Changing Trends with Field Programmable Analog Array (FPAA)

In the world of microprocessors and digital design, change has been fast, furious and deliberate. But not so with analog, they say. They say change is inevitable. They say change is hard. Change is time consuming. Change is next to impossible. **Until now.**

by Vinay Sharma

The tedious and inflexible process of designing and implementing analog circuits could often take weeks or even months; and changes to ASIC or discrete design functionality in the field …well, forget about it.

'The design of analog components has traditionally pivoted around low-level "clever tricks" (art or black magic?) that involve transistor layout and parameter selection, thus making virtually impossible to use higher level of abstraction'

Author : The Art and Science of Integrated Systems Design, Alberto L. Sangiovanni-Vincentelli.

Analog design has been left in the cold as software-centric systems are developed and verified with powerful and complex design tools. Currently most of the digital processing is done through programmable logic devices like FPGA (Field Programmable Gate Arrays), CPLD's etc. Absence of analog equivalent of FPGA has kept analog out of dialog between programmable devices and EDA tools.

Now it is going to be changed forever. An engineer can design complex analog circuits, test and modify the design and finalize them in few hours using *FPAA (Field programmable Analog Array)* technology. Currently FPAAs are available which can be configured in real time which allows the designers to modify their analog design in real time.

A Field-Programmable Analog Array, usually abbreviated *FPAA*, is the analog equivalent of the FPGA. This reduces the complexity of analog design and reduces the time required for designing analog circuit from months to minutes. The reconfigurable feature of FPAA enables repurposing and real time updating of analog functions within the system.

In this article, we would try to put light on the FPAA technology, its key benefits, and its applications for electronic & embedded system designers.

Overview of Analog Circuits & FPAA Alternative

Signal conditioning is divided in to two main sections

- Analog signal conditioning
- Digital signal conditioning

Until now digital signal conditioning is preferred over analog because of the complexity and the lack of precision involved with analog circuitry. Moreover, the tolerance of devices associated with analog devices make it very difficult to calibrate. So analog signal processing requires a high level of expertise.

By providing the analog equivalent of logic gates, FPAAs 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, trans-conductors, and current mirrors. Lifted to this higher level of abstraction, the design process becomes so simple that non-specialists can create sophisticated circuits that would require weeks or months of design work with ASICs or discretes.

Motivation: Programmability

- Instant prototyping and reprogramming
- On-the-fly reconfiguration
- High levels of integration
- Design using PC-based CAD tools
- Reduced level of expert knowledge required to build working (analog) ICs
- Less costly for small numbers

Motivation: Analog

- No converters required for real-world signals
- Lower die area
- Lower power
- Speed
- Some applications only require low accuracy
- Applications: Signal processing, Neural networks, Communications, Control and monitoring

Dynamic configurability 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 on the fly, 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.

Comparison for Analog design solution and FPAA advantage

SOLUTION	DISCRETES	ASICs	FPAAs
Design Time (1 Project)	10 Weeks	25 Weeks	2 - 3 Weeks
Flexibility	Low, requires board re-layout	None after early stages	Totally flexible
NRE	Cost of analog specialist and PCB re-works	Up to $500K	Very low. Cost of FPAA Kit
Risk	Medium	High	Low
Cost of ownership	High	> $500K	Low (includes eng)
Manufacturability and repeatability	Low - Depends on components availability & tolerances	High	High

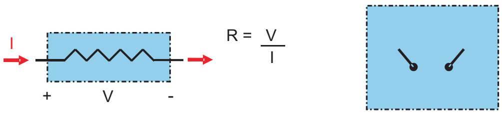
Anadigm's field programmable analog arrays (FPAAs) introduces the ability to translate complex analog circuits to a simple set of low-level functions, and thus to give designers the analog equivalent of an FPGA. Anadigm's FPAA elevates the design and implementation process of analog design to high levels of abstraction.

