Achievements of Professor Emeritus Matsuzawa for the 2022 IEEE Donald O. Pederson Award in Solid-State Circuits

1. Development of bipolar ADCs for digital TV and video systems

Technological development for digitizing TV and video equipment began very soon after the time when I joined Matsushita Electric. A major challenge at that time was the analog-digital converter (ADC), which converts wideband video signals to digital values. There was a board-level ADC for a standard TV signal, but it was not an integrated circuit (IC). Its power consumption was 20 W, and the price was as much as USD 10,000 (the price of new car at the time). It was therefore not possible to use it in business or consumer equipment. However, in 1982, we developed the world's first integrated video-rate 10-bit ADC, which reduced both price and power consumption to 1/10 of what it had been and contributed to the achievement of digital TV and studio digital video systems. We also developed the Hi-Vision TV that relayed the Seoul Olympics in 1988. Our ADC received the IR 100 Award in 1983.

High-Definition signal has a wide bandwidth and requires conversion frequencies of 75 MHz or higher, but there was no ADC capable of that at that time. Therefore, in 1984, we developed the world's first 8-bit ADC with a conversion frequency exceeding 100 MHz, contributing to the realization of High-Definition TV cameras. Then, in 1990, we developed a low-power ADC for commercial Hi-Vision receivers. And in 1992, we developed a 10-bit ADC for 300 MHz, which was a conversion frequency four times higher than any other ADC, and was used for optical High-Definition transmission. It received the R&D 100 Award in 1994. These ADCs contributed to the development of High-Definition TV systems, professional digital video equipment, and digital oscilloscopes.

2. Development of an ultra-low-power CMOS ADC and promotion of low-power electronics

In 1993, we developed a video-rate 10-bit CMOS ADC that achieved an overwhelmingly low power consumption just one-eighth that of our competitors' products. Until then, bipolar technology was used in ADCs. Most current integrated circuits use CMOS technology, but CMOS at that time was not only slow, but also two orders of magnitude inferior in accuracy to bipolar. Therefore, we invented a capacitive interpolation technology that accumulates error voltage in capacity, making it available for cancellation and further dispersing errors. By developing various circuit techniques, we raised accuracy to the bipolar level and power consumption was further greatly reduced. The success of this CMOS ADC development led to rapid CMOS technology changes in ADCs, and today all ADCs use CMOS technology.

Integrating CMOS ADCs with logic circuits reduced overall power consumption, which spurred the digitalization of the video camera, resulting in the portable camcorder. In 1994, I gave an invited talk at a VLSI symposium on the low-power technology used in portable consumer equipment, and which was published to the IEEE journal. This talk and paper showed the importance of low-power technology in integrated circuits; but, until then, integrated circuit technology was all about high-speed circuits, with a bias towards PC and supercomputer applications mainly in the United States, with no attention given to reducing power consumption. So, in 1995, I organized the world's first international workshop focused on low-power electronics. Today, low-power electronics is recognized as the most important technology for integrated circuits, which are important in achieving carbon neutrality and are being developed vigorously.

Then, in 1997, we developed a low-power digital signal processor (DSP) using an adaptive power supply control and installed it in the watch-type PHS cellphone used for communication between officials at the Nagano Winter Olympics in 1998. I think it was probably the world's first wristwatch-type mobile phone. In 2003, in collaboration with several domestic companies and NTT, we developed an ultra-low power LSI, using FDSOI, that worked using natural energy such as temperature difference, as well as a wireless information terminal that used it. Traditionally, in Japan, we do not like seeing things go to waste, so this has played a leading role in low-power electronics.

3. Development of a low-power ultra-high-speed ADC and development of Mixed Signal system LSIs (SoC)

DVDs appeared in the late 1990s. DVD recorders require digital equalizer and error correction technology to address the insufficient SNR of the pickup signal. For this, an ultra-high-speed ADC for the measurement instrument, such as 7-bit 400 MHz, was required. The power consumption was several hundred mW, which was one order of magnitude too large for consumer equipment. So, in 2002, we invented gate interpolation using CMOS flip-flops, which do not have a steady current, and thereby developed an ADC that reduced power consumption down to 1/10 that of other competitors' products.

As a result, it became possible to integrate high-speed analog circuits into CMOS LSI; and, in 2003, we succeeded in developing the world's first completely one-chip system LSI (SoC) for DVD, which integrated all the circuits necessary for DVDs, including analog, on a single chip. The SoC contributed significantly to cost reduction and performance enhancement for DVDs; and, with the ensuing series of SoCs that were developed, shipments of 520 million chips representing sales of USD 2.5 billion were achieved over the next nine years. With this success, inclusion of mixed-signal SoC has become a major trend in integrated circuit design since then, and chip integration of large-scale systems, including analog circuits, is becoming ever more advanced. In fact, this mixed signal SoC technology is one reason why smartphones can be equipped with so many functions in such a small body.

4. Development of millimeter-wave CMOS transceivers

In 2003, I joined Tokyo Tech as a professor and, in 2007, started a Ministry of Internal Affairs and Communications project aimed at achieving millimeter-wave communication. Until then, millimeter-wave transceivers had used compound semiconductors such as GaAs with excellent high-frequency characteristics, but ultra-high-speed and large-capacity communication was not available due to low integration and an inability to use advanced modulation technology. Therefore, with then Associate Professor Okada and then Assistant Professor Miyahara, we set our sights on future development and started work on a 60 GHz millimeter wave transceiver using CMOS technology, which, at that time, was not up to the demands we were trying to make of it.

The key to increasing the data rate was reducing the phase noise of the oscillator. The higher the frequency of the millimeter wave, the lower the Q of the LC oscillation circuit, and the higher the phase noise. Therefore, by injecting 20GHz of oscillating power with low-phase noise into the 60 GHz oscillator, we reduced low-phase noise to 1/100 of what it had been. This enabled multi-value modulation and dramatically increased the data-rate. The first millimeter-wave CMOS transceiver LSI was announced in 2011, and the world record for millimeter wave data-rate has been updated since then, with 56 Gbps being achieved in 2016. In addition, we developed a transceiver with radio-frequency LSI, and a baseband LSI, developed in his laboratory, and achieved the world's fastest wireless communication between a PC and smartphone at a practical level of 6.1 Gbps. This achievement formed the technological base for today's wireless communication standard, the 5G system.

Today, Japan's presence in the integrated circuit field is declining; but its contribution over the past four decades to the development of digital video equipment and systems, such as digital TV and video, High-Definition TV, portable video equipment, and DVD, has been huge. In this regard, I hope people will recognize the major contributions that Japan has made to the further development of integrated circuit technologies, such as video-rate ADC and mixed-signal SoC, and in promoting low-power electronics.

The development of integrated circuits requires the cooperation of a great many people, and I would like to thank all those who have been involved in their development so far.