bit commands that can be followed with additional bytes of input data, or can be followed by the Le88221/241 device sending out bytes of data. All data input and output is MSB (D7) first and LSB (D0) last. All data bytes are read or written one at a time, with $\overline{CS}$ going High for at least a minimum off period (see Figure 14, on page 50) before the next byte is read or written. Only a single channel should be enabled during read commands.

All commands that require additional input data to the device must have the input data as the next N words written into the device (for example, framed by the next N transitions of $\overline{CS}$). All unused bits must be programmed to 0 to ensure compatibility with future parts. All commands that are followed by output data will cause the device to output data for the next N transitions of $\overline{CS}$ going Low. The Le88221/241 device will not accept any commands until all the data has been shifted out. The output values of unused bits are not specified. Note that the Voice Channel Enable bits, EC1, EC2 in command *4A/4Bh Write/Read Channel Enable and Operating Mode Register, on page 66* are used to control access to voice channel specific registers within the device.

Figure 6. Microprocessor Interface Timing



An MPI cycle is defined by transitions of $\overline{CS}$ and DCLK. If the $\overline{CS}$ lines are held in the High state between accesses, the DCLK may run continuously with no change to the internal control data. Using this method, the same DCLK can be run to a number of Le88221/241 devices and the individual $\overline{CS}$ lines will select the appropriate device to access. Between command sequences, DCLK can stay in the High state indefinitely with no loss of internal control information regardless of any transitions on the $\overline{CS}$ lines. Between bytes of a multi byte read or write command sequence, DCLK can also stay in the High state indefinitely. DCLK can stay in the Low state indefinitely with no loss of internal control information, provided the $\overline{CS}$ line remains at a High level. If the system controller has a single bi-directional serial data pin, the DOUT pin of the Le88221/241 device can be connected to its DIN pin.

If a low period of $\overline{CS}$ contains less than 8 positive DCLK transitions, it is ignored. If it contains 8 to 15 positive transitions, only the last 8 transitions matter. If it contains 16 or more positive transitions, a hardware reset in the part occurs. If the chip is in the middle of a read sequence when $\overline{CS}$ goes Low, data will be present at the DOUT pin even if DCLK has no activity.

Interrupt Servicing in MPI Mode

The Le88221/241 device has a well-defined interrupt structure. All the interrupts in the Le88221/241 device can be masked. Interrupts are caused only when a status bit is unmasked and the status bit is subsequently set or toggles (depending on the interrupt).

The Le88221/241 device generates interrupts in response to a number of line supervision events. When an interrupt is generated, its status is placed in the *4D/4Fh Read Signaling Register, on page 67*. Multiple interrupts can be reported in the signaling register. When the first interrupt occurs, the interrupt pin, $\overline{INT}$, will be pulled Low to signal the external microprocessor that an interrupt has occurred. When the external microprocessor has serviced the interrupts by reading *4D/4Fh Read Signaling Register* and clearing the interrupt (Command 4Fh) or *CDh Read Transmit PCM/Test Data, on page 82* (if ATI is set), the $\overline{INT}$ pin will go High. An interrupt is generated whenever a signaling register status bit changes (1 to 0 or 0 to 1) and the corresponding mask bit in *6C/6Dh Write/Read Interrupt Mask Register, on page 73* is unmasked. Therefore, the software application is responsible for keeping track of the previous status and deciding the transition type (rising edge transition or falling edge transition). The interrupt pin drive mode can be programmed to be 3.3 V CMOS push/pull or open drain. Signaling status can also be polled without upsetting any pending interrupt status by using command 4Dh.

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The following status bits related to channel 1 and channel 2 can cause an interrupt to occur:

Table 3. Definitions of Status Bits

CFAIL:	PCM clock (PCLK) or 8 kHz frame sync (FS) failure
OCALMY:	Switching regulator Y over current indication
$TEMPA_1$:	Thermal Fault has been detected
$IO2_1$:	Input 2 Status. The input value at $IO2_1$ has changed
CAD_1:	Cadencer interrupt when programmed on period is completed
CID_1:	Caller ID Buffer Ready
GNK_1:	Ground-key status has changed
$HOOK_1$:	Hook status has changed
DAT:	Measurement data available in XDAT register
OCALMZ:	Switching regulator Z over current indication
$TEMPA_2$:	Thermal Fault has been detected
$IO2_2$:	Input 2 Status. The input value at $IO2_2$ has changed
CAD_2:	Cadencer interrupt when programmed on period is completed
CID_2:	Caller ID Buffer Ready
GNK_2:	Ground-key status has changed
$HOOK_2$:	Hook status has changed

General Circuit Interface (GCI)

In GCI mode, this block carries both control and data on the same serial bus, replacing both MPI and PCM functionality. When the $\overline{CS}$/PG device pin is connected to DGND and DCLK/S0 is static (not toggling), GCI operation is selected. The Le88221/241 device conforms to the GCI standard where data for eight GCI packets are combined into one serial bit stream. A GCI packet contains the control and voice data for the two analog channels of the Le88221/241 device. The Le88221/241 device sends Data Upstream out of the DU pin and receives Data Downstream on the DD pin. Data clock rate and frame synchronization information goes to the Le88221/241 device on the DCL (Data Clock) and FSC (Frame Sync.) input pins, respectively.

GCI Format and Command Structure

The GCI interface provides communication of both control and voice data between the GCI highway and subscriber Voice Ports over a single pair of pins on the Le88221/241 device. A complete GCI frame is sent upstream on the DU pin and received downstream on the DD pin every 125 µs. Each frame consists of eight 4-byte GCI packets that contain voice and control information for 8 pairs of channels. The overall structure of the GCI frame is shown in Figure 7. The four-time slot GCI packets contain the following:

- Two voice-data channels
  - B1 provides compressed PCM data for Voice Channel 1
  - B2 provides compressed PCM data for Voice Channel 2
- One Monitor (M) channel for reading and writing control data and coefficients to the chip set in combination with the MX and MR bits in the Signaling and Control channel
- One Signaling and Control (SC) channel containing a 6-bit Command/Indicate (C/I) field for real time control information and a two-bit field with Monitor Receive and Monitor Transmit (MR and MX) bits for handshaking functions linked to the Monitor channel. All principal signaling (real-time critical) information is carried on the C/I channel.

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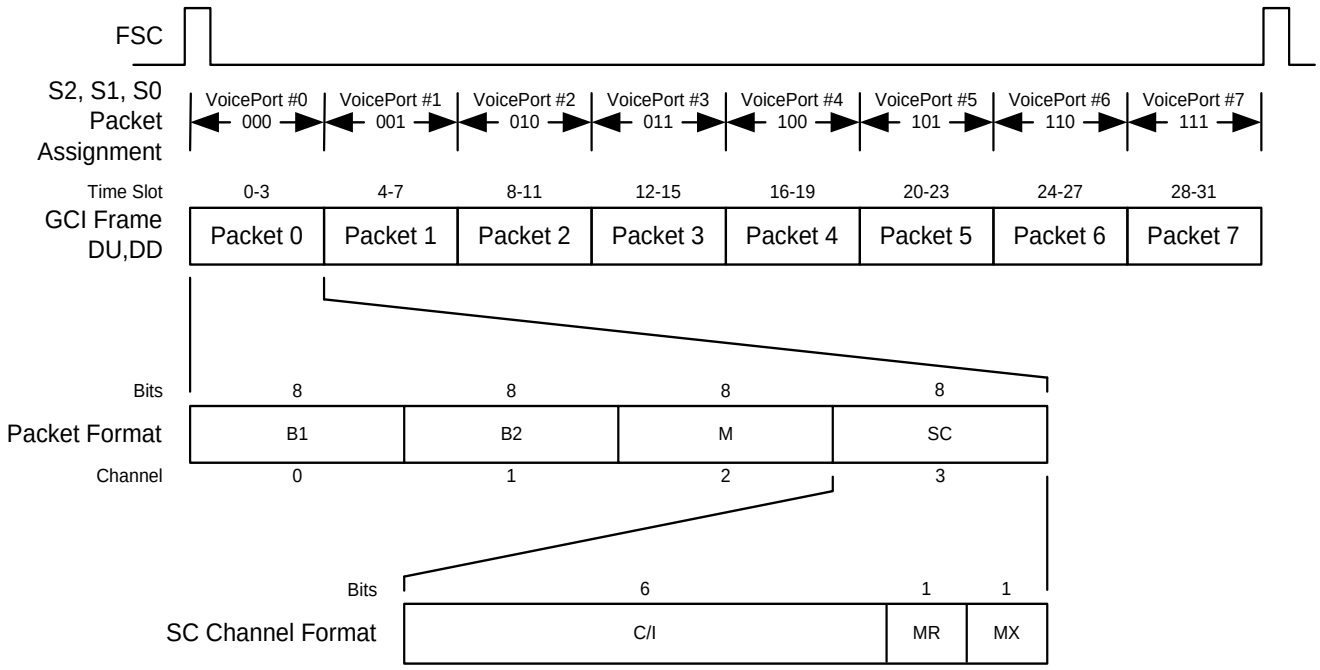
Figure 7. Multiplexed GCI Time Slot Structure



In the packet control block (shown in Figure 8), the Frame Sync (FSC) pulse identifies the beginning of the Transmit and Receive frames and all GCI packets are referenced to it. Voice (B1 and B2), C/I, and Monitor data are sent to the Upstream Multiplexer where they are combined and serially shifted out of the DU pin in the selected GCI packet time slots. The Downstream Demultiplexer uses the same packet control block information to demultiplex the incoming GCI packet into separate voice (B1 and B2), C/I, and Monitor channels.

Table 4. GCI Packet Assignment Codes

$\overline{\text{INT}}$/S2	DIN/S1	DCLK/S0	GCI Packet
DGND	DGND	DGND	0
DGND	DGND	DVDD	1
DGND	DVDD	DGND	2
DGND	DVDD	DVDD	3
DVDD	DGND	DGND	4
DVDD	DGND	DVDD	5
DVDD	DVDD	DGND	6
DVDD	DVDD	DVDD	7

The external clock applied to the DCL pin must be either 2.048 MHz or 4.096 MHz. The Le88221/241 device determines the incoming clock frequency and adjusts internal timing automatically to accommodate single or double clock rates. Correct clock detection can be determined by reading the CSEL bits in *46/47h Write/Read Device Configuration Register*, on page 65. Upstream and Downstream Data is always transmitted at a 2.048 MHz data rate.

The Le88221/241 device supports access to all eight GCI packets (16 analog channels). The S0, S1 and S2 GCI Packet Assignment pins on the Le88221/241 device are encoded as shown in Table 4.

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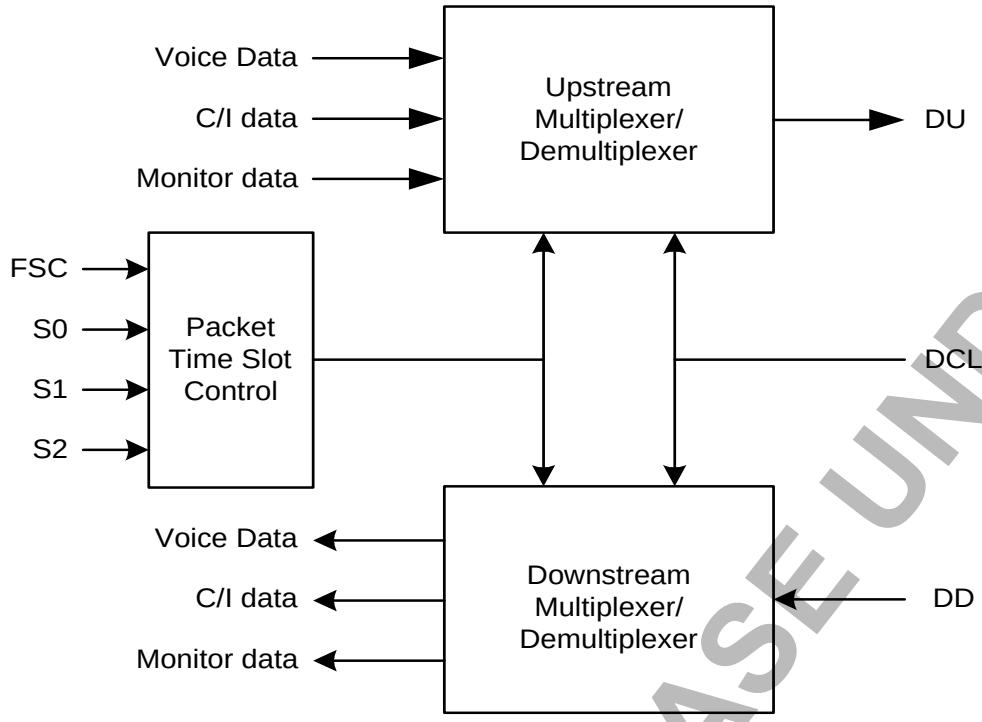
Figure 8. GCI Interface and Packet Time Slot Selection



Signaling and Control (SC)

The downstream and upstream SC channels are continuously sending state control and loop supervision data every frame to and from the Le88221/241 device in the C/I field. This allows the upstream processor to have immediate access to the VoicePort line status. The MR and MX bits are used for handshaking during data exchange on the monitor channel.

The format of the downstream control (C) field is shown in Table 5. The Le88221/241 device receives the most significant bit first.

Table 5. Down Stream SC Channel Definition

Channel	D7	D6	D5	D4	D3	D2	D1	D0
1	A	POLNR	System_State[3:0]				MR	MX

A: Channel address bit.

- 0: Select Channel 1 as the downstream data destination.
- 1: Select Channel 2 as the downstream data destination.

POLNR: VoicePort Feed Polarity

- 0: Normal Polarity feed - TipD more positive than RingD
- 1: Reverse Polarity feed - RingD more positive than TipD

$SS3_i$-$SS0_i$: System State. Valid system states are listed here. All other codes are reserved.

- 0000: Disconnect, ACT = 0
- 0001: Tip Open, ACT = 0
- 0010: Ring Open, ACT = 0
- 0011: Active Low Battery, ACT = 1
- 0100: Idle, ACT = 0
- 0101: Longitudinal Test, ACT = 1
- 0110: Metallic Test, ACT = 1
- 0111: Balanced Ringing, ACT = 1
- 1000: Low Gain, ACT = 1
- 1010: Unbalanced Ringing, ACT = 1
- 1011: Active Mid Battery, ACT = 1
- 1111: Shutdown, ACT = 0

See *56/57h Write/Read System State, on page 70* for more description of the system states.

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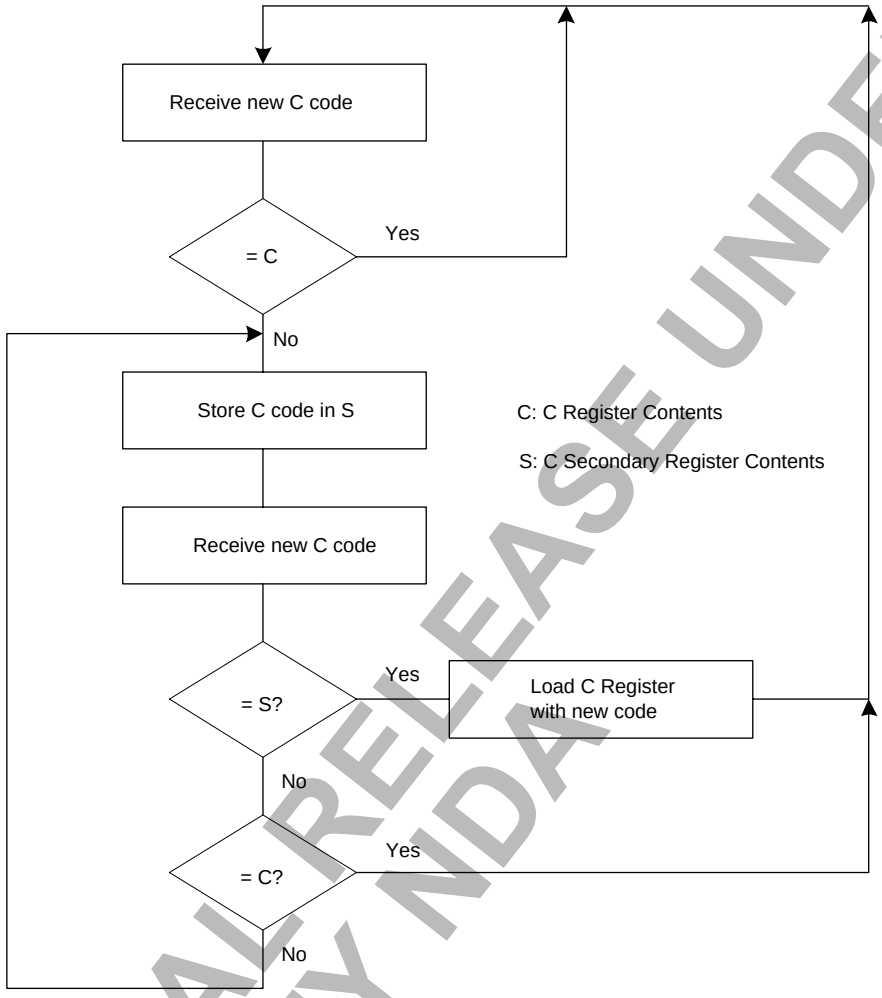
Figure 9 shows a flow chart describing the transmission protocol for the downstream channel, which provides a high level of security for the C field data exchange. Whenever the received pattern of C bits 6 through 1 is different from the pattern currently in the C input register, the new pattern is loaded into a secondary C register, and a latch is set. When the next pattern is received (in the following frame) while the latch is set, the following rules apply:

Figure 9. Security Procedure For C Downstream Byte



- If the received pattern corresponds to the pattern in the secondary register, the new pattern is loaded into the C register, and the latch is reset.
- If the received pattern is different from the pattern in the secondary register and different from the pattern currently in the C register, the newly received pattern is loaded into the secondary C register, and the latch remains set.
- If the received pattern is the same as the pattern currently in the C register, the C register is unchanged, and the latch is reset.

The format of the upstream indication (I) field is shown in Table 6. The Le88221/241 device transmits the I field most significant bit first each frame.

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Table 6. Upstream SC Channel

D7	D6	D5	D4	D3	D2	D1	D0
$SLCX_2$	GNK_2	$HOOK_2$	$SLCX_1$	GNK_1	$HOOK_1$	MR	MX

$SLCX_2$ Summary output of the Channel 2 Signaling Register

1: One or more of the unmasked bits in the Signaling Register has toggled.
0: None of the unmasked bits in the Signaling Register has toggled.
This is a logic "or" of $TEMPA_2$, DAT, $IO2_2$, CAD_2, GNK_2, $HOOK_2$ and $OCALM_2$. This bit is reset when the signalling register is read using the 4F read and clear interrupt from *4D/4Fh Read Signaling Register*, on page 67.

GNK_2: Indication if a ground connection is taking place

1: Ground connection
0: No ground connection

$HOOK_2$: Indication of loop condition

1: Subscriber is off-hook
0: Subscriber is on-hook

$SLCX_1$ Summary output of the Channel 1 Signaling Register

1: One or more of the unmasked bits in the Signaling Register has toggled.
0: None of the unmasked bits in the Signaling Register has toggled.
This is a logic "or" of $TEMPA_1$, CFAIL, $IO2_1$, CAD_1, GNK_1, $HOOK_1$ and $OCALM_1$. This bit is reset when the signalling register is read using the 4F read and clear interrupt from *4D/4Fh Read Signaling Register*, on page 67.

GNK_1: Indication if a ground connection is taking place

1: Ground connection
0: No ground connection

$HOOK_1$: Indication of loop condition

1: Subscriber is off-hook
0: Subscriber is on-hook

Data from the loop supervision circuitry (with applicable debouncing) is latched by a derivative of Frame Sync every 125 µs. This real-time latched data is transmitted upstream in the I field every frame (125 µs). Note that it is not the data in the Signaling Register. Hence masking or unmasking of the HOOK and GNK interrupts in the interrupt mask register will not affect the HOOK and GNK data in the SC channel.

Monitor Channel Protocol

The Monitor (M) channel (see Figure 10) loads the Le88221/241 device internal device registers, reads the status of the device and the contents of the internal registers, and provides supplementary signaling. Information is transferred on the Monitor Channel using the MR and MX bits of the third (SC) channel to provide a reliable method of data exchange between the higher level processor and the Le88221/241 device (see Figure 10).

The monitor channel is the third channel in the 4-channel packet sent and received every 125 µs. A monitor command consists of one address byte and one or more command bytes followed by additional bytes of input data. The command can be followed by the Le88221/241 device sending data bytes upstream via the DU pin.

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Figure 10. Maximum Speed Monitor Handshake Timing

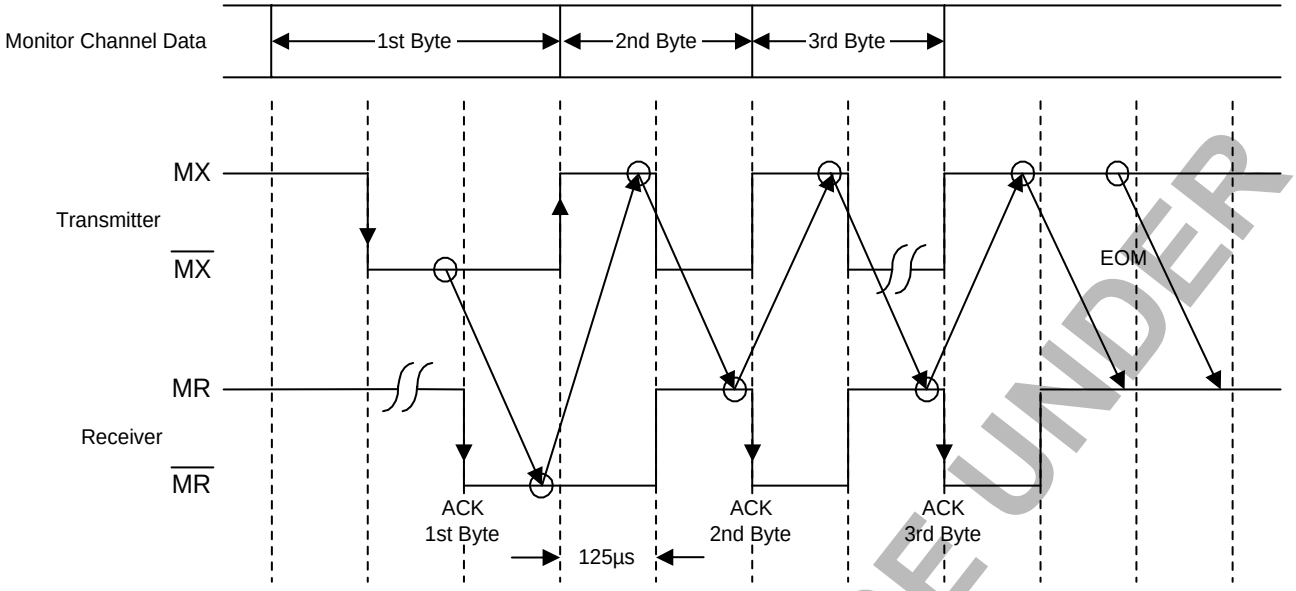
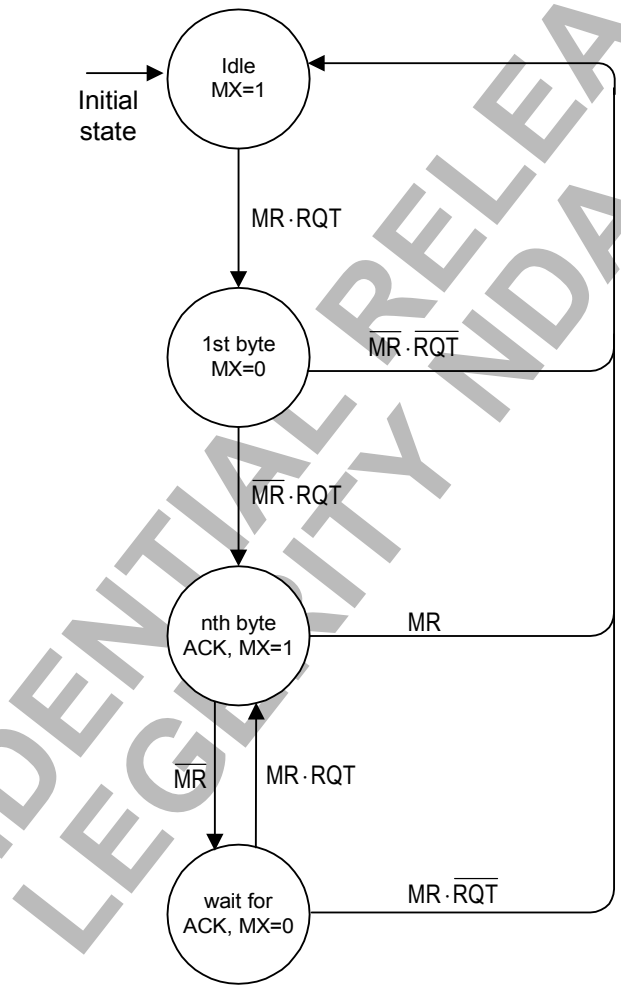


Figure 11. Monitor Transmitter Mode Diagram



MR ... MR - bit received
MX ... MX - bit calculated and expected on the DU line
RQT ... Request for transmission from internal source

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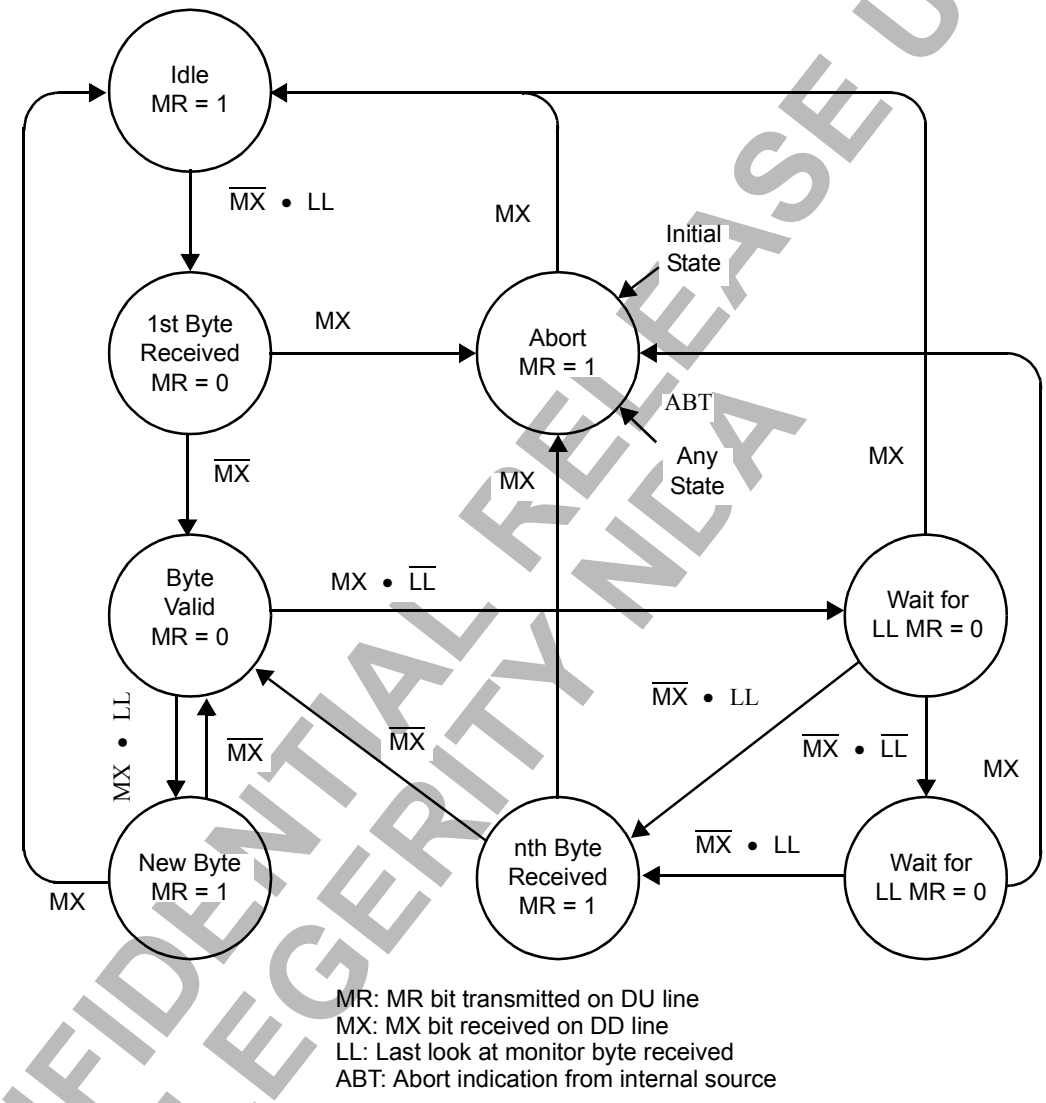
- An inactive (High) MX and MR pair bit for two or more consecutive frames shows an idle state on the monitor channel and the end of message (EOM).
- Figure 10 shows that transmission is initiated by the transition of the transmitter MX bit from the inactive to the active state. The transition coincides with the beginning of the first byte sent on the monitor channel. The receiver acknowledges the first byte by setting MR bit to active and keeping it active for at least one more frame.
- The same data must be received in two consecutive frames in order to be accepted by the receiver.
- The same byte is sent in each of the succeeding frames until either a new byte is transmitted, the message ends, or an abort occurs. Any abort command resets any pending commands in the Le88221/241 device. The device remains in the previous configuration and is ready to receive a new command.
- Any false MX or MR bit received by the receiver or transmitter leads to a request-for-abort or an abort, respectively.
- To obtain maximum data transfer speed, the transmitter anticipates the falling edge of the receiver's acknowledgment as shown in Figure 10.

Figure 11 and Figure 12 are state diagrams that define the operation of the monitor transmitter and receiver sections in the Le88221/241 device.

Figure 12. Monitor Receiver Mode Diagram



MR: MR bit transmitted on DU line
MX: MX bit received on DD line
LL: Last look at monitor byte received
ABT: Abort indication from internal source

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Programming with the Monitor Channel

The Le88221/241 device uses the monitor channel for the transfer of status or mode information to and from higher level processors. The higher level processor is synchronized to the Le88221/241 device using the time slot straps S0, S1 and S2.

The messages transmitted in the monitor channel have different structures. The first byte of monitor channel data in the GCI format indicates the address of the device either sending or receiving the data. All monitor channel messages to/from the Le88221/241 device begin with this address byte:

Bit	7	6	5	4	3	2	1	0
Address	1	0	0	A	B	0	0	C

A

0: Channel 1 is the source (upstream) or destination (downstream)
1: Channel 2 is the source (upstream) or destination (downstream)

B

0: Data destination determined by A
1: Both Channel 1 and 2 receive the data

C

0: Address for channel identification command
1: Address for all other commands

Transmission in the GCI monitor channel starts with an address byte followed by a command byte. If the command byte specifies a write, from 1 to 14 additional data bytes can follow (see Table 7). If the command byte specifies a read, additional data bytes can follow. The Le88221/241 device responds to the read command by sending out the original address byte and up to 14 bytes upstream that contain the information requested by the upstream controller. Generic byte transmission sequence over the GCI monitor channel is shown in Table 7.

Table 7. Monitor Byte Transmission Sequence

GCI Monitor Channel	
Downstream	**Upstream**
ADDRESS Control byte, write Data byte 1* • Data byte m* ADDRESS Control byte, read m ≤ 14	 Data byte 1 • Data Byte n* n ≤ 14

Note:
** May or may not be present*

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Channel Identification Command (CIC)

When the monitor channel address byte is 80H or 90H, a command of 00H is interpreted by the Le88221/241 device as a two-byte Channel Identification Command (CIC).

The format for this command is shown next:

	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
Address Byte	1	0	0	A	0	0	0	0
Command Byte	0	0	0	0	0	0	0	0

A

0: Channel 1 is the destination
1: Channel 2 is the destination

Immediately after the last bit of the CIC command is received, the Le88221/241 device responds with the two-byte channel ID code indicating an analog transceiver device type in bits 6 and 7 of byte 2, with the following configuration options:

	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
Byte 1	1	0	0	A	PCN4	PCN3	PCN2	PCN1
Byte 2	1	0	0	0	0	1	1	1

A

0: Channel 1 is the destination
1: Channel 2 is the destination

PCN[4:1] Product Code Number

Ch Le88221 device
Dh Le88241 device

When the Le88221/241 device has completed transmission of the channel ID information, it sends an EOM (MX = 1 for two successive frames) on the upstream C/I channel. The Le88221/241 device also expects an EOM to be received on the downstream C/I channel before any further message sequences are received.

General Structure of Other Commands

When the monitor channel address byte is 81h, 89h, 91h, or 99h, the command byte is interpreted by the Le88221/241 device as either a Transfer Operation (TOP), Status Operation (SOP), or a Coefficient Operation (COP).

	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
Address Byte	1	0	0	A	B	0	0	1

A

0: Channel 1 is the source (upstream) or destination (downstream)
1: Channel 2 is the source (upstream) or destination (downstream)

B

0: Data destination determined by A
1: Both Channel 1 and 2 receive the data

Commands are sent to the Le88221/241 device to:

- Read the status of the system without changing its operation
- Write/read the Le88221/241 device operating mode
- Write/read filter coefficients

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Input / Output Block

This block controls general-purpose pins that can be configured by the user as inputs, outputs, or relay drivers. CMOS-compatible I/O pins (I/O1 and I/O2) are provided per channel. I/O1 can act either as a standard digital input, as a CMOS output, or can be configured as a 5-V tolerant open drain relay driver. When configured as such, it is capable of directly driving a 150-mW 3-V or 5-V relay and has an integrated protection circuit. I/O2 is a standard digital I/O pin that can also generate interrupts when configured as an input. The pins are accessed using Command *52/53h Write/Read Input/Output Data Register,* on page 69. The direction of the I/O pins (input or output) and output type is specified by programming *54/55h Write/Read Input/Output Direction Register,* on page 70.

