Throughout the history of the electronics industry there have been advances in technology that have evolved and revolutionized the industry. These advances have brought on new branches and new fields of electronics that were previously unobtainable. New silicon materials and methodologies have created their own group of explosive technology areas, along with a subset of mathematical equations and graphs required to understand and design them into electronic systems. These newly amalgamated ICs are based upon the marriage of existing technologies, but applied and incorporated in such a radical new fashion that they give birth to a new breed of smaller, faster, inexpensive, and more versatile electronic components.

Today we are in the process of experiencing the development of a new electronic component based on a marriage of technologies that is destined to revolutionize the analog electronics industry. This new component is the Field Programmable Analog Array, or FPAA. The Field Programmable Analog Array is in some ways equivalent to the Field Programmable Gate Array, or FPGA. Both are technologies that are entirely reprogrammable and reconfigurable by the user. They can be custom programmed to the requirements of an entire electronic system design or to just a particular system function. That is where the similarities end. Where the FPGA’s core structure is based upon and targeted for digital electronics, the FPAA’s core structure is based upon and targeted for the analog electronics sector. In this article, Joel and Nathan introduce new dynamic analog capabilities.
FPAA application advantages
FPAA application advantages

FPAs can simplify your analog implementation while providing you with an unprecedented degree of system-level control. The following is but a brief list of analog technology applications and benefits that the FPAA can provide:

- **Closed loop control applications:** Closed loop control systems based on a Proportional Integral Derivative (PID) control methodology are used in a wide range of industries to help ensure peak performance from motors, lasers, chemical systems, industrial ovens, and many other applications. Dynamically reconfigurable FPAs are an ideal analog front-end solution for PID systems. The FPAA allows control system parameters to be tuned and updated in real time from within the system software to adjust for factors such as sensor aging and actuator degradation.

- **Audio applications:** FPAs are the first analog components for audio that can change their parameters in real time and even undergo a complete state change all so instantaneously as to be inaudible even to the most experienced ear. The FPAA can be configured to provide second, third, and fourth order crossovers with minimal impact on phase response or offer user-selectable bass and treble tilt settings as pre-set configurations with no additional component cost. It’s even possible to create an equalizer that adjusts automatically to the characteristics of the room where the speakers are placed.

- **Sensor applications:** The FPAA can provide multiple sensor conditioning circuits under the real-time control of a digital microprocessor. Sensor signal linearization, offset compensation, calibration, and signal modulation circuits can now be implemented in minutes on a drift-free integrated silicon platform. The reprogrammable and reconfigurable advantage of the FPAA allows for partial or complete microprocessor controlled reconfiguration of the FPAA based upon external events.

- **Communication applications:** Communication applications implement a wide range of analog processing technologies. These range from closed-loop control systems for adjusting the biasing of a laser in a long-haul DWDM system to the simple gain and filtering stages required in various communication products. The FPAA allows for all control loop coefficients to be adaptive and under real-time control providing the ability to tune the response characteristics of the closed loop system or accommodate different external component types and respond to component aging profiles. The strength and advantage of the FPAA can be applied in multiple analog system applications including:
  - Signal linearization
  - Line equalization and termination
  - Proportional, integral, derivative signal control
  - Complex filtering

**Keeping it analog**

The FPAA is true analog technology that is entirely reprogrammable and reconfigurable. In contrast to Digital Signal Processors (DSPs), the FPAA does not convert the analog signals into the digital domain. Rather all the signal processing is performed in the native analog form, thus preserving the high precision nature of the original signals. The FPAA is comprised of multiple high precision op amps whose functional parameters are configured by a surrounding programmable switch-capacitor network. This utilization of the established technology of a switch-capacitor network within the silicon allows each high
precision op amp to be completely reprogrammable and reconfigurable. Not only does it allow the parameters of each op amp to be entirely reconfigurable and reprogrammable, but the interconnections of the op amps with respect to each other within the FPAA are completely reconfigurable and reprogrammable as well.

