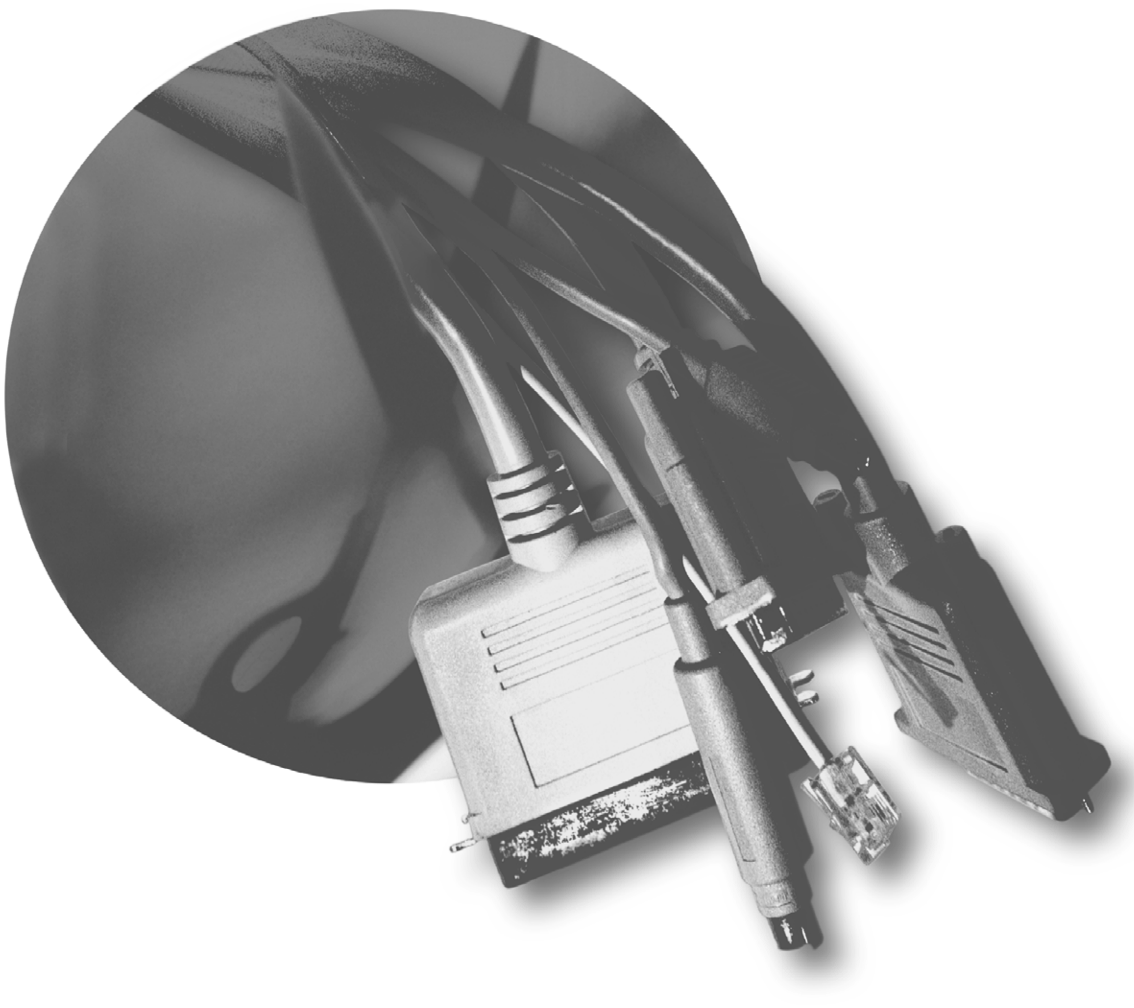
Agilent
Performing Bluetooth™ RF Measurements Today

Application Note 1333



Agilent Technologies

Introduction

Bluetooth™ wireless technology is an open specification for a wireless personal area network. It provides limited range RF connectivity for voice and data transmissions between information appliances. *Bluetooth* wireless technology eliminates the need for interconnecting cables and enables ad hoc networking among devices.

Named after a tenth-century Danish King, *Bluetooth* invokes images of Viking conquests and plundering; notwithstanding this, the good King Harald Blatand is credited with uniting Denmark and Norway during his reign. Similarly today, *Bluetooth* unites technologies.

Bluetooth wireless technology will allow seamless interconnectivity among devices. Computers and personal digital assistants (PDAs) will share files and synchronize databases remotely; laptop PCs will access e-mail by linking to nearby cellular phones; and wireless headsets will permeate the cellular phone market to simplify hands-free operation. Applications for this technology are already underway in many R&D labs around the world. The technology's potential is limitless when one considers the growing sector of information appliances that would benefit from wireless connectivity.

This application note describes transmitter and receiver measurements to test and verify today's *Bluetooth* RF designs. Since the *Bluetooth* wireless technology is in its early development stages, test methodologies will differ from those typically seen in mature technologies. Test procedures will range from manual intervention or custom software control, to easy-to-use, one-button measurements. A list of Agilent Technologies solutions for *Bluetooth* measurements is provided in Appendix A. This application note assumes a basic understanding of RF measurements. To learn more about basic RF measurements, refer to Appendix B, "Recommended Reading," at the end of this application note.

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1. Basic concepts of Bluetooth

Bluetooth, in its most elementary form, is defined as a global specification for wireless connectivity. Because it is intended to replace cables, cost must be low and operation must be intuitive and robust. These requirements for *Bluetooth* create many challenges. *Bluetooth* meets these challenges by several means. The radio unit employs Frequency Hopping Spread Spectrum (FHSS), and the design emphasis is on very low power, extremely low cost, and robust operation in the uncoordinated, interference-dominated RF environment of the Industrial, Scientific, and Medical (ISM) radio band.

A wide variety of *Bluetooth* radio block diagrams are in use. For transmission, these range from direct VCO modulation to IQ mixing at the final RF. In the receiver, a conventional frequency discriminator or IQ down-conversion combined with analog-to-digital conversion has been noted. While many options can satisfy the *Bluetooth* radio specifications, each will have its own characteristics if not operating correctly.

The *Bluetooth* system consists of a radio unit, a baseband link control unit, and link management software. It also includes higher-level software utilities that focus on interoperability features and functionality. Figure 1 is a block diagram for this type of frequency hopping system, showing the baseband controller and the RF transmitter and receiver sections.

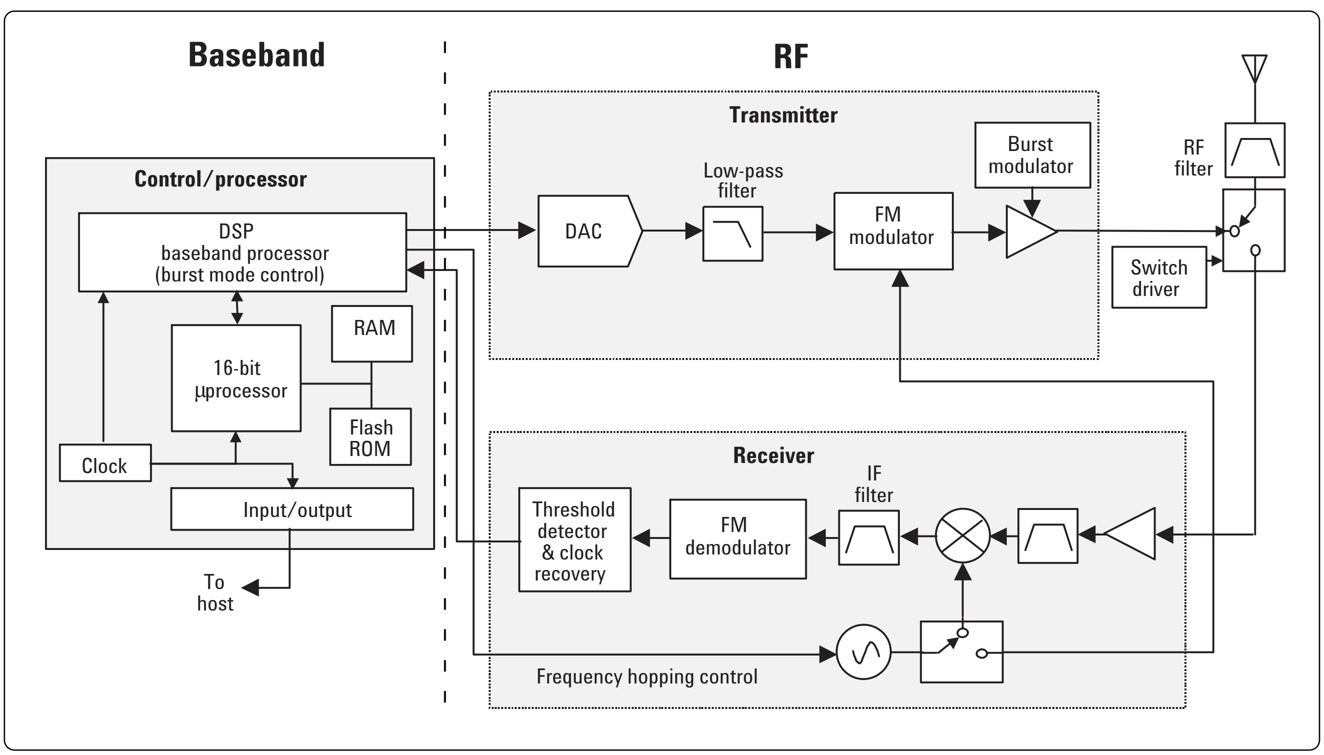

Figure 1. Block diagram of a Bluetooth system

1.1 Bluetooth radio unit

The *Bluetooth* radio unit is shown in figure 1 as the transmitter and receiver sections of the block diagram. The transmitter upconverts the baseband information to the frequency-modulated carrier. Frequency hopping and bursting are performed at this level. Conversely, the receiver downconverts and demodulates the RF signal. Table 1 summarizes some of the key RF characteristics of *Bluetooth*.

The *Bluetooth* channels are each 1 MHz wide. The frequency hopping occurs over the 79 channels. Figure 2 depicts the frequency hopping channels, divided by geographic regions.

Table 1. Key Bluetooth RF characteristics

Characteristic	Specification	Notes
Carrier frequency	2400 to 2483.5 MHz (ISM radio band)	f = 2402 + k MHz, k = 0, 1, 2...,78
Modulation	0.5 BT Gaussian-filtered 2FSK at 1 Msymbol/s Modulation index: 0.28 to 0.35 (0.32 nominal)	Digital FM scheme The peak frequency deviation allowed is 175 kHz
Hopping	1600 hops/s (in normal operation)[1] 1 MHz channel spacing The system has five different hopping sequences: 1) Page hopping sequence 2) Page response sequence 3) Inquiry sequence 4) Inquiry response sequence 5) Channel hopping sequence The first four are restricted hopping sequences used during connection setup. The normal channel hopping sequence is pseudorandom based on the master clock value and device address.	The channel hopping sequence is designed to visit each frequency regularly and with roughly equal probability. It has a periodicity of 23 hours and 18 minutes.
Transmit power	Power Class 1: 1 mW (0 dBm) to 100 mW (+20 dBm) Power Class 2: 0.25 mW (–6 dBm) to 2.5 mW (+4 dBm) Power Class 3: 1 mW (0 dBm)	Class 1 power control: +4 to +20 dBm (required) –30 to 0 dBm (optional) Class 2 power control: –30 to 0 dBm (optional) Class 3 power control: –30 to 0 dBm (optional)
Operating range	10 cm to 10 m (100 m with Power Class 1)	
Maximum data throughput	The asynchronous channel can support an asymmetric link of maximally 721 kbps in either direction while permitting 57.6 kb/s in the return direction, or a 432.6 kbps symmetric link.	Data throughput is lower than the 1 Msymbol/s rate as a result of the overhead, which is inherent in the protocol.