Voice Signal Processors

This block performs digital signal processing for the transmission and reception of voice. It includes G.711 compression/ decompression, impedance matching, filtering, gain control, DTMF generation and general-purpose tone generators for each channel. Additionally caller ID FSK generation and metering generation are provided.

This block performs the codec and filter functions associated with the four-wire section of the subscriber line circuitry in a digital switch. These functions involve converting an analog voice signal into digital PCM samples and converting digital PCM samples back into an analog signal. During conversion, digital filters are used to band-limit the voice signals.

The user-programmable filters perform the following functions:

- Sets the receive and transmit gain
- Performs the transhybrid balancing function
- Permits adjustment of the two-wire termination impedance
- Provides frequency attenuation adjustment (equalization) of the receive and transmit paths

All programmable digital filter coefficients can be calculated using Legerity's WinSLAC software. The PCM codes can be either 16-bit linear two's-complement or 8-bit companded A-law or µ-law.

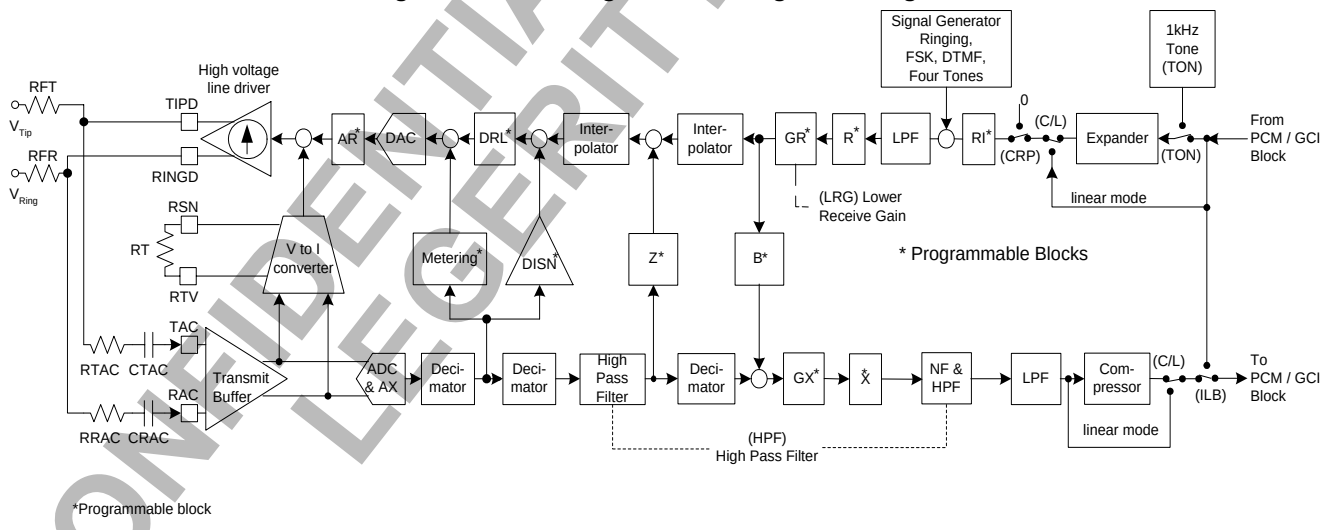
Overview of Digital Filters

Several of the blocks in the signal processing section are user programmable. These allow the user to optimize the performance of the Le88221/241 device for the system. Figure 13 shows the Le88221/241 device signal processing for one channel and indicates the programmable blocks and how this section interfaces with the high voltage line driver and line sensing circuits.

The advantages of digital filters are:

- High reliability
- No drift with time or temperature
- Unit-to-unit repeatability
- Superior transmission performance
- Flexibility
- Maximum bandwidth for V.90 modems

Figure 13. Voice Signal Processing Block Diagram



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Analog Impedance Synthesis

The analog impedance synthesis loop is comprised of the high voltage line driver, the AC sense path components, the transmit amplifier, and a voltage to current converter. Nominally, this converter uses an external resistor, R_T. R_T synthesizes the nominal impedance in the analog domain.

Two-Wire Impedance Matching

Two feedback paths in the voice signal processor modify the two-wire input impedance by providing a programmable feedback path from the AC sense path to the line driver outputs.

The DISN path is comprised of the voice A/D and its first stage of decimation, a Digital Impedance Scaling Network (DISN), and the voice DAC. The DISN synthesizes a portion of the ac impedance which appears in parallel with R_T and is used to modify the impedance set by the external analog network. The DISN is controlled by an 8-bit word. See *CA/CBh Write/Read Digital Impedance Scaling Network (DISN)*, on page 82.

The Z filter is a programmable digital filter providing an additional path and programming flexibility over the DISN in modifying the transfer function of the synthesis loop. Together, the RT, DISN, and Z-Filter enable the user to synthesize virtually all required telephony device input impedances.See *98/99h Write/Read Z Filter FIR Coefficients*, on page 78 and *9A/9Bh Write/Read Z Filter IIR Coefficients*, on page 78.

Frequency Response Correction and Equalization

The voice signal processor contains programmable filters in the receive (R) and transmit (X) directions that may be programmed for line equalization and to correct any attenuation distortion caused by the Z filter. See *8A/8Bh Write/Read R Filter Coefficients*, on page 77 and *88/89h Write/Read X Filter Coefficients*, on page 76.

Transhybrid Balancing

The voice signal processor's programmable B filter is used to adjust transhybrid balance. The filter has a single pole IIR section (BIIR) and an eight-tap FIR section (BFIR), both operating at 16 kHz. See *86/87h Write/Read B Filter FIR Coefficients*, on page 75 and *96/97h Write/Read B Filter IIR Coefficients*, on page 78.

Gain Adjustment

The transmit path has two programmable gain blocks. Gain block AX is an analog gain of 0 dB or 6.02 dB (unity gain or gain of 2.0), located immediately before the A/D converter. See *50/51h Write/Read Voice Path Gains*, on page 69. GX is a digital gain block that is programmable from 0 dB to +12 dB, with a worst-case step size of 0.1 dB for gain settings below +10 dB, and a worst-case step size of 0.3 dB for gain settings above +10 dB. The filters provide a net gain in the range of 0 dB to 18 dB. See *80/81h Write/Read GX Filter Coefficients*, on page 74.

The receive voice path has three programmable gain blocks. GR is a digital loss block that is programmable from 0 dB to 12 dB, with a worst-case step size of 0.1 dB. See *82/83h Write/Read GR Filter Coefficients*, on page 75. DRL is a digital loss block of 0 dB or 6.02dB. AR is an analog gain of 0 dB or 6.02 dB (unity gain or gain of 2) or a loss of 6.02 dB (gain of 0.5), located immediately after the D/A converter. See *50/51h Write/Read Voice Path Gains*, on page 69. This provides a net loss in the range of 0 dB to 18 dB.

Metering is affected by the AR gain block. To achieve the specified levels, the DRL loss is enabled, and AR gain is applied whenever metering is used.

Transmit Signal Processing

In the transmit path (A/D), the AC Tip - Ring analog input signal is sensed by the TAC and RAC pins, buffered, amplified by the analog AX gain and sampled by the A/D converter, filtered, companded (for A-law or µ-law), and made available to the PCM or GCI blocks. Linear mode is only available in the PCM/MPI mode. If linear format is selected, the 16-bit data will be transmitted in two consecutive time slots starting at the programmed time slot. The B, X, and GX digital filter blocks are user-programmable digital filter sections with coefficients stored in the coefficient RAM. The B, X, and GX filters can also be operated from an alternate set of default coefficients stored in ROM. See *60/61h Write/Read Operating Functions*, on page 71.

The first high-pass filter is for DC rejection, and the second high pass and notch filters reject low frequencies such as 50 Hz or 60 Hz. All of these filters may be disabled with the DHP bit in command *70/71h Write/Read Operating Conditions*, on page 73.

Receive Signal Processing

In the receive path (D/A), the digital signal is expanded (for A-law or µ-law), filtered, interpolated, converted to analog, and driven onto the TIPD and RINGD pins by the high voltage line driver. The DRL, DISN, Z, R, and GR blocks are user-programmable filter sections with their coefficients stored in the coefficient RAM, while AR is an analog amplifier. The Z, R, GR and RI filters can also be operated from an alternate set of default coefficients stored in ROM. See *60/61h Write/Read Operating Functions*, on page 71.

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Programmable Filters

The filter coefficients that the user sends to the voice ALU are in a form known as Canonical Signed Digits (CSDs). The coefficients take the following general form:

$$h = I0 + C1 \bullet 2^{-m1} \bullet (1 + C2 \bullet 2^{-m2} \bullet (1 + I3 \bullet C3 \bullet 2^{-m3} \bullet (1 + I4 \bullet C4 \bullet 2^{-m4})))$$

where: Cj = –1 or +1 (represented as 1 or 0 in user programming)

mj = 0, 1, 2,... or 7 (user programming)

I0 = 1 for GX; I0 = 0 for all other coefficients

I4 = 1 for 4 • CSD coefficients; I4 = 0 otherwise

I3 = 1 for 3 and 4 CSD coefficients; I3 = 0 for 2 CSD coefficients

Calculating Coefficients with WinSLAC™ Software

The WinSLAC™ software is a program that models the Le88221/241 device, the line conditions, and the external VoicePort components to calculate the coefficients of the programmable filters and predict important transmission performance plots.

The following parameters relating to the desired line conditions and the external components are provided as input to the program:

- Line impedance or the balance impedance of the line is specified by the local telephone system.
- Desired two-wire impedance that is to appear at the line card terminals of the exchange.
- Tabular data for templates describing the frequency response or attenuation distortion limits of the design.
- Relative analog signal levels for both the transmit and receive two-wire signals.
- Component values for the analog portion of the VoicePort.
- Two-wire return loss template that is usually specified by the local telephone system.
- Four-wire return loss template that is usually specified by the local telephone system.

The output from the WinSLAC program includes the coefficients of the AR, AX, DRL, DISN, GR, GX, Z, R, X, and B filters as well as transmission performance plots of stability, input impedance, two-wire return loss, receive and transmit path frequency responses, and four-wire return loss.

The coefficients are formatted in a way that allows easy integration with the VoicePath API software or VP Script demonstration software.

Speech Coding

The A/D and D/A conversion follows either the A-law or the µ-law standard as defined in ITU-T Recommendation G.711. A-law or µ-law operation is programmed using command *60/61h Write/Read Operating Functions*, on page 71. Alternate bit inversion is performed as part of the A-law coding. In PCM/MPI mode linear code is an option on both the transmit and receive sides of the device. Linear code is also selected using Command 60/61h. Two successive time slots are required for linear code operation. The linear code is a 16-bit two's-complement number which appears sign bit first on the PCM highway.

Voice Path Test States and Operating Conditions (per channel)

The Le88221/241 device supports testing by providing test states and special operating conditions as shown in Figure 13, on page 22 (see *70/71h Write/Read Operating Conditions*, on page 73).

Cutoff Transmit Path (CTP): When CTP = 1, DXA and $\overline{\text{TSCA}}$ are high impedance and the transmit time slot does not exist. This state takes precedence over the Interface Loopback (ILB).

Cutoff Receive Path (CRP): When CRP = 1, the receive signal is forced to 0 just ahead of the low pass filter (LPF) block. This state blocks the 1 kHz receive tone (TON). The signal generators can still be used to send signals in the receive path.

High Pass Filter disable (HPF): When HPF = 1, all of the high pass and notch filters in the transmit path are disabled.

Lower Receive Gain (LRG): When LRG = 1, an extra 6.02 dB of digital loss is inserted into the receive path.

Interface Loopback (ILB): When ILB = 1, data from the TSA receive time slot is looped back to the TSA transmit time slot. Any other data in the transmit path is overwritten.

1 kHz Receive Tone (TON): When TON = 1, a 1 kHz digital mW is injected into the receive path, replacing any receive signal from the TSA.

Signal Generation and Cadence Control

Up to five digital signal generators are available for each channel (see Figure 14) that are summed into the receive path, as shown in Figure 13. They are configured with commands *D2/D3h Write/Read Signal Generator A, B and Bias Parameters.*, on page 84 and *D4/D5h Write/Read Signal Generator C and D Parameters.*, on page 86 and controlled with command *DE/DFh*

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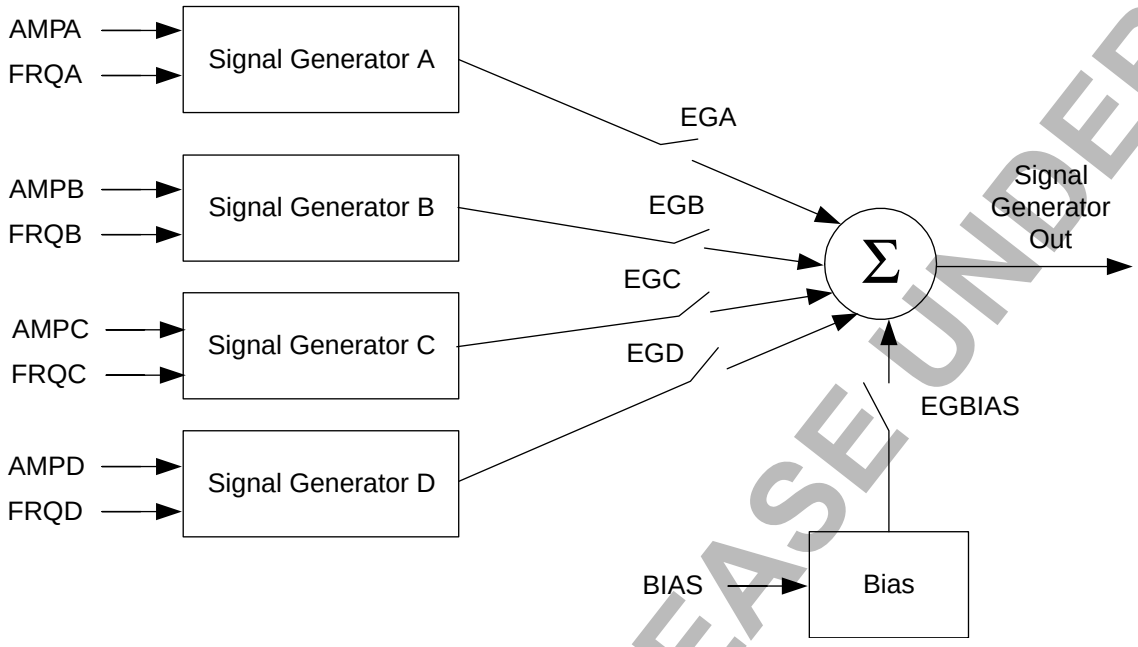
Write/Read Signal Generator Control, on page 87 in combination with the cadencer configuration in *E0/E1h Write/Read Cadence Timer*, on page 88.

The Bias generator produces a DC bias that can be used to provide DC offset during ringing or DC test signals during diagnostic tests. This generator is automatically enabled when entering the ringing state.

Figure 14. Signal Generator



Signal Generator A is used for ringing signal generation and is automatically enabled when entering the ringing state. It can produce sinusoidal or trapezoidal signals. When generating a trapezoid, Signal Generator B is not available and some of its parameters are used to configure the trapezoid.

In addition, Signal Generator A can be used with the Bias Generator to produce slow ramps. This allows a complex sequence of diagnostic test voltages to be generated in a controlled manner without generating unwanted transients on the line.

When available, Signal Generator B produces a programmable sine wave and can be used for call progress tone generation.

Signal generators C and D are also used for call progress tone generation, DTMF generation and can be configured for FSK based Caller ID generation in combination with command *EA/EBh Write/Read Caller Identification Number Parameters*, on page 91.

Each generator has independent frequency and amplitude parameters. The frequency accuracy is basically the same as the crystal accuracy of the system. The amplitude accuracy and spectral purity are limited only by the voice DAC.

Cadencing

The signal generator may be sequenced with an on and off time controlled by the user. This feature allows the Le88221/241 device to automatically cadence the ringing bursts. The cadence function can also be used to control the general purpose signal generator during the Active state to send call progress or other specialized tones. Additionally, the sequencer may be used as a general purpose timer/counter which can send interrupts to the user's micro controller after timing out events.

The cadencer has 5 ms resolution, with a maximum on time of 10.24 s and a maximum off time of 10.24 s. See *E0/E1h Write/Read Cadence Timer*, on page 88. It is enabled with the SGCAD bit in command *DE/DFh Write/Read Signal Generator Control*, on page 87. The CAD bit in the Signalling register is set at the end of the on period, and this event can generate an interrupt if the bit is unmasked.

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Calling Number Identification (CID)

The CID block uses tone generators C and D for each channel to generate phase continuous 1200 baud FSK tones for on or off hook data transmission such as caller ID information. The duration of each (bit) tone is fixed at 0.833 ms (1200 baud).

When the CID bit is 0 (space), the transmitted tone is from signal generator C

When the CID bit is 1 (mark), the transmitted tone is from signal generator D

The typical configurations for signal generators C and D when used for CID is shown in Table 8.

The GR-30 frequencies are used in the US market, and the V.23 frequencies are used in most other international markets. The signal generator amplitude may need to be adjusted depending on the programmed loss plan. Data transmission levels are normally specified as -13.5 dBm +/-1.5 dB. The default amplitude of -7 dBm0 can be used if the programmed receive relative level is -6 or -7 dBr. The amplitudes of AMPC and AMPD are normally set equal, and the dBm0 level from the generator is given by

$$AC(dBm0) = 20 \cdot \log\left(\frac{|AMPCd|}{22827}\right)$$

$$AD(dBm0) = 20 \cdot \log\left(\frac{|AMPDd|}{22827}\right)$$

The programmed parameters FRQC and FRQD can be determined with the following equations:

$$FRQCh = (FC \bullet 2.73)h$$

$$FRQDh = (FD \bullet 2.73)h$$

From the CID block point of view, once generators C and D have been programmed, the CID generation is configured and can be monitored using command *EA/EBh Write/Read Caller Identification Number Parameters*, on page 91 which allows control of framing, end of message, and disabling the block. Information to be transmitted is received from the MPI as a string of characters using command *E2/E3h Write/Read Caller Identification Number Data*, on page 88. Each character is 8 bits wide, and is assumed to include appropriate parity information according to the character set being used. If framing is enabled, for each character, the CID block first transmits a start bit, then it serially transmits the 8-bit character, LSB first, followed by a stop bit, giving a total of 10 bits sent for each character. The CID block sets the CID bit in the signaling register whenever it needs data to transmit, and this can generate an interrupt if the bit is unmasked.

Table 8. CID Tone Programming

Parameter	Number of Bits	Value	Description
FRQC	14	1777h	2200 Hz GR30 space frequency (Default)
FRQC	14	1666h	2100 Hz ITU V.23 space frequency
AMPC	15	27D4h	-7 dBm0 level (Default)
FRQD	14	0CCDh	1200 Hz GR30 mark frequency (Default)
FRQD	14	0DDEh	1300 Hz ITU V.23 mark frequency
AMPD	15	27D4h	-7 dBm0 level (Default)

Exact preamble and mark sequences can be generated by adjusting the framing mode and sending the appropriate number of characters.

Signaling Control

The Signaling Control blocks handle the System State and performs the related control functions such as DC feed, metering and ringing generation and line test for each channel. The System State register has a 4-bit System State field and three state modifier bits, POLNR, ACT and METR (see command *56/57h Write/Read System State*, on page 70). All channel specific control requires that the *4A/4Bh Write/Read Channel Enable and Operating Mode Register*, on page 66 select the channel to be accessed.

Ten system states are possible for the Le88221 device: Shutdown, Disconnect, Idle, Active Low Battery, Active Medium Battery, Tip Open, Ring Open, Balanced Ringing, Unbalanced Ringing, and Low Gain. An additional two states, Metallic Test and Longitudinal Test, are also available on the Le88241 device.

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Shutdown

Shutdown is the power-up and hardware reset state of the device. When the System State register is in Shutdown, the voice channel is deactivated (ACT = 0) and the switching regulators are off. Once the correct clocks have been programmed and the device registers initialized, the switching regulators can be enabled to generate the fixed battery voltages, and writing disconnect to *56/57h Write/Read System State*, on page 70 places the device in the normal disconnect state from which other state transitions can occur.

Disconnect

In the Disconnect state, the high voltage line drivers are shut off providing a high impedance to the line. This state can be used for denial of service. VBM is the selected battery.

The voice channel and associated analog circuitry is normally deactivated, but can be activated and used with the converter configuration command to monitor the voltages on Tip or Ring for line diagnostics by setting the ACT bit in the system state register and sending the following byte sequence to the channel:

```
F401010000F220200000        ;# enable line voltage sensing via codec transmit path
F400000000F200000000        ;# disable line voltage sensing via codec transmit path
```

Low Power Idle

The Low Power Idle state is used when on hook. In this state, the DC feed is active, and hook and ground key supervision functions are operating. The loop feed polarity is controlled by the POLNR bit. VBM is the selected battery, and the DC feed drives tip and ring to the programmed VOC. Voice transmission is disabled to minimize power dissipation.

The Disconnect to Idle state transition introduces a short reverse polarity feeding before reaching the correct idle state. This can be avoided if the state transition sequence is Disconnect to Active VBM to Idle.

Active Low Battery, Active Medium Battery

The Active state is used when off hook or for on hook transmission (OHT) such as CID. In this state the DC feed is activated and voice transmission is controlled by the ACT bit. Metering signals can be generated in this state using the METR bit. The loop feed polarity is controlled by the POLNR bit. Hook and ground key supervision functions are operating. VBM is selected if the line voltage is greater than VBL plus the programmed VAS plus |200 * ILoop|. VBL is selected if the line voltage is less than VBL plus the programmed VAS plus |200 * ILoop| plus 4 V hysteresis.

Tip Open

In the Tip Open state, the Le88221/241 device provides a high impedance on the Tip lead and drives the Ring lead to the programmed VOC voltage. The loop supervision detector monitors the Ring current. When this current is larger than the programmed threshold, the HOOK bit is set which reports a ground start event. An automatic state transition to the Active state can be enabled to occur upon a ground start detection. VBM is the selected battery.

Ring Open

In the Ring Open state, the Le88221/241 device provides a high impedance on the Ring lead and drives the Tip lead to the programmed VOC voltage. VBM is the selected battery.

DC Feed

DC feed is active in the Idle, Active Low Battery, Active Medium Battery and Tip and Ring Open states. The parameters that control DC feed are summarized in Table 9 and programmed in *C6/C7h Write/Read DC Feed Parameters*, on page 81. The Idle and Active feed characteristics appear between Tip and Ring, while the feed characteristic appears from Ring to ground in the Tip Open state, and from Tip to ground in the Ring Open state.

The DC feed parameters produce a DC feed curve at Tip and Ring as shown in Figure 15 when the fuse resistors are inside the feedback loop formed by the RTDC, RRDC feedback network.

The power supply must provide enough voltage at VBM to ensure there is overhead for the amplifiers when on hook to support on hook transmission with the programmed open circuit (VOC) voltage. This requires a mid battery of at least -57 V when VOC is programmed to 48 V.

In addition, when VBM is high (for example in a dual battery switching configuration where VBM = VBH > |-60 V|) a -30 V longitudinal clamp circuit limits the voltage on the more negative lead to ensure compliance with safety requirements. This limits the programmable range of VOC voltages to less than 51 V while complying with these limits and also supporting on hook transmission.

Operation of these devices with a programmed VOC of greater than 48 V requires some additional device initialization which disables the longitudinal clamp. The consequence of this is that the longitudinal point will be nominally half of the applied VBM voltage.

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The following byte sequence should be sent to each channel of the device during initialization and before the increased VOC is programmed in *C6/C7h Write/Read DC Feed Parameters*, on page 81:

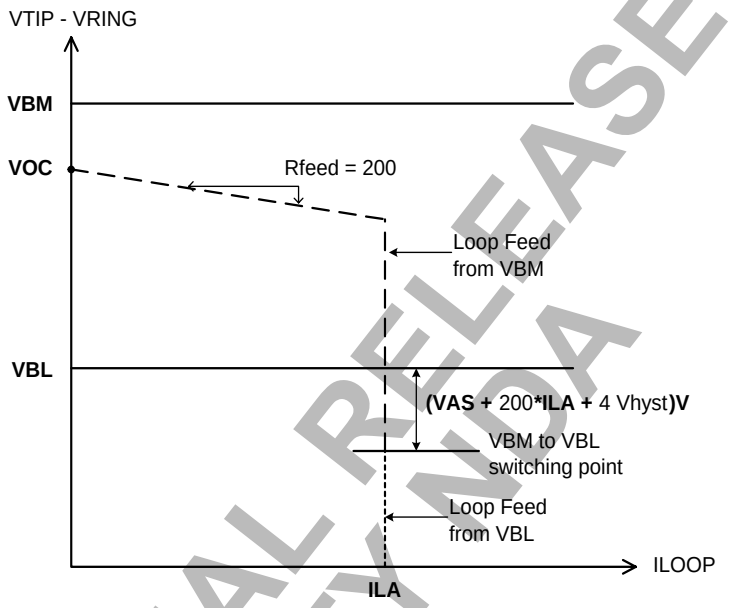
F2 00 00 40 40

For correct battery switching threshold setting, both switching regulator controllers must be enabled, even if they are not being used to generate battery voltages. Ensure the ZM and YM bits are non zero after initialization.

Table 9. DC Feed Programmable Parameters

Parameter	Number of Bits	Range	Description
VOC	3	12 - 57 V	Sets open circuit DC feed voltage. Two ranges, 12 - 33 V and 36 - 57 V provided by VOCSFT bit
VAS	4	1.5 – 7.25 V	Allows for some programmability for the automatic battery switching point
ILA	5	18 - 49 mA	Sets the current limit for DC feed

Figure 15. DC Feed I / V Characteristic



Metering

The Le88221/241 device is capable of 0.5 Vrms metering into a 200-Ω metering load at either 12 kHz or 16 kHz. Smooth metering application and abrupt metering application are supported. A typical metering sequence is shown in Figure 16.

The duration of the metering pulses may be programmed by the user via the MTRDR parameter. This off loads much of the timing from the user's micro controller. Table 10 lists the programmable metering parameters which are accessed either in command *D0/D1h Write/Read Metering Parameters*, on page 83 or command *56/57h Write/Read System State*, on page 70.

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Figure 16. Metering Pulse Definitions

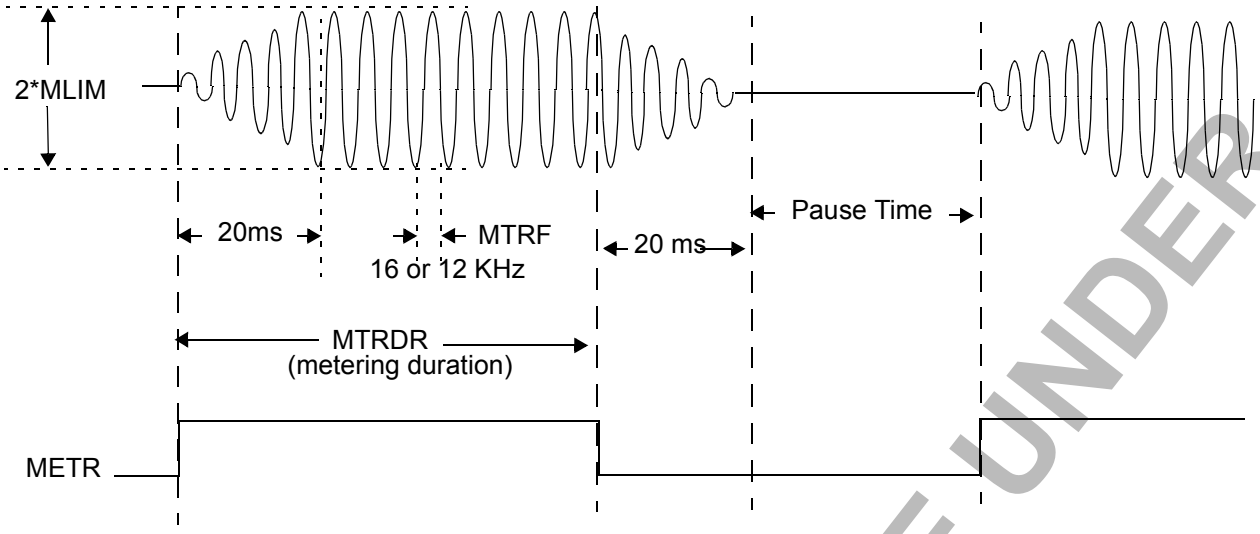

Table 10. Metering Programmable Parameters

Parameter	Number of Bits	Range	Description
METR	1	0, 1	"1" starts a metering pulse.
MTRF	1	0, 1	Metering frequency. "1" is for 16 khz. "0" is for 12 khz (default).
MLIM	7	0 - 1.9 V 0 - 2.3 V	RMS limit voltage of 12 kHz metering signal sensed at tip-ring RMS limit voltage of 16 kHz metering signal sensed at tip-ring
SOREV	1	0, 1	Controls the ramping of the metering signal. "1" abrupt ramping. "0" smooth ramping (default).
MTRSL	7	0 - 8.636 mA	RMS output current of the ramped metering signal with TIPD-RINGD short circuit
MTRDR	8	2.5 - 637.5 ms	Metering duration. From 2.5 to 637.5 ms with step size of 2.5ms 0 produces continuous metering
MTRPK	8	0 - 2 V	Peak voltage of metering signal at AC sense point (read only)

Ringing

In this state, the voice DAC is used to apply the ringing signal generated from Signal Generator A and the Bias generator to the high voltage line driver. Internal feedback maintains a low (200-Ω) system output impedance during ringing. The current limit is increased in the Ringing state and is programmable via the parameter, ILR in register *C2/C3h Write/Read Loop Supervision Parameters*, on page 81. In order to minimize line transients, entry and exit from the Ringing states are intelligently managed by the Le88221/241 device. When ringing is requested by the user, the signal generator is started but not applied to the subscriber line until the ringing voltage is equal to the on-hook Tip-Ring voltage. This algorithm, known as *Ring Entry*, assures that there is a smooth line transition when entering ringing. Ring entry is guaranteed to occur within one period of the programmed ringing frequency. Ring Exit is an analogous procedure whereby the ringing signal is not immediately removed from the line after a ring trip or new state request. The ringing signal will persist until its voltage is equal to the required line voltage. The Ringing state uses the VBH supply, and the peak ringing voltage that can be generated is equal to VBH - 4 V.

Balanced Ringing

Internal balanced ringing drives the subscriber line with balanced ringing voltage waveforms (see Figure 17). The Le88221/241 device can be programmed to output either sinusoidal or trapezoidal ringing waveforms. The ringing amplitude, frequency, and DC bias is also programmable in register *D2/D3h Write/Read Signal Generator A, B and Bias Parameters.*, on page 84. In the balanced ringing mode, the ringing signal is driven differentially, thus maximizing the ringing signal swing. The DC bias parameter should always be programmed as a positive value. This will normally generate a negative bias between TIP and RING, and a positive bias can be generated if the POLNR bit is set in *56/57h Write/Read System State*, on page 70. When in the balanced

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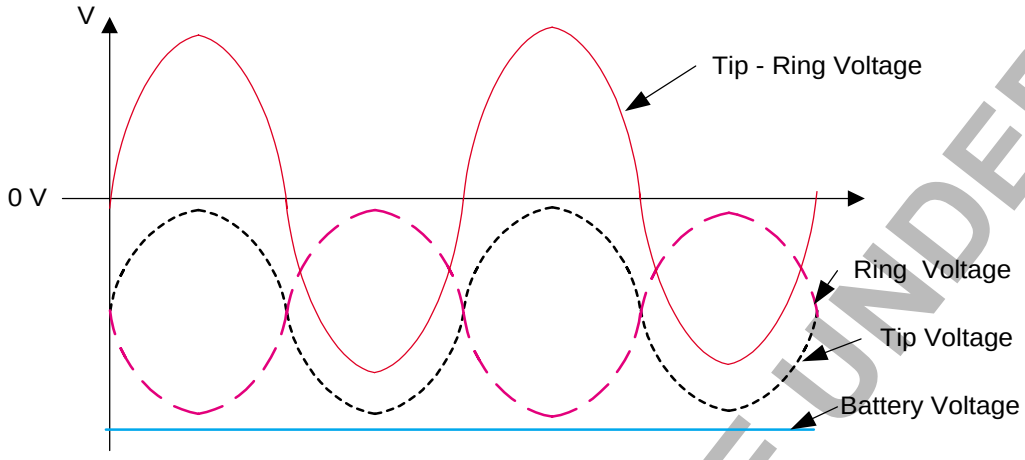
ringing mode, the Le88221/241 device appears to the subscriber line as a voltage source with an output impedance of 200Ω. The Le88221 is capable of 92-V peak ringing in balanced mode, and the Le88241 is capable of 110-V peak ringing in balanced mode (Maximum AC plus DC ringing voltage).

