The SA601: The First System-On-Chip for Guitar Effects

By
Thomas Irrgang, Analog Devices, Inc.
&
Roger K. Smith, Source Audio LLC

Introduction

The SA601 is a mixed signal device fabricated in 0.18u CMOS. The product is housed in a tiny 48 pin surface mount package. It is manufactured by Analog Devices, Inc., one of the leading mixed signal semiconductor companies in the world. The SA601 implements a complete analog and digital signal chain for musical instrument effects processing. The device is the result of a joint design effort between Analog Devices, and Source Audio LLC.

Access to State-of-the-art

Founded by a former MIT student in 1965, Analog Devices, Inc. (ADI) is a multi-billion dollar technology company based in Norwood, Massachusetts. ADI's primary business is the design and manufacturing of high performance analog and digital signal processing semiconductors (chips).

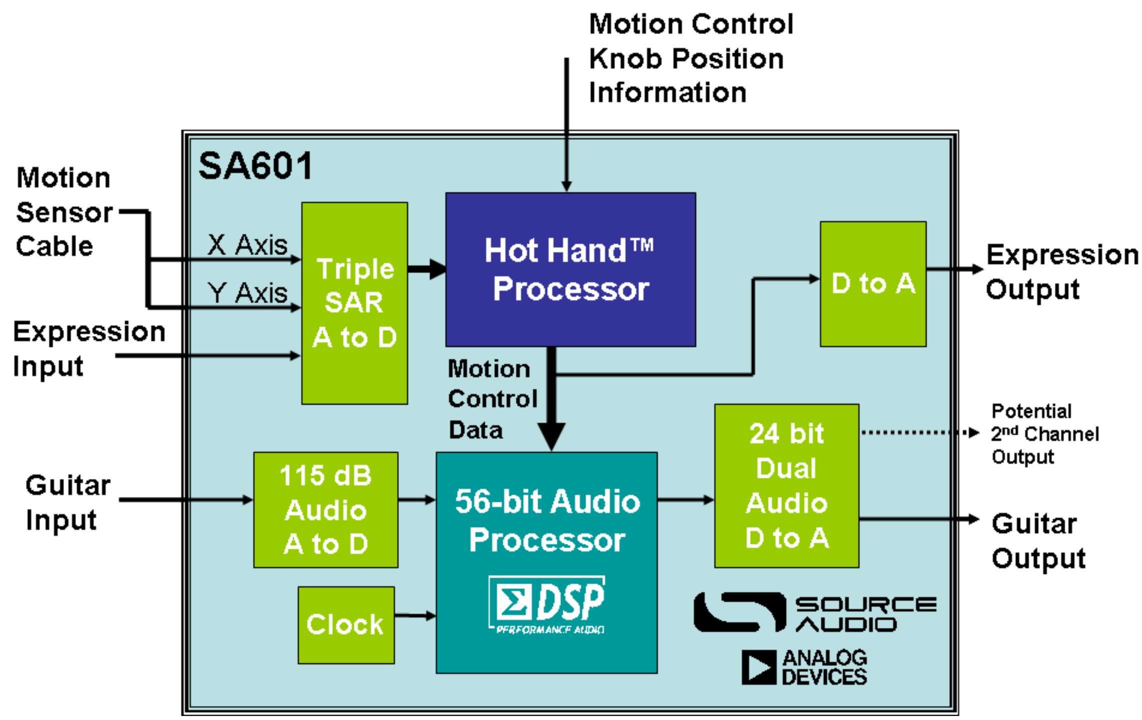
ADI is a world leader in many of the key competencies required in mixed signal "system on chip" designs, where an entire analog and digital signal path is implemented on one single chip of silicon. There are significant benefits in integrating as much of a system onto one chip. First, the long-term reliability of any system is directly related to the number of components in that system. This is widely recognized in the electronics industry, and component reduction is always a key objective when designing for long-term reliability. Second, any circuit which is manufactured on the same slice of silicon will have component matching characteristics which cannot be replicated with separate components. The matching of device characteristics is a key ingredient to superior signal processing performance. Third, mixed signal semiconductor chips are subjected to extensive characterization and testing of a wide range of static and dynamic parameters. This ensures that each system will conform to an exact set of specifications with no variability. Fourth, a system-on-chip allows for “one analog-in” and “one analog-out” external interfacing. When everything is on one chip there is no need for numerous interconnection wires between separate chips and the result is a simple and small circuit board. Finally, a single chip can typically be produced at less cost than 2 or more separate chips, which ultimately enables a lower final consumer price.

System-on-chip designs are not without significant challenges, risk, and cost. The challenge arises when a big noisy digital chip is on the same slice of silicon as a delicate analog signal. There is significant skill required to keep everything quiet in all the right places, and it is often said in the industry that this is a “black art”. The risk arises from putting many separate sub-circuits on one device. If any single sub-circuit has a design flaw, then the entire design may not work and the chip must go through an expensive redesign process. This is one reason why it can take years for a system-on-chip design to work correctly. Finally, development cost is a very significant factor. As more and more circuits are packed into one chip, the devices become more and more microscopic. This forces the designer to utilize manufacturing and prototyping facilities that literally cost billions of dollars. While a single circuit board can be put together by one engineer, a catalog of off the shelf parts, a circuit board, and a few thousand dollars, a system-on-a-chip design will often start at a million dollars.

