32-kbit/s ADPCM with the TMS32010

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Abstract

This report discusses 32-kbit/s Adaptive Differential Pulse Code Modulation (ADPCM) transcoders. A half-duplex ADPCM transcoder, which complies with the CCITT recommendation (G.721), can be achieved with a single TMS32010. If the transcoder is used only for private lines, a full duplex non-CCITT ADPCM transcoder is more cost-effective and can be designed with a single TMS32010 processor. Both the CCITT and non-CCITT algorithms and code implementations are covered in the report.

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INTRODUCTION

Digital voice communication is typically transmitted in a 64-kbit/s PCM bit stream. Voice and data communications demand increasing capacities for signal transmission without significant degradation in the quality of the transmitted signal. One of the recommended solutions for accomplishing this task is that of Adaptative Differential Pulse Code Modulation (ADPCM). This solution has been reviewed by CCITT (International Telegraph and Telephone Consultative Committee), and a specific standard* has been recommended. Two solutions, a full-duplex solution and a half-duplex solution, are discussed in this application report. Both follow the model recommended by CCITT for 32-kbit/s ADPCM, although only the half-duplex solution provides a bit-for-bit compatible data stream as required by the recommendation. At 32 kbit/s, the ADPCM solution provides double the channel capacity of the current 64-kbit/s PCM technique. Each solution has been totally incorporated in the internal memory space of the Texas Instruments TMS32010 microprocessor.

This application report presents a brief review of the basic principles of PCM and ADPCM. Hardware requirements, software logic flow, and key features of the TMS32010 microprocessor for the implementation of ADPCM are also given. Source code is provided for the implementation and creation of an ADPCM transmission channel.

DIGITIZATION

Over the past 20 years, the telecommunications industry has changed from totally analog circuits to networks which integrate both analog and digital circuits. Digital signal encoding has the advantages of greater noise immunity, efficient regeneration, easy and effective encryption, and uniformity in transmitting voice and data signals. Increased bandwidth is required to transmit digital signals while maintaining a given analog signal quality at the receiver.

Voice store and forward systems have been changing from totally analog storage media, such as audio tape, to digitized storage which allows random access of stored data, but with the tradeoff of increased storage media requirements.

Signal quality begins with the digitization of the original analog signal. The process of digitization and coding introduces a distortion associated with the quantization of the digitized signal, as shown in Figure 1. This signal distortion or noise is different from the channel noise normally associated with a transmitted signal. After a signal has been digitized, the signal is much less susceptible to channel noise since the signal can be regenerated as well as amplified along the way, thus reducing the possibility of being corrupted by the transmission system. The overall quality of digital transmission is then limited by the digitization process in an error-free transmission system.

Figures 2 and 3 show general representations of a digital communication channel. The actual transmission (and storage of a digital waveform) uses an analog channel. The outside points of the communications channel are the transmitter and receiver, as shown in Figure 2. These are commonly combined in a single device known as a combo-CODEC (CODing and DECoding device). The codec supplies, on the coding or transmitting side, the necessary filtering to bandlimit the analog signal and avoid signal alias and A/D conversion. On the decoding or receiving side, the codec performs a D/A conversion and then interpolates or smooths the resultant signal.

Figure 3 shows the digitized signal modulated for transmission in the network and then demodulated at the receiving end to retrieve the transmitted digital signal.

PCM

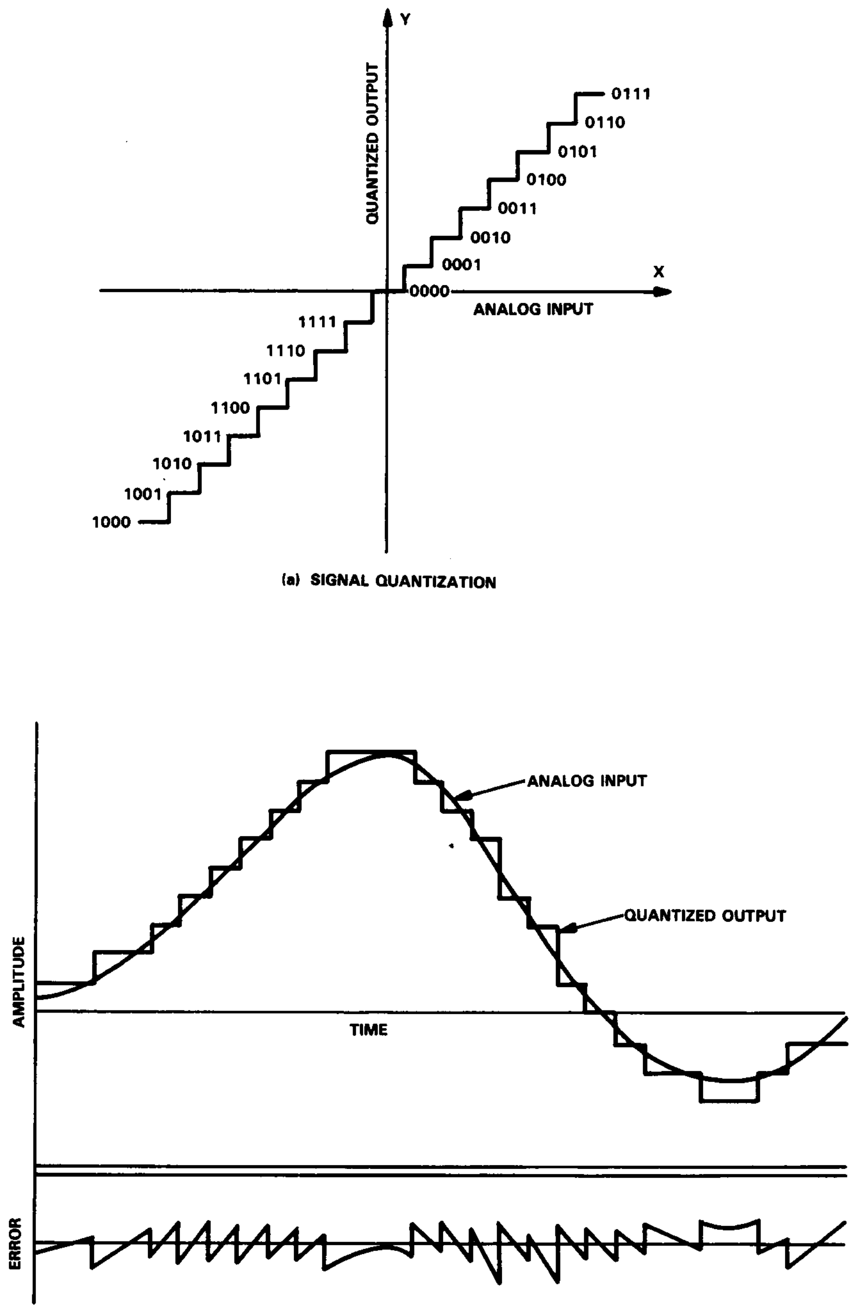
Digitization and coding of the analog signal at the transmitter can be performed in several ways. The complexity of the chosen method is related to availability of encoder memory and to the resultant delay in the encoding process.

When digital signal transmission is implemented, memory and the resultant delay dictate that a simple scheme, such as Pulse Code Modulation (PCM), be implemented. PCM codes each sampled analog value of the input waveform to a unique or discrete value. The digital quantization introduces distortion into the signal waveform, as shown in Figure 1.

A nonuniform quantization scheme may be used to COMPAND (COMpress and exPAND) the signal in the waveform coding and decoding blocks in the system, generating log-PCM. By using larger quantization steps for large amplitude signals and smaller steps for small amplitude signals, efficient use is made of the data bits for digital transmission while maintaining specific signal-to-quantization noise thresholds. With the two current methods of COMPANDING (A-law and μ-law), the signal quality of a 13-bit digitized signal is maintained while transmitting only 8 bits per sample.

While quantizers remove the irrelevancy in a signal, coders remove the redundancy. In PCM encoding, each sample of the input waveform is independent of all previous samples; no encoder memory is required.

*Recommendation G.721, 32 kbits/s Adaptive Differential Pulse Code Modulation'', CCITT, 1984.



(a) SIGNAL QUANTIZATION

(b) SIGNAL QUANTIZATION ERROR

Figure 1. Quantization Errors in a Digitized Signal

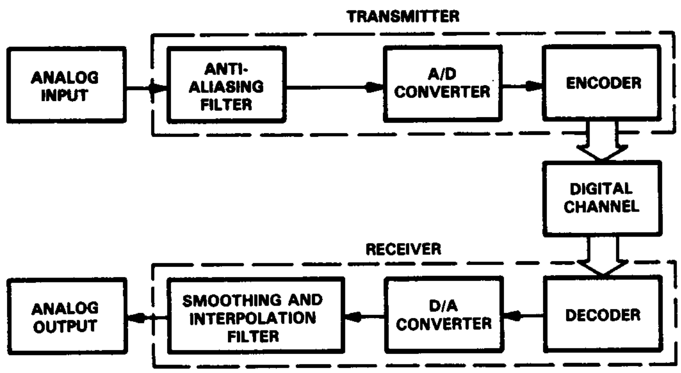


Figure 2. Digital Communication of Waveforms

Figure 3. Digital Channel

ADPCM

Analysis of speech waveforms shows a high sample-to-sample correlation. By taking advantage of this property in speech signals, more efficient coding techniques have been designed to further reduce the transmission bit rate while preserving the overall signal quality.

APCM

Adaptive PCM (APCM) is a method that may be applied to both uniform and nonuniform quantizers. It adapts the stepsize of the coder as the signal changes. This accommodates amplitude variations in a speech signal between one speaker and the next, or even between voiced and unvoiced segments of a continuous signal. The adaptation may be instantaneous, taking place every few samples. Alternatively, it may occur over a longer period of time, taking advantage of more slowly varying features. This is known as syllabic adaptation.

The basic concept for an adaptive feedback system, APCM, is shown in Figure 4. An input signal, s(k), in the transmitter is quantized and coded to an output, I(k). This output is also processed by stepsize adaptation logic to create a signal, q(k), that adapts the stepsize in the quantizer. Correspondingly, in the receiver, the received signal, I(k), is processed by an inverse quantizer (i.e., decoded), producing the reconstructed signal, $s_r(k)$. Like the transmitter, the quantized signal, I(k), is processed by adaptation logic to create a stepsize control signal, q(k), for the inverse quantizer.

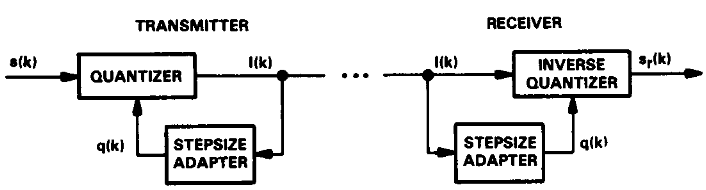


Figure 4. APCM Block Diagram

DPCM

The method of using the sample-to-sample redundancies in the signal is known as differential PCM (DPCM). The overall level of high correlation on a sample-by-sample basis indicates that the difference between adjacent samples produces a waveform with a much lower dynamic range. Correspondingly, an even lower variance can be expected between samples in the difference signal. A signal with a smaller dynamic range may be quantized to a specific signal-to-noise ratio with fewer bits.

A differential PCM system, DPCM, is shown in Figure 5. In Figure 5, the signal difference, d(k), is determined using a signal estimate, $s_e(k)$, rather than the actual previous sample. By using a signal estimate, $s_e(k)$, the transmitter uses the same information available to the receiver. Each successive coding actually compensates for the quantization error in the previous coding. In this way, the reconstructed signal, $s_r(k)$, can be prevented from drifting from the input signal, s(k), as a result of an accumulation of quantization errors. The reconstructed signal, $s_r(k)$, is formed by adding the quantized difference signal, $d_q(k)$, to the previous signal estimate, $s_e(k)$. The sum is the input to predictor logic which determines the next signal estimate. A decoding process is used in both the transmitter and receiver to determine the quantized difference signal, $d_q(k)$, from the transmitted signal, I(k).

ADPCM

ADPCM combines the features of both the APCM and DPCM systems. Figure 6 shows the basic blocks combining adaptation and differencing features in an ADPCM system. Both quantizer adaptation and signal differencing require the storage (in memory) of one or more samples in both the transmitter and receiver. Furthermore, the transmitter must use some method to ensure that the receiver is operating synchronously. This is accomplished by using only the transmitted signal, I(k), to determine stepsize adaptation in the quantizer and inverse quantizer and to predict the next signal estimate. In this way, the blocks in the receiver can be identical to those in the transmitter. Additionally, the specific adaptation techniques are designed to be convergent and thereby help provide quick recovery following transmission errors.

The ADPCM system, as used in digital telephony, is not an original signal coding system, but is actually a transcoder, converting between log-PCM and ADPCM codes. Currently there are a large number of systems using log-PCM for transmission. The ADPCM system incorporates both an adaptive quantizer and an adaptive predictor. The adaptive quantizer contains speed-control and scale-factor adaptation. A measure of the rate-of-change of the difference signal provides a means of determining the speed control. The scale factor adjustments to the difference signal adapt the fit of the quantization levels to minimize the signal-to-noise ratio. With speed control, the system can take advantage of both the instantaneous and syllabic adaptation rates, thereby adapting better to both speech and data signals. In the adaptive predictor, the prediction filter coefficients are updated by a gradient algorithm. Predictor adaptation improves the performance of the predictor for nonstationary signals (e.g., speech).

Figure 5. DPCM Block Diagram

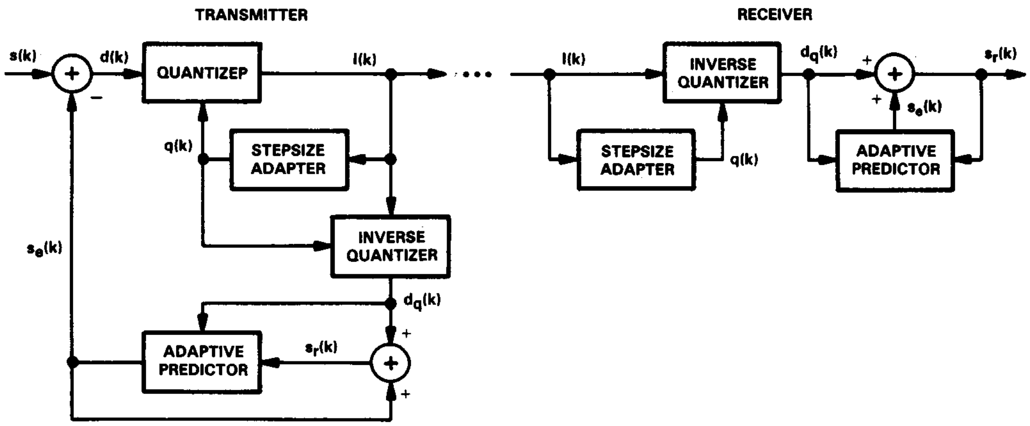


Figure 6. ADPCM Block Diagram

THE ADPCM ALGORITHM

The ADPCM algorithm has a receiver imbedded in the transmitter. This is important since, if the signal feedback used to determine the signal estimate, $s_e(k)$, and consequently the quantized difference signal, $d_q(k)$, is the same as in the decoder, then the compensation for quantization errors can be made with subsequent difference samples. Since the decoder is actually imbedded in the encoder, each of the common blocks for transmitting and receiving is discussed in the following paragraphs.

Figures 7 and 8 show block diagrams of an ADPCM transmitter and receiver as specified by CCITT.

Encoder

The function of the encoder or transmitter, shown in Figure 7, is to receive a 64-kbit/s log-PCM signal and transcode it to a 32-kbit/s ADPCM signal. This is accomplished by converting the log-PCM signal, s(k), to a linear signal, $s_l(k)$, from which an estimate, $s_e(k)$, of the signal is subtracted to obtain a difference signal, d(k). The next step is to adaptively quantize this difference signal, d(k), by first taking the log (base 2), then normalizing by the quantization scale factor, y(k), and finally coding the result, I(k). A more uniform signal-to-noise ratio can be achieved by coding the log of the signal rather than the linear representation. The normalization provides the adaptation to the quantization and is based on past coded samples. Adaptation is controlled bimodally, being comprised of a fast adaptation factor for signals with large amplitude fluctuations (i.e., speech) and a slow adaptation factor for signals which vary more slowly (i.e., data). A speed-control factor, $a_l(k)$, weights the fast and the slow adaptation factors to form a single quantization scale factor, y(k).

The inverse adaptive quantizer uses the same signal, I(k), that has been transmitted to reconstruct a quantized version of the difference, $d_q(k)$, and the same adaptive quantization characteristics as the adaptive quantizer section.

The quantized difference signal, $d_q(k)$, is input to an adaptive predictor which uses this input to compute a signal estimate, $s_e(k)$. The signal estimate, $s_e(k)$, is combined with the difference signal, $d_q(k)$, to determine a reconstructed signal, $s_r(k)$, which is the output in the decoder. This output is then subtracted from the next input sample to complete the feedback loop.

The adaptive predictor makes use of both an all-pole filter and an all-zero filter. The all-pole filter is a second-order filter with constrained adaptive coefficient values designed to match the slowly varying aspects of the speech signal. Since an all-pole predictor is particularly sensitive to errors, the predictor makes use of a sixth-order all-zero filter to offer signal stability even with transmission errors.

Decoder

The function of the decoder or receiver, shown in Figure 8, is to receive a 32-kbit/s ADPCM signal and transcode it to a 64-kbit/s log-PCM signal. To accomplish this, the decoder utilizes many of the elements used by the encoder. The received data, I(k), is processed by an inverse adaptive quantizer, identical to the one in the corresponding encoder, to determine a quantized difference signal, $d_q(k)$. By filtering the difference signal, $d_q(k)$, through the adaptive predictor together with the previously reconstructed signal, $s_r(k)$, a signal estimate, $s_e(k)$, is obtained. The signal estimate, $s_e(k)$, is added to the difference signal, $d_q(k)$, to compute the reconstructed signal, $s_r(k)$. The reconstructed signal, $s_r(k)$, is converted from a linear-PCM to a log-PCM signal, $s_p(k)$, which is then output following a synchronous

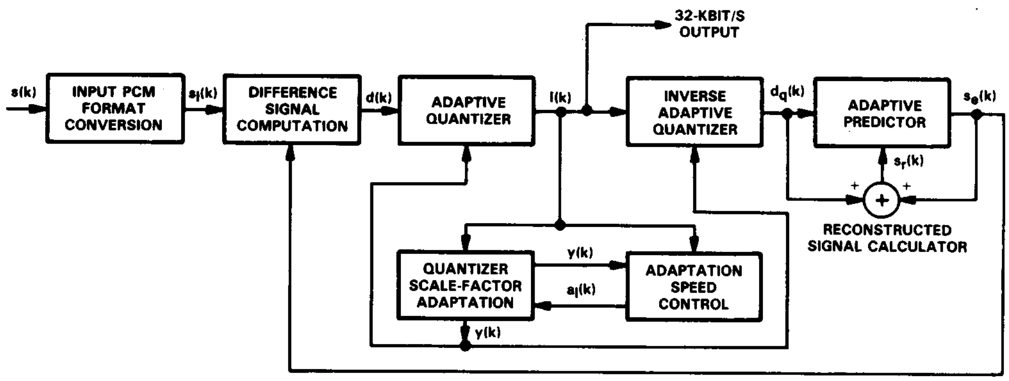


Figure 7. ADPCM Encoder Block Diagram
(Diagram taken from CCITT Recommendation G.721)

coding adjustment. The coding adjustment limits the errors in tandem codings of a signal.

Note that the algorithm design achieves a convergence of the states of the encoder and decoder in spite of transmission errors. This convergence is a part of each of the adaptation computations and is demonstrated equationally in the following sections. The convergence is brought about by the inclusion of $(1\text{-}2^{-N})$ terms which provide a finiteness to the memory of the adaptation parameters.

Adaptive Quantization

Adaptive quantization, a multistage process, is used to determine the quantization scale factor and the speed control that controls the rate at which the scale factor is adapted. Quantization is actually a four-bit quantization (a sign bit plus three-bit magnitude), since a four-bit signal is the transmitted output of the ADPCM transcoder. The adaptive quantizer block can be noted in Figure 7.

The difference signal, d(k), an input to the quantization process, is calculated by subtracting the signal estimate, $s_e(k)$, from the linear-PCM signal, $s_l(k)$.

$$d(k) = s_l(k) - s_e(k) \tag{1}$$

This difference signal is normalized by taking the log (base 2) and subtracting from it the quantizer scale factor, y(k).

$$|I(k)| \leftarrow \log_2 |d(k)| - y(k) \tag{2}$$

Table 1 is used to provide the magnitude of the quantization result, |I(k)|, from this normalized input. The sign bit of the ADPCM output value, I(k), is the sign of the difference signal, d(k).

The quantizer scale factor, y(k), is comprised of two parts, and therefore bimodal in nature. The two parts, $y_l(k)$ and $y_u(k)$, are weighted by the speed-control factor, $a_l(k)$. For speech signals, $a_l(k)$ will tend toward a value of one; for voiceband data, $a_l(k)$ will tend toward zero. Refer to both Figures 7 and 8 for the inclusion of the quantizer scale factor and speed-control factor adaptation blocks.

$$y(k) = a_l(k)y_u(k-1) + [1 - a_l(k)]\, y_l(k-1) \tag{3}$$

where $0 \leq a_l(k) \leq 1$

One of the factors, $y_u(k)$, is considered to be unlocked, since it can adapt quickly to rapidly changing signals (e.g., speech) and has a relatively short-term memory. This factor, $y_u(k)$, is recursively determined from the quantizer factor, y(k), and the discrete function, W(I).

$$y_u(k) = [1 - 2^{-5}]\, y(k) + 2^{-5}W[I(k)] \tag{4}$$

where $1.06 \leq y_u(k) \leq 10.00$

The factor, W(I), found in Table 2, is a function of I which causes $y_u(k)$ to adapt by larger steps for larger values of I. This gives $y_u(k)$ the freedom to track a signal almost instantaneously. Since y(k) is in the logarithmic domain, W(I) is effectively a multiplier of the scale factor.

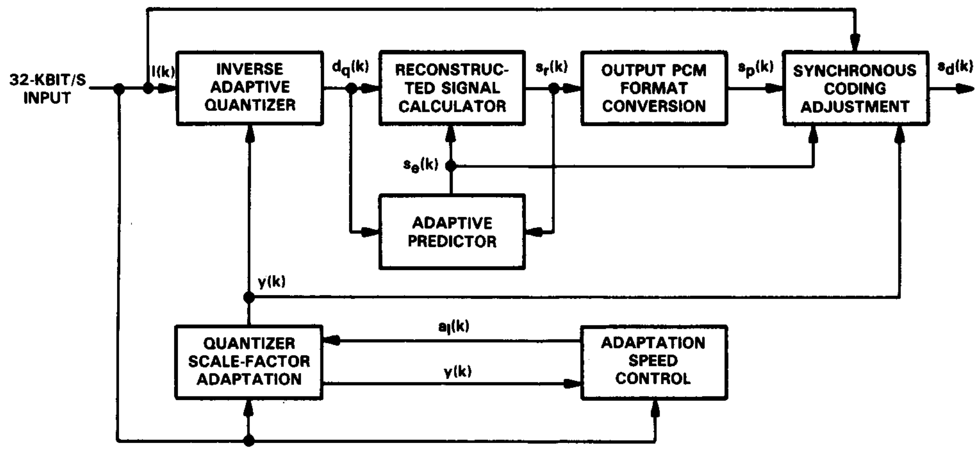


Figure 8. ADPCM Decoder Block Diagram (Diagram taken from CCITT Recommendation G.721)

Table 1. I/O Characteristics of the Normalized Quantizer

Normalized Quantizer Input Range $\log_2\lvert d(k)\rvert - y(k)$	$\lvert I(k)\rvert$	Normalized Quantizer Output $\log_2\lvert d_q(k)\rvert - y(k)$
[3.16, +∞)	7	3.34
[2.78, 3.16)	6	2.95
[2.42, 2.78)	5	2.59
[2.04, 2.42)	4	2.23
[1.58, 2.04)	3	1.81
[0.96, 1.58)	2	1.29
[-0.05, 0.96)	1	0.53
(-∞, -0.05)	0	-1.05

The other factor, $y_l(k)$, adapts more slowly and tracks signals which change slowly (e.g., voiceband data). This factor includes a lowpass filtering of the unlocked factor, $y_u(k)$. By including $y_u(k)$ in the manner shown, $y_l(k)$ is implicitly limited to the same range of values as the explicit limit placed on $y_u(k)$. Furthermore, the unity limit of $a_l(k)$ provides the same limit implicitly for y(k) as for $y_l(k)$ and $y_u(k)$.

$$y_l(k) = [1 - 2^{-6}]\, y_l(k-1) + 2^{-6} y_u(k) \qquad (5)$$

A speed-control factor, $a_l(k)$, adjusts the relative weighting of these two scale factors by making use of the short- and long-term averages, $d_{ms}(k)$ and $d_{ml}(k)$, respectively, of the coded output to determine how rapidly the signal is changing. The combined scale factor, y(k), cannot be larger than either the unlocked, $y_u(k)$, or locked $y_l(k)$, terms. Therefore, $a_l(k)$ is limited to one even if the predicted speed control, $a_p(k)$, is larger than one.

$$a_l(k) = \begin{cases} 1 & \text{,if } a_p(k-1) > 1 \\ a_p(k-1) & \text{,if } a_p(k-1) \leq 1 \end{cases} \qquad (6)$$

Note that $a_p(k)$ is implicitly limited to a maximum value of 2, while the speed-control factor used to mix the two scale factors is capped at a value of 1. In determining $a_p(k)$, an additional term of 1/8 is added each time if the difference in the short- and long-term averages becomes too large (i.e., $\lvert d_{ms}(k) - d_{ml}(k) \rvert \geq 2^{-3} d_{ml}(k)$) or if there is an idle channel (i.e., $y(k) < 3$). Where neither of these conditions exist, a uniform, slowly varying signal can be assumed, such as occurs in data transmission.

Table 2. Scale-Factor Multipliers

|I|	7	6	5	4	3	2	1	0
W(I)	69.25	21.25	11.50	6.12	3.12	1.69	0.25	-0.75

$$a_p(k) = \begin{cases} [1 - 2^{-4}]\, a_p(k-1) + 2^{-3}, \text{ if } |d_{ms}(k) - d_{ml}(k)| \geq 2^{-3} d_{ml}(k) \\ [1 - 2^{-4}]\, a_p(k-1) + 2^{-3}, \text{ if } y(k) < 3 \\ [1 - 2^{-4}]\, a_p(k-1), \text{ otherwise} \end{cases} \quad (7)$$

The short-, $d_{ms}(k)$, and long-term, $d_{ml}(k)$, averages of the transmitted ADPCM signal, I(k), are actually determined by averaging a weighted function, F(I), of the transmitted I, shown in Table 3.

$$d_{ms}(k) = [1 - 2^{-5}]\, d_{ms}(k-1) + 2^{-5} F\,[I(k)] \quad (8)$$

$$d_{ml}(k) = [1 - 2^{-7}]\, d_{ml}(k-1) + 2^{-7} F\,[I(k)] \quad (9)$$

The scale-factor and speed-control adaptations are a part of both the encoder and decoder logic. The adaptive quantization block has been specifically included in Figure 7, showing the encoder. For the decoder, the adaptive quantizer is included as part of the synchronization block to aid in the reduction of errors in tandem codings.

Table 3. Rate-of-Change Weighting Function

|I|	7	6	5	4	3	2	1	0
F(I)	7	3	1	1	1	0	0	0

Inverse Adaptive Quantization

Inverse adaptive quantization is a process in which the four-bit ADPCM signal, I(k), is used to determine the normalized log of the difference signal from Table 1. The result is actually a quantized version of the difference signal, $d_q(k)$, determined by adding the scale factor, y(k), to the value specified by Table 1 and calculating, the inverse log (base 2) of this sum.

$$d_q(k) = \log_2^{-1} [\{\log_2 |d_q(k)| - y(k)\} + y(k)] \quad (10)$$

For both the encoder and decoder, this quantized difference signal is the input to the reconstruction signal calculator and the adaptive predictor, as shown in Figures 7 and 8.

