Bringing the Flexibility of "Software Defined Radio" to Narrowband and Industrial Wireless Applications

Introduction

A Software-Defined Radio (SDR) is one that implements some traditional hardware radio functions in software. For example, in the extreme case one can use a high performance Analog-to-Digital Converter (ADC) to digitize a wide swath of RF spectrum, then implement functions in software to provide the down-conversion mixer, filtering, and baseband recovery. Such a radio implementation is very powerful, as it can make "on the fly" adjustments to recover different types of radio signals across a wide range of frequencies. However, this ultimate flexibility comes at the cost of high power consumption, the expense of cutting-edge performance ADC and Digital Signal Processor (DSP) devices and the significant challenge of developing underlying software algorithms.

Many robust communications networks that are used for industrial control or simple communications could benefit from an SDR, as they too have to be able to recover and transmit different modulation types and signal bandwidths, usually within a modest range of frequencies. However, these applications are cost, size and power sensitive, meaning that they cannot be realized using a traditional SDR approach.

Enter the concept of a "Firmware-Defined Radio" (FDR). An FDR uses more traditional RF components, such as variable gain amplifiers, demodulators, filters, and baseband decoders – but it allows them to be customized in such a way that a wide number of radio protocols can be implemented on a single hardware/firmware foundation. While an FDR lacks the ultimate flexibility of the extreme SDR approach, it more than makes up for this in terms of cost, power consumption, and simplicity.

In fact, by using free (including royalty-free) IP cores to implement baseband recovery, such a radio can be designed to be both inexpensive and also power efficient. A modestly sized engineering team can leverage several specialized and flexible RF Integrated Circuits (RFICs) to design their own radio terminal products.

CML Microcircuits, a UK based manufacturer of wireline and wireless communications integrated circuits, has implemented an FDR, and packaged it into a convenient and easy-to-use demonstrator board, the DE9941. This kit is available though its North American distribution partner, Component Distributors, Inc.

Capabilities of the DE9941 Demonstrator Board

The DE9941 can be used to demonstrate transmit and receive operation with 4/16/64 QAM linear modulation and constant-envelope modulation schemes such as 2/4-level RRC (Root Raised Cosine) FSK and GMSK. This provides a great deal of flexibility to the radio designer, who can support "next generation" QAM signals for higher data rates and/or smaller bandwidths, while still supporting legacy systems that may use RRC FSK or GMSK type modulation.

Included on board is a 1W power amplifier and RF performance is designed to be compliant with EN 302 561. The operating frequency range of the demonstrator board is between 452 and 467 MHz.

The design is aimed to be small (about the size of a business card) and low cost, with the minimal number of components and values. It connects to the modular PE0002 Interface Board, which serves as a convenient C-BUS (SPI) host that is controlled by a host PC to download scripts and manage register settings. A block diagram of the DE9941 demonstration board is shown below.

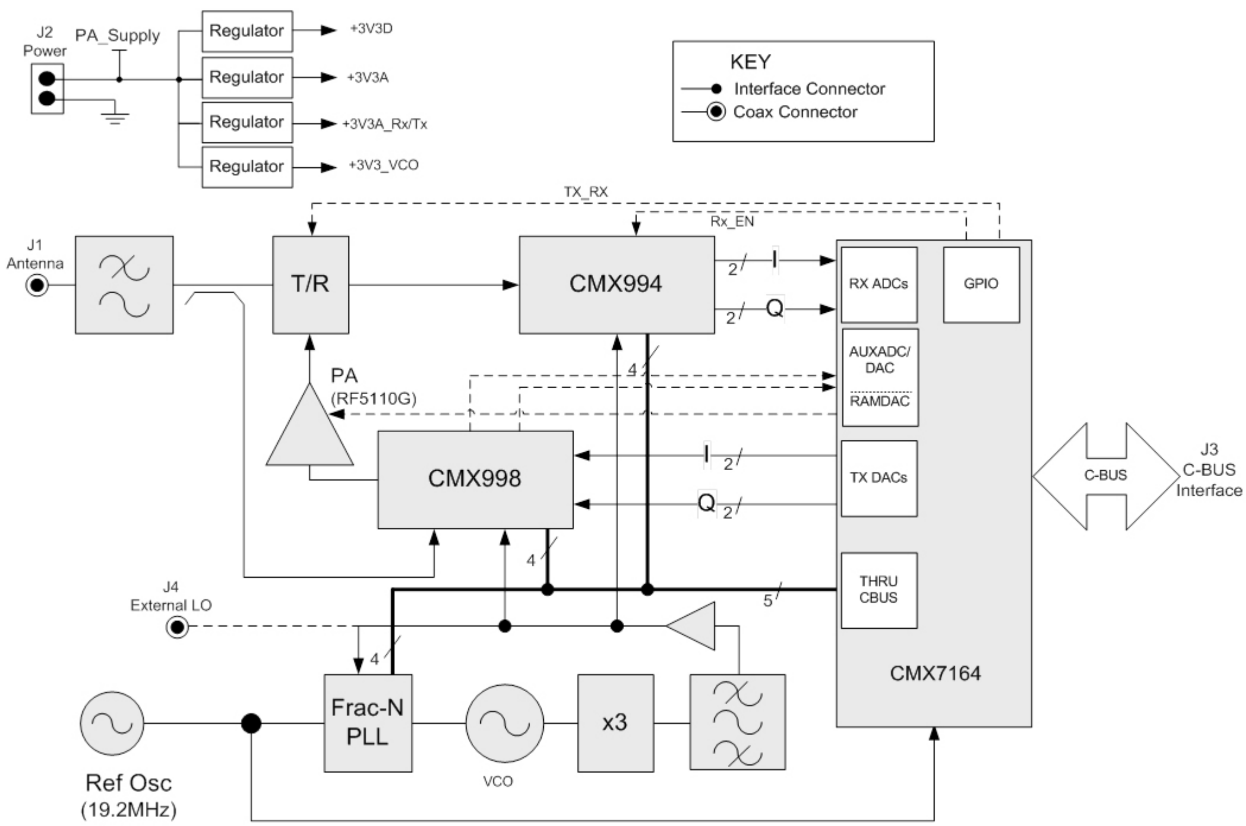

Figure 1. DE9941 Demonstration Board Block Diagram

DE9941 Building Blocks

Major building blocks of the DE9941 Evaluation Board include:

