Preliminary

Technical Data Sheet
for the

Q4400
Variable Rate Vocoder

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DL80-3749-8 X2

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- Data rates that adjust dynamically 50 times per second
- Variable data rates from 800 bps to 9.6 kbps
- Fixed data rates of 4 kbps, 4.8 kbps, 8 kbps and 9.6 kbps
- Full-duplex operation
- Proprietary QCELP speech coding algorithm with voice compression better than 16:1
- Digitized speech sample interface to standard telephone analog-to-digital codecs
- Compressed speech packet interface to standard 8-bit microprocessor bus

APPLICATIONS

- Digital VSAT voice systems
- Digital wireless personal communications systems
- Secure telephone or wireless equipment
- Digital cellular telephone systems
- Speech synthesis systems
- Voice mail systems
- Long distance transcript services
- Voice storage systems
- Voice annotation applications
- Voice response systems

GENERAL DESCRIPTION

The QUALCOMM Q4400 Variable Rate Vocoder is a full-duplex speech encoder and decoder that produces near toll-quality speech at compressed data rates of under 9.6 kilobits per second(kbps). The Q4400 vocoder provides a single-chip solution to the speech compression requirements for digital telephone, wireless communications, voice storage, and speech synthesis systems. The Q4400 vocoder uses the proprietary QUALCOMM Codebook Excited Linear Predictive (QCELP) speech coding algorithm to achieve high speech quality at low data rates.

The Q4400 vocoder has the unique ability to code speech at fixed or variable data rates. In Fixed Rate mode, the Q4400 vocoder can code speech at rates of 4 kbps, 4.8 kbps, 8 kbps or 9.6 kbps. In Variable Rate mode, the Q4400 vocoder automatically adjusts the data rate from 800 bps to 8 kbps (Normal Variable Rate mode) or from 800 bps to 9.6 kbps (Enhanced Variable Rate mode) every 20 milliseconds (ms). When in Variable Rate mode, the Q4400 vocoder codes speech at under 7 kbps in continuous speech applications and at under 3.5 kbps in typical two-way telephone conversations, without degrading the speech quality.

The Q4400 vocoder is a masked ROM version of a digital signal processor (DSP) device operating at 30 million instruction per second (MIPS). Digitized speech is transferred to and from the Q4400 vocoder via a digital serial interface that connects to a 64 Kbps μ-law speech codec. Compressed speech packets are transferred to and from the Q4400 vocoder via an 8-bit parallel data bus interface that connects to standard microprocessor buses. The Q4400 vocoder is also controlled via this processor interface.

THEORY OF OPERATION

Digital speech systems convert analog speech signals to a digital format for processing, storage, or transmission. Digitized speech can be stored using digital storage technology (i.e., disks, tape, ROM, or RAM) or can be transmitted using digital communications systems. Error protection and correction techniques, such as Viterbi decoding, can be used to minimize the effects of noise or errors on the speech, and encryption methods may be employed to increase security.

In telephone quality digital speech systems, the bandwidth of the speech signal is limited to 3 to 4 kHz. For a 4 kHz bandwidth speech signal, the analog speech signal must be digitally sampled at least 8000 times per second to be able to reconstruct the original signal from the samples. In standard μ–law encoding, each sample is companded and quantized using 8 bits, creating an overall data rate of 64 kbps. Through the use of modern speech coding technology, this data rate can be reduced to under 10 kbps with only a slight change in quality, allowing for much higher storage or transmission capacities in digital speech systems.

Different speech coding technologies have different benefits and limitations. Some of the factors that vary between technologies are the quality of the reconstructed speech (including intelligibility, speaker recognition, performance in noisy environments, and performance on different male and female speakers); the encoded data rate; the processing delay; the size of the vocoder; the power dissipation; interoperability with existing systems; and the ability to process non speech signals (i.e., music, fax, data, and dual-tone multi-frequency [DTMF]).

Speech Coders

There are roughly two classes of speech coding algorithms: waveform coders and vocoders. Both classes are discussed below.

Waveform Coders

Waveform coders are essentially sophisticated analog-to-digital converters. Waveform coders are good for processing both voice and non-voice signals. They often have short processing delays (typically less than 5 ms), and use simple, low cost algorithms. However, high data rates are required to provide good quality reconstructed speech.

Some examples of waveform coders follow:

- Pulse Code Modulation (PCM). Usually more than 64 kbps
- Companded PCM. The US. phone system uses 64 kbps μ-law 255 companded PCM
- Adaptive Delta PCM (ADPCM). Usually 24 to 32 Kbps
- Continuously Variable Slope Delta (CVSD) modulation- Usually 16 to 32 kbps
- Subband coding. Usually 16 kbps

Vocoders

Vocoders code speech by using a sophisticated model of human speech production. Often the model includes specific components for modeling the pitch and the spectral characteristics of the speech. When encoding, vocoders extract the model parameters from the input speech, and when decoding, vocoders reconstruct the speech from the model parameters.

Vocoders operating at data rates from 4 to 10 kbps can provide speech quality with only slight degradation from that of waveform coders. However, the vocoder algorithms generally are more complex and may require greater delays, larger sizes, more power consumption, and higher costs. Also, due to the model of the human speech production system inherent in vocoder algorithms, music and other types of signals are not reproduced very accurately. Vocoders are often used in digital speech systems that require minimal data rates while maintaining near toll-quality speech.

Q4400 Variable Rate Vocoder

QUALCOMM's Q4400 Variable Rate Vocoder provides the next generation in vocoder technology. Figure 1 shows how variable rate operation allows speech coding at lower data rates while maintaining high speech quality. This is accomplished by coding the natural pauses in speech (for example, while listening, inhaling, or pausing between sentences) at lower data rates. The QCELP algorithm dynamically adjusts the encoded data rate based on the energy in the speech signal. The QCELP algorithm codes the active, high energy speech segments at higher data rates while coding the silent, low energy periods at lower data rates.

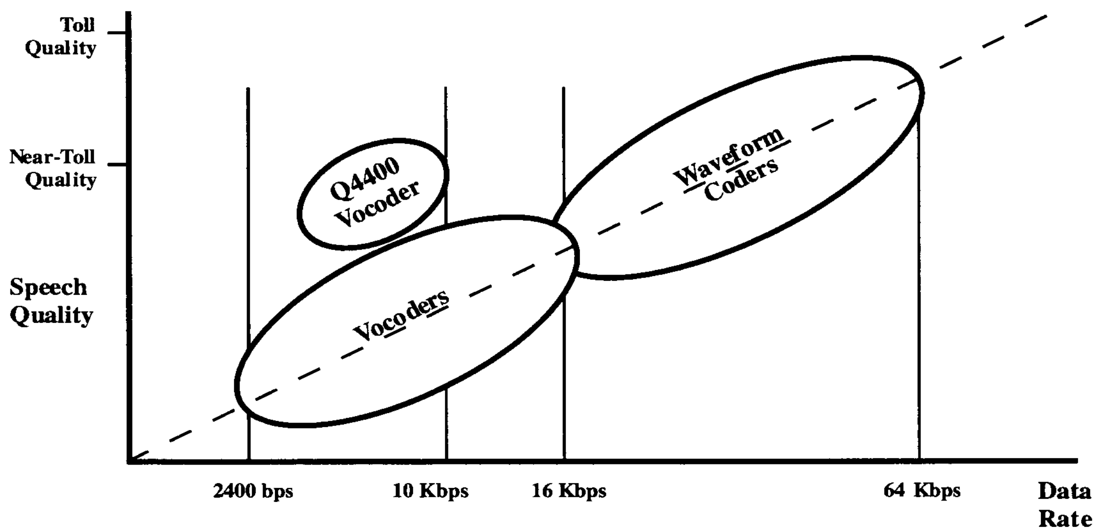


Figure 1. Waveform Coders vs. Vocoders

Figure 2 displays the operation of the QCELP data rate decision algorithm. The figure shows three phrases spoken over a 12-second period. The input speech energy and the adaptive thresholds, which "float" above the level of the background noise, are shown at the bottom half of the figure. The actual encoded data rate is shown at the top half of the figure. When the input speech signal energy is above these thresholds, the speech is coded at the highest rate. When the input speech signal energy is below these thresholds, the speech is coded at the lowest rate. The intermediate rate is used when the input speech signal energy is between the thresholds or when transitions between speech and silence periods occur. The active portions of the three phrases are coded at the high rate, producing good quality speech, while the background noise and the pauses in the speech are coded at the lower rates, creating a lower average data rate.

The thresholds are dynamically adjusted based on the level of background noise in the input speech signal, so background noise will be coded at the lower rates regardless of its volume. The data rate is determined every 20 ms, (or once every frame) allowing for accurate reproduction of short duration events in the background. Once the data rate is determined, the 20 ms frame is encoded and converted to a packet of encoded speech that can be stored or transmitted.

The QCELP decoder is used to convert each packet of encoded speech back into 20 ms frames of digitized speech samples. These samples can then be converted back to an analog signal by a codec and fed to a loud speaker or handset for listening. The QCELP algorithm encodes and decodes speech with end-to-end delays of less than 50 ms.

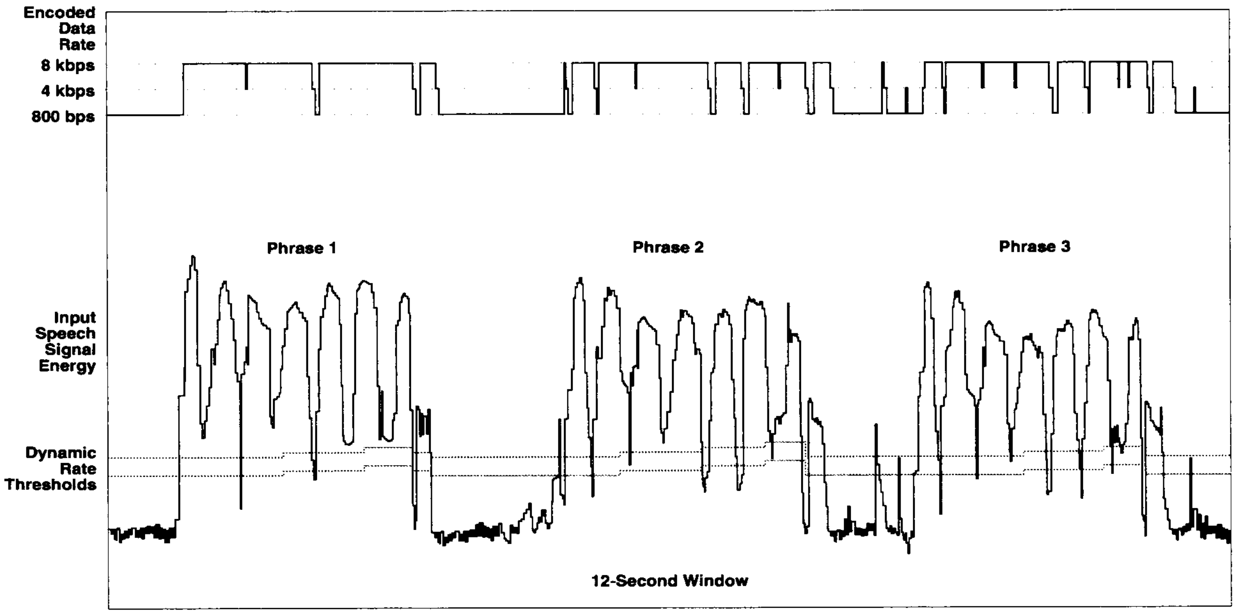


Figure 2. QCELP Rate Decision Algorithm

FUNCTIONAL OVERVIEW

The operation of the Q4400 vocoder is controlled through an 8-bit parallel Processor Interface using a set of pre-defined vocoder commands. Digitized speech samples are transferred to and from the Q4400 vocoder via a standard serial interface that is compatible with many μ-law PCM codecs. Compressed packets of speech data are transferred to and from the Q4400 vocoder via the same 8-bit parallel Processor Interface used for controlling the Q4400 vocoder. Figure 3 shows how the Q4400 vocoder interfaces to the other system components, such as the μ-law codec and processor.

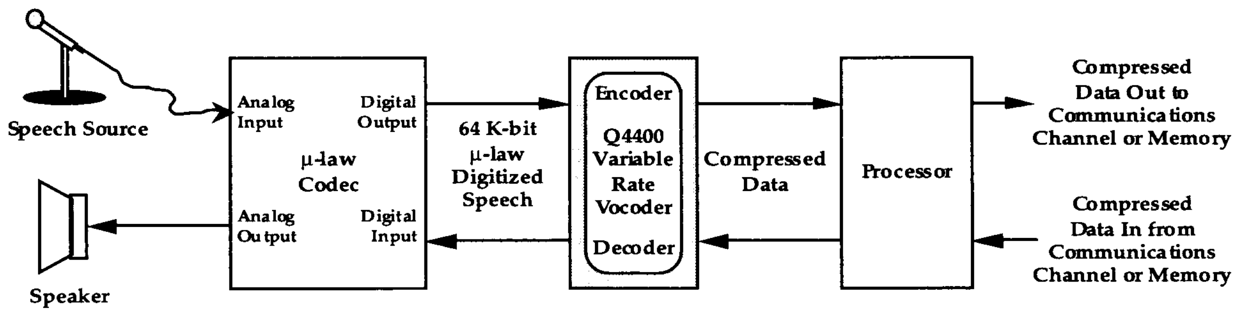


Figure 3. Q4400 Vocoder Support Circuitry

The Q4400 vocoder includes many functions in addition to the basic vocoder operation, making it a full-featured speech compression system. Figure 4 shows the functional block diagram of the Q4400 vocoder. The QCELP Encoder and QCELP Decoder, along with the Frame Timing section, make up the core of the Q4400 vocoder that provides the speech compression and decompression functions. The PCM Interface sends and receives μ-law PCM data to and from the codec. The Processor Interface sends and receives commands and compressed data to and from the system processor. The Input Muting feature allows muting of the input speech, and the Output Muting feature allows muting of the output speech. The Output Volume control feature adjusts the output volume. The Tone Generator feature provides single or dual frequency tones, including DTMF tones, to the codec. The Voice-Activated Switch (VOX) feature may be used for hands-free telephone operation (for example, a speaker phone). The Audio Loopback function allows testing of the PCM interface, and the Packet Loopback function allows testing of the microprocessor interface. Each of the functions in this diagram is explained in detail in the following sections.

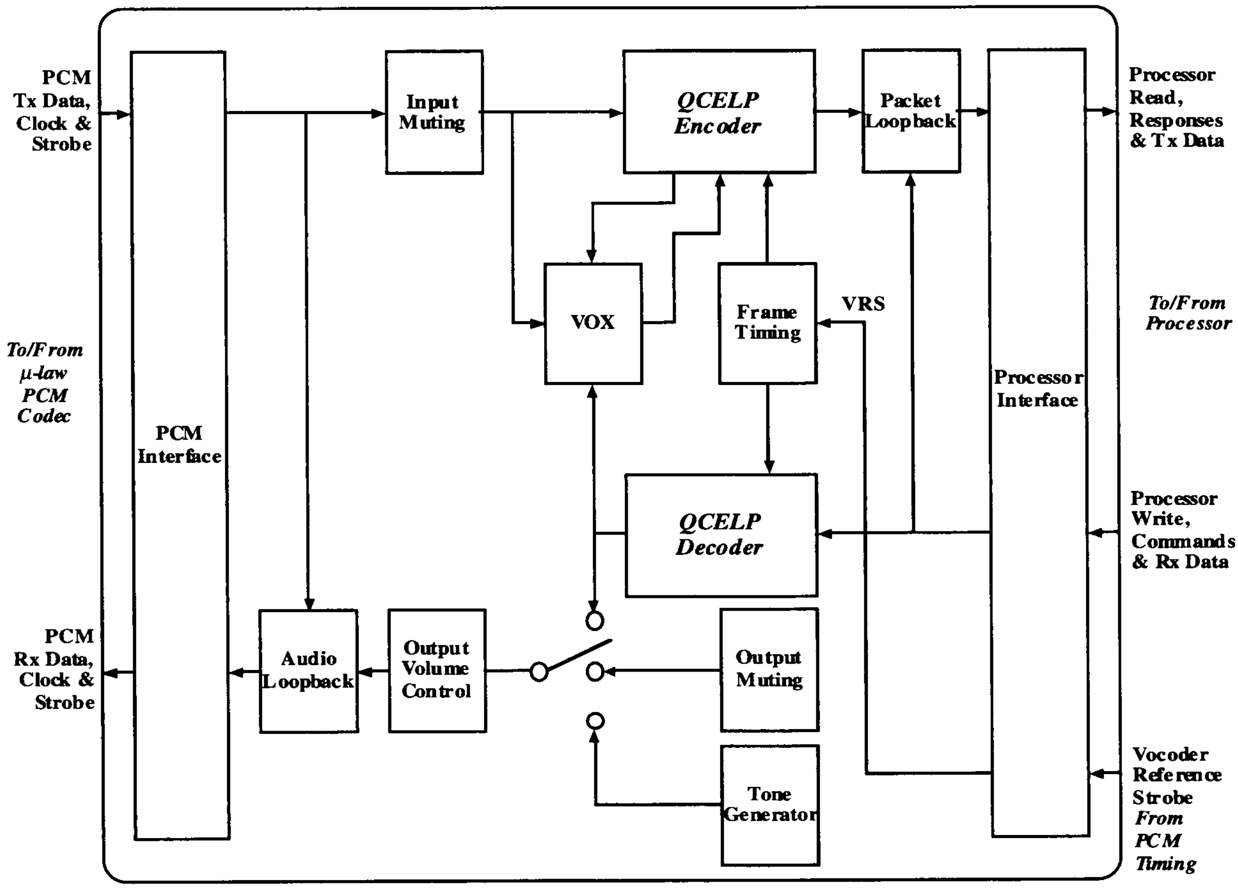


Figure 4. Q4400 Vocoder Block Diagram

QCELP Encoder

The QCELP Encoder is the most complex function of the Q4400 vocoder. The Encoder operates on one 20 ms frame at a time (which is 160 samples long). The encoding process includes measurement of the speech energy, data rate determination, dynamic adjustment of the rate thresholds, and encoding the speech into packets of compressed data. The Encoder provides a 25-byte packet of data to the processor for each 20 ms frame. Each packet contains the chosen data rate and 24 bytes of encoded data information needed for reconstructing the speech in each frame. This packet is transferred to the processor every 20 ms. The number of valid data bits within the 25-byte packet depends on the chosen data rate, as shown in figure 15. The invalid bits in the packet are arbitrarily set to zero. The processor formats the valid data bits contained in the packet from the Q4400 vocoder for storage or transmission.

The Encoder operates in one of two compression modes: Fixed Rate or Variable Rate. The Fixed Rate mode compresses the speech at a fixed data rate of 4000, 4800, 8000, or 9600 bits per second (bps). Variable Rate mode compresses the speech at data rates of 800, 4000, or 8000 bps in Normal Variable Rate mode and 800, 4800, or 9600 bps in Enhanced Variable Rate mode. The Q4400 vocoder achieves near toll-quality speech with both Variable Rate modes and data rates of 8000 bps or 9600 bps in Fixed Rate mode.

