Clock Solutions for WiFi (IEEE 802.11)

By Brandon Ogilvie

Introduction

As the number of mobile computing and small-office home-office (SOHO) networks with broadband data service continues to increase, the requirement to provide high-bandwidth yet hassle-free connections between the broadband gateway and the user-client in the local area network (LAN) is also increasing. Although copper or fibre optic wires deliver such bandwidth in the LAN, neither is relatively hassle-free in the mobile or SOHO environments. Wires limit mobility and require installation within the subscriber's premise, which may be costly. The alternate solution – wireless – is quite hassle-free, however historically has been limited in bandwidth, thus resulting in unacceptably low data rates. To address the wireless bandwidth issue, the Institute of Electronic and Electrical Engineers (IEEE) developed a set of standards to govern wireless networking protocols and equipment performance.

The IEEE 802.11 standard establishes the protocols for using multiple radio frequency (RF) channels in the 2.4 or 5 GHz band to network devices together over tens, hundred, or even thousands of meters. Such networks are termed wireless local area networks (WLAN), commonly nicknamed WiFi. The WiFi equipment market is expected to reach $2B in CY2003, with strong growth expected to continue.

To ensure reliable, reasonably-secure wireless network connections at optimum data rates while supporting the maximum number of simultaneous user-clients, a high-performance quartz crystal (xtal) or crystal clock oscillator (XO) stabilizes the radio RF and baseband/MAC processors in each WiFi device.

Background

Wireless local area networks (WLAN) consist of several key elements, namely the client and access point. The client represents the group of devices within the WLAN that are connected to the single point of aggregation – the access point – that connects to the Internet or other network infrastructure.

Clients may be a notebook or desktop computer, workstation, printer, or other point-of-use device. Access points (AP) are location-fixed, serving as the bridge between the wireless user and the wired LAN. As such, an AP is analogous to a cellular base station. **Figure 1** represents a typical WLAN network configuration.

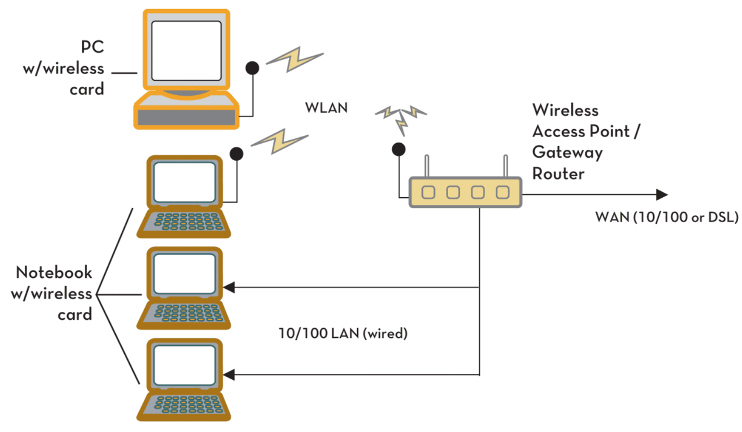

Figure 1: Typical WLAN environment

In today's WiFi marketplace, equipment vendors offer a variety of products, including:

- Client NICs (PCMCIA, USB, PCI, etc);
- Access Points with 10/100 Ethernet;
- Access Points with Routing (multiple 10/100/1000 Ethernet up/downlinks);
- Access Points with embedded broadband uplinks (DSL, etc);
- Access Points serving as point-to-point Bridges;
- Inter-Access Points (IAP) for moving (roaming) users.

As a result of technology advancements that enable more data throughput per wireless client-AP connection, several versions of the IEEE 802.11 standard exist. **Table 1** summarizes the three primary versions of the standard.

Standard	Year	Data Rate	RF	Range	RefClk (typ)
802.11a	1999	54 Mbps	5 GHz	short	20, 40, 80 MHz
802.11b	1999	11 Mbps	2.4 GHz	med	22, 44 MHz
802.11g	2003	54 Mbps	2.4 GHz	med	20, 40, 80 MHz

Table 1: IEEE 802.11 standards

With the presence of multiple standards, two client NICs served by a given access point may operate with different radio frequencies or maximum data rates (bandwidth). Moreover, data encoding schemes may differ between standards. Consequently, access points are often backwards compatible with legacy standards, and as each new standard is introduced, public

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"hotspots" (access points made generally available to the public) must be upgraded to deliver comprehensive support for the various clients that may roam into the coverage area of the hotspot. This, in addition to new hotspot installations, client upgrades, and new clients seeking more flexible network connectivity, contributes to the explosive growth of the WiFi marketplace.

