

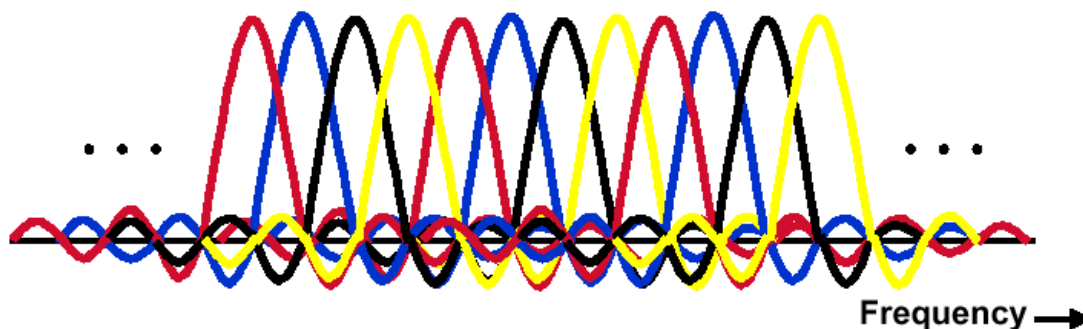
**Why  
License  
CommStack's  
OFDM Modem  
IP Cores?**

## Why License CommStack's OFDM Modem IP Cores?

CommStack has developed several OFDM (Orthogonal Frequency Division Multiplexing) modems as synthesizable Hardware Description Language (HDL) cores that are available for license. CommStack's OFDM Modem cores allow its licensees to implement such standards as 802.11a, 802.11g, 802.16a, and 802.15.3a as well as to develop custom applications.

### **OFDM Technology**

In Orthogonal Frequency Division Multiplexing systems, the data to be transmitted modulates multiple subcarrier frequencies rather than a single carrier. Typical subcarrier modulation schemes include Bi Phase Shift Keying (BPSK), Quadrature Phase Shift Keying (QPSK), or Quadrature Amplitude Modulation (QAM), where each subcarrier in an OFDM signal could even be modulated with a different scheme if so desired. In the frequency domain, the multiple carriers of an OFDM system appear as shown below:



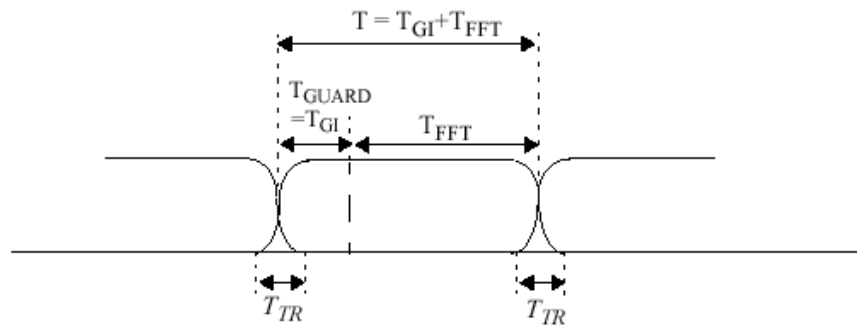
OFDM's parallel transmission of data over multiple simultaneous carriers provides a measure of protection against frequency-selective fading – while some subcarriers may be degraded, others will be unaffected. Performance is further improved by employing forward error correction coding to introduce redundancy so that correctly received bits can be used to correct errors. Bursts of errors in a given interval or over a given frequency band are fought in the time domain by interleaving the coded bit's time sequence and in the frequency domain by interleaving the coded bit's mapping to specific subcarriers.

Moreover, OFDM intrinsically helps reduce intersymbol interference. For a given overall data rate, the data rate that each individual carrier must support is reduced (and the symbol period increased) as the number of subcarriers increases. The resulting extended symbol period for each subcarrier implies reduced intersymbol interference as the symbol duration becomes greater than the channel impulse response.

