Development of an ultra-low-power 8-bit microcomputer

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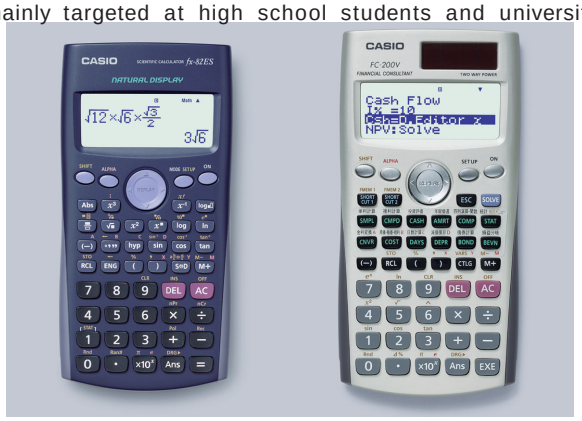
Casio, which holds the top share of the world's calculator market, has a 40% share of the scientific calculator market (the world's No.1 share of the scientific calculator market).

In recent years, an increasing number of countries are adopting scientific calculators as a subject for university entrance exams and classes, and there is a growing tendency to use scientific calculators as teaching materials. Naturally, this movement is also progressing in Japan, and a number of educational papers have been published by eminent teachers on the merits of using calculators in subjects such as arithmetic and mathematics in elementary, junior high and high schools. Demand is expected to grow in the domestic market in the future.

Currently, sales of Casio scientific calculators are slightly less than 20 million units per year, but as for the future market trend of Casio, sales are expected to increase by 150% due to the expansion of the market for China.

In order to capture this large scientific calculator market, Oki Electric developed an ultra-low-power 8-bit microcomputer that surpassed the specifications of conventional low-power microcomputers and was able to enter the scientific calculator market.

P.1 shows the product developed this time: a scientific calculator equipped with ML610901. The scientific calculator on the left side of P.1 is a scientific calculator from the "Natural Textbook Display" series, which is mainly targeted at high school students and university students studying science and mathematics, and can display formulas such as fractions and $\sqrt{}$ (square roots) in the same way as textbooks. It is "fx-82ES" [2].



P.1 - A scientific calculator equipped with a true product
(left: fx-82es right: FC-200V)

The right side of P.1 is a full-fledged financial calculator "FC-200V" [3] aimed at certified public accountants, tax accountants, security analysts, financial planners and others. ML610901 is also installed in many scientific calculators for overseas.
The main specifications required by Casio for the development of this scientific calculator are shown below.

① Built-in multi-common LCD driver
② Built-in solar/internal battery toggle function
③ Supply voltage: Guaranteed operation at 1.0V
④ Low power consumption

① realizes a large display that is slightly larger and easier to see. ② differs from conventional solar powered calculators in that even if the light is blocked during calculation, the contents of the calculation are protected by the built-in battery. ③ ensures low-voltage operation so that malfunctions don't occur due to switching between the built-in and solar battery. ④ prolongs battery life (the battery life was 2 years for the conventional product, but 3 years for this product) [4]. It aims to use solar cells with low supply capacity.

A multi-Vt process was adopted to capture the above 4 major specifications. This process has a high and low-voltage MOS, and was suitable for the specs of scientific calculators including a built-in LCD driver and a guaranteed operation at 1.0V.

In addition, because this process is an existing process, it reduces the development man-hours and shortens the schedule, making it possible to meet the development schedule presented by Casio.

In the face of competition with other companies, it can be said that one of the major factors for adoption was not only surpassing the specifications with low power consumption and low voltage operation, but also the excellent performance of Oki Electric's original CPU core: nX-U8/100.

This article describes the functional calculator LSI (product name: ML610901) for Casio Computer Co., Ltd.,

which realized an ultra-low-power 8-bit microcomputer with a built-in LCD driver by adopting the multi-Vt process.