Market research firms estimate that 35 million chipsets will be shipped in CY2003 with 50% CAGR through CY2006 (*IC Insights 2003*). Of these, approximately 20% are incorporated into access points and 80% are incorporated into client NICs (*iSuppli 2003*). Although WiFi clients are consumed in significantly higher volumes than access points, 63% of the estimated US$2 billion WLAN equipment market in CY2003 stems from access points, with client NICs accounting for the remaining 37% (*Infometrics 2003*). The added functionality of access points compared with client NICs accounts for this price differential.

Application: Overview

Within each client, an 802.11-enabled network interface card (NIC) with a radio transceiver communicates with a similar radio located in the access point. In addition to a radio, each client and access point also contains a baseband/MAC controller. This controller regulates the flow of data between the radio and the host device.

Numerous semiconductor manufacturers have introduced chipsets that perform the radio and baseband/MAC function (although previous generations of chipsets consisted of up to five devices each, today's chipsets typically consist of two chips – one radio and one baseband/MAC). WiFi chipset vendors include **Aetheros**, **AMD**, **Broadcom**, **Marvell**, **RF Micro Devices**, and **TI**. Overall, more then fifty (50) IC vendors were offering 802.11-ready chipsets at the end of CY2002 (IC Insights 2003). **Figure 2** is a typical functional block diagram for an 802.11 application.

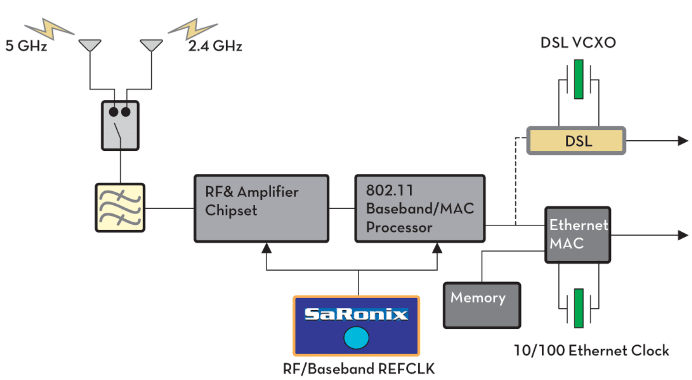

Figure 2a: Typical functional block diagram, 802.11a/b/g Access Point with Gateway/Router & DSL

Depending on particular application, the following frequency control devices may be incorporated into the design:

- RF & baseband/MAC reference clock;
- Sleep-mode reference clock;
- 10/100/1000 Ethernet reference clock;
- DSL VCXO;
- IF SAW Filter.

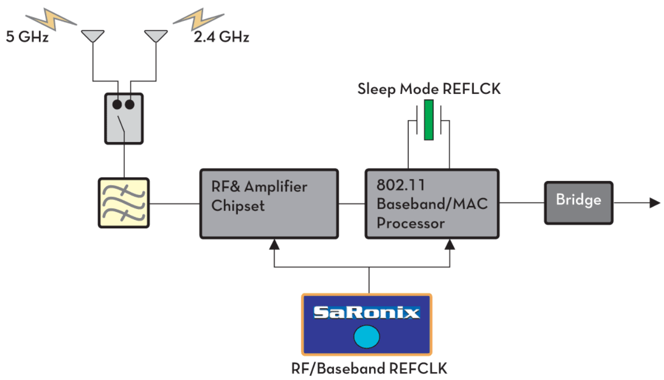

Figure 2b: Typical functional block diagram, 802.11a/b/g Network Interface Card

Although SaRonix does not currently offer SAW filters, SaRonix does offer a set of crystal, clock oscillator, and VCXO products with optimal performance for WiFi equipment. The following sections present the primary factors involved in selecting the frequency control device for each type of reference clock.

Application: RF & Baseband/MAC REFCLK

Both client and AP designs incorporate a RF transceiver and a baseband/MAC that operate with a common reference clock (REFCLK) input. Typical reference clock frequencies are **22** or **44** MHz (802.11b), and **20**, **40**, or **80** MHz (802.11a or 802.11g).

The baseband/MAC uses the reference clock to control access to the wireless network by regulating timing, encryption, encoding and decoding, and the movement of data between the radio (WLAN) and the host device.

The RF transceiver uses the reference clock to generate a high frequency reference that stabilizes the radio's VCO (2.4 or 5 GHz), which is either embedded on the IC or specified as an external component. In order to ensure frequency lock between the two radios – one in the access point and one in the client – a tight-stability reference clock is necessary. The typical performance requirement is **±25ppM all-inclusive frequency stability** (includes initial calibration tolerance at 25°C and frequency changes over operating temperature, power and load fluctuations, and aging). Moreover, access points with dense channel spacing (capable of serving several hundred clients simultaneously) require particularly **low phase noise**.