Adaptive Prediction

The adaptive predictive filter is a two-pole, six-zero filter used to determine the signal estimate. The combination of both poles and zeroes allows the filter to model more effectively any general input signal. The sixth-order all-zero section helps to stabilize the filter and prevent it from drifting into oscillation. For both the poles and the zeroes, the coefficients, $a_i(k)$ and $b_i(k)$, respectively, are adapted. This adaptation is based upon a gradient algorithm to further adjust the filter model to the input signal. Figures 9 and 10 show the sixth-order and second-order filters, respectively.

The signal estimate, $s_e(k)$, represents the sum of the all-pole filter and the all-zero filter. Since the sum of the all-zero filter is used to aid the determination of the pole coefficients, it is also extracted as a separate sum, $s_{ez}(k)$. The reconstructed signal, the output in the receiver, is the sum determined by the quantized difference signal $d_q(k)$, and the signal estimate, $s_e(k)$.

$$s_e(k) = \sum_{i=1}^{2} a_i(k-1) s_r(k-i) + s_{ez}(k) \quad (11)$$

$$s_{ez}(k) = \sum_{i=1}^{6} b_i(k-1) d_q(k-i) \quad (12)$$

$$s_r(k-i) = s_e(k-i) + d_q(k-i) \quad (13)$$

The adaptation of the pole coefficients, $a_i(k)$, is shown in the equations below. The gradient function is determined from a signal, p(k), that is equivalent to the reconstructed signal minus the contribution of the pole filter output. Stability of the filter is further provided by explicitly limiting the coefficients.

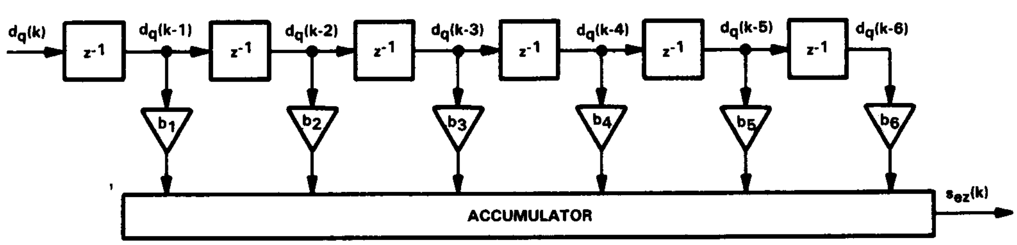


Figure 9. Sixth-Order All-Zero (FIR) Filter

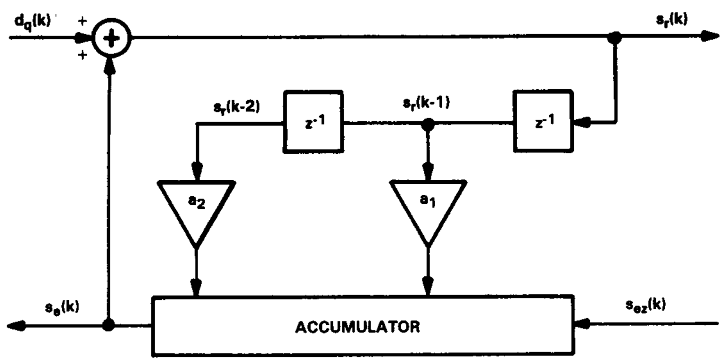


Figure 10. Second-Order IIR Filter

$$a_1(k) = [1 - 2^{-8}]\, a_1(k-1) + 3 \cdot 2^{-8} \text{sgn}\, [p(k)]\, \text{sgn}[p(k-1)] \quad (14)$$

where $|a_1(k)| \leq 1 - 2^{-4} - a_2(k)$

$$a_2(k) = [1 - 2^{-7}]\, a_2(k-1) + 2^{-7}\{\text{sgn}\, [p(k)]\, \text{sgn}\, [p(k-2)] - f[a_1(k-1)]\, \text{sgn}\, [p(k)]\, \text{sgn}\, [p(k-1)]\} \quad (15)$$

where $|a_2(k)| \leq 0.75$

$$p(k) = d_q(k) + s_{ez}(k) \quad (16)$$

$$f(a_1) = \begin{cases} 4a_1 & , \text{if} |a_1| \leq 1/2 \\ 2\text{sgn}(a_1), & \text{if} |a_1| > 1/2 \end{cases} \quad (17)$$

where $\text{sgn}(0) = +1$

For the coefficients, $b_i(k)$, of the sixth-order all-zero filter, the adaptation procedure is similar, but the limit is implicit in the equations to a maximum of ± 2. The gradient function, in this case, is determined by the current difference signal, $d_q(k)$, and corresponding difference signal, $d_q(k-i)$, at the specific filter tap.

$$b_i(k) = [1 - 2^{-8}]\, b_i(k-1) + 2^{-7}\text{sgn}\, [d_q(k)]\, \text{sgn}\, [d_q(k-i)] \quad (18)$$

where $i = 1, 2, \ldots 6$ and $-2 \leq b_i(k) \leq +2$

Signal Conversion

Signal conversion consists of the conversion from an 8-bit log-PCM representation of a signal to a 13-bit linear PCM representation (note Figure 7), or the reverse (note Figure 8). Signal conversions of this type are described in the application report on COMPANDING ROUTINES FOR THE TMS32010. In the encoder, the log-PCM signal, s(k), is expanded to create the linear-PCM value, $s_l(k)$. The decoder, on the other hand, compresses the reconstructed signal, $s_r(k)$, to create the log-PCM signal, $s_p(k)$.

Reconstructed Signal Synchronization

To avoid a cumulative distortion in synchronous tandem codings, an adjustment to the reconstructed signal is specified. The adjustment block, shown in Figure 8, estimates the quantization of the encoder by determining a difference signal and executing the adaptive quantization logic. The quantization result is an estimate of the received value of I(k).

The difference signal, $d_x(k)$, is determined by subtracting the signal estimate, $s_e(k)$, from the linear-PCM signal, $s_{lx}(k)$, which is itself determined by expanding the log-PCM signal, $s_p(k)$.

$$d_x(k) = s_{lx}(k) - s_e(k) \quad (19)$$

The adaptive quantization process produces the estimate of the ADPCM code value, $I_d(k)$. If the estimate implies a difference signal that is lower than the received interval boundary, the log-PCM code is changed to the next most positive value. An estimate implying a difference signal larger than the received interval boundary requires the log-PCM code to be changed to the next most negative value; otherwise, the log-PCM value is left unchanged. The adjusted log-PCM value is denoted as $s_d(k)$ in the following equation to differentiate it from the input value, $s_p(k)$.

$$s_d(k) = \begin{cases} s_p^+(k), & d_x(k) < \text{lower interval boundary} \\ s_p^-(k), & d_x(k) \geq \text{upper interval boundary} \\ s_p(k), & \text{otherwise} \end{cases} \quad (20)$$

where

$s_d(k)$ = output PCM of the decoder

$s_p^+(k)$ = next more positive PCM level (if $s_p(k)$ is the most positive level, then $s_p^+(k) = s_p(k)$)

$s_p^-(k)$ = next more negative PCM level (if $s_p(k)$ is the most negative level, then $s_p^-(k) = s_p(k)$)

FULL-DUPLEX IMPLEMENTATION OF ADPCM ON A TMS32010

The specific implementation of ADPCM presented here involves the use of a single TMS320M10 to accomplish a full-duplex transcoder. The TMS320M10 is a masked ROM, microcomputer version of the TMS32010, which requires no external program memories. A full-duplex transcoder provides transmission in both directions simultaneously. Such a transcoder is depicted in Figure 11. A complete system diagram of a full-duplex communications channel is shown in Figure 12. In comparison to current systems that modulate a 64-kbit/s A-law or μ-law PCM signal on a carrier for transmission, the described system transcodes the 64-kbit/s code to a 32-kbit/s code. This 32-kbit/s code, which requires correspondingly less bandwidth, is modulated on the carrier for transmission.

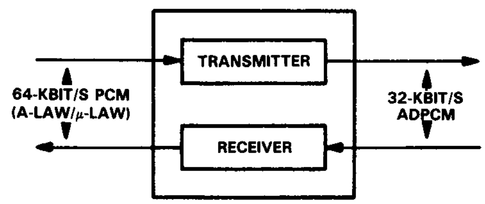


Figure 11. Full-Duplex ADPCM Transcoder

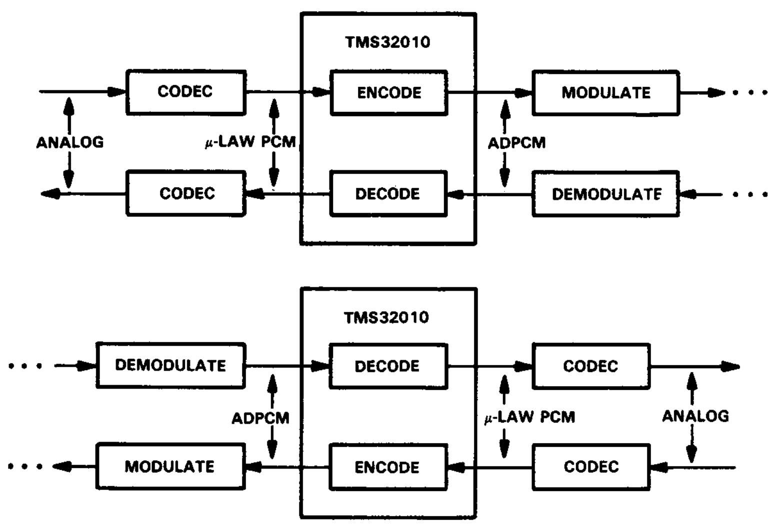


Figure 12. Full-Duplex Telecommunications Channel

Hardware Logic and I/O

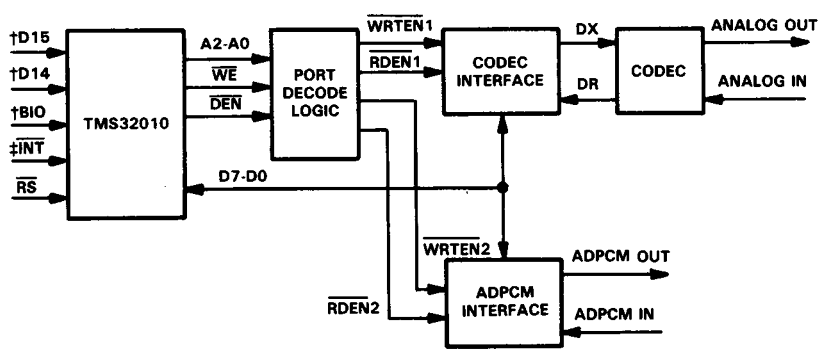
The hardware required to implement the ADPCM system consists of an addition to an existing circuit. As shown in Figure 13, the TMS32010 addresses the external I/O blocks through its port addressing structure. The lower three address lines, A2-A0, form a port address that can be decoded by port decode logic to provide specific enable lines (e.g., $\overline{\text{WRTEN}}$1 and $\overline{\text{RDEN}}$1) to the various peripheral blocks. The TMS32010 reads and writes the 64-kbit/s data through the codec interface eight bits at a time. The sampling frequency is 8 kHz. For this full-duplex implementation, one sample is written and one sample is read every 125 μs.

Figure 13 also shows the serial interface to the codec that provides the μ-law companded PCM data, although this is not part of the transcoding system itself. The log-PCM signal may already be available (e.g., in existing digital telecom networks) and, as such, may be interfaced to the TMS32010 either directly as parallel data or serially through conversion logic. Parallel codecs are also becoming available to reduce the hardware logic and interface required for those systems which do not already include a codec. The TMS32010 is available at crystal and clock input rates of 20.5 MHz which may be divided down to provide the codec timing and further reduce the logic requirement.

At the other end of the transcoder function, the TMS32010 reads and writes the 32-kbit/s ADPCM data through the ADPCM interface four bits at a time for each 125-μs period. This interface provides four-bit parallel data which may be serialized, if required, for transmission or storage.

Software Logic and Flow

Tables 4 and 5 list the various blocks in the algorithm, directly relating them to Figures 7 and 8 by the signal names given in the description and function. The blocks are listed in the order in which they are executed. Also listed is processor demand or loading which consists of the amount of program memory used to implement the given function and the number of instruction cycles executed in worst case. There are more blocks in the table than are shown in the figures (e.g., the algorithm uses the adaptive predictor at one point to produce the signal estimate, and later returns to update or adapt the predictor coefficients). Each block has been implemented using the equations given in previous sections concerning the ADPCM algorithm. For convenience, the equations implemented in each block are listed in the description section for the block. A more detailed description of the TMS32010 implementation is given in the next section.



† Half-duplex, CCITT bit-compatible, version only
‡ Full-duplex version only

Figure 13. System Interface of a TMS32010 ADPCM Transcoder

Table 4. Full-Duplex Transmitter

Order	Function	Description	CPU Clocks	Program Memory (Words)
1.	INPUT PCM	Read an 8 bit μ-law PCM sample [s(k)] and linearize it to a 12-bit sample [s_l(k)].	7	0004
2.	COMPUTE SIGNAL ESTIMATE	Calculate the signal estimate [s_e(k)] from the previous data samples [d_q(k)] and reconstructed samples [s_r(k)] through the predictor filter. (12),(11)	30	001E
3.	COMPUTE ADAPTIVE QUANTIZER	Calculate speed control [a_l(k)] and quantizer scale factor [y(k)] from past quantizer output [I(k)]. (6),(3)	33	0021
4.	COMPUTE DIFFERENCE SIGNAL	Calculate the difference signal [d(k)] from the current sample [s_l(k)] and signal estimate [s_e(k)]. (1)	3	0003
5.	COMPUTE QUANTIZED OUTPUT	Calculate the log of the difference signal [d(k)] and adaptively quantize the result to yield the ADPCM output [I(K)]. (2)	46	00AD
6.	OUTPUT ADPCM	Write the ADPCM output [I(k)].	2	0001
7.	COMPUTE RECON-STRUCTED SIGNAL	Calculate the inverse of the adaptively quantized signal [d_q(k)] and the reconstructed signal difference [s_r(k)]. (10),(13)	43	0027
8.	COMPUTE SCALE FACTOR	Calculate the updates for the scale-factor adaptation. (4),(5)	46	002F
9.	COMPUTE SPEED CONTROL	Calculate the update for the speed-control adaptation. (8),(9),(7)	30	001B
10.	COMPUTE PREDICTOR ADAPTATION	Calculate the updates for the adaptive predictor filter coefficients. (18),(16),(17),(14),(15)	102	006B

Table 5. Full-Duplex Receiver

Order	Function	Description	CPU Clocks	Program Memory (Words)
1.	INPUT ADPCM	Read the ADPCM input [I(k)].	2	0001
2.	COMPUTE SIGNAL ESTIMATE	Calculate the signal estimate [$s_e(k)$] from the previous data samples [$d_q(k)$] and reconstructed samples [$s_r(k)$] through the predictor filter. (12),(11)	30	001E
3.	COMPUTE ADAPTIVE QUANTIZER	Calculate speed control [$a_l(k)$] and quantizer scale factor [y(k)] from the past quantizer output [I(k)]. (6),(3)	33	0021
4.	COMPUTE QUANTIZED DIFFERENCE	Calculate the inverse of the adaptively quantized signal [$d_q(k)$]. (10)	47	002F
5.	COMPUTE SCALE FACTOR	Calculate the updates for the scale-factor adaptation. (4),(5)	48	002F
6.	COMPUTE SPEED CONTROL	Calculate the update for the speed-control adaptation. (8),(9),(7)	29	001B
7.	COMPUTE RECON-STRUCTED SIGNAL	Calculate the reconstructed signal [$s_r(k)$]. (13)	3	0003
8.	COMPUTE PREDICTOR ADAPTATION	Calculate the updates for the adaptive predictor filter coefficients. (18),(16),(17),(14),(15)	90	006B
9.	COMPUTE LOG-PCM	Convert the reconstructed linear-PCM signal [$s_r(k)$] to a μ-law PCM signal [$s_p(k)$].	39	0074
10.	OUTPUT PCM	Write the μ-law output [s_p)k)].	2	0001
11.	WAIT	Spin until the next interrupt.	–	0006

Implementation and Advantages of TMS32010 Architecture

This implementation is only concerned with μ-law PCM, although A-law PCM may also be used. Additional information on log-PCM companding is found in an application report, COMPANDING ROUTINES FOR THE TMS32010. The implementation is simplified here so that the expansion is a simple table lookup which saves 21 instruction cycles over the algorithmic approach.

The processing of the signal through the predictor filter is similar to the processing discussed in the application report, IMPLEMENTATION OF FIR/IIR FILTERS WITH THE TMS32010. The filter used in this ADPCM algorithm is a combination of a second-order IIR filter and a sixth-order all-zero or FIR filter. The filters are shown in Figures 9 and 10, respectively, with the system interaction shown in Figure 14.

Several manipulations of data format occur in adapting the predictor coefficients. In updating the coefficients of the all-zero filter (the B_i's), the coefficients that are normally Q14 numbers are loaded with a shift allowing the calculations to be done in a Q29 representation. This greatly simplifies the subtraction of the leakage term and the prediction gain. The leakage term, which occurs here in the predictor coefficient adaptation and also in the speed-control and scale-factor adaptation, controls the rate of change of the parameter away from zero and towards the absolute maximum limits of the particular parameter. The prediction gain also uses

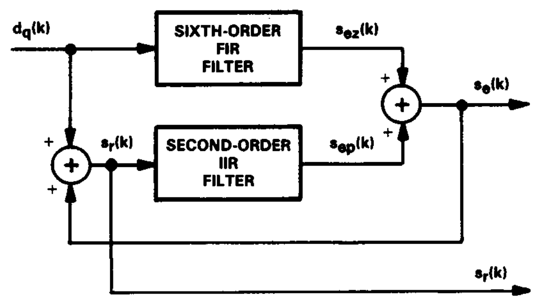


Figure 14. Predictor Filter

an approach whereby the signs are actually stored as a signed Q11 value. In this way, the product is a Q22 value of the correct sign and can be added to the B value, equivalent to a Q29 value times 2^{-7}. As with the filter process itself, the signs of the Dq values are propagated through each filter tap delay with the LTD instruction. An example for one of the B_i values is shown in Figure 15.

A similar process takes place in adapting the prediction coefficients (A_i's) in the second-order filter, although the fixed-point representation of the coefficients is Q26. The remaining requirement is to limit-check the A_i values.

The adaptive quantization section requires that the log (base 2) of the difference signal be taken, the result normalized, and the normalized value quantized. Taking the log (base 2) of a number is accomplished by using the approximation

$$\log_2(1 + x) = x \qquad (21)$$

```
*;*****************************************************************
*;
*;   COMPUTE COEFFICIENTS OF THE 6TH-ORDER PREDICTOR
*;
*;   Bi(k) = [1 - 2**-8] * Bi(k-1)
*;           + 2**-7 * SGN[DQ(k)] * SGN[DQ(k-i)]
*;
*;         FOR  i = 1 ... 6
*;         AND Bi IS IMPLICITLY LIMITED TO +/- 2
*;
*;         NOTATION:   Bn   -- 16b TC (Q14)
*;                     SDQn -- +2048 IF DQn POSITIVE (Q11)
*;                             -2048 IF DQn NEGATIVE (Q11)
*;
*;*****************************************************************
*;
GETB6  LT    SDQ6       * (Q11)
       LAC   B6,15      * (Q29)
       SUB   B6,7       * B6 * 2**-8  (Q29)
       MPY   SDQ        * SGN(SDQ)*SGN(SDQ6)*2**-7 (Q29)
       LTD   SDQ5       * (Q11)
       SACH  B6,1       * (Q14)
       .
       .
       .
```

Figure 15. Predictor Coefficient Adaptation Code

The characteristic of the result is the bit position of the most significant one digit in the absolute value. The result can be represented as a Q7 value. Finding the most significant digit is most efficiently done by a binary search technique. This technique is discussed in the application report, FLOATING-POINT ARITHMETIC WITH THE TMS32010. Since the exponent is part of the number instead of being stored in a separate register, one of the auxiliary registers is loaded with the exponent value. The auxiliary register stores it in memory and adds it to the mantissa in the accumulator. A short example of this is shown in the excerpted code in Figure 16 where the signal has an assumed exponent value of 9.

Normalization of this log value is simply a subtraction of a scale factor which may be as large in fixed magnitude as the largest logarithmic value represented in Q7 notation. The result of the subtraction may be a negative value. Since the normalized result is to be quantized in a nonuniform manner and one of the quantization levels could contain both positive and negative values, the normalized result is scaled by adding a fixed value of 2048. Nonuniform quantization can be performed by a binary-type search technique. The normalization and quantization are included in the program shown in Figure 16.

```
       SACL D           * STORE THE DIFFERENCE SIGNAL
       SACH DS          * SAVE THE SIGN OF D
*;
*;*******************************************************************
*;  ADAPTIVE QUANTIZER
*;
*;      INPUTS:  DIFFERENCED PCM SAMPLE  -- D
*;               QUANTIZER SCALE FACTOR  -- Y
*;
*;      OUTPUT:  4-BIT QUANTIZED, NORMALIZED DIFFERENCE -- I
*;
*;      NOTATION:  D     -- 16b TC (Q0)
*;                 Y     -- 13b SM (Q9) POSITIVE VALUE ONLY
*;
*;*******************************************************************
*;
*;                              DS
*;            +-------------------------------+
*;            |                               |
*;            |                               V
*;   D    +---+---+  DL    +--------+  DLN  +---------+    I
*; ------>|  LOG  |------->|  SUB   |------>|  QUAN   |------>
*;        +-------+        +--------+       +---------+
*;                             ^
*;                             | Y
*;
*;*******************************************************************
*;
*;  COMPUTE THE LOG OF THE DIFFERENCE SIGNAL
*;
AQUAN  ABS              * LOGS OF NEGATIVES ARE UNREAL.
       SACL TEMP1       * SAVE THE ABSOLUTE DIFFERENCE.
GETEXP SUB  ONE,8       * BEGIN BINARY SEARCH.
        .
        .
        .
EXP9   LARK 0,9         * EXP = 9; STORE IN AR0.
       LAC  TEMP1,14    * LOAD TO ISOLATE 8 MSB'S.
```

Figure 16. Adaptive Quantization Code

```
        SACH TEMP1        * SAVE MANTISSA.
        LAC  TEMP1        * RELOAD FOR MANTISSA RECOMBINATION.
        B    GETMAN
        .
        .
        .
GETMAN  AND  M127         * MASK TO RETAIN ONLY SEVEN BITS.
        SAR  0,TEMP1      * MOVE EXPONENT TO MEMORY FROM AR0.
        ADD  TEMP1,7      * ADD EXPONENT TO MANTISSA FOR LOG VALUE.
*;
*;  SCALE BY SUBTRACTION
*;
SUBTB   ADD  ONE,11       * ADD AN OFFSET OF 2048.
        SUB  TEMP3        * TEMP3 = Y(K) >> 2

*;
*;  4-BIT QUANTIZER
*;
*; QUANTIZATION TABLE FOR 32KB OUTPUT (OFFSET: 2048)
*;
ITAB1   EQU  2041
ITAB2   EQU  2171
ITAB3   EQU  2250
ITAB4   EQU  2309
ITAB5   EQU  2358
ITAB6   EQU  2404
ITAB7   EQU  2453
*;
QUAN    SUB  K2309        * ITAB4
        BGEZ CI4TO7
CI0TO3  ADD  K138         * ITAB2          I = 0-3
        BGEZ CI2TO3
CI0TO1  ADD  K130         * ITAB1          I = 0-1
        BGEZ IEQ1
IEQ0    LACK 0
        B    GETIM
IEQ1    LACK 1
        B    GETIM
CI2TO3  SUB  K79          * ITAB3          I = 2-3
        BGEZ IEQ3
IEQ2    LACK 2
        B    GETIM
IEQ3    LACK 3
        B    GETIM
CI4TO7  SUB  K95          * ITAB6          I = 4-7
        BGEZ CI6TO7
CI5TO6  ADD  K46          * ITAB5          I = 5-6
        BGEZ IEQ5
IEQ4    LACK 4
        B    GETIM
IEQ5    LACK 5
        B    GETIM
CI6TO7  SUB  K49          * ITAB6          I = 6-7
        BGEZ IEQ7
```

Figure 16. Adaptive Quantization Code (Continued)

```
IEQ6    LACK 6
        B    GETIM
IEQ7    LACK 7
GETIM   SACL IM           * ACCUM = ¦I¦
        XOR  DS           * ADD SIGN BIT AND FLIP IF NECESSARY.
        AND  M15          * MASK FINAL FOUR-BIT VALUE.
        SACL I            * SAVE ADPCM OUTPUT VALUE.
        .
        .
```

Figure 16. Adaptive Quantization Code (Concluded)

Determining the inverse of the 4-bit quantized ADPCM value involves another technique. The code to complete this task is much shorter in program memory requirement and somewhat faster in execution time. The same type of approximation is involved in determining the antilog as used in taking the log,

$$\log_2^{-1}(x) = 1 + x \quad (22)$$

After separating the exponent from the mantissa in the log representation, the quantized difference signal may be recovered by using the exponent to select a scaling factor. The scaling factor or multiplier is used to shift the mantissa to the proper representation, either right or left. Some of the multipliers may be stored as negative values rather than positive values, using the sign of the result to determine whether the answer is obtained from the high half of the accumulator (effectively a right shift) or from the low half of the accumulator (a left shift). The program for this process is shown in Figure 17.

```
*;
*;************************************************************
*;   INVERSE ADAPTIVE QUANTIZER
*;
*;      INPUTS:  4-BIT QUANTIZED SAMPLES -- IM
*;               QUANTIZER SCALE FACTOR  -- Y
*;
*;      OUTPUT:  RECONSTRUCTED DIFFERENCE SIGNAL  -- DQ
*;
*;      NOTATION:  Y     -- 13b SM (Q9) POSITIVE VALUE ONLY
*;                 DQ    -- 16b TC (Q0)
*;                 SDQ   -- +2048 IF DQ POSITIVE (Q11)
*;                          -2048 IF DQ NEGATIVE (Q11)
*;
*;************************************************************
*;
*;                                DQS
*;              +--------------------------------+
*;              ¦                                ¦
*;              ¦                                V
*;     I     +---+---+ DQLN  +-------+  DQL  +---------+  DQ
*;  ------>¦RECONST¦------>¦  ADD  ¦------>¦ANTILOG ¦------>
*;         +-------+       +-------+       +---------+
*;                             ^
*;                             ¦ Y
*;
*;*************************************************************
*;
*;   CONVERT QUANTIZED DIFFERENCE BACK TO LOG DOMAIN
*;
```

Figure 17. Inverse Adaptive Quantization Code

```
IAQUAN LAC   IM
       ADD   INQTAB       * RECONSTRUCTION TABLE
       TBLR TEMP1         * READ NORMALIZED VALUE.
*;
*;  ADD NORMALIZING SCALE FACTOR BACK IN
*;
ADDA   LAC   TEMP1
       ADD   TEMP3        * Y >> 2
       AND   M2047
       SACL TEMP2
*;
*;  CONVERT THE LOG VALUE TO THE LINEAR DOMAIN
*;
*;
ALOG   LAC   TEMP2,9      * EXTRACT EXPONENT.
       SACH TEMP1         * SAVE EXPONENT VALUE.
       LACK 127
       AND   TEMP2        * MASK FOR LOG MANTISSA ONLY.
       ADD   ONE,7        * 1+x
       SACL TEMP2         * EXTRACT MANTISSA.
       LT    TEMP2        * PREPARE TO SHIFT.
       LAC   TEMP1
       ADD   SHIFT        * LOOK UP MULTIPLIER.
       TBLR TEMP3
       MPY   TEMP3        * MULTIPLY MANTISSA BY SHIFT FACTOR.
       PAC
       BLZ   LEFTSF       * NEGATIVE VALUES CORRESPOND TO LEFT SHIFT.
       SACH DQ,1          * RIGHT SHIFT; SAVE MAGNITUDE OF DQ.
       B     ADDSGN
LEFTSF ABS                * LEFT SHIFT; RESTORE MAGNITUDE.
       SACL DQ            * SAVE MAGNITUDE OF DQ.
ADDSGN LAC   ONE,11       * ASSUME POSITIVE AND SAVE THE SIGN.
       SACL SDQ           *   (SIGN IS Q11; REMEMBER FILTER.)
       LAC   I            * CHECK SIGN OF SAMPLE.
       SUB   ONE,3
       BLZ   QSFA         * FINISHED FOR POSITIVE VALUES (I<8).
       ZAC
       SUB   DQ           * COMPUTE TWO'S COMPLEMENT OF THE MAGNITUDE.
       SACL DQ            * SAVE NEGATIVE DQ VALUE.
       LAC   MINUS,11     * SIGN IS Q11; REMEMBER FILTER.
       SACL SDQ           * SAVE SIGN.
       .
       .
       .
*;
*; INVERSE QUANTIZING TABLE
*;
IQTAB  BSS   0
       DATA 65401
       DATA 68
       DATA 165
       DATA 232
       DATA 285
       DATA 332
       DATA 377
       DATA 428
```

Figure 17. Inverse Adaptive Quantization Code (Continued)

```
*;
*; SHIFT MULTIPLIER TABLE
*;
SHFT    BSS  0
        DATA 256
        DATA 512
        DATA 1024
        DATA 2048
        DATA 4096
        DATA 8192
        DATA 16384
        DATA -1
        DATA -2
        DATA -4
        DATA -8
        DATA -16
        DATA -32
        DATA -64
        DATA -128
```

Figure 17. Inverse Adaptive Quantization Code (Concluded)

The adaptation of the speed-control and the scale-factor parameters, used to adapt the stepsize in the adaptive quantizer and inverse adaptive quantizer, requires multiple uses of the technique of adjusting the fixed-point representation. The Q point is adjusted for convenience of the table constants which are part of the adaptation process and for saving the output value from the accumulator. Some limit-checking must also take place in calculating the unlocked-scale factor and the speed-control parameter.