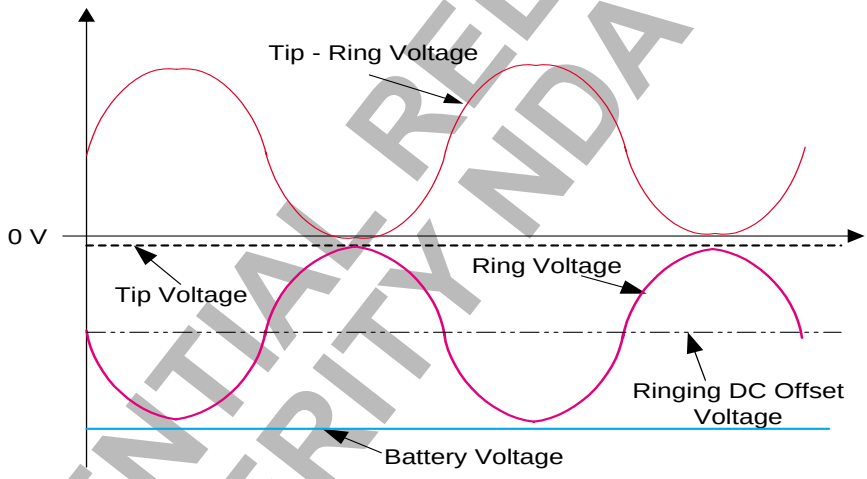
Figure 17. Balanced Ringing with Fixed Supply



Unbalanced Ringing (Le88241 Device Only)

Unbalanced ringing holds the TIPD output to a voltage close to ground while applying the ringing in a single ended fashion to the ring lead (see Figure 18). When in the unbalanced ringing mode, the Le88241 device appears to the subscriber line as a voltage source with an output impedance of 200 Ω. The Le88241 device is capable of 55-V peak AC ringing in unbalanced mode with a 55-V DC offset. Setting the POLNR bit in the System State register allows the ringing signal to be applies on the TIP lead while RING is held near ground.

Figure 18. Unbalanced Ringing with Fixed Supply



Ringing Cadencing

The on-chip cadencer is available to automate the cadencing of the ringing signal. When this feature is used, ring entry and exit are smooth when the ZXR bit in *68/69h Write/Read System State Configuration*, on page 72 is 0.

If the system provides control for the cadence, then the system state used between ringing bursts should be the Idle (no voice transmission) or Active VBM states.

Low Gain

The Low Gain state reduces the gain of the internal high voltage line driver. This special mode increases the accuracy of certain line diagnostic measurements, in particular leakage tests. This can be used to enable line testing in line with requirements described in GR-909.

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Metallic Test (Le88241 Device Only)

The Metallic Test State configures the device to control the line voltage via the DC Feed VOC parameter and monitor the corresponding metallic voltage in the transmit path (High pass filter needs to be disabled). Other converter configurations can then be used to measure other signals such as metallic current.

In addition, for the Le88241 device, the Metallic Test state connects the external test load resistor across the TIPD and RINGD terminals. This allows current to flow through the resistor enabling system tests of supervision functions such as hook switch and ring trip. The use of a precision external test load resistor opens the possibility for special calibration of the user's telephony system. The subscriber line is not disconnected from the Le88241 device when the test load is engaged and should be considered in parallel with the test load.

Longitudinal Test (Le88241 Device Only)

The Longitudinal Test State configures the device to control the longitudinal line voltage via the receive path and DC bias generator and monitor the corresponding longitudinal current in the transmit path (High pass filter needs to be disabled). In this mode, tip and ring are nominally at the same voltage. Other converter configurations can then be used to measure other signals such as tip or ring voltage.

In addition, for the Le88241 device, the Longitudinal Test state connects the test load from Tip and Ring to ground. In this mode, one end of the test load is connected to ground and both the TIPD and RINGD pins are connected to the other end of the test load through diodes. This mode allows the testing of the ground key detector and external calibration of the user's telephony system.

Supervision Processing

The programmable supervision parameters are accessed using register *C2/C3h Write/Read Loop Supervision Parameters*, on page 81.

Switch Hook Detection

The supervision circuits of the Le88221/241 device provides de-bounced off-hook indications to an external processor via the MPI for each channel. The supervision circuit compares a scaled version of the Tip-Ring current to a programmed off-hook threshold, TSH. The output of the comparator is debounced by a programmable debounce timer, DSH. A debounced off-hook indication generates an interrupt to the user's micro-controller.

Ground Key Detection

A separate detector is provided for ground key detection for each channel. This detector is similar to the supervision detector and monitors a scaled version of the longitudinal drive current. The scaled longitudinal drive current is compared to a ground key threshold, TGK to determine the existence of a ground key. The positive detection of a ground key will generate an interrupt to the user's micro-controller.

Table 11. Programmable Supervision Parameters

Parameter	Number of Bits	Range	Description
TSH	3	8 - 15 mA	Sets the threshold for supervision detector.
DSH	5	0 - 62 ms	Sets the debounce time for the supervision detector
TGK	3	0 - 42 mA	Sets the threshold for ground key detector.
DGK	5	0 - 28 ms	Sets the debounce time for the ground key detector

Ring Trip Detection

The ring trip detection circuit for each channel provides de-bounced ring trip indications to an external processor via the MPI. The Ring Trip circuit compares a scaled version of the Tip-Ring current to a programmed Ring Trip Threshold, RTTH. The output of the comparator is processed by the ring trip algorithm on a cycle by cycle basis to provide immunity to false ring trips and filter transients common to ringing and ring trip. In addition, more than 50% of the time near ringing current limit will generate a trip indication. A positive Ring Trip occurs if a trip indication is present for two complete ring cycles, and an interrupt can be raised to the user's micro-controller.

The device default configuration is for AC only sinusoidal ringing capable of driving 5 REN ringing loads and a 750 Ω total loop resistance. The following equations can be used to select new ring trip settings when using different ringing waveforms and different loads. They allow the ratio of the open circuit ringing voltage to the ringing threshold current to vary by +/-20%, which is conservative.

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Table 12. Ring Trip Parameters

Name	Description
AMPA	Amplitude of signal generator A which is used for ringing.
FREQA	Frequency of signal generator A which is used for ringing.
BIAS	DC bias for ringing.
RTDCAC	Ringing trip based on AC only or Battery Backed (DC) Ringing
RTTH	Ringing trip threshold in 0.5 mA steps from 0 to 63.5 mA
ILR	Ringing current limit programmed in 2 mA steps. ILR=0 represents 50 mA. ILR = 31 represents 112 mA
HOOK	Interrupt in signalling register indicating a ring trip occurred.

For AC only ringing, RTDCAC is 1 and the ringing current is half-wave rectified and averaged over a ringing cycle. If this result exceeds the RTTH threshold for two successive cycles, the HOOK bit will be set. This method limits the supported loop length depending on the minimum must not trip ringing impedance (Rmnt in Ohms) and allowing for errors in the applied ringing voltage and trip level. The maximum loop resistance is given by:

$$RLOOP(max) = 0.67 \cdot Rmnt - Rphone - 66 \cdot \Omega$$

RLOOP(max) excludes the DC resistance of the phone (Rphone, typically 430 Ω in the U.S.), and the fuse resistance if DC line sensing is behind the fuse resistors.

For a sinusoidal ringing waveform of VRING rms volts, and Rmnt impedance, the following ring trip settings should be used:

$$RTTH = \frac{0.54 \cdot VRING}{Rmnt + 200 \cdot \Omega}$$

$$ILR = \frac{1.4 \cdot VRING}{Rmnt + 200 \cdot \Omega}$$

In the case of battery backed ringing where ring trip is based on the DC ringing current, RTDCAC is 0 and the ringing current is averaged over each ringing cycle. If this result exceeds the RTTH threshold for two successive cycles, the HOOK bit will be set. In this case the loop length is limited by the ability to deliver the required AC ringing voltage at the end of the loop (VPHONE, typically 40vrms in the U.S.) to the must not trip ringing load (Rmnt) for a given open loop ringing voltage, VRING.

$$RLOOP(max) = Rmnt \cdot \left(\frac{0.9 \cdot VRING - VPHONE}{VPHONE}\right) - 200 \cdot \Omega$$

For reliable ring trip, the ringing DC bias (VRINGDC) should be greater than 20V, and the following ring trip settings should be used:

$$RTTH = \frac{0.8 \cdot VRINGDC}{RLOOP(max) + RPHONE + 200 \cdot \Omega}$$

$$ILR = \frac{1.4 \cdot VRING}{Rmnt + 200 \cdot \Omega}$$

Note that the ringing source impedance is nominally 200 Ω.

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Analog Reference Circuits

The analog reference circuit generates a reference voltage and reference current for use by both channels. The reference current is generated through the external resistor RREF and the external capacitor, CREF, provides filtering on the reference voltage.

High Voltage Line Driver

The High Voltage Line Drivers interface to Tip/Ring and drive all DC and AC signals onto the line, including the ringing signal. The Line Drivers are capable of driving a 92 Vpk(Le88221 device) or 110 Vpk (Le88241 device) differential signal. The Line Drivers are current limited and have integrated thermal shutdown protection.

Test Load Switch (Le88241 Device Only)

An integrated bi-directional test load switch resides in the Le88241 device's high voltage line driver. When connected to an external resistor, the test load switch can be used to test system functionality and to calibrate the system for diagnostic tests.

Simple on/off test load control is provided on the Le88241 device by sending the following byte sequences to Channel 1 or Channel 2, which are normally executed in Idle, Active (Normal and Reverse) or Ringing system states:

- To connect the test load between TIPD and RINGD, send EC 0F 6A 40 56
- To disconnect the test load between TIPD and RINGD, send EC 0F 6A 40 16 EC 0F 6A 00 1C
- To connect the test load from the more negative of TIPD or RINGD and ground, send EC 0F 6A 80 96
- To disconnect the test load from the more negative of TIPD or RINGD and ground, send EC 0F 6A 80 16 EC 0F 6A 00 1C

Switching Regulator Controllers

The switching regulator controllers on the Le88221/241 device allow the fixed voltages used by the devices in the system to be generated from a single external power supply, typically +12 V. Various combinations of power supplies can be configured depending on the requirements of the target application. In addition, the controller detects over current events which will terminate the output pulse. If seven successive over current events are detected, an over current alarm (OCALMx) is set. The alarm can be programmed to shut down the controller.

For the applications circuit shown in Figure 40, on page 59, Switcher Y has been configured to generate two fixed supplies, VBH/VBM and VBL where the VBL supply is regulated. By regulating VBL at the 30 VDC SWYV setting with BSI = 00b and using a transformer with a 3:1 turns ratio, VBH will be centered around 90 VDC. Refer to Figure 41, on page 60 for a more detailed schematic of the external components needed to implement the regulator. The regulator shown is a typical Fly-Back configuration with a multi-tap transformer configured for two outputs. A bleeder resistor from VBH to VBL should be used to pre-load the VBH supply and prevent VBH from exceeding 100 volts when VBL is heavily loaded.

Alternatively, using a different sense resistor arrangement and setting the BSI bits in the *E4/E5h Write/Read Switching Regulator Parameters*, on page 89 to 10b, the mid (and high) battery is the regulated output. Depending on the application, the power supplies can be sized (mainly the external transformer and filtering components) to support a number of separate devices.

The LFC pins support a soft start for the switching regulator controllers by filtering the internally generated switcher output reference using an external capacitor. LFC_1 is associated with Switcher Y, and LFC_2 is associated with Switcher Z. The pole is set with a nominal 4 kΩ internal resistance, allowing a 0.1 µF capacitor to provide a 10 ms ramp time. It is also possible to control the power-up of the switching regulators by appropriate use of the switcher power modes, eliminating the need for external capacitors. If the switcher controller is not being used, the corresponding LFC pin can be left open.

Even if the Le88221/241 device is not using the switching regulator controllers to generate the battery supplies, it must sense each of the applied batteries through the SWVSY, SWVSZ and XB pins for correct longitudinal control and battery switching. The meaning of each pin can be controlled by the BSI bits according to Table 13. This allows flexible connection options for each power supply controller to regulate one of two battery inputs, either VBL or VBM for switcher Y, or the VBH or VBM supply for switcher Z. In addition, both switching regulator controllers must be enabled in register *E6/E7h Write/Read Switching Regulator Control*, on page 90 for proper battery switch threshold setting.

Table 13. Battery Input Selections

BSI1	BSI0	Low Battery Sense Pin	Mid Battery Sense Pin	High Battery Sense Pin
0	0	SWY	XB	SWZ
0	1	SWY	SWZ	XB
1	0	XB	SWY	SWZ
1	1	RSVD	RSVD	RSVD

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CONNECTION DIAGRAMS

Figure 19. Le88221 Device 80 eLQFP Package

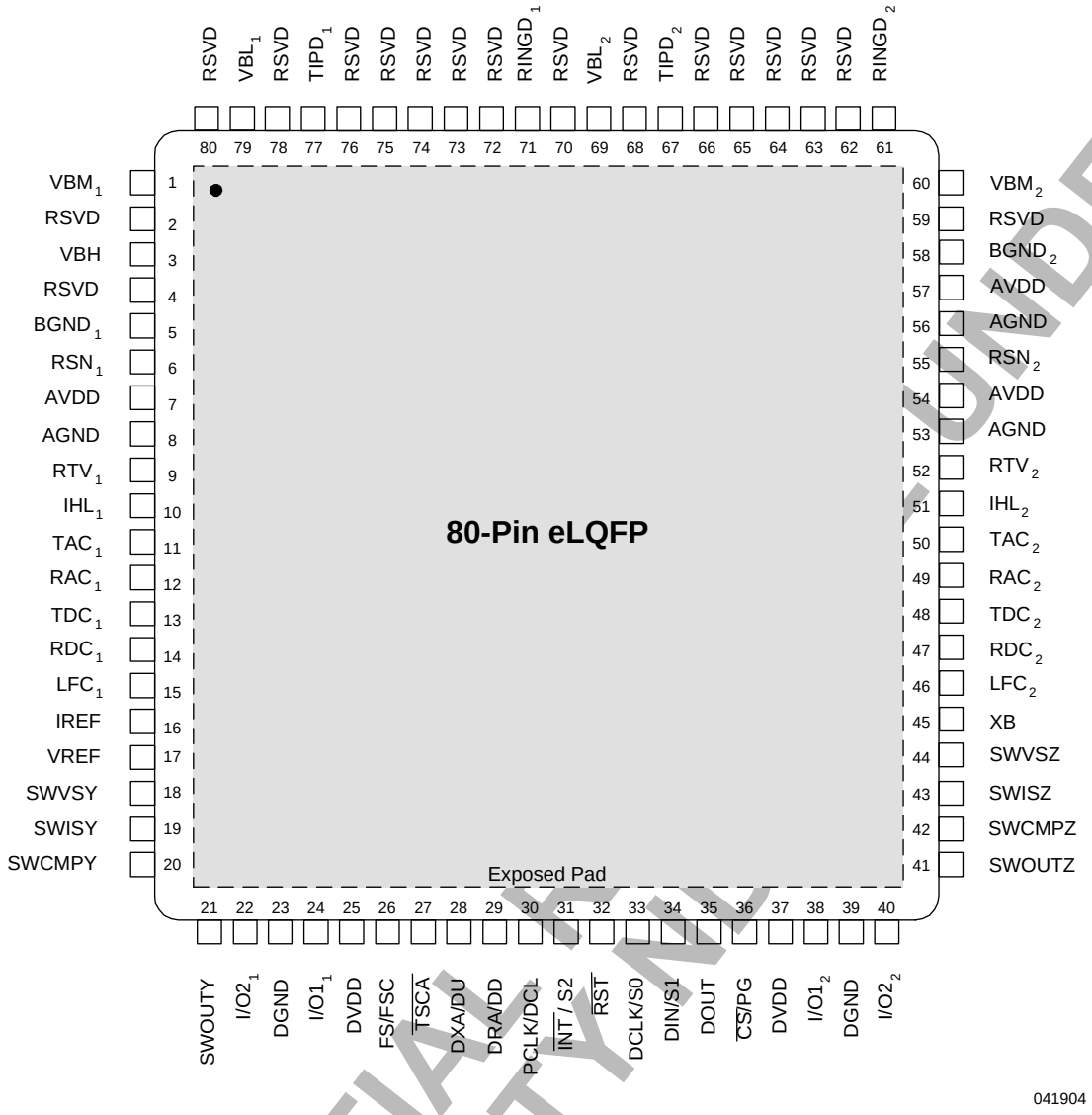

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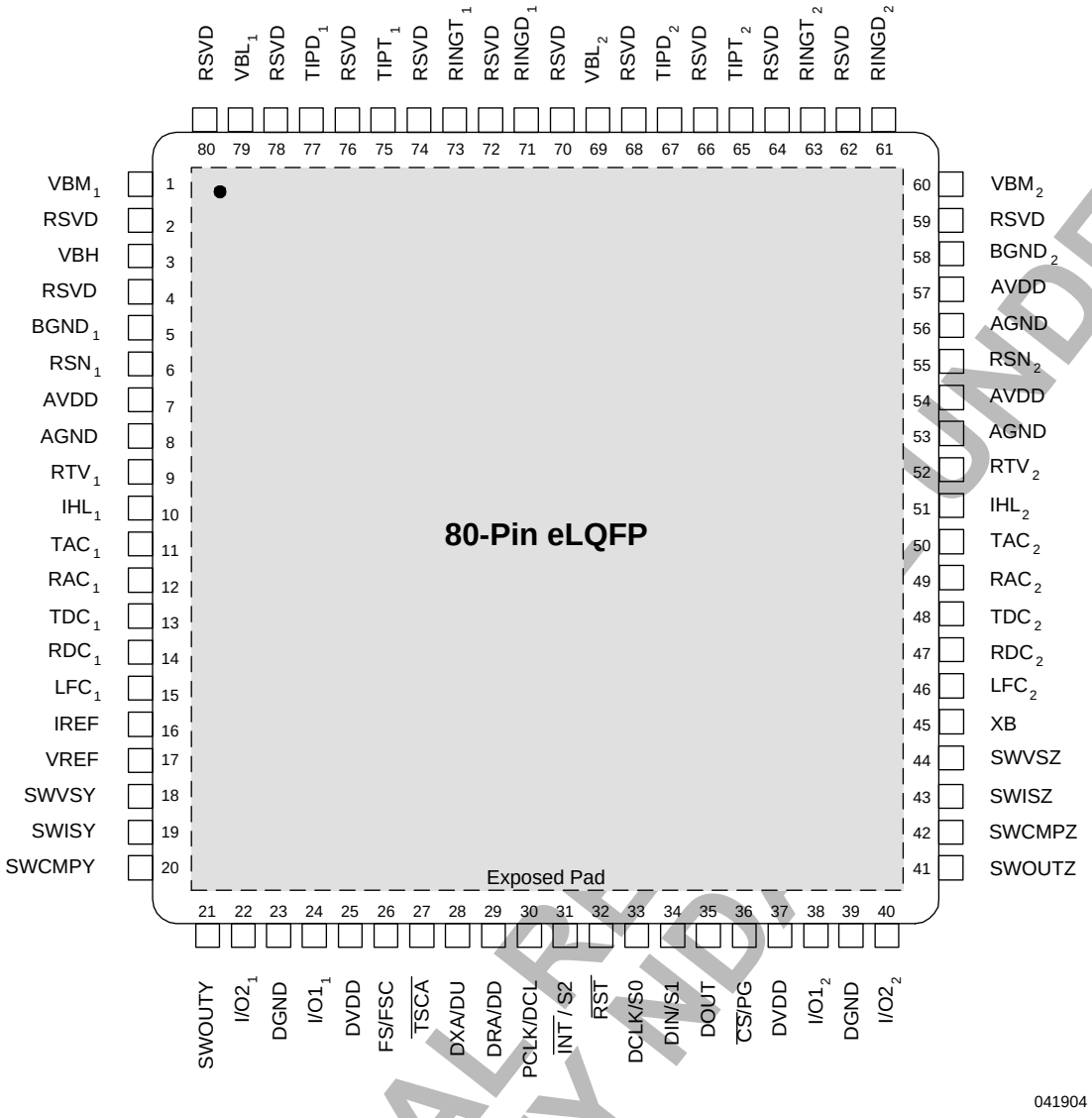
Figure 20. Le88241 Device 80 eLQFP Package



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PIN DESCRIPTIONS

NAME	Type	Description
AVDD/DVDD	Power	Analog and digital power supply inputs. AVDD and DVDD are provided to allow for noise isolation and proper power supply decoupling techniques. For best performance, all of the VDD power supply pins should be connected together at the power supply or power connection to the printed circuit board.
AGND/DGND	Power	Separate analog and digital grounds are provided to allow noise isolation; however, the grounds are connected inside the part, and must also be connected together on the circuit board.
BGND	Power	Battery Ground Reference.
$\overline{CS}$/PG	Input	Chip Select/PCM-GCI. The $\overline{CS}$/PG input along with the DCLK/S0 input are used to determine the operating state of the programmable PCM/GCI interface. On power up, the device will initialize to GCI mode if $\overline{CS}$/PG is low *and* there is no toggling (no high to low or low to high transitions) of the DCLK/S0 input. The device will initialize to the PCM/MPI mode if either $\overline{CS}$ is high *or* DCLK is toggling. Once the device is in PCM/MPI mode, it is ready to receive commands through its serial interface pins, DIN, DOUT and DCLK. Once a valid command has been sent through the MPI serial interface, GCI mode cannot be entered unless a hardware reset is asserted or power is removed from the part. If a valid command has not been sent since the last hardware reset or power up, then GCI mode can be re-entered (after a delay of one PCM frame) by holding $\overline{CS}$/PG low and keeping DCLK static. While the part is in GCI mode, $\overline{CS}$/PG going high or DCLK toggling will immediately place the device in PCM/MPI mode. In the PCM/MPI mode, the Chip Select input (active Low) enables the device so that control data can be written to or read from the part. The device coefficient registers selected by the write or read command must be enabled by writing a 1 to the EC bit in the Channel Enable Register. See the Channel Enable Register and Command 4A/4Bh for more information. If Chip Select is held Low for 16 rising edges of DCLK, a hardware reset is executed when Chip Select returns High.
DCLK/S0	Input	Data Clock. In addition to providing both a data clock input and an S0 GCI address input, DCLK/S0 acts in conjunction with $\overline{CS}$/PG to determine the operational mode of the system interface, PCM/MPI or GCI. See $\overline{CS}$/PG for details. In the PCM/MPI mode, the Data Clock input shifts data into and out of the microprocessor interface of the device. The maximum clock rate is 8.192 MHz.
	Input	Packet assignment bit 0. In GCI mode, S0 is one of three inputs (S0, S1, S2) that is decoded to determine in which GCI packet the device transmits and receives data.
DIN/S1	Input	Data Input. In the PCM/MPI mode, control data is serially written into the device via the DIN pin, most significant bit first. The Data Clock determines the data rate.
	Input	Packet assignment bit 1. In GCI mode, S1 is one of three inputs (S0, S1, S2) that is decoded to determine in which GCI packet the device transmits and receives data.
DOUT	Output	Data Output. In the PCM/MPI mode, control data is serially written from the device via the DOUT pin, most significant bit first. The Data Clock determines the data rate. DOUT is high impedance except when data is being transmitted, which allows DIN and DOUT to be directly tied together in systems which use a single line for data input and output.
DRA/DD	Input	PCM Data Receive. In the PCM/MPI mode, the PCM data is serially received on the DRA port during the user-programmed time slot. Data is always received with the most significant bit first. For compressed signals, 1 byte of data is received every 125 µs at the PCLK rate. In the Linear mode, 2 consecutive bytes of data for each channel are received every 125 µs at the PCLK rate.
	Input	GCI Data Downstream. In GCI mode, the B1, B2, Monitor and SC channel data is serially received on the DD input. The device uses one of the eight GCI packets for operation. Which of the 8 GCI packets is determined by the S0, S1 and S2 inputs. Data is always received with the most significant bit first. 4 bytes of data is received every 125 µs at the 2.048 Mbit/s data rate.
DXA/DU	Output	PCM Data Transmit. In the PCM/MPI mode, the transmit data is sent serially on the DXA port during the programmed time slot. Data is always transmitted most significant bit first. The output is available every 125 µs and the data is shifted out in 8-bit (16-bit in Linear or PCM Signaling mode) bursts at the PCLK rate. DXA is high impedance between time slots, while the device is in the Inactive mode with no PCM signaling, or while the Cutoff Transmit Path bit (CTP) is on.
	Output	GCI Data Upstream. In the GCI mode, the B1, B2, Monitor and SC channel data is serially transmitted on the DU output. Which GCI packet the device uses is determined by the S0, S1 and S2 inputs. Data is always transmitted with the most significant bit first. 4 bytes of data is transmitted every 125 µs at the 2.048 Mbit/s data rate.
EPAD	Power	Exposed pad substrate connection. This pad is at ground potential and should be soldered to the PCB and connected by multiple vias to a heatsink area on the bottom of the board and to the internal ground plane if present.
FS/FSC	Input	Frame Sync. In the PCM/MPI mode, the Frame Sync (FS) pulse is an 8 kHz signal that identifies Time Slot 0 and Clock Slot 0 of a system's PCM frame. Individual time slots are referenced to this input, which must be synchronized to PCLK.
FS/FSC	Input	Frame Sync. In GCI mode, the Frame Sync (FSC) pulse is an 8 kHz signal that identifies the beginning of GCI packet 0 of a system's GCI frame. The device can access packets 0 to 7 based on the setting of the S0, S1 and S2 inputs. FSC must be synchronized to DCL.

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NAME	Type	Description
$I/O1_1$,$I/O1_2$	I/O	General Purpose Input/ Output (Can directly drive a 150 mW 3-V or 5-V relay).
$I/O2_1$, $I/O2_2$	I/O	General Purpose Input/ Output.
IHL_1,IHL_2	Output	High Level Current Drive.
$\overline{INT}$/S2	Output	Interrupt. $\overline{INT}$ is an active Low output signal, which is programmable as either 3V CMOS-compatible or open drain. The $\overline{INT}$ output goes Low any time one of the input bits in the Signaling register changes state and is not masked. It also goes Low any time new transmit data appears if the ATI interrupt is armed. $\overline{INT}$ remains Low until the appropriate register is read via the microprocessor interface, or the device receives either a software or hardware reset. The individual bits in the Signaling register can be masked from causing an interrupt by using MPI Command 6C/6Dh.
	Input	Packet assignment bit 2. In GCI mode, S2 is one of three inputs (S0, S1, S2) that is decoded to determine in which GCI packet the device transmits and receives data.
IREF	Input	Current Reference. An external resistor R_{REF} connected between this pin and analog ground generates an accurate current reference used by the analog circuits on the chip.
LFC_1,LFC_2	Output	Optional Component. LFC capacitor modifies the power up time. 0.1 µf will result in about 15 ms delay. Power Up Time (s) = 240000 * (LFC Capacitor)
PCLK/DCL	Input	PCM Clock. The PCM clock determines the rate at which data is serially shifted in and out on the PCM highway and provides the clock reference for the internal PLL.
	Input	GCI Data Clock. In GCI mode, DCL is either 2.028 MHz or 4.096 MHz and an integer multiple of the FSC frequency. The internal PLL is automatically configured to run from this clock.
RAC_1,RAC_2	Input	Ring lead AC sense. A series R + C network is connected from this pin to the Ring lead. The connection can be to either side of the protection resistor.
RDC_1,RDC_2	Input	Ring lead DC Sense. A resistor is connected from this pin to the Ring lead. The connection can be to either side of the protection resistor.
$\overline{RST}$	Input	Device Hardware Reset. A logic Low signal at this pin resets the device to its default state.
$RINGD_1$, $RINGD_2$	Output	RING-lead (B) output to the two-wire line.
$RINGT_1$, $RINGT_2$	Output	RING-lead (B) test switch connection. A resistor can be connected from this pin to TIPT to implement a line test load. (Le88241 only).
RSN_1, RSN_2	Input	High voltage line drive receive current summing node.
RSVD	Open	Reserved. Make no connection to this pin.
RTV_1, RTV_2	Output	Drive output for two-wire AC impedance scaling resistor.
SWVSY, SWVSZ	Input	Voltage sense for switching regulator controller.
SWISY, SWISZ	Input	Current sense input for switching regulator controller.
SWOUTY, SWOUTZ	Output	Pulse output for gate drive to switching regulator FET.
SWCMPY, SWCMPZ	Output	Compensation connection for switching regulator controller.
TAC_1,TAC_2	Input	Tip lead AC Sense. A series R + C network is connected from this pin to the Tip lead. The connection can be to either side of the protection resistor.
TDC_1,TDC_2	Input	Tip lead DC Sense. A resistor is connected from this pin to the Tip lead. The connection can be to either side of the protection resistor.
$TIPD_1$, $TIPD_2$	Output	TIP-lead (A) output to two-wire line.
$TIPT_1$, $TIPT_2$	Output	TIP-lead (A) Test Switch Connection. A resistor can be connected from this pin to RINGT to implement a line test load. (Le88241 only).
$\overline{TSCA}$	Output	Time Slot Control. The Time Slot Control output is open-drain (requiring a pull-up resistor to DVDD) and is normally inactive (high impedance). In the PCM/MPI mode, $\overline{TSCA}$ is active (low) when PCM data is transmitted on the DXA pin. In GCI mode, $\overline{TSCA}$ is active (low) during the GCI packet selected by S0, S1 and S2.
VBH	Supply	High (Ringing) Battery supply, and bias voltage for the high voltage line driver.
VBM_1, VBM_2	Supply	Medium (On Hook) Battery supply.
VBL_1, VBL_2	Supply	Low (Off Hook) Battery Supply.
VREF	Output	Analog Voltage Reference. The VREF output is provided in order for an external capacitor to be connected from VREF to ground, filtering noise present on the internal voltage reference. VREF is buffered before it is used by internal circuitry. The voltage on VREF and the output resistance are given in *Electrical Characteristics*, on page 40.
XB	Input	External Battery Voltage Sense.

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ABSOLUTE MAXIMUM RATINGS

Stresses above those listed under *Absolute Maximum Ratings* can cause permanent device failure. Functionality at or above these limits is not implied. Exposure to absolute maximum ratings for extended periods may affect device reliability.

Storage Temperature	–55° C < T_A < +125° C
Ambient Temperature, under Bias	–40° C < T_A < +85° C
Ambient relative humidity (non condensing)	5 to 95%
VBH, VBM_i, VBL_i with respect to BGND for Le88221 device for Le88241 device	 -105 V to +0.4 V -125 V to +0.4 V
|VBH| with respect to |VBM|	> |VBM + 1| V
|VBH| with respect to |VBL|	> |VBL + 1| V
BGND with respect to AGND	-0.4 V to +0.4 V
TIPD, RINGD to BGND: Continuous 10 ms (F = 0.1 Hz) 1 µs (F = 0.1 Hz) 250 ns (F = 0.1 Hz)	 V_{BH} –1 to BGND +1 V_{BH} –5 to BGND +5 V_{BH} –10 to BGND +10 V_{BH} –15 to BGND +15
Current from TIPD or RINGD	±150 mA
AVDD with respect to AGND	–0.4 V to + 4.0 V
AVDD with respect to DVDD	–0.4 V to + 4.0 V
DVDD with respect to DGND	–0.4 V to + 4.0 V
AGND with respect to DGND	–0.05 V to + 0.05 V
Digital pins with respect to DGND	–0.4 V to the smaller of +4.0 V or DVDD + 0.4 V
$I/O1_i$ with respect to DGND	–0.4 V to the smaller of +5.5 V or DVDD + 2.37 V
$I/O1_i$ current sink to DGND	70mA
Latch up immunity (any pin)	± 100 mA
Maximum power dissipation, T_A = 85° C (See notes)	2.2 W
Thermal Data: In 80-pin eLQFP package	θ_{JA} 27° C/W
Thermal Data: In 80-pin eLQFP package	θ_{JC} TBD° C/W
ESD Immunity (Human Body Model)	JESD22 Class 1C compliant

Notes:

Thermal limiting circuitry on chip will shut down the circuit at a junction temperature of about 165ºC. Continuous operation above 145ºC junction temperature may degrade device reliability.

The thermal performance of a thermally enhanced package is assured through optimized printed circuit board layout. Specified performance requires that the exposed thermal pad be soldered to an equally sized exposed copper surface, which, in turn, conducts heat through multiple vias to a large internal copper plane.

Package Assembly

The green package devices are assembled with enhanced, environmental and compatible lead-free, halogen-free, and antimony-free materials. The leads possess a matte-tin plating which is compatible with conventional board assembly processes or newer lead-free board assembly processes. The peak soldering temperature should not exceed 245°C during printed circuit board assembly.

Refer to IPC/JEDEC J-Std-020B table 5-2 for the recommended solder reflow temperature profile.

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OPERATING RANGES

Legerity guarantees the performance of this device over commercial (0ºC to 70ºC) and industrial (-40ºC to 85ºC) temperature ranges by conducting electrical characterization over each range and by conducting a production test with single insertion coupled to periodic sampling. These characterization and test procedures comply with section 4.6.2 of Bellcore GR-357-CORE Component Reliability Assurance Requirements for Telecommunications Equipment.