Two new capabilities are needed in the analog world:

- Translation of complex analog circuits to a simple set of low-level functions thus giving designers the analog equivalent of an FPGA
- Placing analog functions under real-time software control within the system

By providing the analog equivalent of logic gates, FPAA's give designers the ability to describe analog functions such as gain stages and filters without reference to the underlying function. In other words, without having to think on the level of such components as op amps, capacitors, resistors, transconductors, and current mirrors. Lifted to this higher level of abstraction, the design process becomes so simple that nonspecialists can create sophisticated circuits that would require weeks or months of design work with ASICs or discretes.

**FPAA technology**

Anadigm's FPAA is based upon the implementation of programmable switched-capacitor technology. Switched-capacitor networks surround each high precision op amp within the FPAA. This combination of switched-capacitor networks and high precision op amps along with a specialized signal routing topology are configured into a specialized matrix referred to as Configurable Analog Blocks or CABs as shown in Figure 1. The core of the Anadigm FPAA is an array of identical CABs. The versatility and function of the CABs are additionally enriched with the incorporation of addressable memory (look-up table), programmable comparators and references, and dedicated signal interfacing functions.

![Figure 1](image)

Just as the digital FPGA has physical programmable blocks or macrocells that can be configured to implement a range of logical functions, the Anadigm FPAA also has CABs that can be programmed and assembled to create analog functions. These analog functions are represented in software tools as Configurable Analog Modules (CAMs) – the abstract analog equivalent of the logic function. The CAB architecture combines as small a diversity of component types as possible with maximum versatility (providing as varied and extensive a deployment of resources as possible) and maximized utilization (affording minimum component redundancy for any function). Switched-capacitor techniques offer exactly this combination of characteristics. Two pairs of switches and a single programmable capacitor can be configured to perform at least nine different tasks. Combine a number of these with active elements (op amps, comparator), with complex logic control, and then combine the CABs themselves: the resulting diversity and scope of signal processing functions is immense.

In addition to their simplicity and flexibility, switched-capacitor-based circuits have an inherent precision, being reliant only on matching of component values, rather than their absolute values. This provides for high initial accuracy in these devices, as well as very low levels of drift over time (the underlying component drift will affect each of the elements in the same manner, and will ultimately be cancelled out in the device operation). The inherent routing benefits that arise from the CMOS switch fabric, all of which can be driven from digital programming, means that such
architectures lend themselves extremely well to field programming and real-time reprogramming.

The CAB structure is the result of application experience gained from previous products combined with advanced place and route features within the FPAA tools. The net effect is a highly versatile building block whose components can be assembled in a predetermined way to reliably implement a desired function.

**The advantage of the FPAA CAMs**
The CAM completely insulates the designer from the underlying circuit design and silicon by transforming analog design know-how into functional software elements. Examples of such elements are:

- filter stages
- gain stages
- summing/difference stages
- voltage multipliers
- phase/voltage comparators
- rectifiers
- oscillators
- references

New, highly customizable functions, such as arbitrary waveform synthesis or arbitrary voltage transfer functions, further exploit the programmable nature of the FPAA. As an abstraction, the CAM in fact offers much higher complexity and flexibility than a logic gate. Nevertheless, it performs much the same role: a functional block that can be considered independently of the silicon and support true design abstraction. Access to the CAM is via a high-level design tool, the AnadigmDesigner2 software FPAA development tool. The CAMs are contained within a design library. They can be dragged and dropped onto a schematic canvas within the design tool, on which the FPAA devices that will realize the final design are depicted (shown in Figure 2). The software assembles the configuration data set(s) for the entire design, and delivers it in a form ready to be programmed in a FPAA or FPAAAs from an EEPROM, a host microprocessor, or directly programmed from the FPAA software development tool.
The CAM is thus entirely self-contained and is a full representation, in software, of a physical analog signal processing function. It can even be seen as an analog standard cell, capable of integration with established third party system design and verification tools. Higher-level synthesis tools, such as filter synthesis, are also available and readily interact with these abstracted blocks.