In the calculation of the locked-scale factor and its inclusion in the mixing process for determining the overall scale factor used for stepsize quantization, the parameter is maintained with a greater resolution (19 bits of value plus its sign) than can be stored in a single memory. Calculations involving this parameter must then become two stage, both in terms of accumulations and in determining products. The code involving this parameter is listed in Figures 18 and 19.

```
*;
*;*********************************************************
*;
*;  QUANTIZER SCALE FACTOR ADAPTATION
*;
*;      INPUT:    I : 32KB CODED SAMPLES
*;
*;      OUTPUT:  YU,YL : NEXT SAMPLE SCALE FACTOR
*;
*;      NOTATION:  Y     -- 13b SM (Q9) POSITIVE VALUE ONLY
*;                 YU    -- 13b SM (Q9) POSITIVE VALUE ONLY
*;                 YL    -- 19b SM (Q15) POSITIVE VALUE ONLY
*;
*;*********************************************************
*;

      .
      .
      .
*;
*;  UPDATE SLOW ADAPTATION SCALE FACTOR -- CONSTANT = 1/64
*;
*;  YL(k) = (1-2**-6)*YL(k-1) + 2**-6 * YU(k)
*;
FILTE  LAC  YLH,6       * SHIFT YL LEFT BY 6.
       SACL TEMP1       * TEMP1 = YLH * 2**6
       LAC  YLL,6
       SACL TEMP2
       SACH TEMP3       * TEMP3 | TEMP2 = YLL * 2**6
       LAC  TEMP3       * SUPPRESS SIGN EXTENSION.
       AND  M63
       SACL TEMP3
       ZALH TEMP1
       ADDH TEMP3
       ADDS TEMP2       * ACCUM = YL * 2**6
       SUBH YLH
       SUBS YLL         * ACCUM = YL * 2**6 - YL
       ADD  YU,6        * ACCUM = YL * 2**6 - YL + YU
       SACL TEMP1
       SACH TEMP2       * RESULT = YL (SHIFTED LEFT BY 6)
       LAC  TEMP1,10    * SHIFT RESULT RIGHT 6 --> q15
       SACH TEMP1
       LAC  TEMP1
       AND  M1023       * MASK SIGN EXTENSION.
       ADD  TEMP2,10
       SACL YLL         * SAVE YLL.
       SACH YLH
       LACK 7           * MASK UPPER 13 BITS.
       AND  YLH
       SACL YLH         * SAVE YLH.
       .
       .
       .
```

Figure 18. Quantizer Scale-Factor Adaptation: Locked-Factor Calculation

```
        .
        .
        .
*;
*;   FORM LINEAR COMBINATION OF FAST AND SLOW SCALE FACTORS
*;
*;   Y(k) = (1-AL(k))*YL(k-1) + AL(k)*YU(k-1)
*;
MIX     LAC  YLL,10      * SHIFT YL RIGHT BY 6.
        SACH TEMP3       * (IE SCALE YL TO MATCH YU SINCE YL
        LAC  TEMP3       *  CONTAINS 6 MORE LSB'S)
        AND  M1023
        ADD  YLH,10
        SACL TEMP3       * LOW HALF
        LAC  YU
        SUB  TEMP3       * YU-(YLL>>6)
        SACL TEMP3
        ZALH YLH
        ADDS YLL
        LT   AL          * AL IS IN 1.Q6
        MPY  TEMP3
        APAC             * YL + AL*(YU-(YLL>>6))
        SACL TEMP3
        SACH TEMP2       * TEMP2 | TEMP3 = Y * 2**6
        LAC  TEMP3,10    * SHIFT RIGHT BY 6.
        SACH TEMP3
        LAC  TEMP3
        AND  M1023       * MASK SIGN EXTENSION.
        ADD  TEMP2,10
        AND  M8191
        SACL Y           * SAVE Y.
        LAC  Y,14
        SACH TEMP3       * SAVE Y >> 2 .
        .
        .
        .
```

Figure 19. Quantizer Scale-Factor Adaptation: Mixing

CCITT IMPLEMENTATION OF ADPCM ON A TMS32010

The implementation of ADPCM that produces a bit-for-bit compatible solution with the CCITT test vectors uses a single TMS320M10 to accomplish a half-duplex transcoder. This solution can provide capability as either a transmitter or a receiver using either A-law or μ-law companding.

Hardware Logic and I/O

The hardware system for this transcoder implementation differs from Figure 13 in that data pins D15 and D14 are used to determine the mode of operation. Table 6 shows the operating mode for the various combined states of the data pin inputs.

Additionally, as has been noted in Figure 13, the interrupt or sample timing is an input to the $\overline{\text{INT}}$ pin in the full-duplex implementation; here it is an input to the $\overline{\text{BIO}}$ pin. Each 125-μs period, the TMS32010 reads a 64-kbit/s sample from the codec and writes a 32-kbit/s sample to the ADPCM interface, or it reads the 4-bit ADPCM sample and writes an 8-bit PCM sample to the codec.

For real-time execution, the TMS32010 requires the use of a 25-MHz clock input.

Table 6. Operating Mode Selection

D15*	D14*	Operating Mode
L	L	μ-law transmitter
L	H	μ-law receiver
H	L	A-law transmitter
H	H	A-law receiver

*H = High logic level
 L = Low logic level

Software Logic and Flow

Tables 7 and 8 list the various blocks in the algorithm, directly relating them to Figures 7 and 8 by the signal names given in the description and function. No differentiation is made between the transmitter or receiver using A-law or μ-law. The blocks are listed in the order in which they are executed. Also listed is processor demand or loading which consists of the amount of program memory used to implement the given function and the number of instruction cycles executed in worst case. There are more blocks in the tables than are shown in the figures (e.g., the algorithm uses the adaptive predictor at one point to produce the signal estimate, and later returns to update or adapt the predictor coefficients). Each block has been implemented using the equations given in previous sections concerning the ADPCM algorithm. For convenience, the equations implemented in each block are listed in the description section for the block. Additional details of the TMS32010 implementation are given in the next section, especially as they differ from the full-duplex implementation. The appendix contains a complete listing of the code.

Table 7. CCITT Transmitter

Order	Function	Description	CPU Clocks	Program Memory (Words)
1.	INPUT PCM	Read an 8 bit log-PCM sample [s(k)] and linearize it to a 12-bit sample [$s_l(k)$].	25 μ-law 24 A-law	0024 μ-law 0031 A-law
2.	COMPUTE SIGNAL ESTIMATE	Calculate the signal estimate [$s_e(k)$] from the previous data samples [$d_q(k)$] and reconstructed samples [$s_r(k)$] through the predictor filter. (12), (11)	396	0167
3.	COMPUTE ADAPTIVE QUANTIZER	Calculate speed control [$a_l(k)$] and quantizer scale factor [y(k)] from past quantizer output [I(k)]. (6), (3)	30	001E
4.	COMPUTE DIFFERENCE SIGNAL	Calculate the difference signal [d(k)] from the current sample [$s_l(k)$] and signal estimate [$s_e(k)$]. (1)	3	0003
5.	COMPUTE QUANTIZED OUTPUT	Calculate the log of the difference signal [d(k)] and adaptively quantize the result to yield the ADPCM output [I(k)]. (2)	42	00AD
6.	OUTPUT ADPCM	Write the ADPCM output [I(k)].	6	0005
7.	COMPUTE RECON-STRUCTED SIGNAL	Calculate the inverse of the adaptively quantized signal [$d_q(k)$] and the reconstructed signal difference [$s_r(k)$]. (10), (13)	66	00B0
8.	COMPUTE SCALE FACTOR	Calculate the updates for the scale-factor adaptation. (4), (5)	33	0022
9.	COMPUTE SPEED CONTROL	Calculate the update for the speed-control adaptation. (8), (9), (7)	30	001C
10.	COMPUTE PREDICTOR ADAPTATION	Calculate the updates for the adaptive predictor filter coefficients. (18), (16), (17), (14), (15)	111	0074
11.	WAIT	Spin until the next sample is available.	2+	0004

Table 8. CCITT Receiver

Order	Function	Description	CPU Clocks	Program Memory (Words)
1.	INPUT ADPCM	Read the ADPCM input [I(k)].	10	0009
2.	COMPUTE SIGNAL ESTIMATE	Calculate the signal estimate [$s_e(k)$] from the previous data samples [$d_q(k)$] and reconstructed samples [$s_r(k)$] through the predictor filter. (12), (11)	396	0167
3.	COMPUTE ADAPTIVE QUANTIZER	Calculate speed control [$a_l(k)$] and quantizer scale factor [y(k)] from past quantizer output [I(k)]. (6), (3)	30	001E
4.	COMPUTE QUANTIZED DIFFERENCE AND RECON-STRUCTED SIGNAL	Calculate the inverse of the adaptively quantized signal [$d_q(k)$] and the reconstructed signal [$s_r(k)$]. (10), (13)	66	00B0
5.	COMPUTE SCALE FACTOR	Calculate the updates for the scale-factor adaptation. (4), (5)	33	0022
6.	COMPUTE SPEED CONTROL	Calculate the update for the speed-control adaptation. (8), (9), (7)	30	001C
7.	COMPUTE PREDICTOR ADAPTATION	Calculate the updates for the adaptive predictor filter coefficients. (18), (16), (17), (14), (15)	111	0074
8.	COMPUTE LOG-PCM	Convert the reconstructed linear-PCM signal [$s_r(k)$] to a log-PCM signal [$s_p(k)$].	35 μ-law 33 A-law	0074 μ-law 0072 A-law
9.	SYNCHRON-OUS CODING ADJUSTMENT	Calculate an ADPCM signal from the output [$s_p(k)$] and adjust to create [$s_d(k)$] if it differs from [I(k)].	63	00DA
10.	OUTPUT PCM	Write the log-PCM output [$s_d(k)$].	4	0003
11.	WAIT	Spin until the next interrupt.	2+	0004

Implementation and Advantages of TMS32010 Architecture

Many of the same features are used in the bit-compatible implementation as were discussed in the full-duplex implementation. Some changes are imperative, since performance to the recommended specification requires executing certain calculations in a floating-point representation. These changes or additions require further modifications in order to limit the required amount of program memory to the internal memory space of the TMS32010.

One of the first observed requirements is that the processor must be capable of doing either A-law or μ-law companding and function as either a transmitter or a receiver. The burden of determining the mode of operation is simplified by selecting one of the four modes from information available at the time of reset, and then executing from one of the four control loops until the next reset. Each loop, therefore, tests the $\overline{\text{BIO}}$ pin to determine when the next input sample is ready, rather than depending on the hardware interrupt.

The requirement of selecting either A-law of μ-law companding also means that a table lookup approach is beyond the program memory capacity. The conversion must be done algorithmically to reduce the amount of memory. Figures 20 and 21 illustrate μ-law companding as it is implemented in this algorithm.

```
XMTMU   IN      SCRACH,ADC
EXPNDU  LAC     SCRACH,8     ; SEEE MMMM 0000 0000
        XOR     KFF00        ; INVERT FROM TRANSMISSION FORMAT
        SACL    TEMP1        ; SAVE VALUE FOR PCM SIGN
        AND     M32767       ; 0EEE MMMM 0000 0000
        SACH    TEMP2,4      ; SAVE EXPONENT VALUE
        AND     M4095        ; 0000 MMMM 0000 0000
        ADD     BIAS,7       ; 0001 MMMM 1000 0000
        SACL    SCRACH
        LAC     TEMP1
        SACH    TEMP1        ; SIGN = FFFF OR 0000
        LACK    SBASE
        ADD     TEMP2,1      ; CALCULATE PCM SHIFT ADDRESS
        CALA
        SUB     BIAS,12      ; 0000000X XXXXXXXX XXXX0000 00000000
        SACH    SAMPLE,4
        LAC     SAMPLE       ; 000XXXXX XXXXXXXX
        XOR     TEMP1        ; POS - DO NOTHING : NEG - 1's COMP
        SUB     TEMP1        ; POS - DO NOTHING : NEG - 2's COMP
        SACL    SAMPLE
        .
        .
        .
*;
SBASE   LAC     SCRACH,5     ; 00000000 0000001M MMM10000 00000000
        RET
        LAC     SCRACH,6     ; 00000000 000001MM MM100000 00000000
        RET
        LAC     SCRACH,7     ; 00000000 00001MMM M1000000 00000000
        RET
        LAC     SCRACH,8     ; 00000000 0001MMMM 10000000 00000000
        RET
        LAC     SCRACH,9     ; 00000000 001MMMM1 00000000 00000000
        RET
        LAC     SCRACH,10    ; 00000000 01MMMM10 00000000 00000000
        RET
        LAC     SCRACH,11    ; 00000000 1MMMM100 00000000 00000000
        RET
        LAC     SCRACH,12    ; 00000001 MMMM1000 00000000 00000000
        RET
```

Figure 20. μ-Law Expansion Code

```
        LAC     SR              ; GET RECONSTRUCTED SIGNAL
*;
*; COMPRESS--CONVERT TO PCM
*;
CMPRSU  SACH    TEMP4           ; SAVE SIGN OF SR
        ABS
        ADD     BIAS            ; ADD BIAS
        SACL    SCRACH          ; SAVE BIASED PCM VALUE
        SUB     ONE,9           ; EXP = 7 - 4 OR 3 - 0
        BGEZ    SCL427
SCL023  ADD     THREE,7         ; EXP = 3 - 2 OR 1 - 0
        BGEZ    SCL223
SCL021  ADD     ONE,6           ; EXP = 1 OR 0
        BGEZ    SCALE1
SCALE0  LAC     M15,1           ; EXP = 0
        AND     SCRACH          ; MASK FOR MANTISSA
        SACL    SCRACH
        ADD     BIAS
        SACL    SAMPLE          ; BIASED QUANTIZED VALUE
        LAC     SCRACH,15
        LARK    0,0
        B       FINI
SCALE1  LAC     M15,2           ; EXP = 1
        AND     SCRACH          ; MASK FOR MANTISSA
        SACL    SCRACH
        ADD     BIAS,1
        SACL    SAMPLE          ; BIASED QUANTIZED VALUE
        LAC     SCRACH,14
        LARK    0,1
        B       FINI
        .
        .
        .
FINI    SACH    SCRACH          ; SAVE NORMALIZED MANTISSA
        LAC     SCRACH
        SAR     0,TEMP1
        ADD     TEMP1,4         ; ADD EXPONENT
CLNUP   ADD     TEMP4,7
        AND     M255
        SACL    SCRACH          ; 2's COMPLEMENT OF MULAW-PCM
        LAC     SAMPLE          ; REMOVE BIAS FROM QUANTIZED VALUE
        SUB     BIAS
        XOR     TEMP4
        SUB     TEMP4
        SACL    SAMPLE          ; 2's COMPLEMENT OF QUANTIZED SAMPLE
*;
        CALL    AQUAN
*;
        CALL    SYNC
*;
        XOR     M255            ; FLIP BITS FOR TRANSMISSION
        SACL    SCRACH
        OUT     SCRACH,DAC
```

Figure 21. μ-Law Compression Code

The predictor filter implementation is also modified from what has been previously presented. In the CCITT recommendation, the processing of the signal through the predictor filter is performed in a floating-point format. This requirement leads to several modifications. First, all input signals to the filter, $d_q(k)$ and $s_r(k)$, must be converted to a floating-point notation. The conversion to this notation is accomplished by a binary search of the original fixed-point word. As previously mentioned, this technique is explained in some detail in the application report, FLOATING-POINT ARITHMETIC WITH THE TMS32010. Second, the filter coefficients, $a_i(k)$ and $b_i(k)$, must also be floated for each sample so that a floating-point multiply can be executed for each filter tap.

Accumulation of the filter taps is carried out in fixed-point notation. Fixing a floating-point number is equivalent to the scaling presented for taking the anti-log of a number. Some of the floating-point results must be left-shifted, while others need to be right-shifted. The shift is accomplished by use of a scaling factor or multiplier, selected by the exponent sum of the floating-point multiply. Positive multipliers are used to indicate what is effectively a right shift with the result being stored from the high half of the accumulator. Negative multipliers indicate that the result is in the low half of the accumulator and is used for values which have been left shifted.

The process of a single filter tap, not including the code to float the signal and the coefficient, is shown in Figure 22.

```
*;*********************************************************
*;
*;  COMPUTE SEZ -- PARTIAL SIGNAL ESTIMATE
*;
*;  SEZ(k) = B1(k-1)*DQ(k-1) + ... + B6(k-1)*DQ(k-6)
*;
*;      MULTIPLIES ARE DONE IN FLOATING POINT
*;        DQ's ARE STORED IN FLOATING-POINT NOTATION
*;        B's ARE FLOATED EACH PASS
*;
*;      NOTATION: DQnEXP    -- 4 bits + OFFSET
*;                DQnMAN*8 -- 9 bits
*;                Bn        -- 16 b TC ; q14
*;                SEZ       -- 16 b TC ; q0
*;
*;*********************************************************
*;
SIGDIF  LAC     B6,14     ; COMPUTE B6*DQ5.
        CALL    FLOAT     ; RET/W MANTISSA IN TEMP1; EXP IN ACC.
        ADD     DQ5EXP
        SACL    SUM1
        LAR     0,SUM1    ; EXP OF PRODUCT.
        LT      DQ5MAN    ; DQnMAN SCALED BY 2**3.
        LAC     THREE,7   ; PRODUCT FUDGE FACTOR (48*8).
        MPY     TEMP1
        LTA     *,0       ; B6MAN*(DQ5MAN*8)+(48*8)
        AND     KFF80     ; SAVE ONLY 8 MSB'S.
        SACL    TEMP1
        MPY     TEMP1     ; APPLY SHIFT FACTOR.
        PAC
        BLZ     RS1       ; EXP >= 26
        SACH    SUM1,1    ; EXP <  26
CHK1    ZALS    B6        ; CHECK SIGN OF PRODUCT.
        XOR     SDQ6
        AND     K32768
        BZ      POS1
NEG1    ZAC               ; NEGATE IF NECESSARY.
        SUB     SUM1
```

Figure 22. Predictor Filter Execution

```
         SACL    SUM1
POS1     LAC     B5,14     ; COMPUTE B5*DQ4.
         .
         .
         .
RS1      ABS               ; MAKE POSITIVE BEFORE MASK.
         AND     M32767    ; KEEP LOWER 15 BITS.
         SACL    SUM1      ; SAVE RESULT.
         B       CHK1
```

Figure 22. Predictor Filter Execution (Concluded)

SUMMARY

The TMS32010 provides an efficient solution to transcoding a 64-kbit/s PCM signal to a 32-kbit/s bit stream. Transcoding, as described in this application report, is an effective way to maintain the signal quality provided by 7-bit PCM while reducing the data rate.

The basic ADPCM algorithm has been implemented in two slightly different ways. One solution provides CCITT bit-for-bit compatibility. Using this algorithm, a half-duplex transcoder is created that can transcode either A-law or μ-law signals as either a transmitter or a receiver. No external program memory is required for this implementation, although it does require the use of a 25-MHz TMS32010 microprocessor. The second described solution is particularly attractive since it uses a single, 20.5-MHz TMS32010 microprocessor that requires no external program memory to perform a real-time full-duplex (non-CCITT) channel transcoding.

In selecting one of these two solutions, the primary consideration is the network interfacing requirement. For systems that only have analog interfaces to other parts of the network, the full-duplex solution will provide the best choice. On the other hand, a network that may include a digital interface to other ADPCM transcoders will probably require the CCITT bit-compatible solution. Both solutions provide high-quality signal transcoding.

A complete assembled code listing is provided in the appendix of this report and is also available in 1600-BPI VAX/VMS tape format. The software may be purchased by ordering the TMS32010 Software Exchange Library, TMDC3240212-18, from Texas Instruments. For further information, please contact your nearest TI sales representative.

REFERENCES

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Companding Routines for the TMS32010, Texas Instruments Incorporated (1984).