Environmental Ranges

Ambient Temperature	–40° C < T_A < +85° C
Ambient Relative Humidity	15 to 85%

Electrical Ranges

Analog Supply AVDD	+3.3 V ± 5% DVDD ± 50 mV
Digital Supply DVDD	+3.3 V ± 5%
VBM_i Supply	VBH to -(VOC + 7) V
VBL_i Supply	VBH to -20 V
DGND	0 V
AGND with respect to DGND	±10 mV
BGND with respect to AGND/DGND	±100 mV
Voltage Reference Capacitor: VREF to AGND	10 µF ± 20%
Current Reference Resistor: IREF to AGND	75 kΩ ± 1%
Digital Pins	DGND to 3.465 V
$I/O1_i$	DGND to +5.25 V
Analog Pins	AGND – 0.3 V to AVDD + 0.3 V

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ELECTRICAL CHARACTERISTICS

Test Conditions

Unless otherwise noted, test conditions are:

- Typical values are for TA = 25º C and nominal supply voltages. Minimum and maximum values are over the temperature and supply voltage ranges shown in Operating Ranges, except where noted
- Default (unity) gain in X, R, DRL, AX and AR blocks. Default coefficients in DISN, Z and B filters
- Test circuit is as shown in Figure 39, on page 58.
    - VBH = VBM = -99 V, VBL = -26 V for Le88221 device
    - VBH = -120 V, VBM = -57 V, VBL = -35 V for Le88241 device
    - DC feed programmed to ILA = 26 mA, VOC = 48.0 V, VAS = 1.5 V, ILR = 78mA
    - AC and DC load resistance R_L = 600 Ω
    - 0 dBm0 = 0 dBm (600 Ω) = 0.7746 Vrms. Digital gains GX0 and GR0 to achieve 0 dBr relative levels are
      GX0 = +6.797 dB (7A20h) A-law or linear and
      GX0 = +6.737 dB (2A20h) µ-Law to set A/D transmit gain to 0dB
      GR0 = -1.793 dB (6AA0h) A-law or linear and
      GR0 = -1.720 dB (3AA0h) µ-Law to set D/A receive gain to 0dB
    - Ringing Tests have two conditions: C1 and C2
    - C1 programmed ringing 110 V_{PK} (78.5 Vrms) 0 V_{DC} offset and 1386 Ω + 40-µF load (Le88241 device only)
    - C2 programmed ringing 92 V_{PK} (65 Vrms) 0 V_{DC} offset and 1386 Ω + 40-µF load (Le88221 device only)

Supply Currents and Power Dissipation

- Supply currents and power consumption are per channel based on both channels in the same state
- Device or package power does not include power delivered to the load
- Fuse resistors for power tests are R_F = 0 Ω

Le88221 Operational State	Condition	I_{DD} mA (Note 2.)	I_{VBH} + I_{VBM} mA	I_{VBL} mA	Package Power mW	Note
		Typ	Typ	Typ	Typ	
Shutdown	Disconnect, Battery Supplies off	4.5	0	0	15	1.
Disconnect	V_{BH}, V_{BM}	14	0.2	0.05	60	1.
Idle	V_{BH}, V_{BM}, On-Hook	14	0.8	0.05	125	1.
Active (Normal or Polarity Reversal)	V_{BH}, V_{BM}, On-Hook Transmission	25	2.0	0.05	250	1.
	V_{BL}, 600 Ω	25	0.4	27.6	480	1.
Ringing	V_{BH}, C2	26	48.0	0.05	1800	1.3.

Le88241 Operational State	Condition	I_{DD} mA (Note 2.)	I_{VBH} mA	I_{VBM} mA	I_{VBL} mA	Package Power mW	Note
		Typ	Typ	Typ	Typ	Typ	
Shutdown	Disconnect, Supplies off	4.5	0	0	0	15	1.
Disconnect	V_{BM}	14	0.2	0.05	0.05	70	1.
Idle	V_{BM}, On-Hook	14	0.2	0.4	0.05	105	1.
Active (Normal or Polarity Reversal)	V_{BM}, On-Hook Transmission	25	0.4	1.1	0.05	220	1.
	V_{BL}, 600 Ω	25	0.4	0.05	27.6	700	1.
Ringing	V_{BH}, C1	26	57.0	0.05	0.05	2500	1.3.

Notes:

1. *Not Tested in Production. Parameter is guaranteed by characterization or correlation to other tests.*
2. *I_{DD} supply current is the sum of I_{AVDD} and I_{DVDD} for the package divided by 2.*
3. *Ringing signal must be cadenced to produce an average power that can be handled by the package.*

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DC Characteristics

Symbol	Parameter Descriptions	Min	Typ	Max	Unit	Note
V_{IL}	Digital Input Low voltage			0.8	V	
V_{IH}	Digital Input High voltage	2.0				
I_{IL}	Digital Input leakage current	–7		+7	µA	
I_{AIL}	Analog input leakage current	–1		+1		
V_{HYS}	Digital Input hysteresis	0.16	0.25	0.34	V	
V_{OL}	Digital Output Low voltage I/O1 (I_{OL} = 50 mA) I/O2 and SWOUTx (I_{OL} = 4 mA) I/O2 and SWOUTx (I_{OL} = 8 mA) $\overline{TSCA}$ (I_{OL} =14 mA) Other digital outputs (I_{OL} = 2 mA)			 0.8 0.4 0.8 0.4 0.4	V	1.
V_{OH}	Digital Output High voltage I/O1, I/O2 (I_{OH} = 4 mA) I/O1, I/O2 (I_{OH} = 8 mA) Other digital outputs (I_{OH} = 400 µA)	 V_{DVDD} – 0.4 V V_{DVDD} – 0.8 V 2.4				1.
I_{OL}	Digital Output leakage current (Hi-Z state) 0 < V < DVDD	–7		+7	µA	
V_{REF}	VREF output open circuit voltage (I_{VREF} = +/- 100 µA)	1.43	1.5	1.57	V	
C_{IREF}	IREF pin maximum load capacitance			20	pF	
C_I	Digital Input capacitance			4		
C_O	Digital Output capacitance			4		
$PSRR_1$	AVDD, DVDD Power supply rejection ratio (1.02 kHz, 100 mV_{RMS}, either path, GX = GR = 0 dB)	34			dB	
$PSRR_2$	VBH, VBM_i, VBL_i Power supply rejection ratio (1.02 kHz, 100 mV_{RMS}, either path, GX = GR = 0 dB)	40				

Notes:

1. The I/O1, I/O2 outputs are resistive for less than a 0.8 V drop. Total current must not exceed absolute maximum ratings.

DC Feed and Signaling

Description	Test Conditions	Min	Typ	Max	Unit	Note
I_L, Loop-current accuracy, Active state	I_L in constant-current region	-10		+10	%	
I_{RINGD}, RINGD leakage, Ring Open state	R_L = 0 to GND or VBM			1000	µA	
I_{TIPD}, TIPD leakage, Tip Open state	R_L = 0 to GND or VBM			1000	µA	
TIPD, RINGD leakage, Disconnect state	R_L = 0 to GND or VBM			10	µA	
I_{RINGD}, RINGD current accuracy, Tip Open state	RINGD to ground	-10		+10	%	
V_{TIPD}, ground-start signaling	TIPD to –48 V = 7 kΩ, RINGD to ground = 100 Ω	–7.5	–5		V	1.,2.
TDC, RDC input offset current		3.3	3.7	4.1	µA	1.,3.
Ground key accuracy		-15		+15	%	
Switch hook accuracy		-15		+15		
Open circuit voltage	VOC = 48V	-8		+8		
VBM switch to VBL loop resistance	Standard	TBD	600		Ω	
VBL switch to VBM loop resistance	Standard		600	TBD		

Notes:

1. This parameter is guaranteed by characterization or correlation to other tests. Typical values not tested in production.

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2. *The following bytes must be sent to the device in the Normal Active state in order to meet this specification when responding to a ground start: F2 00 00 80 00.*

3. *Analog input pad leakage can add to this value - see specification under DC Characteristics*

Metering

Description	Test Conditions	Min	Typ	Max	Unit	Note
Level accuracy	0.5 Vrms, 12 or 16 kHz 200 or 3000 Ω AC load	-5		+10	%	
Frequency accuracy	12 or 16 kHz	–0.1		+0.1	%	1.

Notes:

1. *This parameter is guaranteed by characterization or correlation to other tests. Typical values not tested in production.*

Ringing

Description	Test Conditions	Min	Typ	Max	Unit	Note
Ringing Voltage Accuracy	Case C1 or C2	-8		+8	%	
V_{AB}, Ringing DC offset	R_L = open, V_{RING} = 0 V	TBD		TBD	V	
Harmonic distortion	Case C1 or C2		3	5	%	
Ringing current limit accuracy	R_L = 300 Ω	-10		10	%	
Ringing source impedance			200		Ω	1.
DC ring trip accuracy	EGBIAS = 1	-15		+15	%	2.
AC ring trip accuracy	EGBIAS = 0	-15		+15	%	
Ring trip delay	Periods of ringing	1		3	cycles	1.

Notes:

1. *This parameter is guaranteed by characterization or correlation to other tests. Typical values not tested in production.*

2. *If the ringing current in the loop is near the current limit more than 50% of the time, a ring trip will occur regardless of the average current.*

Switching Regulator Controller

The following specifications apply to switching regulator controllers Y and Z.

Description	Test Conditions	Min	Typ	Max	Unit	Note
SWISx shutdown threshold	Referenced to AGND	85	100	115	mV	
SWISx hysteresis			5		mV	1.
SWISx input bias current		-10		10	µA	1.
SWISx shutdown delay	V_{SWISx} > 115mV	12		88	ns	2.
SWCPMx output current		-200		200	µA	
SWCMPx operating range		0.4		2.6	V	
SWVSx to SWCMPx gain		0.4		40	V/nA	
SWVSx to SWCMPx bandwidth		100			kHz	
SWVSx input offset current		3.3	3.7	4.1	µA	**3.**
LFC output impedance			80		kΩ	1.
SWxV output voltage accuracy	SWxV = -55V	-58.0		-50.0	V	

Notes:

1. *This parameter is guaranteed by characterization or correlation to other tests. Typical values not tested in production.*

2. *Time from SWISx exceeding threshold to SWOUTx voltage passing through VDD/2.*

3. *Analog input pad leakage can add to this value - see specification under DC Characteristics*

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Converter Configuration Signal Sense Accuracy

See command A6/A7h Write/Read Converter Configuration, on page 79 for measurement ranges and resolution.

Description	Test Conditions	Min	Typ	Max	Unit	Note
Metallic AC coupled voltage	Converter Configuration = 00h	-4		+4	%	
Battery input at SWVSY	Converter Configuration = 01h	-2.0 V - 3%		+2.0 V + 3%	V	1.,2.
Battery input at SWVSZ	Converter Configuration = 02h	-2.0 V - 3%		+2.0 V + 3%	V	
Battery input at XB	Converter Configuration = 03h	-2.0 V - 3%		+2.0 V + 3%	V	
Tip voltage to ground	Converter Configuration = 04h	-1.5 V - 3%		+1.5 V + 3%	V	
Ring voltage to ground	Converter Configuration = 05h	-1.5 V - 3%		+1.5 V + 3%	V	
Metallic DC line voltage	Converter Configuration = 06h	-2.5 V - 3%		+2.5 V + 3%	V	
Metallic loop current	Converter Configuration = 07h	-1.5 mA - 3%		1.5 mA + 3%	mA	
Total longitudinal current	Converter Configuration = 08h	-2.0 mA - 3%		2.0 mA + 3%	mA	
Voice DAC (Full loopback)	Converter Configuration = 0Ah	-1		+1	dB	
Tip voltage to ground, low scale	Converter Configuration = 0Dh	-0.5V - 3%		+0.5V + 3%	V	
Ring voltage to ground, low scale	Converter Configuration = 0Eh	-0.5V - 3%		+0.5V + 3%	V	
Tip Voltage to Longitudinal Current Ratio	Ratio of Voltage to current in Low Gain state, low voltage scale, two point measurement	-6.5		+6.5	%	
Ring Voltage to Longitudinal Current Ratio		-6.5		+6.5	%	
Metallic Voltage to Metallic Current Ratio		-9		+9	%	

Notes:

1. *The % limits are defined as the % of programmed threshold value or the % of the actual voltage on Tip / Ring*
2. *For DC measurements these limits require that the high pass filters are disabled in the operating conditions register and the residual A/D offset is removed by reading the no connect value (Converter Configuration 0Bh) and subtracting it from the measured value. DISN should be cut off (00h), the analog Voice Path Gains set to unity (00h) and the operating functions register set to linear mode (80h)*

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Transmission Characteristics

Description	Test Conditions	Min	Typ	Max	Unit	Note
TAC - RAC overload level	Active state, GX = AX = 0 dB	3.4			Vpk	1.,2.
Transmit level, A/D	0 dBm, GX = GX0, 1014 Hz		0		dBm0	
Receive level, D/A	0 dBm0, GR = GR0, 1014 Hz		0		dBm	
Gain accuracy, D/A or A/D	0 dBm0, 1014 Hz	–0.35		+0.35	dB	
Idle channel noise V_{TIPD} - V_{RINGD} DXA, Digital out	 DRA, Digital input = 0 A-law, -6 dBr DRA, Digital input = 0 µ-law, -6 dBr V_{TIPD} - V_{RINGD} = 0 VAC A-law, 0 dBr V_{TIPD} - V_{RINGD} = 0 VAC µ-law, 0 dBr			 –71 19 –65 19	 dBm0p dBrnC0 dBm0p dBrnC0	 5. 1., 5. 5. 1., 5.
Two-wire return loss	200 to 3400 Hz	26			dB	1.
Longitudinal to Metallic balance TIPD - RINGD or DXA	200 to 3400 Hz	50			dB	7.
DRA to Longitudinal signal generation	300 to 3400 Hz	42				7.
Longitudinal current capability, TIPD or RINGD	Active state	8.5			mArms	1.
Longitudinal impedance at TIPD or RINGD	0 to 100 Hz		100		Ω/pin	1.
Crosstalk between channels TX or RX to TX RX or TX to RX	 0 dBm0, 1014Hz, Average 0 dBm0, 1014Hz, Average			 -76 -78	dBm0	
Attenuation distortion	300 to 3000 Hz	–0.125		+0.125	dB	1.,3.
Single frequency distortion				–46		4.
Second harmonic distortion, D-A	GR = 0 dB, linear mode			–55		
End-to-end absolute group delay	B = Z = 0; X = R = 1, C/L = 0			678	µs	1.,6.

1. *This parameter is guaranteed by characterization or correlation to other tests. Typical values not tested in production.*
2. *Overload level is defined when THD = 1%.*
3. *See Figure 21 and Figure 22.*
4. *0 dBm0 input signal, 300 to 3400 Hz measurement at any other frequency, 300 Hz to 3400 Hz.*
5. *No single frequency component in the range above 3800 Hz may exceed a level of –55 dBm0.*
6. *The End-to-End Group Delay is the absolute group delay of the echo path with the B filter turned off*
7. *This parameter is tested at 1 kHz in production. Performance at other frequencies is guaranteed by characterization.*

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Attenuation Distortion

The signal attenuation in either path is nominally independent of the frequency. The deviations from nominal attenuation will stay within the limits shown in Figure 21 and Figure 22. The reference frequency is 1014 Hz and the signal level is –10 dBm0.

Figure 21. Transmit Path Attenuation vs. Frequency

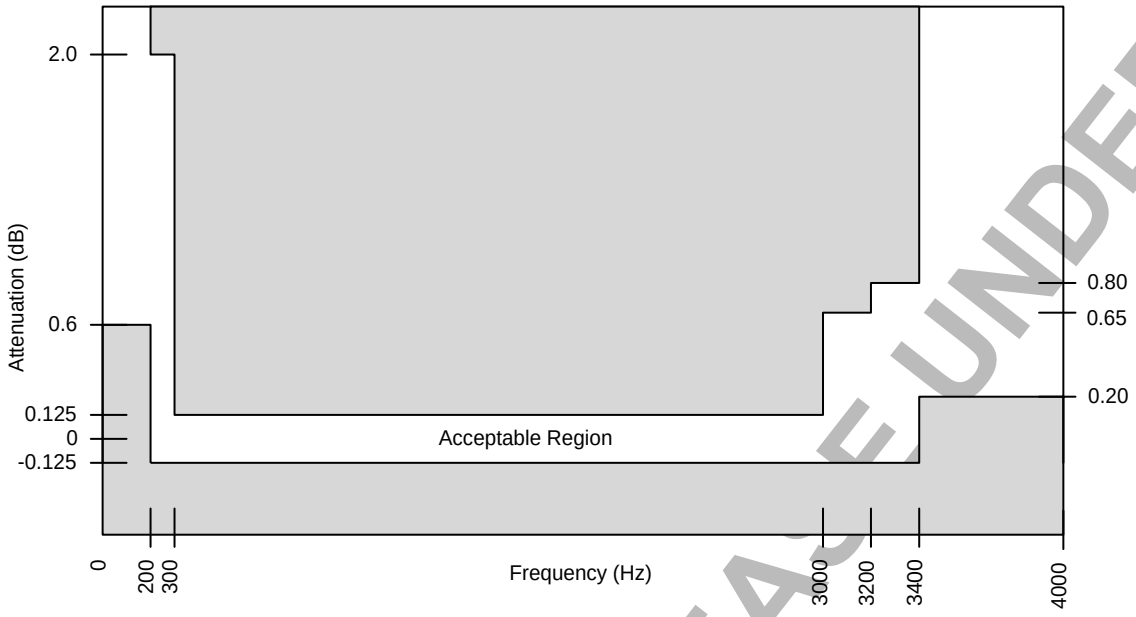
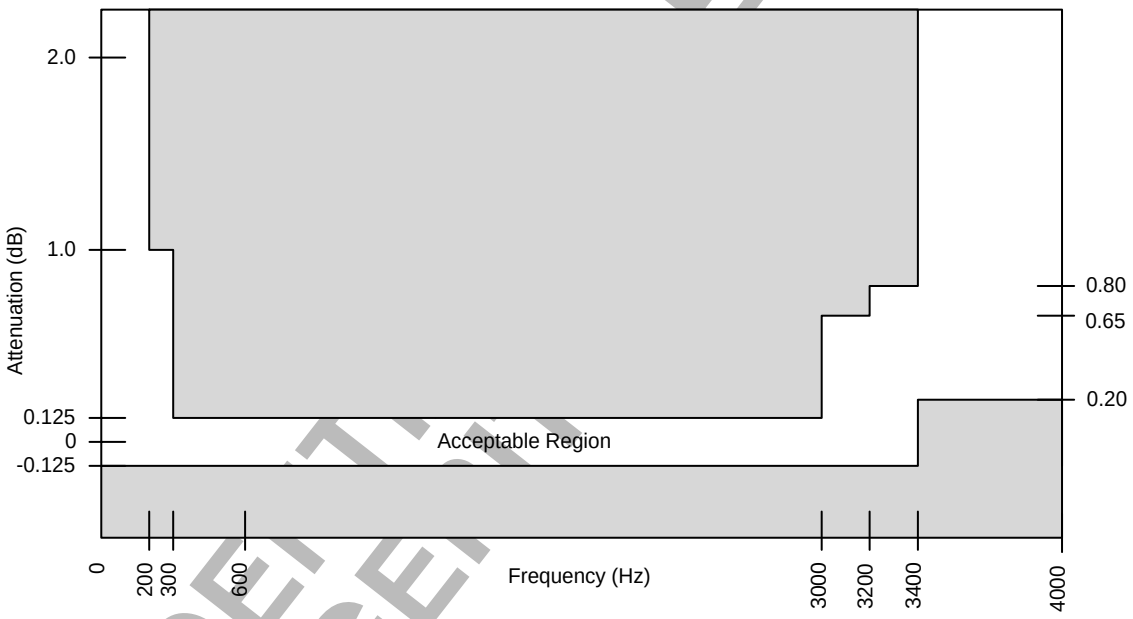


Figure 22. Receive Path Attenuation vs. Frequency



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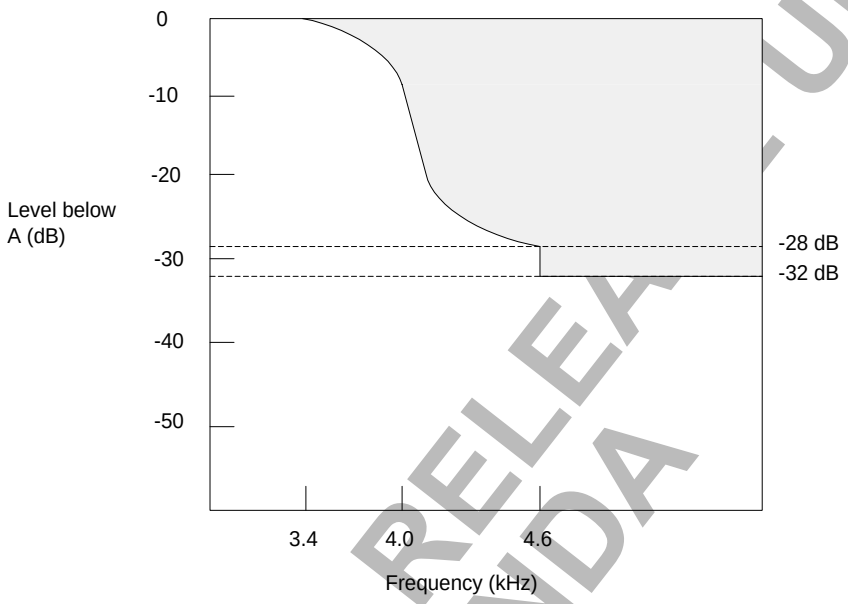
Discrimination Against Out-of-Band Input Signals

When an out-of-band sine wave signal of frequency f, and level A is applied to the analog input, there may be frequency components below 4 kHz at the digital output which are caused by the out-of-band signal. These components are at least the specified dB level below the level of a signal at the same output originating from a 1014-Hz sine wave signal with a level of A dBm0 also applied to the analog input. The minimum specifications are shown in the following table.

Frequency of Out-of-Band Signal	Amplitude of Out-of-Band Signal	Level below A
16.6 Hz < f < 45 Hz	–25 dBm0 < A ≤ 0 dBm0	18 dB
45 Hz < f < 65 Hz	–25 dBm0 < A ≤ 0 dBm0	25 dB
65 Hz < f < 100 Hz	–25 dBm0 < A ≤ 0 dBm0	10 dB
3400 Hz < f < 4600 Hz	–25 dBm0 < A ≤ 0 dBm0	see Figure 23
4600 Hz < f < 100 kHz	–25 dBm0 < A ≤ 0 dBm0	32 dB

Figure 23. Discrimination Against Out-of-Band Signals



Note:

The attenuation of the waveform below amplitude A, between 3400 Hz and 4600 Hz, is given by the formula:

$$\text{Attenuation} = \left[14 - 14\sin\left(\frac{\pi(4000 - f)}{1200}\right)\right] \text{dB}$$

Discrimination Against 12- and 16-kHz Metering Signals

If the Le88221/241 device is used in a metering application where 12- or 16-kHz tone bursts are injected onto the telephone line toward the subscriber, a portion of these tones may also appear at the transmit input. These out-of-band signals may cause frequency components to appear below 4 kHz at the digital output. For a 12-kHz or 16-kHz tone, the frequency components below 4 kHz are reduced from the input by at least 70 dB. The sum of the peak metering and signal voltages must be within the TAC - RAC pin overload level.

Spurious Out-of-Band Signals at the Analog Output

With PCM idle code being applied to the digital input and either a quiet 600 ohm termination or an open being applied to Tip and Ring, any single frequency tone between 0 and 16kHz measured at the analog output shall be less than -50dBm0.

With PCM code words representing a sine wave signal in the range of 300 Hz to 3400 Hz at a level of 0 dBm0 applied to the digital input, the level of the spurious out-of-band signals at the analog output is less than the limits shown below.

Frequency	Level
4.6 kHz to 40 kHz	–32 dBm0
40 kHz to 240 kHz	–46 dBm0
240 kHz to 1 MHz	–36 dBm0

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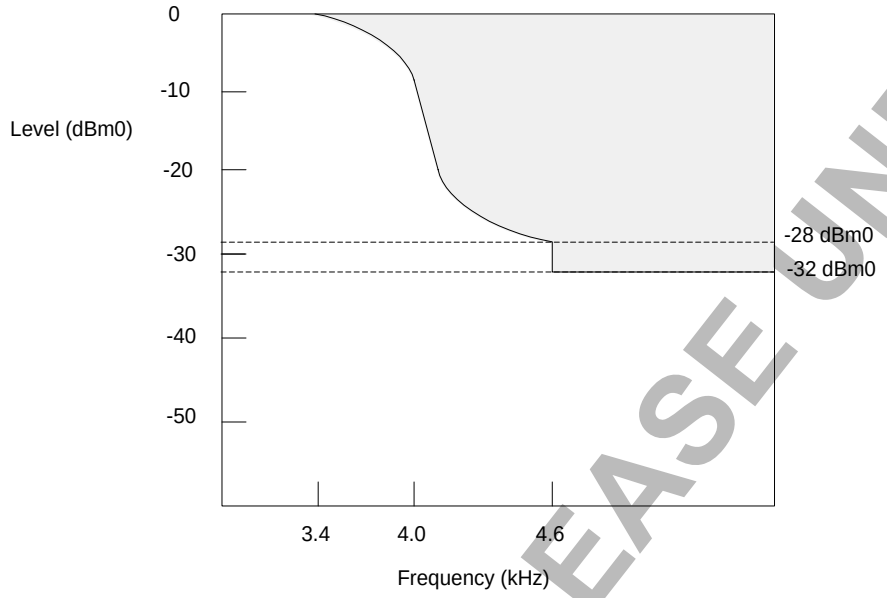
With code words representing any sine wave signal in the range 3.4 kHz to 4.0 kHz at a level of 0 dBm0 applied to the digital input, the level of the signals at the analog output are below the limits in Figure 24. The amplitude of the spurious out-of-band signals between 3400 Hz and 4600 Hz is given by the formula:

$$\text{Level} = \left[-14 - 14\sin\left(\frac{\pi(f-4000)}{1200}\right)\right] \text{dBm0}$$

Figure 24. Spurious Out-of-Band Signals

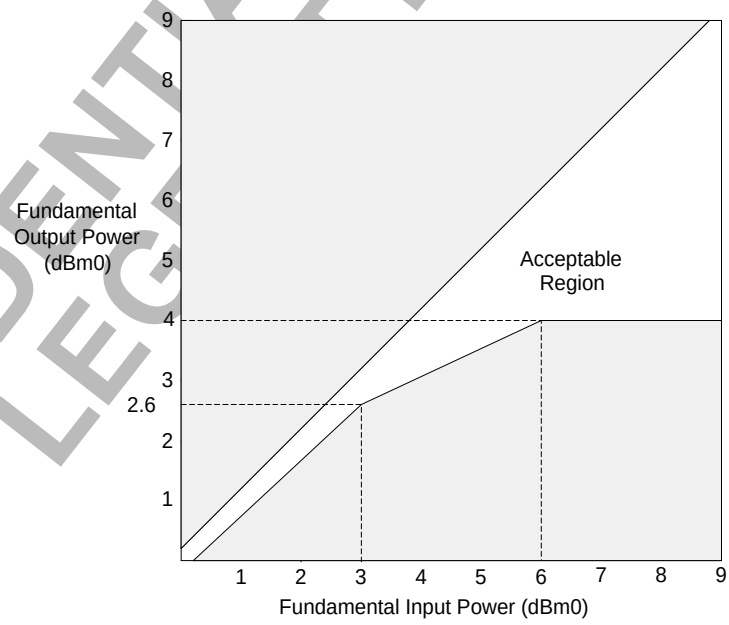


Overload Compression

Figure 25 shows the acceptable region of operation for input signal levels above the reference input power (0 dBm0). The conditions for this figure are:

1. 1.2 dB < GX ≤ + 12 dB
2. –12 dB ≤ GR < –1.2 dB
3. Digital voice output of one VoicePort device connected to digital voice input of a second VoicePort device.
4. Measurement analog-to-analog.

Figure 25. Analog-to-Analog Overload Compression



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Gain Linearity

The gain deviation relative to the gain at –10 dBm0 is within the limits shown in Figure 26 (A-law) and Figure 27 (µ-law) for either transmission path when the input is a sine wave signal of 1014 Hz.

Figure 26. A-law Gain Linearity with Tone Input (Both Paths)

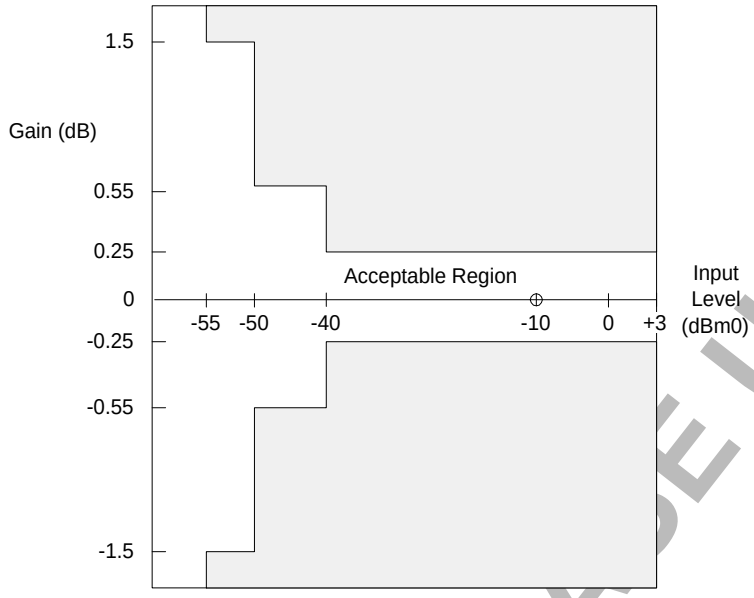
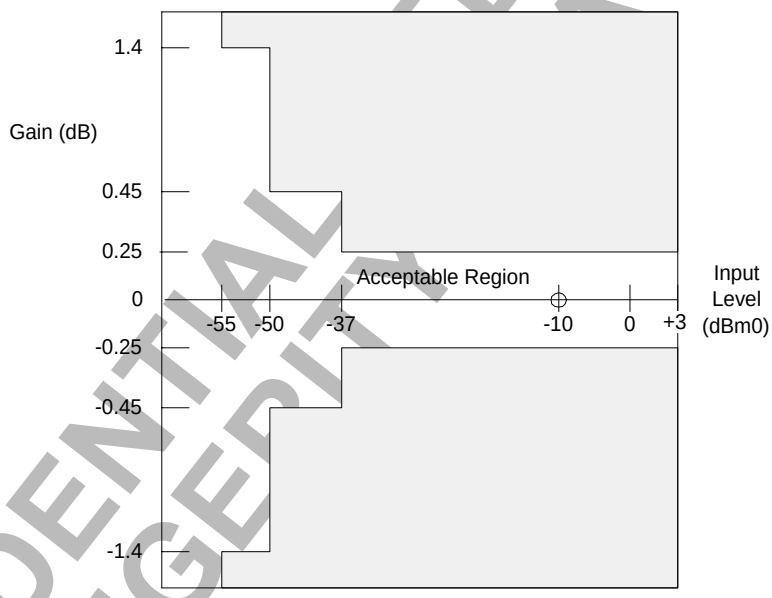


Figure 27. µ-law Gain Linearity with Tone Input (Both Paths)



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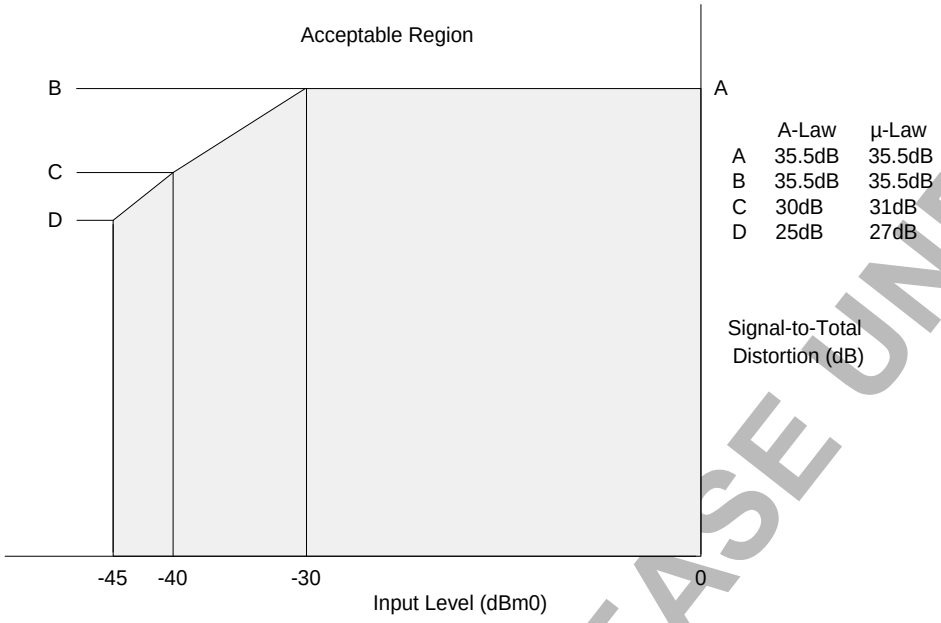
Total Distortion Including Quantizing Distortion

The signal to total distortion ratio will exceed the limits shown in Figure 28 for either path when the input signal is a sine wave with a frequency of 1014 Hz, using psophometric weighting for A-law and C-message weighting for µ-law

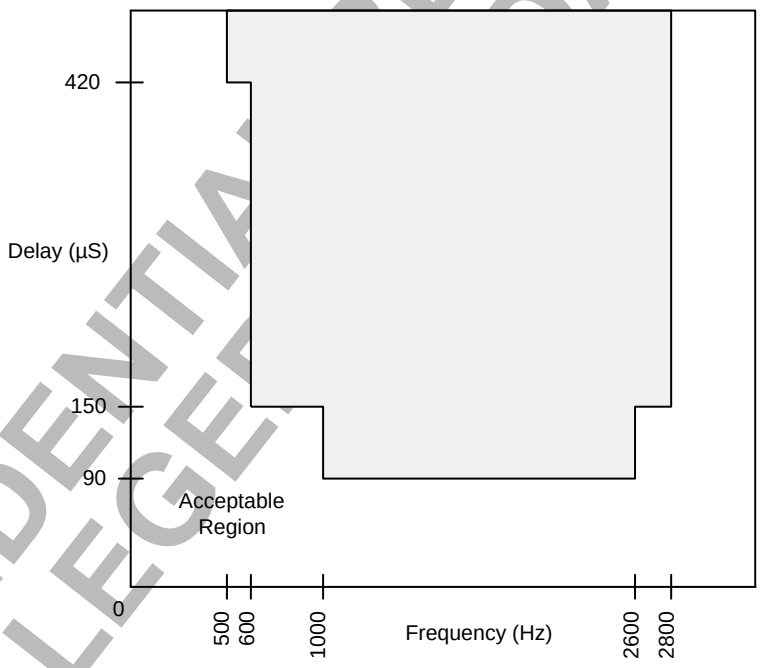
Figure 28. Total Distortion with Tone Input (Both Paths)



Group Delay Distortion

For either transmission path, the group delay distortion is within the limits shown in Figure 29. The minimum value of the group delay is taken as the reference. The signal level should be 0 dBm0.

