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Radical new way to process RF signals for electronic warfare and communications systems

Patented architecture combines DSP, FFT, digital down converters and FIR filters for improved frequency transformation

Exhibiting at COTScon, San Diego, USA (4-5 December) on Booth 202
and presenting a paper on PFT on 5th December

RF Engines Limited, a British high technology company based on the Isle of Wight, has created a new way of simultaneously processing digital signals across a wide spectrum in real time that is faster, smaller (a single chip), more accurate and lower cost than existing solutions. It is ideal for advanced radar systems, signals intelligence, secure wireless communications and electronic warfare systems as it can identify and track small, rapidly moving signals across a wide slice of the spectrum (of up to 100 MHz) in real time. It can even focus in on these signals whilst still maintaining its watch on the rest of the spectrum. RF Engines is making this innovative architecture, **Pipelined Frequency Transform™** (PFT)**,** available as licensable Intellectual Property (IP) in the form of IP cores (or 'engines') that can be included in programmable logic devices or System On Chip (SOC) designs.

The challenge of data processing at high speed

The key element of any modern electronic warfare system is its ability to acquire enemy signals, identify them, and decide the appropriate action to take. Speed of operation and the ability to detect and acquire signals that are only fleetingly apparent, or which are tracking across the spectrum very quickly, or which can barely be 'seen' against the background electronic 'noise' - particularly across a wide frequency range, are the key requirements of any signals intelligence system.

Similarly, modern radar systems such as multi-beam or synthetic aperture radar (SAR) require very sophisticated real-time signal processing. This ranges from channelisation and matched filtering to pulse compression and wide-band frequency analysis with the object of extracting echoes of small and fast-moving targets from a background of noise and clutter (echoes from ground, sea, false targets etc.) This enables targets to be pinpointed in time and space with an accurate knowledge of their direction and speed of movement.

In a hostile environment where a microsecond can mean the difference between the survival or destruction of a fighter aircraft, the designer of the radar warning receiver plays the key role. Often presented with design issues that may include constraints on space, cost, environment, power and other factors, the designer has to trade these to achieve the optimum performance for his system design. Any signal detection system must be able to "see" the enemy as far away as possible and therefore have the maximum time to act, this means being able to detect signals at low levels with a high degree of sensitivity. The PFT provides a broad range of signal level detection or dynamic range by use of unique filter architecture.

Pipelined Frequency Transform

The digital world starts with the conversion of analogue (waveform) signals into the digital (binary) world. Examples of this are voice signals or radio signals converted into a binary digital stream (noughts and ones). The speed of this analogue to digital conversion determines the amount of information (bandwidth) that can be gathered. High-speed analogue to digital conversion silicon chips are already available but the ability to process their high-speed digital outputs has been, until the invention of PFT, a serious constraint on high performance electronic system design.

PFT provides conversion and filtering of channels (from a few to many thousand) in real time with all channel signals being available for onward processing. It enables a stack of Digital Frequency Converters or a massively parallel processed pipeline FFT (Fast Fourier Transform) to be replaced with a single chip rather than a number of components, thereby reducing overall system cost, size and power consumption by up to 50%, whilst significantly improving performance. These are key factors for airborne or portable systems.

"As this is a hardware implementation rather than software running on a programmable DSP," explains John Lillington, RF Engines' CTO, "we achieve up to twenty times better performance in high end applications. In fact, PFT makes possible a solution to high-end problems that was not practical before, due to the cost and size of silicon needed for conventional methods. For example, it would take a huge number of Digital Frequency Converters and filters or 86 GMACs on a programmable DSP with a total memory band width of 78 Gbytes/sec, which is not very practical, to match the performance of a 10 stage PFT producing a 1024 point output with a usable bandwidth of 80MHz. Each bin is equivalent to a digital downconverter followed by a decimate-by-64 CIC and a decimating Tap FIR filter with a 75dB stopband rejection."

The Pipelined Frequency Transform™ is a specially developed architecture that is optimised for the real time signal analysis of ultra wideband signals and transforms the signals from the time domain to the frequency domain as an FFT (Fast Fourier Transform) would do. However, unlike an FFT, the PFT also provides high performance filtering across hundreds of channels. This could not be done practically in real time on a general purpose DSP running FFT routines.

For example, a demonstration implementation of PFT using FPGAs can handle in excess of 100MHz bandwidth signal at 8-bit resolution and extract 1,024 channels with sharp channel filter characteristics of, typically, a filter stop-band rejection of better than 75dB (with 8 bit A/D data input). Moreover, it can do a 1024-point transform up to 20 times faster than an FFT implemented on a DSP.

