

Performance Analysis of Line Echo Cancellation Implementation Using TMS320C6201

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Performance Analysis of Line Echo Cancellation Implementation Using TMS320C6201

Abstract

This document summarizes the results of a performance analysis on the LMS-filter based line echo canceller (LEC) implementation using TMS320C6201 digital signal processor. The CPU throughput, internal data memory, and power dissipation requirements for processing are discussed.



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Overview of Line Echo Cancellation

Telephone calls are often subjected to distortion or echo as they go through various network components. The primary cause of line echo is an analog device called a hybrid. Due to the electric current leakage in the hybrid, a part of the signal energy is reflected back to the source of the signal, which causes the speaker on each end of the connection hear an echo of their own voice.

To improve the quality of telephone conversation, a line echo canceller needs to be placed in the network. In a line echo canceller, a transversal FIR filter is typically used to predict the echo from the history of the far-end signal, and the echo residue is calculated as:

$$e(n) = d(n) - \sum_{k=1}^M H_k(n)x(n-k) \quad (1)$$

where $e(n)$ is the value of residue at time n , $d(n)$ is the value of echo at time n , $H_k(n)$ is the k^{th} filter coefficient at time n , and $x(n-k)$ is the value of the far-end signal at time $n-k$. M is the length of the filter, which is determined by the maximum echo tail length to be processed.

The filter is usually updated by the LMS (least mean square) algorithm as:

$$H_k(n+1) = H_k(n) + \mu e(n)x(n-k) \quad (2)$$

where $\mu \geq 0$ is the adaptation step size.

For the leaky LMS algorithm, the filter is updated by:

$$H_k(n+1) = \beta H_k(n) + \mu e(n)x(n-k) \quad (3)$$

where $0 \leq \beta \leq 1$ is the leaky factor, which is introduced to gain more control of the filter response.

The performance requirements of a line echo canceller is given in the ITU G.165/G.168 specifications. It generally requires that the echo residue be reduced to 30 dB below the far-end signal level at the convergence of the cancellation filter.

'C6201 Performance in Echo Cancellation

The TMS320C6201 currently delivers up to 1600 MIPS at 200 MHz with a roadmap to double this performance by the end of the decade. This high performance solution is driven by the key features such as dual data paths from 8 functional units including 2 multipliers and 6 arithmetic units allowing execution of 8 32-bit instructions in parallel, and 5 DMA channels with automatic address generation features. Those key features enable TMS320C6201 to deliver up to 10 times the performance of the previous DSPs, providing an ideal solution for multi-channel telephony applications such as line echo cancellation.

In the analysis of TMS320C6201 performance in line echo cancellation, we assume a normal sampling rate of 8 kHz (125 μ s loop time), and 16 bit filter coefficients. The performance is primarily limited by the available internal data memory (64 Kbytes) and CPU throughput. Multi-channel operation and variation of echo tail length have no effect on the small program memory required for the LMS algorithm. The effectiveness of using 16 bit filter coefficients is discussed in another application report.

Data Memory Requirement

In general, the data memory requirement for processing a channel with N ms echo tail is shown in the table below. We assume that the algorithm is based on a normalized LMS or leaky LMS. For completeness, we also reserved 30 variables per channel for Modem Tone Detection, Phase Reversal Detection, Double Talk Detection, and Non-Linear-Processing (NLP). In the existing code [2], Modem Tone Detection uses 16 variables and the data memory for the rest procedures are negligible.

Table 1. Data Memory Requirement for a Channel with N ms Echo Tail.

| | |
|----------------------|--------------------------|
| Processing Variables | 30 (16 bit) |
| Circular Data Buffer | $2^K \geq 8N$ (16 bit) |
| Filter Coefficients | $8N$ (16 bit) |
| Total | $8N + 30 + 2^K$ (16 bit) |

The data memory required for each channel to process echoes with tail length of 32 ms, 48 ms, and 64 ms are listed in Table 2.



Table 2. Data Memory Requirement per Channel.

| | 32 ms Echo Tail | 48 ms Echo Tail | 64 ms Echo Tail |
|----------------------|--------------------|--------------------|--------------------|
| Processing Variables | 60 bytes | 60 bytes | 60 bytes |
| Circular Data Buffer | 512 bytes | 1024 bytes | 1024 bytes |
| Filter Coefficients | 512 bytes | 768 bytes | 1024 bytes |
| Total | 1084 bytes | 1852 bytes | 2108 bytes |

Table 3 illustrates the maximum number of echo cancellation channels that can be implemented on 200 MHz 'C6201's 64 Kbytes (65,536 bytes) internal data memory. In calculating the data in Table 3, we reserve 1000 byte for data I/O buffer. Again, the table reflects the data requirements for normalized LMS/leaky LMS, Modem Tone Detect, Phase Reversal Detect, Double Talk Detect, and NLP.