Intersymbol interference can still be present, however, if the channel creates echoes of the signal. To combat intersymbol interference, each modulation symbol period per subcarrier – the “active symbol period” over which the receiver integrates the signal for demodulation -- is extended by a guard interval longer than the channel impulse response. Introduction of such a guard interval reduces the data capacity, but if the

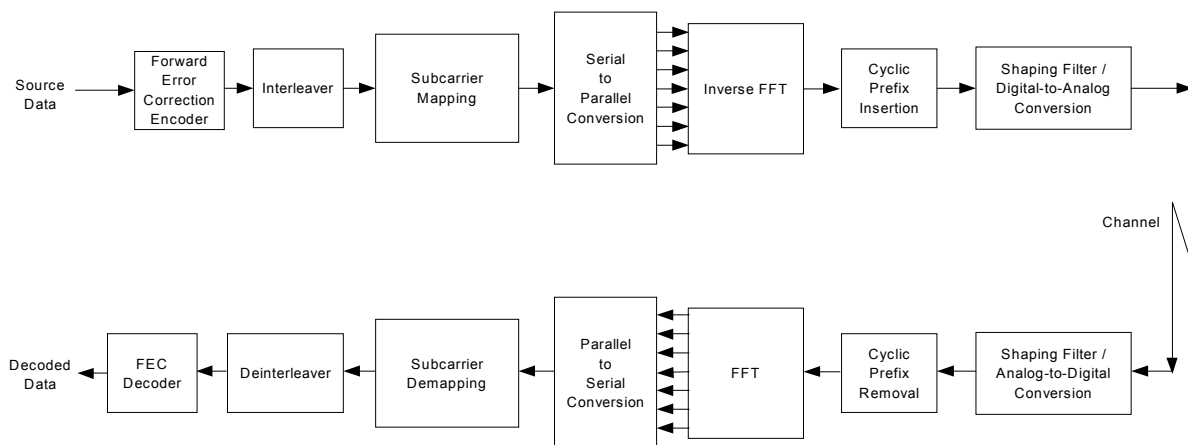
number of subcarriers is high enough and the subcarrier symbol periods thus long enough, the guard interval can be chosen to be less than or equal to 1/4 of the active symbol period but still protect against fairly long echo delays.

The figure below illustrates how a guard interval  $T_{GI}$ , is introduced to extend the duration of the active symbol period,  $T_{FFT}$ , to create the total symbol duration,  $T$ .



The transmission of multiple simultaneous carriers can create interchannel interference. To avoid such interference, the subcarrier frequencies are precisely spaced by the inverse of the active symbol period. By making the contents of the guard interval a “cyclic prefix” of data repeated from the end of the active symbol period, a time window of length equal to the active symbol period can vary its position by as much as the guard interval and still recover the complete symbol without intersymbol interference. At the same time, the guard interval has a duration such that an integer number of cycles occur over the total symbol period. The subcarriers are then mutually orthogonal and non-interfering – although the sidebands of the subcarriers may overlap, different subcarriers are “orthogonal” in that their correlation and integration over the active symbol period result in zero contribution.

Practical implementations of OFDM rely upon the Fast Fourier Transform (FFT) and the inverse FFT (IFFT) to eliminate the need to separately demodulate and modulate the many different subcarriers. The concept is illustrated in the figure below:



At the transmitter, the data is coded and interleaved. If there are to be  $M$  subcarriers, baseband processing allows  $M$  parallel subcarrier modulation streams to be generated in the frequency domain as complex vectors reflecting the amplitude and phase of each subcarrier. An inverse FFT of size  $N \geq M$  converts the complex data from the frequency domain into the time domain, effectively modulating the parallel streams onto  $M$  subcarriers. The cyclic prefix is then appended to each symbol prior to digital-to-analog conversion and transmission.

At the receiver, after analog-to-digital conversion and removal of the cyclic prefix, a size  $N$  FFT acts as a bank of matched filters to translate the received signal to a parallel stream of  $M \leq N$  complex data representations of the received modulation constellation values for each of the  $M$  subcarriers. Equalization for channel distortions, deinterleaving, and decoding then result in the receiver's estimate of the transmitted data stream.