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Appendix

ADPCM Assembly Language Programs

```
                    COPY    INPUT.ASM
                    IDT     'CCITT'
                    OPTION  XREF
                *;
                *;*******************************************************
                *;*******************************************************
                *; This is the source module for a half-duplex CCITT
                *; compatible 32-kbps ADPCM speech system. The transmitter
                *; assumes that log-PCM data will be available at each
                *; interrupt (every 125 microseconds) in the lower 8 bits of
                *; the data bus via I/O port 1 and it supplies ADPCM data on
                *; the lower 4 bits of the bus via port 2. The receiver does
                *; the inverse.  An interrupt in this case is determined by
                *; polling the BIO line, with a low signal level signifying
                *; the presence of a new data sample.
                *;
                *; The 'R' reset function in the CCITT spec is implemented
                *; with a hardware reset. At the time of reset, it is
                *; assumed that the operating mode has been established and
                *; input via the upper two bits of the data bus.  The bit
                *; condition is read from port 0 so as not to disrupt any
                *; pending data sample on either of the other two ports.
                *; Since it is anticipated that the mode pins will be
                *; selected and maintained in a manner similar to a hardwire
                *; selection, the actual port from which the mode is read
                *; is arbitrary.
                *;
                *;*******************************************************
                *;
                *; System I/O channel assignments
                *;
          0001  ADC     EQU     1       ; codec input
          0001  DAC     EQU     1       ; codec output
          0002  CCITT   EQU     2       ; adpcm output/input
          0000  CTL     EQU     0       ; control input to select mode
                *;                      ; 0000 = mulaw transmitter
                *;                      ; 4000 = mulaw receiver
                *;                      ; 8000 = alaw transmitter
                *;                      ; C000 = alaw receiver
                *;
                *;*******************************************************
     0000               AORG    0
                *;
     0000 F900          B       RESET   ; power-up reset
     0001 0542
                *;
                *;*******************************************************
                *; INTERRUPT HANDLING ROUTINE -- SYSTEM HANDLES CODEC
                *; SAMPLES ON A SAMPLE BY SAMPLE BASIS.
                *;*******************************************************
                *;
     0002 F900  INTRPT B        INTRPT
     0003 0002
                *;
```



```
                *;
                *;  MU-LAW TRANSMITTER
                *;
     0004 411B  XMTMU  IN       SCRACH,ADC  ; input mu-law PCM
                *;
                *;*******************************************************
                *; MU-LAW TO LINEAR PCM EXPANSION
                *;
                *;     INPUT:  MU-LAW PCM SAMPLE  -- S  (SCRACH)
                *;
                *;     OUTPUT: LINEAR PCM SAMPLE  -- SL (SAMPLE)
                *;
                *;     NOTATION:  S  -- 8b SM (Q4)
                *;                SL -- 14b TC (Q0)
                *;
                *;*******************************************************
                *;
                *;              S    +--------+  SL
                *;          ------->| EXPAND |------->
                *;                   +--------+
                *;
                *;*******************************************************
                *;
     0005 281B  EXPNDU LAC      SCRACH,8    ; seee mmmm 0000 0000
     0006 7875         XOR      KFF00       ; SEEE MMMM 0000 0000
     0007 5021         SACL     TEMP1       ; save value for PCM sign
     0008 7974         AND      M32767      ; 0EEE MMMM 0000 0000
     0009 5C22         SACH     TEMP2,4     ; save exponent value
     000A 7972         AND      M4095       ; 0000 MMMM 0000 0000
     000B 074D         ADD      BIAS,7      ; 0001 MMMM 1000 0000
     000C 501B         SACL     SCRACH
     000D 2021         LAC      TEMP1
     000E 5821         SACH     TEMP1       ; sign = FFFF or 0000
     000F 7E24         LACK     SBASE
     0010 0122         ADD      TEMP2,1     ; calculate PCM shift address
     0011 7F8C         CALA
     0012 1C4D         SUB      BIAS,12 ; 0000000X XXXXXXXX XXXX0000 00000000
     0013 5C26         SACH     SAMPLE,4
     0014 2026         LAC      SAMPLE      ; 000X XXXX XXXX XXXX
     0015 7821         XOR      TEMP1       ; pos - no change : neg - 1's compl
     0016 1021         SUB      TEMP1       ; pos - no change : neg - 2's compl
     0017 5026         SACL     SAMPLE
                *;
                *; Now convert PCM value in SAMPLE to ADPCM value in I
                *;
     0018 F800  GETI   CALL     SIGDIF
     0019 01B3
     001A F800         CALL     AQUAN
     001B 02AA
     001C 5001         SACL     I
     001D 4A01         OUT      I,CCITT     ; output ADPCM
     001E F800         CALL     PRDICT
     001F 0355
     0020 F600  MULAWX BIOZ     XMTMU       ; wait for next sample
     0021 0004
     0022 F900         B        MULAWX
     0023 0020
```

```
A0105                  *;
A0106 0024 251B  SBASE  LAC     SCRACH,5  ; 00000000 0000001M MMM10000 00000000
A0107 0025 7F8D         RET
A0108 0026 261B         LAC     SCRACH,6  ; 00000000 000001MM MM100000 00000000
A0109 0027 7F8D         RET
A0110 0028 271B         LAC     SCRACH,7  ; 00000000 00001MMM M1000000 00000000
A0111 0029 7F8D         RET
A0112 002A 281B         LAC     SCRACH,8  ; 00000000 0001MMMM 10000000 00000000
A0113 002B 7F8D         RET
A0114 002C 291B         LAC     SCRACH,9  ; 00000000 001MMMM1 00000000 00000000
A0115 002D 7F8D         RET
A0116 002E 2A1B         LAC     SCRACH,10 ; 00000000 01MMMM10 00000000 00000000
A0117 002F 7F8D         RET
A0118 0030 2B1B         LAC     SCRACH,11 ; 00000000 1MMMM100 00000000 00000000
A0119 0031 7F8D         RET
A0120 0032 2C1B         LAC     SCRACH,12 ; 00000001 MMMM1000 00000000 00000000
A0121 0033 7F8D         RET
```



```
A0123                  *;
A0124                  *;  A-LAW TRANSMITTER
A0125                  *;
A0126 0034 411B  XMTA   IN      SCRACH,ADC  ; input A-law PCM
A0127                  *;
A0128                  *;*******************************************************
A0129                  *; A-LAW TO LINEAR PCM EXPANSION
A0130                  *;
A0131                  *;      INPUT:  A-LAW PCM SAMPLE  -- S  (SCRACH)
A0132                  *;
A0133                  *;      OUTPUT: LINEAR PCM SAMPLE  -- SL (SAMPLE)
A0134                  *;
A0135                  *;      NOTATION:  S  -- 8b SM (Q4)
A0136                  *;                 SL -- 14b TC (Q0)
A0137                  *;
A0138                  *;*******************************************************
A0139                  *;
A0140                  *;               S    +--------+  SL
A0141                  *;            ------->| EXPAND |------->
A0142                  *;                    +--------+
A0143                  *;
A0144                  *;*******************************************************
A0145                  *;
A0146 0035 281B  EXPNDA LAC     SCRACH,8    ; sEEE MMMM 0000 0000
A0147 0036 7848         XOR     K32768      ; SEEE MMMM 0000 0000
A0148 0037 5021         SACL    TEMP1       ; save value for PCM sign
A0149 0038 7974         AND     M32767      ; 0EEE MMMM 0000 0000
A0150 0039 5C22         SACH    TEMP2,4     ; save exponent value
A0151 003A 7972         AND     M4095       ; 0000 MMMM 0000 0000
A0152 003B 501B         SACL    SCRACH
A0153 003C 2021         LAC     TEMP1
A0154 003D 5821         SACH    TEMP1       ; sign = FFFF or 0000
A0155 003E 7E52         LACK    SBASEA
A0156 003F 0222         ADD     TEMP2,2     ; calculate PCM shift address
A0157 0040 7F8C         CALA
A0158 0041 5C26         SACH    SAMPLE,4
A0159 0042 2026         LAC     SAMPLE      ; 000X XXXX XXXX XXXX
A0160 0043 7821         XOR     TEMP1       ; pos - no change : neg - 1's compl
A0161 0044 1021         SUB     TEMP1       ; pos - no change : neg - 2's compl
A0162 0045 5026         SACL    SAMPLE
A0163                  *
A0164                  *;
A0165                  *; Now convert PCM value in SAMPLE to ADPCM value in I
A0166                  *;
A0167 0046 F800         CALL    SIGDIF
      0047 01B3
A0168 0048 F800         CALL    AQUAN
      0049 02AA
A0169 004A 5001         SACL    I
A0170 004B 4A01         OUT     1,CCITT     ; output ADPCM
A0171 004C F800         CALL    PROICT
      004D 0355
A0172 004E F600  ALAWX  BIOZ    XMTA        ; wait for next sample
      004F 0034
A0173 0050 F900         B       ALAWX
      0051 004E
A0174                  *;
```

```
A0175 0052 261B  SBASEA LAC     SCRACH,6   ; 00000000 000000MM MM000000 00000000
A0176 0053 0D4C         ADD     ONE,13     ; 00000000 000000MM MM100000 00000000
A0177 0054 7F8D         RET
A0178 0055 7F80         NOP
A0179 0056 261B         LAC     SCRACH,6   ; 00000000 000001MM MM100000 00000000
A0180 0057 0671         ADD     BIASA,6    ; 00000000 000001MM MM100000 00000000
A0181 0058 7F8D         RET
A0182 0059 7F80         NOP
A0183 005A 271B         LAC     SCRACH,7   ; 00000000 00000MMM M0000000 00000000
A0184 005B 0771         ADD     BIASA,7    ; 00000000 00001MMM M1000000 00000000
A0185 005C 7F8D         RET
A0186 005D 7F80         NOP
A0187 005E 281B         LAC     SCRACH,8   ; 00000000 0000MMMM 00000000 00000000
A0188 005F 0871         ADD     BIASA,8    ; 00000000 0001MMMM 10000000 00000000
A0189 0060 7F8D         RET
A0190 0061 7F80         NOP
A0191 0062 291B         LAC     SCRACH,9   ; 00000000 000MMMM0 00000000 00000000
A0192 0063 0971         ADD     BIASA,9    ; 00000000 001MMMM1 00000000 00000000
A0193 0064 7F8D         RET
A0194 0065 7F80         NOP
A0195 0066 2A1B         LAC     SCRACH,10  ; 00000000 00MMMM00 00000000 00000000
A0196 0067 0A71         ADD     BIASA,10   ; 00000000 01MMMM10 00000000 00000000
A0197 0068 7F8D         RET
A0198 0069 7F80         NOP
A0199 006A 2B1B         LAC     SCRACH,11  ; 00000000 0MMMM000 00000000 00000000
A0200 006B 0B71         ADD     BIASA,11   ; 00000000 1MMMM100 00000000 00000000
A0201 006C 7F8D         RET
A0202 006D 7F80         NOP
A0203 006E 2C1B         LAC     SCRACH,12  ; 00000000 MMMM0000 00000000 00000000
A0204 006F 0C71         ADD     BIASA,12   ; 00000001 MMMM1000 00000000 00000000
A0205 0070 7F8D         RET
```



```
A0207                *;
A0208                *;  MU-LAW RECEIVER
A0209                *;
A0210 0071 4201 RCVMU  IN     I,CCITT       ; input ADPCM
A0211                *;
A0212 0072 2001        LAC    I             ; determine magnitude of ADPCM
A0213 0073 5002        SACL   IM
A0214 0074 134C        SUB    ONE,3
A0215 0075 FA00        BLZ    DO32KU
      0076 007A
A0216 0077 2002        LAC    IM
A0217 0078 786D        XOR    M15
A0218 0079 5002        SACL   IM
A0219                *;
A0220                *; compute pcm output
A0221                *;
A0222 007A F800 DO32KU CALL   SIGDIF
      007B 01B3
A0223 007C F800        CALL   PRDICT
      007D 0355
A0224                *;
A0225                *;*******************************************************
A0226                *; LINEAR TO U-LAW PCM COMPRESSION/U-LAW TO LINEAR EXPANSION
A0227                *;
A0228                *;     INPUT:  LINEAR PCM SAMPLE  -- SR
A0229                *;
A0230                *;     OUTPUT: A-LAW PCM SAMPLE   -- SP  (SCRACH)
A0231                *;             LINEAR PCM SAMPLE  -- SLX (SAMPLE)
A0232                *;
A0233                *;     NOTATION:  SR  -- 16b TC (Q0)
A0234                *;                SP  -- 8b SM (Q4)
A0235                *;                SLX -- 14b TC (Q0)
A0236                *;
A0237                *;*******************************************************
A0238                *;
A0239                *;      SR   +----------+       SP    +--------+  SLX
A0240                *;    ------>| COMPRESS |-----*------>| EXPAND |------->
A0241                *;           +----------+     |       +--------+
A0242                *;                            |                  SP
A0243                *;                            +---------------------->
A0244                *;
A0245                *;*******************************************************
A0246                *;
A0247 007E 2013        LAC    SR            ; get reconstructed signal
A0248                *;
A0249                *; compress--convert to pcm
A0250                *;
A0251 007F 5824 CMPRSU SACH   TEMP4         ; save sign of SR
A0252 0080 7F88        ABS
A0253 0081 004D        ADD    BIAS          ; add bias
A0254 0082 501B        SACL   SCRACH        ; save biased PCM value
A0255 0083 194C        SUB    ONE,9         ; exp = 7 - 4 or 3 - 0
A0256 0084 FD00        BGEZ   SCL427
      0085 00B3
A0257 0086 077D SCL023 ADD    THREE,7       ; exp = 3 - 2 or 1 - 0
A0258 0087 FD00        BGEZ   SCL223
```

```
A0259 0089 064C  SCL021 ADD   ONE,6        ; exp = 1 or 0
A0260 008A FD000        BGEZ  SCALE1
      008B 0095
A0261 008C 2160  SCALE0 LAC   M15,1        ; exp = 0
A0262 008D 791B         AND   SCRACH       ; mask for mantissa
A0263 008E 501B         SACL  SCRACH
A0264 008F 004D         ADD   BIAS
A0265 0090 5026         SACL  SAMPLE       ; biased quantized value
A0266 0091 2F1B         LAC   SCRACH,15
A0267 0092 7000         LARK  0,0
A0268 0093 F900         B     FINI
      0094 00E6
A0269 0095 2260  SCALE1 LAC   M15,2        ; exp = 1
A0270 0096 791B         AND   SCRACH       ; mask for mantissa
A0271 0097 501B         SACL  SCRACH
A0272 0098 014D         ADD   BIAS,1
A0273 0099 5026         SACL  SAMPLE       ; biased quantized value
A0274 009A 2E1B         LAC   SCRACH,14
A0275 009B 7001         LARK  0,1
A0276 009C F900         B     FINI
      009D 00E6
A0277 009E 174C  SCL223 SUB   ONE,7        ; exp = 3 or 2
A0278 009F FD00         BGEZ  SCALE3
      00A0 00AA
A0279 00A1 236D  SCALE2 LAC   M15,3        ; exp = 2
A0280 00A2 791B         AND   SCRACH       ; mask for mantissa
A0281 00A3 501B         SACL  SCRACH
A0282 00A4 024D         ADD   BIAS,2
A0283 00A5 5026         SACL  SAMPLE       ; biased quantized value
A0284 00A6 2D1B         LAC   SCRACH,13
A0285 00A7 7002         LARK  0,2
A0286 00A8 F900         B     FINI
      00A9 00E6
A0287 00AA 246D  SCALE3 LAC   M15,4        ; exp = 3
A0288 00AB 791B         AND   SCRACH       ; mask for mantissa
A0289 00AC 501B         SACL  SCRACH
A0290 00AD 034D         ADD   BIAS,3
A0291 00AE 5026         SACL  SAMPLE       ; biased quantized value
A0292 00AF 2C1B         LAC   SCRACH,12
A0293 00B0 7003         LARK  0,3
A0294 00B1 F900         B     FINI
      00B2 00E6
A0295 00B3 197D  SCL427 SUB   THREE,9      ; exp = 7 - 6 or 5 - 4
A0296 00B4 FD00         BGEZ  SCL627
      00B5 00CB
A0297 00B6 0A4C  SCL425 ADD   ONE,10       ; exp = 5 or 4
A0298 00B7 FD00         BGEZ  SCALE5
      00B8 00C2
A0299 00B9 256D  SCALE4 LAC   M15,5        ; exp = 4
A0300 00BA 791B         AND   SCRACH       ; mask for mantissa
A0301 00BB 501B         SACL  SCRACH
A0302 00BC 044D         ADD   BIAS,4
A0303 00BD 5026         SACL  SAMPLE       ; biased quantized value
A0304 00BE 2B1B         LAC   SCRACH,11
A0305 00BF 7004         LARK  0,4
A0306 00C0 F900         B     FINI
      00C1 00E6
```



```
A0307 00C2 266D  SCALE5 LAC   M15,6        ; exp = 5
A0308 00C3 791B         AND   SCRACH       ; mask for mantissa
A0309 00C4 501B         SACL  SCRACH
A0310 00C5 054D         ADD   BIAS,5
A0311 00C6 5026         SACL  SAMPLE       ; biased quantized value
A0312 00C7 2A1B         LAC   SCRACH,10
A0313 00C8 7005         LARK  0,5
A0314 00C9 F900         B     FINI
      00CA 00E6
A0315 00CB 1B4C  SCL627 SUB   ONE,11       ; exp = 7 or 6
A0316 00CC FD00         BGEZ  SCALE7
      00CD 00D7
A0317 00CE 276D  SCALE6 LAC   M15,7        ; exp = 6
A0318 00CF 791B         AND   SCRACH       ; mask for mantissa
A0319 00D0 501B         SACL  SCRACH
A0320 00D1 064D         ADD   BIAS,6
A0321 00D2 5026         SACL  SAMPLE       ; biased quantized value
A0322 00D3 291B         LAC   SCRACH,9
A0323 00D4 7006         LARK  0,6
A0324 00D5 F900         B     FINI
      00D6 00E6
A0325 00D7 1C4C  SCALE7 SUB   ONE,12       ; exp = 7
A0326 00D8 FA00         BLZ   NORMAL       ; mag > 8191 ?
      00D9 00DF
A0327 00DA 2767  SATCH  LAC   K63,7
A0328 00DB 5026         SACL  SAMPLE       ; save max biased quantized value
A0329 00DC 7E7F         LACK  127          ; set maximum mulaw magnitude
A0330 00DD F900         B     CLNUP
      00DE 00EA
A0331 00DF 286D  NORMAL LAC   M15,8
A0332 00E0 791B         AND   SCRACH       ; mask for mantissa
A0333 00E1 501B         SACL  SCRACH
A0334 00E2 074D         ADD   BIAS,7
A0335 00E3 5026         SACL  SAMPLE       ; biased quantized value
A0336 00E4 281B         LAC   SCRACH,8
A0337 00E5 7007         LARK  0,7
A0338 00E6 581B  FINI   SACH  SCRACH       ; save normalized mantissa
A0339 00E7 201B         LAC   SCRACH
A0340 00E8 3021         SAR   0,TEMP1
A0341 00E9 0421         ADD   TEMP1,4      ; add exponent
A0342 00EA 0724  CLNUP  ADD   TEMP4,7
A0343 00EB 7947         AND   M255
A0344 00EC 501B         SACL  SCRACH       ; signed magnitude of mulaw-PCM
A0345 00ED 2026         LAC   SAMPLE       ; remove bias from quantized value
A0346 00EE 104D         SUB   BIAS
A0347 00EF 7824         XOR   TEMP4
A0348 00F0 1024         SUB   TEMP4
A0349 00F1 5026         SACL  SAMPLE       ; 2's complement of quantized sample
A0350                  *;
A0351 00F2 F800         CALL  AQUAN
      00F3 02AA
A0352                  *;
A0353 00F4 F800         CALL  SYNC
      00F5 0188
A0354                  *;
A0355 00F6 7847         XOR   M255         ; flip bits for transmission
A0356 00F7 501B         SACL  SCRACH
```

```
A0357 00F8 491B          OUT     SCRACH,DAC   ; output mu-law PCM
A0358 00F9 F600  MULAWR BIOZ     RCVMU        ; wait for next sample
      00FA 0071
A0359 00FB F900          B       MULAWR
      00FC 00F9
```



```
A0361            *;
A0362            *;  A-LAW RECEIVER
A0363            *;
A0364 00FD 4201  RCVA   IN      1,CCITT     ; input ADPCM
A0365            *;
A0366 00FE 2001         LAC     I           ; determine magnitude of ADPCM
A0367 00FF 5002         SACL    IM
A0368 0100 134C         SUB     ONE,3
A0369 0101 FA00         BLZ     DO32KA
      0102 0106
A0370 0103 2002         LAC     IM
A0371 0104 786D         XOR     M15
A0372 0105 5002         SACL    IM
A0373            *;
A0374            *; compute pcm output
A0375            *;
A0376 0106 F800  DO32KA CALL    SIGDIF
      0107 01B3
A0377 0108 F800         CALL    PRDICT
      0109 0355
A0378            *;
A0379            *;*******************************************************
A0380            *; LINEAR TO A-LAW PCM COMPRESSION/A-LAW TO LINEAR EXPANSION
A0381            *;
A0382            *;     INPUT:  LINEAR PCM SAMPLE  -- SR
A0383            *;
A0384            *;     OUTPUT: A-LAW PCM SAMPLE   -- SP  (SCRACH)
A0385            *;             LINEAR PCM SAMPLE  -- SLX (SAMPLE)
A0386            *;
A0387            *;     NOTATION:  SR  -- 16b TC (Q0)
A0388            *;                SP  -- 8b SM (Q4)
A0389            *;                SLX -- 14b TC (Q0)
A0390            *;
A0391            *;*******************************************************
A0392            *;
A0393            *;     SR   +----------+       SP    +--------+  SLX
A0394            *;    ------>| COMPRESS |-----*------>| EXPAND |------->
A0395            *;          +----------+     |       +--------+
A0396            *;                           |                 SP
A0397            *;                           +---------------------->
A0398            *;
A0399            *;*******************************************************
A0400            *;
A0401 010A 2013         LAC     SR          ; get reconstructed signal
A0402            *;
A0403            *; compress--convert to pcm
A0404            *;
A0405 010B 5824  CMPRSA SACH    TEMP4       ; save sign of SR
A0406 010C 7F88         ABS
A0407 010D 0024         ADD     TEMP4       ; add 1 for negative vals
A0408 010E 501B         SACL    SCRACH      ; save PCM value
A0409 010F 194C         SUB     ONE,9       ; exp = 7 - 4 or 3 - 0
A0410 0110 FD00         BGEZ    SCL4T7
      0111 013F
A0411 0112 077D  SCL0T3 ADD     THREE,7     ; exp = 3 - 2 or 1 - 0
A0412 0113 FD00         BGEZ    SCL2T3
      0114 012A
```

```
A0413 0115 064C  SCL0T1 ADD    ONE,6        ; exp = 1 or 0
A0414 0116 FD00         BGEZ   SCAL1A
      0117 0121
A0415 0118 226D  SCAL0A LAC    M15,2        ; exp = 0
A0416 0119 791B         AND    SCRACH       ; mask for mantissa
A0417 011A 501B         SACL   SCRACH
A0418 011B 014C         ADD    ONE,1
A0419 011C 5026         SACL   SAMPLE       ; quantized value
A0420 011D 2E1B         LAC    SCRACH,14
A0421 011E 7000         LARK   0,0
A0422 011F F900         B      FINISH
      0120 0172
A0423 0121 226D  SCAL1A LAC    M15,2        ; exp = 1
A0424 0122 791B         AND    SCRACH       ; mask for mantissa
A0425 0123 501B         SACL   SCRACH
A0426 0124 014D         ADD    BIAS,1
A0427 0125 5026         SACL   SAMPLE       ; quantized value
A0428 0126 2E1B         LAC    SCRACH,14
A0429 0127 7001         LARK   0,1
A0430 0128 F900         B      FINISH
      0129 0172
A0431 012A 174C  SCL2T3 SUB    ONE,7        ; exp = 3 or 2
A0432 012B FD00         BGEZ   SCAL3A
      012C 0136
A0433 012D 236D  SCAL2A LAC    M15,3        ; exp = 2
A0434 012E 791B         AND    SCRACH       ; mask for mantissa
A0435 012F 501B         SACL   SCRACH
A0436 0130 024D         ADD    BIAS,2
A0437 0131 5026         SACL   SAMPLE       ; quantized value
A0438 0132 2D1B         LAC    SCRACH,13
A0439 0133 7002         LARK   0,2
A0440 0134 F900         B      FINISH
      0135 0172
A0441 0136 246D  SCAL3A LAC    M15,4        ; exp = 3
A0442 0137 791B         AND    SCRACH       ; mask for mantissa
A0443 0138 501B         SACL   SCRACH
A0444 0139 034D         ADD    BIAS,3
A0445 013A 5026         SACL   SAMPLE       ; quantized value
A0446 013B 2C1B         LAC    SCRACH,12
A0447 013C 7003         LARK   0,3
A0448 013D F900         B      FINISH
      013E 0172
A0449 013F 197D  SCL4T7 SUB    THREE,9      ; exp = 7 - 6 or 5 - 4
A0450 0140 FD00         BGEZ   SCL6T7
      0141 0157
A0451 0142 0A4C  SCL4T5 ADD    ONE,10       ; exp = 5 or 4
A0452 0143 FD00         BGEZ   SCAL5A
      0144 014E
A0453 0145 256D  SCAL4A LAC    M15,5        ; exp = 4
A0454 0146 791B         AND    SCRACH       ; mask for mantissa
A0455 0147 501B         SACL   SCRACH
A0456 0148 044D         ADD    BIAS,4
A0457 0149 5026         SACL   SAMPLE       ; quantized value
A0458 014A 2B1B         LAC    SCRACH,11
A0459 014B 7004         LARK   0,4
A0460 014C F900         B      FINISH
      014D 0172
```



```
A0461 014E 266D  SCAL5A LAC    M15,6        ; exp = 5
A0462 014F 791B         AND    SCRACH       ; mask for mantissa
A0463 0150 501B         SACL   SCRACH
A0464 0151 054D         ADD    BIAS,5
A0465 0152 5026         SACL   SAMPLE       ; quantized value
A0466 0153 2A1B         LAC    SCRACH,10
A0467 0154 7005         LARK   0,5
A0468 0155 F900         B      FINISH
      0156 0172
A0469 0157 1B4C  SCL6T7 SUB    ONE,11       ; exp = 7 or 6
A0470 0158 FD00         BGEZ   SCAL7A
      0159 0163
A0471 015A 276D  SCAL6A LAC    M15,7        ; exp = 6
A0472 015B 791B         AND    SCRACH       ; mask for mantissa
A0473 015C 501B         SACL   SCRACH
A0474 015D 064D         ADD    BIAS,6
A0475 015E 5026         SACL   SAMPLE       ; quantized value
A0476 015F 291B         LAC    SCRACH,9
A0477 0160 7006         LARK   0,6
A0478 0161 F900         B      FINISH
      0162 0172
A0479 0163 1C4C  SCAL7A SUB    ONE,12       ; exp = 7
A0480 0164 FA00         BLZ    NORMLA       ; mag > 8191 ?
      0165 0168
A0481 0166 2767  SATCHA LAC    K63,7
A0482 0167 5026         SACL   SAMPLE       ; save maximum quantized value
A0483 0168 7E7F         LACK   127          ; save maximum alaw magnitude
A0484 0169 F900         B      CLNUPA
      016A 0176
A0485 016B 286D  NORMLA LAC    M15,8
A0486 016C 791B         AND    SCRACH       ; mask for mantissa
A0487 016D 501B         SACL   SCRACH
A0488 016E 074D         ADD    BIAS,7
A0489 016F 5026         SACL   SAMPLE       ; quanitzed value
A0490 0170 281B         LAC    SCRACH,8
A0491 0171 7007         LARK   0,7
A0492 0172 581B  FINISH SACH   SCRACH       ; save normalized mantissa
A0493 0173 201B         LAC    SCRACH
A0494 0174 3021         SAR    0,TEMP1
A0495 0175 0421         ADD    TEMP1,4      ; add exponent
A0496 0176 0724  CLNUPA ADD    TEMP4,7
A0497 0177 7947         AND    M255
A0498 0178 501B         SACL   SCRACH       ; signed magnitude of alaw-PCM
A0499 0179 2026         LAC    SAMPLE
A0500 017A 7824         XOR    TEMP4
A0501 017B 1024         SUB    TEMP4
A0502 017C 5026         SACL   SAMPLE       ; 2's complement of quantized sample
A0503            *;
A0504 017D F800         CALL   AQUAN
      017E 02AA
A0505            *;
A0506 017F F800         CALL   SYNC
      0180 0188
A0507            *;
A0508 0181 787F         XOR    M0080        ; flip bits for transmission
A0509 0182 501B         SACL   SCRACH
A0510 0183 491B         OUT    SCRACH,DAC   ; output A-law PCM
```

```
0184 F600  ALAWR  BIOZ    RCVA          ; wait for next sample
0185 00FD
0186 F900         B       ALAWR
0187 0184
```



```
                  *;
                  *;*******************************************************
                  *; SYNCHRONOUS CODING ADJUSTMENT
                  *;
                  *;     INPUT:  LOG PCM SAMPLE      -- SP  (SCRACH)
                  *;             RECEIVED ADPCM      -- I
                  *;             REGENERATED ADPCM   -- ID  (TEMP1)
                  *;
                  *;     OUTPUT: ADJUSTED LOG PCM    -- SD  (SCRACH)
                  *;
                  *;     NOTATION:  I   -- 4b SM (Q0)
                  *;                ID  -- 4b SM (Q0)
                  *;                SP  -- 8b SM (Q4)
                  *;                SD  -- 8b SM (Q4)
                  *;
                  *;*******************************************************
                  *;
                  *;                I    +------+
                  *;              ------>|      |
                  *;                ID   |      |   SD
                  *;              ------>| SYNC |-------->
                  *;                SP   |      |
                  *;              ------>|      |
                  *;                     +------+
                  *;
                  *;*******************************************************
                  *;
0188 7838  SYNC   XOR     EIGHT
0189 5021         SACL    TEMP1         ; flip the polarity bit in ID
018A 234C         LAC     ONE,3
018B 7801         XOR     I             ; flip the polarity bit in I
018C 1021         SUB     TEMP1         ; IM - ID
018D FA00         BLZ     IDGTIM        ; ID > IM ... -
018E 01A0
018F FF00         BZ      IDEQIM        ; ID = IM
0190 01B1
0191 201B  IDLTIM LAC     SCRACH        ; ID < IM ... +
0192 106F         SUB     M127
0193 FC00         BGZ     SUBONE
0194 019B
0195 FF00         BZ      MAXPOS
0196 0199
0197 074C         ADD     ONE,7         ; SD = SP + 1 : 0 <= SP < 127
0198 7F8D         RET                   ,
0199 7E7F  MAXPOS LACK    127           ; SD = 127    : SP = 127
019A 7F8D         RET
019B 104C  SUBONE SUB     ONE
019C FF00         BZ      ANOMLE        ; SD = 0      : SP = 128
019D 019F
019E 006F         ADD     M127          ; SD = SP + 1 : 255 >= SP > 128
019F 7F8D  ANOMLE RET
01A0 201B  IDGTIM LAC     SCRACH
01A1 174C         SUB     ONE,7
01A2 FD00         BGEZ    ADDONE
01A3 01A8
01A4 006F         ADD     M127          ; SD = SP - 1 : 0 < SP <= 127
01A5 FA00         BLZ     ANOMLY
```

```
      01A6 01AF
A0565 01A7 7F8D               RET
A0566 01A8 106F   ADDONE SUB     M127
A0567 01A9 FD00          BGEZ    MAXNEG
      01AA 01AD
A0568 01AB 084C          ADD     ONE,8        ; SD = SP - 1 : 255 > SP >= 128
A0569 01AC 7F8D          RET
A0570 01AD 7EFF   MAXNEG LACK    255          ; SD = 255    : SP = 255
A0571 01AE 7F8D          RET
A0572 01AF 7E80   ANOMLY LACK    128          ; SD = 128    : SP = 0
A0573 01B0 7F8D          RET
A0574 01B1 201B   IDEQIM LAC     SCRACH       ; SD = SP
A0575 01B2 7F8D          RET
```



```
 0002                         COPY    SIGDIF.ASM
B0001                  *;
B0002                  *;*****************************************************
B0003                  *; SIGDIF
B0004                  *;
B0005                  *; Implements the following modules (per CCITT spec):
B0006                  *;
B0007                  *;     DELAY D -- delay of DQ and SR derivatives
B0008                  *;     FMULT   -- Bn * DQn, An * SRn
B0009                  *;     DELAY A -- (implicit in use of last frames data)
B0010                  *;     ACCUM   -- Accumulate partial products for SEZ, SE
B0011                  *;
B0012                  *;     LIMA    -- compute AL(k)
B0013                  *;     MIX     -- compute Y(k)
B0014                  *;
B0015                  *;*****************************************************
B0016                  *;
B0017                  *; compute SEZ-- partial signal estimate
B0018                  *;
B0019                  *;  SEZ(k) = B1(k-1)*DQ(k-1) + ... + B6(k-1)*DQ(k-6)
B0020                  *;
B0021                  *;     Multiplies are done in floating pt
B0022                  *;       DQ's are stored in f.p. notation
B0023                  *;       B's are floated each pass
B0024                  *;
B0025                  *;*****************************************************
B0026                  *; FLOATING POINT MULTIPLY (FMULT)
B0027                  *;
B0028                  *;     INPUT:  QUANTIZED DIFFERENCE   -- DQn (DQnEXP/DQnMAN)
B0029                  *;             PREDICTOR COEFFICIENTS -- Bn
B0030                  *;
B0031                  *;     OUTPUT: FILTER TAP OUTPUTS     -- WBn (SUMn)
B0032                  *;
B0033                  *;     NOTATION: DQnEXP   -- 4b + offset
B0034                  *;               DQnMAN*8 -- 9b magnitude
B0035                  *;               Bn       -- 16b TC (Q14)
B0036                  *;               SUMn     -- 16b TC (Q1)
B0037                  *;
B0038                  *;*****************************************************
B0039                  *;
B0040                  *;     -1      -1      -1      -1      -1      -1
B0041                  *; DQ  z       z       z       z       z       z
B0042                  *; o--->---o--->---o--->---o--->---o--->---o--->---o
B0043                  *;         :       :       :       :       :       :
B0044                  *;         :       :       :       :       :       :
B0045                  *;        vB1(k)  vB2(k)  vB3(k)  vB4(k)  vB5(k)  vB6(k)
B0046                  *;         :       :       :       :       :       :
B0047                  *;         :       :       :       :       :       :
B0048                  *;         o--->---o--->---o--->---o--->---o--->---o--->---o
B0049                  *;        WB1     WB2     WB3     WB4     WB5     WB6    SEZ
B0050                  *;
B0051                  *;*****************************************************
B0052                  *;
B0053 01B3 2E0F   SIGDIF LAC     B6,14    ; compute B6*DQ5
B0054 01B4 F800          CALL    FLOAT    ; ret/w mantissa in TEMP1; exp in ac
      01B5 04DE
B0055 01B6 001A          ADD     DQ5EXP
```

```
B0056 01B7 5022         SACL   SUM1
B0057 01B8 3822         LAR    0,SUM1   ; exp of product offset by table add
B0058 01B9 6A60         LT     DQ5MAN   ; scaled up by 2**3
B0059 01BA 277D         LAC    THREE,7  ; multiply fudge factor
B0060 01BB 6D21         MPY    TEMP1
B0061 01BC 6C80         LTA    *,0      ; mult mant, add 48, fetch shift fac
B0062 01BD 796E         AND    KFF80
B0063 01BE 5021         SACL   TEMP1
B0064 01BF 6D21         MPY    TEMP1    ; apply shift factor = f(exp)
B0065 01C0 7F8E         PAC
B0066 01C1 FA00         BLZ    RS1      ; exp >= 26
      01C2 04B6
B0067 01C3 5922         SACH   SUM1,1   ; exp <  26
B0068 01C4 660F  CHK1   ZALS   B6       ; check sign of product
B0069 01C5 785A         XOR    SDQ6
B0070 01C6 7948         AND    K32768
B0071 01C7 FF00         BZ     POS1
      01C8 01CC
B0072 01C9 7F89  NEG1   ZAC             ; negate if necessary
B0073 01CA 1022         SUB    SUM1
B0074 01CB 5022         SACL   SUM1
B0075 01CC 2E0E  POS1   LAC    B5,14    ; compute B5*DQ4
B0076 01CD F800         CALL   FLOAT    ; ret/w mantissa in TEMP1; exp in ac
      01CE 04DE
B0077 01CF 0019         ADD    DQ4EXP
B0078 01D0 6919         DMOV   DQ4EXP
B0079 01D1 5023         SACL   SUM2
B0080 01D2 3823         LAR    0,SUM2   ; exp of product offset by table add
B0081 01D3 6B5F         LTD    DQ4MAN   ; scaled up by 2**3
B0082 01D4 277D         LAC    THREE,7  ; multiply fudge factor
B0083 01D5 6D21         MPY    TEMP1
B0084 01D6 6C80         LTA    *,0      ; mult mant, add 48, fetch shift fac
B0085 01D7 796E         AND    KFF80
B0086 01D8 5021         SACL   TEMP1
B0087 01D9 6D21         MPY    TEMP1    ; apply shift factor = f(exp)
B0088 01DA 7F8E         PAC
B0089 01DB FA00         BLZ    RS2      ; exp >= 26
      01DC 04BB
B0090 01DD 5923         SACH   SUM2,1   ; exp < 26
B0091 01DE 660E  CHK2   ZALS   B5       ; check sign of product
B0092 01DF 7859         XOR    SDQ5
B0093 01E0 7948         AND    K32768
B0094 01E1 FF00         BZ     POS2
      01E2 01E6
B0095 01E3 7F89  NEG2   ZAC             ; negate if necessary
B0096 01E4 1023         SUB    SUM2
B0097 01E5 5023         SACL   SUM2
B0098 01E6 2E0D  POS2   LAC    B4,14    ; compute B4*DQ3
B0099 01E7 F800         CALL   FLOAT    ; ret/w mantissa in TEMP1; exp in ac
      01E8 04DE
B0100 01E9 0018         ADD    DQ3EXP
B0101 01EA 6918         DMOV   DQ3EXP
B0102 01EB 5025         SACL   SUM3
B0103 01EC 3825         LAR    0,SUM3   ; exp of product offset by table add
B0104 01ED 6B5E         LTD    DQ3MAN   ; scaled up by 2**3
B0105 01EE 277D         LAC    THREE,7  ; multiply fudge factor
B0106 01EF 6D21         MPY    TEMP1
```



```
B0107 01F0 6C80         LTA    *,0      ; mult mant, add 48, fetch shift fac
B0108 01F1 796E         AND    KFF80
B0109 01F2 5021         SACL   TEMP1
B0110 01F3 6D21         MPY    TEMP1    ; apply shift factor = f(exp)
B0111 01F4 7F8E         PAC
B0112 01F5 FA00         BLZ    RS3      ; exp >= 26
      01F6 04C0
B0113 01F7 5925         SACH   SUM3,1   ; exp < 26
B0114 01F8 660D  CHK3   ZALS   B4       ; check sign of product
B0115 01F9 7858         XOR    SDQ4
B0116 01FA 7948         AND    K32768
B0117 01FB FF00         BZ     POS3
      01FC 0200
B0118 01FD 7F89  NEG3   ZAC             ; negate if necessary
B0119 01FE 1025         SUB    SUM3
B0120 01FF 5025         SACL   SUM3
B0121 0200 2E0C  POS3   LAC    B3,14    ; compute B3*DQ2
B0122 0201 F800         CALL   FLOAT    ; ret/w mantissa in TEMP1; exp in ac
      0202 04DE
B0123 0203 0017         ADD    DQ2EXP
B0124 0204 6917         DMOV   DQ2EXP
B0125 0205 501E         SACL   SUM4
B0126 0206 381E         LAR    0,SUM4   ; exp of product offset by table add
B0127 0207 6B5D         LTD    DQ2MAN   ; scaled up by 2**3
B0128 0208 277D         LAC    THREE,7  ; multiply fudge factor
B0129 0209 6D21         MPY    TEMP1
B0130 020A 6C80         LTA    *,0      ; mult mant, add 48, fetch shift fac
B0131 020B 796E         AND    KFF80
B0132 020C 5021         SACL   TEMP1
B0133 020D 6D21         MPY    TEMP1    ; apply shift factor = f(exp)
B0134 020E 7F8E         PAC
B0135 020F FA00         BLZ    RS4      ; exp >= 26
      0210 04C5
B0136 0211 591E         SACH   SUM4,1   ; exp < 26
B0137 0212 660C  CHK4   ZALS   B3       ; check sign of product
B0138 0213 7857         XOR    SDQ3
B0139 0214 7948         AND    K32768
B0140 0215 FF00         BZ     POS4
      0216 021A
B0141 0217 7F89  NEG4   ZAC             ; negate if necessary
B0142 0218 101E         SUB    SUM4
B0143 0219 501E         SACL   SUM4
B0144 021A 2E0B  POS4   LAC    B2,14    ; compute B2*DQ1
B0145 021B F800         CALL   FLOAT    ; ret/w mantissa in TEMP1; exp in ac
      021C 04DE
B0146 021D 0016         ADD    DQ1EXP
B0147 021E 6916         DMOV   DQ1EXP
B0148 021F 501F         SACL   SUM5
B0149 0220 381F         LAR    0,SUM5   ; exp of product offset by table add
B0150 0221 6B5C         LTD    DQ1MAN   ; scaled up by 2**3
B0151 0222 277D         LAC    THREE,7  ; multiply fudge factor
B0152 0223 6D21         MPY    TEMP1
B0153 0224 6C80         LTA    *,0      ; mult mant, add 48, fetch shift fac
B0154 0225 796E         AND    KFF80
B0155 0226 5021         SACL   TEMP1
B0156 0227 6D21         MPY    TEMP1    ; apply shift factor = f(exp)
B0157 0228 7F8E         PAC
```

```
0229 FA00        BLZ    RS5       ; exp >= 26
022A 04CA
022B 591F        SACH   SUM5,1    ; exp < 26
022C 660B CHK5   ZALS   B2        ; check sign of product
022D 7856        XOR    SDQ2
022E 7948        AND    K32768
022F FF00        BZ     POS5
0230 0234
0231 7F89 NEG5   ZAC              ; negate if necessary
0232 101F        SUB    SUM5
0233 501F        SACL   SUM5
0234 2E0A POS5   LAC    B1,14     ; compute B1*DQ
0235 F800        CALL   FLOAT     ; ret/w mantissa in TEMP1; exp in accum
0236 04DE
0237 0015        ADD    DQEXP
0238 6915        DMOV   DQEXP
0239 5020        SACL   SUM6
023A 3820        LAR    0,SUM6    ; exp of product offset by table addr
023B 6B5B        LTD    DQMAN     ; scaled up by 2**3
023C 277D        LAC    THREE,7   ; multiply fudge factor
023D 6D21        MPY    TEMP1
023E 6C80        LTA    *,0       ; mult mant, add 48, fetch shift factor
023F 796E        AND    KFF80
0240 5021        SACL   TEMP1
0241 6D21        MPY    TEMP1     ; apply shift factor = f(exp)
0242 7F8E        PAC
0243 FA00        BLZ    RS6       ; exp >= 26
0244 04CF
0245 5920        SACH   SUM6,1    ; exp < 26
0246 660A CHK6   ZALS   B1        ; check sign of product
0247 7855        XOR    SDQ1
0248 7948        AND    K32768
0249 FF00        BZ     POS6
024A 024E
024B 7F89 NEG6   ZAC              ; negate if necessary
024C 1020        SUB    SUM6
024D 5020        SACL   SUM6
     024E POS6   EQU    $
          *;
          *;*******************************************************
          *;
          *; compute SE -- signal estimate
          *;
          *;  SE = A1(k-1)*SR(k-1) + A2(k-1)*SR(k-1) + SEZ(k)
          *;
          *;     Multiplies are dONE in floating pt
          *;       SR's are stored in f.p. notation
          *;       A's are floated each pass
          *;
          *;*******************************************************
          *; FLOATING POINT MULTIPLY (FMULT)
          *;
          *;     INPUT:  RECONSTRUCTED SIGNAL    -- SRn (SRnEXP/SRnMAN)
          *;             PREDICTOR COEFFICIENTS -- An
          *;
          *;     OUTPUT: FILTER TAP OUTPUTS      -- WAn (SUMn+6)
          *;
```



```
          *;     NOTATION: SRnEXP   -- 4b + offset
          *;               SRnMAN*8 -- 9b magnitude
          *;               An       -- 16b TC (Q14)
          *;               SUMn+6   -- 16b TC (Q1)
          *;
          *;*******************************************************
          *;
          *;                 -1      -1
          *;           SR  z       z
          *;           o--->---o--->---o
          *;                   |       |
          *;                   |       |
          *;                 vA1(k)  vA2(k)
          *;                   |       |
          *;                   |       |
          *;           o---<---o---<---o---<---o
          *;           SE     WA1     WA2     SEZ
          *;
          *;*******************************************************
          *;
024E 2E12 GETSE  LAC    A2,14     ; compute A2*SR1
024F F800        CALL   FLOAT     ; ret/w mantissa in TEMP1; exp in accum
0250 04DE
0251 001D        ADD    SR1EXP
0252 5027        SACL   SUM7
0253 3827        LAR    0,SUM7    ; exp of product offset by table addr
0254 6A53        LT     SR1MAN    ; scaled up by 2**3
0255 277D        LAC    THREE,7   ; multiply fudge factor
0256 6D21        MPY    TEMP1
0257 6C80        LTA    *,0       ; mult mant, add 48, fetch shift factor
0258 796E        AND    KFF80
0259 5021        SACL   TEMP1
025A 6D21        MPY    TEMP1     ; apply shift factor = f(exp)
025B 7F8E        PAC
025C FA00        BLZ    RS11      ; exp >= 26
025D 04D4
025E 5927        SACH   SUM7,1    ; exp < 26
025F 6612 CHK11  ZALS   A2        ; check sign of product
0260 7814        XOR    SR1
0261 7948        AND    K32768
0262 FF00        BZ     POS11
0263 0267
0264 7F89 NEG11  ZAC              ; negate if necessary
0265 1027        SUB    SUM7
0266 5027        SACL   SUM7
0267 2E11 POS11  LAC    A1,14     ; compute A1*SR
0268 F800        CALL   FLOAT     ; ret/w mantissa in TEMP1; exp in accum
0269 04DE
026A 001C        ADD    SREXP
026B 691C        DMOV   SREXP
026C 5028        SACL   SUM8
026D 3828        LAR    0,SUM8    ; exp of product offset by table addr
026E 6B52        LTD    SRMAN     ; scaled up by 2**3
026F 277D        LAC    THREE,7   ; multiply fudge factor
0270 6D21        MPY    TEMP1
0271 6C80        LTA    *,0       ; mult mant, add 48, fetch shift factor
0272 796E        AND    KFF80
```

```
0273 5021          SACL    TEMP1
0274 6D21          MPY     TEMP1    ; apply shift factor = f(exp)
0275 7F8E          PAC
0276 FA00          BLZ     RS21     ; exp >= 26
0277 04D9
0278 5928          SACH    SUM8,1   ; exp < 26
0279 6913  CHK21   DMOV    SR
027A 6613          ZALS    SR       ; check sign of product
027B 7811          XOR     A1
027C 7948          AND     K32768
027D FF00          BZ      POS21
027E 0282
027F 7F89  NEG21   ZAC              ; negate if necessary
0280 1028          SUB     SUM8
0281 5028          SACL    SUM8
     0282  POS21   EQU     $
                   *;
                   *;*******************************************************
                   *; ACCUMULATE FILTER TAP OUTPUTS (ACCUM)
                   *;
                   *;      INPUT:  FILTER TAP OUTPUTS -- WAn & WBn (SUMm)
                   *;
                   *;      OUTPUT: PARTIAL SUM OF ZEROES FILTER -- SEZ
                   *;              SIGNAL ESTIMATE              -- SE
                   *;
                   *;      NOTATION: SUMm -- 16b TC (Q1)
                   *;                SEZ  -- 15b TC (Q0) [sign extended]
                   *;                SE   -- 15b TC (Q0) [sign extended]
                   *;
                   *;*******************************************************
                   *;
0282 2F20          LAC     SUM6,15 ; accumulate products
0283 0F1F          ADD     SUM5,15
0284 0F1E          ADD     SUM4,15
0285 0F25          ADD     SUM3,15
0286 0F23          ADD     SUM2,15
0287 0F22          ADD     SUM1,15
0288 5904          SACH    SEZ,1
0289 0F27          ADD     SUM7,15
028A 0F28          ADD     SUM8,15
028B 5903          SACH    SE,1
028C 2F03          LAC     SE,15
028D 5803          SACH    SE
                   *;
                   *;*******************************************************
                   *; limit speed control parameter: AL <= 1.0
                   *;
                   *;      AL = 1          if APP >  1
                   *;      AL = APP        if APP <= 1
                   *;
                   *;      INPUT:  UNLIMITED SPEED CONTROL -- AP (APP)
                   *;
                   *;      OUTPUT: LIMITED SPEED CONTROL -- AL
                   *;
                   *;      NOTATION:  APP -- unsigned 10b (Q8)
                   *;                 AL  -- unsigned  7b (Q6)
                   *;
```



```
                   *;*******************************************************
                   *;
028E 2C4C  LIMA    LAC     ONE,12
028F 5006          SACL    AL
0290 2005          LAC     APP              ; check if APP >=1
0291 184C          SUB     ONE,8
0292 FD00          BGEZ    MIX              ;APP >= 1
0293 0297
0294 2405          LAC     APP,4
0295 7970          AND     MFFC0
0296 5006          SACL    AL               ;APP  < 1
                   *;
                   *;*******************************************************
                   *; MIX
                   *; form linear combination of fast and slow scale factors
                   *;
                   *;     Y(k) = (1-AL(k))*YL(k-1) + AL(k)*YU(k-1)
                   *;
                   *;     INPUT:  SLOW QUANTIZER SCALE FACTOR -- YL (YLL/YLH)
                   *;             FAST QUANTIZER SCALE FACTOR -- YU
                   *;             LIMITED SPEED CONTROL       -- AL
                   *;
                   *;     OUTPUT: QUANTIZER SCALE FACTOR          -- Y
                   *;             RESCALED QUANTIZER SCALE FACTOR -- YOVER4
                   *;
                   *;     NOTATION: YL     -- 19b unsigned (Q15)
                   *;                      stored as:
                   *;                         low 15b -- YLL
                   *;                         hi   4b -- YLH
                   *;               YU     -- 13b unsigned (Q9)
                   *;               AL     -- 7b unsigned  (Q6)
                   *;               Y      -- 13b unsigned (Q9)
                   *;               YOVER4 -- 11b unsigned (Q7)
                   *;
                   *;*******************************************************
                   *;
0297 2A4A  MIX     LAC     YLL,10           ; shift yl right by 6
0298 5823          SACH    TEMP3
0299 2949          LAC     YLH,9
029A 0023          ADD     TEMP3
029B 5023          SACL    TEMP3            ; YL>>6
029C 204E          LAC     YU
029D 1023          SUB     TEMP3            ; YU-(YL>>6)
029E 5021          SACL    TEMP1
029F 6A06          LT      AL
02A0 6D21          MPY     TEMP1
02A1 7F8E          PAC                      ; AL*(YU-(YL>>6))
02A2 FD00          BGEZ    NONNEG           ; negative truncation
02A3 02A5
02A4 0072          ADD     M4095
02A5 0C23  NONNEG  ADD     TEMP3,12
02A6 5C09          SACH    Y,4
02A7 2E09          LAC     Y,14             ; compute and save y>>2
02A8 5829          SACH    YOVER4
02A9 7F8D          RET                      ; ret from SIGDIF
```

```
                      COPY    AQUAN.ASM
               *;
               *;*******************************************************
               *; DIFFERENCE SIGNAL COMPUTATION
               *;
               *;    INPUT:  LINEAR PCM SAMPLE -- SL (SAMPLE)
               *;            SIGNAL ESTIMATE   -- SE
               *;
               *;    OUTPUT: DIFFERENCE SIGNAL -- D (accumulator)
               *;
               *;    NOTATION:  SL -- 14b TC (Q0) [sign extended]
               *;               SE -- 15b TC (Q0) [sign extended]
               *;               D  -- 16b TC (Q0)
               *;
               *;*******************************************************
               *;
               *;              SL   +-------+
               *;          ------->|       |   D
               *;              SE   | SUBTA |------->
               *;          ------->|       |
               *;                   +-------+
               *;
               *;*******************************************************
               *;
02AA 2026      AQUAN  LAC    SAMPLE          ; compute difference sig
02AB 1003             SUB    SE
               *;
               *;*******************************************************
               *;  ADAPTIVE QUANTIZER
               *;
               *; Implements the following modules (per CCITT spec):
               *;
               *;    LOG     -- computes log of difference signal
               *;    SUBTB   -- scales log by subtracting Y
               *;    QUAN    -- computes 4b output
               *;
               *;*******************************************************
               *;
               *;    INPUT:  DIFFERENCED PCM SAMPLE -- D (accumulator)
               *;            QUANTIZER SCALE FACTOR -- Y (YOVER4)
               *;
               *;    OUTPUT: ADPCM OUTPUT SAMPLE     -- I
               *;
               *;    NOTATION:  D      -- 16b TC (Q0)
               *;               YOVER4 -- 11b SM (Q7) POSITIVE VALUE ONLY
               *;               I      -- 4b SM (Q0)
               *;
               *;*******************************************************
               *;
               *;                            DS
               *;         +-----------------------------------+
               *;         |                                   |
               *;         |                                   V
               *;    D    +---+---+  DL   +--------+  DLN  +---------+    I
               *; ------>|  LOG  |------>| SUBTB  |------>|  QUAN   |------>
               *;         +-------+       +--------+       +---------+
               *;                             ^
```



```
               *;                                    | Y
               *;
               *;*******************************************************
               *;
               *; first get log of difference signal -- express
               *; as unsigned 11b number (4b exp/7b mantissa)
               *;
               *; First order log approximation: log2 (1+x) = x.
               *;
02AC 5824             SACH   TEMP4     ; -1 if neg; 0 if positive (DS)
02AD 7F88             ABS
02AE 5021             SACL   TEMP1
02AF 184C      GETEXP SUB    ONE,8     ; binary search to get exponent
02B0 FD00             BGEZ   C8TO14
02B1 02E7
02B2 046D      C0TO7  ADD    M15,4     ; TEMP1-16        exp = 0-7
02B3 FD00             BGEZ   C4TO7
02B4 02CE
02B5 027D      C0TO3  ADD    THREE,2   ; TEMP1-4         exp = 0-3
02B6 FD00             BGEZ   C2TO3
02B7 02C3
02B8 014C      C0TO1  ADD    ONE,1     ; TEMP1-2         exp = 0-1
02B9 FD00             BGEZ   EXP1
02BA 02BF
02BB 7000      EXP0   LARK   0,0       ; exp = 0
02BC 2721             LAC    TEMP1,7
02BD F900             B      GETMAN    ; save exponent and get mantissa
02BE 0321
02BF 7001      EXP1   LARK   0,1       ; exp = 1
02C0 2621             LAC    TEMP1,6
02C1 F900             B      GETMAN
02C2 0321
02C3 124C      C2TO3  SUB    ONE,2     ; TEMP1-8         exp = 2-3
02C4 FD00      .      BGEZ   EXP3
02C5 02CA
02C6 7002      EXP2   LARK   0,2       ; exp = 2
02C7 2521             LAC    TEMP1,5
02C8 F900             B      GETMAN
02C9 0321
02CA 7003      EXP3   LARK   0,3       ; exp = 3
02CB 2421             LAC    TEMP1,4
02CC F900             B      GETMAN
02CD 0321
02CE 1470      C4TO7  SUB    THREE,4   ; TEMP1-64        exp = 4-7
02CF FD00             BGEZ   C6TO7
02D0 02DC
02D1 054C      C4TO5  ADD    ONE,5     ; TEMP1-32        exp = 4-5
02D2 FD00             BGEZ   EXP5
02D3 02D8
02D4 7004      EXP4   LARK   0,4       ; exp = 4
02D5 2321             LAC    TEMP1,3
02D6 F900             B      GETMAN
02D7 0321
02D8 7005      EXP5   LARK   0,5       ; exp = 5
02D9 2221             LAC    TEMP1,2
02DA F900             B      GETMAN
02DB 0321
```

```
C0101 02DC 164C  C6TO7  SUB    ONE,6    ; TEMP1-128      exp = 6-7
C0102 02DD FD00         BGEZ   EXP7
      02DE 02E3
C0103 02DF 7006  EXP6   LARK   0,6      ; exp = 6
C0104 02E0 2121         LAC    TEMP1,1
C0105 02E1 F900         B      GETMAN
      02E2 0321
C0106 02E3 7007  EXP7   LARK   0,7      ; exp = 7
C0107 02E4 2021         LAC    TEMP1
C0108 02E5 F900         B      GETMAN
      02E6 0321
C0109 02E7 186D  C8TO14 SUB    M15,8    ; TEMP1-4096     exp = 8-14
C0110 02E8 FD00         BGEZ   CCTOE
      02E9 030B
C0111 02EA 0A7D  C8TO11 ADD    THREE,10 ;TEMP1-1024      exp = 8-11
C0112 02EB FD00         BGEZ   CATOB
      02EC 02FC
C0113 02ED 094C  C8TO9  ADD    ONE,9    ; TEMP1-512      exp = 8-9
C0114 02EE FD00         BGEZ   EXP9
      02EF 02F6
C0115 02F0 7008  EXP8   LARK   0,8      ; exp = 8
C0116 02F1 2F21         LAC    TEMP1,15
C0117 02F2 5821         SACH   TEMP1
C0118 02F3 2021         LAC    TEMP1
C0119 02F4 F900         B      GETMAN
      02F5 0321
C0120 02F6 7009  EXP9   LARK   0,9      ; exp = 9
C0121 02F7 2E21         LAC    TEMP1,14
C0122 02F8 5821         SACH   TEMP1
C0123 02F9 2021         LAC    TEMP1
C0124 02FA F900         B      GETMAN
      02FB 0321
C0125 02FC 1A4C  CATOB  SUB    ONE,10   ; TEMP1-2048     exp = 10-11
C0126 02FD FD00         BGEZ   EXP11
      02FE 0305
C0127 02FF 700A  EXP10  LARK   0,10     ; exp = 10
C0128 0300 2D21         LAC    TEMP1,13
C0129 0301 5821         SACH   TEMP1
C0130 0302 2021         LAC    TEMP1
C0131 0303 F900         B      GETMAN
      0304 0321
C0132 0305 700B  EXP11  LARK   0,11     ; exp = 11
C0133 0306 2C21         LAC    TEMP1,12
C0134 0307 5821         SACH   TEMP1
C0135 0308 2021         LAC    TEMP1
C0136 0309 F900         B      GETMAN
      030A 0321
C0137 030B 1C70  CCTOE  SUB    THREE,12 ; TEMP1-16384    exp = 12-14
C0138 030C FD00         BGEZ   EXP14
      030D 031D
C0139 030E 0D4C  CCTOD  ADD    ONE,13   ; TEMP1-8192     exp = 13-14
C0140 030F FD00         BGEZ   EXP13
      0310 0317
C0141 0311 700C  EXP12  LARK   0,12     ; exp = 12
C0142 0312 2B21         LAC    TEMP1,11
C0143 0313 5821         SACH   TEMP1
C0144 0314 2021         LAC    TEMP1
```



```
C0145 0315 F900         B      GETMAN
      0316 0321
C0146 0317 700D  EXP13  LARK   0,13     ; exp = 13
C0147 0318 2A21         LAC    TEMP1,10
C0148 0319 5821         SACH   TEMP1
C0149 031A 2021         LAC    TEMP1
C0150 031B F900         B      GETMAN
      031C 0321
C0151 031D 700E  EXP14  LARK   0,14     ; exp = 14
C0152 031E 2921         LAC    TEMP1,9
C0153 031F 5821         SACH   TEMP1
C0154 0320 2021         LAC    TEMP1
C0155 0321 796F  GETMAN AND    M127
C0156 0322 3021         SAR    0,TEMP1
C0157 0323 0721         ADD    TEMP1,7  ; DL  4e...7m (sign=SGN(D))
C0158                   *;
C0159                   *;------------------------------------------------
C0160                   *;
C0161                   *; scale LOG D by subtraction (Y>>2 is in YOVER4)
C0162                   *;
C0163                   *;------------------------------------------------
C0164                   *;
C0165 0324 0B4C  SUBTB  ADD    ONE,11   ; offset by 2K
C0166 0325 1029         SUB    YOVER4
C0167                   *;
C0168                   *;------------------------------------------------
C0169                   *; 16 LEVEL quantizer
C0170                   *;
C0171                   *; Table values defined in CCITT spec p67
C0172                   *; Implemented table is offset by 2048
C0173                   *;------------------------------------------------
C0174                   *;
C0175      07F9  ITAB1  EQU    2041     ; bottom of level 1
C0176      087B  ITAB2  EQU    2171     ; bottom of level 2
C0177      08CA  ITAB3  EQU    2250     ; bottom of level 3
C0178      0905  ITAB4  EQU    2309     ; bottom of level 4
C0179      0936  ITAB5  EQU    2358     ; bottom of level 5
C0180      0964  ITAB6  EQU    2404     ; bottom of level 6
C0181      0995  ITAB7  EQU    2453     ; bottom of level 7
C0182                   *;
C0183 0326 107C  QUAN   SUB    K2309    ; TEMP2-2309
C0184 0327 FD00         BGEZ   C14TO7
      0328 033E
C0185 0329 007B  C10TO3 ADD    K138     ; TEMP2-2171    I = 0-3
C0186 032A FD00         BGEZ   C12TO3
      032B 0335
C0187 032C 007A  C10TO1 ADD    K130     ; TEMP2-2041    I = 0-1
C0188 032D FD00         BGEZ   IEQ1
      032E 0332
C0189 032F 7E00  IEQ0   LACK   0
C0190 0330 F900         B      GETIM
      0331 0351
C0191 0332 7E01  IEQ1   LACK   1
C0192 0333 F900         B      GETIM
      0334 0351
C0193 0335 1078  C12TO3 SUB    K79      ; TEMP2-2250    I = 2-3
C0194 0336 FD00         BGEZ   IEQ3
```

```
0337 033B
0338 7E02  IEQ2   LACK   2
0339 F900         B      GETIM
033A 0351
033B 7E03  IEQ3   LACK   3
033C F900         B      GETIM
033D 0351
033E 1079  CI4TO7 SUB    K95     ; TEMP2-2404    I = 4-7
033F FD00         BGEZ   CI6TO7
0340 034A
0341 0064  CI5TO6 ADD    K46     ; TEMP2-2358    I = 5-6
0342 FD00         BGEZ   IEQ5
0343 0347
0344 7E04  IEQ4   LACK   4
0345 F900         B      GETIM
0346 0351
0347 7E05  IEQ5   LACK   5
0348 F900         B      GETIM
0349 0351
034A 1065  CI6TO7 SUB    K49     ; TEMP2-2453    I = 6-7
034B FD00         BGEZ   IEQ7
034C 0350
034D 7E06  IEQ6   LACK   6
034E F900         B      GETIM
034F 0351
0350 7E07  IEQ7   LACK   7
0351 5002  GETIM  SACL   IM      ; accumulator = |I|
0352 7824         XOR    TEMP4   ; add sign bit and flip if necessary
0353 796D         AND    M15     ; mask for final four-bit value
0354 7F8D  QDONE  RET            ; return from AQUAN
```



```
                      COPY    PRDICT.ASM
                 *;
                 *;*****************************************************
                 *; ADAPTATION/PREDICTION
                 *;
                 *;  Implements the following modules per CCITT spec:
                 *;
                 *;    Inverse Adaptive Quantizer
                 *;     RECONST         -- reconstructs D from I
                 *;     ADDA            -- adds back scale factor
                 *;     ANTILOG         -- log to lin conversion to get DQ
                 *;     FLOAT A         -- float DQ
                 *;    Scale Factor Adaptation
                 *;     FUNCTW          -- map I to log scale factor
                 *;     FILTD           -- update fast scale factor
                 *;     LIMB            -- limit scale factor
                 *;     FILTE           -- update slow scale factor
                 *;    Adaptation Speed Control
                 *;     FUNCTF          -- map I to F function
                 *;     FILTA           -- update short term ave of F
