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Development of Microcontroller for Digital Audio Application

Shoji TANOUCHI*, Mitsuya OHIE**, Hiroshi SHINOTSUKA*

Abstract

We developed the ML66525 microcontroller which is optimized for digital audio players. Some features of the ML66525 are a function for communication between PC's and peripheral equipment and a flash media control function. In addition various kinds of measures have been taken to reduce power consumption of the overall system. Not only can this product, as a software platform, respond quickly to the diverse and fast changing market, it can also, through hardware, speedily adapt to flash media which are becoming more varied.

1. Introduction

The market for portable audio players using high data compression formats such as MP3, as [part of] the next generation of digital audio such as CD, MD, etc., is growing rapidly.

The characteristic function of this kind of player is downloading compressed audio data from a PC (personal computer) into flash memory and then decoding audio data in the memory for music playback.

The specifications demanded of digital audio players include such things as:

1. High speed downloading of audio data,
2. Low power consumption
3. Small size and light weight
4. Dealing with copyright protection

The major components which make up the player are a decoder for decompressing data, a microcontroller for system control, and flash memory for data storage. However, since we are still in the ramp up period of this market, many other compression formats besides MP3 are being proposed and put into actual use. Also, flash memory cards with a variety of forms and capacities are being built or proposed.

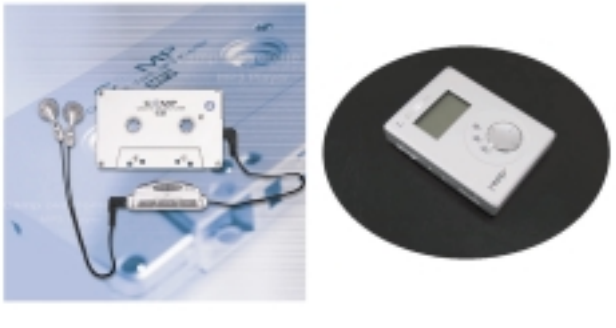

Photo 1: MP3 Player example controlled by OKI Microcontroller

In such a situation, our company has already provided to many MP3 audio makers our multi-purpose 16bit microcontroller, MSM66573L, which offers high performance and low power consumption with many power management features. (Refer to Photograph 1.) In the present case, we describe the features of ML66525, a microcontroller for digital audio which we have developed. In it, we have incorporated USB, as a circuit for interfacing to PC's, and a circuit to interface to various kinds of flash media and externally connected stand-alone flash memories for content storage.

2. Outline of the Product and Target Application Products

ML66525 is a microcontroller developed to target digital audio applications. However, it is not limited to that. It is also the optimal microprocessor for electronic devices which have USB interfaces, as PC communications means, or flash memory as a content storage means. It is well suited to voice memo (voice recorder) systems, for example, which utilize solid state recording into a flash memory, and to personal digital assistants (PDA's) which handle character, voice and image data.

In Table 1 we show an outline of the specifications. This product has adopted as its CPU core our company's original 16bit CPU core nX-8/500S. With features like high speed interrupt processing, a broad array of bit handling commands, compact code size through use of a C compiler, etc., it is ideal as a microcontroller for use in systems built into portable equipment, etc.

In particular for MP3, MD or other such portable players, 66K series aimed at consumer equipment has been widely used with good results and, as a microcontroller of the same class, has an established reputation for low current consumption.

With the ML66525, we make full use of the low current consumption feature of this microcontroller series. In addition we gave special consideration (explained in 3. Outline of Functions), to achieving a system design that could

* Silicon Solution Company, LSI Division, Marketing Dept., Advanced Digital Consumer Business Unit
**Silicon Solution Company, LSI Division, Marketing Dept., Business Planning Team

