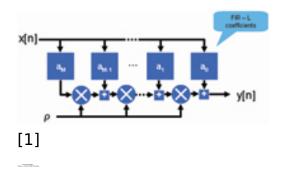
Diverse modulation formats and sampling rates between various standards make designing common building blocks challenging.

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Remote radio heads (RRH) technology with support for simultaneous operation of multiple air-interface protocols is an emerging product requirement for operators. The diverse modulation formats and sampling rates between standards such as MC-GSM, WCDMA, and LTE make designing common building blocks, including digital upconverters (DUCs) and digital downconverters (DDCs), challenging. This article explores potential filter-chain architectures and building blocks to simplify the design of simultaneous multimode digital intermediate frequency (IF) processing.

Multimode basestations capable of supporting multiple standards such as MC-GSM, WCDMA, WiMAX, and LTE offer numerous benefits for both operators and infrastructure OEMs.

Benefits to operators include:

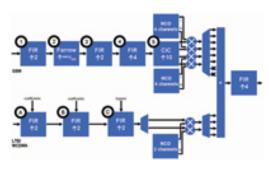
- Flexible use of available spectrum via inlay deployment of new networks such as LTE;
- Reduction of capital expenses by reusing existing basestation equipment and making only software or board level upgrades for deploying new networks;
- Reduction of operating expenses by reusing cell sites (saves on rental costs), reusing RRHs (saves on installation costs), and reusing backhaul;
- Ability to future-proof networks and reduction of long-term total cost of ownership.

Benefits to infrastructure OEMs include:

 Reduction of R&D expenses via universal basestation approach for multiple standards;

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- Simplification of product line management;
- Ability to quickly adapt to evolving standards and bug fixes via programmable hardware;
- Ability to differentiate from competition and charge a premium for futureproof equipment



[2]

While separate cost-optimized channel cards can be added to a basestation cabinet to deploy the modem functionality for various standards, upgrading tower-mounted RRHs with corresponding standard-specific cards is not a desirable solution for operators from an operating expense standpoint. Hence, a universal RRH capable of supporting multiple standards via only software upgrades is an emerging market requirement. The emergence of MC-GSM deployment using multicarrier power amplifier (MC-PA) technology also enables the multimode RRH trend.

MC-PAs and digital IF architectures are predominantly used for developing multicarrier 3G basestations, including those operating on WCDMA and CDMA2000 standards. With MC-GSM moving to a similar architecture, it is now possible to build multimode RRHs that support MC-GSM, WCDMA, and LTE.

While support for run-time reconfiguration is a "nice-to-have" feature for operators and provides significant flexibility in addressing a varying mix of voice and data traffic, support for factory reconfiguration and simultaneous operation are "must-have" features to enable cost-effective deployment of inlay networks in the short term.

Factory reconfiguration is supported by FPGAs including Altera's Stratix IV GX and Arria II GX families, which are inherently programmable devices that offer a high-performance platform for implementing multimode RRHs. These FPGAs offer highly integrated system-on-chip (SoC) options for implementing multicarrier, multi-antenna RRH systems. A single high performance FPGA with transceivers can be used to implement all the digital functionality in a RRH that supports a single sector, 20 MHz LTE carrier with 4x4 multiple input/multiple output (MIMO). The same FPGA can be reprogrammed in the factory, or remotely in the field, to support 12 MC-GSM carriers or four WCDMA carriers.

In the remainder of this article, a key challenge in the design of this type of system is introduced before proposing an efficient architecture for implementing a

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multimode RRH on an FPGA.

Sampling-Rate Equalization

A major challenge of multimode design is the sampling-rate requirements that are completely different. This makes choosing a clock frequency difficult, and because it is necessary to equalize the sampling frequency before sharing hardware, it also makes hardware sharing difficult. Even if there is no need to share hardware, it is still necessary to equalize the sampling frequencies to combine the multiple air interface signals before using a DAC to convey them across the wireless channel. LTE and WCDMA systems share similar sampling frequencies, but WiMAX and GSM are completely different. In addition, the ratio of the GSM baseband sampling frequency to the LTE baseband sampling frequency is irrational. For GSM, the baseband data must be resampled by a total factor of 4 (4608/325) before it is possible to share LTE hardware.