General FPAA Overview

Unlike the FPGAs, which contain a large number of modules and interconnections allowing arbitrary configurations of combinatorial and sequential logic, FPAA devices typically contain a small number of CABs (Configurable Analog Blocks). The resources of each CAB varies widely between different commercially available and research devices. FPAAs directed toward standard analog design typically feature a CAB containing an operational amplifier, programmable capacitor arrays (PCAs), and either programmable resistor arrays for continuous-time circuits or configurable switches for switched-capacitor circuits. Anadigm FPAA family is based on switched capacitor architecture.

Switched Capacitor Technology

The switched capacitor technology is the technique by which an "equivalent resistance" can be implemented by alternatively switching the inputs of a capacitor. The figure given illustrates how switched capacitors are configured as resistors.

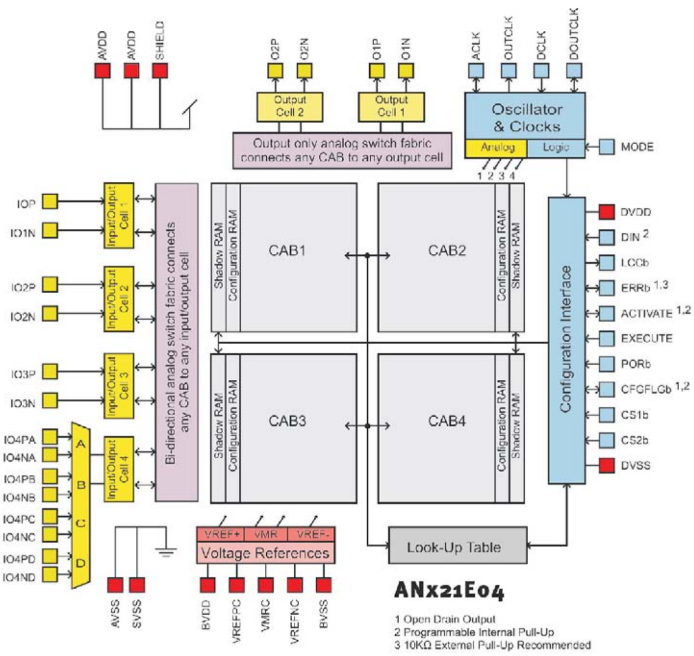


Advantages of 'Switched Capacitor'

- Much Larger resistance for a given area
- Temperature and process independent ratio
- Transfer function with "Negative resistors"
- Corner frequencies scale linearly with sample clock
- Better "Resistor' value
- Better Tolerance typically ± 1.0%
  - Better matching typically ± 0.1%
  - Better temperature co-efficient ~ $1/20^{th}$ to $1/300^{th}$
  - Better voltage linearity ~ $1/5^{th}$ to $1\ 2000^{th}$
  - Wide Range

Anadigm's *AN221E04 FPAA* Architecture

The AN221E04 device consists of a 2x2 matrix of fully Configurable Analog Blocks (CABs), surrounded by a fabric of programmable interconnect resources. Configuration data is stored in an on-chip SRAM configuration memory. Compared with the first-generation FPAAs, the Anadigm vortex architecture provides a significantly improved signal-to-noise ratio as well as higher bandwidth. These devices also accommodate nonlinear functions such as sensor response linearization and arbitrary waveform synthesis.



Architecture of AN221E04 FPAA

The analog designs that can be implemented in an FPAA is done through CAM's (Configurable analog Modules). These CAM's uses the resources of CAB. The various CAM's are amplifiers, filters, comparators, multipliers, differentiators, integrators, dividers etc. These CAM's can be connected together to form the desired analog systems. Cam's parameters can be configured in real time the capability of dynamic configuration. The architecture of AN221E04 is shown with all basic internal blocks.