The basic PFT architecture uses a series of frequency splitting stages to sub-divide the original signal band. The first stage splits the band in half; the second splits the two bands into four, and so on until the required number of bins is achieved. Decimation at each stage ensures a constant data rate through the pipeline, and hence a continuous data throughput with no loss of data. Gain across each bin is flat (typically less than +/- 0.2 dB) and bin-to-bin isolation can be tailored using highly optimised filters within each stage to meet the dynamic range requirements of the system.

An N-point PFT is functionally equivalent to a parallel bank of N individual complex down-converters; i.e. all frequency channels are available all of the time. For large values of N, the PFT solution requires significantly less silicon than the equivalent bank of down-converters. Thus, for example, a 16K point transform needs only 14 PFT stages as compared to 16384 Digital Frequency Converter modules.

The architecture is totally scaleable with intermediate stage outputs simultaneously available if required. It is configurable so that trade-offs between dynamic range, selectivity, throughput rate and silicon gate requirements can be done under the designer's control to provide the optimal solution for each application.

Being pipelined means that there are no time gaps and therefore no missed data, which is crucial for very fast or fleeting signals. In addition, it is completely cascadable by adding additional PFT stages to provide higher resolution by increasing the number of points or, conversely, finer resolutions can be achieved if a smaller input bandwidth is used.

Furthermore, and of major significance, an enhanced PFT is being developed which will allow flexible dynamic channelisation of broadband spectrum. This will allow more efficient processing of sparsely populated spectrum, and provide for the independent tuning of the final channel bandwidth, centre frequency and filter shape.

PFT TRACKING RATE EXAMPLES

Bandwidth	Points	Resolution (bin spacing)	Tracking Speed
100 MHz	1024 (800 Usable)	125 kHz	100 GHz/Sec
100 MHz	512 (400 Usable)	62.5 kHz	200 GHz/Sec
100 MHz	256 (200 Usable)	31.25 kHz	400 GHz /Sec
80 MHz	1024 (800 Usable)	100 kHz	80 GHz/Sec
80 MHz	512 (400 Usable)	50 kHz	160 GHz/Sec
80 MHz	256 (200 Usable)	25 kHz	320 GHz /Sec
40 MHz	1024 (800 Usable)	50 kHz	40 GHz/Sec
40 MHz	512 (400 Usable)	25 kHz	80 GHz/Sec
40 MHz	256 (200 Usable)	12.5 kHz	160 GHz /Sec

Notes: For a minimum spectral spread, the signal would track no more than 1 PFT Bin per PFT repetition period. For example, with 100kHz bin spacing, 5µs repetitions, the signal could track 100kHz in 5µs, which is 20 GHz/sec. However, at 80 GHz/sec useful tracking with slightly reduced signal-to-noise and some bin spreading can still be achieved.

TWO EXAMPLES OF TYPICAL PFT DESIGNS

1) High bandwidth medium resolution project.
This project is required to continuously monitor an entire 80MHz band with a resolution <100KHz, an update rate >200KHz, a dynamic range >75dB and across-bin ripple <0.1dB.

A PFT based implementation could be achieved as follows: *80MHz wide signal centred 51.2MHz IF, sampled by an 8-bit ADC sampling at 204.8MHz, followed by a digital half-band filter, I and Q data rate of 102.4MHz, followed by a 10-stage PFT with the required bin shape, giving 1024 bins each of 100KHz wide and a continuous update rate of 200KHz.* All the digital hardware fits within a single XCV3200E Xilinx Virtex-E FPGA (3.2 million gate part, 35mm x 35mm).

2) Medium bandwidth high resolution project.
This project is required to continuously monitor an entire 4MHz band with a resolution <200Hz, an update rate >200Hz, a dynamic range >130dB and across-bin ripple <0.2dB.

A PFT based implementation could be achieved as follows: *A high dynamic range ADC sampling at 10.24 MHz, followed by a digital half-band filter with an output data rate of 5.12MHz, followed by a 15-stage PFT giving 32K bins each of 156.25Hz wide and a continuous update rate of 312.5Hz.* All digital hardware fits within two XCV2000E Xilinx Virtex-E FPGA (2 million gate parts) and eight external RAM devices.

For further information, please see the website at www.rfel.com or contact RF Engines at Innovation Centre, St Cross Business Park, Newport, Isle of Wight, PO30 5WB, Great Britain. Tel +44 (0) 1983 550330. E-mail info@rfel.com.

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