Modulation Series

Modulation - Fundamentals 2

Bluetooth EDR Demodulation on the V93000

Joe Kelly, Ph.D.

Verigy

July 2008

Modulation Fundamentals – The Series

Preface to the Series

Modulation analysis is increasingly integral to the test strategies of integrated RF SoC transceivers. The trend is that as the industry gets closer to a single-chip cell phone, more and more mission mode tests need to be performed on the transceivers to make sure that all components of the radio are working together flawlessly. In RF SoC, nothing represents mission mode test better than error vector magnitude (EVM). An acceptable EVM measurement for a complex modulation format implies that a whole host of transmitter or receiver components are within specification.

This article is the second in a series appearing in *go/semi* over several months. The goal of these articles is to cover the fundamentals and challenges of different types of modulation, and show how these challenges are met by the V93000 and SmarTest. For earlier articles in the series, please visit www.verigy.com/go/gosemi.

Bluetooth EDR Demodulation on the V93000

Introduction

Although Bluetooth has been around for years and was thought to be mature in the automated test equipment (ATE) world, new test requirements have arisen. In 2005, Bluetooth EDR (Enhanced Data Rate) v2.0 was introduced, adding increased data throughput over first-generation Bluetooth (v1.0 and v1.2). Although it has kept the occupied bandwidth the same, this additional data rate has introduced many new test requirements that need to be explained and understood. This discussion takes the approach that the reader is somewhat familiar with traditional Bluetooth testing (v1.0 and v1.2) and the focus will be on the new high-volume manufacturing (HVM) test-related methodologies that impact the test list, with an emphasis on modulation-related parameters.

Bluetooth Modulation Formats

Bluetooth v1.0 and v1.2 used a GFSK[1] modulation format which allowed data to be transferred at up to 1 Megabit-per-second (Mbps). With Bluetooth EDR (v2.0), data transfer rates of up to 2 and 3 Mbps can be achieved. GFSK (FM) is still the default modulation type and it is still used in the EDR packet header, but the payload portions of the EDR packet will be one of two types of DPSK[2][3] modulation (either PI/4-DQPSK or 8DPSK). Bluetooth EDR is backwards compatible with Bluetooth 1.x. One obvious advantage of this new standard is a higher data transmission rate, but an additional advantage is lower device power consumption because of reduced duty cycle. Of course, this comes at the expense of additional required SNR at the receiver.

The physical channel in a Bluetooth signal is subdivided into time slots, and signal transmission uses time division duplexing (TDD) [1]. There is a master-slave relationship, with the master transmitting on even-numbered time slots and the slave transmitting on odd-numbered slots. The time slot length is a function of the frequency hop rate resulting in a nominal length of 625 us. Data is transmitted between the master and slaves in packets that are contained within the time slots. A packet may be transmitted using one, three, or five consecutive time slots (designated as DH1, DH3, or DH5, respectively) as coordinated by the master. The packet contains an access code, header, guard band, and payload as shown in Figure 1. The payload contains the data that is modulated onto the RF carrier using one of several different modulation schemes such as GFSK as specified in v1.0 and v1.2, and PI/4-DQPSK or 8DPSK introduced in v2.0+EDR.

---

[1] Gaussian Frequency-Shift Keying (GFSK) is a type of Frequency Shift Keying modulation that utilizes a Gaussian filter to smooth positive/negative frequency deviations, which represent a binary 1 or 0. It is used by DECT, Bluetooth and z-wave devices. For Bluetooth the minimum deviation is 115 kHz. *(Wikipedia)*

[2] Phase-shift keying (PSK) is a digital modulation scheme that conveys data by changing, or modulating, the phase of a reference signal (the carrier wave). Any digital modulation scheme uses a finite number of distinct signals to represent digital data. PSK uses a finite numberof phases, each assigned a unique pattern of binary bits. *(Wikipedia)*