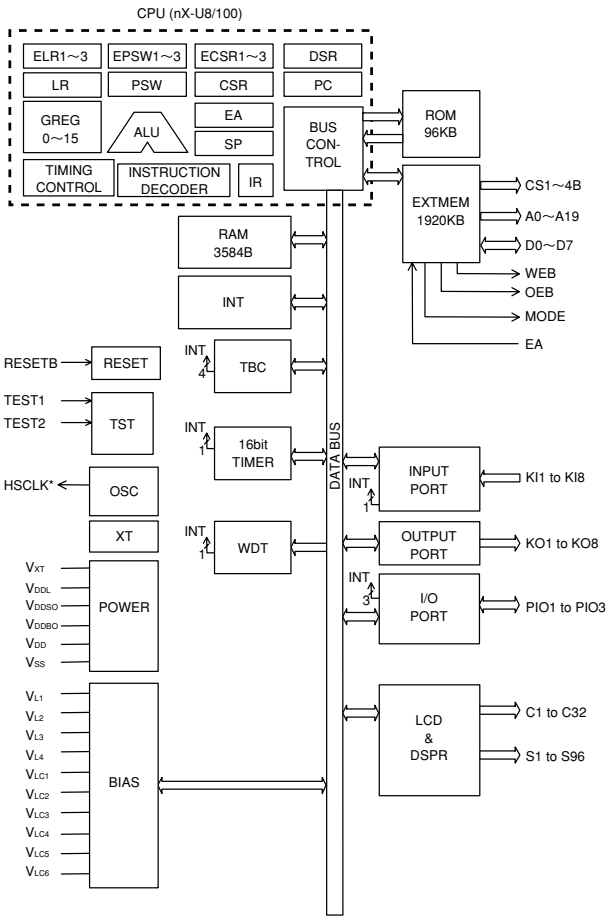
ML610901 Overview

The ML610901 is an 8-bit microcontroller with a built-in 96-segment x 32-common LCD driver.

8-bit CPU core: The nX-U8/100 divides instructions into three phases: instruction fetch, instruction decode, and instruction execution, and processes them sequentially in a pipeline. This 3-stage pipeline processing RISC architecture allows efficient instruction execution.

The circuit configuration consists of memory (ROM/RAM), power supply circuit, oscillation, logic (including 8-bit CPU core), port/LCD driver.

F.1 is a block diagram of the ML610901, and T.1 lists its features.



F.1 ML610901 Block

T.1 ML610901 Features

Function		ML610901
CPU		nX-U8/100
Memory		
	ROM	96K bytes
	RAM	3584 bytes
	External Data Memory	1920K bytes
Oscillation		
	Clock Generator	500kHz (system clock) 19kHz (LCD clock)
Logic		
	16-bit timer	1ch
	Watchdog Timer	1ch
	Time Base Counter	2ch
	Interrupts	10 factors
Ports・LCD driver		
	LCD Driver	3072 (96seg×32com)
	Input Ports	8
	Output Ports	8
	Input/Output Ports	3
	External Memory I/F	35
Power Circuit		
	Power Supply for Logic	VDDL
	Supply for LOSP OSC	VXT
	Bias Generation Circuit	VL1～VL4
	Power Switch Circuit	VDD
Main Electrical Properties		
	Temperature Range	−20℃～70℃
	Power Supply Voltage	1.0V～
	Current Use at STOP	0.6μA(Typ.)
	Current Use@CPU Opr.	50μA(Typ.)

About multi-Vt process

The multi-Vt process consists of three types of MOS shown in T.2.

Taking advantage of these features, HV-MOS is used for LCD drivers, ports, and power supply circuits that require high withstand voltage, and MV-MOS is used for logic (including the 8 bit CPU core), which accounts for most of the chip configuration o suppress leakage current, LV-MOS is used for the circuit part that is a concern during low voltage operation.

T.2 MOS structure of multi-Vt process and its application

	Usage	PreRes (Max)
HV-MOS	Used in high withstand voltage circuits	7V
MV-MOS	Used in general logic (no problem of leakage current)	4.6V
LV-MOS	Used where sufficient capacity is required at low voltage (partial use) (Leakage current occurs)	

Efforts toward low power and voltage

Details of efforts to reduce power consumption [5] are shown below.