Model name	ML66525	USB control (conforms to version 1.1)	12Mbps high speed data transfer
Operating temperature range	-30°C to +70°C		EP0 (IN 32-byte, OUT 32-byte) control transmission
Power supply voltage/ maximum frequency	V_{DD} = 2.4 to 3.6 V/f = 24 MHz		EP1 (64-byte x 2) bulk/interrupt transmission
Minimum command execution time	83 nsec@24 MHz		EP2 (64-byte x 2) bulk/interrupt transmission
	61 μsec@32.768 kHz		EP3 (32-byte) bulk/interrupt transmission
Size of built-in ROM	128K byte (external Max: 1M byte)		EP4 (64-byte x 2) bulk/isochronous/interrupt transmission
Size of built-in RAM	6K byte (external Max: 1M byte)		EP5 (64-byte x 2) bulk/isochronous/interrupt transmission
I/O ports	64 input/output terminals (programmable pull ups at the bit unit), 6 dedicated input terminals, 1 dedicated output terminal		Built-in transceiver, bus powered compatible, V-bus detection circuit, (detection of connection/disconnection to USB host)
Timer	16-bit auto-reload timer x 2ch, 8-bit auto-reload timer x 2ch, 8-bit auto-reload timer (also serves as baud rate generator for serial communication) x 3ch, 8-bit auto-reload timer (also serves as watchdog timer) x 1ch, clock-use timer x 1ch, 8-bit PWM x 2ch (16-bit PWM x 1ch possible)	NAND Flash Memory control	ECC circuit
			512-byte high speed/automatic data transfer function
Serial port	32-byte synchronized type with FIFO x 1ch, Synchronized (shift register type) x 1ch Synchronized type/UART x 2ch	Other	External bus interface (address/data separate bus type)
A/D converter	10-bit x 4ch		Dual clock function
External interrupt	Non-maskable x 1ch; maskable x 6ch		Clock gear function
Flash ROM version	ML66Q525		CPU portion, I/O portion: separate power supply type

Table 1: Specification

support lowering of power of the overall system and of the products is applied to when those devices are actually used (connected to a PC, or used as independent units.) For example, even if one seeks to lower the power of a piece of equipment which uses a microcontroller product which simply has low voltage and low current specifications, there may be cases where due to the specifications of peripheral components, such as the flash memory connected to the microcontroller, 3.3V power must be provided. Thus, in designing a microcontroller, it is not easy to achieve low voltage.

The ML66525, considering the overall system configuration, has achieved a reduction in current consumption, and through reduction in peripheral parts a reduction in total system cost.

3. Functional Outline

In this section we explain several functions which have features that we developed giving though to the LSI's eventually being built in to digital audio and other portable electronic equipment.

3.1 Handling the requirement for low power consumption

A variety of low power consumption features are built into the ML66525. Low power consumption is achieved through the following functions which are built into 16bit microcontroller 66K series family of consumer micro-controllers: 1. 32kHz subsidiary clock, 2. frequency control of the CPU fundamental clock by means of software, and 3. intermittent operation of the embedded peripheral module. Power management of elements 1 and 2 can be controlled by the users software, so reduction in the current consumption of the microcontroller is done by making the CPU operate at the minimum load required by the system. 3 is a function incorporated internally to the microcontroller. It automatically transitions to low power during non-operating times and access times for A/D converter operation, internal memory operation, etc.

In addition, many features have been built in to deal with "overall system" power consumption, taking account of the microcontroller use situation. For example, with ML66525, because the standard voltage specification for flash media is a 3.3V interface, it is possible to apply a 3.3V power supply (Vdd2 in Figure 1) to the external interface portion only and have internal circuits operate from a 2.4V power supply (Vdd1 in Figure 1.) Also, the USB block is provided with an independent power supply within the microcontroller, and only when the equipment is communicating, connected to the PC by a USB cable, is power supplied to the USB block via the USB bus (bus powered USB.) We have made it so that, at times when it is not communicating, supply of power to the USB block can be entirely cut. Consequently, during non-communication times, as for example, times when a portable player is used for music playback, the consumption of power can be reduced.

In the past, when USB was incorporated in battery-operated portable equipment, designing for lowered power was difficult. At present most digital audio players with