Dynamic reconfigurability of the Anadigm FPAA adds to these capabilities by allowing analog functions to be updated in real time using automatically generated C-code. With analog functions under the control of the system processor, new device configurations can be loaded into the FPAA in real time, allowing the device’s operation to be time-sliced, or to manipulate the tuning or the construction of any part of the circuit without interrupting operation of the FPAA, thus maintaining system integrity.

Example of an FPAA based PC/104 board
Jacyl Technology, Inc. has developed the AXR-16 PC/104 board based upon the Anadigm FPAA. The AXR-16 shown in Figure 3 features:

- Four Anadigm AN221E04 FPAA components
- Xilinx XC95288 CPLD
- Programmable Direct Digital Synthesis (DDS) component (programmable up to 33 MHz)
- 25 differential or single-ended analog inputs/outputs
- Five additional dedicated differential or single-ended analog outputs
- 42 user configurable digital I/O lines

**Figure 3**

The FPAA
Each Anadigm AN221E04 FPAA incorporated on the AXR-16 consists of a 2 x 2 matrix of fully Configurable Analog Blocks, surrounded by a fabric of programmable interconnect resources. The AN221E04 is dynamically reconfigurable allowing it to be updated or programmed partially or completely while the FPAA is active and running. Once the new configuration data is loaded into the FPAA, the transfer to the new analog configuration occurs in a single clock cycle. The four CABs have access to a single look-up table that offers adjusting of any programmable element within the device in response to an analog signal change or time base. In addition, the CABs can be used to create arbitrary input-to-output transfer functions, generate arbitrary signals, and perform voltage dependent filtering or dynamic system calibration. The AN221E04 also has an integrated 8 bit analog-to-digital converter that can be used to digitize an analog signal within the FPAA. Also, each of the analog inputs and outputs can be configured for signal-ended or differential signal configurations.

Configuration of the four FPAA
Each FPAA on the board can be configured to function independently of each other or all four of the FPAA can be cascaded together. When the FPAA functions independently the CABs and associated input/output analog signal lines for each FPAA can be programmed with a unique configuration and utilized for a unique separate analog system function. An alternative configuration is for each of the four FPAA’s outputs to serve as the input of the adjacent FPAA, allowing all four FPAA to be serially cascaded or daisy-chained together. This configuration allows up to a total of 16 CABs to be utilized for applications requiring special analog processing. Also, the 8 bit analog-to-digital converter located within each AN221E04 can be individually routed to the Xilinx CPLD for further processing, or be a separate microprocessor board attached to the AXR-16 PC/104 bus. Each FPAA on the AXR-16 has the capability of being programmed from multiple sources. It features an onboard RS-232 connector, allowing the FPAA’s to be programmed directly from a host computer running the AnadigmDesigner2 FPAA software development tool. Each FPAA can also be programmed from an onboard socket configured for a Xilinx XC1700E serial EPROM, or each FPAA can be configured and programmed through the PC/104 bus.

The PC/104 board clock sources
The PC/104 board provides three separate digital clock sources for the CPLD for each of the FPAA:

- 50 MHz digital clock source
- 12 MHz master clock from the PC/104 bus
- Programmable DDS component

Each of the clock sources is routed through the CPLD and can be utilized in multiple combinations for each of the FPAA. This allows the AXR-16 to be very flexible on single, multiple, or system clock requirements. The DDS can provide a programmable clock source of up to 33 MHz and is capable of being reprogrammed in real time to a new clock frequency. One unique application of the DDS programmable clock output is serving as the source clock for the switched capacitor networks within each of the FPAA. Programming a specialized analog filter function into the FPAA and then programming the DDS to sweep a frequency range allows the FPAA to dynamically move the tuned frequency of the filter circuit through a frequency spectrum in real time. This unique versatility of the AXR-16 allows for simple design and incorporation of complex analog signal processing capabilities that are only limited by the design engineer’s imagination.