① Lower the power supply voltage for logic
② Slim CPU core (removing unused circuits)
③ Remove built-in capacitance (oscillation circuit)

① Reducing the power supply voltage for logic is the most effective measure. T.3 shows a comparison of the power supply voltage for logic between a conventional low-power microcomputer and the ML610901.

T.3 Comparison of power supply voltage for logic

Power Supply Voltage for Logic	ML610901	ML610501 (conventional)
VDDL	1.16V	1.60V

The ML610901 reduces the voltage by about 27.5% compared to the ML610501 (conventional product), so power consumption can be expected to be reduced by that percentage.

② Slimming down the CPU core (removing unused circuits) has taken measures to suppress excess power consumption.

The CPU core of a conventional low-power microcomputer is equipped with a debug function and a tool mode function, and this circuit remains active even while the CPU is operating, resulting in excessive current consumption. The removal of this circuit section is effective in reducing power consumption.

The removal of the built-in capacitance (oscillation circuit section) in ③ will be explained. The ML610901 oscillator circuit is a CR oscillation type with built-in resistors and capacitors.

Since the power consumption of CR oscillation depends on the charging and discharging of the capacitor, the power consumption can be reduced by reducing the capacitance value and the current. However, in the specifications of the conventional product, the resistor is attached externally, and the frequency varies due to the influence of parasitic capacitance. If the built-in capacitance is reduced as a countermeasure against power consumption, the influence of parasitic capacitance becomes even more dominant, and this becomes a factor that greatly varies the frequency. Therefore, the ML610901 eliminates the effects of parasitic capacitance by incorporating resistors into the LSI, making it possible to reduce frequency variation characteristics and power consumption.

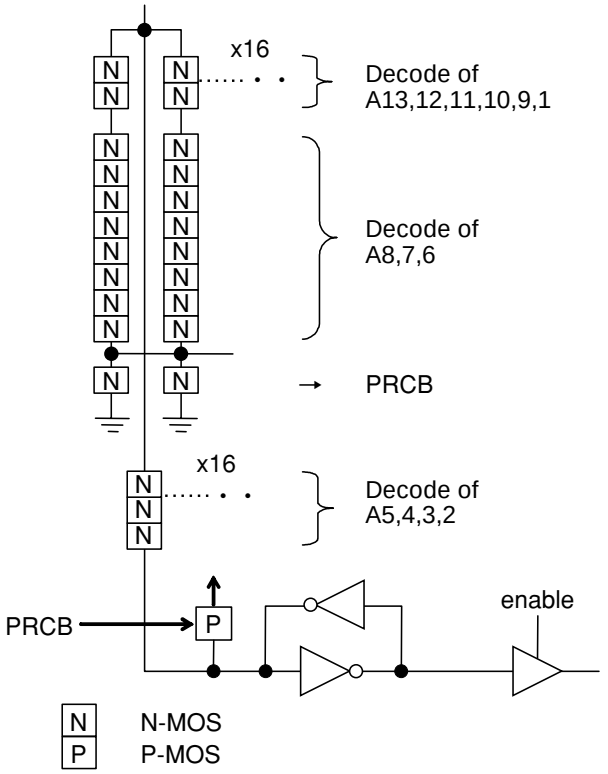
How to achieve low voltage operation

The approach to low-voltage operation is to tune the Vt value of the existing multi-Vt process andexpand the low-voltage operation margin of CMOS transistors. This approach will make it possible to reduce the power supply voltage for logic in ① above.