The AN221E04 device features an advanced input/output structure that allows the FPAA to be programmed with up to six outputs or triple the number provided by the ANx20E04 devices. The AN221E04 devices have four configurable I/O cells and two dedicated output cells. For I/O-intensive applications, this means a single FPAA can now be used to process multiple channels of analog signals where two or more such devices were previously needed. Out of the four configurable input/output cells one is of 4:1 multiplexer type.

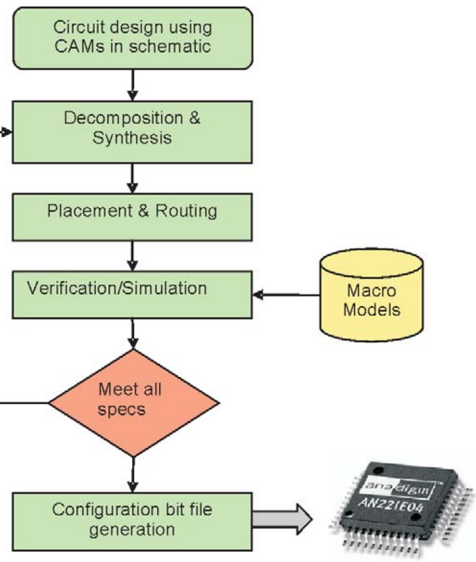
The input cells of AN221E04 FPAA can be configured as a differential input cell as well as a single ended differential input. Input cell itself consists of configurable amplifiers (chopper amplifier and unit gain differential amplifier) and anti aliasing filters. The stabilized chopper amplifier allows an DC offset down to 100uV. Anti aliasing filter is of continuous time, second order filter type with corner frequency adjustable between 34 KHz to 470 KHz.

The output cell of AN221E04 chip can be configured in three different modes- bypass mode, voltage output mode and digital mode. In voltage output mode, a second order, continuous time smoothing filter with corner frequency adjustable from 34 KHz to 470 KHz. When digital output mode is selected, internal comparators are used.

AnadigmDesigner®2 EDA tool

Anadigm®'s second-generation *AnadigmDesigner®2* EDA tool lets you design and implement dynamically reconfigurable analog circuits within a matter of minutes. Build your circuit by dragging and dropping Configurable Analog Modules (CAMs), each of which can be used to implement a range of analog functions for which you set the parameters.

AnadigmDesigner®2 includes a time domain functional simulator which provides a convenient way to assess your circuit's behavior without the need for a lab set-up.



The simulator's user interface is intuitive and easily learned. Most of the steps are the same that you would take while bench testing. Whether or not you're an analog expert, you can build a complete analog system rapidly, simulate it immediately and then just point and click to download it to an FPAA chip for testing and validation.

AnadigmDesigner®2 is the world's first EDA product that lets you develop designs using FPAAs that can be reconfigured by the MCU in *real-time* to change the function they perform within a system or to adapt on-the- fly to maintain precision despite system degradation and aging.

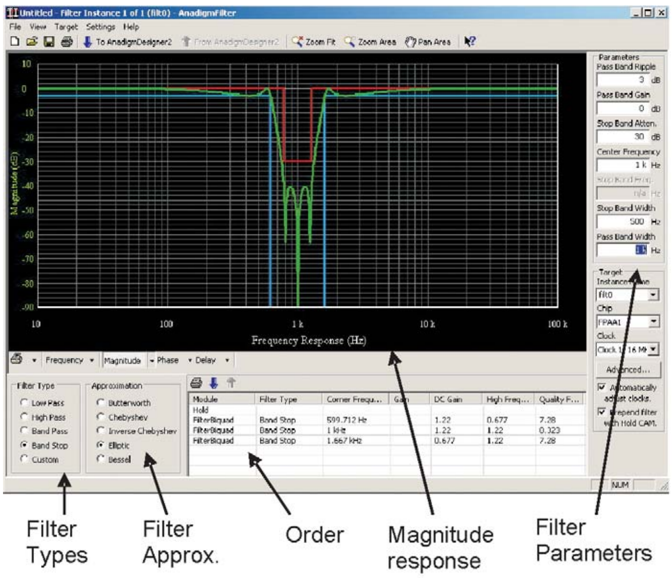
AnadigmDesigner®2 takes your design and automatically translates it into *C-code* that allows the design to be adjusted and controlled by a microprocessor within an embedded system. That means you can now control and adjust analog functions using system software in real time - a breakthrough capability for the analog world!

