The fully digital radio transmitter: Is it real or more hype?

Steve Taranovich - March 05, 2015

Cambridge Consultants are claiming the world’s first fully digital radio transmitter built only from computing power. There are no analog components like a high-speed D to A converter with amplifier, although I would think they would need a Power Amplifier (PA) to broadcast a great distance. This is a Digital Radio transmitter and not part of a Software Defined Radio (SDR) architecture which requires analog components. They are demonstrating the transmitter at the Mobile World Congress (MWC).

The Pizzicato radio (my Italian wife tells me that Pizzicato means pinched or to pluck as in a stringed instrument). More about this new architecture later; now let’s see what came before this effort leading up to the Cambridge solution.

Many so-called All-Digital Radios have been tried in the past. Here are some that stand out, but in my skeptical analog brain I find it hard to conceive a truly All-Digital Radio, only possibly some main architectural sections as is evidenced in the following examples from some EEs in IEEE tech papers.

The pulsed UWB transmitter

In Reference 1 we see a 2008 design for pulsed-ultra-wideband transmitter architectures. The developers have two designs: delay line-based and ring oscillator-based. To illustrate the advantage of a digital format architecture, the author shows that the two architectures are synthesized and place-and-routed (PAR) using existing design tools---no custom routing or care as is typical in analog layout and routing. Another advantage of a digital system is that when the desired center frequency and bandwidth are slightly off due to variations induced by PAR, those frequency-related parameters can be easily tuned digitally. See Figure 1 for the architecture block diagram.
Figure 1 Reference 1 architecture for the “all-digital” pulsed UWB transmitter. (Image courtesy of Reference 1)

Not bad, but not my idea of a fully-flexible all-digital radio design.

Radio transmitter architecture with all-digital modulator

Reference 2 is a mid-2000 design with somewhat limited application to an “Opportunistic Radio” which shares spectrum in licensed and unlicensed bands for secondary users. The architecture used for this need of a flexible and reconfigurable radio type is a direct modulation type architecture based on an all-digital I&Q modulator followed by a linear power amplifier. With a digital modulator, the D to A conversion is able to take place at the speed of RF, so no less than $2\times$ the channel frequency of the signal in order to meet the Nyquist criteria (Figure 2).

Figure 2 The “all-digital” radio transmitter architecture based on sigma-delta modulation. (Image courtesy of Reference 2)

The “all-digital” modulator is based upon the sigma-delta filtering plus a set of analog band-pass BAW-CRF (bulk acoustic wave-coupled resonator filter) filter where only one path to the filter is active at any one time. The D to A converter is clocked by and “all-Digital” RF synthesizer. There is no Power Amplifier (PA) used so this solution is very linear and good for a Zigbee protocol with low power and shorter range. Noise shaping is done at higher frequencies similar to the original sigma-
delta designs that handles lower audio-type frequencies.

In most of these architectures, we look five or ten years in the future to the maturity of such architectures. The maximum speed of the sigma-delta modulators needs to be increased, higher power levels and the PA issue needs to be addressed, and power system efficiency needs to be improved.

**FPGA-based all-digital transmitter with RF output for software defined radio**

This mid-2000s effort used an FPGA that directly synthesizes the RF signal in the digital domain which eliminates most analog and RF components ([Figure 3](#)).

![Figure 3](#) The all-digital transmitter architecture. (Image courtesy of Reference 3)

This is another architecture that uses digital architecture as well as a band-pass delta-sigma modulation scheme to generate binary signals at radio frequency. Binary signaling coupled with a switch mode PA will result in higher efficiency than conventional PAs.

One shortcoming about this architecture is that the band-pass delta-sigma modulator has to operate at four times the output center frequency in the multi-GHz region in most cases.

The Double-sided Pulse Width Modulation (DPWM) waveform consists of two PWM waveforms. One PWM to the left of the reference point has its leading edge modulated by one PCM sample, while the other PWM to the right of the reference point has its trailing edge modulated by another PCM sample. By generating these two PWM waveforms independently and later combining them, the effective processing rate is halved to Pulse Repetition Frequency (PRF). With this parallel transformation of DPWM generation, they are able to implement a real time RFPWM to demonstrate the all-digital transmitter ([Figure 4](#)).
The generation of a double-sided PWM waveform—this generates a real-time RF pulse width modulator and leads to the all-digital transmitter. (Image courtesy of Reference 3)

Just Like in over-sampled data converters, noise shaping can be performed in PWM to preserve the SNR performance in the frequency band of interest. The FPFA can be created to implement all of these parts of the architecture as seen in Figure 5.