1. Cartesian Feedback Loop Transmitter - CMX998
2. Direct Conversion Receiver - CMX994
3. Multi-mode Wireless Data Modem - CMX7164
4. 1W Power Amplifier
5. Fractional-n PLL and VCO with reference oscillator
6. Transmit/Receive Switch
7. Power Supply Regulation

Of these, items 1-3 provide the backbone of the "FDR" implementation. Each is summarized below.

CMX998

The CMX998 is an integrated solution for a power efficient, Cartesian Feedback Loop based linear transmitter. Acting as a direct conversion quadrature mixer from I and Q to RF output, it linearizes the external Power Amplifier (PA) via feedback from the PA's output. Included are forward and feedback paths; local oscillator circuitry including loop phase control; an instability detector, and uncommitted op-amps that can be used for input signal conditioning. Detailed product information can be found at this link.

CMX994

The CMX994 is a direct conversion receiver IC. It includes a broadband LNA with gain control followed by a very high IIP2 I/Q demodulator with output DC trim controls. The receiver baseband section includes variable gain amplifiers and precision baseband filter stages. Local Oscillator (LO) generation is provided by an integer-n PLL and a VCO negative resistance amplifier; an external LO may also be used. Configurable Rx and Tx LO dividers are provided for flexible multi-band operation. Detailed product information can be found on the CML website at this link. Note also that the CMX994 can also be used for wide signal bandwidths, up to 20 MHz, by bypassing the onboard filter networks.

The CMX994 interfaces with the CMX7164 RF modem, described below.

CMX7164

The heart of the DE9941 Demonstration Board FDR system, the CMX7164 is a multi-mode RF modem, which is based on CML's FirmASIC® Technology. It is a half-duplex baseband processor with integrated I/Q analog radio interface ADCs and DACs and it currently supports GMSK/GFSK, 4/16/64 QAM, and 2/4-Level RRC FSK modes with forward error correction options and configurable channel spacing i.e. a flexible receiver digital IF channel filter. A host controller loads a "Function Image™" (FI™) to initialize the device and determine modulation types. The standard Function Images™ are available to CML customers as a free download, and are royalty free. Standard Function Images™ support all of the modulation types and features listed above. Additionally, it is possible to have a custom Function Image™ developed for a specific application.

The FI™ provides all of the "signal processing" functions in conversion to and from baseband data that flows between the CMX7164 and the host controller. This relieves the radio design team of a significant amount of work, freeing them to concentrate on optimizing the RF performance of the radio itself.

GMSK/GFSK modulation is supported, with BT=0.5, 0.3, 0.27 or 0.25. Custom pulse shaping filters are also possible. Flexible bit rates, up to 20 kbps, support a wide range of applications requiring a selectable bit rate and robustness.

Both 2FSK and 4FSK modulations are supported, root raised cosine filtered with α=0.2 with optional sync filtering. Custom pulse shaping filters are also possible. In RRC FSK mode, the CMX7164 supports up to 20kbps in a 25kHz channel spacing. Again, flexible bit rates support a wide range of applications requiring a selectable bit rate and associated robustness.

The CMX7164 supports 4-, 16- and 64-QAM modulations, root raised cosine filtered with user choice of α=0.2 or 0.35. Using QAM, the CMX7164 supports up to 96kbps in a 25kHz channel, with channel estimation and equalization to provide robust performance under realistic channel conditions.

Forward error correction and raw modes are provided for all modulation types and flexible packet structures are included to easily support a range of applications. For greater flexibility, in QAM mode, twelve different FEC modes are provided. Receive signal quality measurement is supported, making a useful assessment of link conditions.

The host controller, which is typically a microprocessor or microcontroller, communicates with the CMX7164 via a "C-bus" [SPI] three wire interface which is familiar to most embedded system programmers. Additionally, the CMX7164 provides a secondary C-bus that it uses, in Master mode, to communicate with the slave CMX994 and CMX998 RFIC peripherals.

More detailed technical information regarding the CMX7164 can be found at this link.

Simplified Radio Operation

As noted above, the CMX7164 provides the option to autonomously control key functions of the CMX998 and CMX994 RFICs. This provides a tremendous advantage in simplifying the design, control and operation of the radio. For example, the CMX7164 includes a configurable receiver AGC "engine" that can autonomously control CMX994 direct conversion receiver VGA register settings. The CMX7164 can similarly autonomously control a CMX998 DC offset calibration sequence. The host controller doesn't need to worry about managing the two Radio ICs, as the CMX7164 will handle this work automatically. This greatly reduces the amount of coding required by the development team, reducing design complexity and cycle time.

Conclusions

The power and flexibility of a Software Defined Radio solution can easily be realized via FDR for narrowband and industrial radio applications. A high performance, inexpensive and power efficient radio design can be accomplished through use of three tightly integrated RFICs that are available from CML Microcircuits. The use of different Function Images™, downloaded from a host controller to change the behavior of the radio, is demonstrated using the DE9941 Demonstration Board and PE0002 Interface Board. These boards, which are available from Component Distributors, Inc., provide everything that a customer needs to test the power of a Firmware Defined Radio in their own application.