QCELP Decoder

The QCELP Decoder receives 25-byte packets of compressed speech from the processor every 20 ms. The packet contains the data rate chosen for the corresponding frame of speech and 24 bytes of compressed data needed for reconstructing the speech. The Decoder provides a reconstructed speech output of 160 8-bit μ-law companded speech samples every 20 ms to the PCM interface. The 25-byte packets input to the decoder contain a varying number of valid data bits depending on the data rate that was used to encode the frame. The processor must properly format the data from the transmission channel or storage device into the packet structure used by the Decoder.

Frame Timing

The Frame Timing section of the Q4400 vocoder determines the beginning of each 20 ms frame for the Encoder and Decoder. A single input signal, Vocoder Reference Strobe (VRS), provides the basis for this 20 ms timing. The Encoder frame timing and Decoder frame timing are independently set by the Tx Offset and Rx Offset from the VRS. These offsets are programmed through the "Initialize" command described in the "Q4400 Vocoder Commands" section of this document. The frame timing is initiated by providing a single strobe (or a repetitive 20 ms signal) to the VRS input pin or by sending a "Software VRS" command to the Q4400 vocoder. The initial VRS typically occurs at initialization or when the system configuration is changed.

PCM Interface

The PCM Interface of the Q4400 vocoder interfaces to a μ-law PCM codec. This interface receives and transmits 64 kbps μ-law companded speech samples. These samples are transferred as 8-bit serial words every 125 ms. The PCM interface is shown in figure 5. All data is transferred synchronously with externally sourced clocks and strobes. The operation of this interface is discussed in the "Operational Interface" section. Two optional PCM Interface handshake signals, Tx Buffer Full (TXBF) and Rx Buffer Empty (RXBE), are provided to facilitate PCM data transfer for applications that do not require the use of a codec.

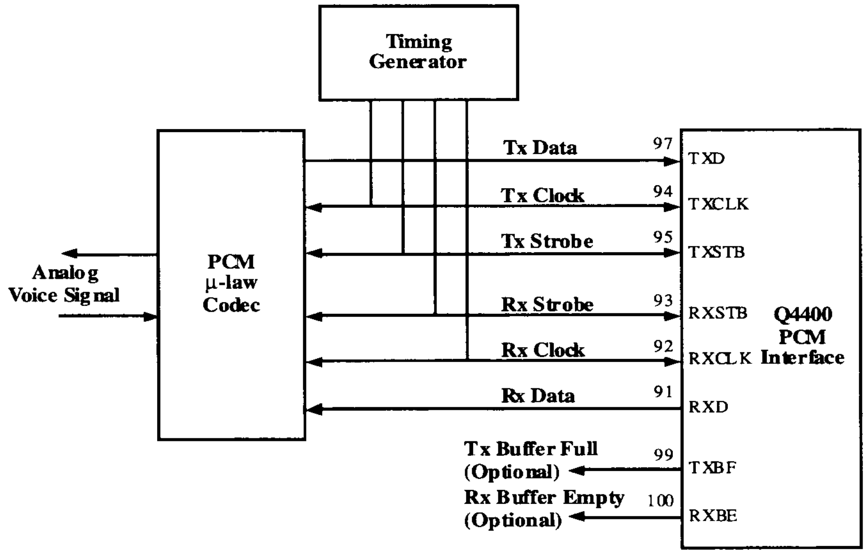


Figure 5. The Q4400 Vocoder to PCM Codec Interface

Processor Interface

The Q4400 vocoder is controlled by a processor via the 8-bit parallel Processor Interface. The packets of compressed data are also transmitted and received over the Processor Interface. Communication between the Q4400 vocoder and the processor is governed by a protocol that defines the Q4400 vocoder commands and responses (described in the "Q4400 vocoder Commands" section). The Q4400 vocoder acts as a slave peripheral to the processor. Therefore, the processor always initiates communication. Commands sent to the Q4400 vocoder from the processor are called Command Packets. Responses sent from the Q4400 vocoder to the processor are called Response Packets. Data is transferred via the 8-bit data bus using the Read and Write signals from the processor. The Processor Interface is shown in figure 6.

The Q4400 vocoder contains a Sleep mode for power reduction when it is not in use. The power dissipation while in Sleep mode is less than 50 mW, about 10% the power of normal operation. The Q4400 vocoder is reinitialized from Sleep mode by an "Initialize Vocoder" command from the processor.

The Q4400 vocoder features two self-diagnostic tests: a RAM test and an ALU test. The RAM test verifies that the RAM locations can be written to and read from properly. The ALU test verifies that the DSP core is functioning properly.

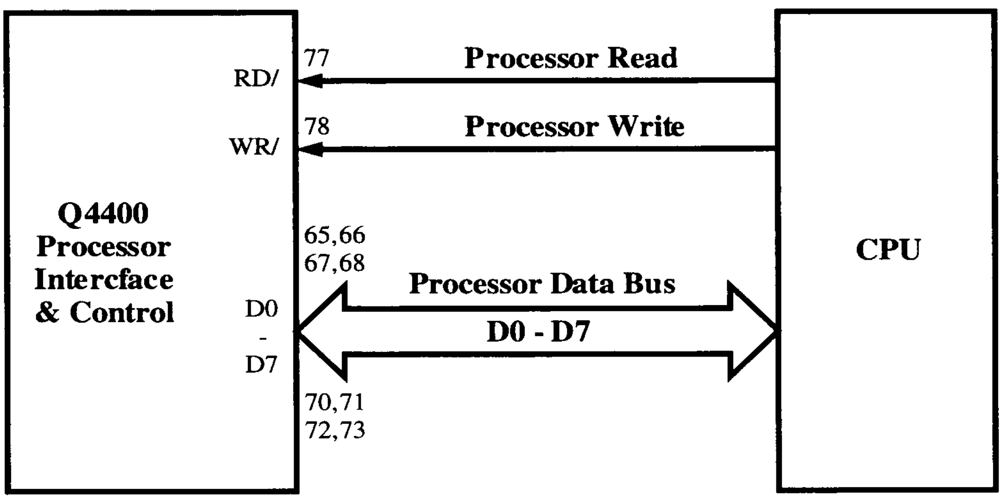


Figure 6. The Q4400 Vocoder to Processor Interface

Input Muting

The Input Muting function suppresses the input speech so that it is not encoded. Comfort noise is the only data that is encoded. The reconstructed signal at the decoder contains only comfort noise. In Variable Rate mode, the Encoder encodes the input speech at the low, 800 bps data rate. For more information, see the "Input Muting" command in the "Q4400 Vocoder Commands" section.

Output Muting

The Output Muting function replaces the reconstructed speech samples with comfort noise before the samples are sent to the PCM Interface. Output Muting is often used to eliminate pops and glitches that may be caused by the switching of processing paths or data sources. When the processor is aware of any system configuration changes that might cause errors to be heard, the Output Muting feature should be enabled and then disabled after the event has passed. For more information, see the "Output Muting" command in the "Q4400 Vocoder Commands" section.

Output Volume Control

The Output Volume Control function controls the volume of the reconstructed speech samples out of the decoder. The 16-bit value is completely programmable from the processor. The Output Volume Control can be varied between 42 dB of gain, 42 dB of attenuation, and muting (i.e., no output). Caution should be used when applying gain. Large gain increases can cause clipping of the speech samples sent to the codec, resulting in distortion. Also, some unavoidable quantization noise will be added when gain is applied. For more information, see the "Output Volume Control" command in the "Q4400 Vocoder Commands" section.

Tone Generator

The Tone Generator synthesizes single or dual frequency tones at the RXD output of the Q4400 vocoder. Two completely programmable tones can be generated with arbitrary volume and duration of the tones. Tone generation overrides the voice output to the PCM interface. However, the Q4400 vocoder continues to operate during tone generation. Therefore, received packets must continue to be passed to the Q4400 vocoder decoder to ensure that the speech is reconstructed properly when the tones are discontinued. Standard DTMF signals can be generated using this tone generator. For more information, see the "Tone Generation" command in the "Q4400 Vocoder Commands" section.

VOX - Voice Activated Switch

The VOX function is used in real-time, full-duplex applications where hands-free telephone operation is required. In hands-free operation, the microphone is typically near the speaker output, which can result in feedback between the speaker output and the microphone. This phenomenon, coupled with the inherent processing delay of the Q4400 vocoder, will result in an echo heard by users at the far end as they speak. ("Far end" refers to the other end of the link; "near end" refers to the end with VOX mode enabled.) VOX mode will allow only one side of the full-duplex link to be transmitted when there is voice activity, thus removing the return path for possible echo. VOX mode operational parameters are completely programmable and are described in the "Operating Modes" section. Also, see the "VOX" command in the "Q4400 Vocoder Commands" section.

Audio Loopback

The Audio Loopback function causes the digitized speech samples provided to the Q4400 PCM input to be looped back to the PCM output without being processed by the encoder. This is useful for verifying the correct operation of the PCM interface. The output PCM samples will not match the input PCM samples on a bit-by-bit basis due to the DC block implemented by the Q4400 vocoder, but the speech output will still sound identical to the input. For more information, see the "Audio Loopback" command in the "Q4400 Vocoder Commands" section.

Packet Loopback

The Packet Loopback function loops back unchanged Rx packets to the processor as Tx packets. This is useful for verifying the correct operation of the processor interface. For more information, see the "Packet Loopback" command in the "Q4400 Vocoder Commands" section.

OPERATING MODES

The Q4400 Variable Rate Vocoder operates in a variety of modes to provide maximum performance in a wide range of applications. The two main operating modes are Fixed Rate and Variable Rate modes. Fixed Rate mode provides one of four selectable data rates at 4000, 4800, 8000, and 9600 bps. There are two Variable Rate modes, Normal and Enhanced, which dynamically adjust the speech data rate for each frame based on the speech signal energy. Normal Variable Rate mode varies the data rate between 800, 4000, and 8000 bps. Enhanced Variable Rate mode varies the data rate between 800, 4800, and 9600 bps.

In addition to these two main operating modes, the Q4400 vocoder provides a wide range of commands to enhance speech compression operation. The Initialization mode is used to configure the Q4400 vocoder timing and operating mode for speech encoding and decoding. The Average Rate Limit mode is used with Variable Rate mode to limit the maximum average data rate to between 4000 and 9600 bps. The VOX mode is used for hands-free operation similar to a speaker phone. Sleep mode saves power when the Q4400 vocoder is not in use at a given time. Sample Slipping is a mechanism that adjusts for timing differences between the PCM Interface and the transmission channel. Each of these modes is described in the following sections.

Q4400 Vocoder Initialization

The Q4400 vocoder must be initialized at power up, after a reset condition, or when new system parameters are required, such as when a new two-way voice connection is made. The initialization process wakes up the Q4400 vocoder if it is in Sleep mode, specifies the Tx and Rx Timing parameters, starts the 20 ms frame timing, and establishes the background noise estimate for the current environment.

Initialization typically starts after the assertion of the hardware RESET signal. The "Initialize" command may be issued by the processor 1 ms after the reset is complete to configure the Tx Offset and Rx Offset timing parameters. Tx Offset and Rx Offset determine the timing relationships between the VRS and the Tx Tick and Rx Tick, respectively. This configures the Q4400 vocoder timing so that the "Tx Frame" and "Rx Frame" commands are aligned with the internal processing of the Q4400 vocoder. The "Initialize" command also causes the Q4400 vocoder to look for the VRS, which starts the internal frame timing. The external hardware VRS signal may be asserted any time after the "Initialize" command has been issued. Alternatively, the "Software VRS" command may be issued from the processor 250 micro seconds (μs) after the "Initialize" command has been issued. Once the VRS occurs, the "Reinitialize Background Noise Estimate" command should be issued to initialize the data rate thresholds. After the Initialization process is complete the Q4400 vocoder will be ready to perform speech compression via the "Tx Frame" and "Rx Frame" commands. The following is a summary of the initialization procedure:

- Reset the Q4400 vocoder (Hardware Reset or Software Reset via the "Diagnostic Test" or "Sleep Mode" command) and wait 1 ms
- Select Tx Offset and Rx Offset via the "Initialize" command
- VRS may be asserted at any time, or the "Software VRS" command may be issued 250 μs after the "Initialize" command.
- Initialize background noise by issuing the "Initialize Background Noise Estimate" command.
- Start data transfer using the "Tx Frame" and "Rx Frame" commands.

After the Q4400 vocoder is initialized, the first encoded frame will be a "blanked" frame (i.e., no valid data will be present). Each frame following the "blanked" frame will be encoded and decoded based on the parameters defined by the "Tx Frame" and "Rx Frame" commands.

Speech Encoding and Decoding

After the initialization sequence is complete, speech encoding and decoding may begin. PCM data samples at the TXD Input are internally grouped together into 20 ms frames. These frames are encoded into packets and output to the processor every 20 ms via the "Tx Frame" command. The decoder path of the Q4400 vocoder receives packets of compressed speech data from the processor every 20 ms via the "Rx Frame" command. Each frame of compressed speech information is decoded and provided to the RXD Output as PCM samples.

The processor on the encoder side receives an encoded packet of compressed speech data every 20 ms by issuing a "Tx Frame" command to the Q4400 vocoder. The "Tx Frame" command must be issued within a 19 ms window after the Tx Frame Tick. Each packet of compressed speech data is transferred to the processor in the "Tx Frame" response packet. Due to double buffering of the packets in the Q4400 vocoder, the data contained in the "Tx Frame" response packet corresponds to the speech encoded during the previous 20 ms frame. The "Tx Frame" response packet contains the data rate for the frame as well as the valid data bits. The "Tx Frame" command contains the maximum and minimum data rate limits for the next 20 ms frame to be processed. Alternatively, the processor can also provide only data rate parameters for the current frame being processed using the "Tx Frame Rate Only" command, which is discussed in the "Operational Interface" section. Each packet of compressed speech data received by the processor is then formatted for transmission over a digital communications channel or for sending to a storage medium. The processing delay between the arrival of the first PCM sample in a 20 ms frame and the completion of the encoding process for that frame is approximately 47.5 ms.

The decoding process begins when the processor on the decoder side receives a packet of information from the transmission channel or storage medium and constructs an "Rx frame" command packet to send to the Q4400 vocoder. The "Rx Frame" command provides a frame of compressed speech data from the processor to the Q4400 vocoder for decoding. The "Rx Frame" command is issued every 20 ms within a 19 ms window before the Rx Frame Tick. The "Rx Frame" command packet contains the data rate for the frame as well as the valid data bits needed to reconstruct the speech signal. The decoder reconstructs the speech from the received packet and provides the reconstructed PCM speech samples to the RXD output. The processing delay between the arrival of the "Rx Frame" command packet and transmission of the first PCM sample to the codec is approximately 3 ms.

The Q4400 vocoder contains a feature that allows selected data frames to be "Blanked" or "Erased" to reduce the effects of system noise and transmission errors. The result of system noise and transmission errors are pops and clicks heard at the decoder end. The "Blank" feature is used by the encoder when a known disruption in the system occurs to eliminate these pops and clicks. Such disruptions could include configuration changes or transmission of a frame of control information instead of compressed speech data. The "Blank" indication is provided in the "Tx Frame" command and sent to the decoder in an "Rx Frame" command. The "Erase" feature eliminates the pops and clicks caused by transmission errors over the transmission medium. This feature is used by the processor on the decoder side when a packet of information is received from the transmission channel with bit errors. One bit error could have a major affect (or minor affect depending on which bits are in error) on the decoded speech quality. Therefore, when a packet is received with errors, it is best to use the "Erase" feature. The "Erase" indication is sent by the processor to the decoder in the "Rx Frame" command. Both the "Blank" and "Erase" features command the decoder to estimate what the reconstructed frame of speech data should be without having actual compressed speech data. Both of these features are described in the "Q4400 Vocoder Commands" section.

Fixed Rate Mode

In Fixed Rate mode, the same data rate is used for compressing and decompressing each frame. This is accomplished by setting the maximum and minimum data rate limits in the "Tx Frame" command to be equal. Valid fixed rates are 4000, 4800, 8000, and 9600 bps. The decoder operates the same way as described above in the "Speech Encoding and Decoding" section.

Variable Rate Mode

Variable Rate mode dynamically varies the data rate of each frame based on the speech signal energy. There are two Variable Rate modes to choose from; Normal mode and Enhanced mode. The Normal Variable Rate mode selects from data rates of 800, 4000, and 8000 bps. The Enhanced Variable Rate mode selects from data rates of 800, 4800, and 9600 bps. The Enhanced mode will provide slightly better voice quality because of the higher data rates.

Variable Rate mode determines the data rate for each frame based on the energy of the speech. If the signal energy is high then the maximum (or full) rate will be used. If the signal energy is at a medium level then the intermediate (or half) rate will be used. If the signal energy is low, then 800 bps data rate will be used. (Full rate is defined as 8000 bps for Normal Variable Rate mode and 9600 bps for Enhanced Variable Rate mode. Half rate is defined as 4000 bps for Normal Variable Rate mode and 4800 bps for Enhanced Variable Rate mode.) See Figure 2 in the "Theory of Operation" section.

The "Tx Frame" command provides the maximum and minimum data rate parameters. In Normal mode the maximum is set to 8000 bps, and the minimum is set to 800 bps. In Enhanced mode, the maximum is set to 9600 bps, and the minimum remains set to 800 bps. The "Tx Frame" response packet contains the data rate that the encoder selects for each frame and the compressed speech data.

The Q4400 vocoder Encoder also contains a unique feature for tracking the background noise level to optimize the voice quality and compression rate when in Variable Rate mode. The Background Noise Estimate gradually adjusts the adaptive rate thresholds to float above the level of the background noise. A "Reinitialize Background Noise Estimate" command may be issued at any time to set the compression rate thresholds. The processor typically issues the "Reinitialize Background Noise Estimate" command when the Q4400 vocoder is initialized or at the initial onset of valid PCM data to the Q4400 vocoder.

The decoder operates the same way as described above in the "Speech Encoding and Decoding" section.

Average Rate Limit

The Average Rate Limit mode is used when the desired maximum average encoded data rate must be limited between half rate and full rate for active speech. The "Average Rate Limit" command is used to enable this mode and set the maximum average rate between half rate and full rate. One of the Variable Rate modes must be selected for this mode to operate properly. The Average Rate Limit works by forcing some frames that would normally be coded at full rate to be coded at half rate instead. For example, an Average Rate Limit selection of 7/8 will cause 75% of the full rate frames to be coded at full rate and 25% of the full rate frames to be coded at half rate. The resulting maximum average is 7000 bps in Normal mode and 8400 bps in Enhanced mode. In a normal conversation where each person talks around 40% of the time, this would drop the overall average data rate from 3680 bps to 3280 bps in Normal mode and from 4320 bps to 3840 bps in Enhanced mode. See figure 7 for an example.