Applications of FPAA

FPAA has wide application in diverse fields like Audio, Telecom, Signal Conditioning systems, Medical etc.

Complex analog filtering circuits

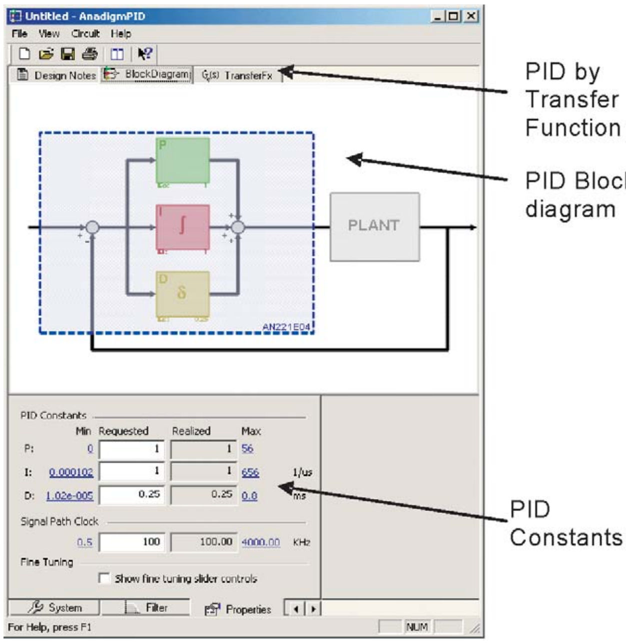
- Guaranteed and repeatable filter implementation
- Filter design and implementation takes minutes
- Implemented filter is drift-free and immune to aging or component variations



The implementation of complex analog filters has be been made easy by the assistant tool.
Anadigm Filter which is provided along with Anadigm Designer®2, with which you can design complex analog filter of different types; Butterworth, Chebyshev, Bessel function, Elliptical etc for all types of filter. The designer can set the corner frequency, Q-factor , stop band, pass band etc. of the filter and view the transfer function. The designer can directly import the filter design into Anadigm Designer®2, using which it can be downloaded into FPAA.

Closed loop control systems

- **P**roportional-**I**ntegral-**D**erivative controllers can be implemented within minutes
- Low latency control