Figure 29. Group Delay Distortion



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SWITCHING CHARACTERISTICS AND WAVEFORMS

The following are the switching characteristics over operating range (unless otherwise noted). Min and max values are valid for all digital outputs with a 115-pF load. (See Figure 30 and Figure 31 for the microprocessor interface timing diagrams.)

Microprocessor Interface

Table 14. Microprocessor Interface

No.	Symbol	Parameter	Min	Typ	Max	Unit	Note
1	t_{DCY}	Data clock period	122			ns	
2	t_{DCH}	Data clock HIGH pulse width	48				
3	t_{DCL}	Data clock LOW pulse width	48				
4	t_{DCR}	Rise time of clock			25		
5	t_{DCF}	Fall time of clock			25		
6	t_{ICSS}	Chip select setup time, Input mode	30		t_{DCY} –10		
7	t_{ICSH}	Chip select hold time, Input mode	0		t_{DCH} –20		
8	t_{ICSL}	Chip select pulse width, Input mode		$8t_{DCY}$			
9	t_{ICSO}	Chip select off time, Input mode	2500				
10	t_{IDS}	Input data setup time	25				
11	t_{IDH}	Input data hold time	20				
12	t_{OLH}	I/O1, I/O2 output latch valid			2500		
13	t_{OCSS}	Chip select setup time, Output mode	30		t_{DCY} –10		
14	t_{OCSH}	Chip select hold time, Output mode	0		t_{DCH} –20		
15	t_{OCSL}	Chip select pulse width, Output mode		$8t_{DCY}$			
16	t_{OCSO}	Chip select off time, Output mode	2500				
17	t_{ODD}	Output data turn on delay			36		1.
18	t_{ODH}	Output data hold time	3				
19	t_{ODOF}	Output data turn off delay			36		
20	t_{ODC}	Output data valid			36		
21	t_{RST}	Reset pulse width	50			µs	

Notes:

1. The first data bit is enabled on the falling edge of $\overline{CS}$ or on the falling edge of DCLK, whichever occurs last.

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Figure 30. Microprocessor Interface (Input Mode)

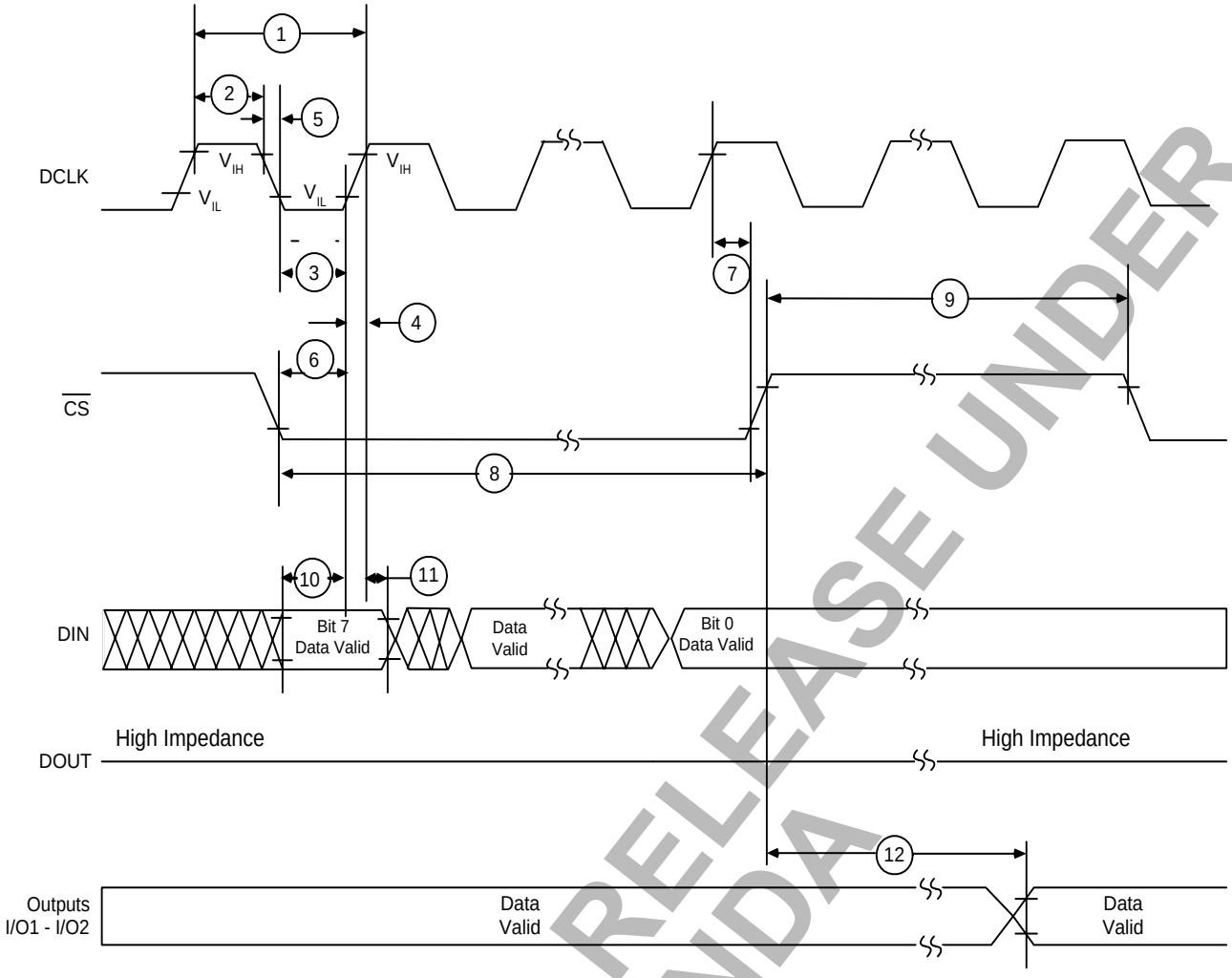
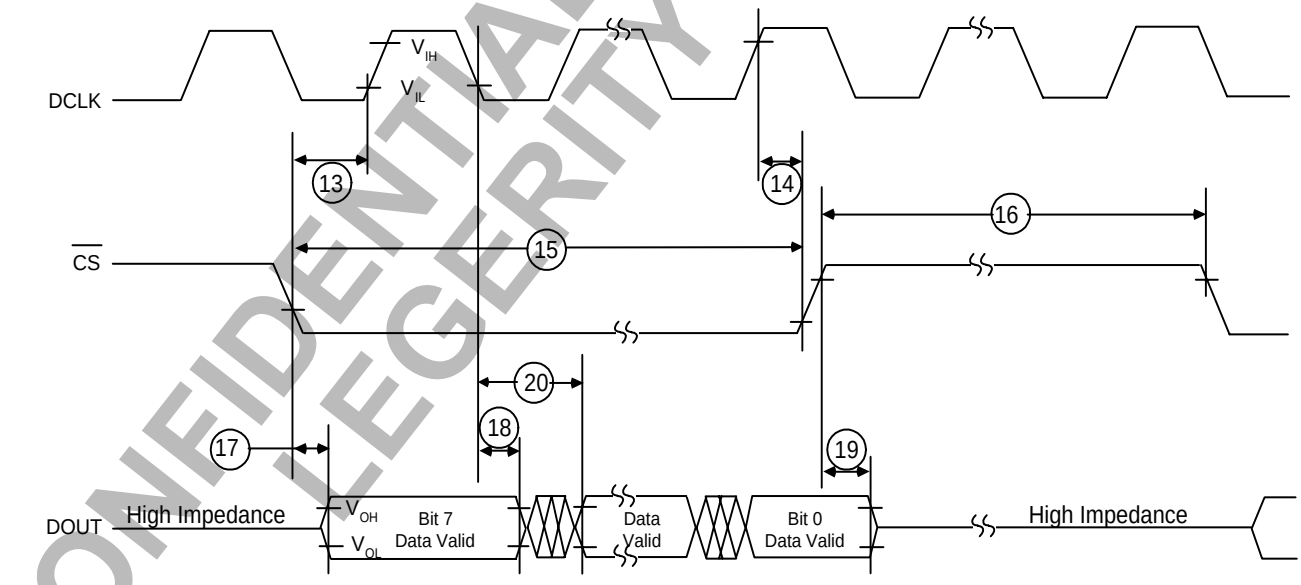


Figure 31. Microprocessor Interface (Output Mode)



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PCM Interface

PCLK shall not exceed 8.192 MHz. Pull-up resistor to DVDD of 240 Ω is attached to $\overline{\text{TSCA}}$.
(See Figure 32 through Figure 34 for the PCM interface timing diagrams.)

No.	Symbol	Parameter	Min.	Typ	Max	Unit	Note
22	t_{PCY}	PCM Clock (PCLK) period	122		651	ns	1.
23	t_{PCH}	PCLK HIGH pulse width	48				
24	t_{PCL}	PCLK LOW pulse width	48				
25	t_{PCF}	PCLK fall time			15		
26	t_{PCR}	PCLK rise time			15		
27	t_{FSS}	FS setup time	25		t_{PCY}–30		
28	t_{FSH}	FS hold time	50				
29	t_{FST}	Allowed PCLK or FS jitter time	–50		50		1.
30	t_{TSD}	Delay to $\overline{\text{TSCA}}$ valid	5		80		2.
31	t_{TSO}	Delay to $\overline{\text{TSCA}}$ off	5				2., 3.
32	t_{DXD}	PCM data output delay	5		70		
33	t_{DXH}	PCM data output hold time	5		70		
34	t_{DXZ}	PCM data output delay to high Z	10		70		
35	t_{DRS}	PCM data input setup time	25				
36	t_{DRH}	PCM data input hold time	5				

Notes:

1. *The PCLK frequency must be an integer multiple of the frame sync (FS) frequency. Frame sync is expected to be an accurate 8-kHz pulse train. The actual PCLK rate depends on the CSEL bit setting in the Chip Configuration register. The minimum frequency is 1.024MHz and the maximum frequency is 8.192 MHz.*
   If PCLK has jitter, care must be taken to ensure that all setup, hold, and pulse width requirements are met.
2. *$\overline{TSC}$ is delayed from FS by a typical value of N • t_{PCY}, where N is the value stored in the time/clock-slot register.*
3. *t_{TSO} is defined as the time at which the output achieves the Open Circuit state.*

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Figure 32. PCM Highway Timing for XE = 0 (Transmit on Negative PCLK Edge)

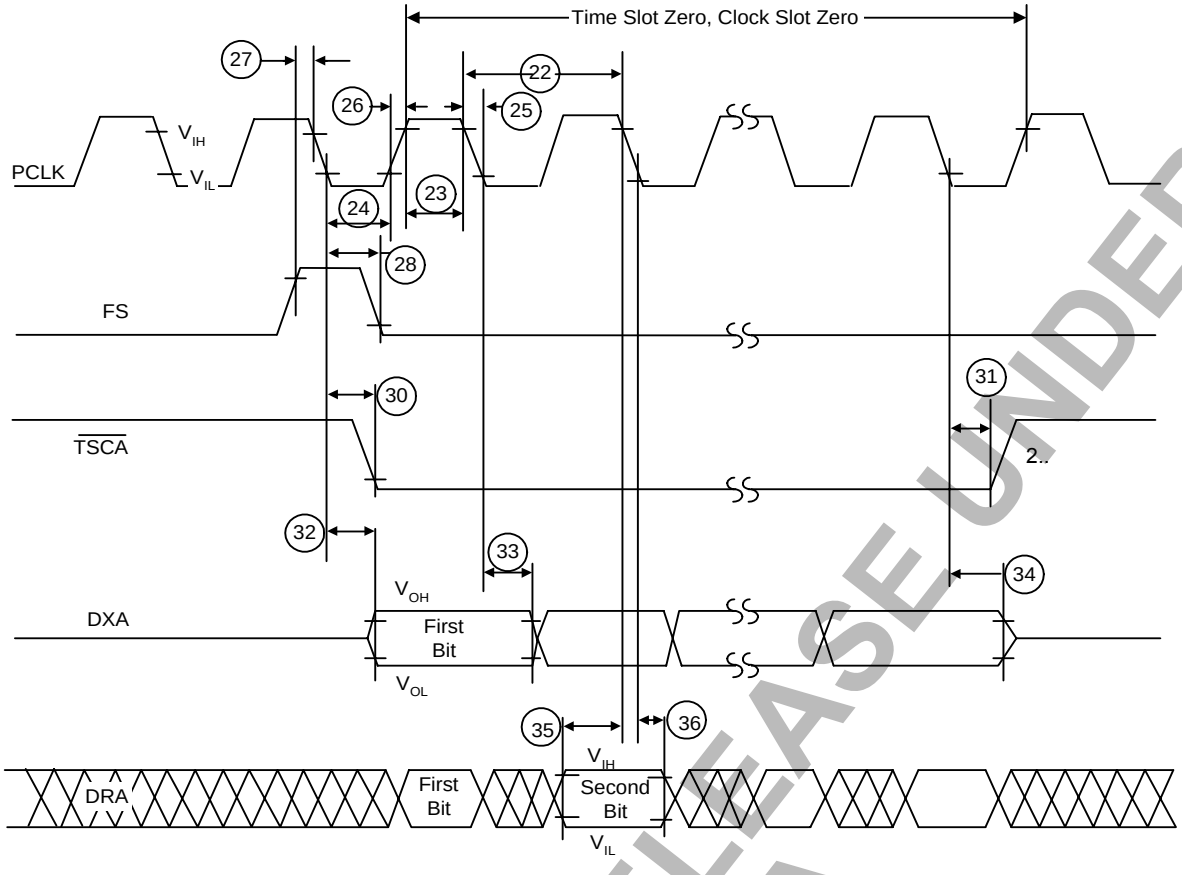

Figure 33. PCM Highway Timing for XE = 1 (Transmit on Positive PCLK Edge)

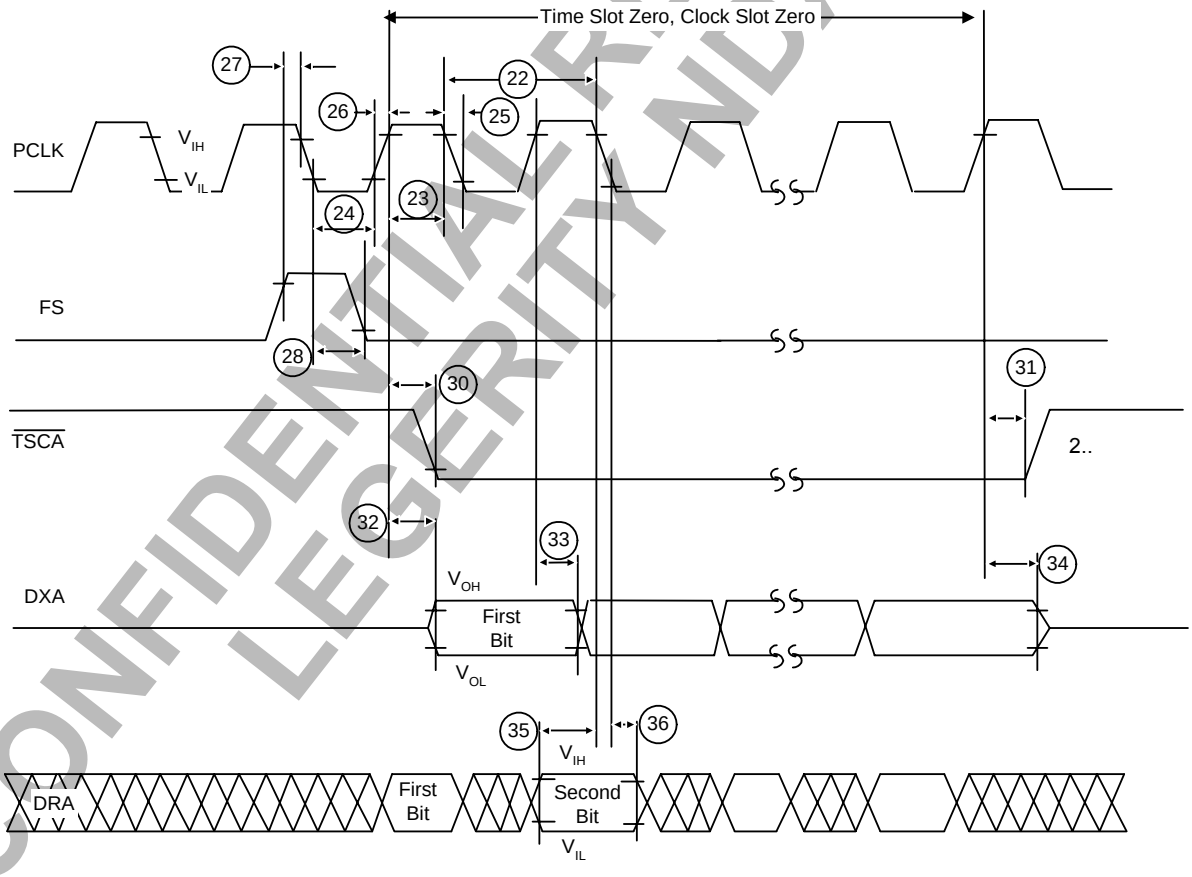

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Figure 34. PCM Clock Timing

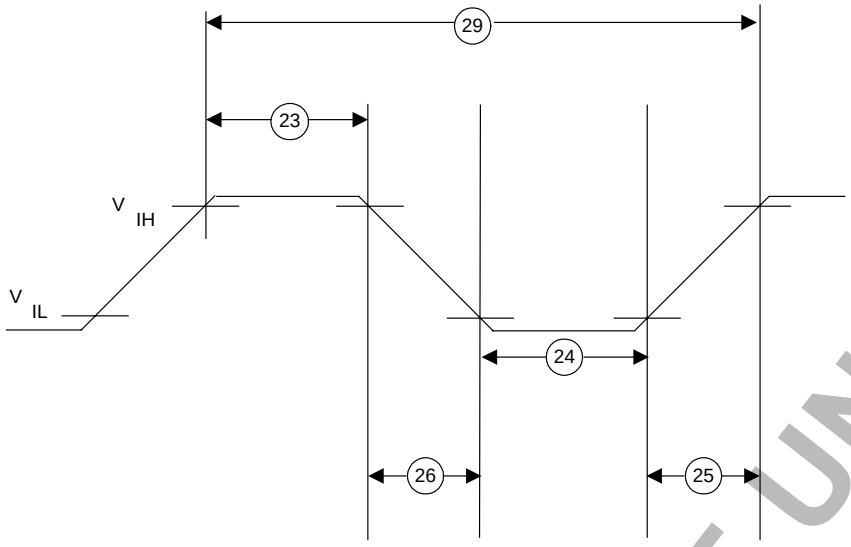
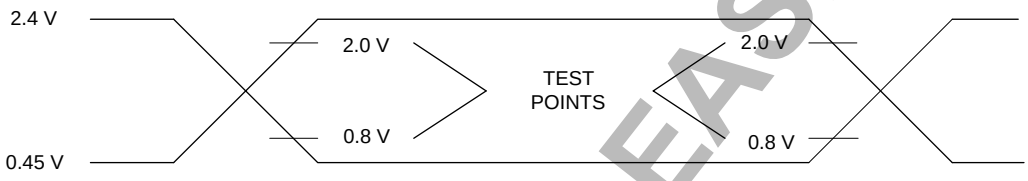


Figure 35. Input and Output Waveforms for AC Tests



GCI Timing

(See Figure 36 and Figure 37 for the GCI interface timing diagrams.)

No.	Symbol	Parameter	Min	Typ	Max	Unit	Note
37	J_{DCL}	DCL Jitter			50	ns	1.
38	t_R, t_F	Rise/fall time			60		
39	t_{DCL}	Period, F_{DCL} = 2048 kHz	488.23	488.28	488.33		
		F_{DCL} = 4096 kHz	244.11	244.14	244.17		
40	t_{WH}, t_{WL}	Pulse width	90				
41	t_{SF}	Setup time	70		t_{DCL}–50		
42	t_{HF}	Hold time	50				
43	t_{WFH}	High pulse width	130				
44	t_{DDC}	Delay from DCL edge			100		
45	t_{DDF}	Delay from FS edge			150		
46	t_{SD}	Data setup	twH+20				
47	t_{HD}	Data hold	50				

Notes:

1. If DCL has jitter, care must be taken to ensure that all setup, hold, and pulse width requirements are met.

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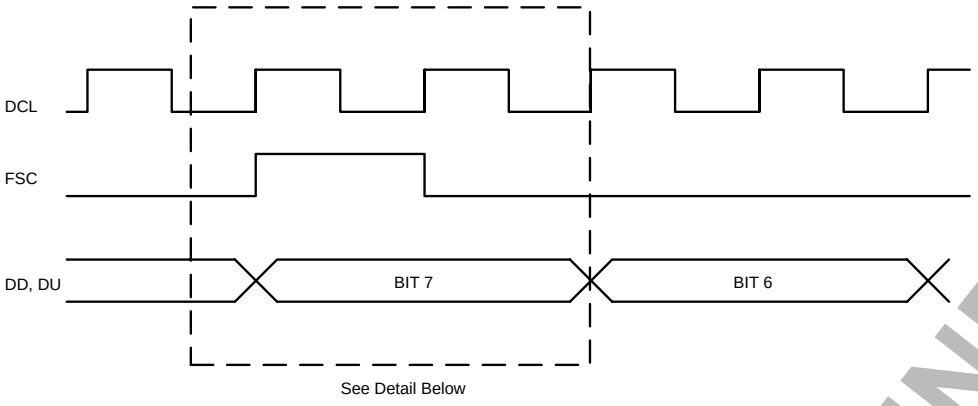
Figure 36. 4.096 MHz DCL Operation



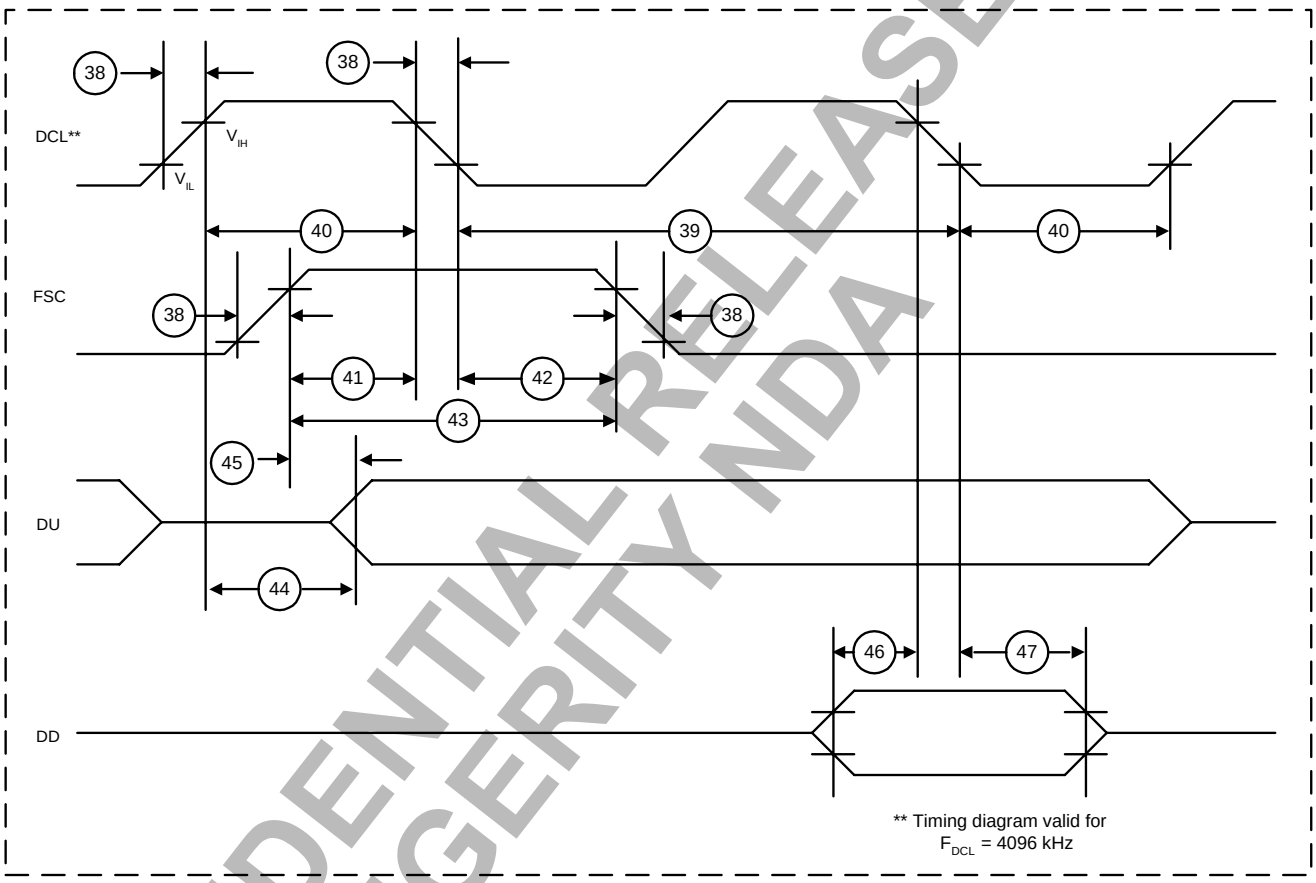


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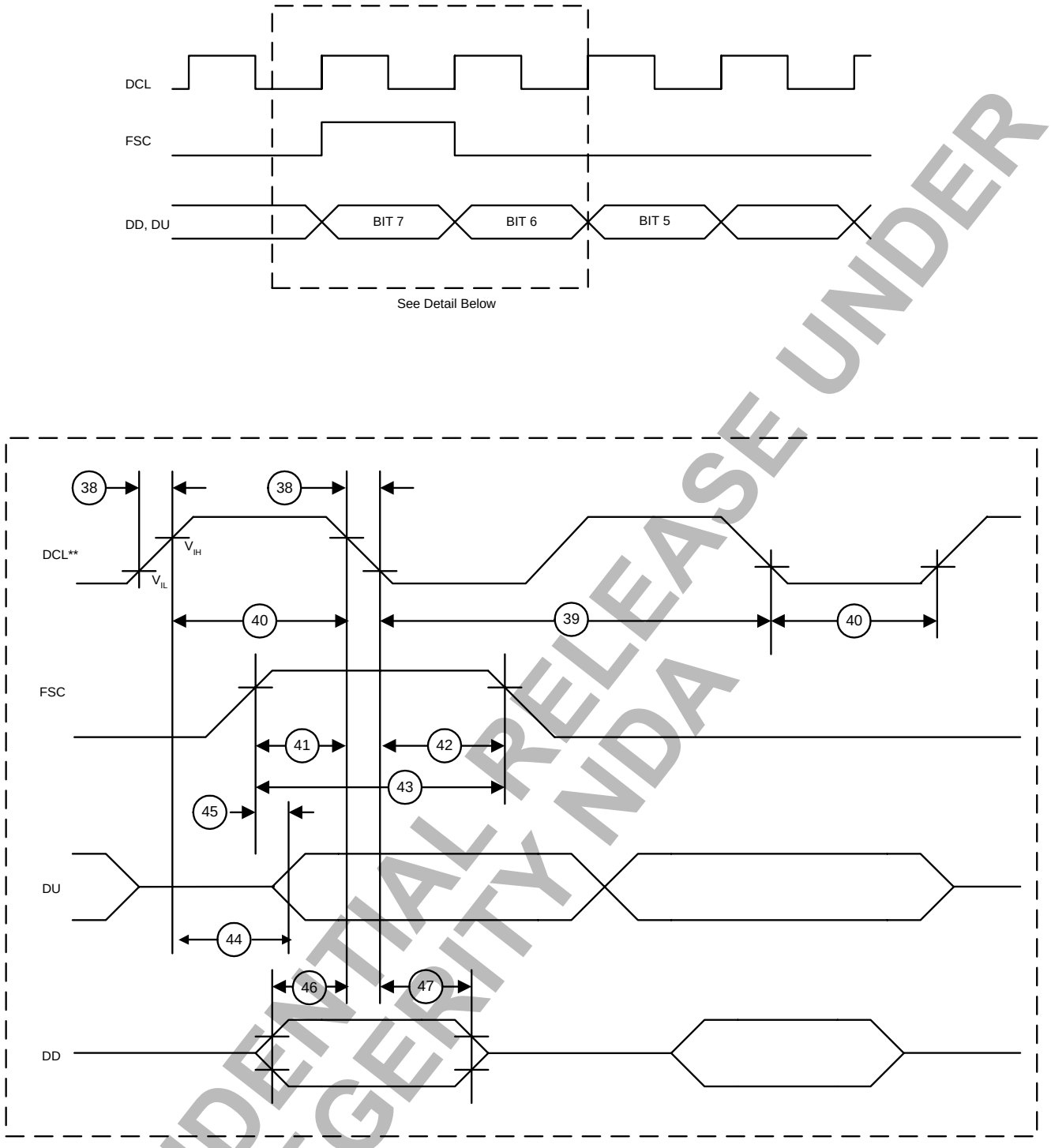
Figure 37. 2.048 MHz DCL Operation



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Switcher Output Timing

(See Figure 38 for the SWOUTY, SWOUTZ timing diagram, and note 5.)