This feature affects only the encoder side of the Q4400 vocoder. The processor handles the compressed data from the "Tx Frame" and "Rx Frame" commands exactly as described in the "Speech Encoding and Decoding" section above.

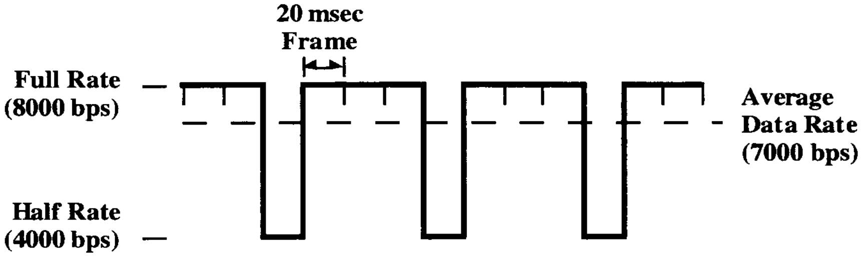


Figure 7. Average Rate Limit Operation During Active Speech (7/8 Normal Mode Example)

VOX Mode

VOX mode is used to eliminate potential echo during hands-free telephone operation (i.e., speakerphone applications). This mode can be used in conjunction with Fixed, Variable, or Average Rate Limit modes described above. In VOX mode, the Q4400 vocoder operates in one of three states: Idle, Tx, and Rx. The Idle state allows transmission in both directions, whereas the Tx and Rx states allow half-duplex operation only. The VOX mode will remain in the Idle state until the decoder signal energy and background noise energy differ by a programmable amount. Once the VOX leaves the Idle state, the active states (Tx or Rx) are entered by comparing the encoder's signal and background noise energy to the decoder's signal and background noise energy. The decoder typically has priority over the encoder. Therefore, if both users are speaking at the same time, the user at the far end will have priority.

The "VOX Mode" command enables and establishes the parameters for VOX mode operation. There are five programmable parameters that enable the processor to tailor the VOX mode operation to the specific requirements of the system. These parameters are as follows:

Energy Decay Factor:
: Selects the sensitivity for the near-end speech input so that it will not be cut off during pauses.

Background Noise Decay Factor:
: Selects the rate at which the background noise estimates are allowed to increase.

Decoder Background Noise Floor:
: Sets the lower limit of the decoder background noise threshold. This is required because VOX mode will not operate efficiently if the background noise is too low.

Decoder VOX Threshold:
: Sets the receive signal (from the far end) energy threshold. VOX is not required if the receive energy from the far-end is less than 6 dB above the decoder's background noise.

Encoder Weighting Factor:
: Sets a weighting factor, which scales the encoder's speech energy before the encoder/decoder energy comparison is made to determine which side will have priority.

For more information, see the "VOX" command in the "Q4400 Vocoder Commands" section.

Sleep Mode

Sleep Mode conserves power when the Q4400 vocoder is not in operation. The Q4400 vocoder can be commanded to enter the Sleep mode by issuing the "Sleep Mode" command or by issuing the "Diagnostic Test" command. (The Q4400 vocoder will automatically enter sleep mode when the diagnostic tests are complete.) The power dissipation during sleep mode is less than 50 mW compared to almost 500 mW during normal operating conditions.

Sleep mode essentially performs a software reset and remains in the reset condition until the processor writes an "Initialize" command. At that time, the initialization sequence must be performed to configure the Q4400 vocoder for desired operation.

Sample Slipping

Sample slipping is a mechanism to adjust the Tx Offset and Rx Offset relative to the VRS without having to reinitialize the Q4400 vocoder. This mode is available to compensate for differences between the PCM timing and the transmission channel timing.

Two alternate commands, "Tx Offset + 1" and "Tx Offset - 1", may be used in place of the "Tx Frame" command to adjust the Tx Offset either backward or forward by one PCM sample relative to the VRS. When the value of the Tx Offset is increased by one, a sample from the PCM input is deleted, and the internal Q4400 vocoder encoder timing is shifted back one sample. When the value of Tx Offset is decreased by one, a sample from the PCM input is repeated, and the internal Q4400 vocoder encoder timing is shifted forward one sample.

Similarly, there are two alternate commands, "Rx Offset + 1" and "Rx Offset - 1", that may be used in place of the "Rx Frame" command to adjust the Rx Offset either backward or forward by one PCM sample period relative to the VRS. When the value of Rx Offset is increased by one, a PCM output sample is repeated and the internal Q4400 vocoder decoder timing is shifted forward one sample. When the value of Rx Offset is decreased by one, a PCM output sample is deleted, and the internal Q4400 vocoder decoder timing is shifted back one sample.

The "Tx Offset" and "Rx Offset" commands take effect immediately. Therefore, the timing of the "Tx Frame" and "Rx Frame" commands that follow these alternate commands must be moved accordingly, either forward or backward.

OPERATIONAL INTERFACES

The Q4400 vocoder Operational Interfaces are comprised of the System Interface, PCM Interface, and Processor Interface. Figure 8 shows the Q4400 Vocoder Interface Diagram. The System Interface provides connections for the general purpose signals used by the Q4400 vocoder. The PCM Interface provides all connections necessary for interfacing to a standard μ-law codec. The Processor Interface provides all connections for interfacing to a standard 8-bit microprocessor data bus. The operation and use of each of these interfaces are discussed in detail below.

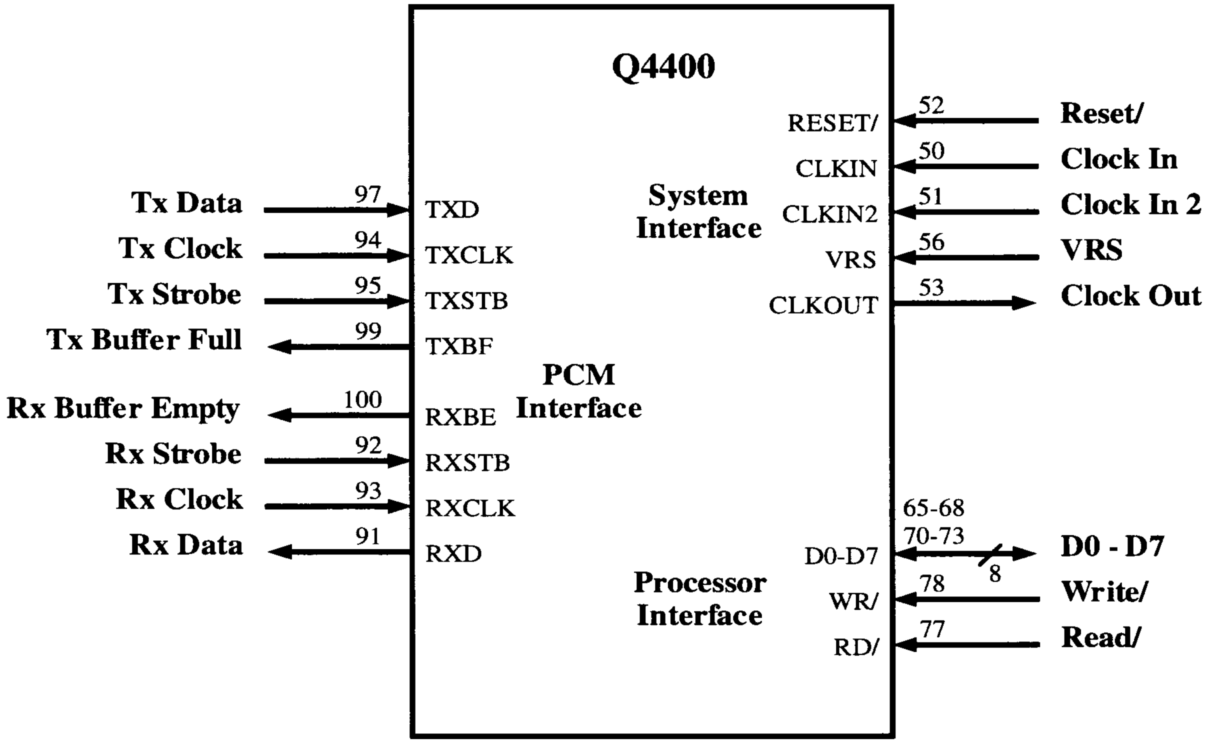


Figure 8. Q4400 Vocoder Interface Diagram

System Interface

The System Interface contains the RESET/, CLKIN, CLKIN2, VRS, and CLKOUT signals. The following is a description of each of these signals.

RESET/

The RESET/ signal is an active-low input that resets the entire Q4400 vocoder. A high-to-low transition causes the Q4400 vocoder to enter the reset state and remain in this condition until the signal returns high again. The RESET/ signal must remain active for at least six input clock periods (198 μs). All output signals are tri-stated during reset, and all internal timers and registers are cleared. After the reset condition is removed, the Q4400 vocoder will initialize the internal QCELP algorithm and wait for the "Initialize" command. There must be at least 1 ms between the end of the reset condition and when the "Initialize" command is passed to the Q4400 vocoder.

CLKIN and CLKIN2

The CLKIN and CLKIN2 inputs are used for the external 30 MHz clock. Two types of clocks may be used, a CMOS level clock input or a crystal oscillator clock input. If a CMOS level clock signal is used, this clock signal should be connected to CLKIN. In this case, CLKIN2 should be left open. If a 30 MHz crystal is used, then one of the two pins of the crystal should be connected to CLKIN, and the other pin should be connected to CLKIN2. In this configuration a 10 pF capacitor is required between each of these inputs and VSS (ground). Figure 9 shows a typical clock input configuration using a CMOS logic level clock input and a crystal clock input.

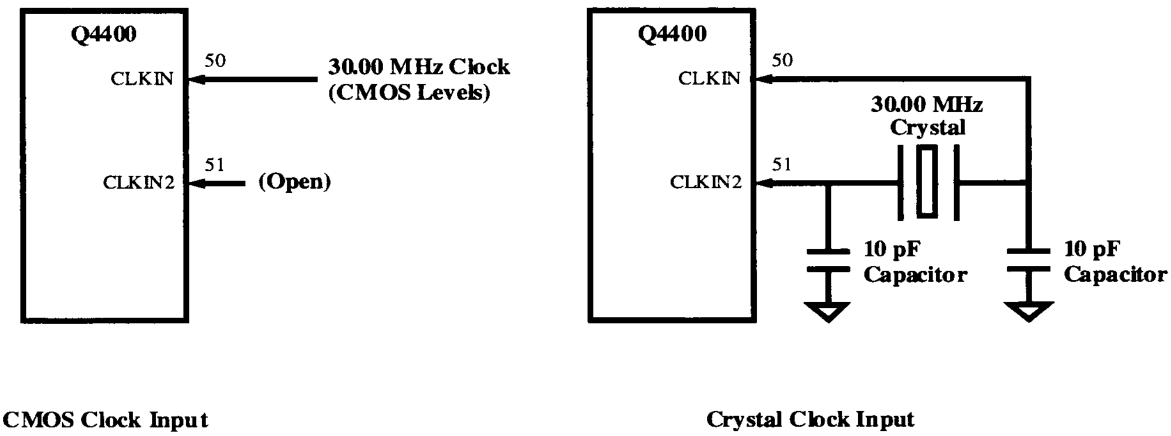


Figure 9. Clock Input Configuration

VRS

The VRS is used to set the 20 ms frame timing for the Encoder and Decoder. This signal is used by the Q4400 vocoder to synchronize the transmission and reception of coded speech data to and from the processor. The Encoder and Decoder frame timing is derived independently from the VRS input. This input can be a single active-high pulse occurring one time after the "Initialize" command has been issued or after a continuous stream of pulses spaced 20 ms apart. The pulse must be high for at least 2 µs, but no more than 50 µs. The VRS signal must be asserted each time that the Q4400 vocoder has been reset or has been reconfigured by the "Initialize" command. The VRS function can also be performed by issuing the "Software VRS" command after the "Initialize" command has been issued.

CLKOUT

The CLKOUT signal is a buffered version of the CLKIN signal (i.e., 30 MHz). This output can be used to clock other devices in the system.

PCM Interface

Figure 5 shows the Q4400 vocoder interface to the PCM Codec via the serial PCM Interface. The input samples from the Codec to the PCM Interface control the timing of the Q4400 vocoder. A frame is encoded every 160 PCM input samples or 20 ms. The TXD and RXD signals are the data lines in and out of the Q4400 vocoder. The TXSTB and RXSTB signals are used to gate the data in and out of the Q4400 vocoder. The TXCLK and RXCLK signals are used to clock the data in and out of the Q4400 vocoder. The TXBF and RXBE are optional signals for transferring data to and from the Q4400 vocoder without a PCM codec device.

TXD and RXD

TXD and RXD are the serial data input and serial data output signals. The Q4400 vocoder sends and receives serial PCM data to and from the PCM Codec. The serial data word length is 8 bits, with the MSB transmitted first and the LSB transmitted last.

TXCLK and RXCLK

The rising edge of the TXCLK input is used to clock each of the eight TXD serial data bits from the PCM codec into the Q4400 vocoder. This clocking operation is enabled by the TXSTB input. Likewise, the rising edge of the RXCLK input is used to clock each of the 8 RXD serial data bits out of the Q4400 vocoder. This clocking operation is enabled by the RXSTB input. In applications where the input and output timing are synchronous, the TXCLK and RXCLK signals can be connected, and the TXSTB and RXSTB signals can be connected. The frequency of the TXCLK and RXCLK can be from 64 kHz to 15 MHz. The Tx timing and Rx timing between the Q4400 vocoder and the codec are shown in figure 10.

TXSTB and RXSTB

The TXSTB and RXSTB inputs are used to enable the clocking of PCM samples into or out of the Q4400 vocoder respectively. These active low inputs must be supplied at an 8 kHz (125 μs) rate to clock PCM data into or out of the Q4400 vocoder. The TXSTB and RXSTB inputs can pulse low for one bit period or pulse low for up to the entire 8-bit transfer. For more information, see PCM Tx Timing and PCM Rx Timing under the "Timing Characteristics" section.

TXBF and RXBE

The optional TXBF and RXBE output signals are used when transferring PCM data to and from the Q4400 vocoder without a PCM codec. The TXBF output indicates whether or not the Q4400 vocoder PCM input buffer is full. Data input to the PCM input buffer when it is full will be lost. The RXBE output indicates whether or not the Q4400 vocoder PCM output buffer is empty. There are several applications where these signals can be used. One such application might be in a system where digitized PCM speech samples are stored in memory and a processor is used to transfer the samples to the Q4400 vocoder PCM Interface. These two handshake signals may be monitored by the processor to speed up the data transfer and minimize external circuitry. The Strobes and Clocks are still required by the Q4400 vocoder for proper data transfer but can be generated by the processor.

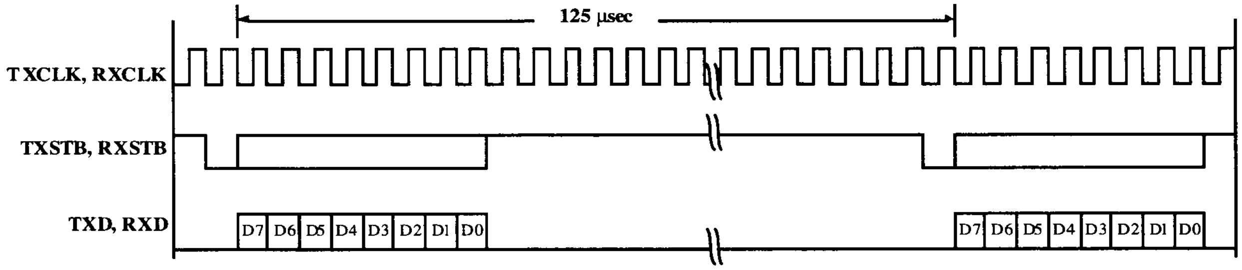


Figure 10. Tx and Rx PCM Timing

Processor Interface

The Q4400 vocoder communicates with the processor via the 8-bit parallel processor interface shown in figure 8. All communication to and from the Q4400 vocoder must be initiated by the processor, since the Q4400 vocoder acts as a slave to the processor. Consequently, the packets sent by the processor to the Q4400 vocoder are called command packets. Packets sent by the Q4400 vocoder to the processor are called response packets. This section also contains a description of the Frame Timing, the data transfer between the Q4400 vocoder and the processor, the Tx and Rx Frame data bit definition, and the Read and Write protocol.

RD/ and WR/

The Read and Write inputs are active-low signals driven by the processor. When the RD/ signal goes low the Q4400 vocoder will place one byte (8 bits) of the response register contents on the processor data bus. The rising edge of the WR/ signal is used to latch data from the processor into the Q4400 vocoder.

D0 to D7

The Processor Data Bus is an 8-bit wide parallel bi-directional bus. Command and response information is transferred between the Q4400 vocoder and Processor using this bus.

Frame Timing

Transmission and reception of packets of compressed speech to and from the processor occur independently. The Tx Offset and Rx Offset parameters are used by the Q4400 vocoder to configure its internal timing with the timing of the "Tx Frame" and "Rx Frame" commands from the processor. Upon reset of the Q4400 vocoder, the processor provides the Tx Offset and Rx Offset parameters (in units of PCM samples) from the VRS via the "Initialize" command as shown in figure 11.

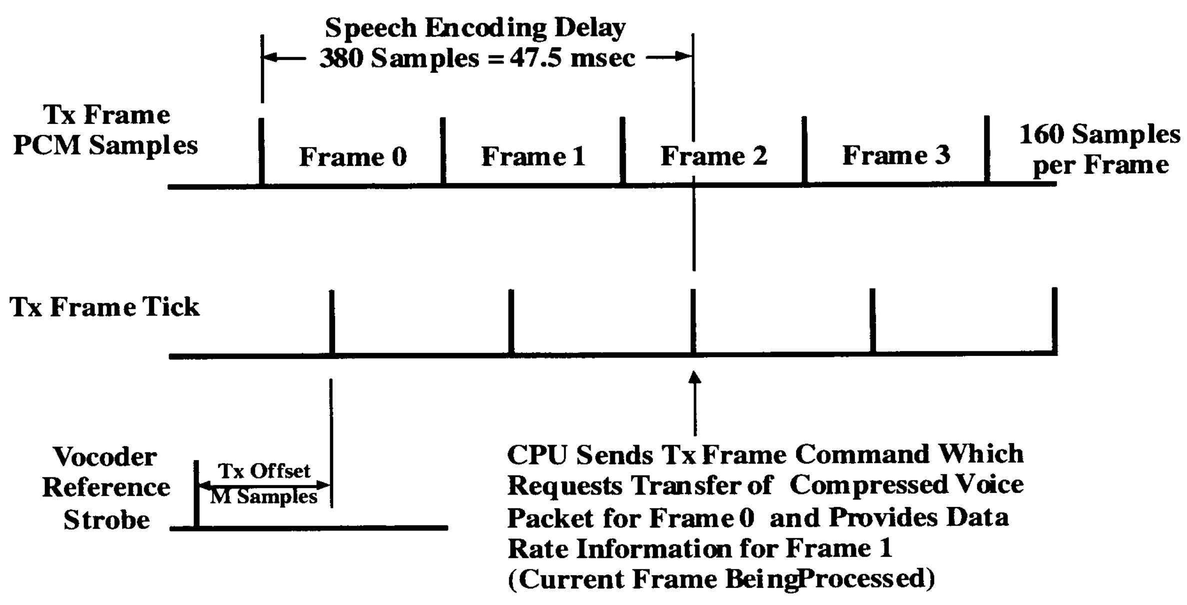


Figure 11. Frame Timing and Encoding Delay

There are typically only two commands transferred between the processor and the Q4400 vocoder during each 20 ms frame. Due to double buffering of the Tx and Rx Frame data, the processor may send the Rx Frame data, via the "Rx Frame" command, to the Q4400 vocoder any time within a 19 ms window before the Rx Frame Tick. Similarly, the processor may obtain Tx Frame data via the "Tx Frame" command from the Q4400 vocoder any time within a 19 ms window after the Tx Frame Tick as shown in figure 12.