1. Hop speed may vary depending on packet length.

The modulation in a *Bluetooth* system is 2-level frequency shift keying (2FSK). This is a digital modulation format in which the modulated carrier shifts between two frequencies representing a “1” and a “0”. As a result, 2FSK provides one bit of data per symbol. Figure 3 is an example of 2FSK modulation illustrating the two discrete frequencies. Unlike many other forms of digital modulation—such as GSM—amplitude and phase are not of primary concern in this type of modulation scheme.

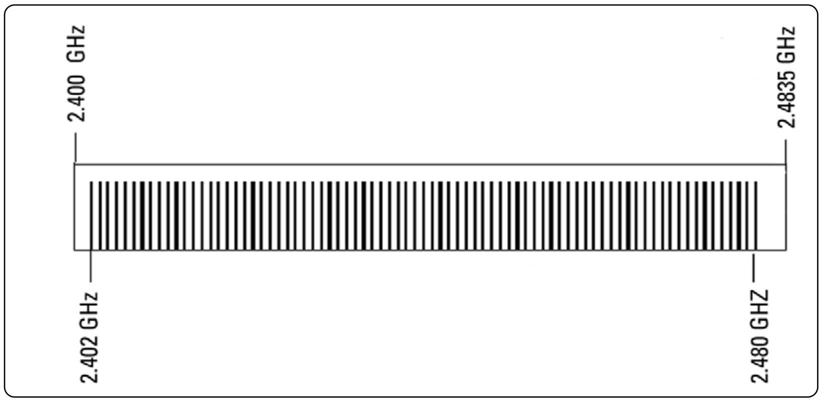

Figure 2. ***Bluetooth*** **frequency channels**

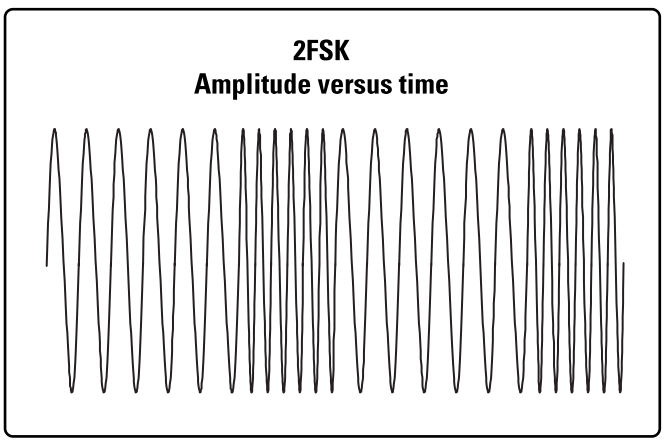

Figure 3. 2FSK modulation

1.2 Bluetooth link control unit and link management

The *Bluetooth* link control unit, also known as the link controller, determines the state of the device and is responsible for establishing the network connections as well as power efficiency, error correction, and encryption.

The link management software works with the link control unit. Devices communicate among each other through the link manager. Table 2 provides a summary of the link control and management functions. More detail follows the table.

Table 2. Summary of link control and management functions

Function	Description	Notes
Network connections	The master's link controller initiates the connection procedure and sets the power saving mode of the slave.	
Link types	Two link types: • Synchronous Connection Oriented (SCO) type, primarily for voice • Asynchronous Connectionless (ACL) type, primarily for packet data	*Bluetooth* can support an asynchronous data channel, up to three simultaneous synchronous voice channels, or a channel that simultaneously supports asynchronous data and synchronous voice. Time-Division Duplexing for full duplex operation.
Packet types	NULL, POLL, FHS—System packets DM1, DM3, DM5—Medium rate, error-protected data packets DH1, DH3, DH5—High rate, non-protected data packets HV1, HV2, HV3—Digitized audio, 3 levels of error protection DV—Mixed data and voice AUX1—For other uses	The 1, 3 and 5 suffixes indicate the number of time slots occupied by the data burst. Nominal burst lengths: DH1–366 µs DH3–1622 µs DH5–2870 µs
Error correction	Three error correction schemes: • 1/3 rate forward error correction (FEC) code • 2/3 rate FEC code • Automatic repeat request (ARQ) scheme for data	Error correction is provided by the Link Manager
Authentication	Challenge-response algorithm. Authentication may be unused, unidirectional, or bi-directional.	Authentication is provided by the Link Manager
Encryption	Stream cipher with secret key lengths of 0, 40, or 64 bits.	
Test modes	Provides the ability to place the device into test loopback mode and allows control of test parameters such as frequency settings, power control, and packet type.	

Bluetooth radios may operate as either master or slave units. The link manager sets up the connection between master and slave units and also determines the slave's power saving mode. A master can be actively communicating with up to seven slaves, while another 200+ slaves can be registered in a noncommunicating, power-saving mode. This area of control is defined as a *piconet*. A master in one piconet may be a slave to a master from a different piconet. Similarly, multiple masters from different piconets may control a single slave. This network of piconets is referred to as a *scatternet.* Figure 4 depicts two piconets comprising a scatternet. Units that are not part of either piconet remain in standby mode.

The *Bluetooth* band is divided into time slots, where each slot corresponds to an RF hop frequency. In the time division duplex (TDD) scheme used, the master transmits in even-numbered time slots, and the slave in odd-numbered time slots. Voice bits or data bits within piconets are transmitted in packets. Packets transmitted by the master or the slave may extend over one, three, or five time slots. A packet, shown in figure 5, contains an access code, a header, and payload. The access code consists of a preamble, a sync word, and an optional trailer. The header contains piconet address and packet information. The payload carries the user's voice or data information. Refer to the *Specification of the Bluetooth System* [2] for further details on packet construction.

The link manager needs to support the *Bluetooth* test modes. These test modes should provide key capabilities for testing *Bluetooth* devices. These include the ability to place the device into test loopback mode and the ability to define transmit and receive frequencies, power control, and other key parameters.

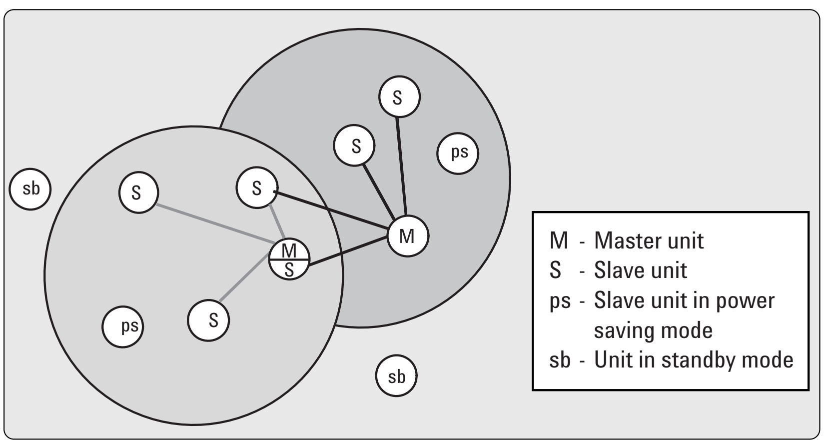

Figure 4. Network topology

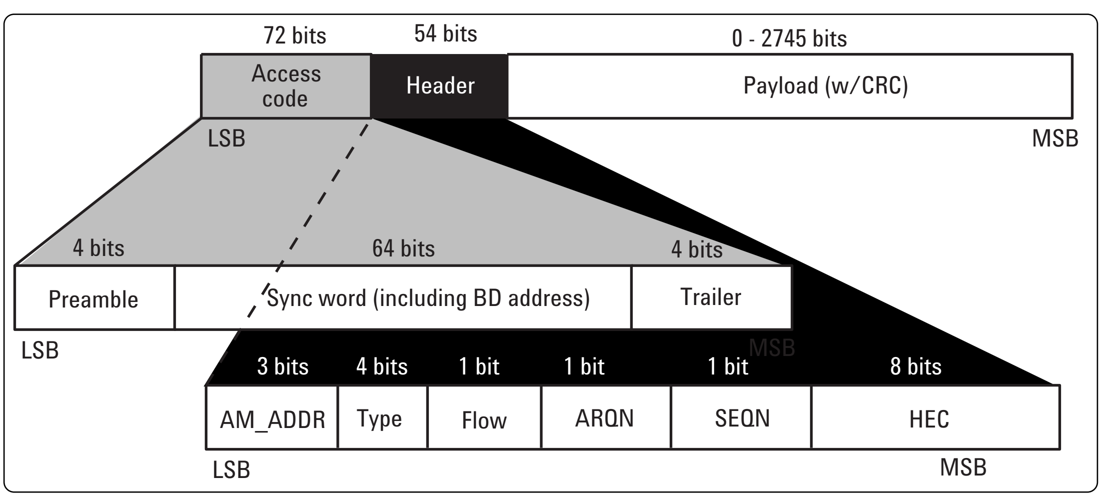

Figure 5. Bluetooth general packet format

2. Transmitter measurements

This chapter provides a framework for the *Bluetooth* transmitter tests and test methodology. It describes the measurements that can be made today on *Bluetooth* components and systems. Examples and supporting information are provided. The *Bluetooth RF Test Specification* [1], which describes the test requirements for certification of the *Bluetooth* RF layer, is the definitive guide.[1]

Figure 6 illustrates an example of a transmitter measurement setup. For transmitter tests, the *Bluetooth* device under test may be placed in loopback. As a slave device it will need to generate its burst timing by receiving poll packets from the signal generator. This allows a signal from the digital signal generator to be transmitted into the device's receiver and looped back through its transmitter for analysis. The *Bluetooth* device's test mode is controlled either by protocol sent over a RF connection or by direct digital control of the device; either method requires a type of *Bluetooth* test mode control. Note that cable losses and mismatches in the frequency band used by the *Bluetooth* system can have severe effects on the signal levels within a test system. It is important to use components whose performance is known to be adequate.

If a direct cable connection is not possible between the *Bluetooth* device and the measurement equipment, a suitable coupling device such as an antenna will be necessary. The path loss between the antenna should be accounted for in the calculations. This can be evaluated using normal swept-frequency testing.

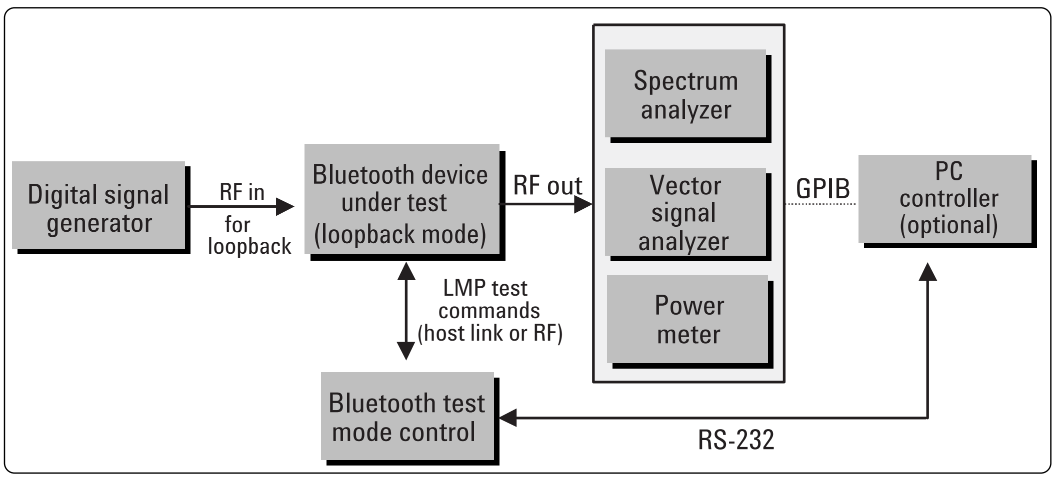

Figure 6. Transmitter measurement setup

1. At the time of writing, RF test requirements for *Bluetooth* are still being defined. Refer to the latest *Bluetooth* RF Test Specification [1] for the most current test requirements.