Client NIC are often designed to incorporate a low power "sleep" mode to conserve battery power. During sleep mode, a continuous reference clock signal for the RF and baseband/MAC is not necessary; a **crystal clock oscillator with low-power stand-by function** is recommended. Oscillators with a low-power stand-by function consume **99.9% less power** when disabled than oscillators with a traditional tri-state or output disable function. Oscillators in low-power stand-by mode do require time to reactivate, however. The typical oscillation output delay is 10 ms.

Advances in crystal oscillator IC performance have enabled reductions in supply voltage, resulting in overall power reductions. Today, XO operating with **2.5V, 2.84V, or 3.3V** supply that meet the stability and phase-noise requirements of WiFi are readily available.

When selecting between a discrete oscillator design based on a quartz crystal (xtal) versus a pre-packaged crystal clock oscillator (XO), **802.11 WiFi designs benefit from the performance and overall cost-savings of using a crystal clock oscillator (XO) instead of a quartz crystal**. Although the direct cost of a quartz crystal is less than that of a crystal clock oscillator, the all-inclusive frequency stability of ±25ppM, 40 MHz or higher frequency requirements, phase noise considerations for tight channel spacing, and PCB real-estate negate the perceived cost-savings of using a quartz crystal resonator.

During the manufacturing process, XO are calibrated and fine-tuned to achieve ±25ppM all-inclusive performance. In the application, the quartz crystal inside the XO is shielded from load variations that would otherwise pull the frequency of a quartz crystal higher or lower, as crystals are susceptible to such when used directly in a circuit. Since ±25ppM overall tolerance + temperature + load + power + aging stability sits at the threshold of manufacturability (barring any costly temperature compensation schemes), slight load variations on a quartz crystal resonator would pull the frequency outside of the ±25ppM allowance, thus resulting in network connection failures. XO are far less susceptible to these external load variations, and as such using XO reduces risk of failure.

Moreover, most quartz crystal resonators above 30~35 MHz must be used in the overtone mode. Attempting to use an overtone crystal directly in an application and successfully minimizing phase noise for tighter channel spacing is a formidable challenge to even the most experienced designer, and consumes significant time and effort to debug the external oscillator circuit. Using a quartz crystal instead of an all-inclusive, pre-packaged XO increases the risk and consumes significant engineering R&D resources. Overall, specifying an XO rather than xtal is the better design alternative.

Finally, a packaged crystal oscillator (XO) occupies less PCB real estate than a conventional quartz crystal + discrete oscillator design. Consequently, using an XO saves overall cost and time-to-market of the system.

Application: Sleep Mode REFCLK

Some designs for client NICs may use an **industry-standard 32.768 kHz crystal** for low-power "sleep" mode to conserve battery power (preferred in most portable applications such as notebook computers). The particular chipset selected for the baseband/MAC determines whether a sleep mode reference clock may be utilized. Tuning fork crystals (32.768 kHz) feature a maximum drive level of a mere 1 μW and as such are used commonly as sleep mode reference clocks.

While in sleep mode, most functions of the baseband/MAC and RF IC are shutdown. Meanwhile, the 32.768 kHz crystal remains active. The baseband/MAC will continue to receive and process the 32.768 kHz signal and use this to establish wake-up intervals. These regular wake-up intervals are necessary to 1) notify the AP that the client is still within the WLAN coverage area, and 2) check for queued data. During this wake-up period, the RF & baseband/MAC reference clock oscillator is activated to re-establish connection with the AP. Without these regular wake-ups, the AP will assume that the client has left the coverage area, rerouting any queued data.

Application: Ethernet REFCLK

Unlike client NICs that connect directly to a host device's PCMCIA, PCI, or USB slot, access points must connect the signals communicated with the clients to other pieces of networking hardware. The most common protocol used for wired network connectivity is 10/100 Ethernet, while highly integrated access points may begin to offer Gigabit Ethernet speed (1000 Base-T). At 54 Mbps of optimal bandwidth for client connections – as is the case with 802.11a – WiFi access points using 10/100/1000 network connections have sufficient bandwidth so as not to incur a data-throughput bottleneck. 10/100/1000 Ethernet MAC and PHY require a local reference clock; typical reference clock frequencies for 10/100 Ethernet are **16**, **20**, or **25** MHz while typical reference clock frequencies for 1000 Base-T Ethernet are **62.5** or **125** MHz.