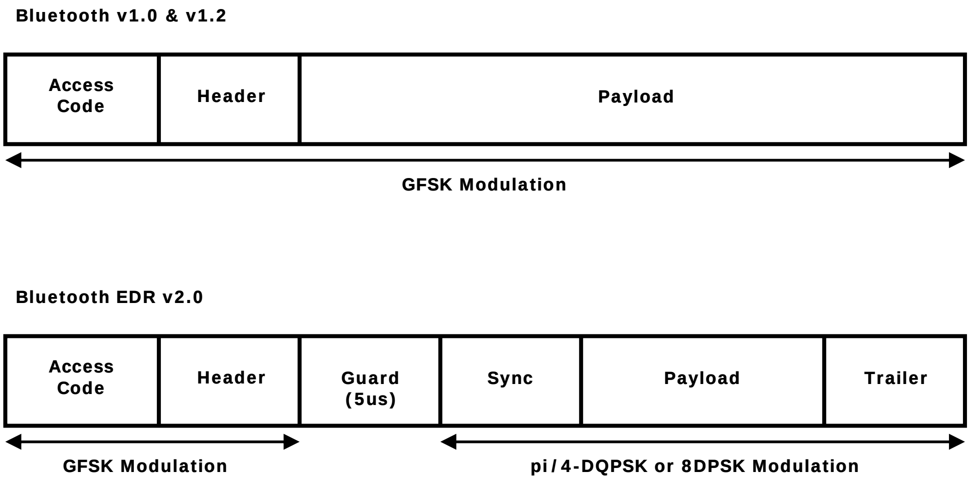

Figure 1. Bluetooth packets, a. v1.x and b. v2.x.

Specific Changes with Bluetooth EDR that Impact HVM Testing

There are a few key changes and additions to tested parameters that can possibly impact how Bluetooth EDR devices are tested in production. The Bluetooth Specification [2] refers to its tests as *test purposes*. The impacted test purposes are summarized in Table 1. Many of the tests as with Bluetooth v1.x are still performed, but in addition, the basic changes following may or may not need to be addressed in migrating a production Bluetooth test program from v1.x to v2.x.

Test Purpose	Description
TRM/CA/10/C	EDR Relative Transmit Power
TRM/CA/11/C	EDR Carrier Frequency Stability and Modulation Accuracy
TRM/CA/12/C	EDR Differential Phase Encoding
TRM/CA/13/C	EDR Inband Spurious Emissions
RCV/CA/07/C	EDR Sensitivity
RCV/CA/08/C	EDR BER Floor Performance
RCV/CA/09/C	EDR C/I Performance
RCV/CA/10/C	EDR Maximum Input Level

Table 1. Test Purposes introduced with Bluetooth EDR.

Adaptive Frequency Hopping

Although this was introduced in v1.2, it is worth mentioning in the context of discussing EDR testing. Adaptive Frequency Hopping (AFH) is a means to combat interference from the co-existence of WLAN radios among Bluetooth radios. AFH reduces the possible hop channels from a maximum of 79 down to a minimum of 20. Frequency hopping is a means to jump between any of the 79 available channels to avoid interference with other wireless devices operating in the same band. Since none of the Bluetooth EDR tests require frequency hopping (in fact, DEVM requires hopping to be turned off), often test plans call for a specific adaptive frequency hopping test.

20 dB Bandwidth

The 20 dB Bandwidth measurement is still performed, as it was with v1.x. However, because of the slight change in spectrum width that comes with the added capacity of the DPSK modulation format over that of GFSK, the specified test limits have been changed. In v1.x, the test limit for occupied bandwidth was set at 1MHz and with EDR it has been widened to 1.5MHz.

BER (Bit Error Rate)

The concept of measuring BER has not changed, but with EDR, in addition to measuring BER on just the GFSK-modulated signal packet payloads, BER must also be performed on EDR PI/4-DQPSK and 8DPSK modulated payloads. The impact on production testing with the added BER tests for EDR is that slightly more complicated modulated signals must be generated by the ATE AWGs (Arbitrary Waveform Generators).

Modulation Accuracy and DEVM

The Modulation Accuracy test requirement is perhaps the most complex new addition due to the test list. It consists of measuring the frequency accuracy within the packet header (GFSK) and the frequency drift within the DPSK modulated payload, and calculates various DEVM (Differential Error Vector Magnitude) results. This is a radically new test that needs to be analyzed and understood. The topic of DEVM is a major one and as such, has a dedicated description in the following section.