The "Tx Frame" command also contains the data rate parameters for the next frame. If the data rate must change for the current frame being processed, then the "Tx Frame" command must be issued within the first 1 ms after the Tx Frame Tick. If the 1 ms window is missed, then the new data rate limits will not take effect until the next frame. If the data rate for the current frame must change and the "Tx Frame" command cannot be issued within the 1 ms window, then the "Tx Frame Rate Only" command may be issued. This command is simple to issue within the 1 ms window since there is no data transferred and minimal additional processing required during this period.

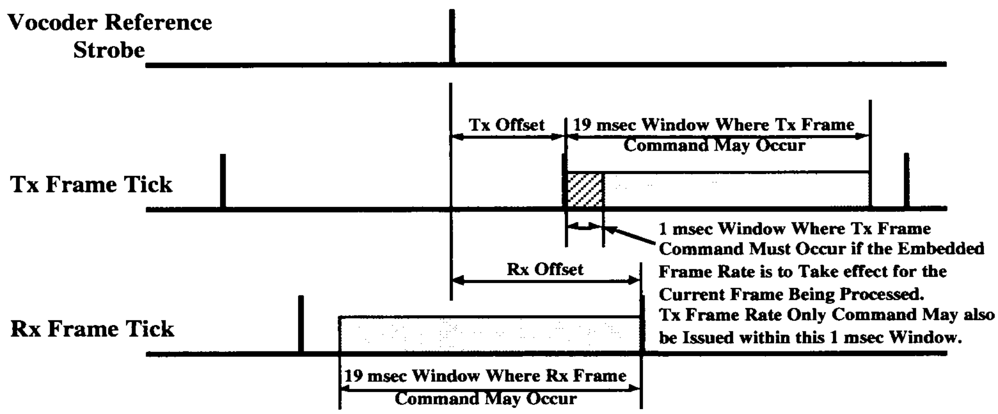


Figure 12. Tx and Rx Frame Timing

Q4400 Vocoder and Processor Data Transfer

Data transfer between the Q4400 vocoder and the processor is always initiated by sending a Command packet from the processor to the Q4400 vocoder. The processor will always read a Response packet from the Q4400 vocoder after a Command packet has been sent. The Command packet always consists of a length byte, followed by a command byte, the associated data bytes (if any), and a checksum byte. Figure 13 shows the format of the Command packet. The checksum byte is calculated as the binary sum of bytes 0 through n-1 with the carry bits added back in. For example, if the sum of bytes 0 through n-1 equaled 5BA (hex), then 5 would be added to BA (hex) to equal a checksum of BF (hex).

Byte 0	Length = n
Byte 1	Command
Byte 2 • • •	Data (Optional)
Byte n	Checksum

Figure 13. Command Packet Format

The Command packets from the processor are always acknowledged by the Q4400 vocoder using Response packets. Response packets always contain two bytes that verify the command was received correctly. First, the Q4400 vocoder indicates whether the packet was received with a good checksum in the form of an Acknowledge (ACK - 0A hex) or Not Acknowledged (NACK - 05 hex). Second, the Q4400 vocoder indicates that it understands and is carrying out the commanded function by echoing the command back to the processor. Following the command echo are the associated data bytes (if any) and then a checksum byte. The checksum byte is computed in the same manner as the checksum byte in the Command packet. Figure 14 shows the format of the Response packet.

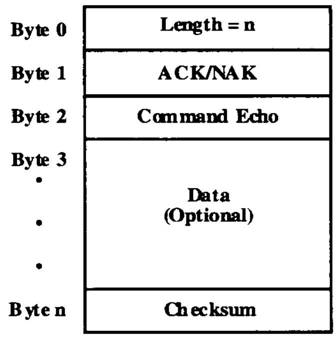


Figure 14. Response Packet Format

The processor initiates communication by only writing the length byte of a command packet to the Q4400 vocoder. The processor then polls (continuously reads) the Q4400 vocoder until it signals that it is ready to receive the remaining bytes of the Command packet. Writing the length byte orders the Q4400 vocoder to prepare to receive a Command packet that is n-bytes long. The Q4400 vocoder needs up to 27 µs to get ready to receive the rest of the Command packet. During this waiting period, the Q4400 vocoder provides a "Not Ready" (00 hex) indication when the processor reads the Q4400 vocoder. After the length byte is written, the processor must continue to poll the Q4400 vocoder until the status byte changes from "Not Ready" (00 hex) to "Write Ready" (FF hex). This is an indication to the processor that all the remaining bytes of the Command packet can now be written to the Q4400 vocoder. After the remaining Command packet bytes have been written, the Q4400 vocoder needs up to 27 µs to process this data and compose a Response packet. During this waiting period, the Q4400 vocoder provides a "Not Ready" (00 hex) indication when the processor reads the Q4400 vocoder. After the Command packet is written, the processor must continue to poll the Q4400 vocoder until the status byte changes from "Not Ready" (00 hex) to "Read Ready" (55 hex). This is an indication to the processor that the Response packet bytes can be read from the Q4400 vocoder. After all the bytes of the Response packet have been read, the Q4400 vocoder provides a "Not Ready" indication until the length byte of the next command packet is written. The "Not Ready" indication is available for the processor to read upon power up and after each packet transfer. Table 1 defines the status bytes that the Q4400 vocoder provides to the processor. The latency of this protocol is described in the 'Read and Write Protocol" section below.

Table 1. Status Bytes to the Processor

Status	Meaning
00 Hex	Not Ready
55 Hex	Read Ready
FF Hex	Write Ready

Tx and Rx Frame Data Bit Definition

Packets of compressed speech data are transferred between the processor and Q4400 vocoder by the "Tx Frame" and "Rx Frame" commands. Although the number of valid compressed data bits varies based on the data rate, the data blocks exchanged between the Q4400 vocoder and the processor are fixed at 25 bytes for simplicity. One byte contains the encoded data rate information. The remaining 24 bytes contain a varying number of valid data bits based on the selected encoded data rate. Figure 15 illustrates the Tx and Rx Frame data bit map that the processor follows to extract useful data for transmitting or storing.

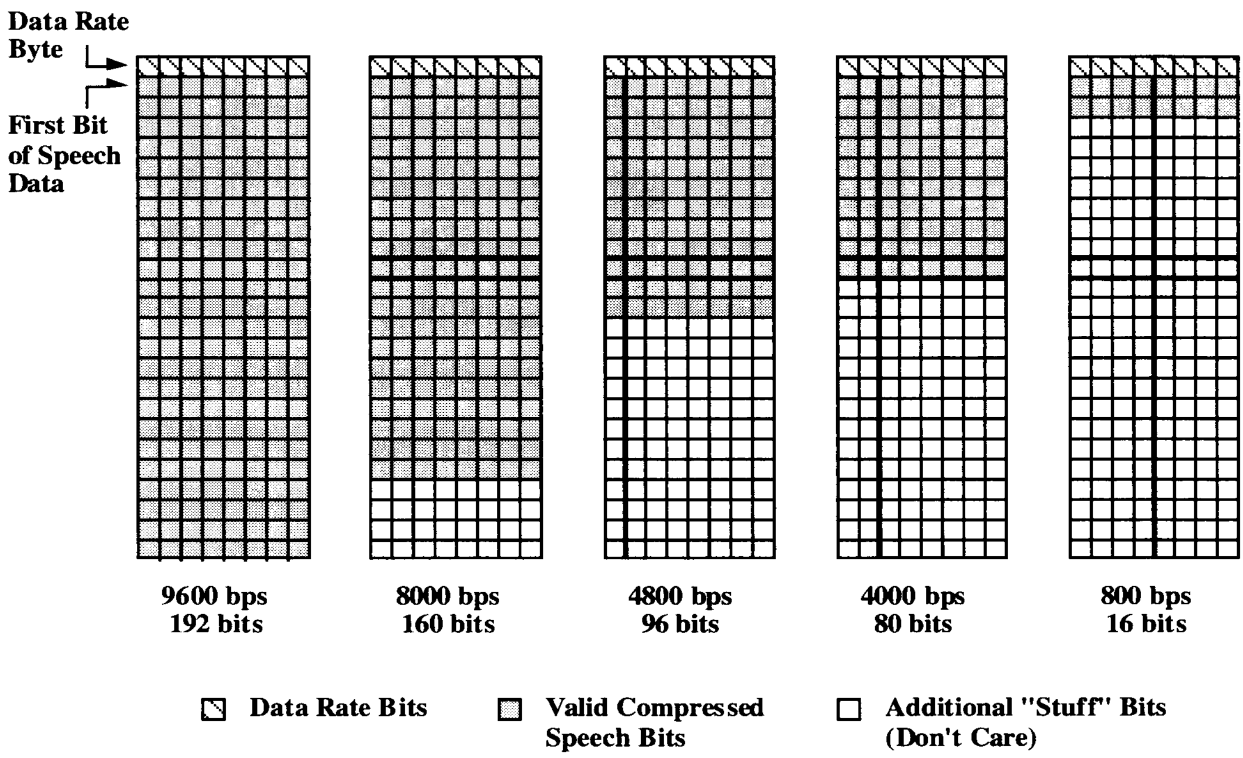


Figure 15. Tx and Rx Frame Data Bit Definition

Read and Write Protocol

The data transfer protocol between the Q4400 vocoder and the Processor is governed by the timing requirements stated in this section. Figure 16 shows a pictorial representation of the Read and Write timing requirements.

After the processor initiates a data transfer by writing the length byte of a command packet to the Q4400 vocoder, the Q4400 vocoder requires up to 27 µs to make a "Write Ready" byte available for the processor to read. During this time interval, the processor continuously reads the Q4400 vocoder status until the "Write Ready" appears. Therefore, the maximum time that it could take for the processor to read the "Write Ready" status is 27 µs + t_r (where t_r is the maximum time interval between successive processor read strobes). The minimum time interval between successive reads from the processor during this time is 0.67 µs. The time interval from a Q4400 vocoder "Write Ready" to a processor write must not exceed 27 µs. Once the processor detects the "Write Ready" status byte, it may consecutively write the remaining bytes in the Command packet with a maximum write rate of up to 0.67 µs per byte. A typical transfer rate is 3.0 µs. The entire write operation from the length byte to the checksum byte MUST NOT exceed 100 µs.

The same requirements hold true for transferring a Response packet from the Q4400 vocoder to the processor. After the checksum byte of the Command packet has been written to the Q4400 vocoder, the processor must continuously read (minimum time between successive reads is 0.67 µs) the Q4400 vocoder until a "Read Ready" appears. Therefore, the maximum time required for the processor to read the "Read Ready" status is 27 µs + t_r. The time interval from a Q4400 vocoder "Read Ready" to a processor read must not exceed 27 µs. Once the processor detects the "Read Ready" status byte, it may consecutively read all the bytes in the Response packet with a maximum read rate up to 0.67 µs per byte. The entire read operation from the length byte to the checksum byte MUST NOT exceed 100 µs.

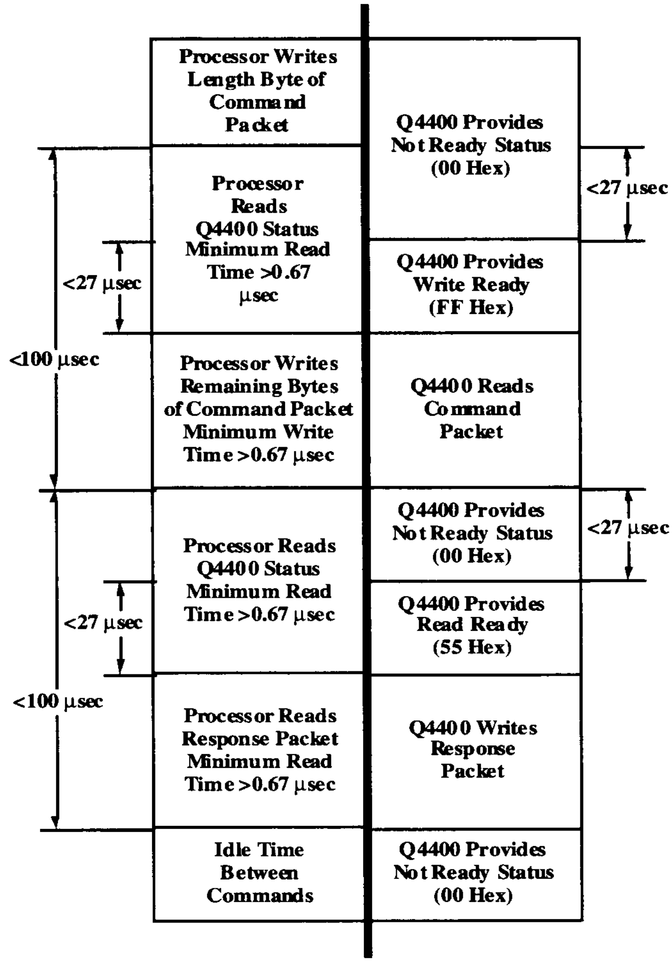


Figure 16. Packet Transfer Latency

After the initialization sequence is completed, the "Tx Frame" and "Rx Frame" commands are typically input to or output from the Q4400 vocoder to perform speech encoding and decoding. A "Tx Frame" command Write and Read timing example is shown in figure 17 and an "Rx Frame" command Write and Read timing example is shown in figure 18.

Tx Frame Command Packet

Byte 0 = 04	Four Bytes to Follow
Byte 1 = 01	Tx Frame Command
Byte 2 = 04	Highest Frame Rate Allowed
Byte 3 = 01	Lowest Frame Rate Allowed
Byte 4 = 0A	Checksum

Tx Frame Response Packet

Byte 0 = 1C	28 Bytes to Follow
Byte 1 = 0A	ACK
Byte 2 = 01	Tx Frame
Byte 3 = 04	Tx Frame Rate
Byte 4 to 01B = XX	Tx Frame Data
Byte 1C = XX	Checksum

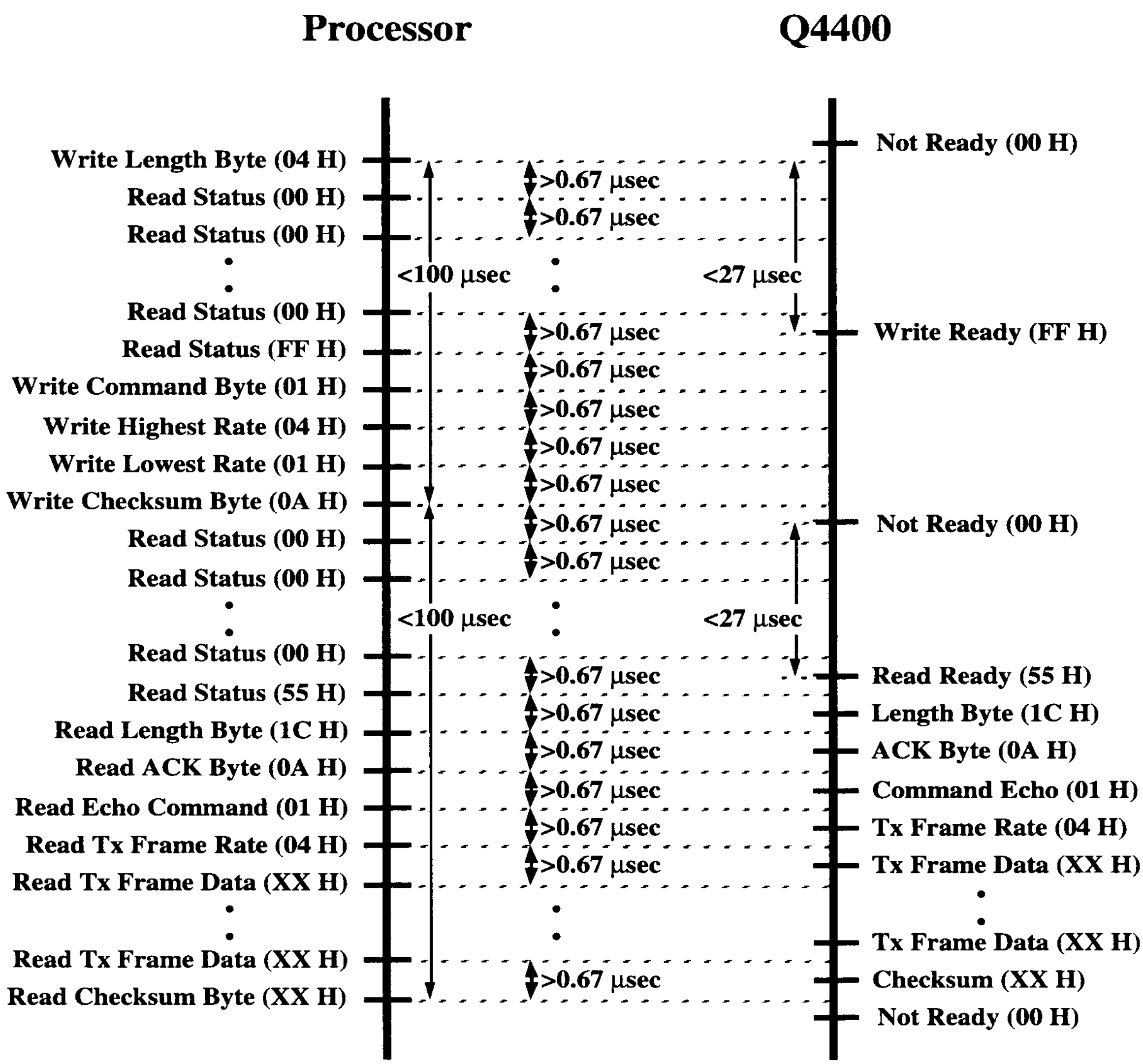


Figure 17. Tx Frame Command Timing Example

Rx Frame Command Packet	
Byte 0 = 1B	27 Bytes to Follow
Byte 1 = 02	Rx Frame Command
Byte 2 = 04	Rx Frame Rate
Byte 3 to 1A = XX	Rx Frame Data
Byte 1B = XX	Checksum