“With analog functions under the control of the system processor, new device configurations can be loaded into the FPAA in real time, allowing the device’s operation to be time-sliced, or to manipulate the tuning or the construction of any part of the circuit without interrupting operation of the FPAA, thus maintaining system integrity.”
The PC/104 board CPLD
A Xilinx XC95288 In-System Programmable CPLD is installed on the board. It features 288 macrocells with 6,400 usable gates, enhanced pin-locking architecture, extensive IEEE 1149.1 JTAG support, and extended pattern security features for design protection. It was incorporated on the AXR-16 as a central signal routing, source clock control, FPAA configuration logic interface, and PC/104 bus interface for the entire board (refer to Figure 4). All configuration control lines for each Anadigm AN221E04 are routed to the CPLD, along with all clock signals and the configuration control lines for the DDS. Even the defined PC/104 data, address, and bus logic signals are routed to the CPLD. The AXR-16 was designed in order to allow it to be as versatile as possible. The CPLD can be user programmed through an on-board IEEE 1149.1 JTAG connector, allowing the CPLD and all associated interface and configuration control lines for the FPAA, clocks, DDS, and PC/104 bus interface to be custom programmed to meet the special requirement of a system design. The AXR-16 can be completely reprogrammed and reconfigured for use in multiple system applications. It also has 42 user programmable digital I/O lines directly controlled by the CPLD. These 42 user programmable digital I/O are both 5VDC and 3.3VDC compliant.

One additional important feature of the AXR-16 is that it has the versatility of being powered from the PC/104 bus, or it can be
Summary of features on the AXR-16

- **Description**
  - Available in commercial or industrial temperature.
  - 25 differential or single-ended analog inputs/outputs (16 dedicated inputs/outputs, 9 additional muxed inputs/outputs).
  - Five additional dedicated differential or single-ended analog outputs.
  - 42 user programmable digital I/O lines.

- **PC/104**
  - PC/104 bus compatible and board compliant.
  - Can be utilized as a PC/104 module or as a standalone prototype, development, or production circuit board.
  - Can be powered through the PC/104 bus or by an external DC power source.
  - 4 user defined LEDs and 4 user defined switches.

- **FPAA**
  - Configured with four Anadigm AN221E04 Field Programmable Analog Array (FPAA) components.
  - FPAA can be programmed and configured through the PC/104 bus, an on board FPGA serial PROM, or directly by the AnadigmDesigner 2 software through an onboard RS-232 port.
  - FPAAAs are fully supported by the complimentary AnadigmDesigner 2 software.

- **FPDs**
  - Configured with a Xilinx 95288 In-System Programmable CPLD.
  - The outputs of the 8 bit A/D converter located within each AN221E04 can be sent directly into the CPLD for digital signal processing.
  - Each FPAA is completely configurable and programmable through the CPLD.
  - Programmable 0 MHz to 33 MHz DDS source clock for the CPLD and FPAAAs.
  - CPLD global clocks include PC/104 bus, 50 MHz onboard oscillator, and the 0 MHz to 33 MHz DDS programmable output.
  - The Xilinx free ISE Webpack software supports CPLD.
  - IEEE 1149.1 JTAG compliant input/output to the CPLD allowing the CPLD to be programmed with custom system configurations.

Powered from an external DC source. This provides the capability for the board to be used as a:

- Stacked module in PC/104 applications
- Standalone product design platform (allowing the AXR-16 to be an integral part of a larger embedded PC/104 stack)
- Standalone circuit board for development platforms, design prototypes, or production products.

**Conclusion**

Analog has been largely left behind in the race to raise abstract system design and verification to even higher levels due to analog design having been constrained by the availability of only discrete components. Although cutting edge analog circuitry will always be a specialist craft, there is a wealth of analog interfacing that can be embraced by a more abstracted design methodology, where significant value can be provided to the systems engineer in terms of both design simplicity and advanced, new dynamic analog capabilities. The Anadigm FPAA incorporates these two facets, bringing a revolutionary technology to the engineers’ toolbox for a completely reprogrammable and reconfigurable analog solution.

The Jacyl Technology AXR-16 PC/104 board leverages the Anadigm FPAA technology, providing significant value to the system engineer at the board level by providing a system reprogrammable and reconfigurable analog design development platform. The compact board size and versatility bring to the system engineer’s toolbox an invaluable and robust analog based PC/104 board solution, making it a prime target for embedded applications or as an integral part of a system design.

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