Table 3 provides a summary of the test parameters required for the transmitter tests.

Because the *Bluetooth* signal is a sequence of TDD bursts, it is necessary to trigger properly. Triggering is on the rising edge of the envelope to obtain a viewable signal.

The frequency hopping of the *Bluetooth* system adds a further degree of complexity to signal analysis. Hopping is needed for testing the functional capability of the *Bluetooth* device, whereas for parametric tests, hopping isn't essential. To reduce the number of variables and identify individual performance characteristics, hopping is turned off for a number of tests. However, the transmit and receive channels can be set at the extreme ends of the band, forcing the voltage-controlled oscillator (VCO) in the device under test to switch frequency. Each method is tailored to the requirements of the test and is documented in the *Bluetooth RF Test Specification* [1].

Three different types of payload data are called for in different test cases. They are PRBS9, 10101010, and 11110000. Each pattern provides different stress mechanisms and is selectively chosen for each measurement. PRBS9 is a pseudorandom bit sequence of period 2^9-1 that is intended to simulate live traffic and so produces a modulated signal with a spectral distribution approximating that of a real signal. The 10101010 pattern provides an additional test for the modulation filter.
It also changes the spectral shape of the transmitter output. The 11110000 pattern allows a check of the Gaussian filtering. After a series of four 1s or four 0s, the output should have reached its fully settled condition. The use of different patterns also helps identify problems with IQ modulation schemes. Note, an ideal Gaussian filter will produce a ratio of 88 percent between the peak frequency deviation of a 10101010 signal and that of the 11110000 signal. The *Bluetooth* radio specification calls for >80 percent to be achieved.

Table 3. Transmitter test parameters

Transmitter test	Frequency hopping	Test mode	Packet type	Payload data	Measurement bandwidths
Tx output spectrum Frequency range	Off	Loopback[1]	DH1	PRBS 9	100 kHz RBW 300 kHz VBW
Tx ouput spectrum –20 dB bandwidth	Off	Loopback[1]	DH1	PRBS 9	10 kHz RBW 30 kHz VBW
Tx output spectrum adjacent channel power	Off	Loopback[1]	DH1	PRBS 9	100 kHz RBW 300 kHz VBW
Modulation characteristics					≥3 MHz

1. If loopback is not initially available, use of a method utilizing a special mode, called Tx Mode, is allowed.

Throughout this transmission measurement section, reference is made to two types of signal analyzers, vector signal analyzers and swept-tuned spectrum analyzers. Vector signal analyzers differ from spectrum analyzers in that they capture both the magnitude and phase of the input signal, allowing them to make a wide selection of measurements in the time, frequency, and modulation domains. In addition, some spectrum analyzers, such as the Agilent ESA-E series, have FM demodulation and DSP capability. This allows these analyzers to perform many of the tests traditionally associated with vector signal analyzers. For many of the *Bluetooth* tests, either type of instrument is capable of performing the measurements; in some cases, one is faster or simpler than the other. Selection of the appropriate instrument will vary depending upon the needs of the user and the status of the product design. Refer to Appendix A for a matrix identifying which type of equipment can be used for each test.

2.1 Power tests

RF transmitter power measurements include average power in a burst, peak power, power density, and power control. Power level is a critical parameter in digital communication systems. These tests help to ensure that power levels are high enough to maintain links, yet low enough to minimize interference within the ISM band and to maximize battery life.

2.1.1 Output power

Output power measurements are performed in the time domain. Figure 7 illustrates power and timing characteristics of a signal burst in the time domain.

Average power is measured over at least 20 percent to 80 percent of the duration of the burst. The duration of the burst (burst width) is the time between the leading and trailing 3 dB points compared to the average power. The average power measurement is performed with a signal analyzer. A signal analyzer allows the signal to be directly analyzed in the time domain. In addition to measuring average power, signal analyzers allow the user to view other meaningful data such as transients. Using a swept-tuned spectrum analyzer, view the envelope of the signal in the time domain by setting the span to zero. External triggering can be used to capture the burst mode signal. The number of periods displayed is controlled by the sweep time. Using peak detector mode, set the trace to max hold and measure the peak power level using peak search. The average power of the burst is also determined by analyzing the trace data. The test is repeated for all frequency channels. Figure 8a shows a display of an average and peak power measurement on a swept-tuned spectrum analyzer.

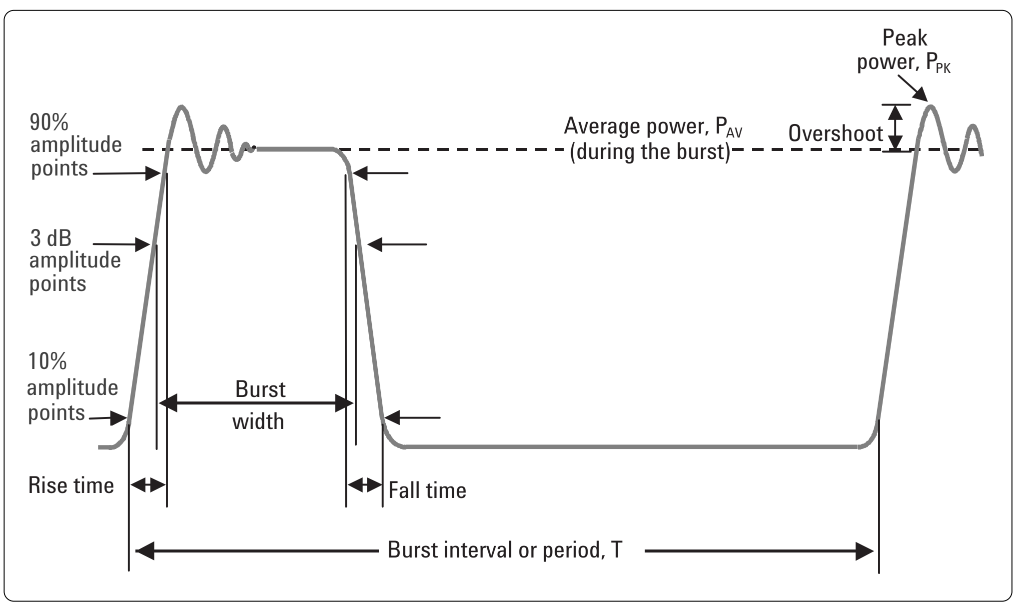

Figure 7. Time-domain power and timing analysis

Average power and peak power are similarly measured with a vector signal analyzer. Vector signal analyzers provide a triggering delay feature to allow viewing of the burst prior to the trigger point. Vector signal analyzers also provide an average or mean power function to automatically determine the average power. Figure 8b shows a display of the average power measurement on a vector signal analyzer. The sweep time and the trigger delay are adjusted to measure the average power of the burst, while avoiding the rising and falling edges.

The results are to be expressed in EIRP (Equivalent Isotropically Radiated Power). Since EIRP is a measure of the radiated power of the system, this measurement includes the effects of the transmitter, cable loss, and antenna gain. When doing tests that use direct port-to-port connections, the gain of the antenna must be added to all measurements to assure that the overall system will not exceed the power output specifications. The plot in figure 8b shows a flat response during the main part of the burst. Incorrectly calibrated IQ modulation may cause ripple to appear.

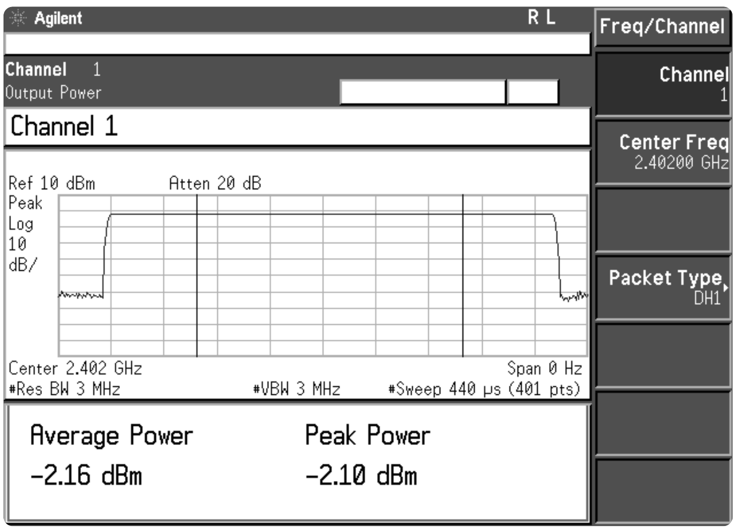

Figure 8a. Agilent ESA-E series spectrum analyzer display of peak and average power measurement using the Bluetooth personality (CF = 2.402 GHz, 1 dB/div, sweep time 380 μms, triggering on IF ch 1, delay = 1 μs)

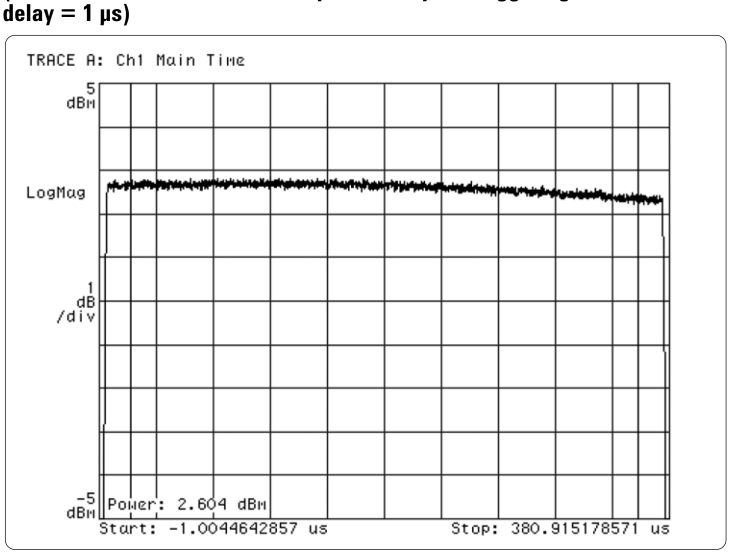

Figure 8b. Agilent 89441A display of average and peak power measurement (CF = 2.402 GHz, 1 dB/div, sweep time 380 μs, triggering on IF ch 1, delay = 1 μs)

2.1.2 Power density

The power density measurement provides the peak power density in a 100 kHz bandwidth. The measurement starts with the signal analyzer in the frequency domain, a center frequency in the middle of the *Bluetooth* frequency band, and a span that is wide enough to view the complete band. The resolution bandwidth is set to 100 kHz. A 1-minute single sweep is performed with the trace in Max Hold. The peak value of the trace can be found using peak detection. This frequency becomes the analyzer's new center frequency. Figure 9a[1] illustrates this portion of the measurement, in which the flatness error in the signal can be readily identified.

For the second part of the measurement, the analyzer is changed to the time domain and a 1-minute single sweep is performed. Refer to figure 9b. The power density is calculated as the average of the trace. This calculation may be performed on a spectrum analyzer by analyzing the trace data and averaging the result. A vector signal analyzer has a utility for determining the mean power of the trace.

2.1.3 Power control

Power control tests allow for testing or calibration to be performed on the level control circuitry. The power control test is only needed for devices that support power control. Power control is performed in the same manner as the average power measurement, but at three discrete frequency channels. The power control test verifies power levels and power control step sizes to ensure that they are within the specified range.