Rx Frame Response Packet	
Byte 0 = 03	3 Bytes to Follow
Byte 1 = 0A	ACK
Byte 2 = 02	Rx Frame
Byte 3 = 0F	Checksum

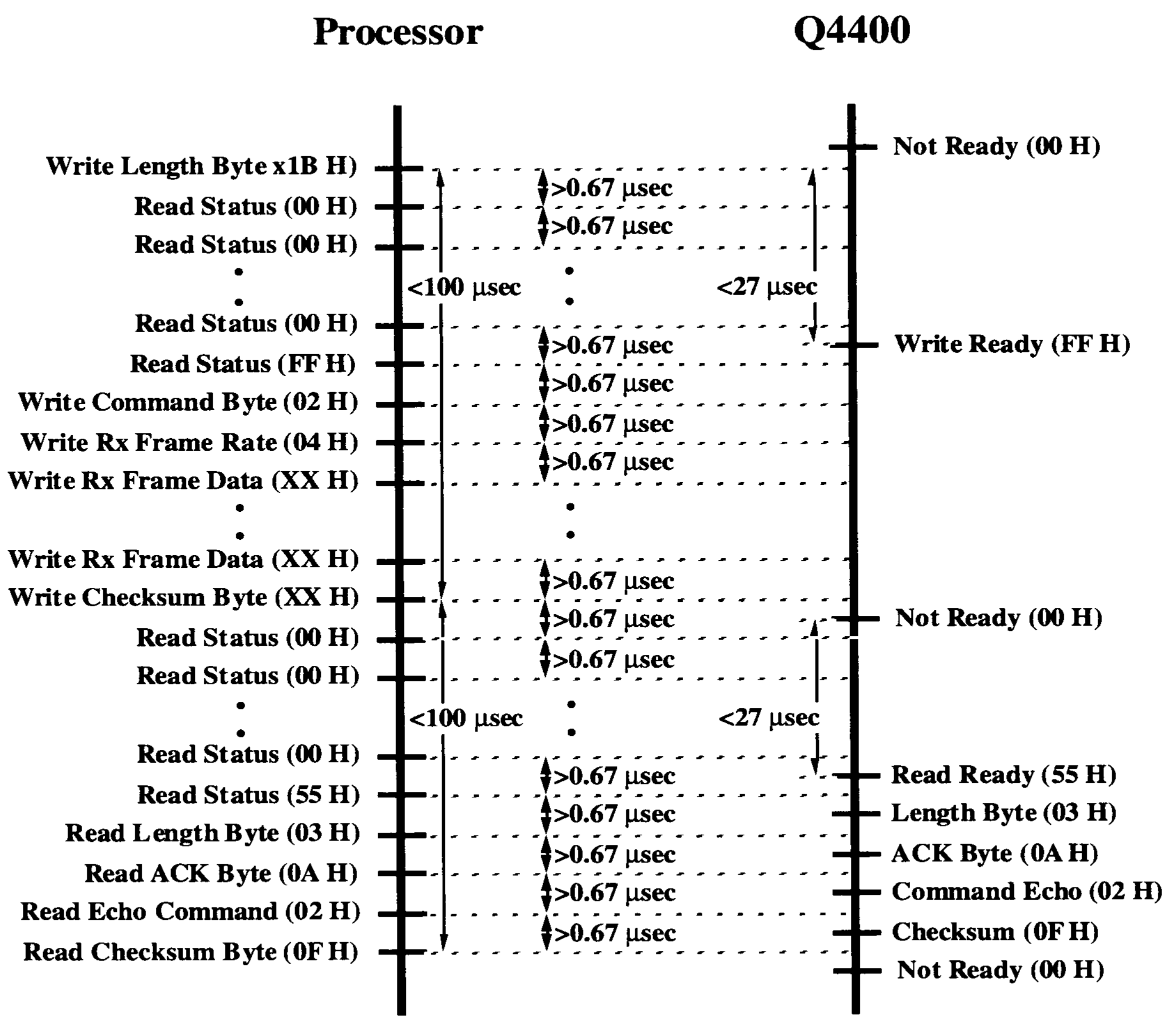


Figure 18. Rx Frame Command Timing Example

Q4400 VOCODER COMMANDS

Control of the Q4400 vocoder and data transfer to and from the processor is accomplished with a predefined command set and response set. This section describes each command and response to and from the Q4400 vocoder. Table 4 provides a summary list of the Q4400 vocoder commands and table 5 provides a summary of responses from the Q4400 vocoder. Data items that are required for each command are described within the angle brackets. Tables 6 through 22 describe the individual commands and responses.

Packet Transfer Error Conditions

If a Command packet is received with a bad checksum or if a time-out occurs during the data transfer, the NACK Response packet is sent to the processor as shown in Table 2. If a length byte of more than 31 is received, a "Write Ready" is sent to the processor, followed by a NACK Response packet.

Table 2. NACK Response Packet

Byte 0 = 02	Two bytes to follow
Byte 1 = 05	NACK
Byte 2 = 07	Checksum

If the command packet is received properly, but the Q4400 vocoder is unable to process this command (because of unknown commands or missing qualifiers), a "Bad Command" response is sent to the processor as shown in table 3.

Table 3. Bad Command Response Packet

Byte 0 = 03	Three bytes to follow
Byte 1 = 0A	ACK
Byte 2 = FF	Bad command received
Byte 3 = 0D	Checksum

Table 4. Q4400 Vocoder Commands

Command	# of Data Bytes	Command Name and Description
01	2	Q4400 to output a Tx frame <frame rate for next Tx frame>
02	25	Q4400 to input an Rx frame <frame rate, frame data>
03	2	Tx Frame Rate Only <frame rate for next frame>
04	0	Reserved (not used)
05	0	Reserved (not used)
06	0	Reinitialize Background Noise Estimate
07	1	Perform Diagnostic Test <type of test>
08	0	Software Reset (enter sleep mode)
09	11	Voice Operated Switch <VOX parameters>
0A	2	Initialize <Tx offset, Rx offset>
0B	2	Output Volume Control <output volume multiplier>
0C	0	Get Diagnostic Test Result
0D	8	Tone Generation <tone parameter>
0E	1	Input Muting <on or off>
0F	1	Output Muting <on or off>
10	2	Q4400 to output Tx frame with new Tx frame offset <frame rate for next Tx frame> New Tx Offset = Old Tx offset + 1 (Q4400 deletes an input sample.)
11	2	Q4400 to output Tx frame with new Tx frame offset <frame rate for next Tx frame> New Tx Offset = Old Tx offset - 1 (Q4400 repeats an input sample.)
12	25	Q4400 to input Rx frame with new Rx frame offset <frame rate, Rx frame data> New Rx Offset = Old Rx offset + 1 (Q4400 repeats an output sample.)
13	25	Q4400 to input Rx frame with new Rx frame offset <frame rate, Rx frame data> New Rx Offset = Old Rx offset - 1 (Q4400 deletes an output sample.)
14	2	Average Rate Limit <rate limit flag, rate limit factor>
15	1	Audio Loopback <on or off>
16	1	Packet Loopback <on or off>
17	0	Software Reference Strobe (VRS)

Table 5. Q4400 Vocoder Responses

Command Echo	# of Data Bytes	Response Name and Description
01	25	Q4400 Tx frame <rate, Tx frame data>
02	00	Q4400 received Rx frame data
03	00	Tx Frame Rate Only command received
04	0	Reserved (not used)
05	0	Reserved (not used)
06	0	Background Noise Estimate Reinitialized
07	10	Perform Diagnostic Test Received <firmware version #, time, date>
08	0	Software Reset (enter sleep mode command received)
09	0	Voice Operated Switch command received
0A	0	Initialize Q4400 command received
0B	0	Output Volume Control command received
0C	1	Return Diagnostic Test Result <diagnostic test result>
0D	0	Tone Generation command received
0E	0	Input Muting command received
0F	0	Output Muting command received
10	25	Q4400 Tx frame with new Tx frame offset <Rate, Tx frame data> New Tx Offset = Old Tx offset + 1 (Q4400 deletes an input sample.)
11	25	Q4400 Tx frame with new Tx frame offset <rate, Tx frame data> New Tx Offset = Old Tx offset - 1 (Q4400 repeats an input sample.)
12	0	Q4400 received Rx frame data with new Rx frame offset New Rx Offset = Old Rx offset + 1 (Q4400 repeats an output sample.)
13	0	Q4400 received Rx frame data with new Rx frame offset New Rx Offset = Old Rx offset - 1 (Q4400 deletes an output sample.)
14	2	Average Rate Limit command received
15	0	Audio Loopback command received
16	0	Packet Loopback command received
17	0	Software Reference Strobe (VRS) command received
FF	0	Bad Command Received

Tx Frame Command

Command: 01 (hex)

Function: Transfers one packet of compressed speech data from the Q4400 vocoder to the processor

Number of data bytes: Command Packet = 2
Response Packet = 25

This command orders the Q4400 vocoder to transfer a packet of compressed speech data to the processor. The response packet from the Q4400 vocoder contains the compressed speech data for the current frame along with a byte containing the specific data rate for the frame. Table 6a and 6b show the Tx Frame command and response Packet structures.

The highest and lowest allowable data rates for the next frame to be processed are also embedded in this command. It is with these data rate parameters that the Fixed Rate, Normal Variable Rate, or Enhanced Variable Rate mode is selected. If one of the Fixed Rate modes is desired, the highest data rate and lowest data rate bytes will contain the same selection. (Valid Fixed Rate selections are 4000, 4800, 8000, 9600 bps and Blanked.) The Blanked selection will cause a "Tx Frame" response packet to be transferred with no valid data. This is typically used when a system control packet must be transmitted over the channel in place of a compressed speech data packet. This is required to keep the Q4400 vocoders at both ends to stay. (Note: The receive side must send the Q4400 vocoder a Blanked selection, versus an Erased selection, upon receiving a system control update. The Normal Variable Rate mode is enabled by selecting 800 bps for the lowest data rate and 8000 bps for the highest data rate. (Valid Normal Variable Rate selections are 800 and 8000 bps, 800 and 4000 bps, or 4000 and 8000 bps.) The Enhanced Variable Rate mode is enabled by selecting 800 bps for the lowest data rate and 9600 bps for the highest data rate. (Valid Enhanced Variable Rate selections are 800 and 9600 bps, 800 and 4800 bps, or 4800 and 9600 bps.)

This command may be issued any time within the 19 ms window after the Tx Frame Tick. The data rates in this command affect the next 20 ms frame. If new data rates need to be applied to the current frame in process, this command must be issued within a 1 ms window after the Tx Frame Tick. The most recent command up to the 1 ms Tx Frame Tick is used. This is described in the "Operational Interface" section.

Table 6a. Tx Frame Command Structure

Byte #	Value								Description
0	0	0	0	0	0	1	0	0	Four bytes to follow (04 hex)
1	0	0	0	0	0	0	0	1	Tx Frame command
2	0	0	0	0	N	N	N	N	N = highest data rate
3	0	0	0	0	M	M	M	M	M = lowest data rate
4	C	C	C	C	C	C	C	C	C = 8-bit checksum

Table 6b. Tx Frame Response Structure

Byte #	Value								Description
0	0	0	0	1	1	1	0	0	28 bytes to follow (1C hex)
1	0	0	0	0	1	0	1	0	ACK
2	0	0	0	0	0	0	0	1	Tx Frame response
3	0	0	0	0	F	F	F	F	F = data rate
4 to 1B	X	X	X	X	X	X	X	X	X = Tx Frame data
1C	C	C	C	C	C	C	C	C	C = 8-bit checksum

Data Rate Definition:

00 (hex)	Blanked
01 (hex)	800 Bps
03 (hex)	4000 Bps
04 (hex)	8000 Bps
0B (hex)	4800 Bps
0C (hex)	9600 Bps

Note: the response packet length will not change for frames that are not full rate. Instead, the unused bytes will contain invalid data.

Rx Frame Command

Command: 02 (hex)

Function: Transfers one packet of compressed speech data from the processor to the Q4400 vocoder

Number of data bytes: Command Packet = 25
Response Packet = 0

This command orders the Q4400 vocoder to receive a compressed packet of speech data from the processor. The data rate for the packet is also included in this packet. An "Erase" indication is caused by transmission errors and should not occur in an error-free environment. However, in an environment where errors are present, the processor should determine when a transmission error occurs within a packet and then issue the "Erase" selection. The Q4400 vocoder provides error masking for erased frames. The "Blanked" selection is discussed in the "Tx Frame" command section. Tables 7a and 7b show the "Rx Frame" command and response structures. The response from the Q4400 vocoder acknowledges that the command was properly received. This command may be issued any time within a 19 ms window before the Rx Frame Tick.

Table 7a. Rx Frame Command Structure

Byte #	Value								Description
0	0	0	0	1	1	0	1	1	27 bytes to follow (1B hex)
1	0	0	0	0	0	0	1	0	Rx Frame command
2	0	0	0	0	F	F	F	F	F = data rate
3 to 1A	X	X	X	X	X	X	X	X	X = Rx Frame data
1B	C	C	C	C	C	C	C	C	C = 8-bit checksum

Table 7b. Rx Frame Response Structure

Byte #	Value								Description
0	0	0	0	0	0	0	1	1	3 bytes to follow (03 hex)
1	0	0	0	0	1	0	1	0	ACK
2	0	0	0	0	0	0	1	0	Rx Frame response
3	0	0	0	0	1	1	1	1	8-bit checksum (0F hex)

Data Rate Definition:

00 (hex)	Blanked
01 (hex)	800 Bps
03 (hex)	4000 Bps
04 (hex)	8000 Bps
0B (hex)	4800 Bps
0C (hex)	9600 Bps
0E (hex)	Erasure

Tx Frame Rate Only Command

Command: 03 (hex)

Function: Uses the specified range of data rates for the current frame being processed

Number of data bytes: Command Packet = 2
Response Packet = 0

This command changes the data rate parameters of the encoder without transferring data. This command is used when the data rate for the current frame must change and a "Tx Frame" command cannot be issued within the required 1 ms window after the Tx Frame Tick. The "Tx Frame Rate Only" command must be issued within the 1 ms window after the Tx Frame Tick in order for the new data rate ranges to take affect on the current frame. Tables 8a and 8b show the "Tx Frame Rate Only" command and response structures. The response packet from the Q4400 vocoder acknowledges that the command was properly received.

Table 8a. Tx Frame Rate Only Command Structure

Byte #	Value								Description
0	0	0	0	0	0	1	0	0	4 bytes to follow (04 hex)
1	0	0	0	0	0	0	1	1	Tx Frame Rate Only command
2	0	0	0	0	N	N	N	N	N = highest data rate
3	0	0	0	0	M	M	M	M	M = lowest data rate
4	C	C	C	C	C	C	C	C	C = 8-bit checksum

Table 8b. Tx Frame Rate Only Response Structure

Byte #	Value								Description
0	0	0	0	0	0	0	1	1	3 bytes to follow (03 hex)
1	0	0	0	0	1	0	1	0	ACK
2	0	0	0	0	0	0	1	1	Tx Frame Rate Only response
3	0	0	0	1	0	0	0	0	8-bit checksum (10 hex)

Data Rate Definition:

00 (hex)	Blanked
01 (hex)	800 Bps
03 (hex)	4000 Bps
04 (hex)	8000 Bps
0B (hex)	4800 Bps
0C (hex)	9600 Bps

Reinitialize Background Noise Estimate

Command: 06 (hex)

Function: Reinitializes the Q4400 vocoder background noise estimate

Number of data bytes: Command Packet = 0
Response Packet = 0

This command reinitializes the background noise estimate to optimize the data rate thresholds in the encoder. This command is typically issued at the onset of valid PCM input data to the Q4400 vocoder. This feature is described in the "Speech Encoding and Decoding" section. Tables 9a and 9b show the "Background Noise Estimate" command and response structures. The response packet from the Q4400 vocoder acknowledges that the command was properly received.

Table 9. Reinitialize Background Noise Estimate Command Structure

Byte #	Value								Description
0	0	0	0	0	0	0	1	0	2 bytes to follow (02 hex)
1	0	0	0	0	0	1	1	0	Reinit Bkgnd Noise Est command
2	0	0	0	0	1	0	0	0	08-bit checksum (08)

Reinitialize Background Noise Estimate Response Structure

Byte #	Value								Description
0	0	0	0	0	0	0	1	1	3 bytes to follow (03 hex)
1	0	0	0	0	1	0	1	0	ACK
2	0	0	0	0	0	1	1	0	Reinit Bkgnd Noise Est response
3	0	0	0	1	0	0	1	1	8-bit checksum (13 hex)

Diagnostic Test Command

Command: 07 (hex)

Function: Perform Q4400 vocoder self diagnostics

Number of data bytes: Command Packet = 1
Response Packet = 10

This command performs an ALU test and a RAM test on the Q4400 vocoder. Each tests is selectable by setting the associated bit in the data word to a 1 as shown in tables 10a and 10b. The Q4400 vocoder will enter the Sleep mode after completion of these diagnostic tests.

The response packet from the Q4400 vocoder acknowledges that the command was properly received along with the Firmware version and time. (Note: This response does not contain the Diagnostic test results. The Diagnostic test results will come from the "Get Diagnostic Test Results" command.) Tables 10a and 10b show the "Diagnostic Test" command and response structures.

Table 10a. Diagnostic Test Command Structure

Byte #	Value								Description
0	0	0	0	0	0	0	1	1	3 bytes to follow (03 hex)
1	0	0	0	0	0	1	1	1	Diagnostic Test command
2	0	0	0	0	0	M1	M2	0	Type of tests. M1 = ALU, M2 = RAM
3	C	C	C	C	C	C	C	C	C = 8-bit checksum

Table 10b. Diagnostic Test Response Structure

Byte #	Value								Description
0	0	0	0	0	1	1	0	1	13 bytes to follow (0D hex)
1	0	0	0	0	1	0	1	0	ACK
2	0	0	0	0	0	1	1	1	Diagnostic Test response
3	X	X	X	X	X	X	X	X	Firmware version (major rev #)
4	X	X	X	X	X	X	X	X	Firmware version (minor rev #)
5 to 7	X	X	X	X	X	X	X	X	Time (minutes after 00:00 Jan. 6,1980
8 to 0C	0	0	0	0	0	0	0	0	Reserved bytes (all 5 bytes = 00 hex)
0D	C	C	C	C	C	C	C	C	C = 8-bit checksum

Sleep Mode Command

Command: 08 (hex)

Function: Enters Q4400 vocoder Sleep mode

Number of data bytes: Command Packet = 0
Response Packet = 0

This command orders the Q4400 vocoder to perform a software reset, enter sleep mode, and then wait for an "Initialize" command from the processor. Sleep mode may be entered to conserve power when there is no requirement for speech compression. Tables 11a and 11b show the "Sleep Mode" command and response structures. The response packet from the Q4400 vocoder acknowledges that the command was properly received.