Table 3. Maximum Number of Channels can be Implemented on Internal Data Memory.

| | 32 ms Echo Tail | 48 ms Echo Tail | 64 ms Echo Tail |
|--------------------|--------------------|--------------------|--------------------|
| Number of Channels | 59 | 34 | 30 |

CPU Throughput Requirement

There are two existing LMS codes implemented on 'C6201. One handles normal LMS algorithm[1], and the other one performs leaky LMS algorithm[2]. Their throughput characteristics are listed in Table 4.

Table 4. Throughput Characteristics of the Existing 'C6201 LMS Code

| | Throughput of Existing Code | Ideal Throughput |
|-----------|-----------------------------|--------------------------|
| LMS | 1.125M + overhead (cycles) | 1.0M + overhead (cycles) |
| Leaky LMS | 1.5M + overhead (cycles) | 1.5M + overhead (cycles) |

Note: *M* is the number of the filter taps.

It can be seen from Equation 1 and 2 that two multiplies are required for processing each LMS filter tap. One is for calculating the echo prediction, and the other one is used to update the filter coefficients. If two multiply units are used simultaneously, the ideal throughput for the LMS algorithm will be M plus overhead, where M is the number of filter taps. Considering the limitation due to the available number of registers on the chip, we think that the throughput achieved by the existing code ($1.125M$) is a realistic upper limit. It can also be seen from Equation 3 that the leaky LMS algorithm requires one more multiply for filter update, which makes the ideal throughput for the leaky LMS algorithm to be $1.5M$. The existing code has already reached the ideal limit.

The 'C6201CPU throughput time required for each echo canceller channel is listed in Table 5. In Table 5, we assume a processing overhead of 100 cycles for Modem Tone Detect, Phase Reversal Detect, Double Talk Detect, NLP, and loop initialization codes. This is a very conservative assumption and is consistent with the code we used in the simulations. For the code we used in simulation [2], NLP takes 16 cycles and Modem tone Detection takes 26 cycles.

Table 5. CPU Throughput Requirement for Each Channel.

| | 32 ms Echo Tail | 48 ms Echo Tail | 64 ms Echo Tail |
|-----------|--------------------|--------------------|--------------------|
| LMS | 388 cycles | 532 cycles | 676 cycles |
| Leaky LMS | 484 cycles | 676 cycles | 868 cycles |

Table 6 displays the maximum numbers of echo canceller channels that can be implemented given the 200MHz 'C6201CPU throughput and zero wait state memory.

Table 6. Maximum Number of Channels that can be Implemented Due To Throughput Limit.

| | 32 ms Echo Tail | 48 ms Echo Tail | 64 ms Echo Tail |
|-----------|--------------------|--------------------|--------------------|
| LMS | 64 | 46 | 36 |
| Leaky LMS | 51 | 36 | 28 |

Combining the internal data memory analysis in Table 3 and throughput analysis in Table 6, we determine the upper bound of the number of LEC channels a single 'C6201 can support as in Table 7.



Table 7. Maximum Number of Channels that can be Implemented on 'C6201.

| | 32 ms Echo Tail | 48 ms Echo Tail | 64 ms Echo Tail |
|-----------|--------------------|--------------------|--------------------|
| LMS | 59 | 34 | 30 |
| Leaky LMS | 51 | 34 | 28 |

Power Dissipation

The power consumption analysis is based on the TI white paper "TMS320C6201 Projected Power Dissipation on TI's TimeLine Technology"[3].

Assume that the only I/O functions are the serial port and the host interface. Since the power consumed in a serial port is very small (< 20 mW @20 MHz) and the host interface activity usually occurs at very low rate, the I/O power consumption is considered negligible in this analysis. The power consumption in 'C6201 is primarily determined by the following factors:

- Level of CPU activity (number and type of instructions in parallel),
- On-chip program memory access rate,
- On-chip data memory access rate,
- Level of activities of the "other" circuits (peripherals, host interface, external memory interface, etc.).