                 *;     FILTB           -- update long term ave of F
                 *;     SUBTC           -- determ speed control update
                 *;                              technique
                 *;     FILTC           -- update speed control
                 *;    Adaptive Predictor
                 *;     ADDB            -- compute reconstructed signal
                 *;     FLOAT A         -- float SR
                 *;     ADDC            -- compute sign of PK
                 *;     UPA2            -- update A2 coeff of 2nd order pred
                 *;     LIMC            -- limit A2
                 *;     UPA1            -- update A1 coeff of 2nd order pred
                 *;     LIMD            -- limit A1
                 *;     UPB             -- update coeffs of 6th order pred
                 *;     XOR             -- compute sign of DQ*DQn
                 *;
                 *;     NOTE: DELAY A/B/C implicit in timing of MIX/LIMA
                 *;           and computation of SEZ/SE
                 *;
                 *;*****************************************************
                 *;
                 *; First convert quantized difference back to log domain.
                 *; This is done by table look-up.  Also use ADPCM magnitude
                 *; to look-up the scale-factor multipliers WI and rate-of-
                 *; change weighting function FI.
                 *;
0355 2002        PRDICT LAC     IM
0356 006A               ADD     INQTAB  ; reconst table
0357 6721               TBLR    TEMP1   ; DQLN
0358 034C               ADD     ONE,3   ; WI table address and offset
0359 6769               TBLR    WI      ; lookup WI
035A 034C               ADD     ONE,3   ; FI table address and offset
035B 6768               TBLR    FI      ; lookup FI
                 *;
                 *;*****************************************************
                 *; INVERSE ADAPTIVE QUANTIZER
                 *;
                 *;      INPUT:  ADPCM INPUT SAMPLE     -- I (IM->TEMP1)
```

```
                *;              QUANTIZER SCALE FACTOR -- Y (YOVER4)
                *;
                *;       OUTPUT: QUANTIZED DIFFERENCE SIGNAL -- DQ
                *;
                *;       NOTATION:  I       -- 4b SM (Q0)
                *;                  IM      -- 3b magnitude (Q0)
                *;                  DQLN(TEMP1) -- 12b TC (Q7) [sign extended]
                *;                  YOVER4 -- 11b SM (Q7) POSITIVE VALUE ONLY
                *;                  DQ      -- 15b TC (Q0) [sign extended]
                *;                  DQMAN*8-- 9b magnitude
                *;                  DQEXP  -- 4b magnitude
                *;
                *;*******************************************************
                *;
                *;                          DQS
                *;           +--------------------------------+
                *;           :                                :
                *;           :                                V
                *;   I   +---+---+ DQLN  +--------+  DQL  +---------+  DQ
                *; ------>:RECONST:------>: ADDA  :------>:ANTILOG :------>
                *;       +--------+      +--------+      +---------+
                *;                           ^
                *;                           : Y
                *;
                *;*******************************************************
                *;
                *; add back scale factor
                *;
035C 2521 ADDA   LAC     TEMP1,5
035D 0529        ADD     YOVER4,5
                *;
                *; now covert to linear domain
                *;
035E 0C4C ALOG   ADD     ONE,12          ; inc exponent for floated value
035F 5C15        SACH    DQEXP,4         ; save exponent + sign ext
0360 7972        AND     M4095           ; isolate mantissa * 2**5
0361 0C4C        ADD     ONE,12          ; Alog x = 1 + x
0362 505B        SACL    DQMAN           ; DQMAN = 0001 XXXX XXX0 0000
0363 2015        LAC     DQEXP
0364 0066        ADD     SHIFT           ; add table ptr
0365 6723        TBLR    TEMP3           ; get multiplier
0366 6A23        LT      TEMP3
0367 044C        ADD     ONE,4           ; offset to mask table
0368 6723        TBLR    TEMP3           ; mask for dqman
0369 6D5B        MPY     DQMAN           ; adjust mantissa
036A 7F8E        PAC
036B 5C10        SACH    DQ,4
036C 2B4C ADDSGN LAC     ONE,11          ; +2048 represents +sign
036D 5054        SACL    SDQ
036E 2001        LAC     I               ; check sign
036F 134C        SUB     ONE,3
0370 FA00        BLZ     FLTDQ
0371 0377
0372 7F89        ZAC                     ; I carried negative sign
0373 1010        SUB     DQ
0374 5010        SACL    DQ
0375 2B4B        LAC     MINUS,11        ; -2048 represents -sign
```



```
0376 5054        SACL    SDQ
                *;
                *;*******************************************************
                *; FLOAT DQ -- convert 2's comp number to floating
                *;
                *;     INPUT:  DQ
                *;
                *;     OUTPUT: 4b exponent in DQEXP (saved from log value)
                *;             6b mantissa*8 in DQMAN (adjusted from log)
                *;             sign preserved in DQ
                *;
                *;*******************************************************
                *;
0377 255B FLTDQ  LAC     DQMAN,5 ; 00000000 0000001X XXXXXX00 00000000
0378 5C5B        SACH    DQMAN,4 ; DQMAN = 0000 0000 001X XXXX
0379 235B        LAC     DQMAN,3 ; DQMAN * 2**3
037A 7923        AND     TEMP3
037B 505B        SACL    DQMAN
                *;
                *;*******************************************************
                *; QUANTIZER SCALE FACTOR ADAPTATION
                *;
                *;     INPUT:  ADPCM SAMPLE  -- I
                *;
                *;     OUTPUT: FAST QUANTIZER SCALE FACTOR -- YU
                *;             SLOW QUANTIZER SCALE FACTOR -- YL (YLL/YLH)
                *;
                *;     NOTATION: I  -- 4b SM (Q0)
                *;              YU -- 13b unsigned (Q9)
                *;              YL -- 19b unsigned (Q15)
                *;                 stored as:
                *;                    low 15b -- YLL
                *;                    hi   4b -- YLH
                *;
                *;*******************************************************
                *;
                *; WI  +--------+YUT +------+YUP +---------+        YU
                *; --->: FILTD :--->: LIMB :-+->: DELAYB :----------------->
                *;     +--------+    +------+ : +---------+
                *;         ^                  :
                *;         : Y                :  +--------+YLP +---------+ YL
                *;         :                  +->: FILTE :--->: DELAYC :-+->
                *;                               +--------+    +---------+ :
                *;                                   ^                      :
                *;                                   +----------------------+
                *;
                *;*******************************************************
                *; Update fast adaptation scale factor
                *;
                *;   YU(k) = (1-2**-5)*Y(k) + (2**-5)*W(I(k))
                *;
                *;     INPUT:  QUANTIZER SCALE FACTOR  -- Y
                *;             SCALE FACTOR MULTIPLIER -- WI
                *;
                *;     OUTPUT: FAST QUANTIZER SCALE FACTOR -- YU
                *;
                *;     NOTATION:  WI -- 12b TC (Q4) [sign extended]
```

```
                   *;                Y  -- 13b unsigned (Q9)
                   *;                YU -- 13b unsigned (Q9)
                   *;
                   *;*******************************************************
                   *;
0375 037C 2C09 FILTD  LAC     Y,12          ; Y      (Q21)
     037D 1709        SUB     Y,7           ; Y/32   (Q21)
     037E 0C69        ADD     WI,12         ; WI/32  (Q21)
     037F 5C4E        SACH    YU,4          ; YU     (Q9)
                   *;
                   *; limit quant scale factor 1.06 <= YU <= 10.0
                   *;
     0380 1C6B LIMB   SUB     K544,12       ; check lo threshold
     0381 FD00        BGEZ    CHKHI
     0382 0386
     0383 206B        LAC     K544
     0384 F900        B       STRLIM        ; go store limited value
     0385 038A
     0386 1C61 CHKHI  SUB     K4576,12      ; check hi threshold
     0387 FB00        BLEZ    FILTE         ; within limits--continue
     0388 038B
     0389 206C        LAC     K5120
     038A 504E STRLIM SACL    YU
                   *;
                   *;*******************************************************
                   *; Update slow adaptation scale factor
                   *;
                   *;   YL(k) = (1-2**-6)*YL(k-1) + 2**-6 * YU(k)
                   *;
                   *;     INPUT:  SLOW QUANTIZER SCALE FACTOR -- YL (YLL/YLH)
                   *;             FAST QUANTIZER SCALE FACTOR -- YU
                   *;
                   *;     OUTPUT: SLOW QUANTIZER SCALE FACTOR -- YL (YLL/YLH)
                   *;
                   *;     NOTATION:  YU -- 13b unsigned (Q9)
                   *;                YL -- 19b unsigned (Q15)
                   *;                     stored as:
                   *;                       low 15b -- YLL
                   *;                       hi   4b -- YLH
                   *;
                   *;*******************************************************
                   *;
     038B 2649 FILTE  LAC     YLH,6         ; shift yl left by 6
     038C 5021        SACL    TEMP1
     038D 2F21        LAC     TEMP1,15      ; YL       (Q21)
     038E 064A        ADD     YLL,6
     038F 1F49        SUB     YLH,15        ; YL/64    (Q21)
     0390 104A        SUB     YLL
     0391 064E        ADD     YU,6          ; YU/64    (Q21)
     0392 5921        SACH    TEMP1,1
     0393 7974        AND     M32767
     0394 5022        SACL    TEMP2         ; result = yl (shifted left by 6)
     0395 2A22        LAC     TEMP2,10      ; shift result right 6 --> 4.Q15
     0396 5822        SACH    TEMP2
     0397 2921        LAC     TEMP1,9       ; YL       (Q15)
     0398 0022        ADD     TEMP2
     0399 5949        SACH    YLH,1
```



```
     039A 7974        AND     M32767
     039B 504A        SACL    YLL
                   *;
                   *;*******************************************************
                   *; ADAPTATION SPEED CONTROL
                   *;
                   *;     INPUT:  ADPCM SAMPLE  -- I
                   *;
                   *;     OUTPUT: UNLIMITED SPEED CONTROL -- AP (APP)
                   *;
                   *;     NOTATION: I    -- 4b SM (Q0)
                   *;               APP -- 10b unsigned (Q8)
                   *;
                   *;*******************************************************
                   *;
                   *;                      | Y
                   *;                      V
                   *; FI  +--------+DMSP+--------+ AX +--------+APP +---------+ AP
                   *; -+->| FILTA |-+->| SUBTC |--->| FILTC |--->| DELAYA |-+->
                   *;  |  +--------+ |  +--------+   +--------+    +---------+ |
                   *;  |      ^      V       ^            ^                   |
                   *;  |  DMS| +---------+   |            +-------------------+
                   *;  |     +-| DELAYA |   |
                   *;  |       +---------+   |
                   *;  |                     |
                   *;  |  +--------+  DMLP   |
                   *;  +->| FILTB |--+-------+
                   *;     +--------+  |
                   *;         ^       V
                   *;     DML| +---------+
                   *;        +-| DELAYA |
                   *;          +---------+
                   *;
                   *;*******************************************************
                   *; update short term average of FI
                   *;
                   *;   DMS(k) = (1-2**-5)*DMS(k-1) + 2**-5 * FI(k)
                   *;
                   *;     INPUT:  SHORT TERM AVERAGE       -- DMS
                   *;             RATE-OF-CHANGE FUNCTION  -- FI
                   *;
                   *;     OUTPUT: SHORT TERM AVERAGE -- DMS
                   *;
                   *;     NOTATION:  DMS -- 12b unsigned (Q9)
                   *;                FI  -- 7b unsigned (Q4)
                   *;
                   *;*******************************************************
                   *;
     039C 2F68 FILTA  LAC     FI,15         ; FI/32   (Q24)
     039D 0F07        ADD     DMS,15        ; DMS     (Q24)
     039E 1A07        SUB     DMS,10        ; DMS/32  (Q24)
     039F 5907        SACH    DMS,1
                   *;
                   *;*******************************************************
                   *; update long term average of FI
                   *;
                   *;   DML(k) = (1-2**-7)*DML(k-1) + 2**-7 * FI(k)
```

```
                  *;
                  *;     INPUT:  LONG TERM AVERAGE        -- DML
                  *;             RATE-OF-CHANGE FUNCTION -- FI
                  *;
                  *;     OUTPUT: LONG TERM AVERAGE -- DML
                  *;
                  *;     NOTATION:  DML -- 14b unsigned (Q11)
                  *;                FI  -- 7b unsigned (Q4)
                  *;
                  *;*******************************************************
                  *;
03A0 2F68  FILTB  LAC    FI,15           ; FI/128    (Q26)
03A1 0F08         ADD    DML,15          ; DML       (Q26)
03A2 1808         SUB    DML,8           ; DML/128   (Q26)
03A3 5908         SACH   DML,1
                  *;
                  *;-------------------------------------------------------
                  *; Compute mag of diff of short and long term functions of
                  *; quantizer output sequence and perform threshold
                  *; comparison to compute speed control parameter--low-pass
                  *; result.
                  *;
                  *;   APP(k) = (1-2**-4)*APP(k-1) + 2**-3 , if Y < 3 or
                  *;                              if |DMS-DML| > 2**-3 * DML
                  *;   else
                  *;
                  *;   APP(k) = (1-2**-4)*APP(k-1)
                  *;
                  *;     INPUT:  SHORT TERM AVERAGE        -- DMS
                  *;             LONG TERM AVERAGE         -- DML
                  *;             UNLIMITED SPEED CONTROL -- APP
                  *;             QUANTIZER SCALE FACTOR  -- Y
                  *;
                  *;     OUTPUT: UNLIMITED SPEED CONTROL -- APP
                  *;
                  *;     NOTATION:  APP -- 10b unsigned (Q8)
                  *;                Y   -- 13b unsigned (Q9)
                  *;                DMS -- 12b unsigned (Q9)
                  *;                DML -- 14b unsigned (Q11)
                  *;
                  *;*******************************************************
                  *;
03A4 6505  FILTC  ZALH   APP             ; APP              (Q24)
03A5 1C05         SUB    APP,12          ; APP/16           (Q24)
03A6 5805         SACH   ARP             ; (1-2**-4)*APP    (Q8)
03A7 2009         LAC    Y
03A8 197D         SUB    THREE,9         ; 3        (Q9)
03A9 FA00         BLZ    ADD18
03AA 03B3
03AB 2D08         LAC    DML,13          ; DML/8    (Q27)
03AC 5823         SACH   TEMP3           ; DML/8    (Q11)
03AD 2207         LAC    DMS,2           ; DMS      (Q11)
03AE 1008         SUB    DML             ; DMS-DML
03AF 7F88         ABS
03B0 1023         SUB    TEMP3           ; |DMS-DML|-DML/8
03B1 FA00         BLZ    APRED
03B2 03B6
```



```
03B3 2005  ADD18  LAC    APP             ; APP      (Q8)
03B4 054C         ADD    ONE,5
03B5 5005         SACL   APP             ; + 1/8    (Q8)
                  *;
                  *;*******************************************************
                  *; ADAPTIVE PREDICTOR
                  *;
                  *;*******************************************************
                  *;
     03B6  APRED  EQU    $
                  *;
                  *;*******************************************************
                  *; compute coeff of 6th order predictor
                  *;
                  *; Bi(k) = (1-2**-8)*Bi(k-1) + 2**-7*SGN[DQ(k)]*SGN[DQ(k-i)]
                  *;     for i = 1...6
                  *;     and Bi is implicitly limited to +/- 2
                  *;
                  *;     NOTATION:          Bn   -- 16b TC (Q14)
                  *;                        SDQn -- +2048 if sign positive
                  *;                                -2048 if sign negative
                  *;
                  *;*******************************************************
                  *;
03B6 6A5A  GETB6  LT     SDQ6
03B7 280F         LAC    B6,8       ; B6 * 2**-8 TRUNCATED
03B8 5821         SACH   TEMP1
03B9 2F0F         LAC    B6,15      ; Q29
03BA 1F21         SUB    TEMP1,15
03BB 6D54         MPY    SDQ        ; SGN(SDQ)*SGN(SDQ6) * 2**-7  (Q29)
03BC 6B59         LTD    SDQ5
03BD 590F         SACH   B6,1       ; Q14
03BE 280E  GETB5  LAC    B5,8       ; B5 * 2**-8 TRUNCATED
03BF 5821         SACH   TEMP1
03C0 2F0E         LAC    B5,15      ; Q29
03C1 1F21         SUB    TEMP1,15
03C2 6D54         MPY    SDQ
03C3 6B58         LTD    SDQ4
03C4 590E         SACH   B5,1       ; Q14
03C5 280D  GETB4  LAC    B4,8       ; B4 * 2**-8 TRUNCATED
03C6 5821         SACH   TEMP1
03C7 2F0D         LAC    B4,15      ; Q29
03C8 1F21         SUB    TEMP1,15
03C9 6D54         MPY    SDQ
03CA 6B57         LTD    SDQ3
03CB 590D         SACH   B4,1       ; Q14
03CC 280C  GETB3  LAC    B3,8       ; B3 * 2**-8 TRUNCATED
03CD 5821         SACH   TEMP1
03CE 2F0C         LAC    B3,15      ; Q29
03CF 1F21         SUB    TEMP1,15
03D0 6D54         MPY    SDQ
03D1 6B56         LTD    SDQ2
03D2 590C         SACH   B3,1       ; Q14
03D3 280B  GETB2  LAC    B2,8       ; B2 * 2**-8 TRUNCATED
03D4 5821         SACH   TEMP1
03D5 2F0B         LAC    B2,15      ; Q29
03D6 1F21         SUB    TEMP1,15
```

```
03D7 6D54          MPY     SDQ
03D8 6B55          LTD     SDQ1
03D9 590B          SACH    B2,1     ; Q14
03DA 280A   GETB1  LAC     B1,8     ; B1 * 2**-8 TRUNCATED
03DB 5821          SACH    TEMP1
03DC 2F0A          LAC     B1,15    ; Q29
03DD 1F21          SUB     TEMP1,15
03DE 6D54          MPY     SDQ
03DF 6B54          LTD     SDQ
03E0 590A          SACH    B1,1     ; Q14
            *;
            *;*******************************************************
            *; To update coefficients of 2nd order predictor,
            *; First get sign of sum of SEZ and DQ
            *;
            *;     NOTATION: if SEZ+DQ >= 0 then PK0 = 512
            *;                else                PK0 = -512
            *;
            *;*******************************************************
            *;
03E1 6950   ADDC   DMOV    PK1              ; PK1==>PK2
03E2 694F          DMOV    PK0              ; PK0==>PK1
03E3 2004          LAC     SEZ
03E4 0110          ADD     DQ,1
03E5 5821          SACH    TEMP1      ; FFFF or 0000
03E6 2A21          LAC     TEMP1,10   ; FC00 or 0000
03E7 094C          ADD     ONE,9      ; FE00 or 0200 | -512 or +512
03E8 504F          SACL    PK0
03E9 6A4F   SUMGTO LT      PK0
            *;
            *;*******************************************************
            *;  now calculate 1/2 * f[A1(k-1)]
            *;
            *;       = 2*A1       if |A1|  <= 1/2
            *;       = SGN(A1)    if |A1|  >  1/2
            *;
            *;*******************************************************
            *;
03EA 2111   GETF   LAC     A1,1             ; 2*A1
03EB 5023          SACL    TEMP3
03EC FA00          BLZ     GETF2
03ED 03F4
03EE 1E4C   GETF1  SUB     ONE,14           ; is |A1| < 1/2
03EF FA00          BLZ     GETA1
03F0 03FA
03F1 2062          LAC     K16382           ; approx 1
03F2 F900          B       DONEF
03F3 03F9
03F4 7F88   GETF2  ABS
03F5 1E4C          SUB     ONE,14           ; is |A1| < 1/2
03F6 FA00          BLZ     GETA1
03F7 03FA
03F8 2063          LAC     M16382           ; approx -1
03F9 5023   DONEF  SACL    TEMP3
            *;
            *;*******************************************************
            *; Compute A1 coeff of 2nd order predictor
```



```
            *;
            *;  A1(k) = (1-2**-8)*A1(k-1)
            *;                + (3*2**-8)*SGN[p(k)]*SGN[p(k-1)]
            *;
            *;    NOTATION:  A1  -- 16b TC (Q14)
            *;               PKn -- +512 if SGN[p(k)] = 1
            *;                      -512 if SGN[p(k)] = -1
            *;
            *;*******************************************************
            *;
03FA 2811   GETA1  LAC     A1,8             ; A1*2**-8 TRUNCATED
03FB 5822          SACH    TEMP2
03FC 2C11          LAC     A1,12            ; Q26
03FD 1C22          SUB     TEMP2,12
03FE 6D50          MPY     PK1              ; SGN[p(k-1)*SGN[p(k)]
03FF 7F8F          APAC
0400 7F8F          APAC
0401 7F8F          APAC                     ; +3*SGN[p(k-1)*SGN[p(k)]
0402 5C11          SACH    A1,4             ; store as Q14
0403 7F8E          PAC                      ; save sign
            *;
            *;*******************************************************
            *; Compute A2 coeff of 2nd order predictor
            *;
            *;  A2(k) = (1-2**-7)*A2(k-1)
            *;          + (2**-7)*{SGN[p(k)]*SGN[(p(k-2)]
            *;                 - f[A1(k-1)]*SGN[p(k)]*SGN[p(k-1)]}
            *;
            *;    NOTATION:  A2        -- 16b TC (Q14)
            *;               F(),TEMP3 -- 16b TC (Q14)
            *;               PKn.      -- +512 if SGN[p(k)] = 1
            *;                            -512 if SGN[p(k)] = -1
            *;
            *;*******************************************************
            *;
0404 FD00   GETA2  BGEZ    SUBF             ; if sign + --> subtract F
0405 0409
0406 7F89          ZAC                      ;  else negate F and subtract
0407 1023          SUB     TEMP3
0408 5023          SACL    TEMP3
            *;
0409 2912   SUBF   LAC     A2,9             ; A2*2**-7 TRUNCATED
040A 581E          SACH    SUM4
040B 6D51          MPY     PK2              ; SGN[p(k-2)]*SGN[p(k)]
040C 7F8E          PAC
040D 7F8F          APAC                     ; 2*2**-8*above  (Q26)
040E 1623          SUB     TEMP3,6          ; 2*TEMP3*2**-7  (Q26)
040F 5C23          SACH    TEMP3,4          ; Q14
0410 2012          LAC     A2
0411 101E          SUB     SUM4             ; leak factor
0412 0023          ADD     TEMP3
0413 5012          SACL    A2               ; Q14
            *
0414 5821          SACH    TEMP1            ; save sign to make +/- .75
            *;
            *; limit A2 to +/- .75 and prevent overflow
            *;
```

```
0415 7F88  LIMC   ABS
0416 1C7D         SUB    THREE,12        ; |value| must be < .75
0417 FB00         BLEZ   LIMD
0418 041D
0419 2C7D         LAC    THREE,12        ; .75  (Q14)
041A 7821         XOR    TEMP1           ; 1's complement if negative
041B 1021         SUB    TEMP1           ; 2's complement if negative
041C 5012  DONEC  SACL   A2              ; Q14
           *;
           *; limit A1(k) to +/- [1-2**-4 - A2(k)]
           *;
041D 2A6D  LIMD   LAC    M15,10          ; 1-2**-4       (Q14)
041E 1012         SUB    A2
041F 5021         SACL   TEMP1           ; 1-2**-4-A2P  (Q14)
0420 2011         LAC    A1
0421 5824         SACH   TEMP4           ; save sign to make +/- LIMIT
0422 7F88         ABS
0423 1021         SUB    TEMP1
0424 FB00         BLEZ   FLTSR           ; A1 <= LIMIT
0425 042A
0426 2021  AILIM  LAC    TEMP1           ; ABS value of LIMIT
0427 7824         XOR    TEMP4           ; 1's complement if negative
0428 1024         SUB    TEMP4           ; 2's complement if negative
0429 5011         SACL   A1              ; Q14
           *;
           *;**********************************************************
           *; COMPUTE RECONSTRUCTED SIGNAL
           *;
           *;      INPUT:  QUANTIZED DIFFERENCE SIGNAL -- DQ
           *;              SIGNAL ESTIMATE             -- SE
           *;
           *;      OUTPUT: RECONSTRUCTED SIGNAL -- SR
           *;
           *;      NOTATION:  DQ -- 15b TC (Q0) [sign extended]
           *;                 SE -- 15b TC (Q0) [sign extended]
           *;                 SR -- 16b TC (Q0)
           *;
           *;**********************************************************
           *; FLOAT SR -- convert 2's comp number to floating
           *;
           *;      INPUT:  accumulator
           *;
           *;      OUTPUT: --4b exponent left in SREXP
           *;              --6b mantissa*8 left in SRMAN
           *;              --sign preserved in SR
           *;
           *;**********************************************************
           *;
042A 2010  FLTSR  LAC    DQ       ; compute reconstructed signal
042B 0003         ADD    SE
042C 5013         SACL   SR
042D 7F88         ABS             ; convert to floating point notation
042E 5052         SACL   SRMAN
042F 174C         SUB    ONE,7    ; binary search to get exponent
0430 FD00         BGEZ   D8TOF
0431 0469
0432 036D  D0TO7  ADD    M15,3    ; TEMP1-8 -- exp = 0-7
```



```
0433 FD00         BGEZ   D4TO7
0434 044A
0435 017D  D0TO3  ADD    THREE,1 ; TEMP1-2 -- exp = 0-3
0436 FD00         BGEZ   D2TO3
0437 043D
0438 2052  D0TO1  LAC    SRMAN   ; exp = 0-1
0439 501C  EXX01  SACL   SREXP
043A 284C         LAC    ONE,8
043B 5052         SACL   SRMAN
043C 7F8D         RET
043D 114C  D2TO3  SUB    ONE,1   ; TEMP1-4 -- exp = 2-3
043E FD00         BGEZ   EXX3
043F 0445
0440 2752  EXX2   LAC    SRMAN,7 ; exp=2
0441 5052         SACL   SRMAN
0442 7E02         LACK   2
0443 501C         SACL   SREXP
0444 7F8D         RET
0445 2652  EXX3   LAC    SRMAN,6 ; exp=3
0446 5052         SACL   SRMAN
0447 7E03         LACK   3
0448 501C         SACL   SREXP
0449 7F8D         RET
044A 137D  D4TO7  SUB    THREE,3 ; TEMP1-32 -- exp = 4-7
044B FD00         BGEZ   D6TO7
044C 045A
044D 044C  D4TO5  ADD    ONE,4   ; TEMP1-16 -- exp = 4-5
044E FD00         BGEZ   EXX5
044F 0455
0450 2552  EXX4   LAC    SRMAN,5 ; exp=4
0451 5052         SACL   SRMAN
0452 7E04         LACK   4
0453 501C         SACL   SREXP
0454 7F8D         RET
0455 2452  EXX5   LAC    SRMAN,4 ; exp=5
0456 5052         SACL   SRMAN
0457 7E05         LACK   5
0458 501C         SACL   SREXP
0459 7F8D         RET
045A 154C  D6TO7  SUB    ONE,5   ; TEMP1-64 -- exp = 6-7
045B FD00         BGEZ   EXX7
045C 0462
045D 2352  EXX6   LAC    SRMAN,3 ; exp=6
045E 5052         SACL   SRMAN
045F 7E06         LACK   6
0460 501C         SACL   SREXP
0461 7F8D         RET
0462 2F52  EXX7   LAC    SRMAN,15
0463 5852         SACH   SRMAN
0464 2352         LAC    SRMAN,3
0465 5052         SACL   SRMAN
0466 7E07         LACK   7
0467 501C         SACL   SREXP
0468 7F8D         RET
0469 1177  D8TOF  SUB    K960,1  ; TEMP1-2048 -- exp = 8-15
046A FD00         BGEZ   DCTOF
046B 0491
```

```
D0606 046C 097D  D8TOB  ADD    THREE,9 ; TEMP1-512 -- exp = 8-11
D0607 046D FD00         BGEZ   DATOB
      046E 0480
D0608 046F 084C  D8TO9  ADD    ONE,8    ; TEMP1-256 -- exp = 8-9
D0609 0470 FD00         BGEZ   EXX9
      0471 0479
D0610 0472 2E52  EXX8   LAC    SRMAN,14 ; exp=8
D0611 0473 5852         SACH   SRMAN
D0612 0474 2352         LAC    SRMAN,3
D0613 0475 5052         SACL   SRMAN
D0614 0476 7E08         LACK   8
D0615 0477 501C         SACL   SREXP
D0616 0478 7F8D         RET
D0617 0479 2D52  EXX9   LAC    SRMAN,13 ; exp=9
D0618 047A 5852         SACH   SRMAN
D0619 047B 2352         LAC    SRMAN,3
D0620 047C 5052         SACL   SRMAN
D0621 047D 7E09         LACK   9
D0622 047E 501C         SACL   SREXP
D0623 047F 7F8D         RET
D0624 0480 194C  DATOB  SUB    ONE,9    ; TEMP1-1024 -- exp=10-11
D0625 0481 FD00         BGEZ   EXX11
      0482 048A
D0626 0483 2C52  EXX10  LAC    SRMAN,12 ; exp=10
D0627 0484 5852         SACH   SRMAN
D0628 0485 2352         LAC    SRMAN,3
D0629 0486 5052         SACL   SRMAN
D0630 0487 7E0A         LACK   10
D0631 0488 501C         SACL   SREXP
D0632 0489 7F8D         RET
D0633 048A 2B52  EXX11  LAC    SRMAN,11 ; exp=11
D0634 048B 5852         SACH   SRMAN
D0635 048C 2352         LAC    SRMAN,3
D0636 048D 5052         SACL   SRMAN
D0637 048E 7E0B         LACK   11
D0638 048F 501C         SACL   SREXP
D0639 0490 7F8D         RET
D0640 0491 1B7D  DCTOF  SUB    THREE,11 ; TEMP1-8192 -- exp=12-15
D0641 0492 FD00         BGEZ   DETOF
      0493 04A5
D0642 0494 0C4C  DCTOD  ADD    ONE,12   ; TEMP1-4096 -- exp=12-13
D0643 0495 FD00         BGEZ   EXX13
      0496 049E
D0644 0497 2A52  EXX12  LAC    SRMAN,10 ; exp=12
D0645 0498 5852         SACH   SRMAN
D0646 0499 2352         LAC    SRMAN,3
D0647 049A 5052         SACL   SRMAN
D0648 049B 7E0C         LACK   12
D0649 049C 501C         SACL   SREXP
D0650 049D 7F8D         RET
D0651 049E 2952  EXX13  LAC    SRMAN,9  ; exp=13
D0652 049F 5852         SACH   SRMAN
D0653 04A0 2352         LAC    SRMAN,3
D0654 04A1 5052         SACL   SRMAN
D0655 04A2 7E0D         LACK   13
D0656 04A3 501C         SACL   SREXP
D0657 04A4 7F8D         RET
```



```
D0658 04A5 1D4C  DETOF  SUB    ONE,13   ; TEMP1-16384 -- exp=14-15
D0659 04A6 FD00         BGEZ   EXX15
      04A7 04AF
D0660 04A8 2852  EXX14  LAC    SRMAN,8  ; exp=14
D0661 04A9 5852         SACH   SRMAN
D0662 04AA 2352         LAC    SRMAN,3
D0663 04AB 5052         SACL   SRMAN
D0664 04AC 7E0E         LACK   14
D0665 04AD 501C         SACL   SREXP
D0666 04AE 7F8D         RET
D0667 04AF 2752  EXX15  LAC    SRMAN,7  ; exp=15
D0668 04B0 5852         SACH   SRMAN
D0669 04B1 2352         LAC    SRMAN,3
D0670 04B2 5052         SACL   SRMAN
D0671 04B3 7E0F         LACK   15
D0672 04B4 501C         SACL   SREXP
D0673 04B5 7F8D         RET
```

```
 0005                   COPY    UTILITY.ASM
E0001            *;
E0002            *;  code to do left shifts for SEZ/SE calculations
E0003            *;
E0004 04B6 7F88  RS1    ABS               ; make positive before mask
E0005 04B7 7974         AND     M32767    ; keep lower 15 bits
E0006 04B8 5022         SACL    SUM1      ; save result
E0007 04B9 F900         B       CHK1      ; return
      04BA 01C4
E0008 04BB 7F88  RS2    ABS
E0009 04BC 7974         AND     M32767
E0010 04BD 5023         SACL    SUM2
E0011 04BE F900         B       CHK2
      04BF 01DE
E0012 04C0 7F88  RS3    ABS
E0013 04C1 7974         AND     M32767
E0014 04C2 5025         SACL    SUM3
E0015 04C3 F900         B       CHK3
      04C4 01F8
E0016 04C5 7F88  RS4    ABS
E0017 04C6 7974         AND     M32767
E0018 04C7 501E         SACL    SUM4
E0019 04C8 F900         B       CHK4
      04C9 0212
E0020 04CA 7F88  RS5    ABS
E0021 04CB 7974         AND     M32767
E0022 04CC 501F         SACL    SUM5
E0023 04CD F900         B       CHK5
      04CE 022C
E0024 04CF 7F88  RS6    ABS
E0025 04D0 7974         AND     M32767
E0026 04D1 5020         SACL    SUM6
E0027 04D2 F900         B       CHK6
      04D3 0246
E0028 04D4 7F88  RS11   ABS
E0029 04D5 7974         AND     M32767
E0030 04D6 5027         SACL    SUM7
E0031 04D7 F900         B       CHK11
      04D8 025F
E0032 04D9 7F88  RS21   ABS
E0033 04DA 7974         AND     M32767
E0034 04DB 5028         SACL    SUM8
E0035 04DC F900         B       CHK21
      04DD 0279
```



```
E0037            *;
E0038            *;------------------------------------------------------------
E0039            *; FLOAT SUBROUTINE--convert 2's comp number to floating
E0040            *;                INPUT: accumulator
E0041            *;               OUTPUT:
E0042            *;                       --4b exponent left in accum
E0043            *;                       --6b mantissa left in TEMP1
E0044            *;                       --sign preserved in original number
E0045            *;
E0046            *;------------------------------------------------------------
E0047      002A  FLTSFT EQU     42        ; address of shift multipliers
E0048            *;
E0049            *;
E0050 04DE 5821  FLOAT  SACH    TEMP1
E0051 04DF 2021         LAC     TEMP1
E0052 04E0 7F88         ABS
E0053 04E1 5021         SACL    TEMP1
E0054 04E2 164C         SUB     ONE,6     ; binary search to get expONEnt
E0055 04E3 FD00         BGEZ    E7TOD
      04E4 0511
E0056 04E5 0076  E0TO7  ADD     K56       ; TEMP1-8 -- exp = 0-6
E0057 04E6 FD00         BGEZ    E4TO6
      04E7 0501
E0058 04E8 017D  E0TO3  ADD     THREE,1 ; TEMP1-2 -- exp = 0-3
E0059 04E9 FD00         BGEZ    E2TO3
      04EA 04F6
E0060 04EB 2021  E0TO1  LAC     TEMP1     ; exp = 0-1
E0061 04EC FE00         BNZ     E1
      04ED 04F2
E0062 04EE 254C  E0     LAC     ONE,5     ; exp=0
E0063 04EF 5021         SACL    TEMP1
E0064 04F0 7E2A         LACK    FLTSFT+0
E0065 04F1 7F8D         RET
E0066 04F2 2521  E1     LAC     TEMP1,5 ; exp=1
E0067 04F3 5021         SACL    TEMP1
E0068 04F4 7E2B         LACK    FLTSFT+1
E0069 04F5 7F8D         RET
E0070 04F6 114C  E2TO3  SUB     ONE,1     ; TEMP1-4 -- exp = 2-3
E0071 04F7 FD00         BGEZ    E3
      04F8 04FD
E0072 04F9 2421  E2     LAC     TEMP1,4 ; exp=2
E0073 04FA 5021         SACL    TEMP1
E0074 04FB 7E2C         LACK    FLTSFT+2
E0075 04FC 7F8D         RET
E0076 04FD 2321  E3     LAC     TEMP1,3 ; exp=3
E0077 04FE 5021         SACL    TEMP1
E0078 04FF 7E2D         LACK    FLTSFT+3
E0079 0500 7F8D         RET
E0080 0501 134C  E4TO6  SUB     ONE,3     ; TEMP1-16 -- exp = 4-6
E0081 0502 FD00         BGEZ    E5TO6
      0503 0508
E0082 0504 2221  E4     LAC     TEMP1,2 ; exp=4
E0083 0505 5021         SACL    TEMP1
E0084 0506 7E2E         LACK    FLTSFT+4
E0085 0507 7F8D         RET
E0086 0508 144C  E5TO6  SUB     ONE,4     ; TEMP1-32 -- exp = 5-6
E0087 0509 FD00         BGEZ    E6
```

```
      050A 050F
E0088 050B 2121  E5     LAC    TEMP1,1 ; exp=5
E0089 050C 5021         SACL   TEMP1
E0090 050D 7E2F         LACK   FLTSFT+5
E0091 050E 7F8D         RET
E0092 050F 7E30  E6     LACK   FLTSFT+6        ; exp=6
E0093 0510 7F8D         RET
E0094 0511 1077  E7TOD  SUB    K960    ; TEMP1-1024 -- exp = 7-13
E0095 0512 FD00         BGEZ   E8TOD
      0513 052D
E0096 0514 087D  E7TOA  ADD    THREE,8 ; TEMP1-256  -- exp = 7-10
E0097 0515 FD00         BGEZ   E9TOA
      0516 0522
E0098 0517 074C  E7TO8  ADD    ONE,7   ; TEMP1-128  -- exp = 7-8
E0099 0518 FD00         BGEZ   E8
      0519 051E
E0100 051A 2F21  E7     LAC    TEMP1,15 ; exp=7
E0101 051B 5821         SACH   TEMP1
E0102 051C 7E31         LACK   FLTSFT+7
E0103 051D 7F8D         RET
E0104 051E 2E21  E8     LAC    TEMP1,14 ; exp=8
E0105 051F 5821         SACH   TEMP1
E0106 0520 7E32         LACK   FLTSFT+8
E0107 0521 7F8D         RET
E0108 0522 184C  E9TOA  SUB    ONE,8   ; TEMP1-512  -- exp = 9-10
E0109 0523 FD00         BGEZ   E10
      0524 0529
E0110 0525 2D21  E9     LAC    TEMP1,13 ; exp=9
E0111 0526 5821         SACH   TEMP1
E0112 0527 7E33         LACK   FLTSFT+9
E0113 0528 7F8D         RET
E0114 0529 2C21  E10    LAC    TEMP1,12 ; exp=10
E0115 052A 5821         SACH   TEMP1
E0116 052B 7E34         LACK   FLTSFT+10
E0117 052C 7F8D         RET
E0118 052D 1A7D  E8TOD  SUB    THREE,10        ; TEMP1-4096 -- exp=11-13
E0119 052E FD00         BGEZ   EDTOE
      052F 053B
E0120 0530 0B4C  E8TOC  ADD    ONE,11  ; TEMP1-2048 -- exp=11-12
E0121 0531 FD00         BGEZ   E12
      0532 0537
E0122 0533 2B21  E11    LAC    TEMP1,11 ; exp=11
E0123 0534 5821         SACH   TEMP1
E0124 0535 7E35         LACK   FLTSFT+11
E0125 0536 7F8D         RET
E0126 0537 2A21  E12    LAC    TEMP1,10 ; exp=12
E0127 0538 5821         SACH   TEMP1
E0128 0539 7E36         LACK   FLTSFT+12
E0129 053A 7F8D         RET
E0130 053B 1C4C  EDTOE  SUB    ONE,12  ; TEMP1-8192 -- exp=0
E0131 053C FD00         BGEZ   E0
      053D 04EE
E0132 053E 2921  E13    LAC    TEMP1,9  ; exp=13
E0133 053F 5821         SACH   TEMP1
E0134 0540 7E37         LACK   FLTSFT+13
E0135 0541 7F8D         RET
```



```
0006                    COPY   INIT.ASM
F0001                *;*********************************************************
F0002                *; SYSTEM INITIALIZATION
F0003                *;*********************************************************
F0004      004A  NOCONS EQU    74
F0005      0036  PTCONS EQU    54
F0006                *;
F0007 0542 7F81  RESET  DINT                           ; Disable interrupts
F0008 0543 6E00         LDPK   0                       ; Initialize data page
F0009                *;
F0010 0544 7035  SETPAC LARK   0,53
F0011 0545 6880         LARP   0
F0012 0546 7F89         ZAC                            ; Zero iram
F0013 0547 5080  ZRAMA  SACL   *,0,0
F0014 0548 F400         BANZ   ZRAMA
      0549 0547
F0015                *;
F0016 054A 7E01         LACK   1
F0017 054B 504C         SACL   ONE
F0018 054C 6A4C         LT     ONE
F0019 054D 859B         MPYK   CONS
F0020 054E 7F8E         PAC                            ; ROM ADDR
F0021 054F 7136         LARK   1,PTCONS                ; RAM ADDR
F0022 0550 7049         LARK   0,NOCONS-1
F0023 0551 6881  NXCONS LARP   1
F0024 0552 67A0         TBLR   *+,0
F0025 0553 004C         ADD    ONE
F0026 0554 F400         BANZ   NXCONS
      0555 0551
F0027                *;
F0028 0556 4021         IN     TEMP1,CTL
F0029 0557 2021         LAC    TEMP1
F0030 0558 FA00         BLZ    ALAW
      0559 055E
F0031 055A FF00  MULAW  BZ     MULAWX
      055B 0020
F0032 055C F900         B      MULAWR
      055D 00F9
F0033 055E 7974  ALAW   AND    M32767
F0034 055F FF00         BZ     ALAWX
      0560 004E
F0035 0561 F900         B      ALAWR
      0562 0184
F0036                *;
```

```
 0007                    COPY    ROMRAM.ASM
G0001           *;
G0002           *;********************************************************
G0003           *;      ROM
G0004           *;********************************************************
G0005 0563      ROMLOC BSS     0
G0006           *; SHIFT MULT TABLE
G0007 0563      SHFT   BSS     0
G0008 0563 0000        DATA    0       ; log dq to fit dq exponent adjustment
G0009 0564 0001        DATA    1
G0010 0565 0002        DATA    2
G0011 0566 0004        DATA    4
G0012 0567 0008        DATA    8
G0013 0568 0010        DATA    16
G0014 0569 0020        DATA    32
G0015 056A 0040        DATA    64
G0016 056B 0080        DATA    128
G0017 056C 0100        DATA    256
G0018 056D 0200        DATA    512
G0019 056E 0400        DATA    1024
G0020 056F 0800        DATA    2048
G0021 0570 1000        DATA    4096
G0022 0571 2000        DATA    8192
G0023 0572 4000        DATA    16384
G0024           *; DQMAN MASK TABLE
G0025 0573 FE00        DATA    65024
G0026 0574 FF00        DATA    65280
G0027 0575 FF80        DATA    65408
G0028 0576 FFC0        DATA    65472
G0029 0577 FFE0        DATA    65504
G0030 0578 FFF0        DATA    65520
G0031 0579 FFF8        DATA    65528
G0032 057A FFF8        DATA    65528
G0033 057B FFF8        DATA    65528
G0034 057C FFF8        DATA    65528
G0035 057D FFF8        DATA    65528
G0036 057E FFF8        DATA    65528
G0037 057F FFF8        DATA    65528
G0038 0580 FFF8        DATA    65528
G0039 0581 FFF8        DATA    65528
G0040 0582 FFF8        DATA    65528
G0041           *; INVERSE QUANTIZING TABLE
G0042 0583      IQTAB  BSS     0
G0043 0583 FF79        DATA    65401
G0044 0584 0044        DATA    68
G0045 0585 00A5        DATA    165
G0046 0586 00E8        DATA    232
G0047 0587 011D        DATA    285
G0048 0588 014C        DATA    332
G0049 0589 0179        DATA    377  ,
G0050 058A 01AC        DATA    428
G0051           *; WI TABLE
G0052 058B      WTABLE BSS     0
G0053 058B FFF4        DATA    65524
G0054 058C 0004        DATA    4
G0055 058D 001B        DATA    27
G0056 058E 0032        DATA    50
```



```
G0057 058F 0062        DATA    98
G0058 0590 00B8        DATA    184
G0059 0591 0154        DATA    340
G0060 0592 0454        DATA    1108
G0061           *; FI TABLE
G0062 0593      FITABL BSS     0
G0063 0593             BSS     0
G0064 0593 0000        DATA    0
G0065 0594 0000        DATA    0
G0066 0595 0000        DATA    0
G0067 0596 0010        DATA    16
G0068 0597 0010        DATA    16
G0069 0598 0010        DATA    16
G0070 0599 0030        DATA    48
G0071 059A 0070        DATA    112
G0072           *;
G0073           *; misc constants to be initialized
G0074           *;
G0075 059B      CONS   BSS     0
G0076 059B 0002        DATA    2    ; 12th entry of shift table (1st 11 all 0)
G0077 059C 0004        DATA    4
G0078 059D 0008        DATA    8
G0079 059E 0010        DATA    16
G0080 059F 0020        DATA    32
G0081 05A0 0040        DATA    64
G0082 05A1 0080        DATA    128
G0083 05A2 0100        DATA    256
G0084 05A3 0200        DATA    512
G0085 05A4 0400        DATA    1024
G0086 05A5 0800        DATA    2048
G0087 05A6 1000        DATA    4096
G0088 05A7 2000        DATA    8192
G0089 05A8 4000        DATA    16384
G0090 05A9 FFFF        DATA    -1
G0091 05AA FFFE        DATA    -2
G0092 05AB FFFC        DATA    -4
G0093 05AC 00FF        DATA    255     ;M255
G0094 05AD 8000        DATA    32768   ;K32768
G0095 05AE 0001        DATA    1       ;YLH
G0096 05AF 0800        DATA    2048    ;YLL
G0097 05B0 FFFF        DATA    -1
G0098 05B1 0001        DATA    1
G0099 05B2 0021        DATA    33      ; BIAS
G0100 05B3 0220        DATA    544     ;YU
G0101 05B4 0200        DATA    512     ;PK0
G0102 05B5 0200        DATA    512     ;PK1
G0103 05B6 0200        DATA    512     ;PK2
G0104 05B7 0100        DATA    256     ;SRMAN
G0105 05B8 0100        DATA    256     ;SRIMAN
G0106 05B9 0800        DATA    2048    ;SDQ
G0107 05BA 0800        DATA    2048    ;SDQ1
G0108 05BB 0800        DATA    2048    ;SDQ2
G0109 05BC 0800        DATA    2048    ;SDQ3
G0110 05BD 0800        DATA    2048    ;SDQ4
G0111 05BE 0800        DATA    2048    ;SDQ5
G0112 05BF 0800        DATA    2048    ;SDQ6
G0113 05C0 0100        DATA    256     ;DQMAN
```

```
05C1 0100          DATA    256      ;DQ1MAN
05C2 0100          DATA    256      ;DQ2MAN
05C3 0100          DATA    256      ;DQ3MAN
05C4 0100          DATA    256      ;DQ4MAN
05C5 0100          DATA    256      ;DQ5MAN
05C6 11E0          DATA    4576     ;K4576
05C7 3FFE          DATA    16382    ;K16382
05C8 C002          DATA    -16382   ;M16382
05C9 002E          DATA    46       ;K46
05CA 0031          DATA    49       ;K49
05CB 0563          DATA    SHFT     ;SHIFT
05CC 003F          DATA    63       ;K63
05CD 0000          DATA    0        ;FI
05CE 0000          DATA    0        ;WI
05CF 0583          DATA    IQTAB    ;INQTAB
05D0 0220          DATA    544      ;K544
05D1 1400          DATA    5120     ;K5120
05D2 000F          DATA    15       ;M15
05D3 FF80          DATA    -128     ;KFF80
05D4 007F          DATA    127      ;K127
05D5 FFC0          DATA    -64      ;MFFC0
05D6 1080          DATA    4224     ; BIAS*2**7
05D7 0FFF          DATA    4095     ;M4095
05D8 0000          DATA    0        ;spare
05D9 7FFF          DATA    32767    ;M32767
05DA FF00          DATA    -256     ;KFF00
05DB 0038          DATA    56       ;K56
05DC 03C0          DATA    960      ;K960
05DD 004F          DATA    79       ;K79
05DE 005F          DATA    95       ;K95
05DF 0082          DATA    130      ;K130
05E0 008A          DATA    138      ;K138
05E1 0905          DATA    2309     ;K2309
05E2 0003          DATA    3        ;THREE
05E3 0000          DATA    0        ;spare
05E4 0080          DATA    128      ;M0080
```



```
                *;*******************************************************
                *;      RAM
                *;*******************************************************
05E5            RAMLOC BSS      0
0000                   DORG     0
                *;
                *;  RAM Location # 000
0000 0000              DATA     0        ; spare
                *;
                *;  RAM Location # 001
0001 0000       I      DATA     0        ; 32Kb output
                *;
                *;  RAM Location # 002
0002 0000       IM     DATA     0        ; 8-level version of I
                *;
                *;  RAM Location # 003
0003 0000       SE     DATA     0        ; signal estimate
                *;
                *;  RAM Location # 004
0004 0000       SEZ    DATA     0        ; partial signal estimate
                *;
                *;  RAM Location # 005
0005 0000       APP    DATA     0        ; unlimited speed control parm
                *;
                *;  RAM Location # 006
0006 0000       AL     DATA     0        ; limited speed control parm
                *;
                *;  RAM Location # 007
0007 0000       DMS    DATA     0        ; short term average of F
                *;
                *;  RAM Location # 008
0008 0000       DML    DATA     0        ; long term average of F
                *;
                *;  RAM Location # 009
0009 0000       Y      DATA     0        ; quantizer scale factor
                *;
                *;  RAM Location # 010
000A 0000       B1     DATA     0        ; 6th order predictor coefficient
                *;
                *;  RAM Location # 011
000B 0000       B2     DATA     0        ; 6th order predictor coefficient
                *;
                *;  RAM Location # 012
000C 0000       B3     DATA     0        ; 6th order predictor coefficient
                *;
                *;  RAM Location # 013
000D 0000       B4     DATA     0        ; 6th order predictor coefficient
                *;
                *;  RAM Location # 014
000E 0000       B5     DATA     0        ; 6th order predictor coefficient
                *;
                *;  RAM Location # 015
000F 0000       B6     DATA     0        ; 6th order predictor coefficient
                *;
                *;  RAM Location # 016
0010 0000       DQ     DATA     0        ; quantized diff signal
                *;
```

```
                  *;  RAM Location # 017
     0011 0000  A1     DATA    0       ; coefficients of 2nd order predictor
                  *;
                  *;  RAM Location # 018
     0012 0000  A2     DATA    0       ; coefficients of 2nd order predictor
                  *;
                  *;  RAM Location # 019
     0013 0000  SR     DATA    0       ; reconstructed signal frame k
                  *;
                  *;  RAM Location # 020
     0014 0000  SR1    DATA    0       ; reconstructed signal frame k
                  *;
                  *;  RAM Location # 021
     0015 0000  DQEXP  DATA    0       ; exponent of DQ
                  *;
                  *;  RAM Location # 022
     0016 0000  DQ1EXP DATA    0       ; exponent of DQ1
                  *;
                  *;  RAM Location # 023
     0017 0000  DQ2EXP DATA    0       ; exp of DQ2
                  *;
                  *;  RAM Location # 024
     0018 0000  DQ3EXP DATA    0       ; exp of DQ3
                  *;
                  *;  RAM Location # 025
     0019 0000  DQ4EXP DATA    0       ; exp of DQ4
                  *;
                  *;  RAM Location # 026
     001A 0000  DQ5EXP DATA    0       ; exp of DQ5
                  *;
                  *;  RAM Location # 027
     001B 0000  SCRACH DATA    0       ; scrach variable
                  *;
                  *;  RAM Location # 028
     001C 0000  SREXP  DATA    0       ; exp of SR
                  *;
                  *;  RAM Location # 029
     001D 0000  SR1EXP DATA    0       ; exp of SR1
                  *;
                  *;  RAM Location # 030
     001E 0000  SUM4   DATA    0       ; temp
                  *;
                  *;  RAM Location # 031
     001F 0000  SUM5   DATA    0       ; temp
                  *;
                  *;  RAM Location # 032
     0020 0000  SUM6   DATA    0       ; temp
                  *;
                  *;  RAM Location # 033
     0021 0000  TEMP1  DATA    0       ; temp
                  *;
                  *;  RAM Location # 034
     0022       SUM1   BSS     0       ; temp
     0022 0000  TEMP2  DATA    0       ; temp
                  *;
                  *;  RAM Location # 035
     0023       SUM2   BSS     0       ; temp
```



```
     0023 0000  TEMP3  DATA    0       ; temp
                  *;
                  *;  RAM Location # 036
     0024 0000  TEMP4  DATA    0       ; temp
                  *;
                  *;  RAM Location # 037
     0025 0000  SUM3   DATA    0       ; temp
                  *;
                  *;  RAM Location # 038
     0026 0000  SAMPLE DATA    0       ; Linear sample
                  *;
                  *;  RAM Location # 039
     0027 0000  SUM7   DATA    0       ; temp storage of SR1*A1 tap
                  *;
                  *;  RAM Location # 040
     0028 0000  SUM8   DATA    0       ; temp storage of SR2*A2 tap
                  *;
                  *;  RAM Location # 041
     0029 0000  YOVER4 DATA    0       ; Y>>2
                  *;
                  *;  RAM Location # 042
     002A 0000         DATA    0       ; first location of shift table
                  *;
                  *;  RAM Location # 043
     002B 0000         DATA    0
                  *;
                  *;  RAM Location # 044
     002C 0000         DATA    0
                  *;
                  *;  RAM Location # 045
     002D 0000         DATA    0
                  *;
                  *;  RAM Location # 046
     002E 0000         DATA    0
                  *;
                  *;  RAM Location # 047
     002F 0000         DATA    0
                  *;
                  *;  RAM Location # 048
     0030 0000         DATA    0
                  *;
                  *;  RAM Location # 049
     0031 0000         DATA    0
                  *;
                  *;  RAM Location # 050
     0032 0000         DATA    0
                  *;
                  *;  RAM Location # 051
     0033 0000         DATA    0
                  *;
                  *;  RAM Location # 052
     0034 0000         DATA    0
                  *;
                  *;  RAM Location # 053
     0035 0000         DATA    0
                  *;
                  *;  RAM Location # 054
```

```
G0322 0036 0000        DATA    0
G0323                *;
G0324                *;  RAM Location # 055
G0325 0037 0000        DATA    0
G0326                *;
G0327                *;  RAM Location # 056
G0328 0038 0000  EIGHT DATA    0
G0329                *;
G0330                *;  RAM Location # 057
G0331 0039 0000        DATA    0
G0332                *;
G0333                *;  RAM Location # 058
G0334 003A 0000        DATA    0
G0335                *;
G0336                *;  RAM Location # 059
G0337 003B 0000        DATA    0
G0338                *;
G0339                *;  RAM Location # 060
G0340 003C 0000        DATA    0
G0341                *;
G0342                *;  RAM Location # 061
G0343 003D 0000        DATA    0
G0344                *;
G0345                *;  RAM Location # 062
G0346 003E 0000        DATA    0
G0347                *;
G0348                *;  RAM Location # 063
G0349 003F 0000        DATA    0
G0350                *;
G0351                *;  RAM Location # 064
G0352 0040 0000        DATA    0
G0353                *;
G0354                *;  RAM Location # 065
G0355 0041 0000        DATA    0
G0356                *;
G0357                *;  RAM Location # 066
G0358 0042 0000        DATA    0
G0359                *;
G0360                *;  RAM Location # 067
G0361 0043 0000        DATA    0
G0362                *;
G0363                *;  RAM Location # 068
G0364 0044 0000        DATA    0
G0365                *;
G0366                *;  RAM Location # 069
G0367 0045 0000        DATA    0
G0368                *;
G0369                *;  RAM Location # 070
G0370 0046 0000        DATA    0        ; last loc of table (42-70)
G0371                *;
G0372                *;  RAM Location # 071
G0373 0047 0000  M255  DATA    0
G0374                *;
G0375                *;  RAM Location # 072
G0376 0048 0000  K32768 DATA   0        ; sign bit
G0377                *;
G0378                *;  RAM Location # 073
```



```
G0379 0049 0000  YLH    DATA    0       ; fast quant scale factor (hi word)
G0380                *;
G0381                *;  RAM Location # 074
G0382 004A 0000  YLL    DATA    0       ; slow quant scale factor (lo word)
G0383                *;
G0384                *;  RAM Location # 075
G0385 004B 0000  MINUS  DATA    0       ; -1
G0386                *;
G0387                *;  RAM Location # 076
G0388 004C 0000  ONE    DATA    0       ; 1
G0389                *;
G0390                *;  RAM Location # 077
G0391 004D 0000  BIAS   DATA    0       ; constant for mulaw conversions
G0392                *;
G0393                *;  RAM Location # 078
G0394 004E 0000  YU     DATA    0       ; fast quant scale factor
G0395                *;
G0396                *;  RAM Location # 079
G0397 004F 0000  PK0    DATA    0       ; sign of p(k)
G0398                *;
G0399                *;  RAM Location # 080
G0400 0050 0000  PK1    DATA    0       ; sign of p(k-1)
G0401                *;
G0402                *;  RAM Location # 081
G0403 0051 0000  PK2    DATA    0       ; sign of p(k-2)
G0404                *;
G0405                *;  RAM Location # 082
G0406 0052 0000  SRMAN  DATA    0       ; mantissa of SR
G0407                *;
G0408                *;  RAM Location # 083
G0409 0053 0000  SR1MAN DATA    0       ; mantissa of SR1
G0410                *;
G0411                *;  RAM Location # 084
G0412 0054 0000  SDQ    DATA    0       ; sign DQ(k)
G0413                *;
G0414                *;  RAM Location # 085
G0415 0055 0000  SDQ1   DATA    0       ; sign DQ(k-1)
G0416                *;
G0417                *;  RAM Location # 086
G0418 0056 0000  SDQ2   DATA    0       ; sign DQ(k-2)
G0419                *;
G0420                *;  RAM Location # 087
G0421 0057 0000  SDQ3   DATA    0       ; sign DQ(k-3)
G0422                *;
G0423                *;  RAM Location # 088
G0424 0058 0000  SDQ4   DATA    0       ; sign DQ(k-4)
G0425                *;
G0426                *;  RAM Location # 089
G0427 0059 0000  SDQ5   DATA    0       ; sign DQ(k-5)
G0428                *;
G0429                *;  RAM Location # 090
G0430 005A 0000  SDQ6   DATA    0       ; sign DQ(k-6)
G0431                *;
G0432                *;  RAM Location # 091
G0433 005B 0000  DQMAN  DATA    0       ; mantissa of DQ
G0434                *;
G0435                *;  RAM Location # 092
```

```
005C 0000  DQ1MAN DATA    0         ; mantissa of DQ1
           *;
           *;  RAM Location # 093
005D 0000  DQ2MAN DATA    0         ; mantissa of DQ2
           *;
           *;  RAM Location # 094
005E 0000  DQ3MAN DATA    0         ; mantissa of DQ3
           *;
           *;  RAM Location # 095
005F 0000  DQ4MAN DATA    0         ; mantissa of DQ4
           *;
           *;  RAM Location # 096
0060 0000  DQ5MAN DATA    0         ; mantissa of DQ5
           *;
           *;  RAM Location # 097
0061 0000  K4576  DATA    0         ; 4576
           *;
           *;  RAM Location # 098
0062 0000  K16382 DATA    0         ; +16382
           *;
           *;  RAM Location # 099
0063 0000  M16382 DATA    0         ; -16382
           *;
           *;  RAM Location # 100
0064 0000  K46    DATA    0         ; 46
           *;
           *;  RAM Location # 101
0065 0000  K49    DATA    0         ; 49
           *;
           *;  RAM Location # 102
0066 0000  SHIFT  DATA    0         ; SHIFT table address
           *;
           *;  RAM Location # 103
0067 0000  K63    DATA    0         ; 63
           *;
           *;  RAM Location # 104
0068 0000  FI     DATA    0         ; FI value
           *;
           *;  RAM Location # 105
0069 0000  WI     DATA    0         ; WI value
           *;
           *;  RAM Location # 106
006A 0000  INQTAB DATA    0         ; Inverse quan table address
           *;
           *;  RAM Location # 107
006B 0000  K544   DATA    0         ; 544
           *;
           *;  RAM Location # 108
006C 0000  K5120  DATA    0         ; 5120
           *;
           *;  RAM Location # 109
006D 0000  M15    DATA    0         ; 15
           *;
           *;  RAM Location # 110
006E 0000  KFF80  DATA    0         ; >FF80
           *;
           *;  RAM Location # 111
```



```
006F 0000  M127   DATA    0         ; 127
           *;
           *;  RAM Location # 112
0070 0000  MFFC0  DATA    0         ; -64
           *;
           *;  RAM Location # 113
0071 0000  BIASA  DATA    0         ; 33*128
           *;
           *;  RAM Location # 114
0072 0000  M4095  DATA    0         ; 4095
           *;
           *;  RAM Location # 115
0073 0000         DATA    0         ; spare
           *;
           *;  RAM Location # 116
0074 0000  M32767 DATA    0         ; 32767
           *;
           *;  RAM Location # 117
0075 0000  KFF00  DATA    0         ; >FF00
           *;
           *;  RAM Location # 118
0076 0000  K56    DATA    0         ; 56
           *;
           *;  RAM Location # 119
0077 0000  K960   DATA    0         ; 960
           *;
           *;  RAM Location # 120
0078 0000  K79    DATA    0         ; constants used for quantizing table
           *;
           *;  RAM Location # 121
0079 0000  K95    DATA    0         ; constants used for quantizing table
           *;
           *;  RAM Location # 122
007A 0000  K130   DATA    0         ; constants used for quantizing table
           *;
           *;  RAM Location # 123
007B 0000  K138   DATA    0         ; constants used for quantizing table
           *;
           *;  RAM Location # 124
007C 0000  K2309  DATA    0         ; constants used for quantizing table
           *;
           *;  RAM Location # 125
007D 0000  THREE  DATA    0         ; 3
           *;
           *;  RAM Location # 126
007E 0000         DATA    0         ; spare
           *;
           *;  RAM Location # 127
007F 0000  M0080  DATA    0         ; alaw mask
           *;
NO ERRORS, NO WARNINGS
```