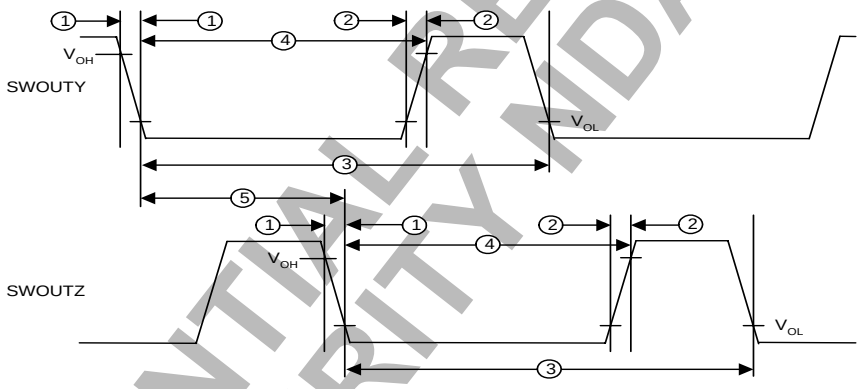
No.	Symbol	Parameter	Min	Typ	Max	Unit	Notes
1	Tfall	Output Fall Time		1	10	ns	1
2	Trise	Output Rise Time		1	10	ns	1
3LP	TPeriod	Period for Low Power Mode		20.833		µs	2
4LP	Tmax	Max On-Time for Low Power Mode		1.830	1.845	µs	2
3MP	TPeriod	Period for Medium Power Mode		10.417		µs	3
4MP	Tmax	Max On-Time for Medium Power Mode		1.830	1.845	µs	3
3HP	TPeriod	Period for High Power Mode		2.604		µs	4
4HP	Tmax	Max On-Time for High Power Mode		1.830	1.845	µs	4
	Duty Cycle LP	Duty Cycle Low Power Mode	0		8.8	%	2
	Duty Cycle MP	Duty Cycle Medium Power Mode	0		17.6	%	3
	Duty Cycle HP	Duty Cycle High Power Mode	0		70.3	%	4
5	Y to Z offset	Delay from SWOUTZ to SWOUTY on		1.302		µs	

Notes:

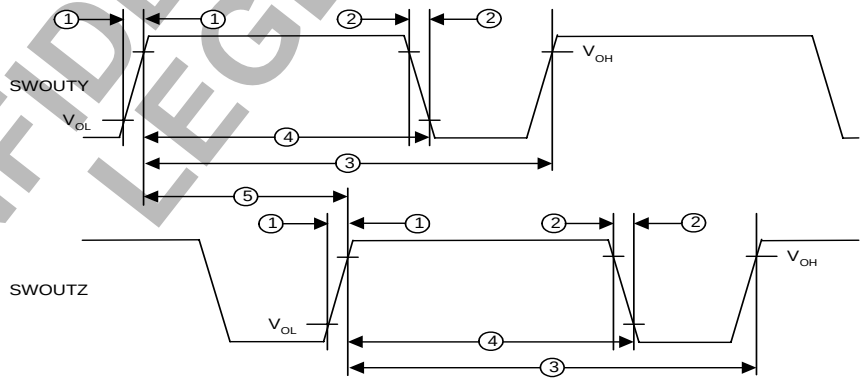
1. *Measured with an RC load on SWOUTY of 330 pF in series with 180 Ω to ground.*
2. *Register E6/E7h Write/Read Switching Regulator Control is loaded with low power mode 01h.*
3. *Register E6/E7h Write/Read Switching Regulator Control is loaded with medium power mode 02h.*
4. *Register E6/E7h Write/Read Switching Regulator Control is loaded with high power mode 03h*
5. *Timing values assume SWFS[1:0] = 00b in E4/E5h Write/Read Switching Regulator Parameters. Stated periods and on times scale inversely with frequency selected.*

Figure 38. Switcher Output Waveform SWOUTY, SWOUTZ

Flyback Mode (Representative of High Power setting)



Inverting Buckboost Mode (Representative of High Power setting)



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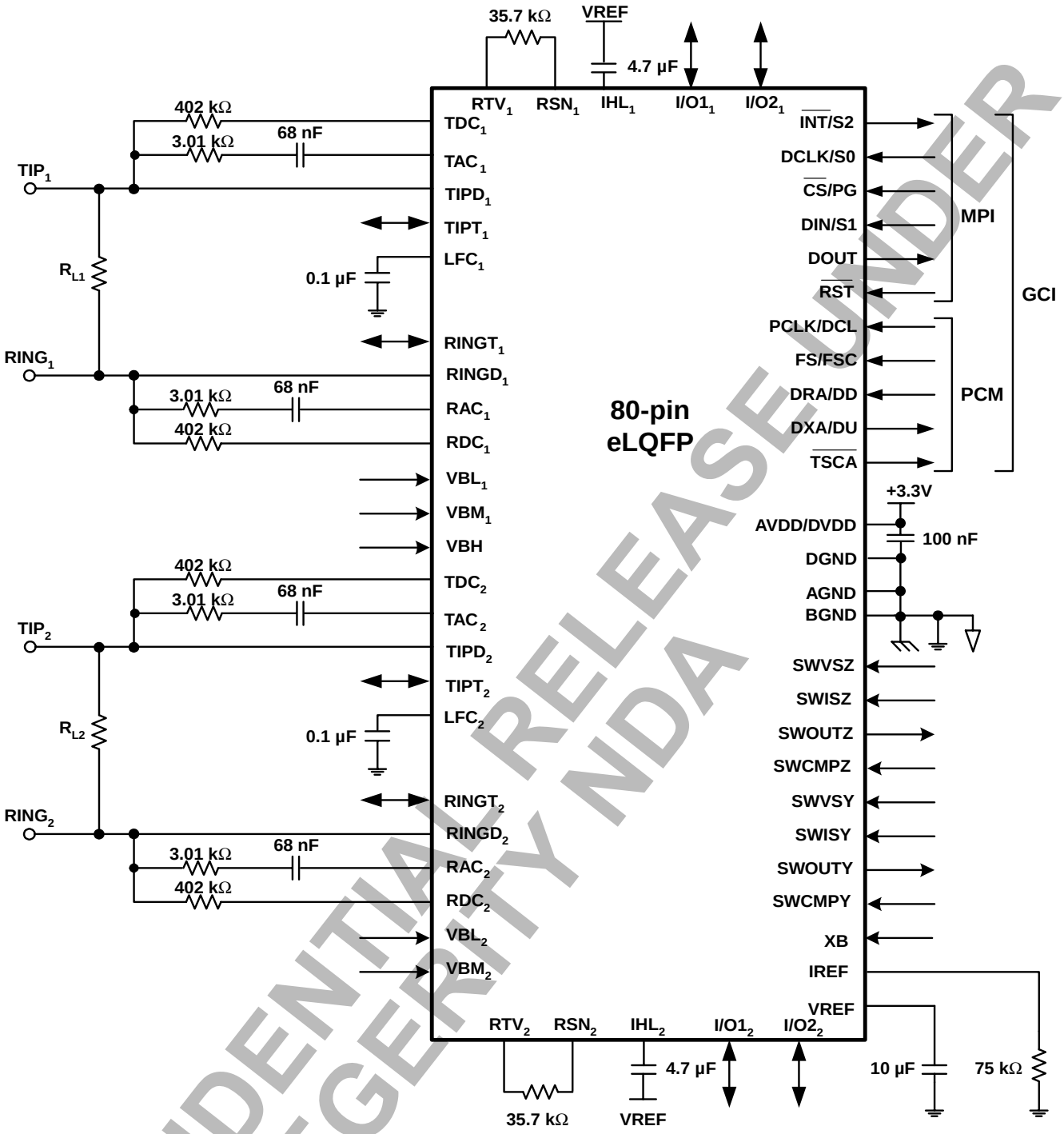
TEST CIRCUIT

Figure 39. Le88221/241 Device Test Circuit



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APPLICATIONS

The Le88221/241 VoicePort device implements a complete dual channel interface between a digital highway (PCM/MPI or GCI) and two telephone lines. The Le88221/241 device provides access to time-critical information, such as off/on-hook and ring trip, via a single read operation. When various country or transmission requirements must be met, the Le88221/241 device can be reprogrammed to meet the required DC feed, ringing and transmission characteristics.

Several Le88221/241 devices can be tied together in one bus interfacing to a common PCM or GCI interface. In MPI mode, the Le88221/241 device is controlled through the microprocessor interface.

The following application example uses the Le88221/241 device in a two-battery switching configuration. The power can be provided by external supplies or from the example dual output supply shown in Figure 41 using the SWOUTY controller.

* For an application using the Le88221 device with lower voltage ringing, some device ratings may be reduced, in particular the 200-V rated capacitors.

Application Circuit

Figure 40. Le88221/241 Device Application Circuit

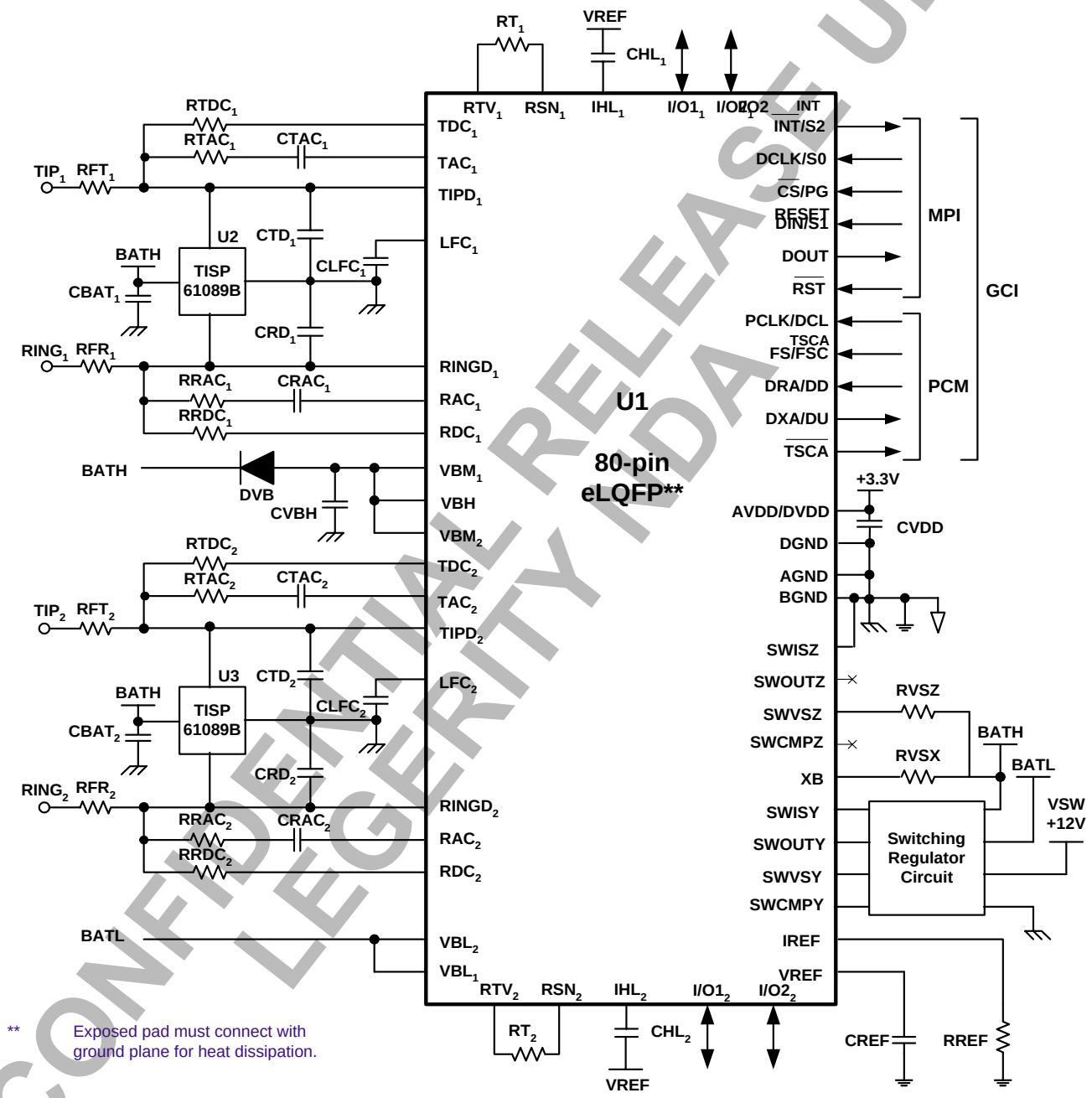

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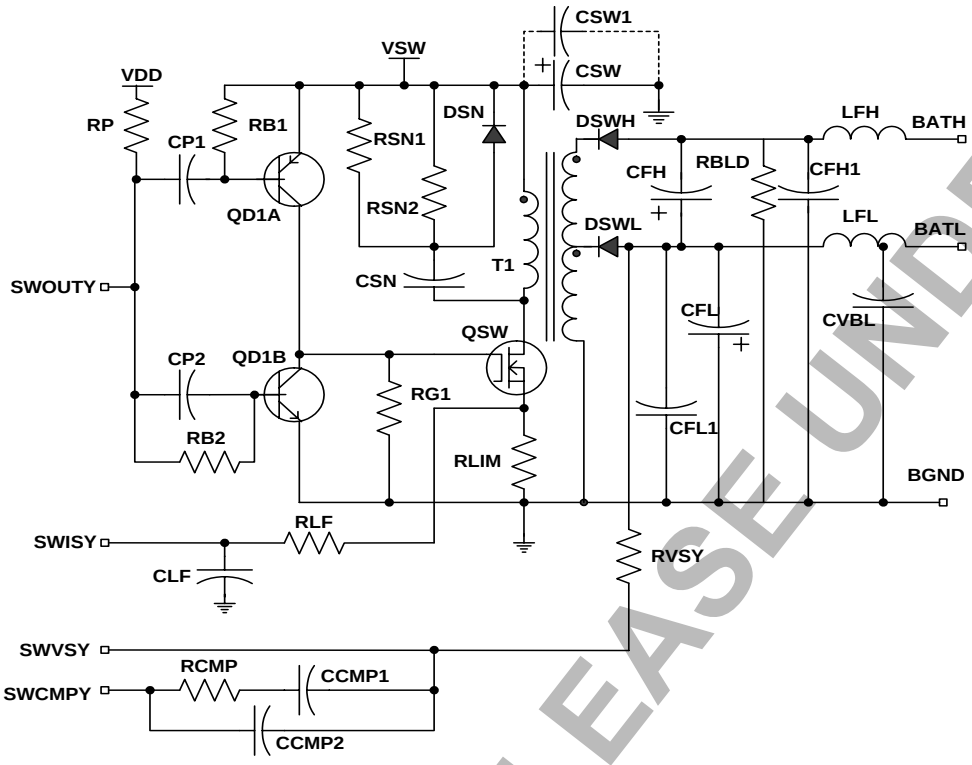
Figure 41. Le88221/241 Switching Regulator Circuit

Circuit shown for a two channel Le88221 battery switching application
90 V high battery (55 vrms ringing with 5REN load)
30 V regulated low battery, with 12 V nominal VSW input



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Le88221/241 VoicePort™ Device Parts List

The following list defines the parts and part values required to meet target specifications based on the application circuits shown in Figure 40 and Figure 41.

Item	Quantity	Type	Value	Tol.	Rating	Comments
$C_{HL1,2}$	2	Capacitor	4.7 µF	10%	6.3 V	Panasonic ECJ1VBOJ475 0603
$C_{LFC1,2}$	2	Capacitor (optional)	0.1 µF	20%	10 V	Murata GRM155R61A104KA01D 0402
$C_{RD1,2}$, $C_{TD1,2}$	4	Capacitor	0.022 µF	10%	200 V*	Kemet 08052C223KAT2A 0805
$C_{RAC1,2}$, $C_{TAC1,2}$	4	Capacitor	0.068 µF	10%	200 V*	Kemet 12062C683KAT2A 1206
C_{REF}	1	Capacitor X7R	10µF	10%	6 V	Panasonic ECJ-2FB0J106M
$C_{VDD1,2,3,4}$	4	Capacitor	0.1 µF	20%	10 V	Murata GRM155R61A104KA01D 0402
D_{VBH}	1	Diode	90 V		1A	Central Semi CMPD1001
$R_{FT1,2}$, $R_{FR1,2}$	4	PTC	50 Ω		250 V	Asiacom MZ2L-50R
$R_{RAC1,2}$, $R_{TAC1,2}$	4	Resistor	3.01 kΩ	1%	1/10 W	Panasonic ERJ-6ENF3011V 0805
R_{REF}	1	Resistor	75 kΩ	1%	1/16 W	Panasonic ERJ-2RKF7502X 0402
$R_{RDC1,2}$, $R_{TDC1,2}$, R_{VSX}, R_{VSY}, R_{VSZ}	7	Resistor	402 kΩ	1%	1/10 W	Panasonic ERJ-6ENF4023V 0805
$R_{T1,2}$	2	Resistor	47.5 kΩ	1%	1/16 W	Panasonic ERJ-2RKF4752X 0402
U1	1	Dual ABS VoicePort device				Le88221/241
U2, U3	1	Protector			170 V	TISP61089BDR
SWICHING POWER SUPPLY COMPONENTS						
C_{BAT1}, C_{BAT2}, C_{VBH}, C_{FH1}, C_{FL1}	5	Capacitor X7R	0.1 µF	10%	200 V*	Kemet C1206C104K1RACTU 1206
C_{CMP1}	1	Capacitor X5R	0.033µF	10%	10 V	Panasonic ECJ-0EB1A333K 0402
C_{CMP2}	1	Capacitor X7R	4 pF	10%	10 V	Panasonic ECJ-1VC1H040C 0402
C_{FH}	1	Capacitor	47 µF	20%	100 V	Panasonic EEV-FK2A470Q TH
C_{FL}	1	Capacitor	100 µF	20%	50 V*	Panasonic EEV-FK1J101P TH
C_{P1},C_{P2}	2	Capacitor X7R	220 pF	10%	25 V	Yageo 0402CG221J8B200 0402
C_{SN}	1	Capacitor X7R	1 nF	10%	25 V	Kemet C0603C102K1RACTU 0603
C_{SW}	1	Capacitor Low ESR	100 µF	20%	25 V	Panasonic EEU-FC1E101S TH
C_{VBL}	1	Capacitor	0.47 µF	10%	50 V	TDK C3216X7R1H474K 1206
D_{SWH}, D_{SWL}	2	Diode	Ultra Fast	<50 nS	1 A/200 V	Fairchild ES1D
D_{SN}	1	Diode	Fast		1 A/100 V	Central Semi CMPD1001
L_{FH}, L_{FL}	2	Inductor	470 µH	10%	>110 mA	Coilcraft 1812FS-474K 1812
$Q_{D1A/B}$	1	Dual transistor	100mA		40V	On Semi MBT3946DW1T1LRG
Q_{SW}	1	MOSFET	170 mΩ	9 A	60 V*	Fairchild NDT3055L SOT-223
R_{B1}	1	Resistor	560 Ω	5%	1/16 W	Panasonic ERJ-2GEJ561X 0402
R_{B2}, R_{G1}, R_P	3	Resistor	10 kΩ	5%	1/16 W	Panasonic ERJ-2GEJ103X 0402
R_{BLD}	1	Resistor	75 kΩ	5%	1/4 W	Panasonic ERJ-8GEYJ753V 1206
R_{CMP}	1	Resistor	1.0 MΩ	5%	1/16 W	Panasonic ERJ-2GEJ105X 0402
R_{SN1}, R_{SN2}	2	Resistor	1.8 kΩ	5%	1/4 W	Panasonic ERJ-8GEYJ182V 1206
R_{LIM}	1	Resistor	0.015 Ω	1%	1/4 W	Vishay WSL1206R0150FBA 1206
T_1	1	Flyback Transformer				Sumida P/N C8100

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COMMAND DESCRIPTION AND FORMATS

Command Field Summary

A microprocessor can program and control the Le88221/241 device using the MPI or GCI. Data programmed previously can be read out for verification. See *Detailed Descriptions Of Commands*, on page 64 for the channel and global chip parameters assigned.

MPI DESCRIPTION

If desired, multiple voice channel data can be programmed simultaneously with identical information by setting multiple Channel Enable bits. Channel Enable bits are contained in the Channel Enable register and written or read using MPI Command 4A/4Bh. If multiple Channel Enable bits are set for a read operation, only voice data from the first enabled channel will be read. Other functions within the device are accessible on a global basis independent of the setting of the Channel Enable bits.

The MPI consists of a serial data input (DIN) a data output (DOUT), a data clock (DCLK), and a chip select ($\overline{CS}$). The scope of the commands can be either Global or Voice Channel specific, as indicated in the *Summary of MPI Commands*, on page 63. Access to the Voice Channel commands are controlled by the voice Channel Enable bits (EC1 and EC2) in the *4A/4Bh Write/ Read Channel Enable and Operating Mode Register*, on page 66. The serial input consists of 8-bit commands that can be followed by additional bytes of input data, or by the Le88221/241 device sending out bytes of data. All data input and output is MSB (D7) first and LSB (D0) last. All data bytes are read or written one at a time, with $\overline{CS}$ going High for at least a minimum off period before the next byte is read or written. Only a single channel should be enabled during read commands.

All commands that require additional input data to the device must have the input data as the next N words written into the device (for example, framed by the next N transitions of $\overline{CS}$). All unused bits must be programmed as 0 (unless otherwise noted) to ensure compatibility with future parts. All commands that are followed by output data will cause the device to output data for the next N transitions of $\overline{CS}$ going Low. The Le88221/241 device will not accept any commands until all the data has been shifted out. The output values of unused bits are not specified.

An MPI cycle is defined by transitions of $\overline{CS}$ and DCLK. If the $\overline{CS}$ lines are held in the High state between accesses, the DCLK may run continuously with no change to the internal control data. Using this method, the same DCLK can be run to a number of Le88221/241 devices, and the individual $\overline{CS}$ lines will select the appropriate device to access. Between command sequences, DCLK can stay in the High state indefinitely with no loss of internal control information regardless of any transitions on the $\overline{CS}$ lines. Between bytes of a multibyte read or write command sequence, DCLK can also stay in the High state indefinitely. DCLK can stay in the Low state indefinitely with no loss of internal control information, provided the $\overline{CS}$ line remains at a High level.

If a low period of $\overline{CS}$ contains less than 8 positive DCLK transitions, it is ignored. If it contains 8 to 15 positive transitions, only the last 8 transitions matter. If it contains 16 or more positive transitions, a hardware reset in the part occurs. If the chip is in the middle of a read sequence when $\overline{CS}$ goes Low, data will be present at the DOUT pin even if DCLK has no activity.

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SUMMARY OF MPI COMMANDS

Hex*	Description	Scope	Page #
02h	Software Reset	Channel	page 64
04h	Hardware Reset	Global	page 64
06h	No Operation	Global	page 64
40/41h	Write/Read Transmit Time Slot	Channel	page 64
42/43h	Write/Read Receive Time Slot	Channel	page 65
44/45h	Write/Read Transmit and Receive Clock Slot and Transmit Clock Edge	Global	page 65
46/47h	Write/Read Device Configuration Register	Global	page 65
4A/4Bh	Write/Read Channel Enable & Operating Mode Register	Global	page 66
4D/4Fh	Read Signaling Register	Global	page 67
50/51h	Write/Read Voice Path Gains	Channel	page 69
52/53h	Write/Read Input/Output Data Register	Channel	page 69
54/55h	Write/Read Input/Output Direction Register	Channel	page 70
56/57h	Write/Read System State	Channel	page 70
60/61h	Write/Read Operating Functions	Channel	page 71
68/69h	Write/Read System State Configuration	Channel	page 72
6C/6Dh	Write/Read Interrupt Mask Register	Global	page 73
70/71h	Write/Read Operating Conditions	Channel	page 73
73h	Read Revision and Product Code Number (RCN, PCN))	Global	page 74
80/81h	Write/Read GX Filter Coefficients	Channel	page 74
82/83h	Write/Read GR Filter Coefficients	Channel	page 75
86/87h	Write/Read B Filter FIR Coefficients	Channel	page 75
88/89h	Write/Read X Filter Coefficients	Channel	page 76
8A/8Bh	Write/Read R Filter Coefficients	Channel	page 77
96/97h	Write/Read B Filter IIR Coefficients	Channel	page 78
98/99h	Write/Read Z Filter FIR Coefficients	Channel	page 78
9A/9Bh	Write/Read Z Filter IIR Coefficients	Channel	page 78
A6/A7h	Write/Read Converter Configuration	Channel	page 79
C2/C3h	Write/Read Loop Supervision Parameters	Channel	page 81
C6/C7h	Write/Read DC Feed Parameters	Channel	page 81
CA/CBh	Write/Read Digital Impedance Scaling Network (DISN)	Channel	page 82
CDh	Read Transmit PCM/Test Data	Channel	page 82
D0/D1h	Write/Read Metering Parameters	Channel	page 83
D2/D3h	Write/Read Signal Generator A, B and Bias Parameters	Channel	page 84
D4/D5h	Write/Read Signal Generator C and D Parameters	Channel	page 86
DE/DFh	Write/Read Signal Generator Control	Channel	page 87
E0/E1h	Write/Read Cadence Timer	Channel	page 88
E2/E3h	Write/Read Caller Identification Number Data	Channel	page 88
E4/E5h	Write/Read Switching Regulator Parameters	Global	page 89
E6/E7h	Write/Read Switching Regulator Control	Global	page 90
EA/EBh	Write/Read Caller Identification Number Parameters	Channel	page 91

Note:
**All codes not listed are reserved by Legerity and should not be used.*

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DETAILED DESCRIPTIONS OF COMMANDS

This section details each command used by the Le88221/241 device. The command is shown, along with the format of any additional data bytes that follow. Unused bits are indicated by “RSVD”; 0’s should be written to these bits (unless otherwise noted), but 0’s are not guaranteed when they are read.

In all commands:

R/$\overline{W}$ = 0: Write

R/$\overline{W}$ = 1: Read

*Default field values are marked by an asterisk. A hardware reset forces the default values.

02h Software Reset

Command	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
W: 02h	0	0	0	0	0	0	1	0

This command only operates on the channels selected by the Channel Enable Register and it does not change clock slots, time slots or global chip parameters. The selected channels will be put into the Disconnect state as a result of a Software reset unless that channel is in the Shutdown state in which case it will stay in the Shutdown state.

04h Hardware Reset

Command	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
W: 04h	0	0	0	0	0	1	0	0

Hardware reset is equivalent to pulling the $\overline{RST}$ pin on the device Low.
This command does not depend on the state of the Channel Enable Register. A Hardware reset will put all channels into the Shutdown state.

Note:
The action of a hardware reset is described in the section on operating the Le88221/241 device.

06h No Operation

Command	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
W: 06h	0	0	0	0	0	1	1	0

40/41h Write/Read Transmit Time Slot

Command	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
W: 40h R: 41h	0	1	0	0	0	0	0	R/$\overline{W}$
I/O Data	RSVD	TTS6	TTS5	TTS4	TTS3	TTS2	TTS1	TTS0

TTS[6:0]: Transmit Time Slot

0–127: Time Slot Number (TTS0 is LSB, TTS6 is MSB)

This command applies to PCM mode only. Its contents are ignored in GCI mode.

Power Up and Hardware Reset ($\overline{RST}$) Value = 00h for Channel 1.

Power Up and Hardware Reset ($\overline{RST}$) Value = 01h for Channel 2.

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42/43h Write/Read Receive Time Slot

Command	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
W: 42h R: 43h	0	1	0	0	0	0	1	R/$\overline{W}$
I/O Data	RSVD	RTS6	RTS5	RTS4	RTS3	RTS2	RTS1	RTS0

RTS[6:0]: Receive Time Slot

0–127: Time Slot Number (RTS0 is LSB, RTS6 is MSB)

This command applies to PCM mode only. Its contents are ignored in GCI mode.

Power Up and Hardware Reset ($\overline{RST}$) Value = 00h for Channel 1.

Power Up and Hardware Reset ($\overline{RST}$) Value = 01h for Channel 2.

44/45h Write/Read Transmit and Receive Clock Slot and Transmit Clock Edge

Command	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
W: 44h R: 45h	0	1	0	0	0	1	0	R/$\overline{W}$
I/O Data	RSVD	XE	RCS2	RCS1	RCS0	TCS2	TCS1	TCS0

XE Transmit Edge

0*: Transmit changes on negative edge of PCLK

1: Transmit changes on positive edge of PCLK

RCS[2:0]: Receive Clock Slot

0*–7: Receive Clock Slot number

TCS[2:0]: Transmit Clock Slot

0*–7: Transmit Clock Slot number

This command does not depend on the state of the Channel Enable Register.
This command applies to PCM mode only. Its contents are ignored in GCI mode.

*Power Up and Hardware Reset ($\overline{RST}$) Value = 00h.

46/47h Write/Read Device Configuration Register

Command	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
W: 46h R: 47h	0	1	0	0	0	1	1	R/$\overline{W}$
I/O Data	INTM	RSVD	SMODE	RSVD	CSEL3	CSEL2	CSEL1	CSEL0

RSVD: Reserved for future use. Always write as 0, but 0 is not guaranteed when read.

INTM: Interrupt Mode

0: CMOS-compatible output

1*: Open drain output

SMODE: PCM Signaling Mode

0*: No signaling on PCM highway

1: Signaling on PCM highway

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The PCM clock frequency can be selected by CSEL. The PCLK frequency selection affects all channels.

CSEL[3:0]:	PCM Clock Frequency
0000	1.536 MHz
0001	1.544 MHz
0010	2.048 MHz
0011	1.024 MHz
0100	3.072 MHz
0101	3.088 MHz
0110	4.096 MHz
0111	Reserved
1000	6.144 MHz
1001	6.176 MHz
1010*	8.192 MHz
1011	Reserved
1100	Reserved
1101	Reserved
1110	Reserved
1111	Reserved

This command does not depend on the state of the Channel Enable Register.
This command applies to PCM mode only. Its contents are ignored in GCI mode.

In the absence of external PCLK, the on chip master clock will slow down to it's minimum operating frequency which will be in the range of 1/5 - 1/2 of its normal operating frequency. If the ACFS bit is reset in command *68/69h Write/Read System State Configuration, on page 72* then this enables a low power system standby state to be implemented where supervision functions are still operational and interrupts can be generated in the absence of any system clocks.

* Power Up and Hardware Reset ($\overline{RST}$) Value = 8Ah.

4A/4Bh Write/Read Channel Enable and Operating Mode Register

Command	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
W: 4Ah R: 4Bh	0	1	0	0	1	0	1	R/$\overline{W}$
I/O Data	RSVD	RSVD	RSVD	RSVD	RSVD	RSVD	EC2	EC1

RSVD: Reserved for future use. Always write as 0, but 0 is not guaranteed when read.

EC2: Channel Enable 2

- 0: Disabled, channel 2 cannot receive commands
- 1*: Enabled, channel 2 can receive commands

EC1: Channel Enable 1

- 0: Disabled, channel 1 cannot receive commands
- 1*: Enabled, channel 1 can receive commands

* Power Up and Hardware Reset ($\overline{RST}$) Value = 03h.

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4D/4Fh Read Signaling Register

This register reads signaling data with (4F) or without (4D) clearing any corresponding interrupt.

Command	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
R: 4Dh R: 4Fh	0	1	0	0	1	1	x	1
I/O Data Byte 1	CFAIL	OCALMY	$TEMPA_1$	$IO2_1$	CAD_1	CID_1	GNK_1	$HOOK_1$
I/O Data Byte 2	DAT	OCALMZ	$TEMPA_2$	$IO2_2$	CAD_2	CID_2	GNK_2	$HOOK_2$

The read without clearing interrupt command (4D) allows signaling bits that are masked (see *6C/6Dh Write/Read Interrupt Mask Register*, on page 73) to be monitored via polling the signaling register, while other bits that are unmasked are serviced in response to interrupts.

An interrupt is generated by pulling the $\overline{INT}$ pin low, or setting the SLCX bit in the upstream GCI SC channel, whenever any unmasked bit in the signaling register changes. There are two types of interrupt:

Type A interrupts are generated on both edge transitions and present the current status of the signal. When the signal state changes, the new state is locked in the signaling register, and an interrupt is generated. When the interrupt is cleared by reading the status in the signaling register (4Fh), the status corresponding to the interrupt is not necessarily cleared. A new interrupt will be generated only when a new change occurs.
CFAIL, OCALMY, OCALMZ, $TEMPA_i$, $IO2_i$, GNK_i, and $HOOK_i$ are type A interrupts

Type B interrupts are generated when a specific event occurs. The corresponding signal is set to 1 and an interrupt is generated. When the read signaling register and clear interrupt (4Fh) command is issued, the interrupt is cleared and the signal is reset.
CAD_i and CID_i are type B interrupts.

Other status bits may change while an interrupt is pending. In this case, an additional interrupt is not generated if the new status is reported when the register is read. If the bit that caused the original interrupt has changed after it was latched in the signaling register but before the interrupt was cleared, the latched value will be read and a new interrupt with the new value (which will be latched) will be generated immediately after the interrupt is cleared.

The behavior of the various signals in this register depends on the contents of *C2/C3h Write/Read Loop Supervision Parameters*, on page 81 where thresholds and debounce periods are set.

This command does not depend on the state of the Channel Enable register

DAT: Converter data.

0: No new data is available in *CDh Read Transmit PCM/Test Data*, on page 82
1: New data is available in *CDh Read Transmit PCM/Test Data*, on page 82

When unmasked by the ATI bit in the *A6/A7h Write/Read Converter Configuration*, on page 79 the DAT interrupt will be asserted at the time new data is ready to be read from *CDh Read Transmit PCM/Test Data*, on page 82. The interrupt pin is returned to a high level after 54 µsec.

CFAIL: Clock Fail

0: The internal clock is synchronized to frame sync.
1: The internal clock is not synchronized to frame sync.

When clock fail is set, the data path is cleared for all channels.

OCALMY: Switching regulator Y overcurrent indicator.

0*: Switching Regulator Y working properly.
1: Switching regulator Y has an overcurrent/power fault problem.

The OCALMY bit is an indicator of a continuing over-current condition. This indicates to the user's system that a fault in switching regulator Y is probably occurring. The Y switcher is automatically shut off when an OCALMY interrupt is generated. The system states of the various channels are not reset and the user must take appropriate action based on the channel's state and the battery currently being used.

OCALMZ: Switching regulator Z over current indicator.

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0*: Switching Regulator Z working properly.
1: Switching regulator Z has an overcurrent/power fault problem.

The OCALMZ bit is an indicator of a continuing over-current condition. This indicates to the user's system that a fault in switching regulator Z is probably occurring. The Z switcher is automatically shut off when an OCALMZ interrupt is generated. The system states of the various channels are not reset and the user must take appropriate action based on the channel's state and the battery currently being used.

TEMPA: Thermal Fault Alarm

0*: High voltage line driver within safe operating temperature region
1: High voltage line driver at unsafe operating temperature and in thermal shutdown.

This bit is not updated when the system is in disconnect.

IO2: Input 2 Status. The input value at $IO2_1$ or $IO2_2$

0: $IO2_i$ input is low
1: $IO2_i$ input is high

CAD: Cadencer status when masked or interrupt if unmasked

0: Cadence timer is in the programmed on period (masked)
1: Cadence timer is in the programmed off period (masked)

0: Cadence interrupt has not occurred (unmasked).
1: Cadence interrupt has occurred (unmasked)
Cadencer has completed the programmed on period

CID: Caller ID Buffer Ready

0: The CID buffer is full
1*: The CID buffer is empty
If unmasked, an interrupt is only generated when the CID buffer becomes empty

GNK: Ground-key or Ground Fault detection.

0: No Ground Key (Longitudinal current less than TGK for longer than DGNK)
1: Ground Key detected (Longitudinal current greater than TGK for longer than DGNK)

HOOK: Hook switch, Ground Start or Ring Trip event

0: On hook
1: Off hook

This bit signals events based on the system state illustrated in the table below.

State	Hook Interrupt Event
Active	On hook (Metallic current less than TSH for longer than DSH Off hook (Metallic current greater than TSH for longer than DSH)
Tip Open	On hook (Metallic current less than TSH for longer than DSH Off hook (Metallic current greater than TSH for longer than DSH)
Ring Open	On hook (Metallic current less than TSH for longer than DSH Off hook (Metallic current greater than TSH for longer than DSH)
Balanced Ringing or Unbalanced Ringing	On hook (Metallic current less than RTTH for two ring periods) Off hook (Metallic current greater than RTTH for two ring periods)

* Power Up and Hardware Reset ($\overline{RST}$) Value = 0000

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50/51h Write/Read Voice Path Gains

Command	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
W: 50h R: 51h	0	1	0	1	0	0	0	R/$\overline{W}$
I/O Data	RSVD	AX	AR1	AR0	DRL	RSVD	RSVD	RSVD

RSVD: Reserved for future use. Always write as 0, but 0 is not guaranteed when read.