Modulation Accuracy and DEVM

Test purpose TRM/CA/11/3, as defined in the Bluetooth Specification [2] calls for the measurement of DEVM (Differential Error Vector Magnitude). At the current time, DEVM is only defined for Bluetooth EDR modulation formats. To describe what DEVM is, consider that a traditional EVM measurement represents the magnitude of the error between an ideal signal and the actual received signal. DEVM represents the magnitude of the error between two received signals spaced one symbol apart in time [2]. DEVM stems from the *differential* nature of the Bluetooth EDR modulation formats, PI/4-DQPSK and 8DPSK. Notice from Figure 2 that DEVM is calculated between symbols instead of relative to an ideal, fixed position symbol as with EVM.

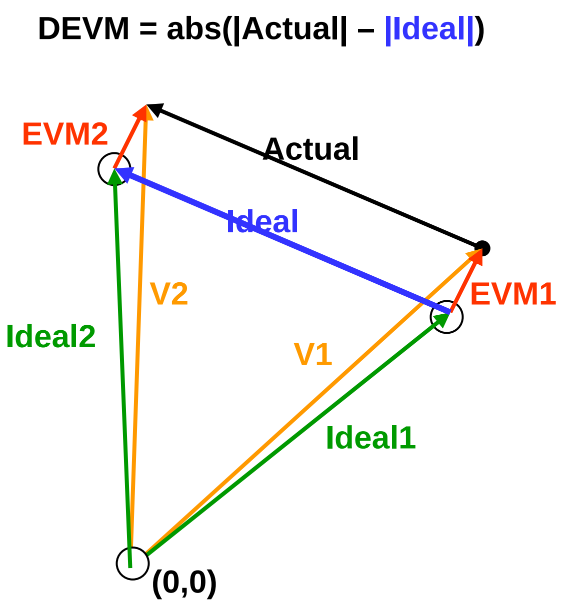

Figure 2. Differences between DEVM and EVM. Notice that DEVM is defined between two consecutive symbols in the constellation.

Both, EVM and DEVM can be measured on DPSK modulation formats, but since the EDR packets use *differential* PSK modulation, only DEVM measurements can provide the necessary information on signal quality as outlined in the Bluetooth Specification. If someone asks to measure EVM on a Bluetooth EDR device, discuss the differences between DEVM and EVM with them to make sure they fully understand that traditional EVM is not what is called for in the Bluetooth v2.0 Specification and Modulation Accuracy measurements.

There are three key DEVM-related tests that are performed at production as described in the following subsections. For each of these tests the payload is to be broken into 50 us blocks (50 symbol blocks). The Bluetooth standard requires the DEVM measurement to be made over a total of 200 non-overlapping blocks.

DEVM (rms)

DEVM (rms), defined as the square root of the normalized power of the error, is measured between symbols in each block. The Bluetooth Standard requires rms DEVM to be less than 13% for 8DPSK (3 Mbps rate) and less than 20% for p/4-DQPSK (2Mbps rate). Most residual DEVM values of ATE and bench equipment are significantly lower than this, so measurement is typically not a problem.

DEVM (peak)

DEVM is measured between symbols in each block. Searching through all of the data, the Bluetooth Standard requires peak DEVM to be less than 25% for 8DPSK (3 Mbps rate) and less than 35% for p/4-DQPSK (2 Mbps rate).

99% DEVM

DEVM is measured between symbols in each block. The Bluetooth Standard requires rms DEVM to be less than 20% for 99% of the symbols in the payload for 8DPSK (3 Mbps rate) and less than 30% for 99% of the symbols in the payload for p/4-DQPSK (2 Mbps rate).

Bluetooth Demodulation on the V93000

The V93000 has built-in digital demodulation capability that is used when measuring DEVM on Bluetooth signals. This digital demodulation takes I/Q symbol data of the measured Bluetooth waveform together with the reference data and calculates the rms DEVM and peak DEVM result for each 50-symbol block and a 99% DEVM result for the whole waveform. Figure 3 shows the block diagram of how this engine is used to calculate the Bluetooth EDR parameters.

The peak, rms, and 99% DEVM values are directly returned from the V93000 demodulation algorithm without the user having to perform the calculations. However, the user can also acquire the necessary arrays to perform the measurement directly if so desired. Also, intermediate standard digital demodulation results, such as traditional EVM and frequency accuracy, can be obtained.

Additionally, the V93000 RF and baseband AWGs have the ability to read Agilent Technologies Signal Studio encrypted waveform files. This allows the user to use the same original waveform files that are used with many bench measurement setups.