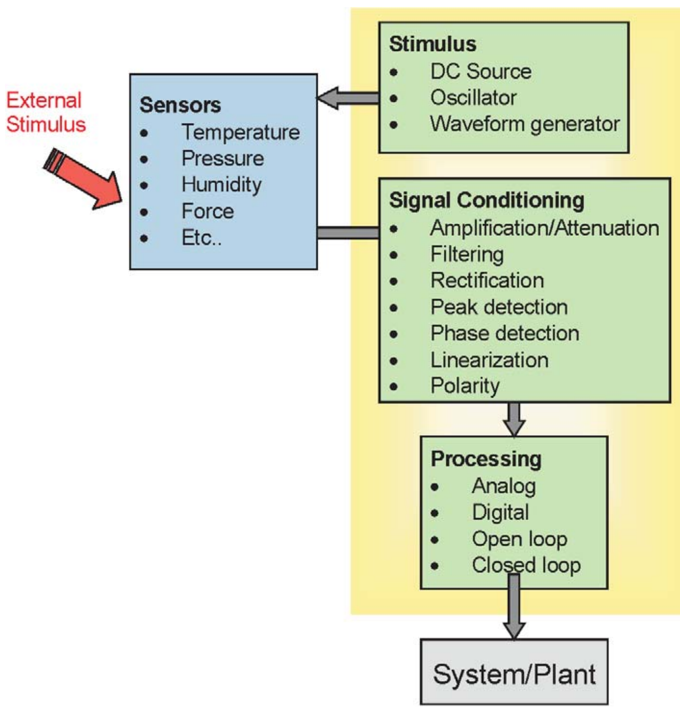
Anadigm PID Assistant Tool

PID controller can be implemented using the *AnadigmPID tool* of Anadigm Designer®2.This helps the designer to design complex P or PI or PD or PID controllers. This tool also shows the block diagram of the PID controller that has been designed along with its mathematical model. In this the designer is allowed to change the proportional constant, integration and differentiation constant dynamically.

Sensor Signal Conditioning

The most common signal conditioning tasks performs:

- Amplification
- Offset removal / correction
- Rectification
- Filtering



What you can do with FPAAs

SUM
FILTER
SHAPE
INVERT
RECTIFY
AMPLIFY
MULTIPLY
SUBTRACT
COMPARE
INTEGRATE
LEVEL SHIFT
DIFFERENTIATE
SAMPLE & HOLD
CONTROL A MOTOR
BUFFER A SENSOR
MULTIPLEX SIGNALS
TAKE A SQUARE ROOT
SELECT A 1 HZ SIGNAL
DETECT ZERO CROSSINGS
PLAY INTERESTING MUSIC
MODULATE A LASER DIODE
REMOVE 60HZ INTERFERENCE
CREATE A VOLTAGE REFERENCE
DRIVE YOUR STEREO SPEAKERS
LINEARIZE A TRANSFER FUNCTION
MAKE SINE WAVES ON DEMAND
GENERATE AN ARBITRARY WAVEFORM
COMMUNICATE WITH YOUR COMPUTER
ACCEPT DIFFERENTIAL OR SINGLE-ENDED SIGNALS
TERMINATE A SIGNAL WITH THE CORRECT IMPEDANCE
DO ALL THE ABOVE IN INTERESTING USEFUL COMBINATIONS
STORE ITS CONFIGURATION FILE IN AN ON-BOARD EEPROM
CHANGE IT TO SOMETHING NEW IN LESS THAN A MINUTE

FPAA Usage Cone

Generally it requires more than 2-3 OP-AMPs for performing conditioning apart from processing.

This in turn cause increase in board space and power consumption.
Whereas with a single FPAA designer can perform signal conditioning and processing in one chip.

The figure on previous page illustrates how FPAA can be used for signal conditioning applications.

FPAA Application Domain

- Real-time software control of analog system peripherals
- Intelligent sensors
- Adaptive DSP front-end
- Adaptive industrial control and automation
- Self-calibrating systems
- Compensation for aging of system components
- Dynamic recalibration of remote systems
- Ultra-low frequency signal conditioning
- Custom analog signal processing

Benefits of FPAA Design technology

- **Simplify analog design and implementation**
  - Fully documented, repeatable analog design
  - Reconfiguration reduces design risk and allows field updates
- **Platform-based design approach**
  - Consolidate the manufacturing of multiple boards by merely using a different configuration file
- **Consolidate of multiple discrete components on a board**
  - Reduce board space
  - Simplify manufacturing
  - Reduce inventory sourcing and management costs
  - Increase system reliability and MTBF(Mean Time Between Failure)
- **High-precision, drift-free operation**
- **Dynamic reconfiguration allows for truly innovative analog systems design**

In the Future

With notable progress in FPAAs in the past few years; analog functions are getting in total control of designers.

Anadigm has also launched low voltage (3.3V) FPAA which has better bandwidth and lower power comsumption. Anadigm also promises to keep upgrading their FPAA architecture, which means we can have more complex and better FPAA what they are today.

Looking at the Time To Market (TTM) requirements of products, new-generation dynamically reprogrammable FPAAs are ready to revolutionize the analog world.

To know more about FPAA technology and products, you can visit www.ni2designs.com