Points to note relating to power control are that all *Bluetooth* modules need to have a properly functioning RSSI detector, and that the signaling uses an incremental, not absolute, command.

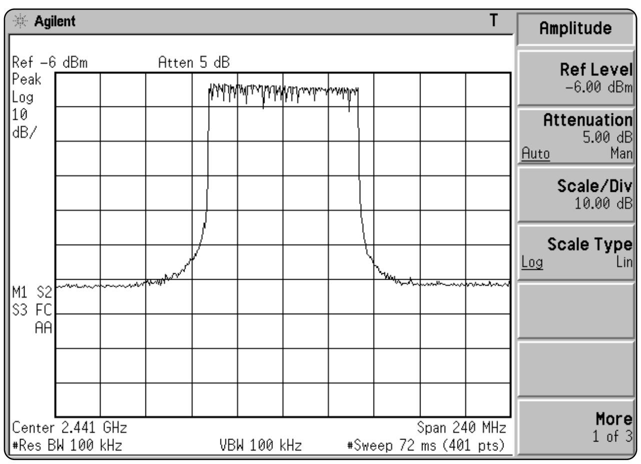

Figure 9a. Agilent ESA-E display of power density measurement (CF = 2.441 MHz, span = 240 MHz, RBW = 100 kHz, VBW = 100 kHz, peak detector, trigger free run, trace on Max Hold, sweep time = 72 ms, continuous sweep)

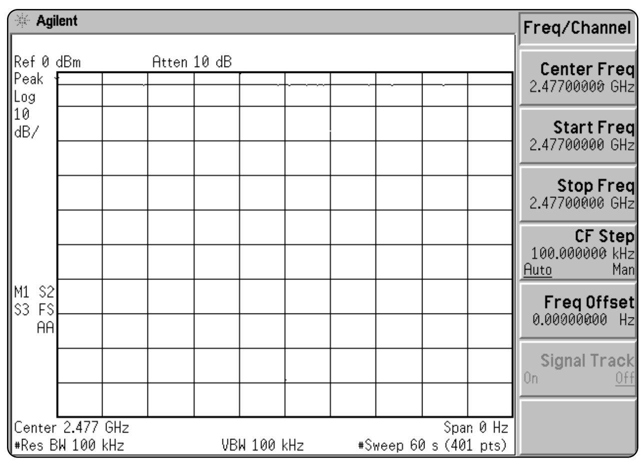

Figure 9b. Agilent ESA-E display of power density measurement (CF = 2.477 MHz, span = 0 Hz, RBW = 100 kHz, VBW = 100 kHz, peak detector, trigger free run, trace on Max Hold, sweep time = 72 ms, continuous sweep)

1. A variation on the specified procedure is shown here for use when fast frequency hopping is not available. Rather than a one-minute single sweep, the spectrum analyzer takes advantage of Max Hold and uses fast sweeps to capture the signal on a slow hopping frequency (hop rate >> sweep time).

2.2 Transmit output spectrum

The transmit output spectrum measurements analyze the power levels in the frequency domain to ensure that out-of-channel emissions are minimized. This helps reduce overall system interference and ensure regulatory compliance. The measurements compare the device's output power spectrum to a predefined mask that has the characteristics shown in table 4.

Table 4. Outline spectrum mask requirements

Frequency offset	Transmit power
M ± [550 – 1450 kHz]	–20 dBc
| M – N| = 2	–20 dBm
| M – N| ≥ 3	–40 dBm

NOTE: M is the integer channel number of the transmitting channel and N is the integer channel number of the adjacent channel that is being measured.

As summarized in table 3, the *Bluetooth* specification splits the test into three parts:

1. frequency range
2. –20 dB bandwidth
3. adjacent channel power

The first two use peak detection; adjacent channel power uses average detection. All three use Max Hold.

For the frequency range test, the carrier is set to the upper and lower channels. Having sampled long enough to capture the highest RF levels, a power density check is made. The signal must be below –80 dbm/Hz EIRP at 2400 MHz and 2483.5 MHz.

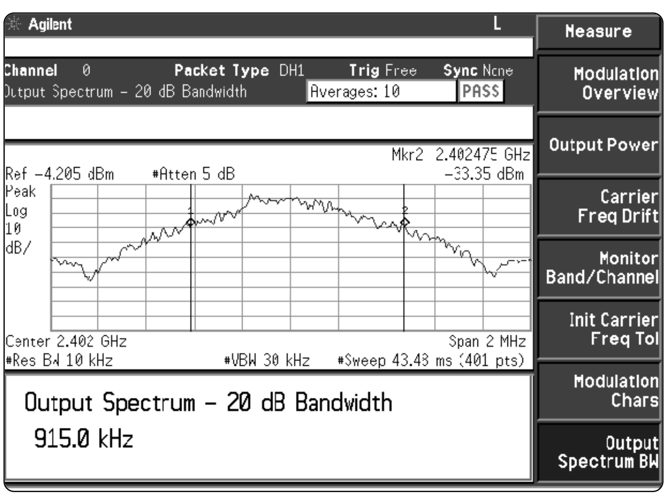

Figure 10a. –20 dB output spectrum bandwidth measurement using Agilent ESA-E with the measurement personality for Bluetooth wireless technology (CF = 2.402 GHz, span = 2 MHz, RBW = 10 kHz, VBW = 30 kHz, sweep time 43.48 ms (4001 pt), markers automatically set to –20 dB points by measurement personality)

Using narrower measurement filters, the –20 dB bandwidth test is performed at the lowest, middle, and highest frequency channels. Using a 2 MHz span, the peak RF level is recorded. The frequency points above and below this, where the level has dropped by 20 dB, must be less than 1 MHz apart. Figure 10a shows the type of waveform that will be observed. When viewing the output spectrum, some asymmetry on the spectral display may be noticed. This is due to the non-whitened parts of the burst, such as the header.

The adjacent channel power test is the most complex of the three measurements. Test transmissions are made on the middle channel, and 3 MHz inside the upper and lower band limits, for example, channels 3 and 75. Starting with RF channel 0, ten level measurements are made at offsets from the carrier of –450 kHz to +450 kHz, see figure 10b. The results are summed. The measurement channel is incremented by 1 MHz and the process repeated until the top of the band is reached. The limits in table 4 are then applied to check for compliance.

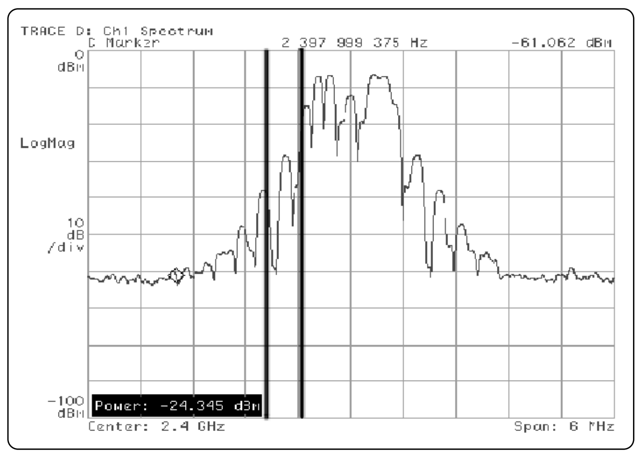

Figure 10b. Adjacent channel power measurement using Agilent 89441. (CF = 2.4 GHz, span = 6 MHz, trigger = IF, band power markers checking 550-950 kHz offset power)

2.3 Modulation tests

Bluetooth modulation measurements consist of modulation characteristics, initial carrier frequency tolerance, and carrier frequency drift. Modulation measurements reflect the performance of the modulator circuitry as well as the stability of the local oscillator. Both the modulator and the VCO may be affected by digital noise on the power supply or by the transmit power bursts. Care is needed in the radio design to avoid frequency pulling by the power supply. Verification of modulation characteristics requires the ability to demodulate the *Bluetooth* signal so that the frequency of each bit can be determined.

2.3.1 Modulation characteristics

The modulation characteristics test is a frequency deviation measurement. For modulation characteristics, two sets of a repeating 8-bit sequence are used in the payload. These are 00001111 and 01010101. The combination of the two sequences checks both the modulator performance and the premodulation filtering.

If a vector signal analyzer is used to demodulate the signal, phase and symbol information are maintained. The frequencies of certain bits in the 8-bit sequence are measured and averaged together. Then, the maximum deviation from the average for these bits is recorded. Finally, an average of the maximum deviations is computed. Both the maximum deviations and the average of the maximum deviations are used in the result. This procedure is performed for the 00001111 payload sequence over a period of at least 10 packets.

This process is then repeated with the 01010101 payload sequence. Because of the numerous data points, this test lends itself to software control. For this reason when the *Bluetooth* measurement personality for the ESA-E spectrum analyzer is used, this measurement can be performed in a few keystrokes. Presented with a 10101010 [F_2] payload, both the maximum deviation $\Delta F_{2\ max}$ and the average of the maximum deviations $\Delta F_{2\ avg}$ are displayed on the screen. The result can then be stored and a burst with the 11110000 pattern presented to the analyzer. The measurement process is then repeated with the 11110000 [F_1] payload sequence. $\Delta F_{1\ max}$ and $\Delta F_{2\ avg}$ are computed and displayed. Then the ratio $\Delta F_{2\ max}/\Delta F_{1\ max}$ is generated using the stored $\Delta F_{2\ max}$. It is also displayed with values below 80 percent flagged as fail.

An example of a demodulated burst is shown in figure 11. The analyzer is measuring the 11110000 pattern and comparing it with the (previously stored) 10101010 pattern.

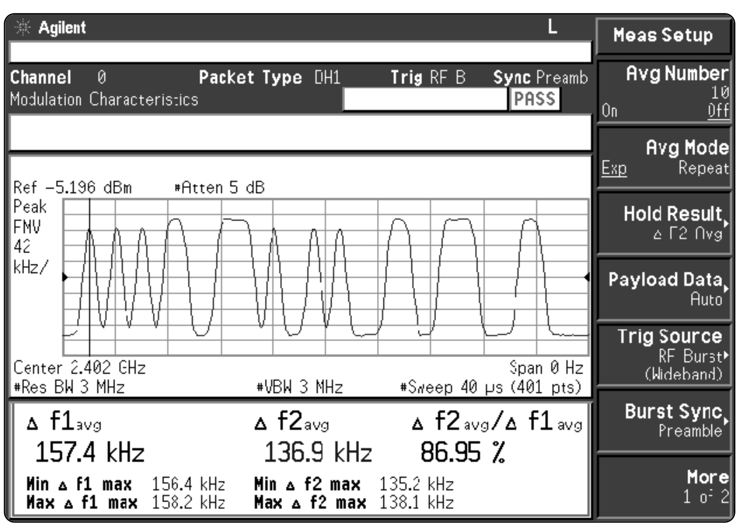

Figure 11. Agilent ESA-E series spectrum analyzer display showing the modulation characteristic measurement (First 16 bits of burst displayed, 100 ns sample rate, analyzer triggering on p0 bit)

2.3.2 Modulation quality

Vector signal analyzers have the ability to provide comprehensive modulation quality measurements, which can detect, quantify, and help track down the sources of signal problems such as intermodulation due to transmitter interference, power supply noise modulation, and power and stability at antenna mismatch. Although not directly a part of the *Bluetooth RF Test Specification* [1], modulation quality measurements such as FSK error, magnitude error, and the eye diagram are valuable troubleshooting tools. Figure 12 provides a four-display view of a demodulation measurement on a *Bluetooth* signal with frequency drift impairment. The frequency drift is easily seen in the lower left display.