Through its relationship with ADI, Source Audio LLC has access to one of the premier analog and digital system-on-chip design and manufacturing companies. Source Audio brings to the relationship knowledge of what the system ultimately needs to do and how it should sound. Through the partnership with Source Audio, ADI is able to deliver a system-on-chip solution that is relevant and appropriate for a specific application.

Architecture of Chip

The diagram below shows a functional schematic of the major processing components in the SA601. One notes that most key functions of Source Audio’s guitar effects products are handled by this chip. The only task not performed by SA601 is general housekeeping tasks such as turning the LEDs on and off when the knobs are turned. This is handled by a micro-controller.



SA601 Functional Block Diagram

SigmaDSP Processing Block

At the core of the SA601 lies ADI's high performance SigmaDSP audio processor. This is a complete audio processor engine including a 56 bit fixed point multiplier/accumulator, on-board data and program memory, clock generation circuit, and special acceleration blocks for many common audio processing macro-functions (such as filters). In addition to the hardware itself, Source Audio's effects algorithms have been programmed at the machine code level to execute large amounts of code quickly and efficiently.

While many competitive solutions utilize either 16 or 24 bit audio processing, the SigmaDSP used in the SA601 is capable of using a full 56 bit processing data path. This ensures there will be no rounding or truncation errors even after long strings of successive computation steps, which can be a source of digital distortion in systems with a more narrow data path.

The Source Audio team has many man-years of experience in both high level and low level coding of the SigmaDSP engine. The Source Audio team also has many man-years of audio effects algorithm experience. This combination of skills allows the company to develop libraries of complex effects algorithms both quickly and efficiently. The end result is a rapidly expanding family of high quality and innovative effects products which would otherwise take decades to develop.

Hot Hand™ Processing Block

The science of extracting effects control parameters from motion sensors was conceived by Source Audio LLC Co-Founder Jesse Remignanti and then later researched and developed by the Source Audio design team. Jesse has a patent pending on the invention.

Unlike the simple up down action of a wah pedal, which produces a predicable linear signal measuring only the position of the pedal, motion sensors can produce either 1, 2 or 3 complex analog signals depending on the number of axes in the motion sensor. After these signals are translated into the digital domain, this processing block extracts information on velocity and orientation relative to the earth's gravitational pull. The final action of this block is the translation of these data (plus the setting of the Motion Knob) into a set of parameters for controlling the selected effect.

Audio Data Converter Blocks

Until very recently it was not possible to integrate delicate high performance analog audio processing blocks on the same chip with a high performance digital processing engine. The first challenge is isolating the analog signal from the digital noise being generated by millions of tiny digital signals being switched on and off millions of time per second. The second challenge relates to the physical size of the analog blocks. Fom practical mixed signal implementation, it is important for the analog processing cells to utilize the same devices sizing parameters as is used with the digital cells. Throughout the 1990s digital cells continued to shrink and shrink with no degradation in the performance. However, the analog cells, particularly audio ones, hit a wall in the late 1990s. As the analog cells got smaller, the sound quality deteriorated well beyond acceptable levels. Many in the industry believed the necessary shrinking of analog cells could not continue, and they could not be integrated with the digital cells in the future.

In early 2005 Analog Devices presented two key papers at the International Solid State Circuit Conference in San Francisco on the novel concept of using both Continuous Time Sigma-Delta conversion techniques with Discrete Time Conversion techniques. When this combination of approaches was utilized on the small devices, the apparent logjam was broken. Analog Devices was now able to place high performance analog processing blocks on the same chip with large digital engines in an aggressive semiconductor manufacturing technology.

The SA601 is one of the first products to utilize this breakthrough technology in all 3 of the audio converter blocks on the chip. A 24 bit 115dB Analog to Digital Converter is the first stage. Since many effects can often boost noise that would not otherwise be heard, it is vital to utilize the widest possible dynamic range as is done with the block. The last 2 blocks are the stereo Digital to Analog Converter pair, which are also 24 bit.

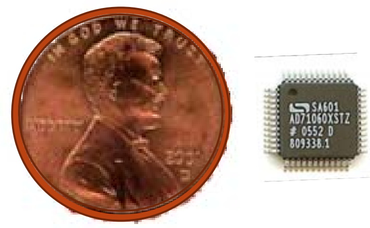
Auxiliary Data Converter Blocks

Audio-style data converters tend to be large and tricky to implement. It would have been a daunting task to implement the same style of converter for all of the motion control signals, and it is unnecessary. A different sort of technology is required. In addition to being an audio converter expert, Analog Devices is also an expert in Successive Approximation (SAR), and other ADC and DAC technologies. These two other approaches were chosen for the SA601, because they offer appropriate levels of performance for the motion signal conversion process, but consume very little chip real estate.

The final product

When all of these blocks are put together on one single system-on-chip, we now have a complete effects processing system which does not compromise either leading edge digital processing or, most importantly, the integrity of the original musical instrument signal.

Enlargement



Actual Size