LABEL	VALUE	DEFN	REFERENCES
A1	0011	G0209	B0252 B0270 D0431 D0456 D0458 D0464 D0515 D0523
A1LIM	0426	D0520	
A2	0012	G0212	B0230 B0245 D0486 D0493 D0496 D0508 D0513
ADC	0001	A0031	A0056 A0126
ADD18	03B3	D0336	D0328
ADDA	035C	D0085	
ADDC	03E1	D0413	
ADDONE	01A8	A0566	A0562
ADDSGN	036C	D0104	
AL	0006	G0176	B0321 B0327 B0361
ALAW	055E	F0033	F0030
ALAWR	0184	A0511	A0512 F0035
ALAWX	004E	A0172	A0173 F0034
ALOG	035E	D0090	
ANOMLE	019F	A0559	A0557
ANOMLY	01AF	A0572	A0564
APP	0005	G0173	B0322 B0325 D0323 D0324 D0325 D0336 D0338
APRED	03B6	D0345	D0335
AQUAN	02AA	C0024	A0099 A0168 A0351 A0504
B1	000A	G0188	B0167 B0183 D0396 D0398 D0402
B2	000B	G0191	B0144 B0160 D0389 D0391 D0395
B3	000C	G0194	B0121 B0137 D0382 D0384 D0388
B4	000D	G0197	B0098 B0114 D0375 D0377 D0381
B5	000E	G0200	B0075 B0091 D0368 D0370 D0374
B6	000F	G0203	B0053 B0068 D0361 D0363 D0367
BIAS	004D	G0391	A0082 A0089 A0253 A0264 A0272 A0282 A0290 A0302 A0310 A0320 A0334 A0346 A0426 A0436 A0444 A0456 A0464 A0474 A0488
BIASA	0071	G0499	A0180 A0184 A0188 A0192 A0196 A0200 A0204
C0TO1	02B8	C0075	
C0TO3	02B5	C0073	
C0TO7	02B2	C0071	
C2TO3	02C3	C0083	C0074
C4TO5	02D1	C0093	
C4TO7	02CE	C0091	C0072
C6TO7	02DC	C0101	C0092
C8TO11	02EA	C0111	
C8TO14	02E7	C0109	C0070
C8TO9	02ED	C0113	
CATOB	02FC	C0125	C0112
CCITT	0002	A0033	A0101 A0170 A0210 A0364
CCTOD	030E	C0139	
CCTOE	030B	C0137	C0110
CHK1	01C4	B0068	E0007
CHK11	025F	B0245	E0031
CHK2	01DE	B0091	E0011
CHK21	0279	B0268	E0035
CHK3	01F8	B0114	E0015
CHK4	0212	B0137	E0019
CHK5	022C	B0160	E0023
CHK6	0246	B0183	E0027
CHKHI	0386	D0186	D0183
C10TO1	032C	C0187	
C10TO3	0329	C0185	
C12TO3	0335	C0193	C0186
C14TO7	033E	C0199	C0184
C15TO6	0341	C0201	