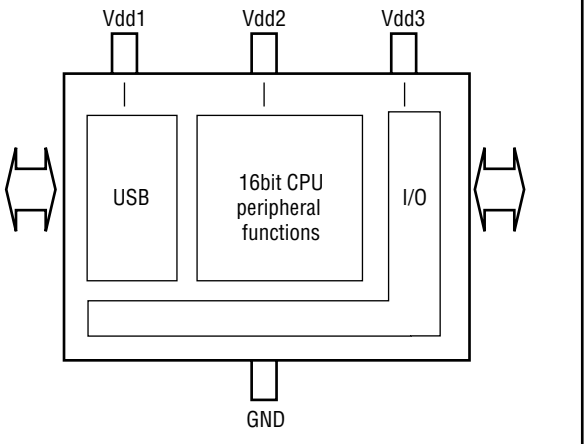

Figure 1: Block diagram of internal power supply

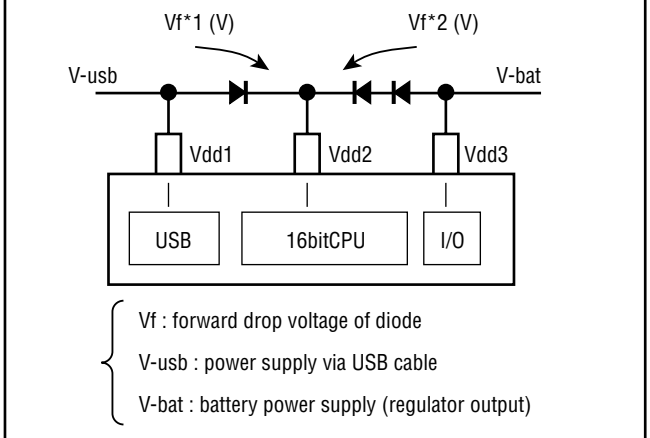

Figure 2: External power supply connection

built in USB, for reasons of ease-of-design, are of the "self-powered type," and current consumption during USB communication becomes a big problem. For that reason, product models using the "bus powered type" USB controller have been introduced, but (at times when USB is not used) the interface between the USB controller and microcontroller becomes an "open terminal," so it is necessary to take special measures, such as adding an analog switch or pull up resistor. However, with the ML66525, all types of peripheral circuits for achieving bus powered USB are built in, so equipment design can be done easily and at a low cost.

Furthermore, making Vdd2=Vdd3=3.3V, equipment design can be done using a single power supply, just as with the products of the past. However, to achieve lower power, it is desirable to apply a two-voltage output type voltage regulator, for Vdd2 and Vdd3, and make Vdd2 a lower voltage.

As another application example, by inserting external diodes, as shown in Figure 2, a low cost single output voltage regulator can be made. Then the operating voltage for the microcontroller part can be lowered and a reduction in current consumption can be achieved.

In the case of this configuration, using the difference in the drop voltage created by the diodes, when USB is connected, the Vdd2 voltage increases, receiving power supplied from Vdd1. Power supply from Vdd3 is stopped and it is possible to operate not only the USB part but also the microcontroller via the power supply route of the PC, thus cutting down battery power consumption during USB communication.

In this way, many functions and structures have been incorporated to achieve low power. In particular, even incorporating the USB function which causes current consumption problems at times of high speed data communication, it is possible to hold battery consumption to a minimum. Thus, this LSI is ideally suited to not only portable audio products but also many types of mobile personal equipment.

3.2 Handling a variety of Flash media interfaces

The present situation for Flash media, which have ramped up due to the proliferation of digital cameras, is that many versions have flooded. The background to this is found in the strong need for digital characteristics which do not degrade in quality at all, compared to the original. There is no problem with image data from digital cameras which individual users enjoy. However, with music content, etc. where copyright management is essential, it is recognized that this could not be adequately done with the Flash media of the past. Therefore, a variety of functions for protecting content have been built in and many versions of Flash media have been proposed (Table 2.)

Flash Media		The digital audio player in which it is applied.
Not suitable for copyright protection	SmartMedia card	Rio500, Nomado II, Yepp, FMP300, MPMan F35, DAP, Jazpiper, MP301
	Compact Flash	KANA2000, (digital camera)
	MultiMediaCard	SSP-PD7, MM-FX500, PDA-01, HyperHyde FMP300s, Mplayer, WMP-1V
	MemoryStick	(PC, digital consumer electronics in general)
Suitable for copyright protection	SmartMedia ID card	SD-1, diGO, musicBIT!, AS2000
	MagicGate memory sticks	NW-MS7, e-musee
	MemoryStick "Duo"	(under development for portable telephones)
	SD memory card	Mobile Audio Player, SV-SD70
	Security MultiMediaCard	(a prototype unit has been made)

Table 2: Flash Media Table

Note: The product names written above are the registered trademarks or trademarks of the subject companies and trademark owners

Considering this situation, we adopted "Flash media SPA" for ML66525. By applying EA (embedded array) for the Flash media control circuit block and changing a few masks, it is possible to complete a new type of Flash media interface in a short development time. Furthermore, the first product to be released will incorporate a Flash media controller optimized for the Smart Media™ Card, and from here on, using the SPA base, we are planning to create products compatible with other Flash media.