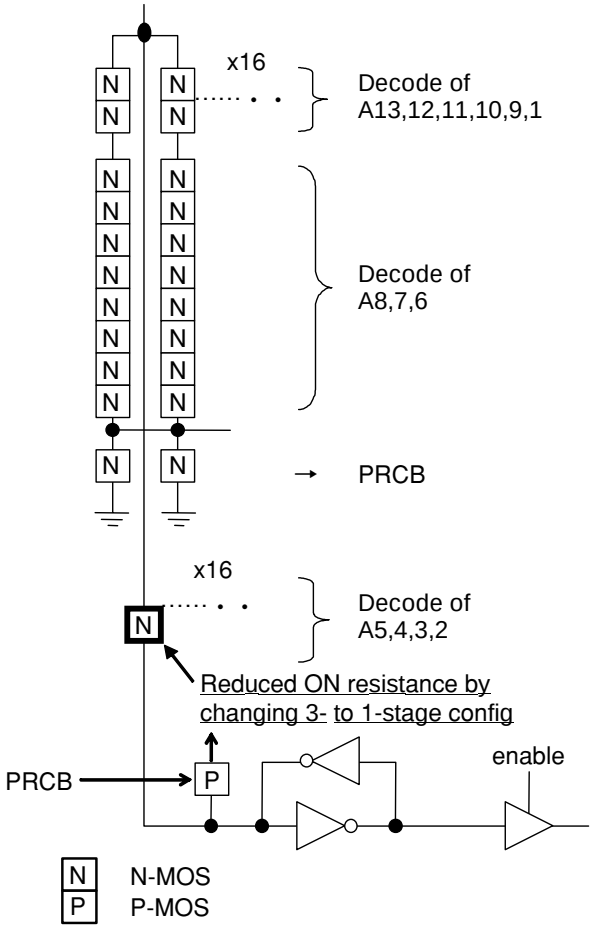
However, memories such as ROM and RAM have higher operating voltages than logic such as CPUs and timers. Therefore, for ROM and RAM memory, we analyzed the conventional memory and implemented low-voltage operation countermeasures by changing the circuit.

ROM improvements

As a result of ROM operation analysis, it was found that ROM has the effect of improving low-voltage operation by reducing the bit line delay. The Y-decoding part of the conventional ROM was composed of three stages of N-MOS. However, in the ML610901, by making the N-MOS in the Y decoding part a single stage configuration, the total ON resistance of the N-MOS can be reduced to 1/3, and the tracking performance is improved. F.2 shows the conventional ROM configuration, and F.3 shows the ROM configuration of the ML610901.



F.2 Conventional ROM configuration



F.3 ROM configuration of ML610901

RAM improvements

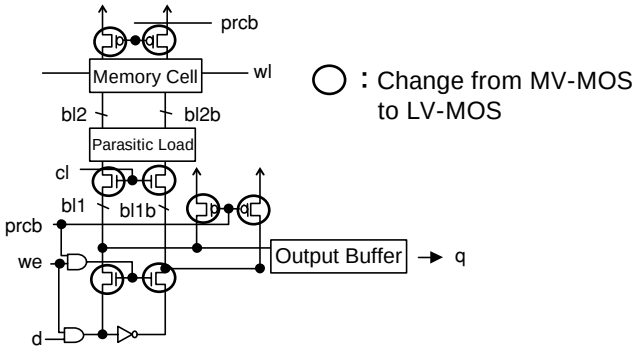
As a result of the analysis of the RAM operation, the RAM has a delay in the column switch and a delay in the precharge operation before going to the next cycle for the read operation, and a delay in the write data transfer gate for the write operation. It was found that reducing the delay of the precharge operation, as well as the read operation, has the effect of improving the low voltage operation.

Conventional RAM circuits use MV-MOS, and by changing this MV-MOS to LV-MOS, the ON resistance of the MOS is reduced and the followability is improved.

F.4 shows the RAM configuration of the ML610901. The circled MOS is where the MV-MOS was changed to the LV-MOS.

As for the device characteristics, the minimum operating voltage was improved from 1.00V to 0.89V by tuning the Vt value and changing the circuit, and the minimum supply voltage of 1V, which is the target specification, was achieved.

Through these efforts, ML610901 completed the start of mass production in June 2004.



F.4 RAM configuration of ML610901

Afterword

The ultra-low-power (low-voltage operation) technology in the development of the ML610901 is a technology that has been achieved through the combined strength of design capabilities that take advantage of the features of the multi-Vt process and the process technology that supports it. In the future, in response to the demand for further low voltage operation and low power consumption, we would like to open up the technology and commercialize it with our comprehensive strengths. ◆◆

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