In order to characterize the power consumption, the execution of a program can be expressed in terms of combination of very high, high, and low levels of activity. The very high DSP activity model fits the intensive operation within a loop and is defined as:

- CPU is running 6-8 instructions in parallel.
- Program memory access is 100%, one fetch every cycle.
- Data memory fetch is greater than 90%.
- "Other" activities are 1.4 times baseline.

The "baseline" activity is the activity due to the clock switching with all other signals in static state. The high DSP activity model fits the intensive operation within a loop with less memory access and is defined as:

- CPU is running 6-8 instructions in parallel.
- Program memory access is greater than 90%, about one fetch every cycle.
- Data memory fetch is about 50%.
- "Other" activities are 1.2 times baseline.

The low DSP activity model fits the codes for control and initialization and is defined as:

- CPU is running 2-4 instructions in parallel.
- Program memory access is no more than 40%.

- ❑ Data memory access is no more than 20%.
- ❑ “Other” activities are in the baseline.

The average power consumption of these two modes at 200MHz for the Rev. 3 device (1.8V core) is listed in Table 8. One can see that the maximum power consumed by a single ‘C6201 will be less than 2 watts.

Table 8. Power Data for the Two DSP Activity Modes.

| DSP Activity | Very High | High | Low |
|------------------|-----------|---------|---------|
| CPU | 0.686 W | 0.686 W | 0.368 W |
| Program Memory | 0.205 W | 0.185 W | 0.073 W |
| Data Memory | 0.279 W | 0.155 W | 0.015 W |
| “Other” Circuits | 0.823 W | 0.686 W | 0.588 W |
| Total | 1.993 W | 1.71 W | 1.04 W |

Note: The power estimate for the “very high” activity mode is extrapolated from the data for the ‘high” and ‘low” activity mode.

In this analysis, we treat DSP activity during the LMS/leaky LMS loops as “very high” and others as “low”. For the LMS algorithm, there will be 1.125 M cycles (looping) in “very high” activity and 100 cycles (overhead) in “low” activity. Consider the 125 μ s (25000 cycles) loop time, the power required to process one echo channel is given by:

$$P_{channel} = \frac{1.125M}{25000} P_{very_high} + \frac{100}{25000} P_{low}$$

where M is the number of filter taps. For the leaky LMS algorithm, there will be 1.5 M cycles (looping) in very high activity and 100 cycles (overhead) in low activity. The power required to process one echo channel is given by:

$$P_{channel} = \frac{1.5M}{25000} P_{very_high} + \frac{100}{25000} P_{low}$$

The average power consumption per channel for processing 32 ms, 48 ms, and 64 ms echo tails are listed in Table 9.

Table 9. The Average Power Consumption for Each LEC Channel.

| | 32 ms Echo Tail | 48 ms Echo Tail | 64 ms Echo Tail |
|----------------------------------|--------------------|--------------------|--------------------|
| Power per Channel (LMS) | 27.1 mW | 38.6 mW | 50.1 mW |
| Power per Channel (Leaky LMS) | 34.8 mW | 50.1 mW | 65.4 mW |



Board Level Consideration

The maximum performance parameters of a single 'C6201 in line echo cancellation are summarized in Table 10. The spare DSP throughput is defined as a percentage of the loop time (125 μ s).

Table 10. Maximum 'C6201 Performance Parameters In Line Echo Cancellation.

| Algorithm | Echo Tail (ms) | Channels/ DSP | Spare Data Memory ¹ | Spare DSP Throughput | Power |
|-----------|----------------|---------------|--------------------------------|----------------------|---------|
| LMS | 32 | 59 | 579 bytes | 8.4 % | 1.559 W |
| LMS | 48 | 34 | 1568 bytes | 27.6 % | 1.312 W |
| LMS | 64 | 30 | 1296 bytes | 18.9 % | 1.503 W |
| Leaky LMS | 32 | 51 | 9252 bytes | 0.0 % | 1.775 W |
| Leaky LMS | 48 | 34 | 1568 bytes | 8.0 % | 1.703 W |
| Leaky LMS | 64 | 28 | 5512 bytes | 0.0 % | 1.831 W |

Note: Additional 1,000 bytes of the internal data memory are reserved as buffer for data I/O.