Table 11a. Sleep Mode Command Structure

Byte #	Value								Description
0	0	0	0	0	0	0	1	0	2 bytes to follow (02 hex)
1	0	0	0	0	1	0	0	0	Sleep Mode command
2	0	0	0	0	1	0	1	0	8-bit checksum (0A)

Table 11b. Sleep Mode Response Structure

Byte #	Value								Description
0	0	0	0	0	0	0	1	1	3 bytes to follow (03 hex)
1	0	0	0	0	1	0	1	0	ACK
2	0	0	0	0	1	0	0	0	Sleep Mode response
3	0	0	0	1	0	1	0	1	8-bit checksum (15 hex)

VOX Command

Command: 09 (hex)

Function: Enables or Disable the VOX function

Number of data bytes: Command Packet = 11
Response Packet = 0

This command enables or disables the VOX function and configures the VOX parameters. The VOX function is enabled when hands free telephone operation is required. The VOX feature is described in the "Operational Modes" section. Tables 12a and 12b show the "VOX" command and response structures. The response packet from the Q4400 vocoder acknowledges that the command was properly received.

Table 12a. VOX Command Structure

Byte #	Value								Description
0	0	0	0	0	1	1	0	1	13 bytes to follow (0D hex)
1	0	0	0	0	1	0	0	1	VOX Mode command
2	0	0	0	0	0	0	0	X	X = VOX ena or disa 1 = ena 00 = disa
3	X	X	X	X	X	X	X	X	Energy decay factor MS byte
4	X	X	X	X	X	X	X	X	Energy decay factor LS byte
5	X	X	X	X	X	X	X	X	Background noise decay factor MS byte
6	X	X	X	X	X	X	X	X	Background noise decay factor LS byte
7	X	X	X	X	X	X	X	X	Decoder noise MS byte
8	X	X	X	X	X	X	X	X	Decoder background noise LS byte
9	X	X	X	X	X	X	X	X	Decoder VOX threshold MS byte
A	X	X	X	X	X	X	X	X	Decoder VOX threshold LS byte
B	X	X	X	X	X	X	X	X	Encoder weighting factor MS byte
C	X	X	X	X	X	X	X	X	Encoder weighting factor LS byte
D	C	C	C	C	C	C	C	C	C = 8-bit checksum

Table 12b. VOX Response Structure

Byte #	Value								Description
0	0	0	0	0	0	0	1	1	3 bytes to follow (03 hex)
1	0	0	0	0	1	0	1	0	ACK
2	0	0	0	0	1	0	0	1	VOX Mode response
3	0	0	0	1	0	1	1	0	8-bit checksum (16 hex)

VOX Parameters:

Enable/Disable   0 = Disable   1 = Enable

Energy Decay Factor in Q14 <MS byte, LS byte>
Reasonable values are between 0.5 and 1.0
Typical value is 0.875 (2^{14} x 0.875 = 14336 => 3800 hex)
The Energy Decay Factor is used to keep the VOX mode from disabling the near-end speaker during pauses between words and syllables. This parameter allows the user to select the speech energy decay time.

Background Noise Decay Factor in Q14 <MS byte, LS byte>
Reasonable values are between 1.0 and 1.2
Typical value is 1.01 (2^{14} x 1.01 = 16548 => 40A4 hex)
This parameter determines how fast the background noise estimate is allowed to increase.

Decoder Background Noise Floor in Q2 <MS byte, LS byte>
Typical value is 40 (2^2 x 40 = 160 => 00A0 hex)
This parameter limits how low the decoder background noise is allowed to drop. VOX mode does not work efficiently if the decoder background noise goes below a certain level.

Decoder VOX Threshold in Q8 <MS byte, LS byte>
Typical value is 6dB (2^8 x 4.0 = 1024 => 0400 hex)
If the far-end speaker energy is less than 6 dB above the decoder's background noise, then there is no need for echo suppression, and the VOX mode stays in the Idle state.

Encoder Weighting Factor in Q8 <MS byte, LS byte>
Typical value is 0 (2^8 x 0 = 0 => 0000 hex)
The encoder's energy is weighted by this parameter to allow switching to be varied on the relative loudness of the two speakers. For typical conversations, it has been found that good performance is obtained by setting this parameter to zero so that the far-end speaker has complete priority. Setting this parameter to a fractional amount will allow the near-end speaker to interrupt the far-end speaker by speaking loudly. It is not recommended to set this parameter to values above one because parts of speech may be cut out due to noise in the environment.

Initialize Command

Command: 0A (hex)

Function: Sets the Tx Offset and Rx Offset and instructs the Q4400 vocoder to look for the VRS

Number of data bytes: Command Packet = 2
Response Packet = 0

This Initialize command sets the Q4400 vocoder Tx Offset and Rx Offset (Frame timing). The two data bytes specify the relative timing of the Tx Frame Tick and the Rx Frame Tick to the VRS. This command resets the memory inside the Q4400 vocoder. Therefore, this command should not be used a second time without ensuring that the Q4400 vocoder on the other end (if the application has one) is at the same reset state as well. Tables 13a and 13b show the "Initialize" command and response structures. The response packet from the Q4400 vocoder acknowledges that the command was properly received.

Table 13a. Initialize Command Structure

Byte #	Value								Description
0	0	0	0	0	0	1	0	0	4 bytes to follow (04 hex)
1	0	0	0	0	1	0	1	0	Initialize command
2	X	X	X	X	X	X	X	X	Tx Offset (0 to A0 (160 samples))
3	X	X	X	X	X	X	X	X	Rx Offset (0 to A0 (160 samples))
4	C	C	C	C	C	C	C	C	C = 8-bit checksum

Table 13b. Initialize Response Structure

Byte #	Value								Description
0	0	0	0	0	0	0	1	1	3 bytes to follow (03 hex)
1	0	0	0	0	1	0	1	0	ACK
2	0	0	0	0	1	0	1	0	Initialize response
3	0	0	0	1	0	1	1	1	8-bit checksum (17 hex)

Tx/Rx Offset Parameters:

Tx Offset - Sets the time from VRS to the Tx Frame Tick. This value represents the number of PCM samples (125 µs) from VRS to the Tx Frame Tick.

Rx Offset - Sets the time from VRS to the Rx Frame Tick. This value represents the number of PCM samples (125 µs) from VRS to the Rx Frame Tick.

Output Volume Control Command

Command: 0B (hex)

Function: Sets output volume

Number of data bytes: Command Packet = 2
Response Packet = 0

This command controls the Q4400 vocoder output volume. The volume control multiplier is in the linear domain. It consists of a 16-bit word with eight fractional bits (i.e., 0100 represents unity gain; 0200 is two times; and 0080 is 1/2). Tables 14a and 14b show the "Output Volume Control" command and response structures. The response packet from the Q4400 vocoder acknowledges that the command was properly received.

Table 14a. Output Volume Control Command Structure

Byte #	Value								Description
0	0	0	0	0	0	1	0	0	4 bytes to follow (04 hex)
1	0	0	0	0	1	0	1	1	Output Volume Control command
2	X	X	X	X	X	X	X	X	Output volume multiplier MS byte
3	X	X	X	X	X	X	X	X	Output volume multiplier LS byte
4	C	C	C	C	C	C	C	C	C = 8-bit checksum

Table 14b. Output Volume Control Response Structure

Byte #	Value								Description
0	0	0	0	0	0	0	1	1	3 bytes to follow (03 hex)
1	0	0	0	0	1	0	1	0	ACK
2	0	0	0	0	1	0	1	1	Output Volume Control response
3	0	0	0	1	1	0	0	0	8-bit checksum (18 hex)

Control Parameters: 16-bit volume control multiplier word

Test Result Command

Command: 0C (hex)

Function: Transfers diagnostic test results from the Q4400 vocoder to the processor

Number of data bytes: Command Packet = 0
Response Packet = 1

This command sends the diagnostic test result to the processor. The test result byte provided in the response packet contains a bit indicating that the test result is ready and 3 bits indicating the results of the two tests (RAM, and ALU). Each bit is set to one if the test passed and zero if the test failed. Tables 15a and 15b show the "Test Result" command and response structures.

Table 15a. Test Result Command Structure

Byte #	Value								Description
0	0	0	0	0	0	0	1	0	2 bytes to follow (02 hex)
1	0	0	0	0	1	1	0	0	Test Result command
2	0	0	0	0	1	1	1	0	8-bit checksum (0E hex)

Table 15b. Test Result Response Structure

Byte #	Value								Description
0	0	0	0	0	0	1	0	0	4 bytes to follow (04 hex)
1	0	0	0	0	1	0	1	0	ACK
2	0	0	0	0	1	1	0	0	Test Result response
3	R	0	0	0	0	M1	M2	0	Test result R = result ready (1= ready) M1 = ALU, M2 = RAM (1= passed)
4	C	C	C	C	C	C	C	C	C = 8-bit checksum

Tone Generation Command

Command: 0D (hex)

Function: Performs tone generation.

Number of data bytes: Command Packet = 8
Response Packet = 0

This command enables or disables and configures the tone generation feature of the Q4400 vocoder. Single tones or DTMF tones may be generated by providing the frequency, volume, and duration parameters. The Q4400 vocoder continues operating during tone generation; thus, received packets must continue to be passed to the Q4400 vocoder even though tone generation overrides voice output. The Q4400 vocoder must receive the "Initialize" command before tone generation can occur. Sending this command a second time with new frequencies while tones are being generated will cause all parameters to be overwritten and an instantaneous change in output frequency will occur. However, sending this command again with the same frequencies results in no change in phase of the output tones. This allows the duration to be extended by sending multiple commands. Tables 16a and 16b show the "Tone Generation" command and response structures. The response packet from the Q4400 vocoder acknowledges that the command was properly received.

Table 16a. Tone Generation Command Structure

Byte #	Value								Description
0	0	0	0	0	1	0	1	0	10 bytes to follow (0A hex)
1	0	0	0	0	1	1	0	1	Tone Generation command
2	X	X	X	X	X	X	X	X	F1 tone MS byte
3	X	X	X	X	X	X	X	X	F1 tone LS byte
4	X	X	X	X	X	X	X	X	F2 tone MS byte
5	X	X	X	X	X	X	X	X	F2 tone LS byte
6	X	X	X	X	X	X	X	X	Volume tone MS byte
7	X	X	X	X	X	X	X	X	Volume LS byte
8	X	X	X	X	X	X	X	X	Duration MS byte
9	X	X	X	X	X	X	X	X	Duration LS byte
A	C	C	C	C	C	C	C	C	C = 8-bit checksum

Table 16b. Tone Generation Response Structure

Byte #	Value								Description
0	0	0	0	0	0	0	1	1	3 bytes to follow (03 hex)
1	0	0	0	0	1	0	1	0	ACK
2	0	0	0	0	1	1	0	1	Tone Generation response
3	0	0	0	1	1	0	1	0	8-bit checksum (1A hex)

Tone Generation Parameters:

First tone (F1) <MS byte, LS byte>
Expressed as 32768 x $\cos \pi F1/4000$

Second tone (F2) <MS byte, LS byte>
Expressed as 32768 x $\cos \pi F2/4000$

Volume <MS byte, LS byte>
7FFF is full scale of a μ-law codec.

Duration <MS Byte, LS Byte>
Duration of the tones in 5 ms increments is expressed as a negative number. For example, 20 ms is expressed as FFFC hex.

Input Muting Command

Command: 0E (hex)

Function: Enables or Disables Input Muting

Number of data bytes: Command Packet = 1
Response Packet = 0

This command enables or disables Input Muting feature of the Q4400 vocoder. Input muting causes "Comfort Noise" Tx packets to be encoded at 800 bps. Tables 17a and 17b show the "Input Muting" command and response structures. The response packet from the Q4400 vocoder acknowledges that the command was properly received.

Table 17a. Input Muting Command Structure

Byte #	Value								Description
0	0	0	0	0	0	0	1	1	3 bytes to follow (03 hex)
1	0	0	0	0	1	1	1	0	Test Result command
2	0	0	0	0	0	0	0	X	X = on = 1 off = 0
3	C	C	C	C	C	C	C	C	C = 8-bit checksum

Table 17b. Input Muting Response Structure

Byte #	Value								Description
0	0	0	0	0	0	0	1	1	3 bytes to follow (03 hex)
1	0	0	0	0	1	0	1	0	ACK
2	0	0	0	0	1	1	1	0	Input Muting response
3	0	0	0	1	1	0	1	1	8-bit checksum (1B hex)

Output Muting Command

Command: 0F (hex)

Function: Enables or Disables Output muting

Number of data bytes: Command Packet = 1
Response Packet = 0

This command enables or disables the Output Muting function of the Q4400 vocoder. Output muting consists of replacing the output samples with "Comfort Noise" at the estimated background noise level. It overrides voice outputs but not Tone Generation outputs. Tables 18a and 18b shows the "Output Muting" command and response structure. The response packet from the Q4400 vocoder acknowledges that the command was properly received.

Table 18a. Output Muting Command Structure

Byte #	Value								Description
0	0	0	0	0	0	0	1	1	3 bytes to follow (03 hex)
1	0	0	0	0	1	1	1	1	Test Result command
2	0	0	0	0	0	0	0	X	X = On = 1 Off = 0
3	C	C	C	C	C	C	C	C	C = 8-bit checksum

Table 18b. Output Muting Response Structure

Byte #	Value								Description
0	0	0	0	0	0	0	1	1	3 bytes to follow (03 hex)
1	0	0	0	0	1	0	1	0	ACK
2	0	0	0	0	1	1	1	1	Input Muting response
3	0	0	0	1	1	1	0	0	8-bit checksum (1C hex)

Advance Tx Frame +1 Command

Command: 10 (hex)

Function: Transfers one packet of compressed speech data from the Q4400 vocoder to the processor and advances Tx timing by 1 sample

Number of data bytes: Command Packet = 2
Response Packet = 25

This command orders the Q4400 vocoder to transfer a packet of compressed speech data to the processor while advancing the Tx Frame Tick by one sample. Otherwise, this command is identical to the "Tx Frame" command. Refer to the "Tx Frame" command in this section for additional information and for the command and response structures.

Slip Tx Frame -1 Command

Command: 11 (hex)

Function: Transfers one packet of compressed speech data from the Q4400 vocoder to the processor and slips Tx timing by 1 sample

Number of data bytes: Command Packet = 2
Response Packet = 25

This command orders the Q4400 vocoder to transfer a packet of compressed speech data to the processor while slipping the Tx Frame Tick by one sample. Otherwise, this command is identical to the "Tx Frame" command. Refer to the "Tx Frame" command in this section for additional information and for the command and response structures.

Advance Rx Frame +1 Command

Command: 12 (hex)

Function: Transfers one packet of compressed speech data from the processor to the Q4400 vocoder and advances Rx timing by 1 sample

Number of data bytes: Command Packet = 25
Response Packet = 0

This command orders the Q4400 vocoder to receive a packet of compressed speech data from the processor while advancing the Rx Frame Tick by one sample. Otherwise, his command is identical to the "Rx Frame" command. Refer to the "Rx Frame" command in this section for additional information and for the command and response structures.

Slip Rx Frame -1 Command

Command: 13 (hex)

Function: Transfers one packet of compressed speech data from the processor to the Q4400 vocoder and slips Rx timing by 1 sample

Number of data bytes: Command Packet = 25
Response Packet = 0

This command orders the Q4400 vocoder to receive a packet of compressed speech data from the processor while slipping the Rx Frame Tick by one sample. Otherwise, his command is identical to the "Rx Frame" command. Refer to the "Rx Frame" command in this section for additional information and for the command and response structures.

Average Rate Limit Command

Command: 14 (hex)

Function: Limit the average data rate of the Q4400 vocoder

Number of data bytes: Command Packet = 2
Response Packet = 0

This command limits the maximum average data rate of the Q4400 vocoder encoder. The average maximum limit is selectable between half and full rates. The average rate is programmed by selecting a rate factor value along with one of the Variable Rate modes of operation. For example, if "S" = 1 and Normal Variable Rate is selected, the average rate of 3/4 is equal to 6000 bps. If Enhanced Variable Rate is selected, the maximum average rate of 3/4 is equal to 7200 bps. If "S" = 1/2 (by setting bit 1 of the Rate Flag to 0 and the Rate Factor to 2), the maximum average rate is 2/3. Tables 19a and 19b show the "Average Rate Limit" command and response structures. The response packet from the Q4400 vocoder acknowledges that the command was properly received.

Table 19a. Average Rate Limit Command Structure

Byte #	Value								Description
0	0	0	0	0	0	1	0	0	4 bytes to follow (04 hex)
1	0	0	0	1	0	1	0	0	Average Rate Limit command
2	0	0	0	0	0	0	R1	R0	Rate limit flag (see below)
3	X	X	X	X	X	X	X	X	Rate limit factor (see below)
3	C	C	C	C	C	C	C	C	C = 8-bit checksum

Table 19b. Average Rate Limit Response Structure

Byte #	Value								Description
0	0	0	0	0	0	0	1	1	3 bytes to follow (03 hex)
1	0	0	0	0	1	0	1	0	ACK
2	0	0	0	1	0	1	0	0	Average Rate Limit response
3	0	0	1	0	0	0	0	1	8-bit checksum (21 hex)

Average Rate Limit Parameters:

Rate Limit Flag
Bit R0 1 = Enable Average Rate Limit
0 = Disable Average Rate Limit
Bit R1 1 = "S"= Rate limit factor
0 = "S"= 1/Rate limit factor

Rate Limit Factor
An 8-bit unsigned integer.
The maximum average rate of the Q4400 vocoder is equal to $(2S+1)/(2(S+1))$.

Audio Loopback Command

Command: 15 (hex)

Function: Enables Audio Loopback mode

Number of data bytes: Command Packet = 1
Response Packet = 0

This commands the Q4400 vocoder to loop back the PCM samples from the encoder's input to the decoder's output. Tables 20a and 20b show the "Audio Loopback" command and response structures. The response packet from the Q4400 vocoder acknowledges that the command was properly received.

Table 20a. Audio Loopback Command Structure

Byte #	Value								Description
0	0	0	0	0	0	0	1	1	3 bytes to follow (03 hex)
1	0	0	0	1	0	1	0	1	Audio Loopback command
2	0	0	0	0	0	0	0	X	1 = enable 0 = disable
3	C	C	C	C	C	C	C	C	C = 8-bit checksum

Table 20b. Audio Loopback Response Structure

Byte #	Value								Description
0	0	0	0	0	0	0	1	1	3 bytes to follow (03 hex)
1	0	0	0	0	1	0	1	0	ACK
2	0	0	0	1	0	1	0	1	Audio Loopback response
3	0	0	1	0	0	0	1	0	8-bit checksum (22 hex)

Packet Loopback Command

Command: 16 (hex)

Function: Enables Packet Loopback mode

Number of data bytes: Command Packet = 1
Response Packet = 0

This commands the Q4400 vocoder to loop back the Rx packets as Tx packets to the processor. Tables 21a and 21b shows the "Packet Loopback" command and response structures. The response packet from the Q4400 vocoder acknowledges that the command was properly received.

