Bluetooth™ RF Measurement Fundamentals

Application Note 1333-1

Introduction

Bluetooth™ wireless technology is an open specification for a wireless personal area network (PAN). It provides limited range wireless connectivity for voice and data transmissions between information appliances. *Bluetooth* wireless technology eliminates the need for interconnecting cables. Unique for most wireless communications systems, *Bluetooth* enables ad hoc networking among devices without the need for infrastructure such as Base stations or access points.

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 devices through its wireless communications link.

Bluetooth wireless technology will allow seamless interconnectivity among devices. Imagine your computer synchronizing files and databases with your personal digital assistant (PDA), simply because you carried the PDA into the vicinity of the PC. Laptop PCs will access e-mail by linking to nearby mobile phones or perhaps with a *Bluetooth* enabled airport lounge internet access device; and wireless headsets will simplify hands-free operation of mobile phones as a convenient and safe way to talk while driving. The potential of this technology 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 *Bluetooth* RF designs. Test procedures 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 D. This application note assumes a basic understanding of RF measurements. To learn more about basic RF measurements, refer to Appendix C, "Recommended Reading," at the end of this application note.

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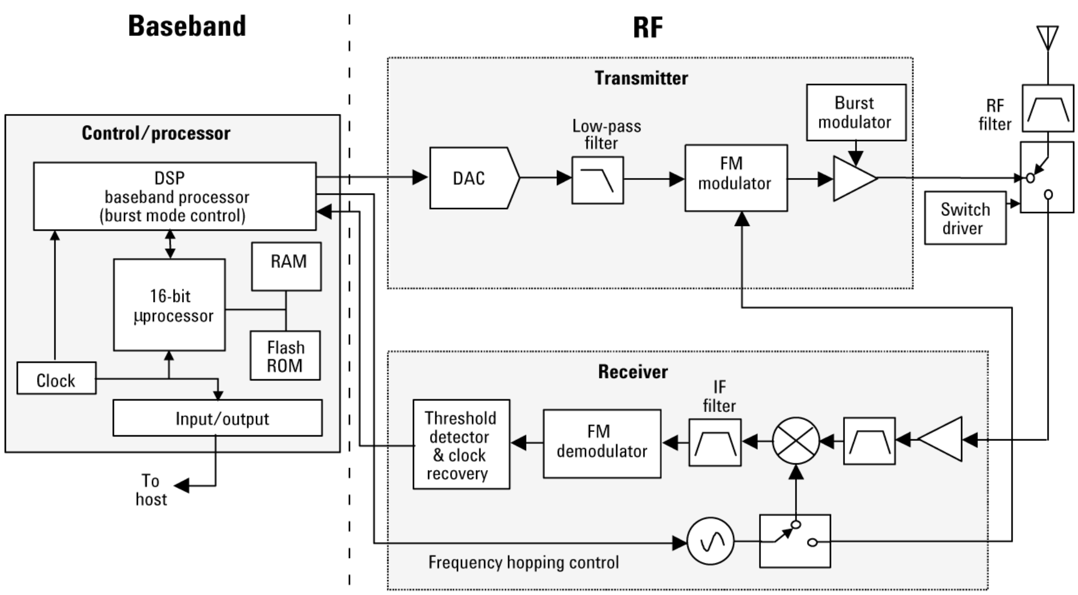
1. Basic Concepts of *Bluetooth*

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 is 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.

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.

Table 1. Key *Bluetooth* RF Characteristics

Characteristic	Specification	Notes
Carrier Frequency [1]	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) [2] 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: 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. The *Bluetooth* Specification includes a special frequency hopping pattern to provide provisions for compliance with national limitations such as those in France. The frequency range for France is 2.4465 - 2.4835 GHz and the corresponding RF channels are f = 2454 + k MHz, k= 0,…,22. A change to persuade France to adopt the full ISM band is scheduled to take place in 2003.
2. Hop speed may vary, depending on packet length.