LABEL	VALUE	DEFN	REFERENCES
C16TO7	034A	C0207	C0200
CLNUP	00EA	A0342	A0330
CLNUPA	0176	A0496	A0484
CMPRSA	010B	A0405	
CMPRSU	007F	A0251	
CONS	059B	G0075	F0019
CTL	0000	A0034	F0028
D0TO1	0438	D0559	
D0TO3	0435	D0557	
D0TO7	0432	D0555	
D2TO3	043D	D0564	D0558
D4TO5	044D	D0578	
D4TO7	044A	D0576	D0556
D6TO7	045A	D0590	D0577
D8TO9	046F	D0608	
D8TOB	046C	D0606	
D8TOF	0469	D0604	D0554
DAC	0001	A0032	A0357 A0510
DATOB	0480	D0624	D0607
DCTOD	0494	D0642	
DCTOF	0491	D0640	D0605
DETOF	04A5	D0658	D0641
DML	0008	G0182	D0293 D0294 D0295 D0329 D0332
DMS	0007	G0179	D0273 D0274 D0275 D0331
DO32KA	0106	A0376	A0369
DO32KU	007A	A0222	A0215
DONEC	041C	D0508	
DONEF	03F9	D0442	D0437
DQ	0010	G0206	D0103 D0110 D0111 D0416 D0548
DQ1EXP	0016	G0224	B0146 B0147
DQ1MAN	005C	G0436	B0150
DQ2EXP	0017	G0227	B0123 B0124
DQ2MAN	005D	G0439	B0127
DQ3EXP	0018	G0230	B0100 B0101
DQ3MAN	005E	G0442	B0104
DQ4EXP	0019	G0233	B0077 B0078
DQ4MAN	005F	G0445	B0081
DQ5EXP	001A	G0236	B0055
DQ5MAN	0060	G0448	B0058
DQEXP	0015	G0221	B0169 B0170 D0091 D0095
DQMAN	005B	G0433	B0173 D0094 D0101 D0126 D0127 D0128 D0130
E0	04EE	E0062	E0131
E0TO1	04EB	E0060	
E0TO3	04E8	E0058	
E0TO7	04E5	E0056	
E1	04F2	E0066	E0061
E10	0529	E0114	E0109
E11	0533	E0122	
E12	0537	E0126	E0121
E13	053E	E0132	
E2	04F9	E0072	
E2TO3	04F6	E0070	E0059
E3	04FD	E0076	E0071
E4	0504	E0082	
E4TO6	0501	E0080	E0057
E5	050B	E0088	
E5TO6	0508	E0086	E0081