Table 11. Echo Cancellation Performance for 48 ms Tail From A Board with 25 'C6201.

| Channels/ DSP | Channels/ Board | Spare Data Memory/DSP | Spare DSP Throughput | Power/DSP | Power/Board | Channels/in ² |
|---------------|-----------------|-----------------------|----------------------|-----------|-------------|--------------------------|
| 34 | 850 | 1568 bytes | 8.0 % | 1.703 W | 42.575 W | 8.854 |
| 32 | 800 | 5272 bytes | 17.5 % | 1.603 W | 40.075 W | 8.333 |
| 30 | 750 | 8976 bytes | 22.5 % | 1.503 W | 37.575 W | 7.812 |
| 28 | 700 | 12680 bytes | 27.5 % | 1.403 W | 35.075 W | 7.292 |
| 26 | 650 | 16384 bytes | 32.6 % | 1.303 W | 32.575 W | 6.771 |
| 24 | 600 | 20088 bytes | 37.8 % | 1.202 W | 30.050 W | 6.250 |

Due to the small package size of TMS320C6201 (35mm by 35 mm), power requirement is usually the primary limiting factor to how many 'C6201 can be put on a circuit board. Consider a board with 25 'C6201 and that the leaky LMS algorithm with 16 bit filter coefficients is used to process 48 ms echo tails, the echo cancellation performance delivered by this board is illustrated in Table 11. Assume the spacing between the processors is 13mm, the size of this board is about 96 square inches. With this board, a user can support leaky LMS echo cancellation anywhere from 600 channels (and have 37.8 % spare throughput) to 850 channels (and have 8 % spare throughput).

System Considerations

Figure 1. A Block Diagram for System Implementation.

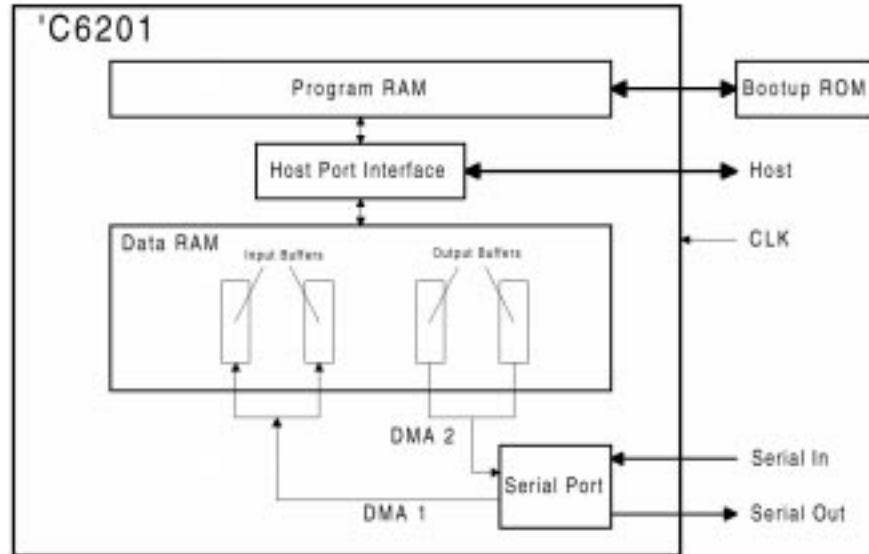


Figure 1 illustrates some thoughts of system implementation on a single 'C6201. The processing should be synchronized with the input data frame. This can be realized by starting processing serving the interrupt on detection of the serial data frame synchronization pulses. Data I/O is handled through two double buffers. On the receive end, the data is passed from the serial port to one buffer through one DMA channel, while the CPU is processing the data saved in another buffer during the past data frame. On the transmission side, DMA is moving the processed data from one buffer to the serial port, while CPU is saving data to another buffer. This approach will result in a $250\ \mu\text{s}$ (two frame) delay between the input and output. The channel switching can be accomplished by directing CPU to read data from predetermined addresses in the input buffer and write to a predetermined address in the output buffer.

Summary

This analysis shows that TMS320C6201 offers a high performance and cost effective solution to multi-channel line echo cancellation. A processor board with 25 'C6201 can process up to 850 echo channels of 48 ms tail. Compared to other dedicated processor for echo cancellation, 'C6201 provides much more flexibility in algorithm design so that users can tailor the implementation to meet the special requirements for their application. The existing TI TMS320C6201 LMS and leaky LMS software modules will also greatly reduce the software development time.



References

- 1) LMSFIR8, 'C6xx assembly benchmark from TI's external web site.
- 2) "Implementation of Echo Control for G165/DECT on Texas Instruments TMS320C62xx Processors", Texas Instruments application report, August 1997
- 3) "TMS320C6201 Projected Power Dissipation on TI's TimeLine Technology", Texas Instruments White Paper by Linda Hurd, October 1997