3.3. Achieving high speed data transmission between PC's and equipment

Many kinds of data are transmitted and received between PC's and peripheral equipment. This data includes music content and/or image data purchased over the Internet, text data such as news, voice data recorded with a voice recorder, etc. The communication time for such activities is an important indicator, showing the "ease of use" of the system.

In the case of conventional digital audio such as MP3, parallel interfaces have been the mainstream for communication between PC's, but recently models with USB built in have increased in number. However, it is hard to say that their data communication speed is adequate. "Data communication speed," as the term is used here, does not simply mean that for the communication channel a 12Mbps USB has been adopted. Rather, it means the "total time required for a series of signal processing." In actual portable digital audio equipment, it takes 5 ~ 10 minutes for data transfer of the music in a single CD (approx. 64 Mbytes) and this is poor "ease of use."

Breaking down "a series of signal processing," certainly the communication speed over the physical USB cable itself is included, but other factors are increasingly involved. The "data processing volume" which a microcontroller must perform is rapidly increasing. This includes, for example, the processing of encryption keys for content protection; watermark processing; in cases of communicating data to Flash media, procedure processing unique to that media; and, when downloading contents over the Internet, handling the signal distribution system and encryption methods, etc. of each provider.

With ML66525, based on the above needs, many special efforts were made to enable the "series of signal processing" to be performed efficiently. Through adoption of a USB controller with the DMA function, a Flash media controller with ECC circuitry built in, and a dedicated internal bus for content transfer, we have been able to build in functionality which utilizes to the maximum the communication capacity of the 12Mbps full speed USB.

Next, we will explain the details of the PC-flash media interface, via the USB.

ML66525 has a built-in USB controller and Flash media controller (the Flash media handled by the ML66525 are the NAND Flash Memory and SmartMedia™ Card) and we have designed the PC-Flash media interface so that offers operations ideally suited to digital audio. These operations include:

1. bilateral high speed data transfer,
2. data manipulation (change) of data being transmitted, and
3. data transfer at low power consumption.

The functional blocks in the PC-Flash media interface are shown in Figure 3.

We will explain how each functional block is used in data transmission between the PC and Flash media.

(1) Bi-lateral high speed data transfer

The data volume handled with digital audio, at several megabytes, is relatively large, and it is necessary to receive such data at high speed from the PC. With ML66525, it is possible to transfer data between the PC and Flash media at 12Mbps which is full speed for the USB.

1. In the case of data transfer from the PC to the Flash media (download), the USB controller receives data from the PC at 12Mbps but the DMA function, by means of the USB side data transfer bus, can store data in data transfer Buffer A, with no lost time. Moreover, Buffer A

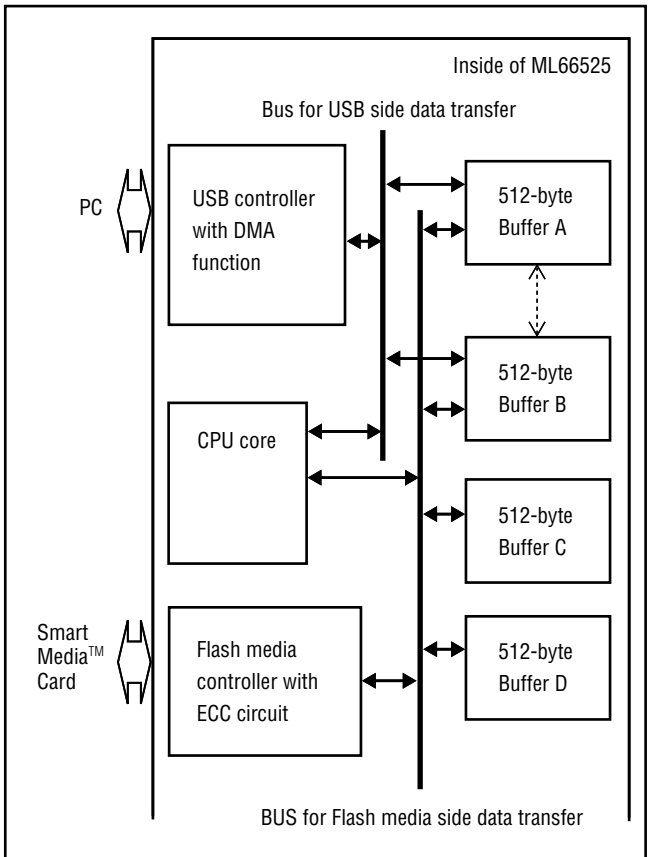

Figure 3: PC-Flash Media Interface Block

becomes full in approx. 340μS (512 x 8bit ÷12Mpbs), but when Buffer A becomes full, it is possible to store data using Buffer B. Therefore, there is no interruption in the reception of data until Buffer A empties.