Farrow Filtering Overview

A farrow filter may be used to resample data by an irrational factor. A benefit of this type of filter is that it may be completely runtime configurable if necessary. To achieve a variable, fractional delay (required to realize the irrational rate change factor), it is necessary to store an oversampled version of the desired impulse response. The appropriate coefficients are then chosen to suit the desired output phase. Unfortunately, this is impractical to implement in most cases because the memory requirements are unacceptable. Instead, memory can be saved by evaluating an approximate polynomial to generate the filter coefficients associated with the phase of interest. This structure may be realized using the block diagram in Figure 1, which consists of M+1, L-tap FIR filters, and M multipliers.

 ρ is used to quantify the sampling phase difference between the current input and desired output sample, and this value varies over time for irrational rate changes. This value is normalized between 0 and 1.

Consideration should be given to the following parameters when designing a multimode system:

- Rate-change factor (usually expressed as a ratio of output rate to input rate)
- Prototype filter (desired filtering response)
- Polynomial order
- Number of sections

These parameters are used to generate the appropriate polynomials and time-shared filters to realize the overall farrow filter structure. Supporting any variable-rate change factor is possible, but the best performance is achieved when the prototype filter is modified to suit the new system and sampling rate. However, this requires that the polynomials are generated in

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the hardware. Assuming the supported air interfaces are relatively static, it is appropriate to calculate the polynomials externally and simply provide the capability to reload this matrix into the core. This can be calculated using a control microprocessor such as Altera's Nios II soft processor.

Implementing a farrow filter requires:

- M+1 FIR filters of L coefficients
- M multiplications and additions to combine the outputs.

Individual FIR filters use a single-rate, non-symmetric architecture and process at a relatively low sampling rate, so it can time-share the multipliers. Stratix IV GX FPGAs have embedded 18x18 multipliers capable of running at speeds over 400 MHz, enabling efficient time-sharing of hardware resources.

Multi-Mode DUC Architecture

Figure 2 shows an architecture that supports:

- 2X 5 MHz LTE
- 1X 10 MHz LTE
- 2X 5 MHz WCDMA
- 1X 5 MHz LTE, + 1X 5-MHz WCDMA
- 12X GSM
- 12X GSM, 1X 5 MHz LTE/WCDMA

Properties of the Multimode DUC

- GSM has a much lower baseband sampling rate than LTE, and as a result better filtering performance and attenuation is achieved compared to sharing hardware with another air interface. All FIR filters operate at a relatively low sampling rate, so significant time-sharing is possible.
- Bullet List The LTE/WCDMA datapath may be shared due to similar sampling rates, but requires coefficient set switching based on the channel number. It may also require a variable number of channels to be supported. This can be avoided if only the worst case is supported (two channels at 15.36 Ms/s). Dummy channels may be used if there are not enough physical layer channels for the desired deployment.
- Bullet List Since the overall spectrum of the signal of interest is around 10 MHz, the carrier frequency may be mixed at a lower sampling rate, such as 61.44 Ms/s. Mixing and combining leads to a final upconversion stage using a multichannel FIR filter. This FIR filter only processes a single IQ channel (for each antenna), leading to significant hardware savings.
- Bullet List Since the LTE chain supports either two 5 MHz carriers or one 10 MHz LTE carrier, some control logic is needed to enable/disable the unnecessary channels. In addition, it needs a bypassable filter to ensure that the overall rate change results in the correct output sampling

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frequency.

• Bullet List The overall filter-chain design for both LTE and GSM must take into account the common final interpolation-by-four filter. This final filter rate can be adjusted to give the appropriate IF frequency.

Conclusion

Simultaneous multimode support is an emerging basestation requirement as operators try to transition their networks flexibly and seamlessly between 2G, 3G, and 4G technologies. The diverse modulation formats and sampling rates between standards make designing common building blocks, including DUC and DDC, challenging. High performance FPGAs provide an ideal SoC implementation platform for flexible simultaneous multimode RRH design. WDD

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