AX: Transmit Analog Gain

- 0*: 0 dB gain
- 1: 6.02 dB gain

AR[1:0]: Receive Analog Loss

- 00*: 0 dB loss
- 01: 6.02 dB loss
- 10: 6.02 dB gain
- 11: RSVD

DRL: Digital Receive Loss. This mode is used in high current metering applications in combination with the 6.02 dB AR gain.

- 0*: No digital receive loss
- 1: A 6.02 dB loss is inserted in the voice receive path.

*Power Up and Hardware Reset ($\overline{RST}$) Value = 00h.

52/53h Write/Read Input/Output Data Register

Command	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
W: 52h R: 53h	0	1	0	1	0	0	1	R/$\overline{W}$
I/O Data	RSVD	RSVD	RSVD	RSVD	RSVD	RSVD	IO2	IO1

RSVD Reserved for future use. Always write as 0, but 0 is not guaranteed when read.

IO1-IO2: Value at general purpose IO pins.

This register provides both data input and data output functions per channel depending on the setting of the corresponding IOD bits in *54/55h Write/Read Input/Output Direction Register*. The data written appears latched on the I/O pin. In input mode, the logic state of the I/O pin is read. In output mode, the state of the I/O pin is read. A logic 1 written to the data register will cause the output to be logic 1. If the IOD1x bits = 10, then the I/O1 pin is an open drain output capable of driving a relay. A logic 1 written to the data register will cause the output to pull low (current flows in the open drain transistor). In this case, a read of IO1 will read the I/O pin voltage and invert the outcome. Thus, in open drain, if the pin voltage is logic low, the system will read back a one.

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54/55h Write/Read Input/Output Direction Register

Command	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
W: 54h R: 55h	0	1	0	1	0	1	0	R/$\overline{W}$
I/O Data	RSVD	RSVD	RSVD	RSVD	RSVD	IOD2	IOD12	IOD11

RSVD: Reserved for future use. Always write as 0, but 0 is not guaranteed when read.

IOD1[2:1]: Direction of the IO1 pins (input or output)

- 00*: IO1 is an input
- 01: IO1 is an output
- 10: IO1 is open drain
- 11: Reserved

IOD2: Direction of the IO2 pins (input or output)

- 0*: IOx is an input
- 1: IOx is an output

*Power Up and Hardware Reset ($\overline{RST}$) Value = 00h

56/57h Write/Read System State

Command	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
W: 56h R: 57h	0	1	0	1	0	1	1	R/$\overline{W}$
I/O Data	REX	METR	ACT	POLNR	SS3	SS2	SS1	SS0

REX: Ringing Status. This bit is read-only. Writes to this bit have no effect.

- 0*: System is not in ring exit state.
- 1: System is in ring exit or ringing state. When the system is in ringing and the user exits to a new state, the state register will reflect the new state that was last written by the user. However, the system may not change immediately to the new state, but may wait for a zero cross, in order to minimizes line transients. During this period, REX will be 1 indicating the system is waiting for a zero cross. REX will also be 1 during ringing.

METR: Metering

- 0*: Metering off
- 1: Metering on. Metering will stay on for the duration specified in the MTRDR parameter of command *D0/D1h Write/Read Metering Parameters*, on page 83 and METR will be reset to zero at the end of this time, terminating the meter pulse.

ACT: Activate Codec

- 0*: Codec deactivated
- 1: Codec Activated

No valid PCM data is transmitted until after the third FS pulse is received after the ACT bit is set.

POLNR: Normal or Reverse Polarity feed

- 0*: Normal Polarity feed - TIPD more positive than RINGD
- 1: Reverse Polarity feed - RINGD more positive than TIPD

SS[3:0]: System State is defined by the table below. These states can be switched between automatically by the Le88221/241 device if the ASSC bit is set. The table lists the default values of the states when the ASSC bit is set. Modifying other bits in this register will subsequently alter these states. Writing a new value to SS will change the system state.

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SS3	SS2	SS1	SS0	Mode
0	0	0	0	Disconnect
0	0	0	1	Tip Open
0	0	1	0	Ring Open
0	0	1	1	Active Low Battery
0	1	0	0	Idle
0	1	0	1	Longitudinal Test
0	1	1	0	Metallic Test
0	1	1	1	Balanced Ringing
1	0	0	0	Low Gain
1	0	0	1	RSVD
1	0	1	0	Unbalanced Ringing
1	0	1	1	Active Mid Battery
1	1	0	0	RSVD
1	1	0	1	RSVD
1	1	1	0	RSVD
1*	1*	1*	1*	Shutdown

Note:

1. *Where there is a conflict on a write to this register between the System State (SS) and the other bits, the other bits take precedence.*
2. *The Longitudinal Test and Metallic Test states activate the corresponding test load switch in the Le88241 device.*
3. *Ringing uses signal generator A and the bias parameter to generate the ringing waveform.*

Power Up and Hardware Reset ($\overline{RST}$) Value = 0Fh

60/61h Write/Read Operating Functions

Command	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
W: 60h R: 61h	0	1	1	0	0	0	0	R/$\overline{W}$
I/O Data	C/L	A/μ	EGR	EGX	EX	ER	EZ	EB

C/L: Linear Code

0*: Compressed coding
1: Linear coding

A/μ: A-law or μ-law

0*: A-law coding
1: μ-law coding

EGR: GR Filter

0*: Default GR filter enabled
1: Programmed GR filter enabled

EGX: GX Filter

0*: Default GX filter enabled
1: Programmed GX filter enabled

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EX: X Filter

0*: Default X filter enabled
1: Programmed X filter enabled

ER: R Filter

0*: Default R filter enabled
1: Programmed R filter enabled

EZ: Z Filter

0*: Default Z filter enabled
1: Programmed Z filter enabled

EB: B Filter

0*: Default B filter enabled
1: Programmed B filter enabled

*Power Up and Hardware Reset ($\overline{RST}$) Value = 00h.

68/69h Write/Read System State Configuration

Command	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
W: 68h R: 69h	0	1	1	0	1	0	0	R/$\overline{W}$
I/O Data	RSVD	RSVD	ACFS	ATFS	ZXR	SPR	ASSC	ABAT

RSVD: Reserved for future use. Always write as 0, but 0 is not guaranteed when read.

ACFS: Automatic Clock Fail Switching

0: Automatic Clock Fail switching disabled
1*: Automatic Clock Fail switching enabled
When a Clock Fail alarm is detected and persists for between 0.5 ms and 3 ms the channel will switch to the Shutdown state.

ATFS: Automatic Thermal Fault Switching

0*: Automatic thermal fault switching disabled
1: Automatic thermal fault switching enabled
The channel will switch to the Disconnect state when a high voltage line driver thermal fault alarm is detected.

See TEMPA bit description in command *4D/4Fh Read Signaling Register*, on page 67.

ZXR: Zero Cross Ringing Entry/Exit

0*: System will enter and exit the Ringing State smoothly by waiting for zero cross between the ringing waveform and the DC Tip-Ring voltage. This ensures a smooth transition between states and gives the switching regulator time to rise to an appropriate ringing voltage on ring entry.
1: System will enter and exit ringing immediately according to command *56/57h Write/Read System State*, on page 70.

SPR: Smooth Polarity Reversal

0*: Polarity reversals will be abrupt.
1: Polarity reversals will be smooth.

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ASSC: Automatic System State Control

0*: Automatic system state switching enabled
System State will change due to the following supervision stimuli:
Hook in Idle will cause a transition to Active.
Hook due to ring trip will cause a transition from Ringing to Active
Hook due to ground start in Tip or Ring Open will cause a transition to Active
In all three cases, the resulting line polarity is defined by the POLNR bit
ACT will be updated appropriately

1: Automatic system state switching disabled
State changes only occur as a result of user commands

ABAT: Auto battery switching

0*: Automatic battery switching enabled.
System will automatically switch between Active States to maintain the lowest battery needed to support Tip - Ring Voltage.

1: User selected Active State battery is selected when user writes Mid or Low battery state. However, if the Battery voltage of low battery is not sufficient to support the tip-ring voltage, mid battery will remain selected. If the ASSC bit is not set (automatic state switching enabled) and ABAT = 1 (no auto battery switching), the user must write the correct Active battery state after an automatic transition.

*Power Up and Hardware Reset ($\overline{RST}$) Value =20h.

6C/6Dh Write/Read Interrupt Mask Register

Command	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
W: 6Ch R: 6Dh	0	1	1	0	1	1	0	R/$\overline{W}$
I/O Data Byte 1	MCFAIL	MOCALMY	$MTEMPA_1$	$MIO2_1$	$MCAD_1$	$MCID_1$	$MGNK_1$	$MHOOK_1$
I/O Data Byte 2	RSVD	MOCALMZ	$MTEMPA_2$	$MIO2_2$	$MCAD_2$	$MCID_2$	$MGNK_2$	$MHOOK_2$

In the MPI mode, this register defines which signals can generate interrupts and be latched in the *4D/4Fh Read Signaling Register*, on page 67. In GCI mode, this register defines which signals can cause the SLCX bit to be set in the upstream signalling channel. In GCI mode, $MGNK_i$, $MHOOK_i$ should always be masked.

RSVD: Reserved for future use. Always write as 1, but 1 is not guaranteed when read.

Mx: Mask Interrupt/Signaling bits

0: Signal is NOT masked, change will generate an interrupt or set SLCX
1*: Signal is masked, a change does not cause an interrupt or set SLCX

This command does not depend on the state of the Channel Enable Register.

*Power Up and Hardware Reset ($\overline{RST}$) Value = FFFFh.

70/71h Write/Read Operating Conditions

Command	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
W: 70h R: 71h	0	1	1	1	0	0	0	R/$\overline{W}$
I/O Data	CTP	CRP	HPF	LRG	RSVD	ILB	RSVD	TON

RSVD: Reserved for future use. Always write as 0, but 0 is not guaranteed when read.

CTP: Cutoff Transmit Path

0*: Transmit path connected
1: Transmit path cut off

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CRP: Cutoff Receive Path

0*: Receive path connected
1: Receive path cutoff

HPF: High Pass Filter

0*: Transmit Highpass filters enabled
1: Transmit Highpass filters disabled

LRG: Lower Receive Gain

0*: 6-dB loss not inserted
1: 6-dB loss inserted

ILB: Interface Loopback

0*: TSA loopback disabled
1: TSA loopback enabled

TON: 1 kHz Receive Tone

0*: 1 kHz receive tone off
1: 1 kHz receive tone on

*Power Up and Hardware Reset ($\overline{RST}$) Value = 00h.

73h Read Revision and Product Code Number (RCN,PCN)

Command	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
R: 73h	0	1	1	1	0	0	1	1
Output Data Byte 1	RCN7	RCN6	RCN5	RCN4	RCN3	RCN2	RCN1	RCN0
Output Data Byte 2	PCN7	PCN6	PCN5	PCN4	PCN3	PCN2	PCN1	PCN0

This command returns an 8-bit number (RCN) describing the revision number of the device and an 8-bit product code number indicating the VE880 series part number.

The revision code (RCN) of the Le88221/241 Rev. 101 device is 01h.

PCN: Product Code Number

B2h Le88221 device
B6h Le88241 device

This command does not depend on the state of the Channel Enable Register.

80/81h Write/Read GX Filter Coefficients

Command	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
W: 80h R: 81h	1	0	0	0	0	0	0	R/$\overline{W}$
I/O Data Byte 1	C40	m40			C30	m30		
I/O Data Byte 2	C20	m20			C10	m10		

Cxy = 0 or 1 in the command above corresponds to Cxy = +1 or –1, respectively, in the equation below.

The coefficient for the GX filter is defined as:

$$H_{GX} = 1 + (C10 \bullet 2^{-m10}\{1 + C20 \bullet 2^{-m20}[1 + C30 \bullet 2^{-m30}(1 + C40 \bullet 2^{-m40})]\}$$

*Power Up and Hardware Reset ($\overline{RST}$) Values = 0190h (H_{GX} = 1 (0 dB)).

Note:
The default value is contained in a ROM register separate from the programmable coefficient RAM and the ROM register's default value can not be read. There is a filter enable bit in Operating Functions register to switch between the default and programmed values.

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82/83h Write/Read GR Filter Coefficients

Command	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
W: 82h R: 83h	1	0	0	0	0	0	1	R/$\overline{W}$
I/O Data Byte 1	C40	m40			C30	m30		
I/O Data Byte 2	C20	m20			C10	m10		

Cxy = 0 or 1 in the command above corresponds to Cxy = +1 or –1, respectively, in the equation below.

The coefficient for the GR filter is defined as:

$$H_{GR} = C10 \bullet 2^{-m10}\{1 + C20 \bullet 2^{-m20}[1 + C30 \bullet 2^{-m30}(1 + C40 \bullet 2^{-m40})]\}$$

*Power Up and Hardware Reset ($\overline{RST}$) Values = 0111h (H_{GR} = 1 (0 dB)).

See note under Command 80/81h on page 74

86/87h Write/Read B Filter FIR Coefficients

Command	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
W: 86h R: 87h	1	0	0	0	0	1	1	R/$\overline{W}$
I/O Input Data Byte 1	C32	m32			C22	m22		
I/O Input Data Byte 2	C12	m12			C33	m33		
I/O Input Data Byte 3	C23	m23			C13	m13		
I/O Input Data Byte 4	C34	m34			C24	m24		
I/O Input Data Byte 5	C14	m14			C35	m35		
I/O Input Data Byte 6	C25	m25			C15	m15		
I/O Input Data Byte 7	C36	m36			C26	m26		
I/O Input Data Byte 8	C16	m16			C37	m37		
I/O Input Data Byte 9	C27	m27			C17	m17		
I/O Input Data Byte 10	C38	m38			C28	m28		
I/O Input Data Byte 11	C18	m18			C39	m39		
I/O Input Data Byte 12	C29	m29			C19	m19		
I/O Input Data Byte 13	C310	m310			C210	m210		
I/O Input Data Byte 14	C110	m110			RSVD	RSVD		

RSVD Reserved for future use. Always write as 0, but 0 is not guaranteed when read.

Cxy = 0 or 1 in the command above corresponds to Cxy = +1 or –1, respectively, in the equation below.

The Z-transform equation for the B filter is defined as:

$$H_B(z) = B_2 \bullet z^{-2} + \ldots + B_9 \bullet z^{-9} + \frac{B_{10} \bullet z^{-10}}{1 - B_{11} \bullet z^{-1}}$$

Sample rate = 16 kHz

The coefficients for the FIR B section and the gain of the IIR B section are defined as:

For i = 2 to 10,

$$B_i = C1i \bullet 2^{-mli}[1 + C2i \bullet 2^{-m2i}(1 + C3i \bullet 2^{-m3i})]$$

The feedback coefficient of the IIR B section is defined as:

$$B_{11} = C111 \bullet 2^{-m111}\{1 + C211 \bullet 2^{-m211}[1 + C311 \bullet 2^{-m311}(1 + C411 \bullet 2^{-m411})]\}$$

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Refer to Command *96/97h Write/Read B Filter IIR Coefficients, on page 78* for programming of the B_{11} coefficients.

*Power Up and Hardware Reset ($\overline{RST}$) Values = 0900 9009 0090 0900 9009 0090 0900h

$$H_B(z) = 0$$

See note under Command 80/81h on page 74.

88/89h Write/Read X Filter Coefficients

Command	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
W: 88h R: 89h	1	0	0	0	1	0	0	R/$\overline{W}$
I/O Input Data Byte 1	C40	m40			C30	m30		
I/O Input Data Byte 2	C20	m20			C10	m10		
I/O Input Data Byte 3	C41	m41			C31	m31		
I/O Input Data Byte 4	C21	m21			C11	m11		
I/O Input Data Byte 5	C42	m42			C32	m32		
I/O Input Data Byte 6	C22	m22			C12	m12		
I/O Input Data Byte 7	C43	m43			C33	m33		
I/O Input Data Byte 8	C23	m23			C13	m13		
I/O Input Data Byte 9	C44	m44			C34	m34		
I/O Input Data Byte 10	C24	m24			C14	m14		
I/O Input Data Byte 11	C45	m45			C35	m35		
I/O Input Data Byte 12	C25	m25			C15	m15		

Cxy = 0 or 1 in the command above corresponds to Cxy = +1 or –1, respectively, in the equation below.

The Z-transform equation for the X filter is defined as:

$$H_x(z) = x_0 + x_1z^{-1} + x_2z^{-2} + x_3z^{-3} + x_4z^{-4} + x_5z^{-5}$$

Sample rate = 16 kHz

For i = 0 to 5, the coefficients for the X filter are defined as:

$$Xi = C1i \bullet 2^{-m1i}\{1 + C2i \bullet 2^{-m2i}[1 + C3i \bullet 2^{-m3i}(1 + C4i \bullet 2^{-m4i})]\}$$

*Power Up and Hardware Reset ($\overline{RST}$) Values = 0111 0190 0190 0190 0190 0190h

($H_X(z) = 1$)

See note under Command 80/81h on page 74.

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8A/8Bh Write/Read R Filter Coefficients

Command	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
W: 8Ah R: 8Bh	1	0	0	0	1	0	1	R/$\overline{W}$
I/O Input Data Byte 1	C46	m46			C36	m36		
I/O Input Data Byte 2	C26	m26			C16	m16		
I/O Input Data Byte 3	C40	m40			C30	m30		
I/O Input Data Byte 4	C20	m20			C10	m10		
I/O Input Data Byte 5	C41	m41			C31	m31		
I/O Input Data Byte 6	C21	m21			C11	m11		
I/O Input Data Byte 7	C42	m42			C32	m32		
I/O Input Data Byte 8	C22	m22			C12	m12		
I/O Input Data Byte 9	C43	m43			C33	m33		
I/O Input Data Byte 10	C23	m23			C13	m13		
I/O Input Data Byte 11	C44	m44			C34	m34		
I/O Input Data Byte 12	C24	m24			C14	m14		
I/O Input Data Byte 13	C45	m45			C35	m35		
I/O Input Data Byte 14	C25	m25			C15	m15		

Cxy = 0 or 1 in the command above corresponds to Cxy = +1 or –1, respectively, in the equation below.

$$HR = H_{IIR} \bullet H_{FIR}$$

The Z-transform equation for the IIR filter (RI) is defined as:

$$H_{IIR} = \frac{1 - z^{-1}}{1 - \left(R_6 \bullet z^{-1}\right)}$$

Sample rate = 8 kHz

The coefficient for the IIR filter is defined as:

$$R_6 = C16 \bullet 2^{-m16}\{1 + C26 \bullet 2^{-m26}[1 + C36 \bullet 2^{-m36}(1 + C46 \bullet 2^{-m46})]\}$$

R6 should normally not be set to unity. If it is required to generate DC levels through the receive path from the PCM, the CRP bit (*70/71h Write/Read Operating Conditions*, on page 73) should be set 5ms before writing R6 to unity. The RTP bit can then be reset and DC or low frequency signals passed from the PCM.

The Z-transform equation for the FIR filter is defined as:

$$H_{FIR}(z) = R_0 + R_1 z^{-1} + R_2 z^{-2} + R_3 z^{-3} + R_4 z^{-4} + R_5 z^{-5}$$

Sample rate = 16 kHz

For i = 0 to 5, the coefficients for the R2 filter are defined as:

$$R_i = C1i \bullet 2^{-m1i}\{1 + C2i \bullet 2^{-m2i}[1 + C3i \bullet 2^{-m3i}(1 + C4i \bullet 2^{-m4i})]\}$$

*Power Up and Hardware Reset ($\overline{RST}$) Values = 2E01 0111 0190 0190 0190 0190 0190h

(H_{FIR} (z) = 1, R_6 = 0.9902)

See note under Command 80/81h on page 74.

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96/97h Write/Read B Filter IIR Coefficients

Command	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
W: 96h R: 97h	1	0	0	1	0	1	1	R/$\overline{W}$
I/O Data Byte 1	C411	m411			C311	m311		
I/O Data Byte 2	C211	m211			C111	m111		

This function is described in command *86/87h Write/Read B Filter FIR Coefficients*, on page 75

*Power Up and Hardware Reset ($\overline{RST}$) Values = 0190h (B_{11} = 0)

See note under Command 80/81h on page 74.

98/99h Write/Read Z Filter FIR Coefficients

Command	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
W: 98h R: 99h	1	0	0	1	1	0	0	R/$\overline{W}$
I/O Data Byte 1	C40	m40			C30	m30		
I/O Data Byte 2	C20	m20			C10	m10		
I/O Data Byte 3	C41	m41			C31	m31		
I/O Data Byte 4	C21	m21			C11	m11		
I/O Data Byte 5	C42	m42			C32	m32		
I/O Data Byte 6	C22	m22			C12	m12		
I/O Data Byte 7	C43	m43			C33	m33		
I/O Data Byte 8	C23	m23			C13	m13		
I/O Data Byte 9	C44	m44			C34	m34		
I/O Data Byte 10	C24	m24			C14	m14		

This function is described in command *9A/9Bh Write/Read Z Filter IIR Coefficients*, on page 78

*Power Up and Hardware Reset ($\overline{RST}$) Values = 0190 0190 0190 0190 0190h

($H_Z(z)$ = 0)

9A/9Bh Write/Read Z Filter IIR Coefficients

Command	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
W: 9Ah R: 9Bh	1	0	0	1	1	0	1	R/$\overline{W}$
I/O Data Byte 1	C45	m45			C35	m35		
I/O Data Byte 2	C25	m25			C15	m15		
I/O Data Byte 3	C26	m26			C16	m16		
I/O Data Byte 4	C47	m47			C37	m37		
I/O Data Byte 5	C27	m27			C17	m17		

Cxy = 0 or 1 in the command above corresponds to Cxy = +1 or –1, respectively, in the equation below.

The Z-transform equation for the Z filter is defined as:

$$H_z(z) = z_0 + z_1 \bullet z^{-1} + z_2 \bullet z^{-2} + z_3 \bullet z^{-3} + z_4 \bullet z^{-4} + \frac{z_5 \bullet z_6 \bullet z_7 \bullet z^{-1}}{1 - z_7 \bullet z^{-1}}$$

Sample rate = 32 kHz

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For i = 0 to 5 and 7

$$z_i = C1i \bullet 2^{-m1i}\{1 + C2i \bullet 2^{-m2i}[1 + C3i \bullet 2^{-m3i}(1 + C4i \bullet 2^{-m4i})]\}$$

$$z_6 = C16 \bullet 2^{-m16}\{1 + C26 \bullet 2^{-m26}\}$$

*Power Up and Hardware Reset ($\overline{RST}$) Values = 0190 01 0190h

($H_Z(z) = 0$)

See note under Command 80/81h on page 74.

Note:

Z_6 is used for IIR filter scaling only. Its value is typically greater than zero but less than or equal to one. The input to the IIR filter section is first increased by a gain of $1/Z_6$, improving dynamic range and avoiding truncation limitations through processing within this filter. The IIR filter output is then multiplied by Z_6 to normalize the overall gain. Z_5 is the actual IIR filter gain value defined by the programmed coefficients, but it also includes the initial $1/Z_6$ gain. The theoretical effective IIR gain, without the Z_6 gain and normalization, is actually Z_5/Z_6.

A6/A7h Write/Read Converter Configuration

Command	D7	D6	D5	D4	D3	D2	D1	D0
W: A6 R: A7h	1	0	1	0	0	1	1	R/$\overline{W}$
I/O Data	ATI	DRAT2	DRAT1	DRAT0	SEL3	SEL2	SEL1	SEL0

ATI: Arm Transmit PCM data Interrupt.

0*: Transmit Data Ready interrupt disabled
1: Transmit Data Ready interrupt enabled

When ATI is 1, the interrupt pin will go active when the transmit data becomes available in *CDh Read Transmit PCM/Test Data*, on page 82. The interrupt will be cleared automatically after 54 µs (or when the data is read from the XDAT register). This interrupt indicates that data is available on both channels.

DRAT[2:0]: Data rate at which the converter data is updated.

The sampled data is output on the PCM highway and in register *CDh Read Transmit PCM/Test Data*, on page 82, as defined below. The ATI interrupt will also occur at this data rate if unmasked.

000*: 8 kHz
001: 4 kHz
010: 2 kHz
011: 1 kHz
100: 500 Hz
101: Reserved
110: Reserved
111: Reserved

SEL[3:0]: This register selects the transmit path analog input source

The bits SEL3 - SEL0 select which input is routed to the A/D converter and hence which measurement shows up at the PCM highway and in register *CDh Read Transmit PCM/Test Data*, on page 82. All unspecified codes are reserved. When selecting a new input source, wait at least 3 ms for the data to become stable.

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SEL3	SEL2	SEL1	SEL0	Value written to measurement register	Operating Range 2.	Scale
0*	0*	0*	0*	Tip - Ring Metallic AC coupled Voltage	-3.44 V to 3.44 V	105 µV
0	0	0	1	Switcher/Battery input at SWY	-160 V to 0 V	-7.324 mV
0	0	1	0	Switcher/Battery input at SWZ	-160 V to 0 V	-7.324 mV
0	0	1	1	Switcher/Battery input at XB	-160 V to 0 V	-7.324 mV
0	1	0	0	Tip Voltage to ground	-240 V to 240 V	-7.324 mV
0	1	0	1	Ring Voltage to ground	-240 V to 240 V	-7.324 mV
0	1	1	0	Tip - Ring Metallic DC coupled Voltage	-240 V to 240 V	-7.324 mV
0	1	1	1	Tip - Ring Metallic Current - Ringing State	-119 mA to 119 mA	-3.63 µA
0	1	1	1	Tip - Ring Metallic Current - DC Feed State	-60 mA to 60 mA	-1.83 µA
0	1	1	1	Total Longitudinal Current - Low Gain State	-600 µA to 600 µA	-18.3 nA
1	0	0	0	Tip + Ring Longitudinal Current, LI = 0	-21 mA to 21 mA	650 nA
1	0	0	0	Tip + Ring Longitudinal Current, LI = 1	-42 mA to 42 mA	1300 nA
1	0	0	0	Metallic Current - Low Gain State, LI = 0	-105 µA to 105 µA	3.20 nA
1	0	0	0	Metallic Current - Low Gain State, LI = 1	-210 µA to 210 µA	6.41 nA
1	0	0	1	Calibration Current (IREF)	-25 µA to 25 µA	2.27 nA
1	0	1	0	Voice DAC Analog Loopback	-3.44 V to 3.44 V	105 µV
1	0	1	1	No connection - read ADC output offset [1]	-3.44 V to 3.44 V	105 µV
1	1	0	1	Tip Voltage to ground Low Scale	-30 V to 30 V	-915 µV
1	1	1	0	Ring Voltage to ground Low Scale	-30 V to 30 V	-915 µV

1. The ADC output offset is defined relative to the default metallic AC coupled tip-ring voltage.
2. Operating ranges assume the standard external application circuit component values are used.

The operating range values may be less than the full scale ranges of the output. The scale assumes:
Register *50/51h Write/Read Voice Path Gains*, on page 69 = 00 h,
Register *60/61h Write/Read Operating Functions*, on page 71 = 80 h,
Register *70/71h Write/Read Operating Conditions*, on page 73 = 20 h and
Register *CA/CBh Write/Read Digital Impedance Scaling Network (DISN)*, on page 82 = 00 h.
Note that the SEL bit settings are overwritten when a system state change occurs. Therefore the desired system state must be selected before configuring the converter. It is also recommended that the ASSC bit in register *68/69h Write/Read System State Configuration*, on page 72 be set when performing measurements to avoid unexpected state changes that would disrupt the measurement.

The voltage and current scales define the typical values and do not imply a specific accuracy for the measurement path and A/D converter. The absolute accuracy of the measurement paths can be found in the electrical specification section. To achieve the specified accuracies, the ADC offset voltage should first be read by selecting the 'No connection' option and subtracting this result from subsequent measurements.
A full digital loop back from the digital input through the DAC to the ADC and back to the digital output is achieved by making the connection to the voice DAC. The nominal gain of this path is 0 dB.

For the battery inputs, Tip and Ring voltages, a negative voltage on the line reads as a positive value.

*Power Up and Hardware Reset ($\overline{RST}$) Value = 00h

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C2/C3h Write/Read Loop Supervision Parameters

Command	D7	D6	D5	D4	D3	D2	D1	D0
W: C2h R: C3h	1	1	0	0	0	0	1	R/$\overline{W}$
I/O Data Byte 1	RSVD	RSVD	TGK2	TGK1	TGK0	TSH2	TSH1	TSH0
I/O Data Byte 2	DGK2	DGK1	DGK0	DSH4	DSH3	DSH2	DSH1	DSH0
I/O Data Byte 3	RTDCAC	RTTH6	RTTH5	RTTH4	RTTH3	RTTH2	RTTH1	RTTH0
I/O Data Byte 4	RSVD	RSVD	RSVD	ILR4	ILR3	ILR2	ILR1	ILR0

RSVD Reserved for future use. Always write as 0, but 0 is not guaranteed when read.

TGK[2:0]: Ground-key threshold; 0–42 mA, with a scale of 6 mA/step.
(default = 011b = 18mA)

TSH[2:0]: Switch hook threshold 8 - 15mA with a scale of 1mA Ω/step
(default = 011b = 11mA)

DGK[2:0]: Ground-key debounce; 0–28 ms, with a scale of 4 ms/step
(default = 100b = 16 ms)

DSH[4:0]: Switch-hook debounce interval; 0–62 ms, with a scale of 2 ms/step
(default = 00100b = 8 ms)

RTDCAC: Ring Trip DC or AC.

0: Use DC ring trip detection algorithm which requires DC bias.
1*: Use AC ring trip detection algorithm which does not require DC bias.

RTTH[6:0]: Ring trip threshold; 0 - 63.5 mA with a scale of 0.5 mA/step.
(default = 110011b = 25.5mA)

ILR[4:0]: Ringing current limit; 50 - 112mA with a scale of 2 mA/step.
(default = 01110b = 78 mA)

*Power Up and Hardware Reset ($\overline{RST}$) Value = 1B84 B30Eh

C6/C7h Write/Read DC Feed Parameters

Command	D7	D6	D5	D4	D3	D2	D1	D0
W: C6h R: C7h	1	1	0	0	0	1	1	R/$\overline{W}$
I/O Data Byte 1	RSVD	VOCSFT	LI	VOC2	VOC1	VOC0	VAS3	VAS2
I/O Data Byte 2	VAS1	VAS0	RSVD	ILA4	ILA3	ILA2	ILA1	ILA0

RSVD Reserved for future use. Always write as 0, but 0 is not guaranteed when read.

VOCSFT: VOC shift

0*: VOC open circuit DC feed voltage. 36 - 57 V, with a step size of 3.0 V
1: VOC open circuit DC feed voltage. 12 - 33 V, with a step size of 3.0 V

LI: Longitudinal Impedance

0*: Longitudinal Impedance set to 100 Ω/leg
1: Longitudinal Impedance set to 50 Ω/leg

VOC[2:0]: Open circuit DC feed voltage. 36 - 57 V, with a step size of 3.0 V, VOCSFT = 0
Open circuit DC feed voltage. 12 - 33 V, with a step size of 3.0 V, VOCSFT = 1
(default = 100b = 48.0 V)

VAS[3:0]: Battery Switching offset voltage: 1.5 - 7.125 V, with a step size of 0.375 V
(default = 1000b = 4.5 V)

The device switches from VBM to VBL when the sensed Tip-Ring Feed voltage is less than |VBL + VAS

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+ |Iloop| * 200 + 4V| for more than 2 ms, and from VBL to VBM when the sensed Tip-Ring Feed voltage is greater than |VBL + VAS + |Iloop| * 200| for more than 2 ms. For correct battery switching threshold setting, both switching regulator controllers must be enabled, even if they are not being used to generate battery voltages. Ensure the ZM and YM bits in *E6/E7h Write/Read Switching Regulator Control*, on page 90 are non zero.

ILA[4:0]: Current Limit Active mode; 18–49 mA, with a step size of 1 mA (default = 01000b = 26 mA)

Power Up and Hardware Reset ($\overline{RST}$) Value = 1108h

CA/CBh Write/Read Digital Impedance Scaling Network (DISN)

Command	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
W: CAh R: CBh	1	1	0	0	1	0	1	R/$\overline{W}$
I/O Data	DISN7	DISN6	DISN5	DISN4	DISN3	DISN2	DISN1	DISN0

DISN[7:0]: Digital Impedance scaling network two's complement gain value.

The DISN gain can be varied from -1.0 to 0.992 in steps of 0.0078. A value of 0 removes the DISN from the impedance loop.

*Power Up and Hardware Reset ($\overline{RST}$) Value = 00h

CDh Read Transmit PCM/Test Data

Command	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
R: CDh	1	1	0	0	1	1	0	1
Output Data Byte 1	XDAT15	XDAT14	XDAT13	XDAT12	XDAT11	XDAT10	XDAT9	XDAT8
Output Data Byte 2	XDAT7	XDAT6	XDAT5	XDAT4	XDAT3	XDAT2	XDAT1	XDAT0

XDAT: Read signal Value.

XDAT[7:0] Contains A-law or µ-law transmit data in Companded mode.
XDAT[15:0] Contains upper and lower data bytes in Linear mode with sign in XDAT15.

XDAT can only be read from one channel at a time as selected by the EC register. If two channels or no channel is selected, the data for Channel 1 will be returned.

In Test mode, as defined by command *A6/A7h Write/Read Converter Configuration*, on page 79, the A/D converter is connected either to the voice path (codec bypass), or to other signals as defined by the SEL bits. In this case the XDAT[0-15] bits indicate the measured value of the signal connected to the A/D converter in 1.15 format assuming linear mode is selected. The maximum values and scales are given in the chart. Negative Tip, Ring and battery voltages are reported as positive values.