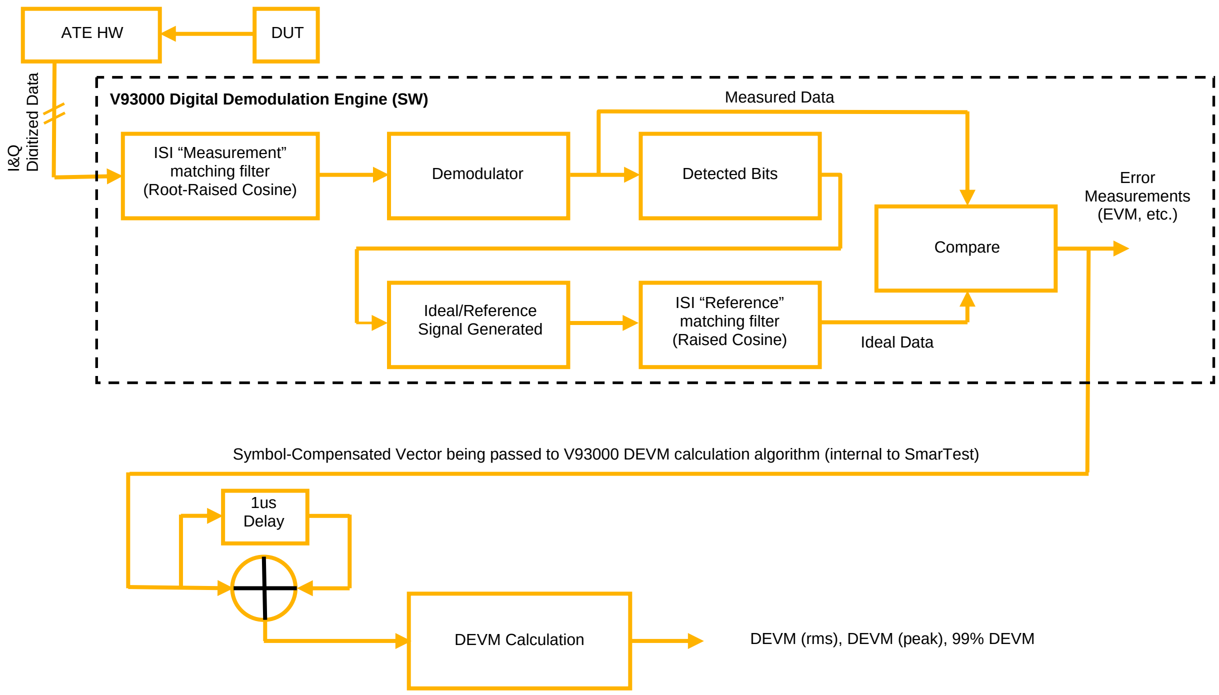

Figure 3. Block diagram showing how digital demodulation of the Bluetooth EDR signal is performed in the V93000. Notice that intermediate results can be obtained between the first stage in the core demodulation engine and the differential calculations.

Within the demodulation algorithm, there are numerous parameters that can be set and numerous results that can be had, including, of course, the DEVM-related test results. Tables 2 and 3 show only a small portion of the common input parameter and output results used with the V93000 demodulation. Although the parameters in Tables 2 and 3 are likely all that will typically be used, there exists an exhaustive list, which provides full flexibility, synonymous with Agilent Technology’s benchtop 89600 family of Vector Signal Analyzers and its software that is shared across many of Agilent’s instruments and design software.

Figure 4 displays the V93000 debugging capability, providing a 8DPSK constellation. Although this is not used during production testing, it is invaluable in test program development and pre-production correlation.

Input Parameter	Description	Value for PI/4=DQPSK	Value for 8DPSK
Alpha	Filter constant (rolloff)	0-1 (typically 0.4 or 0.5)	0-1 (typically 0.4 or 0.5)
Measurement Filter Type	This filter should be selected to match the filter used when transmitting the data (or to simulate the intended receiver)	Root Raised Cosine	Root Raised Cosine
Reference Filter Type	This filter is typically the squared product of the measurement filter and it should match the product of the transmitter and receiver filters	Raised Cosine	Raised Cosine
Symbol Rate (Hz)	Symbol rate of the input signal	1 MHz	1 MHz
Sample Frequency (Hz)	Sample rate of the input signal (sample rate the ATE captured the data with)	Various (depending upon ATE measurement setup)	Various (depending upon ATE measurement setup)
Modulation Format	EDR modulation format	PI/4-DQPSK	D8PSK
Code Word Length	Number of bits represented by each symbol in the constellation	2	3
Result Length in Symbols	Desired result length specified in numbers of symbols (50 for EDR)	50	50

Table 2. Common input parameters used with the V93000 Bluetooth EDR demodulation library.