Figure 2. *Bluetooth* Frequency Bands and Channel Arrangement

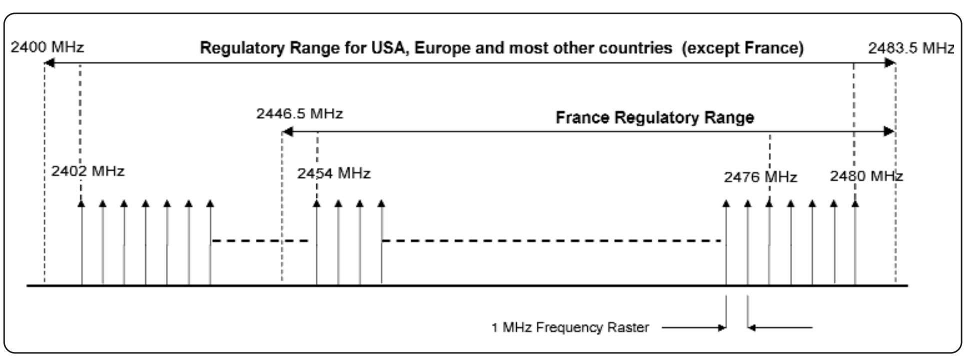
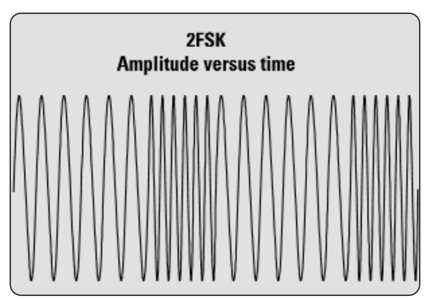


Figure 3. 2FSK Modulation



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.

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 non-communicating, 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** on page 6 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** on page 6, contains an access code, a header, and a 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 Part B, "Baseband Specification", in Specification of the *Bluetooth* System [Reference 2] for further details on packet construction.

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 bidirectional.	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.	

1.3 *Bluetooth* RF Test Suite Structure

The *Bluetooth* radio is Layer 1 of the *Bluetooth* protocol stack. **Figure 6** shows a configuration of this *Bluetooth* protocol stack with the different basic layers.

The *Bluetooth* Special Interest Group (SIG) has proposed a list, entitled "*Bluetooth* RF Test Suite Structure," which defines tests to perform for certification of the *Bluetooth* radio layer. **Table 3** provides this list of tests with their test purpose identifiers.

Figure 4. Network Topology

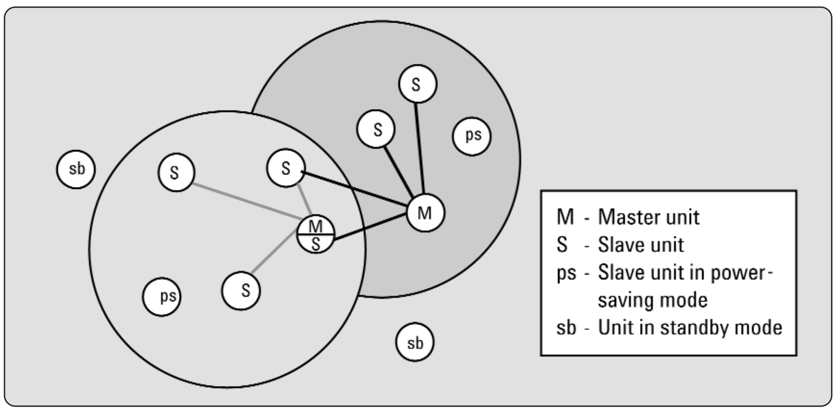


Figure 5. *Bluetooth* General Packet Format

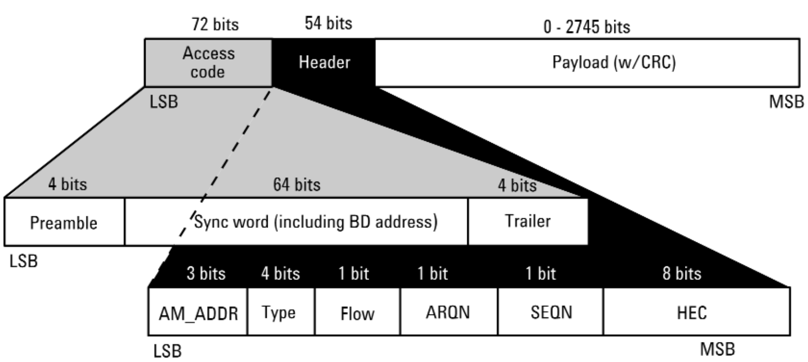


Figure 6. *Bluetooth* Protocol Stack, Basic Layers.