2.3.3 Initial carrier frequency tolerance

The initial carrier frequency tolerance test verifies the accuracy of the transmitter's carrier frequency. A standard DH1 packet with a preamble and with a pseudorandom bit sequence (PRBS) as payload is used. The initial 4 bits of a packet, the preamble bits, are analyzed to determine the extent of the frequency deviation from center frequency. This measurement requires the signal to be demodulated to measure the frequency deviation of each symbol. After demodulation, the frequency offset of each of the preamble bits is measured and averaged. When performing this measurement, make sure that the frequency span of the signal analyzer is wide enough to provide proper demodulation of the wide-bandwidth *Bluetooth* signal.

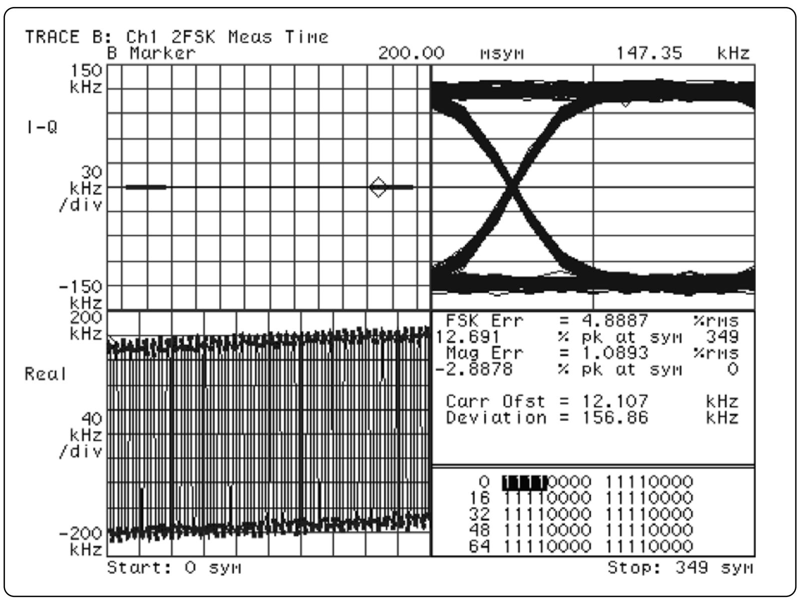

Figure 12. Agilent 89441A display of demodulation quality test

Figure 13 shows an example of the measurement in which the first 8 bits are displayed; the first 4 of these bits comprise the "1010" preamble. Frequency hopping is off. The test specification requires this measurement to be performed both with hopping on and with hopping off. In either case, the signal analyzer will be set to one frequency channel; however, when hopping is on, there will be the additional effect of slew as the transmitter quickly jumps from one frequency to the next. The slew may be noticed in the initial carrier frequency offset as the carrier frequency settles. The additional stress from hopping will help identify amplifier response problems.

An alternative method of measuring the initial carrier frequency tolerance is available with the Agilent 89441A vector signal analyzer in demodulation mode. With its result length set to the minimum number of symbols (10), this analyzer provides the carrier offset at a glance in its symbol error display. Since this minimum number of symbols is greater than four, the user may notice less variation on the result due to noise. It is important that the 0101 pattern is continued. The carrier offset result, which is provided in the summary table of the display shown in figure 12, provides an example of this initial carrier offset measurement.

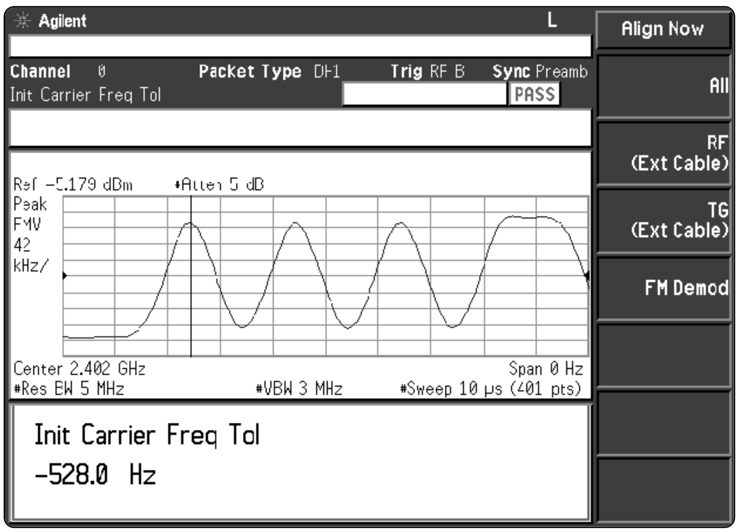

Figure 13. Agilent ESA-E spectrum analyzer display of initial carrier frequency tolerance showing a 8.5 kHz offset (CF = 2.402 GHz, triggered on p0 bit)

2.3.4 Carrier frequency drift

Carrier frequency drift is also measured as a demodulated signal using either a spectrum analyzer capable of FM demodulation or a vector signal analyzer. The payload data consists of a repeating 4-bit 1010 sequence. To perform the measurement, the absolute frequencies of the 4 preamble bits are measured and integrated; this provides the initial carrier frequency. Then the absolute frequencies of each successive 10-bit part in the payload are measured and integrated. The frequency drift is the difference between the average frequency of the 4 preamble bits and the average frequency of any 10 bits in the payload field. The maximum drift rate is also checked, and is defined as the difference between any two adjacent 10-bit groups within the payload field. This measurement is repeated with the lowest, middle, and highest operating frequencies, first with hopping off, then with hopping on. It is also repeated for varying packet lengths. Software control makes this repetitive measurement easier. Figure 14 provides an example of a carrier frequency drift measurement using the *Bluetooth* measurement personality of the ESA-E series spectrum analyzer. It shows an impaired *Bluetooth* signal with a 101010 repeating payload sequence and –35.7 kHz of frequency drift. This is outside the limits set by the standards, so it is flagged as a fail (F) by the automated software.

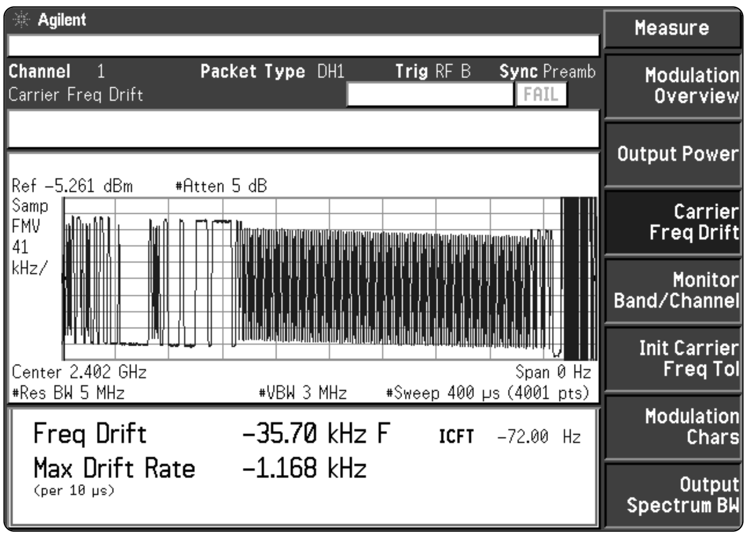

Figure 14. Agilent ESA-E spectrum analyzer display of frequency drift showing an initial carrier frequency (ICFT) of -72 Hz with respect to nominal channel 1 center frequency, –35.7 kHz drift across the burst and –1.168 kHz maximum drift rate. (CF = 2.402 GHz, triggered on p0 bit, DH1 packet length, channel 1, F indicates maximum frequency drift limit exceeded)

2.4 Timing tests

Timing tests may be performed on *Bluetooth* signals; these tests include analysis of the burst profile, phase lock loop (PLL) settling time, and other timing characteristics. These tests, although not part of the specifications, help R&D engineers ensure that their designs meet the criteria of their specifications.

2.4.1 Burst profile

Burst rise and fall time can be measured in the time domain using a signal analyzer. No definitions for rise time and fall time have been developed for *Bluetooth* wireless technology. The conventional industry definition of rise time is the time required to rise from the 10 percent (–20 dB) amplitude point to the 90 percent (–0.9 dB) amplitude point; the fall time is defined with the same amplitude points, but in reverse. Digital enhanced cordless telecommunication (DECT), a standard with similarities to *Bluetooth*, specifies the rise and fall times somewhat differently, with the rise time from the –30 dB to –3 dB amplitude points and the fall time from the –6 dB to –30 dB amplitude points. Pretriggering allows the rise time to be easily captured and measured. There is no defined mask test for the burst profile. Some devices may exhibit considerably faster transients than that shown. Excessively fast switching will cause failures in the output spectrum test by creating increased spectrum spreading due to the sharper edges of the burst. Figure 15 provides a measurement example of a burst rise time and a burst fall time. Additional burst profile characteristics include on/off ratio of the burst and overshoot (refer to figure 7).

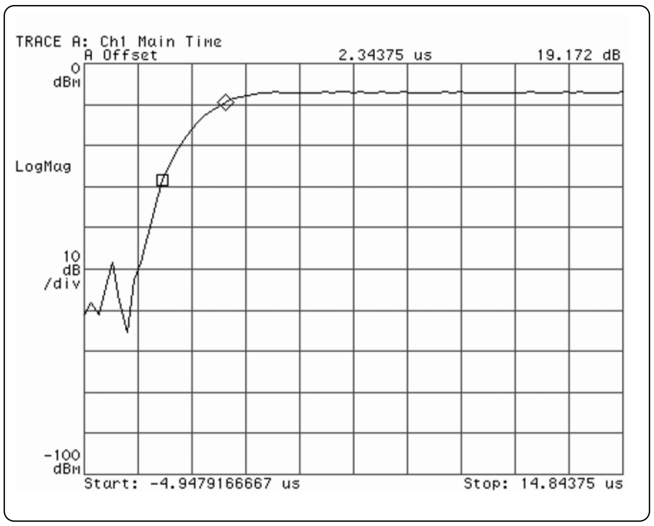

Figure 15a. Agilent 89441A display showing burst rise times (CF = 2.45 GHz, Span = 3 MHz, vector mode, triggering on IF channel 1, main time ch1, magnitude log(dB), main length = 20 µs)

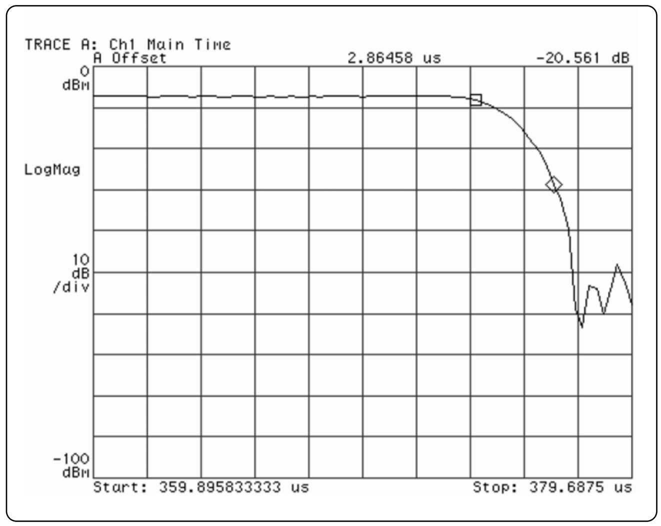

Figure 15b. Agilent 89441A display showing burst fall times (CF = 2.45 GHz, Span = 3 MHz, vector mode, triggering on IF channel 1, main time ch1, magnitude log(dB), main length = 20 µs)

2.4.2 Spectrogram measurements

Figure 16 provides a spectrogram display in which a radio transmitter exhibits poor PLL settling time at turn-on. The spectrogram is useful in analyzing these types of conditions. The spectrogram displays frequency on the x-axis and time on the y-axis. Amplitude is displayed through colors or shades of gray with the brighter colors or shades relating to higher amplitudes.