Output Result	Description
DEVM (rms)	Square root of the normalized power of the error over a block of 50 symbols (50 us block)
DEVM (peak)	Highest DEVM value obtained across all symbols in the block evaluated
99% DEVM	The DEVM value (in percent) within which 99% of all symbols in the 50 symbol block lie
Frequency Deviation	Peak frequency deviation from the carrier for GFSK modulation
Symbol-Compensated Measured Vector	Compensated measured signal containing ("Result Length in Symbols" x "Samples per Symbol") complex IQ pairs. The user can take this returned vector and apply their own DEVM algorithm if so desired.

Table 3. Common output results obtained from the V93000 Bluetooth EDR demodulation library.

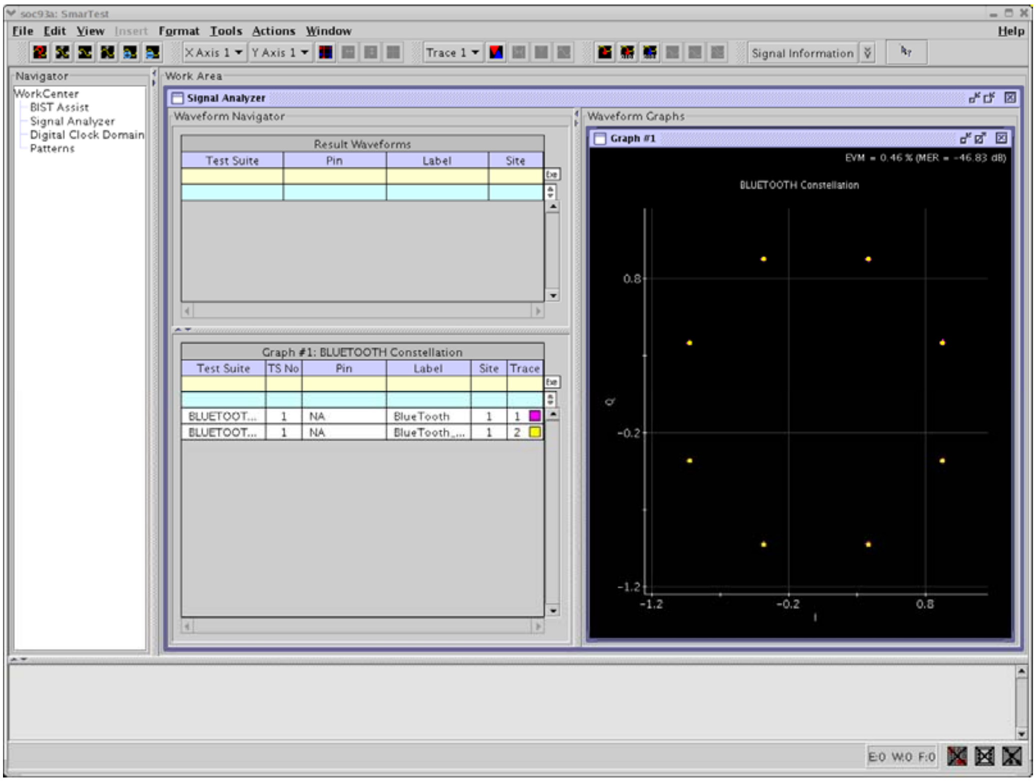

Figure 4. DEVM constellation for an EDR 8DPSK-modulated payload measured with the V93000 Bluetooth EDR demodulation library.

References

[1] Agilent Application Note, "Bluetooth Enhanced Data Rate (EDR): The Wireless Evolution," Part Number 5989-4204EN (2006).
[2] Bluetooth Special Interest Group, "Bluetooth Specification, Version 2.0 + EDR [vol 3]," November 2004.