The all-digital transmitter with RoF remote radio head

The final design done in 2014 is a unique case of a radio over fiber (RoF) system which also uses an all-digital transmitter architecture to create a remote radio head (RRH) made up of an amplifier stage, bandpass filter and antenna. This transmitter creates a flexible centralized digital radio that performs baseband processing as well as transmitting the radio signals over an optical fiber (Figure 6).
This all-digital transmitter processes the baseband signal using delta-sigma modulation as well. A digital up-conversion stage modulates the binary signal with a square wave at RF frequencies. The digital transmitter does the signal shaping and up-conversion of the baseband signal to RF frequency levels. The output is a two-level signal centered at carrier frequency with quantization noise carried in the side bands. The Delta-sigma modulator shapes the quantization noise out of the signal band which greatly the signal to quantization noise ratio. The transmitter architecture shown in Figure 1 uses a Time-Interleaved Delta Sigma approach that boosts to a higher equivalent frequency for the delta-sigma modulator DSM) by paralleling the outputs.

The DSM output is up-converted to RF by using a bit combiner block and an FPGA’s multi-gigabit on-board serializer. Together these blocks effectively multiply the signal by a square up-conversion to achieve the desired carrier frequency.

**Cambridge Consultants all-digital radio transmitter**

Cambridge Consultants just demonstrated their all-digital radio transmitter at the Mobile World Congress. The company, founded in 1960 by Cambridge University graduates, has none of the pressures to get to market quickly. These former and present academic-types spun off Cambridge Silicon Radio (CSR) bought by Qualcomm in October 2014. Prior to the acquisition, CSR created the world’s first single Bluetooth IC in 2000 and went on to become a leader in the Bluetooth IC industry.

I just had the occasion to speak to Tim Fowler, commercial director, wireless division, Cambridge Consultants and Monty Barlow, director, wireless technology, Cambridge Consultants. Their creation, called “Pizzicato”, greatly intrigued me because unlike the previous attempts at the All-Digital radio outlined above and in the five references, Cambridge has taken the design to a new level with their proprietary patented software algorithms and mathematical software prowess.
An interesting note is that they started this design with an old, 3Gbps bitstream from a Xilinx Virtex-5 FPGA serdes port. They use a bandpass sigma-delta converter in the bitstream like the early one bit audio sigma-delta devices (Figure 7).

![Figure 7 Pizzicato (Image courtesy of Cambridge Consultants)](image)

They still do need a PA and that will be with this present design as Option 1. In the future, Option 2 will use something like a Class S Digital Amplifier (Figure 8 and Reference 5).

![Figure 8 The block diagram of a complete digital transmitter with a GaN Voltage Mode Class S-Power Amplifier (VMCS-PA) (Image courtesy of Reference 5)](image)

Cambridge Consultants are sending me some more detailed information which I will include in a follow-up article on EDN shortly. Watch this company because they have some really bright innovator geeks (our brethren) and I expect to see many new enhancements in this technology over the next few years. These types of Digital radios can fully take advantage of Moore’s Law leading to smaller sizes, lower cost and lower power consumption using next-gen digital IC technology node advancements. An example of the architectures that can benefit from this is the 14 simultaneous cellular base station signals they were able to create with this first prototype.
References

Note: All of the following papers can be found on IEEE XPlore site. Registration and a fee will be required to access them.

1. All-Digital Synthesizable UWB Transmitter Architectures, Youngmin Park and David D. Wentzloff, PROCEEDINGS OF THE 2008 IEEE INTERNATIONAL CONFERENCE ON ULTRA-WIDEBAND (ICUWB2008), VOL. 2
2. Radio Transmitter Architecture with All-Digital Modulator for Opportunistic Radio and Modern Wireless Terminals, Patrick Wurm, Alexandre A. Shirakawa
3. An FPGA Based All-Digital Transmitter with Radio Frequency Output for Software Defined Radio, Zhuan Ye, John Grosspietsch, Gokhan Memik
4. All-Digital Transmitter with RoF Remote Radio Head, Rui F. Cordeiro, Arnaldo S. R. Oliveira and Jose Vieira.
5. A Watt-class Digital Transmitter with a Voltage-Mode Class-S Power Amplifier and an Envelope ΔΣ Modulator for 450 MHz band, Shinichi Hori, Andreas Wentzel, Makoto Hayakawa, Wolfgang Heinrich, and Kazuaki Kunihiro