More complex spectrograms may be created by using the time-capture capabilities of a vector signal analyzer. This allows replaying real-time data at a slower speed. Symbol timing and rate may be analyzed in this fashion. Figure 17 shows a spectrogram of the initial 120 µs of a *Bluetooth* burst. The payload data in this example is 11110000, and these alternating patterns of 4 ones and 4 zeros can be seen 157.5 kHz away from either side of the center frequency.

Figure 16. Agilent 89441A spectrogram display for PLL settling time

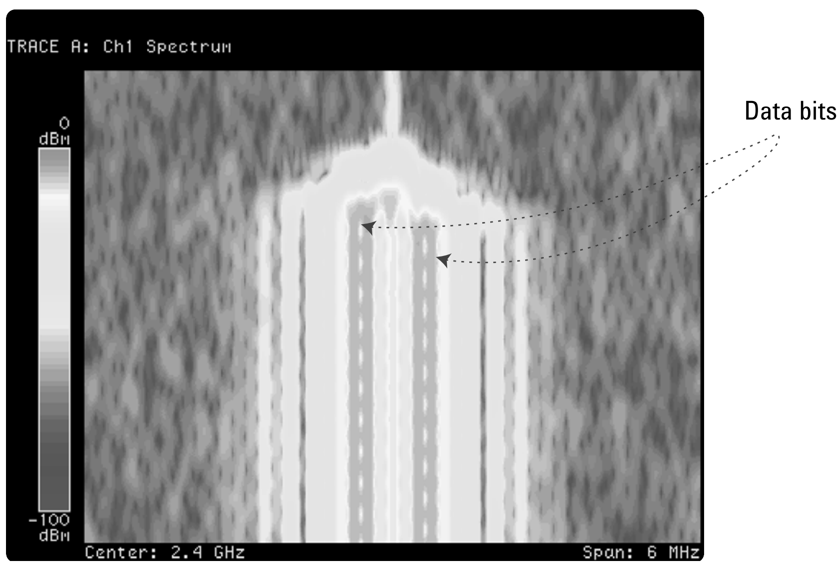

Figure 17. Agilent 89441A spectrogram display for symbol timing and rate

3. Transceiver measurements

3.1 Spurious emissions tests

The out-of-band spurious emissions tests confirm that the *Bluetooth* radio is operating within regulatory requirements. Two types of spurious emissions tests are identified in the specification: conducted emissions and radiated emissions. Conducted emissions are a measure of the spurious emissions generated by the device under test from its antenna or output connector. Radiated emissions are a measure of the spurious emissions leakage from the cabinet of the device under test.

Separate standards are specified for the USA and for Europe. The USA follows the Federal Communications Commission (FCC) part 15.247 standard. Europe follows the European Technical Standards Institute (ETSI) ETS 300 328 standard.

Spurious emissions tests are performed using a spectrum analyzer to sweep through frequency ranges looking for spurs. Specifications for spurious emissions are provided in the *Bluetooth RF Test Specification* [1]. The ETSI standard requires a spectrum analyzer frequency range of up to 12.75 GHz, while the FCC standard specifies a frequency range of up to 25.0 GHz.

Tests requiring compliance to the International Special Committee on Radio Interference (CISPR) publication 16 may require electromagnetic compatibility (EMC) spectrum analyzers with quasi-peak detection. These tests are not covered in this application note. Contact your local Agilent sales representative for more information on Agilent EMC products.

4. Receiver measurements

4.1 Bit error rate (BER) tests

The receiver measurements specified for *Bluetooth* wireless technology include the following:

- sensitivity—single-slot packets
- sensitivity—multi-slot packets
- carrier-to-interference (C/I) performance
- blocking performance
- intermodulation performance
- maximum input level

BER is the criterion used to determine receiver performance. These tests perform BER analysis under various conditions. Table 5 provides a summary of the test parameters required for the receiver tests.

4.1.1 Sensitivity—single-slot packets

Sensitivity is tested by sending various impaired signals to the receiver and then measuring the receiver's BER. The transmit power is chosen so that the input to the receiver is –70 dBm. The test is performed at the lowest, middle, and highest operating frequency. The impairments are defined in the test procedure and include variations in the carrier frequency offset, carrier frequency drift, modulation index, and symbol timing drift. The Agilent ESG-D series signal generators are the ideal tools for generating these signal impairments. Figure 14 provides an example of a signal impairment created by this family of signal generators.

4.1.2 Sensitivity—multi-slot packets

The sensitivity test for multi-slot packets is similar to that of the single-slot packets, except that DH5 packets are used instead of DH1 packets. If DH5 packets are not supported, DH3 packets are used.

Table 5. Receiver test parameters

Receiver tests	Frequency hopping	Test mode	Packet type	Payload data	BER measurement
Sensitivity—single-slot packets	Off On (optional)	Loopback	DH1	PRBS 9	≤ 0.1%
Sensitivity—multi-slot packets	Off On (optional)	Loopback	DH5 (DH3)	PRBS 9	≤ 0.1%
C/I performance	Off	Loopback	Longest supported	PRBS 9	≤ 0.1%
Blocking performance	Off	Loopback	DH1	PRBS 9	≤ 0.1%
Intermodulation performance	Off	Loopback	DH1	PRBS 9	≤ 0.1%
Maximum input level	Off	Loopback	DH1	PRBS 9	≤ 0.1%

4.1.3 Carrier-to-interference (C/I) performance

C/I performance is measured by sending co-channel or adjacent channel *Bluetooth* signals in parallel with the desired signal and then measuring the receiver's BER. The ratio of the carrier signal level to the interfering signal level is specified. The test is performed at the lowest, middle, and highest operating frequencies, with the interfering signals at all operating frequencies within the band.[1]

4.1.4 Blocking performance

The blocking performance test specifies a transmit and receive frequency of 2460 MHz. The tester continuously sends a *Bluetooth* signal that is 3 dB over the reference sensitivity level.[2] Simultaneously, the tester sends a continuous wave interfering signal and measures the BER of the receiver. The full compliance test requires the interfering signal to range from 30 MHz to 12.75 GHz in 1 MHz increments. The power levels associated with each frequency range are provided in the specification.[1]

4.1.5 Intermodulation performance

Intermodulation performance measures unwanted frequency components resulting from the interaction of two or more signals passing through a non-linear device. The test is performed by the tester continuously sending a *Bluetooth* signal that is 6 dB above the reference sensitivity. Simultaneously, the tester sends signals to generate 3rd, 4th, and 5th order intermodulation products. The BER is then measured to determine the performance of the receiver in the presence of intermodulation distortion.[1]

4.1.6 Maximum input level

The maximum input level test measures the BER performance when the input signal is at a maximum power level specified at –20 dBm. The test is performed at the lowest, middle, and highest operating frequencies.

1. When performing the carrier-to-interference test, blocking performance test, and the intermodulation performance test, an additional signal generator may be required to provide the interference signal.
2. The reference sensitivity level is defined as the power level at the receiver input at which the BER is 0.1 percent. The reference sensitivity shall be –70 dBm (± 1 dB) or better.

Section 4.1.7 Signal generation for receiver BER tests

For non-frequency-hopping applications, there are several ways of creating a *Bluetooth* signal using an Agilent ESG-D series signal generator.

Using Option UND

The personality for *Bluetooth* wireless technology illustrated in figure 18 is available with the ESG-D series internal dual arbitrary waveform generator (Option UND). This personality produces high data rate, single time slot (DH1) packets with several user defined signal and impairment parameters as outlined in table 6. The ability to produce a multi-slot packet is not built into the personality. However, multi-slot packet signal generation is still possible with the arbitrary waveform generator.

Custom wave forms can be created using a variety of programming languages and then downloaded to the arbitrary waveform generator for playback. This provides the ability to simulate both normal and impaired multi-slot *Bluetooth* waveforms. Example *Bluetooth* waveforms, including un-impaired DH3 and DH5 packets with truncated PN9 payload data, are available online at: http://www.agilent.com/find/bluetooth_waveforms.

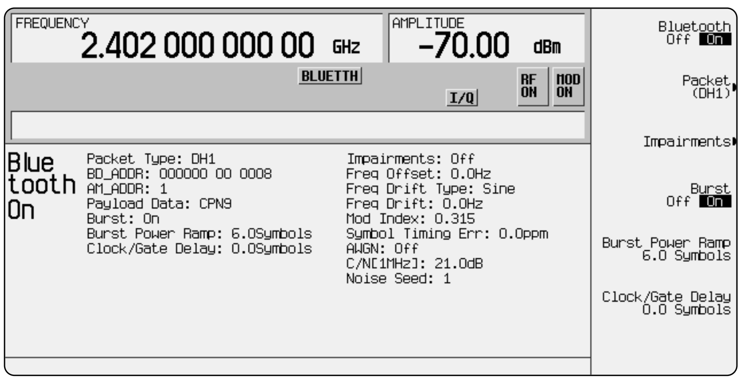

Figure 18. Agilent ESG-D series Option UND configuration menu for Bluetooth wireless technology

Table 6. Signal generation example using the Agilent ESG-D series Option UND personality for Bluetooth

Function	Setup	Notes
Frequency	Set the appropriate *Bluetooth* channel.	f = 2402 + k MHz, k = 0, 1, 2,...,78
Amplitude	Set the appropriate power level depending upon the test.	
Addressing	Set the *Bluetooth* device address and active member address of the DH1 packet: 1) BD-ADDR 2) AM-ADDR	Used by the arbitrary waveform generator when creating the Access Code and Header fields of the DH1 packet.
Payload data	Set payload data type for the DH1 packet: 1) Continuous PN9 2) Truncated PN9 3) User defined 8-bit pattern	Three payload data formats are available for the DH1 packet.
Signal impairments	Set the signal impairment characteristics: 1) Carrier frequency offset 2) Carrier frequency drift 3) Modulation index 4) Symbol timing rrror 5) AWGN with adjustable C/N	Generate normal or impaired signals by turning signal impairments OFF or ON.
Burst	Turn Burst ON or OFF. When ON, set the number of symbols per ramp.	Useful when analyzing a receiver's response to various transmitter burst profiles.
Clock/gate signals with delay control	Set the clock/gate delay in 1/10th symbol increments.	Clock and gate signals are generated on Event 1 and Event 2 ports respectively only when continuous PN9 payload data is selected. Delay control allows re-alignment of the clock and gate signals with the DH1 packet pay load data when performing receiver BER analysis.

Using Option UN8

The ESG-D series real-time I/Q baseband generator (Option UN8) also provides signal generation capability for *Bluetooth*. The baseband generator offers the ability to manually create pulsed 2FSK signals with Gaussian filtering and customizable data patterns. A step-by-step example of a manually configured *Bluetooth* signal is provided in table 7. A one-button *Bluetooth* setup is also available to simplify the configuration process, see figure 19. The real-time I/Q baseband generator does not create structured *Bluetooth* packets. However, it does offer the ability to modulate an assortment of built-in data patterns including PN9, PN15, PN23, and user-defined bit patterns.

Furthermore, custom user data files for *Bluetooth* can be created and downloaded to the real time I/Q baseband generator for modulation. Additional RAM (Option UN9) may be required for generating longer packet data files such as DH3 and DH5. The baseband generator also offers an external data input for modulating *Bluetooth* baseband signals in real time.