This register input is sampled data at a rate set by DRAT in command *A6/A7h Write/Read Converter Configuration*, on page 79 and the register is updated at the programmed data rate. A new measurement may be made by writing the converter configuration register. An interrupt can be generated every time this register is updated by setting the ATI bit in *6C/6Dh Write/Read Interrupt Mask Register*, on page 73. The signal may be sampled by the user as fast as 8KSa/sec in this mode.

To get meaningful DC test data, the device should be configured as described in *A6/A7h Write/Read Converter Configuration*, on page 79. This data will also be transmitted on the DXA pin unless the CTP bit is set.

While this register can be read in GCI mode, the monitor channel protocol only allows this data to be sampled at a slow rate. It is recommended that the compressed B channel data is read directly from the GCI bus in this mode.

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D0/D1h Write/Read Metering Parameters

Command	D7*	D6	D5	D4	D3	D2	D1	D0
W: D0h R: D1h	1	1	0	1	0	0	0	R/$\overline{W}$
I/O Data Byte 1	MTRF	MLIM6	MLIM5	MLIM4	MLIM3	MLIM2	MLIM1	MLIM0
I/O Data Byte 2	SOREV	MTRSL6	MTRSL5	MTRSL4	MTRSL3	MTRSL2	MTRSL1	MTRSL0
I/O Data Byte 3	MTRDR7	MTRDR6	MTRDR5	MTRDR4	MTRDR3	MTRDR2	MTRDR1	MTRDR0
I/O Data Byte 4	MTRPK7	MTRPK6	MTRPK5	MTRPK4	MTRPK3	MTRPK2	MTRPK1	MTRPK0

MTRF: Metering frequency

0*: 12 kHz
1: 16 kHz

MLIM[6:0]: This field sets the peak voltage level of the metering signal voltage at the AC sense point. MLIM is programmed as an unsigned integer.
If MTRF is 0 (12 kHz), MLIM has a step size of 15 mVrms
If MTRF is 1 (16 kHz), MLIM has a step size of 18 mVrms
(default = 0100001b)

Metering signals up to 0.5 Vrms at the line are supported.

SOREV: Smooth ramping or abrupt application

0*: Smooth ramping
1: Abrupt ramping

MTRSL[6:0]: Metering Slope. This parameter sets the metering output current limit into a short circuit between TIPD and RINGD.MTRSL is programmed as an unsigned integer.
MTRSL has a range of 0 – 8.636 mArms and a step size of 68 µA.
The metering ramp lasts for 20 ms or until the voltage specified by MLIM is reached. The slope in mA/ms can be calculated by $\text{slope} = \frac{\text{MTRSL}}{20\text{msec}}$. If MTRSL is too small to generate the voltage MLIM, the ramp will stop at the output current MTRSL after 20 ms.
(default = 0111101b)

MTRDR[7:0]: Metering Duration. MTRDR sets the time metering output current is applied to the line. 0 – 637.5 ms with a step size of 2.5 ms. A value of 00h indicates continuous metering. (default = 3Ch = 150 ms)

MTRPK[7:0]: This field reads the maximum voltage level of the metering signal voltage at the AC sense point.
If MTRF is 0 (12 kHz), MTRPK has a step size of 15 mVrms
If MTRF is 1 (16 kHz), MTRPK has a step size of 18 mVrms
This field is read only. Writes to this location are ignored.

*Power Up and Hardware Reset ($\overline{RST}$) Value = 213D 3C00h

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D2/D3h Write/Read Signal Generator A, B and Bias Parameters.

Command	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
W: D2h R: D3h	1	1	0	1	0	0	1	R/$\overline{W}$
I/O Byte 1	RSVD	RSVD	RSVD	RSVD	RSVD	RMPSLP	CNTRMP	SINTRAP
I/O Byte 2	BIAS15	BIAS14	BIAS13	BIAS12	BIAS11	BIAS10	BIAS9	BIAS8
I/O Byte 3	BIAS7	BIAS6	BIAS5	BIAS1	BIAS3	BIAS2	BIAS1	BIAS0
I/O Byte 4	RSVD	FRQA14	FRQA13	FRQA12	FRQA11	FRQA10	FRQA9	FRQA8
I/O Byte 5	FRQA7	FRQA6	FRQA5	FRQA4	FRQA3	FRQA2	FRQA1	FRQA0
I/O Byte 6	AMPA15	AMPA14	AMPA13	AMPA12	AMPA11	AMPA10	AMPA9	AMPA8
I/O Byte 7	AMPA7	AMPA6	AMPA5	AMPA4	AMPA3	AMPA2	AMPA1	AMPA0
I/O Byte 8	RSVD	FRQB14	FRQB13	FRQB12	FRQB11	FRQB10	FRQB9	FRQB8
I/O Byte 9	FRQB7	BRQA6	FRQB5	FRQB4	FRQB3	FRQB2	FRQB1	FRQB0
I/O Byte 10	AMPB15	AMPB14	AMPB13	AMPB12	AMPB11	AMPB10	AMPB9	AMPB8
I/O Byte 11	AMPB7	AMPB6	AMPB5	AMPB4	AMPB3	AMPB2	AMPB1	AMPB0

RSVD Reserved for future use. Always write as 0, but 0 is not guaranteed when read.

RMPSLP: Ramp Slope

0*: Ramp has a positive slope, e.g. the ramp always increases.
1: Ramp has a negative slope, e.g. the ramp always decreases.

This bit will also have the effect of inverting the sign of a continuous wave driven from signal generator A.

CNTRMP: Continuous or Ramp operation

0*: Signal Generators A and B output continuous waves.
1: A single ramp is output starting from the DC offset set by the BIAS parameter and ramping by an amplitude specified by AMPA.

SINTRAP must be set to 1 if CNTRMP is set to 1.

The ramp is a linear ramp with a transition time of

$$\text{transitiontime} = \frac{1}{(\text{FRQA} \cdot 24000)}$$

where FRQA is an unsigned fractional number which ranges from 1/32768 to 32767/32768.

SINTRAP: Sinusoidal or Trapezoidal output

0*: Signal Generators A and B output sinusoidal waves.
1: Signal Generator A outputs trapezoidal waves and signal generator B outputs nothing.

When the waveshape is set to trapezoidal, the AMPA parameter controls the amplitude, the FRQB parameter controls the frequency and the FRQA parameter controls the transition time according to the following formula.

$$\text{transitiontime} = \frac{1}{(\text{FRQA} \cdot 12000)}$$

$$\text{frequency} = \frac{8000}{\text{FRQB} \times 32768}$$

where FRQA and FRQB are unsigned fractional numbers which range from 1/32768 - 32767/32768.

SINTRAP must be set to 1 if CNTRMP is set to 1.

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BIAS: Generate DC bias offset parameter. ±155 V in ringing with a scale of 4.73mV/step. 1.15 format
(default = 0000h = 0V).

FRQA[14:0]: Frequency/slope parameter of signal generator A
FRQA is an unsigned number with a frequency step size of 0.3662 Hz.
The maximum allowable frequency is 3400 Hz. The signal generator runs through the voice path which has internal filters and a sampling rate of 8KSa/sec.
(default = 0037h = 20.1Hz)

AMPA[15:0]: Amplitude parameter of signal generator A
Up to ±155 V in ringing with a scale of 4.73mV/step
Up to +3.14 dBm0 into the voice path
AMPA is the peak value of the digital sine wave or trapezoid wave.
A positive value will start the wave at 0 with a positive initial first derivative (wave goes up). A negative value will start the wave at 0 with a negative initial first derivative (wave goes down). In ringing, the signal generator is not connected to the line until a zero voltage cross with VOC if ZXR is set to 0.
(default = 4AA4h = 90V)

FRQB[14:0]: Frequency parameter of signal generator B
FRQB is an unsigned number with a frequency step size of 0.3662 Hz.
The maximum allowable frequency is 3400 Hz. The signal generator runs through the voice path which has internal filters and a sampling rate of 8KSa/sec.
(default = 0000h)

AMPB[15:0]: Amplitude parameter of signal generator B
Up to +3.14 dBm0 into the voice path
AMPB is the peak value of the digital sine wave.
A positive value will start the wave at 0 with a positive initial first derivative (wave goes up). A negative value will start the wave at 0 with a negative initial first derivative (wave goes down).
(default = 0000h)

Note: Ringing automatically uses signal generator A's parameters. The POLNR bit will affect the sign of the sum of the tone generators and bias.

*Power Up and Hardware Reset ($\overline{RST}$) Value = 00 0000 0037 4AA4 0000 0000h

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D4/D5h Write/Read Signal Generator C and D Parameters.

Command	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
W: D4h R: D5h	1	1	0	1	0	1	0	R/$\overline{W}$
I/O Byte 1	RSVD	FRQC14	FRQC13	FRQC12	FRQC11	FRQC10	FRQC9	FRQC8
I/O Byte 2	FRQC7	FRQC6	FRQC5	FRQC4	FRQC3	FRQC2	FRQC1	FRQC0
I/O Byte 3	AMPC15	AMPC14	AMPC13	AMPC12	AMPC11	AMPC10	AMPC9	AMPC8
I/O Byte 4	AMPC7	AMPC6	AMPC5	AMPC4	AMPC3	AMPC2	AMPC1	AMPC0
I/O Byte 5	RSVD	FRQD14	FRQD13	FRQD12	FRQD11	FRQD10	FRQD9	FRQD8
I/O Byte 6	FRQD7	BRQA6	FRQD5	FRQD4	FRQD3	FRQD2	FRQD1	FRQD0
I/O Byte 7	AMPD15	AMPD14	AMPD13	AMPD12	AMPD11	AMPD10	AMPD9	AMPD8
I/O Byte 8	AMPD7	AMPD6	AMPD5	AMPD4	AMPD3	AMPD2	AMPD1	AMPD0

FRQC[14:0]: Frequency parameter of signal generator C
FRQC is an unsigned number with a frequency step size of 0.3662 Hz. The maximum allowable frequency is 3400 Hz. The signal generator runs through the voice path which has internal filters and a sampling rate of 8KSa/sec. (default = 1777h = 2200Hz)

AMPC[15:0]: Amplitude parameter of signal generator C
Up to +3.14 dBm0 into the voice path
AMPC is the peak value of the digital sine wave. A positive value will start the wave at 0 with a positive initial first derivative (wave goes up). A negative value will start the wave at 0 with a negative initial first derivative (wave goes down). (default = 27D4h = -7 dBm0)

FRQD[14:0]: Frequency parameter of signal generator D
FRQD is an unsigned number with a frequency step size of 0.3662 Hz. The maximum allowable frequency is 3400 Hz. The signal generator runs through the voice path which has internal filters at a sampling rate of 8KSa/sec. (default = 0CCDh = 1200Hz)

AMPD[15:0]: Amplitude parameter of signal generator D
Up to +3.14 dBm0 into the voice path
AMPD is the peak value of the digital sine wave. A positive value will start the wave at 0 with a positive initial first derivative (wave goes up). A negative value will start the wave at 0 with a negative initial first derivative (wave goes down). (default = 27D4h = -7 dBm0)

Caller ID automatically uses the parameters stored in signal generators C and D.

*Power Up and Hardware Reset ($\overline{RST}$) Value = 1777 27D4 0CCD 27D4

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DE/DFh Write/Read Signal Generator Control

Command	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
W: DEh R: DFh	1	1	0	1	1	1	1	R/$\overline{W}$
I/O Data	SGCAD	CNTOS	RSVD	EGBIAS	EGD	EGC	EGB	EGA

RSVD — Reserved for future use. Always write as 0, but 0 is not guaranteed when read.

SGCAD: Signal Generator Cadencing

- 0*: No Signal generator cadencing
- 1: The enabled tone generators specified by EGA - EGBIAS will cadence on and off as determined by command *E0/E1h Write/Read Cadence Timer*, on page 88

The EGx bits will read back zero in the cadence off time.

This command makes use of the cadence timer. The enabled functions are toggled at a rate specified by the cadence timer. The CAD bit in command *4D/4Fh Read Signaling Register*, on page 67 is set at the end of the on period, which can optionally generate an interrupt if MCAD is reset in command *6C/6Dh Write/Read Interrupt Mask Register*, on page 73. At this time, the user may write new values into the cadence timer and reissue the signal generator control command.

If no enable bits are set, the cadencer will run and will still set the CAD bit at the end of the on period and can produce an interrupt. In this way, the cadencer can be used as a system timer.

CNTOS: Continuous or One Shot cadence operation.

- 0*: Continuous cadencing. Cadencing will continue until the user intervenes.
- 1: One shot. The generators will turn on for one on period only. The dial pulse relay driver will turn off (no current flows) for one on period. All enable bits and SGCAD will be set to zero after the off period. An interrupt will be sent at the end of the on period.

EGBIAS: Enable DC Bias

- 0*: DC Bias disabled
- 1: DC Bias enabled

EGD: Enable Signal Generator D

- 0*: Generator D disabled
- 1: Generator D enabled

EGC: Enable Signal Generator C

- 0*: Generator C disabled
- 1: Generator C enabled

EGB: Enable Signal Generator B

- 0*: Generator B disabled
- 1: Generator B enabled

EGA: Enable Signal Generator A

- 0*: Generator A disabled
- 1: Generator A enabled

*Power Up and Hardware Reset ($\overline{RST}$) Value = 00h

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E0/E1h Write/Read Cadence Timer

Command	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
W: E0h R: E1h	1	1	1	0	0	0	0	R/$\overline{W}$
I/O Byte 1	RSVD	RSVD	RSVD	RSVD	RSVD	CADON10	CADON9	CADON8
I/O Byte 2	CADON7	CADON6	CADON5	CADON4	CADON3	CADON2	CADON1	CADON0
I/O Byte 3	RSVD	RSVD	RSVD	RSVD	RSVD	$CADOFF_{10}$	$CADOFF_9$	$CADOFF_8$
I/O Byte 4	$CADOFF_7$	$CADOFF_6$	$CADOFF_5$	$CADOFF_4$	$CADOFF_3$	$CADOFF_2$	$CADOFF_1$	$CADOFF_0$

RSVD — Reserved for future use. Always write as 0, but 0 is not guaranteed when read.

CADON[10:0]: Cadence On Time. 0 - 10.24 seconds with a scale of 5 ms per step. (default* = 190h = 2 sec)

CADOFF[10:0]: Cadence Off Time. 0 - 10.24 seconds with a scale of 5 ms per step. (default* = 320h = 4 sec)

During the ring off time, the system state is Active.

If the cadence off time is 0, the function will be enabled indefinitely.

The cadencer is a shared timer that is used for a variety of functions including: ringing cadencing, and tone pulsing e.g. howler tone generation.The on and off times are set by this command and the individual commands for these functions enable the cadencer.

*Power Up and Hardware Reset ($\overline{RST}$) Value = 0190 0320h

E2/E3h Write/Read Caller Identification Number Data

Command	D7	D6	D5	D4	D3	D2	D1	D0
W: E2h R: E3h	1	1	1	0	0	0	1	R/$\overline{W}$
I/O Data	CID_7	CID_6	CID_5	CID_4	CID_3	CID_2	CID_1	CID_0

CID: Caller ID Data
Writing to this register will send CID data to the subscriber line based on the status of the CIDDIS bit in command *EA/EBh Write/Read Caller Identification Number Parameters,* on page 91. The CID bit in command *4D/4Fh Read Signaling Register,* on page 67 is set when the Le88221/241 device becomes ready to receive more data, which can optionally generate an interrupt if MCID is reset in command *6C/6Dh Write/Read Interrupt Mask Register,* on page 73.

The amplitude and frequency parameters for caller number delivery are programmed in *D4/D5h Write/Read Signal Generator C and D Parameters.,* on page 86. Except for the first byte, data may not be written to this register until the CID interrupt is received or CID state is Ready in *EA/EBh Write/Read Caller Identification Number Parameters,* on page 91. If data is written before this interrupt is generated by the Le88221/241, the operation of the CID sequence is undefined.

*Power Up and Hardware Reset ($\overline{RST}$) Value = 00h

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E4/E5h Write/Read Switching Regulator Parameters

Command	D7*	D6	D5	D4	D3	D2	D1	D0
W: E4h R:E5 h	1	1	1	0	0	1	0	R/$\overline{W}$
I/O Data Byte 1	BSI1	BSI0	FLYBB	RSVD	RSVD	RSVD	RSVD	RSVD
I/O Data Byte 2	RSVD	SWFS1	SWFS0	$SWYV_4$	$SWYV_3$	$SWYV_2$	$SWYV_1$	$SWYV_0$
I/O Data Byte 3	RSVD	RSVD	RSVD	$SWZV_4$	$SWZV_3$	$SWZV_2$	$SWZV_1$	$SWZV_0$

RSVD — Reserved for future use. Always write as 0, but 0 is not guaranteed when read

FLYBB: Converter mode - Flyback or Inverting Buck-Boost

- 0*: Converters are in Flyback mode
- 1: Converters are in Inverting Buck-Boost mode.

BSI[1:0]: Battery Sense Select Input

The selection of which battery is sensed by which pin is determined by these bits as defined by the following table.

	VBL sense pin	VBM sense pin	VBH sense pin
00*:	SWVSY	XB	SWVSZ
01:	SWVSY	SWVSZ	XB
10:	XB	SWVSY	SWVSZ
11:	RSVD	RSVD	RSVD

SWFS[1:0]: Switching regulator frequency select. Selects the switching regulator clock in the three power modes. Non-default values are normally used in buck-boost applications. Applies to both switching regulators.

	Low Power	Medium Power	High Power
00*:	48 kHz	96 kHz	384 kHz
01:	24 kHz	48 kHz	192 kHz
10:	12 kHz	24 kHz	96 kHz
11:	Reserved		

SWYV[4:0]: Switching regulator Y voltage
Specifies the fixed output voltage for switching regulator Y
Range -5 V to -160 V with a step size of -5 V
(default = 0Ah = -55 V)

SWZV[4:0]: Switching regulator Z voltage
Specifies the fixed output voltage for switching regulator Z.
Range -5 V to -160 V with a step size of -5 V
(default = 0Ah = -55 V)

The available SWxV voltage is internally clamped to -100 V on the low voltage devices and -150 V on the high voltage devices.

This command does not depend on the state of the Channel Enable Register.

*Power Up and Hardware Reset ($\overline{RST}$) Value = 00 040Ah

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E6/E7h Write/Read Switching Regulator Control

Command	D7*	D6	D5	D4	D3	D2	D1	D0
W: E6h R: E7h	1	1	1	0	0	1	1	R/$\overline{W}$
I/O Data	RSVD	RSVD	RSVD	RSVD	ZM_1	ZM_0	YM_1	YM_0

RSVD Reserved for future use. Always write as 0, but 0 is not guaranteed when read.

YM[1:0]: Switcher Y mode bits

ZM[1:0]: Switcher Z mode bits

The mode bits are defined in the following table:

Mode Bit 1	Mode Bit 0	Mode Definition	Designation
0*	0*	**Switching Regulators Disabled**	OFF
0	1	Low Power Lowest Switcher Clock	LP
1	0	Medium Power Medium Switcher Clock	MP
1	1	High Power High Switcher Clock	HP

From the power-up shutdown state, if the on-chip switching regulator controllers are being used to generate the system batteries, the power supplies should be started in mode 1 or 2. After at least 10 ms in these modes, mode 3 can be selected if high power output is required. The system state can then be programmed as desired. The device can only return to the shutdown state if both switching regulators are disabled.

For correct battery switching threshold setting, both switching regulator controllers must be enabled, even if they are not being used to generate battery voltages. Ensure that the ZM and YM bits are non-zero after initialization.

This command does not depend on the state of the Channel Enable Register.

*Power Up and Hardware Reset ($\overline{RST}$) Value = 00h

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EA/EBh Write/Read Caller Identification Number Parameters

Command	D7	D6	D5	D4	D3	D2	D1	D0
W: EAh R: EBh	1	1	1	0	1	0	1	R/$\overline{W}$
I/O Data	CIDST2	CIDST1	CIDST0	EOM	FBDIS	FBSRT	FBSTP	CIDDIS

CIDST[2:0]: These bits report back the state of the CID state machine.

CIDST2	CIDST1	CIDST0	State
0	0	0	Idle*
0	0	1	Ready
0	1	0	Full
0	1	1	Last byte
1	0	0	Last 2 bytes
1	0	1	Underrun
1	1	0	RSVD
1	1	1	RSVD

These bits are read only. Writes to these bits are ignored.

EOM: End of Message

0*: The end of message is not the next byte written

1: The next byte written will be the last byte in the CID message

This bit is reset after the last byte is transmitted

FBDIS: Frame Bit Disable

0*: The CID message data written to Le88221/241 is automatically framed by the Le88221/241 device with the start and stop bit specified in FBSRT and FBSTP

1: No start/stop bit framing is done by the Le88221/241 device. The data written to Le88221/241 is passed directly to the subscriber line. The user may frame their data by embedding start/stop bits within the data.

FBSRT: Frame Bit Start bit

0*: Start bit will be a 0 (space) if FBDIS = 0

1: Start bit will be a 1 (mark) if FBDIS = 0

This bit is ignored if FBDIS = 1.

FRSTP: Frame Bit Stop bit

0: Stop bit will be a 0 (space) if FBDIS = 0

1*: Stop bit will be a 1 (mark) if FBDIS = 0

This bit is ignored if FBDIS = 1

CIDDIS: Caller ID disable

0: Caller ID is enabled. Writes to the CID data register will be driven onto the subscriber line.

1*: Caller ID is disabled. Any writes to the CID data register will not be driven to the subscriber line.

*Power Up and Hardware Reset ($\overline{RST}$) Value = 03h

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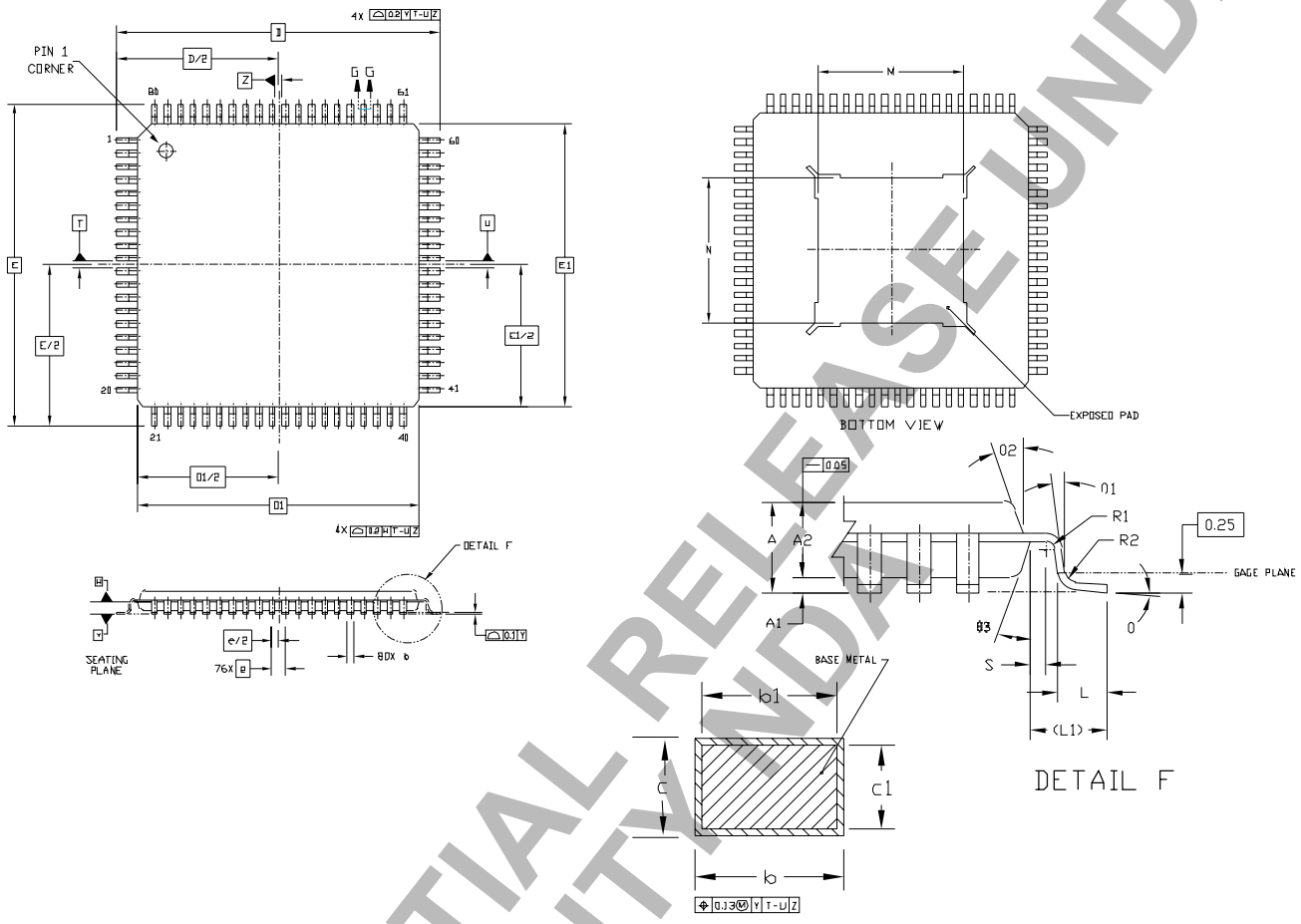
PHYSICAL DIMENSIONS

80-Pin eLQFP

14 x 14 x 1.4 LQFP 80 LD Exposed Pad



DIM	MIN	NOM	MAX	DIM	MIN	NOM	MAX	DIM	MIN	NOM	MAX
A	---		1.6	L1		1 REF					
A1	0.05		0.15	R1	0.08		---				
A2	1.35	1.4	1.45	R2	0.08		0.2				
b	0.22	0.32	0.38	S	0.2		---				
b1	0.22	0.3	0.33	θ	0°	3.5°	7°				
c	0.12		0.2	θ1	0°		---				
c1	0.12		0.16	θ2	11°	12°	13°				
D		16 BSC		θ3	11°	12°	13°				
D1		14 BSC		N	7.3		7.5				
e		0.65 BSC		N	7.3		7.5				
E		16 BSC									
E1		14 BSC									
L	0.45	0.6	0.75								

UNIT	DIMENSION AND TOLERANCES	REFERANCE DOCUMENT
MM		

NOTES:

1. DIMENSIONS D1 AND E1 DO NOT INCLUDE MOLD PROTRUSION. ALLOWABLE PROTRUSION IS 0.25 PER SIDE. DIMENSIONS D1 AND E1 DO INCLUDE MOLD MISMATCH AND ARE DETERMINED AT DATUM PLANE DATUM H.

2. DIMENSION b DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL NOT CAUSE THE LEAD WIDTH TO EXCEED THE MAXIMUM b DIMENSION BY MORE THAN 0.08 mm. DAMBAR CANNOT BE LOCATED ON THE LOWER RADIUS OR THE FOOT. MINIMUM SPACE BETWEEN PROTRUSION AND AN ADJACENT LEAD IS 0.07mm.

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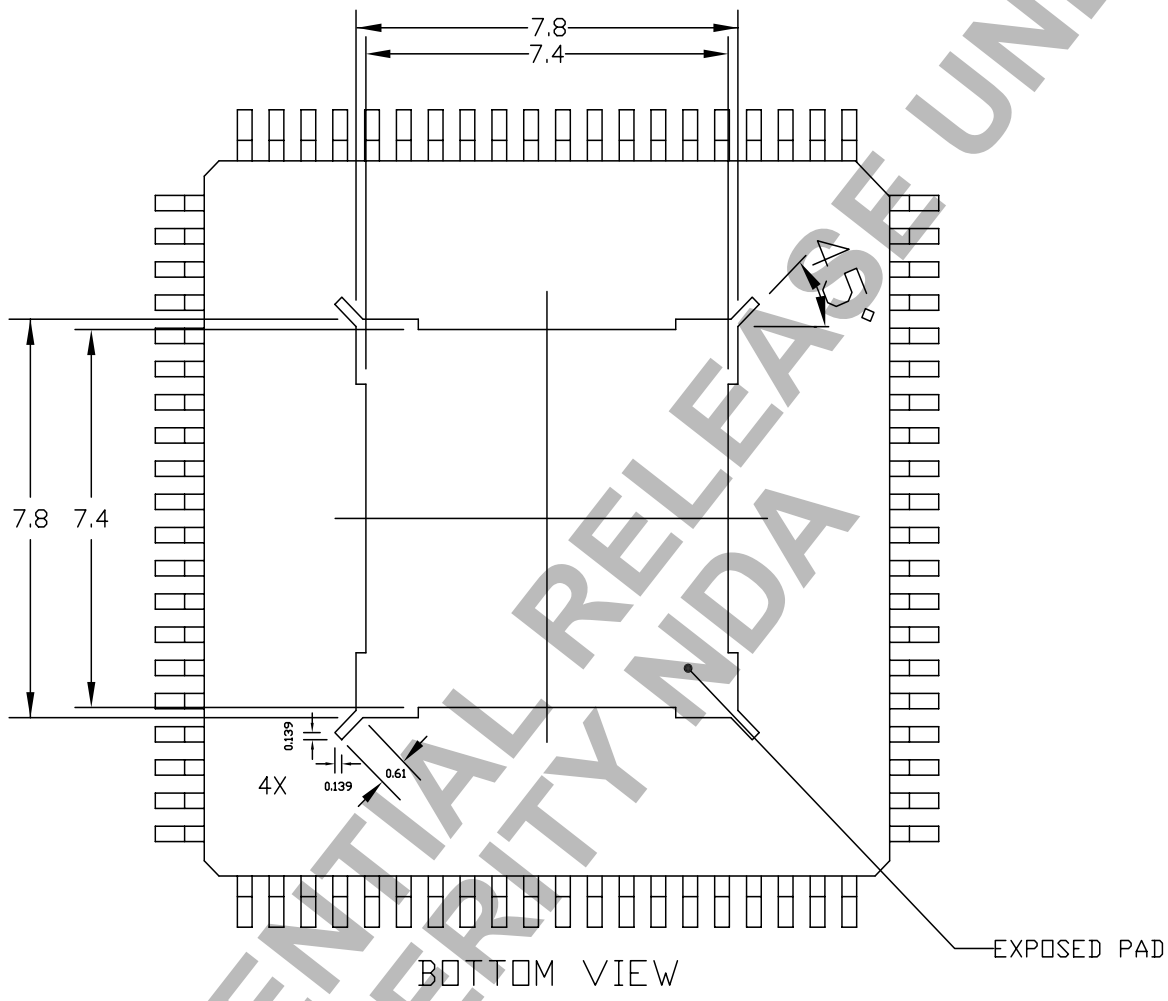
Detailed Bottom View of 80-Pin eLQFP



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REVISION HISTORY

Revision B1 to C1

- Labeled Table 3, *Definitions of Status Bits*, on page 13.
- *Programming with the Monitor Channel*, on page 20; Figure 12 moved into section.
- *Signaling Control*, on page 26; added system state 1111, Shutdown ACT = 0, Additions to Tip Open section.
- *Unbalanced Ringing (Le88241 Device Only)*, on page 30; added description of POLNR bit.
- *Ring Trip Detection*, on page 31; section re-written. Extensive additions, including Table 12.
- *Switching Regulator Controllers*, on page 33; section re-written.
- *Pin Descriptions*, on page 36; Added EPAD and new description for LFC pin.
- *Electrical Characteristics*, on page 40; Test conditions updated.
- *Supply Currents and Power Dissipation*, on page 40; Table entries and conditions changed.
- *DC Characteristics*, on page 41; SWOUT pin specification added.
- *DC Feed and Signaling*, on page 41; Test Conditions altered.
- *Ringing*, on page 42; notes added.
- *Switching Regulator Controller*, on page 42; notes added.
- *Converter Configuration Signal Sense Accuracy*, on page 43; notes added.
- *Transmission Characteristics*, on page 44. added specs, notes.
- *Microprocessor Interface*, on page 50; labeled Table 13.
- *Application Circuit*, on page 59; updated and corrected circuit and BOM, C_{REF} value changed, added R_{BLD} = 75kΩ.
- Figure 24, on page 47; Spurious Out-of-Band Signals at the Analog Output altered.
- *46/47h Write/Read Device Configuration Register*, on page 65; Clock Frequency added.
- *56/57h Write/Read System State*, on page 70; Shutdown state added.
- *68/69h Write/Read System State Configuration*, on page 72; added description.
- *C6/C7h Write/Read DC Feed Parameters*, on page 81, added new bit descriptions.
- *E4/E5h Write/Read Switching Regulator Parameters*, on page 89, added description.
- *Detailed Bottom View of 80-Pin eLQFP*, on page 93 added.

Revision C1 to C2

- *Ordering Information*, on page 1; Added column and note for packing methods.
- *Low Power Idle*, on page 27; added recommendation on Disconnect to Idle transition.
- *DC Feed*, on page 27; added description of longitudinal clamp and applicable VOC range, and expanded programmable VOC selection via VOCSFT bit.
- *Ringing Cadencing*, on page 30; section added.
- *Test Load Switch (Le88241 Device Only)*, on page 33; added method for simple test load control.
- *Switching Regulator Controllers*, on page 33; Added LFC pin description and switching regulator control register setting.
- *Electrical Characteristics*, on page 40; changed value of VBL from –27 V to –26 V
- *Transmission Characteristics*, on page 44; added note 1 to TAC - RAC overload specification.
- *Switching Regulator Controller*, on page 42; defined -55V switcher output accuracy.
- *A6/A7h Write/Read Converter Configuration*, on page 79; updated description and configuration assumptions.
- *CDh Read Transmit PCM/Test Data*, on page 82; changed description.
- *E6/E7h Write/Read Switching Regulator Control*, on page 90; expanded description.

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