2. The Flash media controller can extract data from Buffer A, via the Flash media side data transfer bus, without interrupting the reception of data from the PC by Buffer B. Also, by making the size of each buffer 512 bytes, we have made it the easiest data size to handle conforming to the SmartMedia™ physical format. In addition, by means of an ECC circuit, the Flash media controller calculates a 16 byte redundant portion for error detection / correction, which is a part of the SmartMedia™ specification. Since this can be done while taking data from Buffer A, lost time for ECC calculation can be eliminated.
3. We have made it so that the Flash media controller can perform signal control conforming to SmartMedia™ Card. Consequently, it is possible to transfer consecutive data, and at 25°C and 3.3V, the time for transferring data to a SmartMedia™ Card is approx. 50μS, while data writing time is approx. 200μS. In short, the SmartMedia™ Card can be accessed in a total of 250μS, the minimum possible time.

As can be seen from 1~ 3, it is possible to achieve high speed data transfer of 12Mbps, while still maintaining a margin of 90μS—i.e. subtracting the 250μS from the transfer time from the PC, which is 340μS.

For data transfer (upload) from Flash media to the PC also, high speed transfer is possible through the same kind of operation.

(2)Manipulation (change) of data during transfer In the data which is handled in digital audio, there are cases where the content is encrypted and it is necessary to decipher it during transfer.

With the ML66525, regarding communication between PC's and Flash media, in cases where it is necessary to manipulate the data received from the PC, it is possible to activate the CPU core through software, read out data stored in each buffer, manipulate the data and write them.

Also, in cases where SmartMedia™ Cards are used as PC peripheral devices, it is necessary to update file management information which uses the FAT file system, etc. for data writing. Of course, the file management can be used for digital audio as well.

With ML66525, in cases of updating management information written into a SmartMedia™ Card before writing data to a SmartMedia™ Card, even during data transfer, the Flash media controller can be activated by software, and data read from the SmartMedia™ Card. Then the data can be stored in Buffer C or D, via the Flash media side data transfer bus. Naturally, through software, it is possible to activate the CPU core and read out, change, and write again the data.

(3)Data transfer under low power consumption With digital audio, there are cases where portable equipment, operating on battery power, are used, and converting the system to low power operation is necessary.

With ML66525, by diligently designing each functional block to operate intermittently, it was possible to reduce power consumption during data transfer.

During download, until Buffer A or B becomes full (approx. 340μS), the CPU core is put in the HALT mode, operation is done at 32kHz, and the Flash media controller is also put into the stopped mode. In this way, we achieve low power consumption.

Even if Buffer A or B becomes full, the CPU core and the Flash media controller are made to operate at the minimum required level, and returning to the state of low power consumption can be accomplished simply through software.

Concerning uploading also, low power consumption can be accomplished through the same kind of operation.

As we have explained thus far, in order to utilize the performance and efficiency of the PC-Flash media interface for data transfer, not only hardware, but software as well, has an important meaning.

With the ML66525, by providing software IP's, (data download modules, upload modules,etc.), it was possible to achieve shortened time for system development by users and greater ease of software upgrading.

4. Conclusion

In 1999, worldwide shipments of digital audio players will reach approx. 1 million units. "Combination units," adding the music playback function to portable telephones, digital cameras, or PDA's have appeared, and the market for them is expected to grow at over 50% per year. However this is a market which has just started to ramp up, and there is a flood of different schemes for Flash media, copyright protection and Internet music distribution. This problem and demands for higher data transfer speeds has led to a situation that is unsettled and confused. We developed the ML66525 to incorporate various features, so that users in the area of digital audio could respond quickly to changes in market environment. Not limited to audio only, it is also a micro-controller which is ideally suited to applications of high speed communication between PC's and Flash media.

Moving on, we are studying USB2.0 (transfer speed of 480Mbps) which will make possible even faster

transfer speeds. We are also studying interfaces to SD memory cards with a copyright protection function and to MG memory sticks, and we plan to create products in this area.