Table 7. Bluetooth signal generation example with Agilent ESG series Option UN8 signal generator

Function	Setup
Frequency	Set to the appropriate *Bluetooth* channel, 2.45 GHz, for example
Amplitude	Set to the appropriate conditions depending on the test
Filter	
Filter shape	Gaussian
Filter BbT	0.5
Symbol Rate	1 Msps
Data	
Frequency deviation	–157.5 kHz (for “0”)
Frequency deviation	157.5 kHz (for “1”)
Data bits	four “1s” and four “0s”
Pulse	
Pulse width	366 µs
Pulse period	1.25 ms[1]
Pulse on/off	On

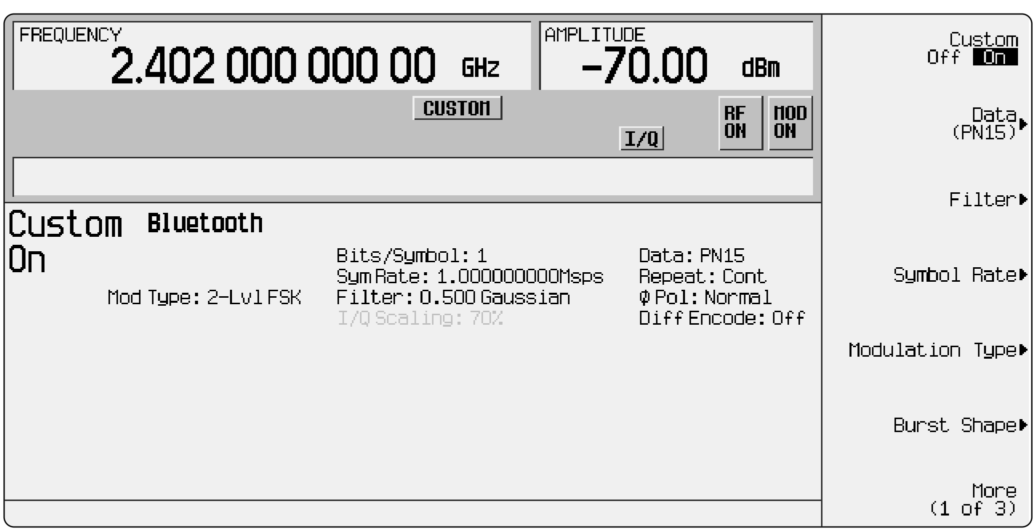

Figure 19. Agilent ESG-D series Option UN8 pre-configured mode for Bluetooth

1. Since *Bluetooth* devices transmit and receive bursts in alternating time slots, the pulse period is defined as two time slots or 2 * 0.625 ms.

Section 4.1.8 BER Test Setup

To perform BER tests, the ESG-D series signal generator can be used to produce and transmit a *Bluetooth* signal to the unit under test. Upon reception, the signal is routed through the UUT and demodulated. The demodulated *Bluetooth* signal is then fed back to the ESG-D series internal BER analyzer (Option UN7) for examination.

The internal BER analyzer must be presented with continuous PN9 or PN15 data for proper operation. The personality for *Bluetooth* wireless technology, available with the ESG-D series arbitrary waveform generator (Option UND) produces DH1 packets. Because of this, clock and gate signals are needed to recover the payload data from the demodulated *Bluetooth* signal (the DH1 packet). When continuous PN9 payload data is selected, as indicated in figure 20, the ESG-D generates the clock and gate signals necessary for the internal BER analyzer to extract the continuous PN9 payload data from the demodulated *Bluetooth* signal.

The demodulated signal at the input of the BER analyzer will have experienced a propagation delay through the UUT. To allow for this, the ESG-D provides delay control over its clock and gate signals. This affords the ability to re-align the clock and gate signals with the continuous PN9 payload data of the DH1 packet at the input of the BER analyzer. Figures 21 and 23 provide examples of two possible setups for testing baseband BER.

If BER tests are being performed on the signal recovered from the FM demodulator of a *Bluetooth* radio unit, the setup in figure 21 can be used. The output of the FM demodulator is routed back to the ESG-D series internal BER analyzer after the

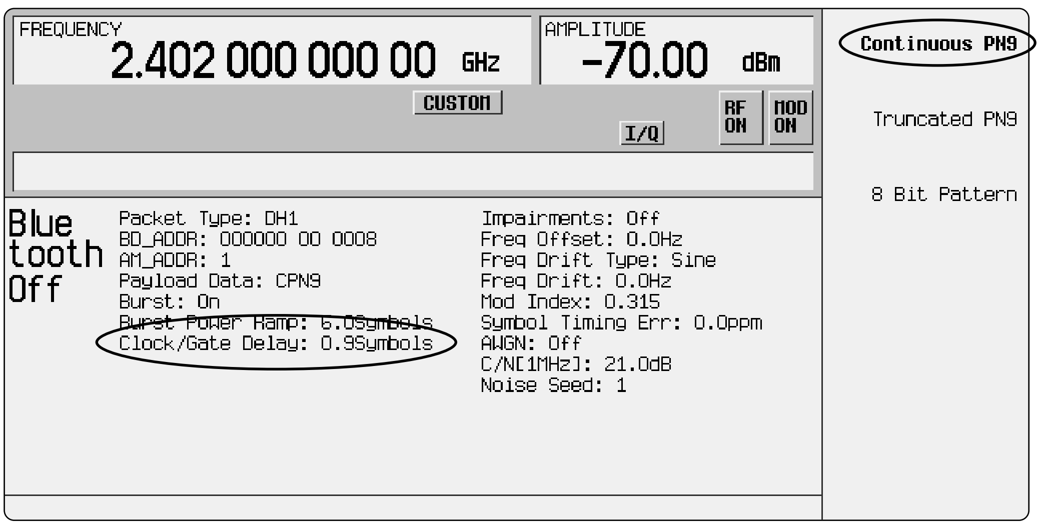

Figure 20. Agilent ESG-D series Option UND display of Bluetooth payload data configuration menu. When continuous PN9 payload data is selected, clock and gate signals with delay control are generated.

signal has been digitized and the clock has been recovered. The gate signal from the ESG-D enables the BER analyzer when continuous PN9 payload data is present for examination. Alternatively, the digitized output of the level detector may be looped back directly to the BER analyzer. In this case, both the clock signal and the gate signal generated by the ESG-D can be used to recover the continuous PN9 payload data from the DH1 packet for BER analysis. The ESG-D clock and gate signal delay is then incrementally adjusted until a minimum BER is achieved, as shown in figure 22. Notice that with a 0.9 symbol delay the BER is approximately 0.3 percent whereas with a 1.3 symbol delay the BER is 0 percent. This indicates that the signal propagation delay through the UUT is 1.3 µsec.

Figure 23 shows an example in which BER tests are being performed on a *Bluetooth* radio unit that has clock recovery capability. In this setup, the clock and data outputs of the UUT baseband processor are routed to the BER analyzer. The gate signal from the ESG-D is again used to enable the BER analyzer when continuous PN9 payload data is present. This method is straight-forward if the clock and data signals are available from the UUT baseband processor. If the UUT does not provide a recovered clock signal from the baseband processor, both the clock signal and the gate signal generated by the ESG-D can be used to recover the continuous PN9 payload data from the DH1 packet as previously described.

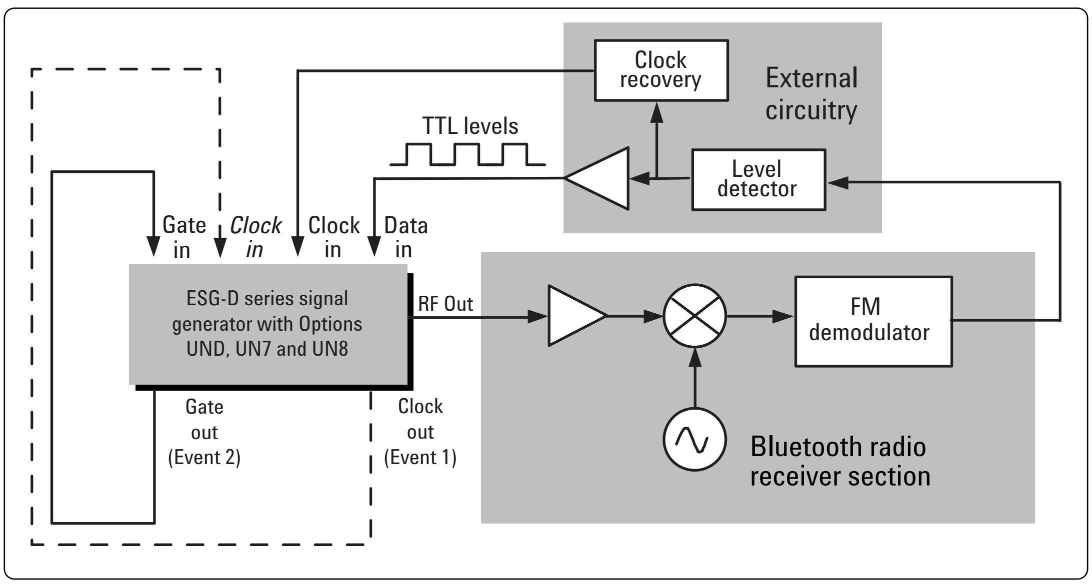

Figure 21. BER test setup for a Bluetooth radio without clock recovery capability. Note: Dashed lines indicate alternate configurations.

Additional BER test setups are possible depending upon the *Bluetooth* module level of integration. BER analysis capability has been incorporated into the baseband processor of some *Bluetooth* devices. In this case, the ESG-D simply provides a *Bluetooth* signal with PN9 payload data to the *Bluetooth* radio unit. When performing receiver tests later in the development stage, BER analysis on a *Bluetooth* device operating in loopback mode may be necessary. This requires some means of demodulating the *Bluetooth* signal prior to baseband BER analysis.

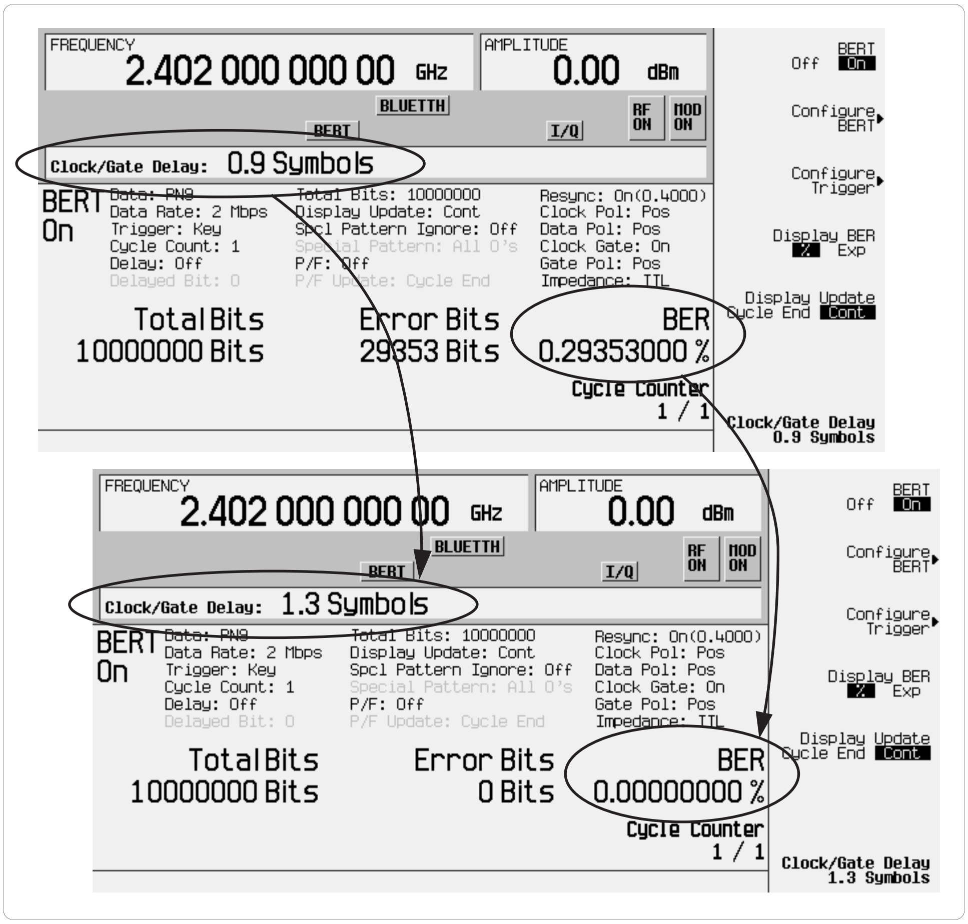

Figure 22. The clock/gate delay can be adjusted in the Agilent ESG-D series Option UN7 interface. The delay is incrementally adjusted to allow for propagation delay through the UUT until 0 percent BER is achieved; i.e., when clock and gate signals have been realigned with the payload data of the DH1 packet.