OFDM's intrinsic ability to handle the distortions of both wired and wireless channels without requiring complex receiver algorithms has made it a popular choice for many applications and standards. For wired environments, OFDM techniques are known as Discrete Multi-Tone (DMT) and are employed in Asymmetric Digital Subscriber Line (ADSL) and High-bit-rate Digital Subscriber Line (HDSL) applications. For wireless environments, OFDM is used in the ETSI standards for Digital Audio Broadcasting (DAB) and Digital Video Broadcasting (DVB), in the ETSI HiperLan2 and the IEEE 802.11a and 802.11g Wireless Local Area Network (WLAN) standards, in the ETSI HiperMAN and the IEEE 802.16a Wireless Metropolitan Area Network (WMAN) standards, and has been proposed for use in the future IEEE 802.15.3a Wireless Personal Area Network (WPAN) standard. These standardized wireline and wireless applications all benefit to various degrees from OFDM's spectral efficiency and its resilience to interference and multipath distortion.

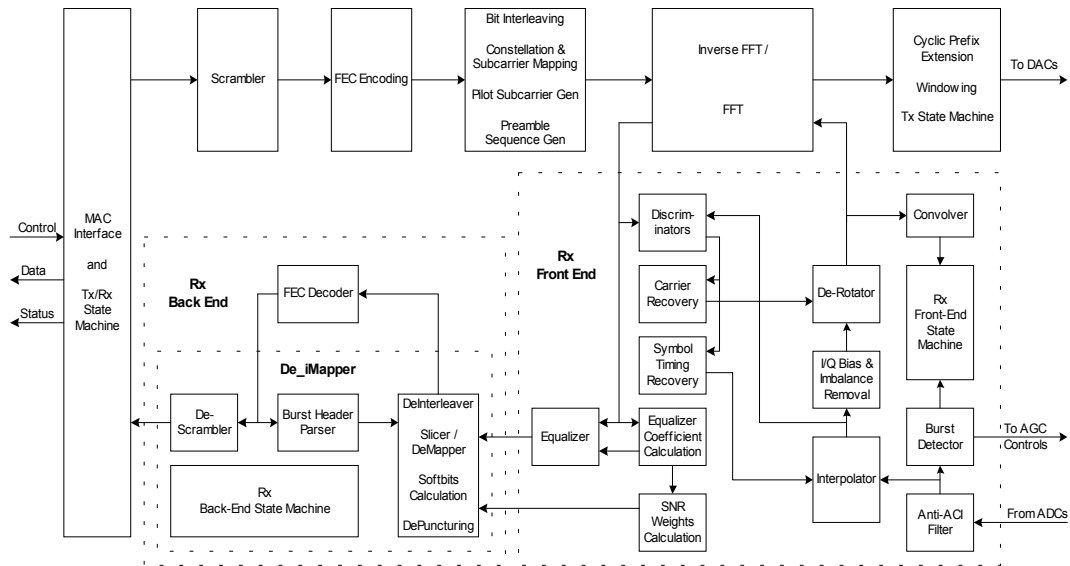
## **CommStack's OFDM Modem Cores**

CommStack's OFDM Modems are developed to be compliant with specific standards or the requirements of a custom application. CommStack's OFDM Modem IP cores are silicon independent and fully synthesizable from Verilog source code. Designed for easy integration, CommStack's OFDM Modems typically provide a simple and flexible data interface toward the data source and sink to allow the Media Access Control (MAC) layer to be either compliant with the relevant standard or be non-standard to support custom OFDM applications. Similarly, the RF interface normally supports I and Q channels at zero IF or at an IF up to, for example, 240 MHz, thereby allowing considerable flexibility in the RF section design.

Transmit functions characteristically include data scrambling, convolutional coding, interleaving, subcarrier modulation mapping, generation of pilot subcarriers, and OFDM modulation (inverse FFT). Similarly, receive functions generally include Automatic Gain Control (with a control interface to the RF section), carrier and clock recovery, OFDM demodulation (FFT), equalization, demapping, deinterleaving, Viterbi decoding, descrambling, and channel assessment and indication to the MAC layer.