LABEL	VALUE	DEFN	REFERENCES
E6	050F	E0092	E0087
E7	051A	E0100	
E7TOB	0517	E0098	
E7TOA	0514	E0096	
E7TOD	0511	E0094	E0055
E8	051E	E0104	E0099
E9	0525	E0110	
E9TOA	0522	E0108	E0097
EBTOC	0530	E0120	
EBTOD	052D	E0118	E0095
EDTOE	053B	E0130	E0119
EIGHT	0038	G0328	A0541
EXP0	02BB	C0077	
EXP1	02BF	C0080	C0076
EXP10	02FF	C0127	
EXP11	0305	C0132	C0126
EXP12	0311	C0141	
EXP13	0317	C0146	C0140
EXP14	031D	C0151	C0138
EXP2	02C6	C0085	
EXP3	02CA	C0088	C0084
EXP4	02D4	C0095	
EXP5	02D8	C0098	C0094
EXP6	02DF	C0103	
EXP7	02E3	C0106	C0102
EXP8	02F0	C0115	
EXP9	02F6	C0120	C0114
EXPNDA	0035	A0146	
EXPNDU	0005	A0076	
EXX01	0439	D0560	
EXX10	0483	D0626	
EXX11	048A	D0633	D0625
EXX12	0497	D0644	
EXX13	049E	D0651	D0643
EXX14	04A8	D0660	
EXX15	04AF	D0667	D0659
EXX2	0440	D0566	
EXX3	0445	D0571	D0565
EXX4	0450	D0580	
EXX5	0455	D0585	D0579
EXX6	045D	D0592	
EXX7	0462	D0597	D0591
EXX8	0472	D0610	
EXX9	0479	D0617	D0609
FI	0068	G0472	D0051 D0272 D0292
FILTA	039C	D0272	
FILTB	03A0	D0292	
FILTC	03A4	D0323	
FILTD	037C	D0175	
FILTE	038B	D0209	D0187
FINI	00E6	A0338	A0268 A0276 A0286 A0294 A0306 A0314 A0324
FINISH	0172	A0492	A0422 A0430 A0440 A0448 A0460 A0468 A0478
FITABL	0593	G0062	
FLOAT	04DE	E0050	B0054 B0076 B0099 B0122 B0145 B0168 B0231 B0253
FLTDQ	0377	D0126	D0108
FLTSFT	002A	E0047	E0064 E0068 E0074 E0078 E0084 E0090 E0092 E0102 E0106 E0112 E0116 E0124 E0128 E0134

LABEL	VALUE	DEFN	REFERENCES
FLTSR	042A	D0548	D0519
GETA1	03FA	D0456	D0435 D0440
GETA2	0404	D0481	
GETB1	03DA	D0396	
GETB2	03D3	D0389	
GETB3	03CC	D0382	
GETB4	03C5	D0375	
GETB5	03BE	D0368	
GETB6	03B6	D0360	
GETEXP	02AF	C0069	
GETF	03EA	D0431	
GETF1	03EE	D0434	
GETF2	03F4	D0438	D0433
GETI	0018	A0098	
GETIM	0351	C0212	C0190 C0192 C0196 C0198 C0204 C0206 C0210
GETMAN	0321	C0155	C0079 C0082 C0087 C0090 C0097 C0100 C0105 C0108 C0119 C0124 C0131 C0136 C0145 C0150
GETSE	024E	B0230	
I	0001	G0161	A0100 A0101 A0169 A0170 A0210 A0212 A0364 A0366 A0544 D0106
IDEQIM	01B1	A0574	A0547
IDGTIM	01A0	A0560	A0546
IDLTIM	0191	A0548	
IEQ0	032F	C0189	
IEQ1	0332	C0191	C0188
IEQ2	0338	C0195	
IEQ3	033B	C0197	C0194
IEQ4	0344	C0203	
IEQ5	0347	C0205	C0202
IEQ6	034D	C0209	
IEQ7	0350	C0211	C0208
IM	0002	G0164	A0213 A0216 A0218 A0367 A0370 A0372 C0212 D0045
INQTAB	006A	G0478	D0046
INTRPT	0002	A0050	A0050
IQTAB	0583	G0042	G0128
ITAB1	07F9	C0175	
ITAB2	087B	C0176	
ITAB3	08CA	C0177	
ITAB4	0905	C0178	
ITAB5	0936	C0179	
ITAB6	0964	C0180	
ITAB7	0995	C0181	
K130	007A	G0526	C0187
K138	007B	G0529	C0185
K16382	0062	G0454	D0436
K2309	007C	G0532	C0183
K32768	0048	G0376	A0147 B0070 B0093 B0116 B0139 B0162 B0185 B0247 B0271
K4576	0061	G0451	D0186
K46	0064	G0460	C0201
K49	0065	G0463	C0207
K5120	006C	G0484	D0188
K544	006B	G0481	D0182 D0184
K56	0076	G0514	E0056
K63	0067	G0469	A0327 A0481
K79	0078	G0520	C0193
K95	0079	G0523	C0199
K960	0077	G0517	D0604 E0094

```
LABEL    VALUE  DEFN   REFERENCES

KFF00    0075   G0511  A0077
KFF80    006E   G0490  B0062 B0085 B0108 B0131 B0154 B0177 B0239 B0262
LIMA     028E   B0320
LIMB     0380   D0182
LIMC     0415   D0502
LIMD     041D   D0512  D0504
M0080    007F   G0541  A0508
M127     006F   G0493  A0549 A0558 A0563 A0566 C0155
M15      006D   G0487  A0217 A0261 A0269 A0279 A0287 A0299 A0307 A0317 A0331
                       A0371 A0415 A0423 A0433 A0441 A0453 A0461 A0471 A0485
                       C0071 C0109 C0214 D0512 D0555
M16382   0063   G0457  D0441
M255     0047   G0373  A0343 A0355 A0497
M32767   0074   G0508  A0079 A0149 D0217 D0224 E0005 E0009 E0013 E0017 E0021
                       E0025 E0029 E0033 F0033
M4095    0072   G0502  A0081 A0151 B0365 D0092
MAXNEG   01AD   A0570  A0567
MAXPOS   0199   A0554  A0551
MFFC0    0070   G0496  B0326
MINUS    004B   G0385  D0112
MIX      0297   B0353  B0324
MULAW    055A   F0031
MULAWR   00F9   A0358  A0359 F0032
MULAWX   0020   A0103  A0104 F0031
NEG1     01C9   B0072
NEG11    0264   B0249
NEG2     01E3   B0095
NEG21    027F   B0273
NEG3     01FD   B0118
NEG4     0217   B0141
NEG5     0231   B0164
NEG6     024B   B0187
NOCONS   004A   F0004  F0022
NONNEG   02A5   B0366  B0364
NORMAL   00DF   A0331  A0326
NORMLA   016B   A0485  A0480
NXCONS   0551   F0023  F0026
ONE      004C   G0388  A0176 A0214 A0255 A0259 A0277 A0297 A0315 A0325 A0368
                       A0409 A0413 A0418 A0431 A0451 A0469 A0479 A0543 A0552
                       A0556 A0561 A0568 B0320 B0323 C0069 C0075 C0083 C0093
                       C0101 C0113 C0125 C0139 C0165 D0048 D0050 D0090 D0093
                       D0099 D0104 D0107 D0337 D0419 D0434 D0439 D0553 D0561
                       D0564 D0578 D0590 D0608 D0624 D0642 D0658 E0054 E0062
                       E0070 E0080 E0086 E0098 E0108 E0120 E0130 F0017 F0018
                       F0025
PK0      004F   G0397  D0414 D0420 D0421
PK1      0050   G0400  D0413 D0460
PK2      0051   G0403  D0488
POS1     01CC   B0075  B0071
POS11    0267   B0252  B0248
POS2     01E6   B0098  B0094
POS21    0282   B0276  B0272
POS3     0200   B0121  B0117
POS4     021A   B0144  B0140
POS5     0234   B0167  B0163
POS6     024E   B0190  B0186
PRDICT   0355   D0045  A0102 A0171 A0223 A0377
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LABEL    VALUE  DEFN   REFERENCES

PTCONS   0036   F0005  F0021
QDONE    0354   C0215
QUAN     0326   C0183
RAMLOC   05E5   G0154
RCVA     00FD   A0364  A0511
RCVMU    0071   A0210  A0358
RESET    0542   F0007  A0043
ROMLOC   0563   G0005
RS1      04B6   E0004  B0066
RS11     04D4   E0028  B0243
RS2      04BB   E0008  B0089
RS21     04D9   E0032  B0266
RS3      04C0   E0012  B0112
RS4      04C5   E0016  B0135
RS5      04CA   E0020  B0158
RS6      04CF   E0024  B0181
SAMPLE   0026   G0274  A0090 A0091 A0094 A0158 A0159 A0162 A0265 A0273 A0283
                       A0291 A0303 A0311 A0321 A0328 A0335 A0345 A0349 A0419
                       A0427 A0437 A0445 A0457 A0465 A0475 A0482 A0489 A0499
                       A0502 C0024
SATCH    00DA   A0327
SATCHA   0166   A0481
SBASE    0024   A0106  A0086
SBASEA   0052   A0175  A0155
SCAL0A   0118   A0415
SCAL1A   0121   A0423  A0414
SCAL2A   012D   A0433
SCAL3A   0136   A0441  A0432
SCAL4A   0145   A0453
SCAL5A   014E   A0461  A0452
SCAL6A   015A   A0471
SCAL7A   0163   A0479  A0470
SCALE0   008C   A0261
SCALE1   0095   A0269  A0260
SCALE2   00A1   A0279
SCALE3   00AA   A0287  A0278
SCALE4   00B9   A0299
SCALE5   00C2   A0307  A0298
SCALE6   00CE   A0317
SCALE7   00D7   A0325  A0316
SCL021   0089   A0259
SCL023   0086   A0257
SCL0T1   0115   A0413
SCL0T3   0112   A0411
SCL223   009E   A0277  A0258
SCL2T3   012A   A0431  A0412
SCL425   00B6   A0297
SCL427   00B3   A0295  A0256
SCL4T5   0142   A0451
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SCL627   00CB   A0315  A0296
SCL6T7   0157   A0469  A0450
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LABEL	VALUE	DEFN	REFERENCES
SCRACH	001B	G0239	A0056 A0076 A0083 A0106 A0108 A0110 A0112 A0114 A0116 A0118 A0120 A0126 A0146 A0152 A0175 A0179 A0183 A0187 A0191 A0195 A0199 A0203 A0254 A0262 A0263 A0266 A0270 A0271 A0274 A0280 A0281 A0284 A0288 A0289 A0292 A0300 A0301 A0304 A0308 A0309 A0312 A0318 A0319 A0322 A0332 A0333 A0336 A0338 A0339 A0344 A0356 A0357 A0408 A0416 A0417 A0420 A0424 A0425 A0428 A0434 A0435 A0438 A0442 A0443 A0446 A0454 A0455 A0458 A0462 A0463 A0466 A0472 A0473 A0476 A0486 A0487 A0490 A0492 A0493 A0498 A0509 A0510 A0548 A0560 A0574
SDQ	0054	G0412	D0105 D0113 D0365 D0372 D0379 D0386 D0393 D0400 D0401
SDQ1	0055	G0415	B0184 D0394
SDQ2	0056	G0418	B0161 D0387
SDQ3	0057	G0421	B0138 D0380
SDQ4	0058	G0424	B0115 D0373
SDQ5	0059	G0427	B0092 D0366
SDQ6	005A	G0430	B0069 D0360
SE	0003	G0167	B0301 B0302 B0303 C0025 D0549
SETPAC	0544	F0010	
SEZ	0004	G0170	B0298 D0415
SHFT	0563	G0007	G0124
SHIFT	0066	G0466	D0096
SIGDIF	01B3	B0053	A0098 A0167 A0222 A0376
SR	0013	G0215	A0247 A0401 B0268 B0269 D0550
SR1	0014	G0218	B0246
SRIEXP	001D	G0245	B0232
SRIMAN	0053	G0409	B0235
SREXP	001C	G0242	B0254 B0255 D0560 D0569 D0574 D0583 D0588 D0595 D0602 D0615 D0622 D0631 D0638 D0649 D0656 D0665 D0672
SRMAN	0052	G0406	B0258 D0552 D0559 D0562 D0566 D0567 D0571 D0572 D0580 D0581 D0585 D0586 D0592 D0593 D0597 D0598 D0599 D0600 D0610 D0611 D0612 D0613 D0617 D0618 D0619 D0620 D0626 D0627 D0628 D0629 D0633 D0634 D0635 D0636 D0644 D0645 D0646 D0647 D0651 D0652 D0653 D0654 D0660 D0661 D0662 D0663 D0667 D0668 D0669 D0670
STRLIM	038A	D0189	D0185
SUBF	0409	D0486	D0481
SUBONE	019B	A0556	A0550
SUBTB	0324	C0165	
SUM1	0022	G0260	B0056 B0057 B0067 B0073 B0074 B0297 E0006
SUM2	0023	G0264	B0079 B0080 B0090 B0096 B0097 B0296 E0010
SUM3	0025	G0271	B0102 B0103 B0113 B0119 B0120 B0295 E0014
SUM4	001E	G0248	B0125 B0126 B0136 B0142 B0143 B0294 D0487 D0494 E0018
SUM5	001F	G0251	B0148 B0149 B0159 B0165 B0166 B0293 E0022
SUM6	0020	G0254	B0171 B0172 B0182 B0188 B0189 B0292 E0026
SUM7	0027	G0277	B0233 B0234 B0244 B0250 B0251 B0299 E0030
SUM8	0028	G0280	B0256 B0257 B0267 B0274 B0275 B0300 E0034
SUMGTO	03E9	D0421	
SYNC	0188	A0541	A0353 A0506

LABEL	VALUE	DEFN	REFERENCES
TEMP1	0021	G0257	A0093 A0148 A0153 A0154 A0160 A0161 A0340 A0341 A0494 A0495 A0542 A0545 B0060 B0063 B0064 B0083 B0086 B0087 B0106 B0109 B0110 B0129 B0132 B0133 B0152 B0155 B0156 B0175 B0178 B0179 B0237 B0240 B0241 B0260 B0263 B0264 B0360 B0362 C0068 C0078 C0081 C0086 C0089 C0096 C0099 C0104 C0107 C0116 C0117 C0118 C0121 C0122 C0123 C0128 C0129 C0130 C0133 C0134 C0135 C0142 C0143 C0144 C0147 C0148 C0149 C0152 C0153 C0154 C0156 C0157 D0047 D0085 D0210 D0211 D0216 D0221 D0362 D0364 D0369 D0371 D0376 D0378 D0383 D0385 D0390 D0392 D0397 D0399 D0417 D0418 D0498 D0506 D0507 D0514 D0518 D0520 E0050 E0051 E0053 E0060 E0063 E0066 E0067 E0072 E0073 E0076 E0077 E0082 E0083 E0088 E0089 E0100 E0101 E0104 E0105 E0110 E0111 E0114 E0115 E0122 E0123 E0126 E0127 E0132 E0133 F0028 F0029
TEMP2	0022	G0261	A0080 A0087 A0150 A0156 D0218 D0219 D0220 D0222 D0457 D0459
TEMP3	0023	G0265	B0354 B0356 B0357 B0359 B0366 D0097 D0098 D0100 D0129 D0330 D0334 D0432 D0442 D0483 D0484 D0491 D0492 D0495
TEMP4	0024	G0268	A0251 A0342 A0347 A0348 A0405 A0407 A0496 A0500 A0501 C0066 C0213 D0516 D0521 D0522
THREE	007D	G0535	A0257 A0295 A0411 A0449 B0059 B0082 B0105 B0128 B0151 B0174 B0236 B0259 C0073 C0091 C0111 C0137 D0327 D0503 D0505 D0557 D0576 D0606 D0640 E0058 E0096 E0118
WI	0069	G0475	D0049 D0177
WTABLE	058B	G0052	
XMTA	0034	A0126	A0172
XMTMU	0004	A0056	A0103
Y	0009	G0185	B0367 B0368 D0175 D0176 D0326
YLH	0049	G0379	B0355 D0209 D0213 D0223
YLL	004A	G0382	B0353 D0212 D0214 D0225
YOVER4	0029	G0283	B0369 C0166 D0086
YU	004E	G0394	B0358 D0178 D0189 D0215
ZRAMA	0547	F0013	F0014