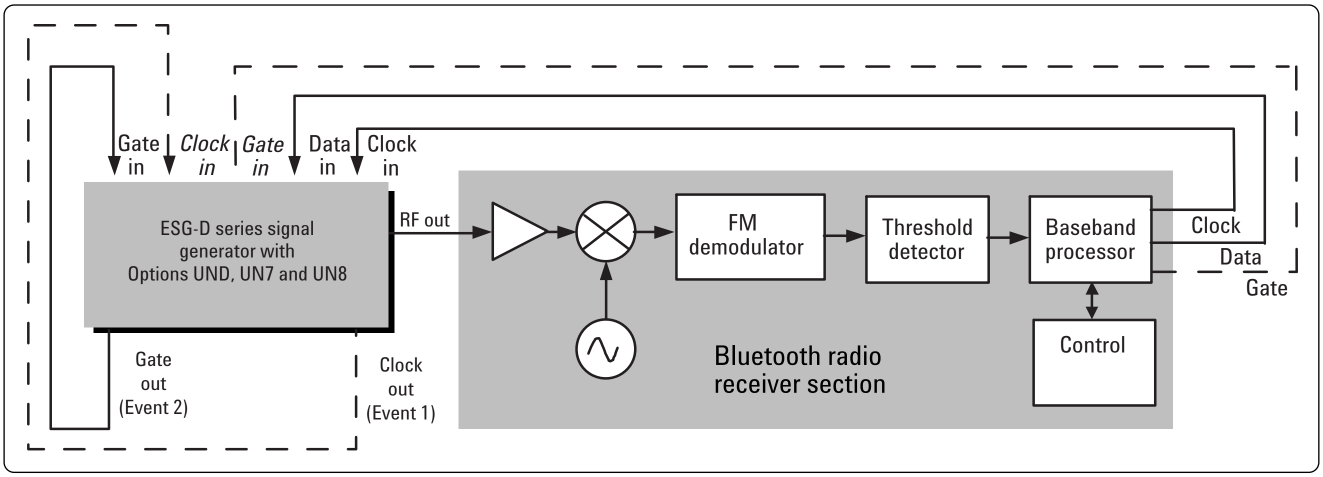

Figure 23. BER test setup for a Bluetooth radio with clock recovery capability. Note: Dashed lines indicate alternate configurations.

4.2 Supplementary receiver tests

Frequency hopping is not required by the *Bluetooth RF Specification* [1] for the receiver tests. It is possible to ensure the main local oscillator switches to its extremes by setting the transmit and receive channels to be at opposite ends of the band. Some choices of intermediate frequency require even larger frequency changes in the VCO.

For situations where more in-depth testing is required, fast frequency hopping may be performed using the Agilent E6432A VXI microwave synthesizer with an Agilent ESG-D series signal generator to modulate the signal. For this measurement, the source, the receiver, and the device under test are controlled so that they frequency hop in unison. The device under test is placed in test loopback mode. The E6432A may also be used as the broadband RF interference source noted in 4.1.4.

5. Power supply measurements

The *Bluetooth RF Test Specification* [1] specifies tests at power source voltages that are extreme for some *Bluetooth* devices.[1] Power supply testing, and the *Bluetooth* device's rejection of spurious signals carried on the power line, are important parts of integration testing for many applications. Measurements of power versus time during DH5 bursts and careful monitoring of the frequency error measurements are good ways to uncover power-line related problems.

Agilent offers a complete line of DC power supplies that are suitable for these tests. These include general-purpose supplies as well as supplies specifically designed to meet the demands of mobile communications products. These DC voltage supplies also offer low-current measuring capability, which is useful for evaluating current consumption during standby and sleep modes.

1. These tests are not required when the equipment under test is designed for operation as part of and powered by another system or piece of equipment.

Appendix A: Agilent solutions for Bluetooth

● = Meets fully specified test requirements

❍ = Not fully compliant to test requirements; characteristics only

	Vector signal analyzers		Spectrum analyzers	Sources
Bluetooth measurements	89400 series vector signal analyzers[1]	E4406A series vector signal analyzers	ESA-E series spectrum analyzers[2]	ESG-D series signal generators[3]
Transmitter tests				
Output power	●	●	●	●
Power density	●	●	●	●
Power control	●	●	●	●
Output spectrum	●	●	●	●
Modulation characteristics	●		●	●
Initial carrier frequency tolerance	●		●	●
Carrier frequency drift	●		●	●
Supplementary modulation measurements	●			●
Burst rise/fall time	●	●	●	●
Spectrogram measurements	●			●
Data Demodulation	●			
Transceiver tests				
Spurious emissions	❍		●	
Receiver tests				
Sensitivity—single-slot packets				●
Sensitivity—multi-slot packets				●
C/I performance				●[5]
Out-of-band blocking performance				●[5]
Intermodulation performance				●[5]
Maximum input level				●
Receiver tests with frequency hopping				●[4]

1. Requires Options AYA (Vector Modulation Analysis) and AY9 (Extended Time Capture). Option AYB (Waterfall and Spectrogram) is required for spectrograms.
2. Requires Options 303 (General Purpose Bundle for *Bluetooth* wireless technology).
3. Requires Options UND (Dual Arbitrary Waveform Generator) for Arb files, UN8 (I/Q Baseband Generator) for 2FSK digital modulation, and UN7 (Baseband BER Analyzer) for receiver tests.
4. Requires Agilent E6432A VXI microwave synthesizer to perform hopping.
5. When performing the C/I, blocking, and intermodulation performance tests, an additional signal generator may be required to provide the interference signal.

Appendix B: Recommended reading

8 Hints for Making Better Measurements Using RF Signal Generators, Application Note 1306-1, literature number 5967-5661E.

8 Hints for Making Better Spectrum Analyzer Measurements, Application Note 1286-1, literature number 5965-7009E.

10 Steps to a Perfect Digital Demodulation Measurement, Product Note 89400-14A, literature number 5966-0444E.

Cookbook for EMC Precompliance Measurements, Application Note 1290-1, literature number 5964-2151E.

Customizing Digital Modulation with the Agilent ESG-D Series Real-Time I/Q Baseband Generator, Option UN8, literature number 5966-4096E

Generating and Downloading Data to the Agilent ESG-D RF Signal Generator for Digital Modulation, literature number 5966-1010E

Generating Digital Modulation with the Agilent ESG-D Series Dual Arbitrary Waveform Generator, Option UND, literature number 5966-4097E

Measuring Bit Error Rate using the Agilent ESG-D Series RF Signal Generators Option UN7, literature number 5966-4098E.

Spectrum Analysis, Application Note 150, literature number 5952-0292.

Testing and Troubleshooting Digital RF Communications Receiver Designs, Application Note 1314, literature number 5968-3579E.

Testing and Troubleshooting Digital RF Communications Transmitter Designs, Application Note 1313, literature number 5968-3578E.

Using Vector Modulation Analysis in the Integration, Troubleshooting, and Design of Digital RF Communications Systems, Product Note 89400-8, literature number 5091-8687E.

Appendix C: Glossary

Hold mode–Power saving mode in which the device is placed in an inactive state, running only an internal timer to occasionally perform a status check.

Information appliances–The category of information-focused devices that provide voice or data to the user. Examples are not limited to, but include cellular phones, Personal Digital Assistants, and digital cameras.

Master unit–The device in a piconet whose clock and hopping sequence are used to synchronize all other devices in a piconet.

Packet–A single bundle of information transmitted within a piconet. A packet is transmitted on a frequency hop and nominally covers a single time slot, but may be extended to cover up to five slots.

Park mode–Power saving mode in which the device is placed in an inactive state. The device is synchronized to the piconet but does not participate in the traffic. Park mode provides the highest power efficiency.

Payload–The user's voice or data information, which is carried in a packet.

Piconet–The piconet is the smallest *Bluetooth* network structure. A piconet consists of one master and up to seven actively communicating or 200+ inactive noncommunicating slaves. The piconet is defined by its hopping sequence.

Power saving mode–Three power saving modes exist–sniff mode, hold mode, and park mode–each of which puts the slave unit in a varying state of sleep. No data is transferred to or from a slave unit while it is in a power saving mode.

Pretriggering–A feature which allows examination of the waveform at a point in time prior to the defined trigger point.

Scatternet–Multiple independent and nonsynchronized piconets form a scatternet. Devices can share piconets.

Slave units–All devices in a piconet that are not the master. Slave units may be in active mode, in which they are actively communicating with the master, or they may be in an inactive sleep mode.

Sniff mode–Power saving mode in which the device listens to the piconet at a reduced rate to conserve power. Sniff mode is the least efficient power saving mode.

Standby mode–The state of a *Bluetooth* unit which is not connected to a piconet. In this mode, devices listen for messages every 1.28 seconds.

Appendix D: Symbols and acronyms

2FSK 2-Level Frequency Shift Keying; also known as binary FSK
ACL Asynchronous Connectionless Link
ARQ Automatic Repeat reQuest error correction scheme for data
BT(BbT) Bandwidth-Time product
BER Bit Error Rate
CF Center Frequency
CISPR International Special Committee on Radio Interference
CW Continuous Wave
dBc Decibels relative to the carrier frequency
dBi Decibels relative to an isotropic radiator in free space
dBm Decibels relative to 1 milliwatt (10log(power/1mW))
DECT Digital Enhanced Cordless Telecommunication
EIRP Equivalent Isotropically Radiated Power (Effective Isotropic Radiated Power)
EMC Electromagnetic Compatibility
ETSI European Technical Standards Institute
EUT Equipment Under Test
EVM Error Vector Magnitude
FCC Federal Communications Commission
FEC Forward Error Correction
FHSS Frequency Hopping Spread Spectrum
GFSK Gaussian-filtered Frequency Shift Keying
GSM Global System for Mobile communications
Hz Hertz or cycles/second
IF Intermediate Frequency
ISM Industrial, Scientific, and Medical radio band
LM Link Manager software
LMP Link Manager Protocol
LO Local Oscillator
PDA Personal Digital Assistant
PLL Phase Lock Loop
PN9 Pseudorandom Noise of period 2^9-1 bits
PRBS 9 PseudoRandom Bit Sequence
PSD Power Spectral Density
RBW Resolution Bandwidth
RF Radio Frequency
SCO Synchronous Connection-Oriented link
SIG *Bluetooth* Special Interest Group
TDD Time Division Duplex
UUT Unit Under Test
VBW Video Bandwidth
VSA Vector Signal Analyzer

Appendix E: References

[1] *Bluetooth RF Test Specification*, revision 0.31, 18.06.99, and revision 0.53r, 27.08.99.

[2] *Specification of the Bluetooth System*, version 1.0, May 10, 1999.

[3] *Official Bluetooth Web site*, **www.bluetooth.com**, 8/99.

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