A simplified block diagram of a typical CommStack OFDM Modem is shown below:

CommStack OFDM Modem Overview



## Superior Performance

CommStack OFDM Modems are fully verified and tested on field programmable gate array development platforms. To achieve a low number of gates and optimum performance, the designs incorporate unique approaches to signal acquisition and phase estimation, to signal path optimization, and to the use of FFT/IFFT blocks.

CommStack's OFDM Modems typically exhibit baseband performance with minimal implementation loss, allowing more flexibility for designers in the implementation of the RF section:

- *spectral purity*: transmit spectral purity as measured at the RF interface is designed to be several dB below the specified spectral mask
- *responsiveness*: transmit bursts appear at the outputs within ~100 nsec after being strobed at the MAC interface, while any channel assessment signal is provided within 1 µsec
- *robustness*: receive adjacent channel rejection performance is designed to exceed specifications by several dB, while the acquisition circuitry typically can pull in large frequency offsets even in the presence of significant I/Q imbalances at low SNR
- *accuracy*: transmit constellation error (Error Vector Magnitude) as measured at the RF interface is designed to exceed specifications by a wide margin, typically at least 10 dB

CommStack OFDM Modems employ a “macro-block” architecture to minimize the size of the design and more readily allow extensions and modifications. CommStack OFDM Modems characteristically use a low number of gates and are generally the smallest of all comparable implementations. Such a small footprint implies reduced per-unit costs, even if the design is customized with expanded features and extensions. At the same time, power consumption is kept low by a synchronous pipelined design that disables those modules not currently in use on a symbol-by-symbol basis.

## **Implementations of CommStack’s IP Cores**

As IP cores, CommStack’s OFDM Modems can be combined with other elements or kept as separate entities. A particular CommStack OFDM Modem can be implemented as an Application-Specific Standard Product (ASSP) for sale as a merchant semiconductor product, as an Application-Specific Integrated Circuit (ASIC) for use in proprietary high-volume products, or as a Field Programmable Gate Array (FPGA) for use in low- or moderate-volume products.

Total chip count of the solution for a specific application can be reduced by combining the OFDM Modem IP core with an embedded microprocessor to support the MAC layer or with a CMOS design of the RF section. Alternatively, separate best-of-breed RF components can be used with CommStack’s OFDM Modem to insure achievement of the best performance.

CommStack normally tests its OFDM Modems by implementing each one as an FPGA, ideally operating the system at full speed. For low- or moderate-volume applications, the family of programmable devices can be selected to balance cost against size. Many device vendors, for example, offer synthesizable microprocessors, one or more of which can be added to a CommStack OFDM Modem in order to support MAC functionality, the host interface, and any desired extensions.

Implementation of the CommStack OFDM Modem as an FPGA can be a good choice for products to be sold in volumes approaching several tens of thousands. Although an FPGA will typically have a higher unit cost than an ASIC, its development does not involve the additional engineering expenses and mask charges required to produce an ASIC. The break-even point between FPGA and ASIC designs using CommStack OFDM Modem cores is estimated to be tens of thousands of units – until at least that number is sold, the FPGA implementation can realize more profit than an ASIC implementation, assuming the same price point for both designs.

## **Applications of CommStack’s OFDM Modems**

CommStack OFDM Modems can be employed and extended to support a variety of different applications:

- WLANs
- WPANs
- multimedia networking

- point-to-point, point-to-multipoint, and multipoint-to-multipoint communications, including WMAN

**WLANS.** CommStack OFDM Modems can be used to support 802.11a or 802.11g WLAN applications as part of a complete WLAN solution. Coupled with an implementation of the appropriate MAC layer and a 2.4 or 5 GHz RF section, the CommStack OFDM Modem can be part of 802.11a or 11g Network Interface Cards (NICs), Access Points (APs), and bridges.