All-inclusive frequency stability of the 10/100/1000 Ethernet clock is typically specified at **±50ppM**. A given Ethernet MAC and PHY chipset usually specifies whether a quartz crystal or crystal clock oscillator (XO) may be used. Common 10/100 applications use a crystal while 1000 Base-T applications utilize the enhanced yet economical performance available with XO.

A single 10/100/1000 Ethernet reference clock may be used to time a single 10/100/1000 uplink or multiple 10/100 ports in an AP-Router configuration.

Application: DSL VCXO

Many WiFi access points are deployed in the SOHO environment to create a WLAN. In the SOHO, digital subscriber line (DSL) is a leading protocol used worldwide to connect the local network to the Internet service provider's (ISP's) wide area network (WAN); a DSL modem (located in the SOHO) connects the SOHO to the WAN. In an effort to add value by reducing the number of pieces of networking equipment in the SOHO, some WiFi equipment vendors offer access points with an embedded DSL modem and DSL port. Such a device requires a DSL VCXO to track and lock to the data stream from the ISP's central office (CO). Two typical frequencies for DSL VCXO are **17.664** or **35.328** MHz.

Discrete crystal + VCXO IC as well as prepackaged all-inclusive VCXOs are readily available in the marketplace as design alternatives. A discrete crystal + IC solution costs less than a prepackaged VCXO, but increases the component count, PCB real-estate, engineering resources required to design and debug the VCXO circuit, and overall risk. Furthermore, crystal selection and long-term reliability of quality is essential to building a successful VCXO circuit. Specifying a crystal with sufficiently high pullability is compulsory to 1) overcome variations in crystal frequency stability, and 2) track and lock to the data stream from the CO. Ensuring such characteristics usually requires a custom crystal specification; off-the-shelf crystals are not guaranteed to meet the pullability requirements of DSL applications..

Solutions

Although SaRonix and Pericom offer a wide range of crystal, clock, and timing products, the following recommendations offer the best solutions for WiFi equipment:

Solutions: RF & Baseband/MAC REFLCK

Common frequencies:	20, 22, 40, 44, or 80 MHz
Typical stability:	±25ppM max (all-inclusive)

NKS6	xtal, 3.5x6mm SMD, seam-seal for tight stability
NKS7	xtal, 5x7mm SMD, seam-seal for tight stability
S1633	XO, 3.2x5mm SMD, ±25ppM, 3.3V
S1634	XO, 3.2x5mm SMD, ±25ppM, 2.5V
S1613	XO, 5x7mm SMD, ±25ppM, 3.3V
S2560	XO, 5x7mm SMD, ±25ppM, 2.84V 40~50MHz
S2580	XO, 5x7mm SMD, ±25ppM, 2.84V 80 MHz
S1614	XO, 5x7mm SMD, ±25ppM, 2.5V

Solutions: Sleep Mode REFCLK

Common frequency: 32.768 kHz

NTF	xtal, d3x8mm or d2x6mm, 32.768 kHz
NSF	xtal, d2x8mm or d1.5x7mm SMD, 32.768 kHz
32S12	xtal, 4x10mm or 3x9mm SMD, 32.768 kHz

Solutions: 10/100/1000 Ethernet REFCLK

Common frequencies:	16, 20, or 25 MHz (10/100 Base-T) 62.5 or 125 MHz (1000 Base-T)
Typical Stability:	±50ppM (all-inclusive)

49S	xtal, 5x11mm, low cost
49S SMD	xtal, 5x12mm SMD, low cost
S1613	XO, 5x7mm SMD, 3.3V
S1614	XO, 5x7mm SMD, 2.5V
S1612	XO, 5x7mm SMD, 1.8V

Solutions: DSL VCXO

Common frequencies: 17.664 or 35.328 MHz

PI6X035	Pericom xtal+IC chipset, xtal
PI6CX100-35	Pericom xtal+IC chipset, IC
ST1307	VCXO, 5x7mm SMD, 3.3V
ST1317	VCXO, 5x7mm SMD, 3.3V
49S	xtal, 5x11mm, low profile
HC-49/U	xtal, 5x11mm, low cost

About the Author

Brandon Ogilvie is the product manager for SaRonix product division of Pericom Semiconductor Corporation, an ISO9001 certified quartz crystal & oscillator designer and manufacturer that has supplied frequency control products since 1975. SaRonix and Pericom support their global customer base with engineering, sales and manufacturing facilities worldwide. For more information about this topic or frequency control products in general, local sales contacts, applications engineering support, or other product and corporate information, please visit the SaRonix web site at www.SaRonix.com or the Pericom website at www.Pericom.com.

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