Table 21a. Packet Loopback Command Structure

Byte #	Value								Description
0	0	0	0	0	0	0	1	1	3 bytes to follow (03 hex)
1	0	0	0	1	0	1	1	0	Packet Loopback command
2	0	0	0	0	0	0	0	X	1 = enable 0 = disable
3	C	C	C	C	C	C	C	C	C = 8-bit checksum

Table 21b. Packet Loopback Response Structure

Byte #	Value								Description
0	0	0	0	0	0	0	1	1	3 bytes to follow (03 hex)
1	0	0	0	0	1	0	1	0	ACK
2	0	0	0	1	0	1	1	0	Packet Loopback response
3	0	0	1	0	0	0	1	1	8-bit checksum (23 hex)

Software VRS Command

Command: 17 (hex)

Function: Replaces the external Reference Strobe function

Number of data bytes: Command Packet = 0
Response Packet = 0

This command may be used instead of the hardware VRS input. This command may be issued one time to establish the Tx Frame and Rx Frame timing. Tables 22a and 22b show the "Software VRS" command and response structures. The response packet from the Q4400 vocoder acknowledges that the command was properly received.

Table 22a. Software VRS Command Structure

Byte #	Value								Description
0	0	0	0	0	0	0	1	0	2 bytes to follow (02 hex)
1	0	0	0	1	0	1	1	1	Software VRS command
2	0	0	0	1	1	0	0	1	8-bit checksum (19 hex)

Table 22b. Software VRS Response Structure

Byte #	Value								Description
0	0	0	0	0	0	0	1	1	3 bytes to follow (03 hex)
1	0	0	0	0	1	0	1	0	ACK
2	0	0	0	1	0	1	1	1	Software VRS response
3	0	0	1	0	0	1	0	0	8-bit checksum (24 hex)

TECHNICAL SPECIFICATIONS

Pin Descriptions

Following are the functions and operations of the input and output pins of the Q4400 vocoder. Figure 19 shows the location of the pins; table 23 describes the function of each pin.

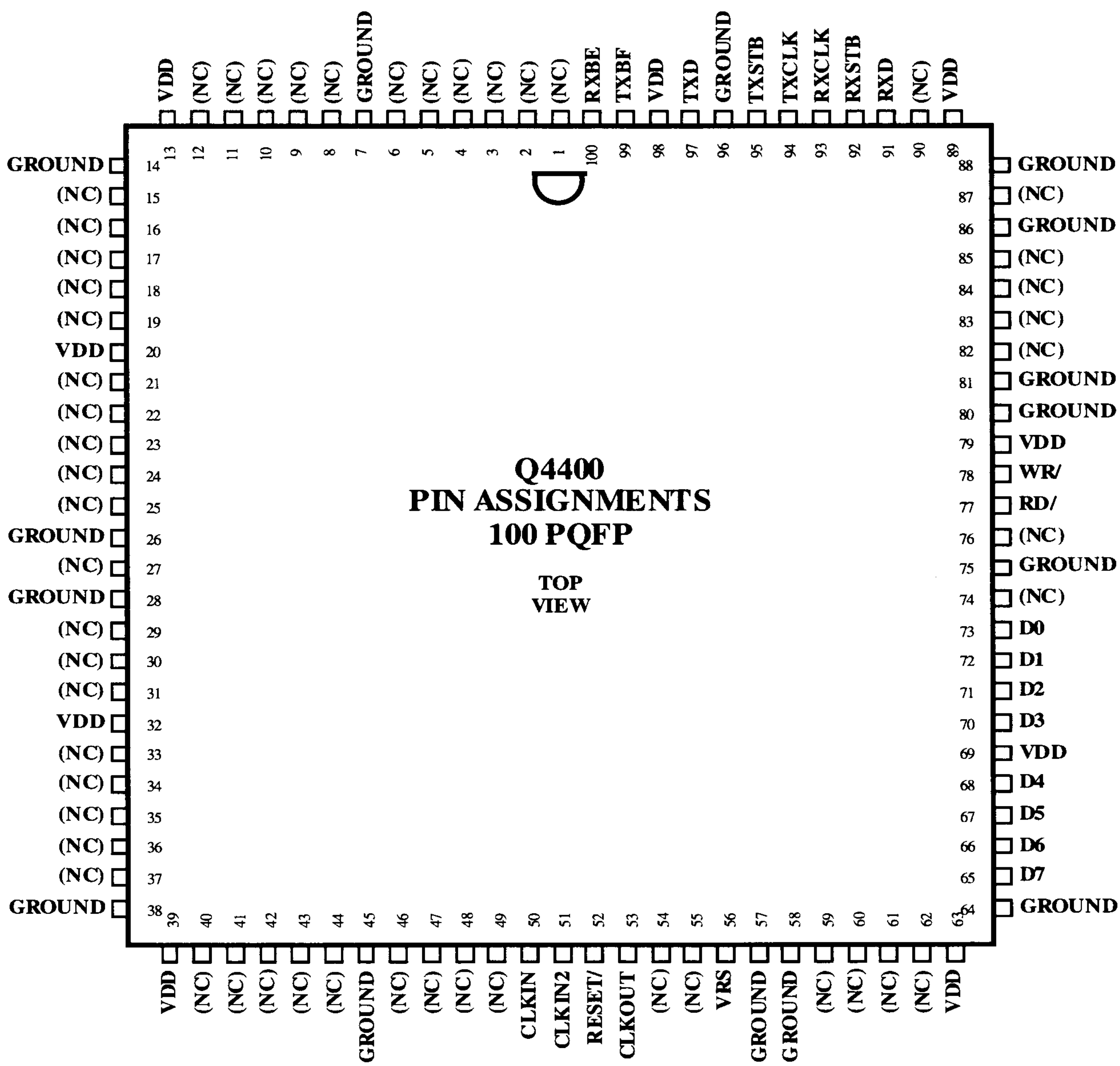


Figure 19. Q4400 Vocoder Pinout Diagram

Table 23. Q4400 Vocoder Pin Functions

Name	Pins	Type	Function
CLKIN	50	Input	Clock input for CMOS clock or crystal input. Use 10 pF cap to VSS for crystal input.
CLKIN2	51	Input	Other clock input for crystal input. Use 10 pF cap to VSS for crystal input. Leave open for CMOS clock
RESET/	52	Input	Q4400 Reset (active low)
CLKOUT	53	Output	Q4400 Clock Output
VRS	56	Input	Vocoder Reference Strobe
D0 - D7	65, 66, 67, 68, 70, 71, 72, 73	Input/Output	CPU Data Bus Interface Pin 65 is the MSB
RD/	77	Input	Output Data Strobe
WR/	78	Input	Input Data Strobe
RXD	91	Output	PCM Data Output
RXSTB	92	Input	PCM Output Load (8 kHz)
RXCLK	93	Input	PCM Output Clock
TXCLK	94	Input	PCM Input Clock
TXSTB	95	Input	PCM Input Load (8 kHz)
TXD	97	Input	PCM Data Input
TXBF	99	Output	PCM Input Buffer Full
RXBE	100	Output	PCM Output Buffer Empty
VDD	13, 20, 32, 39, 63, 69, 79, 89, 98	Power	+5 Volts Power
VSS	7, 14, 26, 28, 38, 45, 57, 58, 64, 75, 80, 81, 86, 88, 96	Ground	Digital Ground
N/C	1-6, 8-12, 15-19, 21-25, 27, 29-31, 33-37, 0-44, 46-49, 54-55, 59-63, 74, 76, 82-85, 87, 90	Unused	Make no connection to these pins

Absolute Maximum Ratings

Parameter	Symbol	Min	Max	Units
Storage temperature	T_S	-65	+150	^oC
Operating temperature	T_A	-40	+85	^oC
Junction temperature	T_J		+125	^oC
Voltage on any input pin		-0.5	+6	V

Note: Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Electrical Characteristics and Requirements

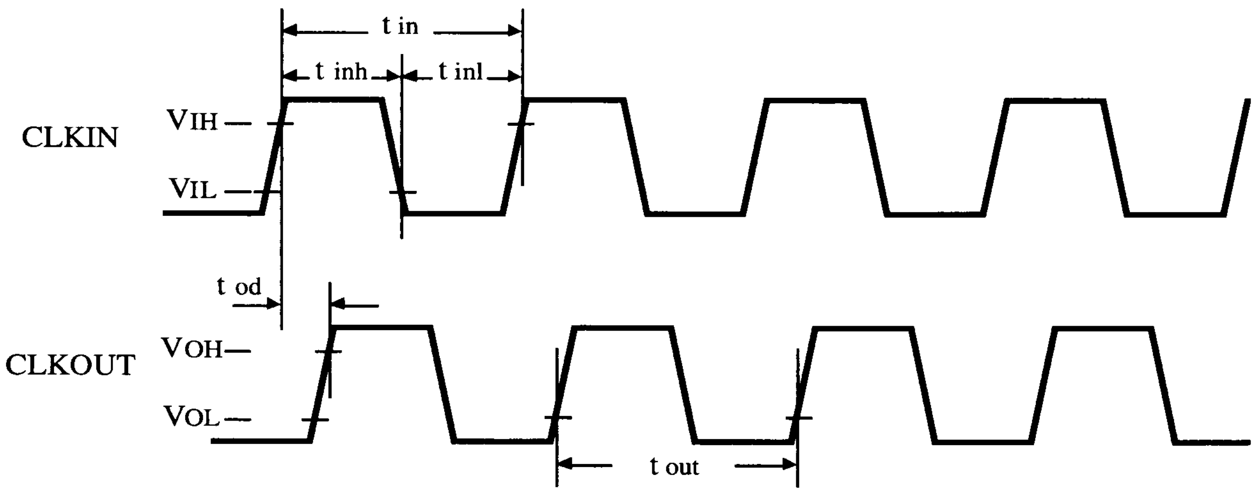
Parameter	Symbol	Min	Max	Units	Notes
Supply voltage	V_{DD}	4.75	5.25	V	
High-level input voltage (non clock inputs)	V_{IH}	2.0		V	
Low-level input voltage (non clock inputs)	V_{IL}		0.8	V	
Clock high-level input voltage (CMOS Input)	V_{IH}	3.15		V	
Clock low-level input voltage (CMOS Input)	V_{IL}		1.35	V	
Frequency of fundamental mode crystal	f_X		30	MHz	
Series resistance of fundamental mode crystal (pins: CLKIN, CLKIN2)	R_S		60	Ω	
Mutual capacitance of fundamental mode crystal	C_O		7	pF	
Input current	I_{IL}	-5		µA	
	I_{IH}		5	µA	
High-level output voltage	V_{OH}	V_{DD}-0.7		V	I_{OH} = -2.0 mA
	V_{OH}	V_{DD}-0.2		V	I_{OH} = -50 µA
Low-level output voltage	V_{OL}		0.4	V	I_{OL} = 2.0 mA
	V_{OL}		0.2	V	I_{OL} = 50 µA
Output tri-state current	I_{OZL}	-10		µA	
Output tri-state current	I_{OZH}		+10	µA	
Input capacitance	C_I		10	pF	
Power dissipation (active mode)	P_D		425	mW	V_{DD} = 5.0 V Fx = 30 MHz
Power dissipation (sleep mode)	P_D		45	mW	V_{DD} = 5.0 V Fx = 30 MHz

Timing Characteristics

The following figures provide the timing specifications for the Q4400 vocoder. These specifications are valid only for the following conditions:

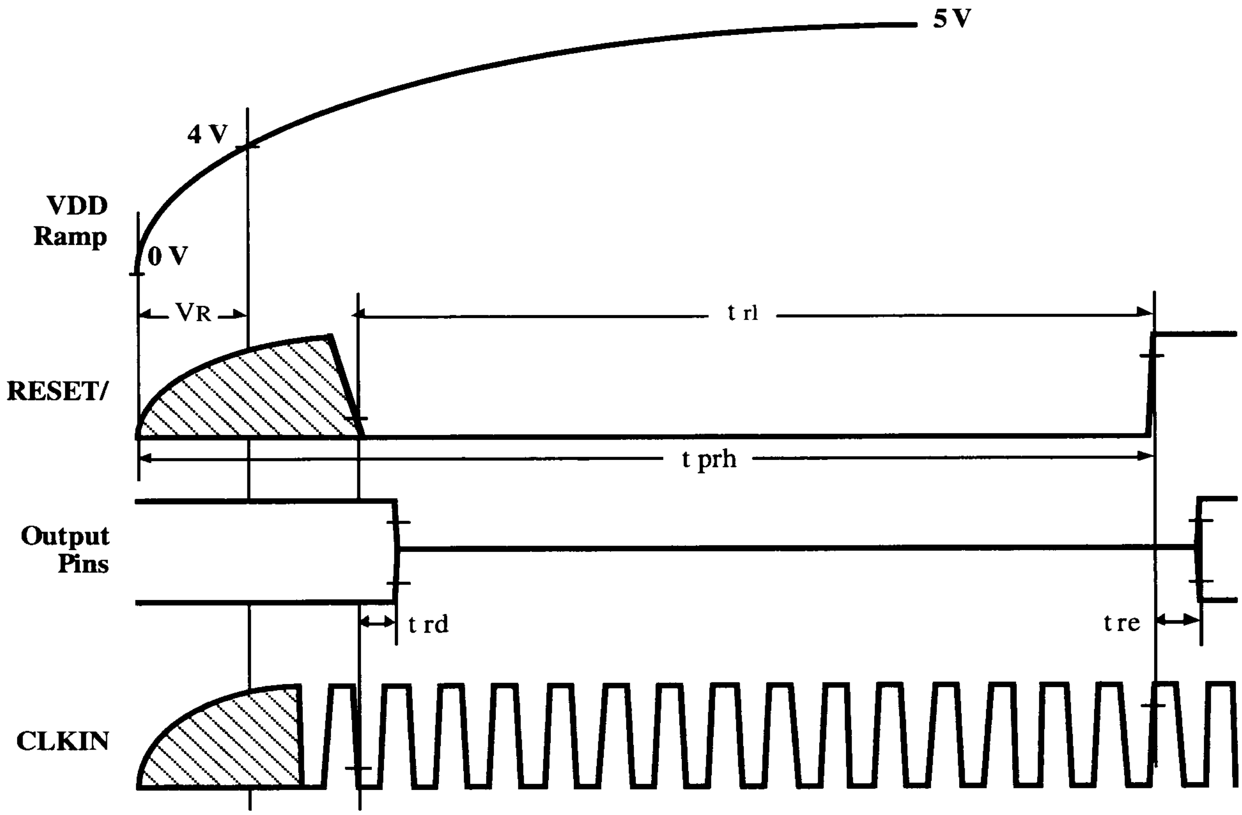
T_A = -40 °C to +85 °C
V_{DD} = 5 V ± 5%, V_{SS} = 0 V
Capacitance load on outputs (C_L) = 50 pF

Q4400 Vocoder Clock Generation



Abbreviated Reference	Parameter	Min	Max	Unit
t_{in}	CLKIN period (high to high)	33		ns
t_{inl}	CLKIN low time (low to high)	15		ns
t_{inh}	CLKIN high time (high to low)	15		ns
t_{od}	CLKOUT delay (high to high)		22.5	ns
t_{out}	CLKOUT period (low to low)	33		ns

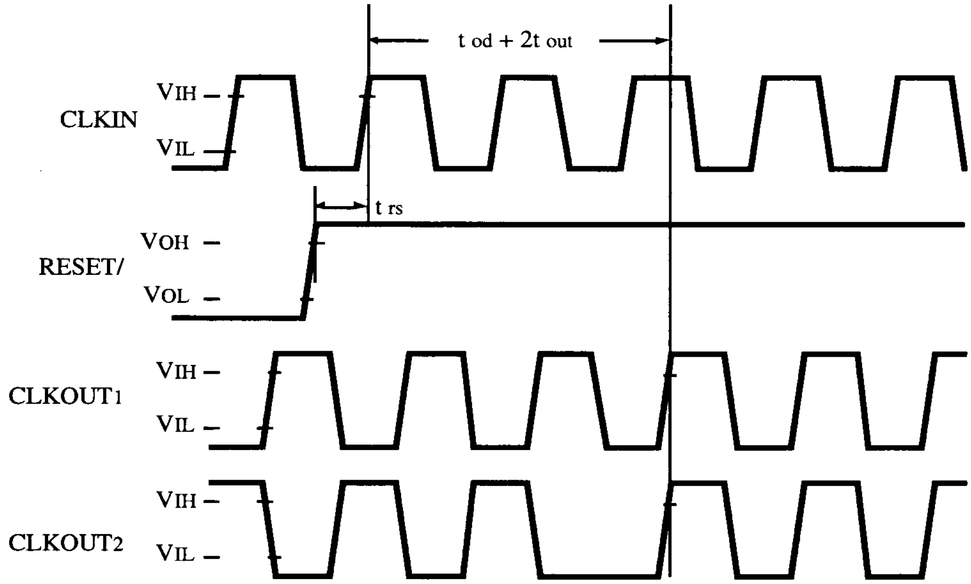
Reset Timing



Abbreviated Reference	Parameter	Min	Max	Unit
t_{prh}	Power on to RESET high	100		ms
t_{rl}	Reset pulse (low to high)	6T*		ns
V_R	V_{DD} ramp		40	ms
t_{rd}	RESET disable time (low to tri state)		100	ns
t_{re}	RESET enable time (high to valid)		100	ns

* $T = t_{in}$

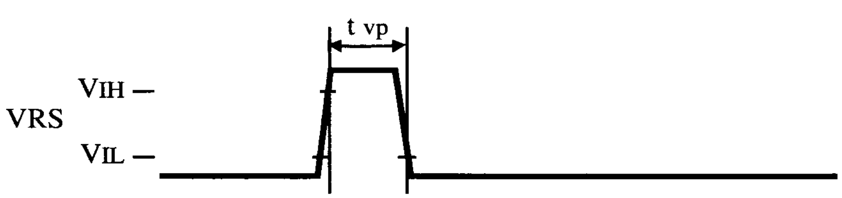
Reset Synchronization



Note: CLKOUT1 and CLKOUT2 are two possible CLKOUT states before RESET/. CLKOUT is free-running.