**WPANs.** Various different proposals using OFDM have been made in the course of the IEEE's 802.15.3a WPAN high-rate alternative PHY standardization process. Because of the high data rates required – from 110 Mbps up to 480 Mbps – and because of the FCC's approval of ultra wideband (UWB) spectrum utilization in February 2002, the 802.15.3a proposals have all involved UWB communications, either using impulse radio or multi-band approaches. Multi-band systems, especially those employing OFDM, provide the advantages of high flexibility in co-existing with other wireless systems and use of more conventional technology. CommStack's OFDM Modem design can readily support the current multi-band OFDM 802.15.3a WPAN proposal, allowing CommStack and its licensees to keep pace with this rapidly evolving new standard.

**Multimedia Networking.** The 802.11a and 11g WLAN standards are targeted for asynchronous traffic such as client-server data exchange but with no intrinsic support of isochronous applications such as voice, video, or audio. These applications require improved QoS to guarantee minimum bit rates per channel and to constrain delay and delay variations (jitter). Video streaming and the distribution of multimedia content especially demand the assured delivery of high data rates.

CommStack's OFDM Modem cores are well suited for such extensions, either by introducing a QoS protocol to better support packet communications or by adapting the modem to support a circuit-switched continuous mode. By virtue of its low gate count and low power consumption, the OFDM Modem can readily be incorporated as an embedded capability into a variety of consumer devices, including home gateways, set-top boxes, DVD servers, televisions, audio equipment, and PDAs. And, because the OFDM Modem allows complete flexibility in the choice of RF section, the ultimate product can be optimized for range performance for the given application.

**Point-To-Point, Point-To-Multipoint, and Multipoint-To-Multipoint Communications.** CommStack's OFDM Modems can be readily adapted for use in standard and non-standard applications in practically any RF band. The designs are robust enough to support data rates greater than 100 Mbps by clocking at higher-than-nominal speeds. As a result, licensees can take advantage of OFDM's intrinsic advantages as well as CommStack's superior design implementation. Example uses include:

- point-to-point architectures to support “trunk” applications such as backhaul from the network edge to its core;

- point-to-multipoint architectures to support “last-mile” applications such as the provision of broadband access; and,
- multipoint-to-multipoint architectures – also known as mesh networks -- where each node can act as a router and repeater for other nodes in order to support the deployment of dynamically evolving wide area networks to deliver broadband service.

Additionally, CommStack’s OFDM Modems can be readily adapted to meet the specifications of the IEEE 802.16a WirelessMAN-OFDM PHY for point-to-multipoint or mesh network operation at frequencies between 2 and 11 GHz. This version of the CommStack OFDM Modem would thus allow the implementation of 802.16a standards-compliant devices for broadband fixed wireless access.

## Conclusion

CommStack’s OFDM Modems provide the means for its licensees to effectively leverage scarce internal engineering resources, to accelerate their product development cycles, and to speed their time to market and time to revenue. At the same time, CommStack’s OFDM Modems generally offer among the smallest gate counts available for its range of features, combined with the highest levels of transceiver performance.

Semiconductor houses, OEMs/ODMs, and system design houses can all potentially benefit from CommStack’s OFDM Modem IP cores for a variety of different communications applications. A specific CommStack OFDM Modem can be implemented as an ASSP for merchant semiconductor sales, as an ASIC for use in high-volume products, or, to minimize initial expenses, as an FPGA for moderate-volume applications. CommStack OFDM Modems are especially valuable when adapted to complement a licensee’s existing technology or to embed new high-data-rate wireless capabilities into an existing product:

- if used to support an implementation of the 802.11a or 11g WLAN standards, the 802.16a WMAN standard, or the future 802.15.3a WPAN standard, a CommStack OFDM Modem can be combined with the appropriate MAC layer and RF components to provide a superior and competitive solution, with the option of including proprietary extensions;
- if integrated into consumer electronics devices, CommStack’s OFDM Modems provide the cornerstone for an advanced multimedia networking solution; or
- if used as a transceiver building block, CommStack’s OFDM Modems can readily support the creation of proprietary point-to-point, point-to-multipoint, or mesh network systems for operation in virtually any frequency band.

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