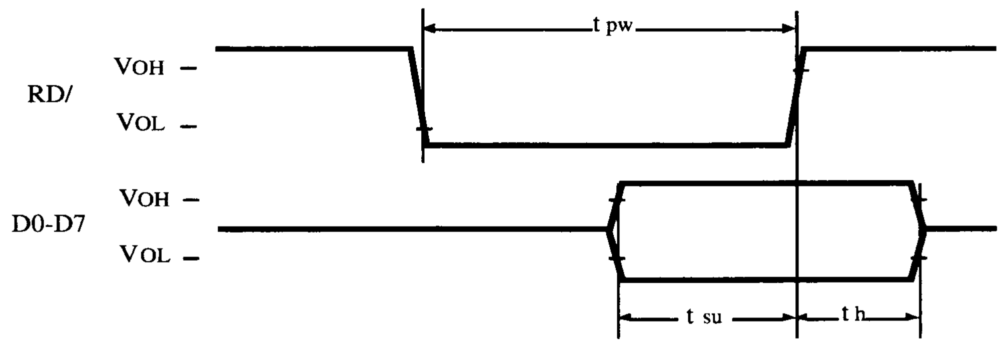
Abbreviated Reference	Parameter	Min	Max	Unit
t_{rs}	Reset setup (high to high)	10		ns

Vocoder Reference Strobe Timing



Abbreviated Reference	Parameter	Min	Max	Unit
t_{vp}	Pulse period (low to high)	2	50	µs

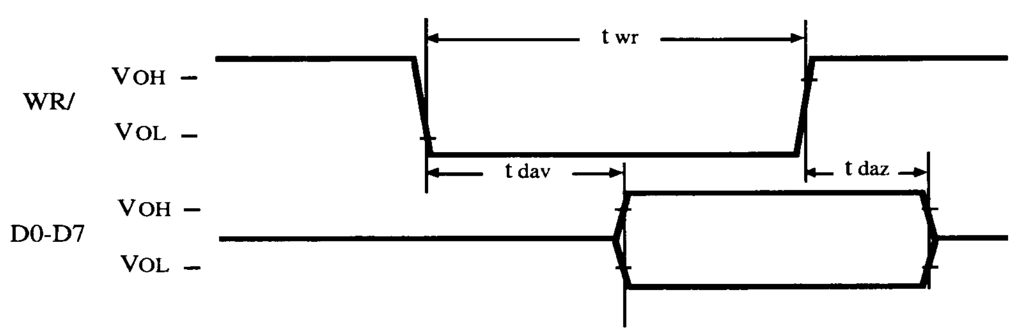
Processor Read Timing



Abbreviated Reference	Parameter	Min	Max	Unit
t_{pw}	RD/ pulse width (low to high)	T*		ns
t_{su}	D0 - D7 setup time (valid to high)	15		ns
t_h	D0 - D7 hold time (high to valid]	0		ns

* T = t_{in}

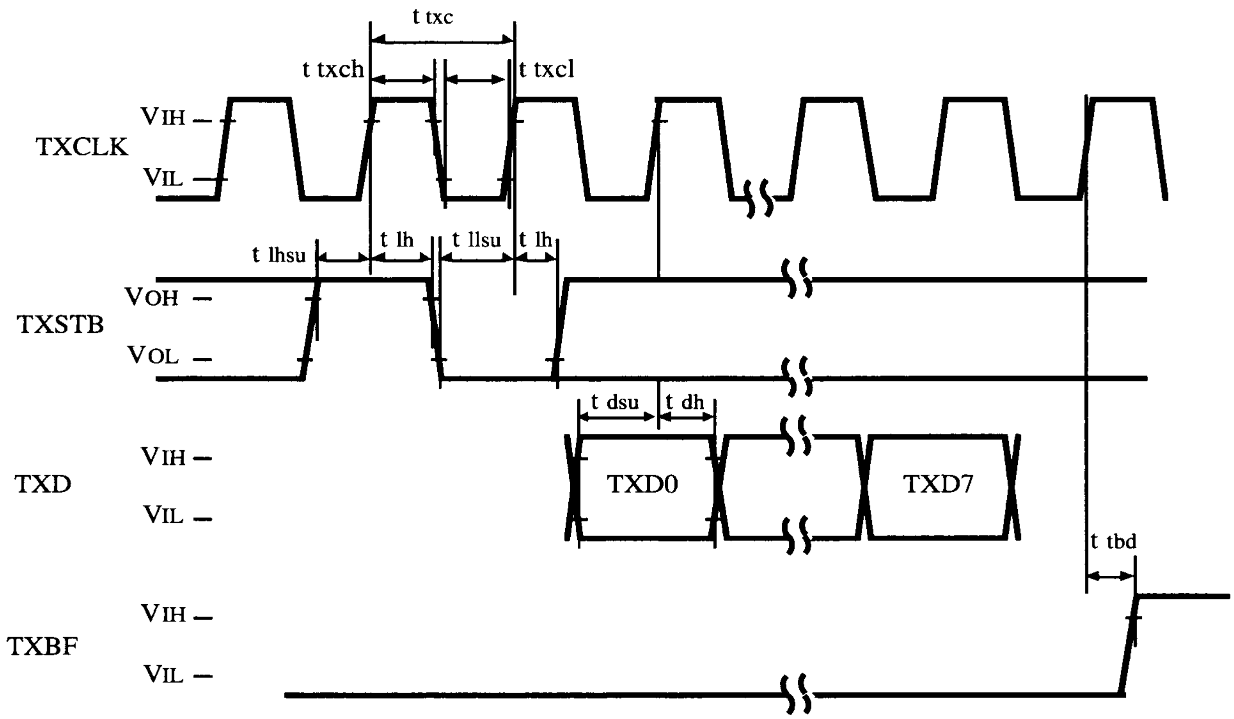
Processor Write Timing



Abbreviated Reference	Parameter	Min	Max	Unit
t_{wr}	WR/ pulse width (low to high)	T*		ns
t dav	WR/ low to D0 to D7 valid		15	ns
t daz	WR/ high to D0 to D7 tri-state	(T/2)-8*		ns

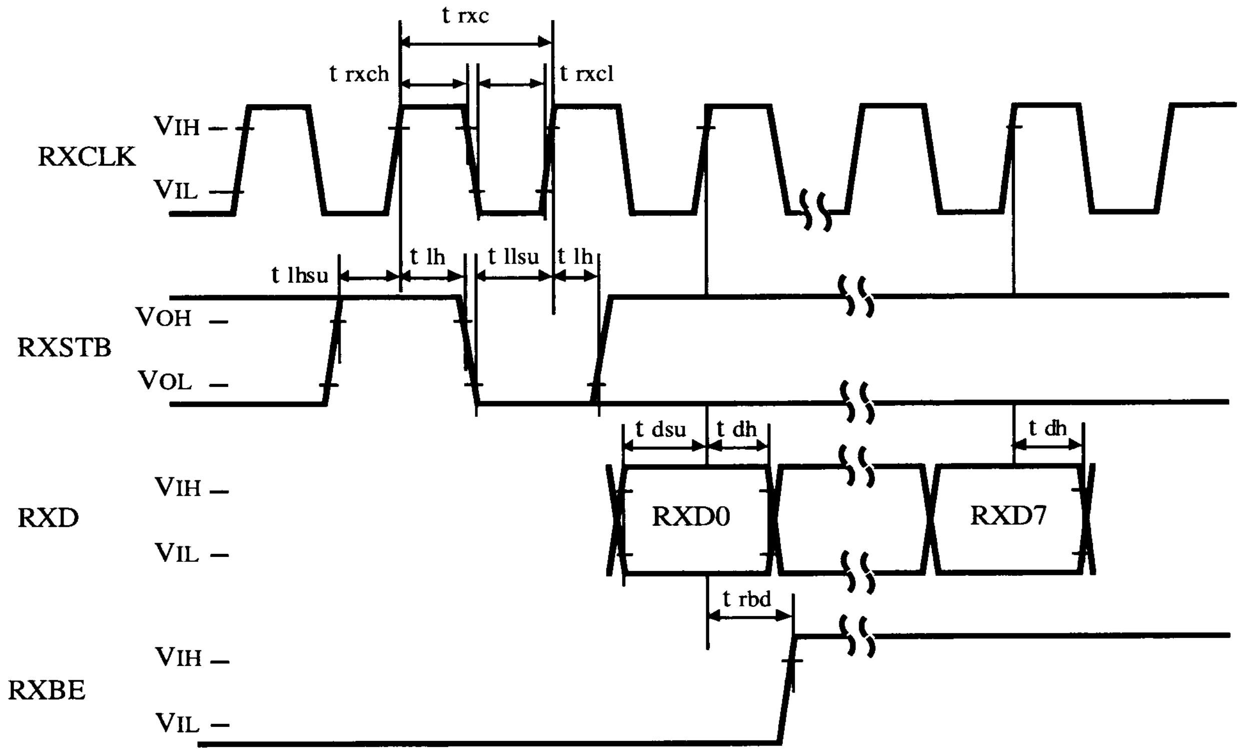
*T = t_{in}

PCM Tx Timing



Abbreviated Reference	Parameter	Min	Max	Unit
t_{txc}	TXCLK period (high to high)	66		ns
t_{txcl}	TXCLK low time (low to high)	30		ns
t_{txch}	TXCLK high time (low to high)	30		ns
t_{lhsu}	TXSTB high setup (high to high)	8		ns
t_{llsu}	TXSTB low setup (low to high)	8		ns
t_{lh}	TXSTB hold (high to invalid)	2		ns
t_{dsu}	TXD setup (valid to high)	7		ns
t_{dh}	TXD hold (high to invalid)	2		ns
t_{tbd}	TXBF delay (high to invalid)		20	ns

PCM Rx Timing



Abbreviated Reference	Parameter	Min	Max	Unit
t_{rcx}	RXCLK period (high to high)	66		ns
t_{rxcl}	RXCLK low time (low to high)	30		ns
t_{rxch}	RXCLK high time (high to low)	30		ns
t_{lhsu}	RXSTB high setup (high to high)	7		ns
t_{llsu}	RXSTB low setup (low to high)	7		ns
t_{lh}	TXSTB hold (high to invalid)	2		ns
t_d	TXD delay (high to valid)		35	ns
t_{dh}	TXD hold (high to invalid)	5		ns
t_{rbd}	RXBE delay (high to high)		25	ns

Q4400 Vocoder Packaging

The Q4400 vocoder is packaged in a 100-pin plastic quad flat pack (PQFP). Figure 20 shows the package outline and dimensions. A recommended socket is 3M P/N 2-0100-07243-000-018.

All dimensions are in inches and (millimeters).

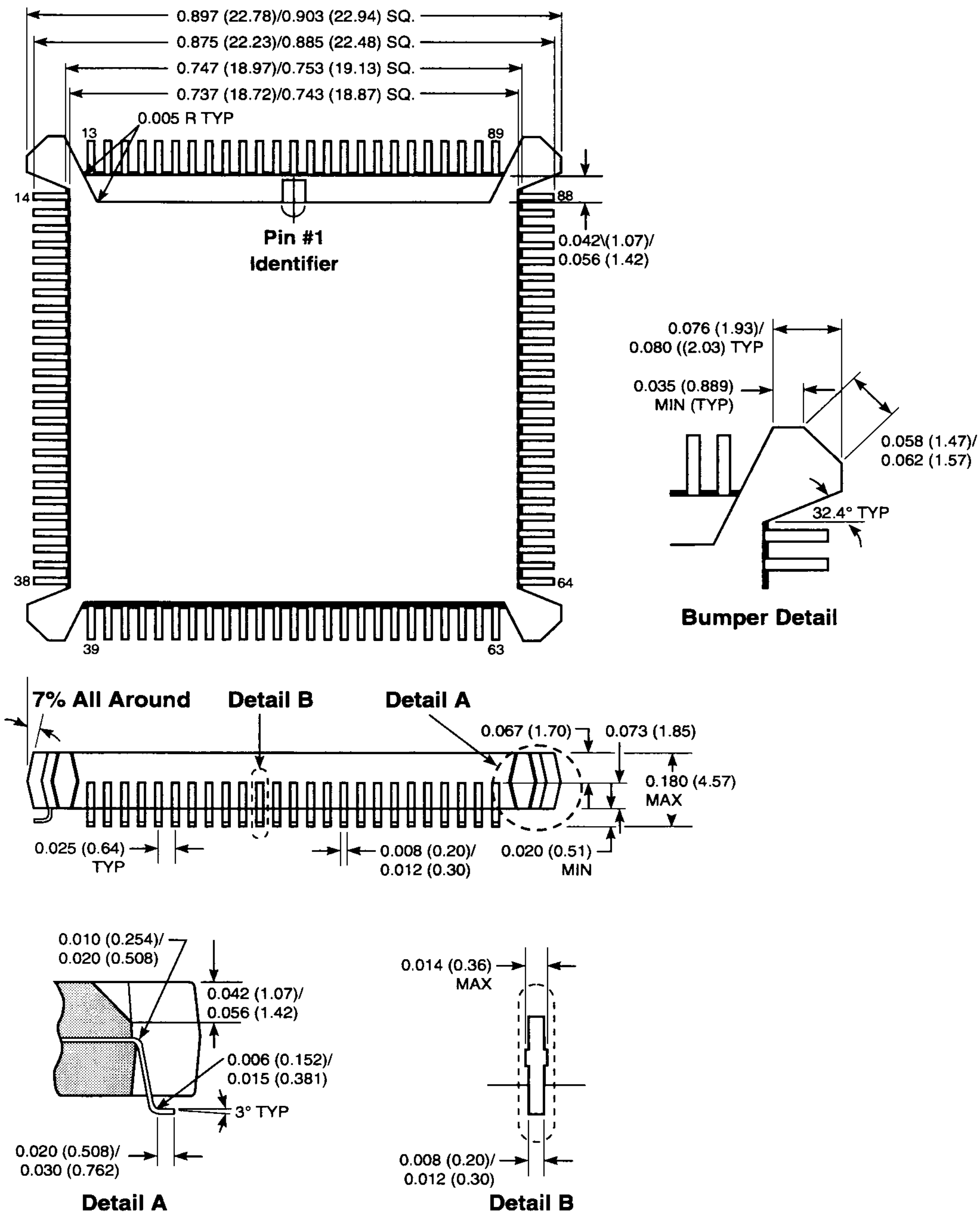


Figure 20. Q4400 Vocoder PQFP Packaging

APPLICATIONS

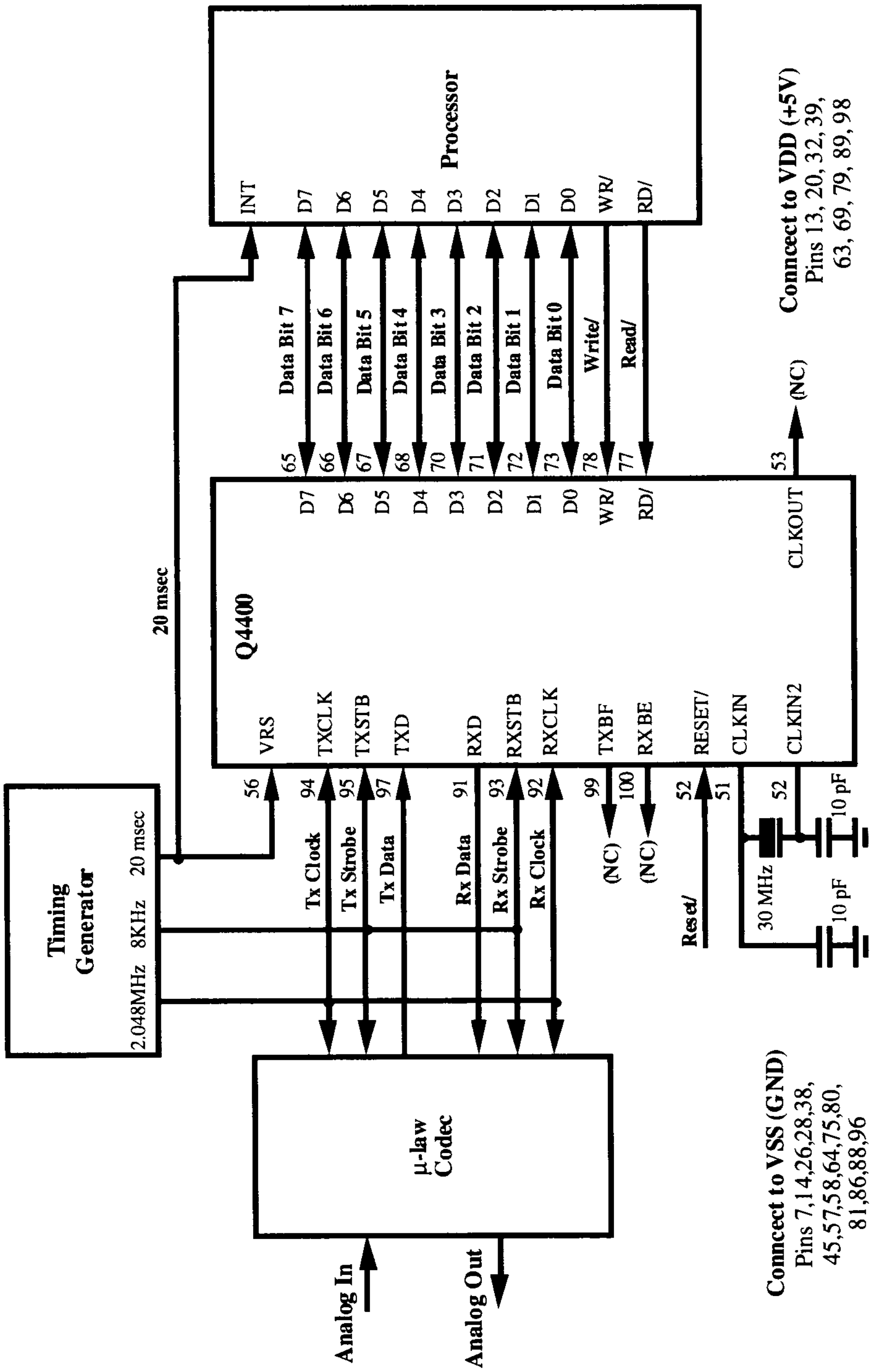


Figure 21. Typical Q4400 Vocoder Configuration Example

REFERENCES

AT&T WE® DSP1616 Digital Signal Processor Preliminary Data Sheet, November 1992.

GLOSSARY

ADPCM - Adaptive Delta Pulse Code Modulation
ALU - Arithmetic Logic Unit (Processor Core)
CVSD - Continuously Variable Slope Delta Modulation
CMOS - Complimentary Metal Oxide Semiconductor
DSP - Digital Signal Processor
DTMF - Dual Tone Multi Frequency
LPC - Linear Predictive Coding
LSB - Least Significant Bit
MIPS - Million Instructions Per Second
MSB - Most Significant Bit
PCM - Pulse Code Modulation
PQFP - Plastic Quad Flat Pack
QCELP - QUALCOMM's Codebook Excited Linear Predictive Coding
RAM - Random Access Memory
ROM - Read Only Memory
TDMA - Time Division Multiple Access
μ-law Codec - Analog/Digital-Digital/Analog Converter for Speech Signals
VOX - Voice-Activated Switch
VRS - Vocoder Reference Strobe
VSS - +5 V

ORDERING INFORMATION

Component Products

Device	Part Number	Package
Q4400 Variable Rate Vocoder	Q4400I-1S1	Plastic Quad Flat Pack (PQFP)

Board Level Products

Product Number	Description
Q0810	Q4400 Vocoder Evaluation Board

For more information or to place an order, contact your local QUALCOMM Engineering Representative or contact QUALCOMM directly:

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