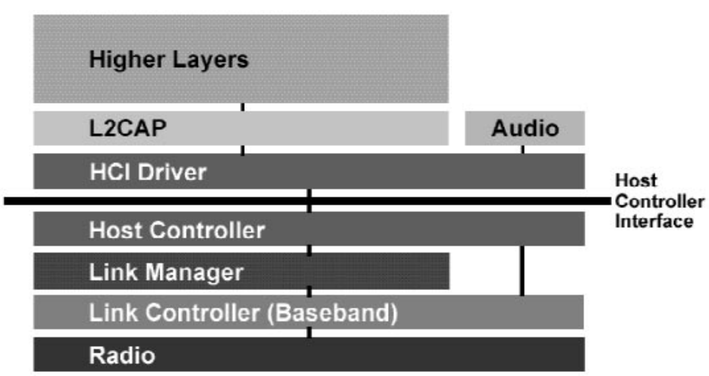


Table 3. *Bluetooth* RF Test Suite Structure

Test Cases for Certification Testing of the *Bluetooth* RF Layer	Identifier*
Transmitter Tests	
Output power	TRM/CA/01/C
Power density	TRM/CA/02/C
Power control	TRM/CA/03/C
TX output spectrum-frequency range	TRM/CA/04/C
TX output spectrum-20 dB bandwidth	TRM/CA/05/C
TX output spectrum-adjacent channel power	TRM/CA/06/C
Modulation characteristics	TRM/CA/07/C
Initial carrier frequency tolerance	TRM/CA/08/C
Carrier frequency drift	TRM/CA/09/C
Transceiver tests	
Out-of-band spurious emission	TRC/CA/01/C
Receiver tests	
Sensitivity/single-slot packets	RCV/CA/01/C
Sensitivity/multi-slot packets	RCV/CA/02/C
C/I performance	RCV/CA/03/C
Blocking performance	RCV/CA/04/C
Intermodulation performance	RCV/CA/05/C
Maximum input level	RCV/CA/06/C

* Note: Identifier format is: (Test)/CA/NN/C, in which
TRM=Transmitter test
TRC=Transceiver test
RCV=Receiver test
CA=Capability test (defines the type of testing)
NN=Test purpose number
C=Conformance test performed on dedicated *Bluetooth* test system (defines the scope)

The following sections of this application note provide a description of these different tests and how they can be performed. For specific information on test requirements, such as initial condition, test procedure, test condition, or expected outcome, refer to the *Bluetooth RF Test Specification* [Reference 1]. This document has been defined by the *Bluetooth* SIG (Special Interest Group) and is the definitive guide.[1]

1. At the time of this writing, the revision of this document is 0.91 (Test specification RF for Specification 1.1 - July 2, 2001). Since then, some errata in this document may have been listed on the *Bluetooth* SIG web site under "TEST SPECIFICATION ERRATA." Refer to this for up-to-date test requirements.

2. Transmitter Measurements

This chapter provides a framework for the *Bluetooth* transmitter tests and test methodology.

It describes the measurements that can be made on *Bluetooth* components and systems.

Examples and supporting information are provided.

2.1 Test Conditions and Setup

2.1.1 Test Conditions

Table 4 is a summary list of the conditions under which the transmitter tests need to be performed.

Payload Data

Notice that 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 that an ideal Gaussian filter will produce a ratio of 88% between the peak frequency deviation of a 10101010 signal and that of the 11110000 signal. The *Bluetooth* radio specification calls for > 80% to be achieved.

Table 4. Transmitter Test Conditions

	Frequency Hopping	Test Mode	Packet Type	Payload Data	Measurement Bandwidth
Output Power	On	Loopback [1]	DH5 [2]	PRBS 9	3MHz RBW 3MHz VBW
Power Density	On	Loopback [1]	DH5 [2]	PRBS 9	100kHz RBW 100kHz VBW
Power Control	Off	Loopback [1]	DH1	PRBS 9	3MHz RBW 3MHz VBW
TX Output Spectrum-Frequency Range	Off	Loopback [1]	DH5 [2,3]	PRBS 9	100kHz RBW 300kHz VBW
TX Output Spectrum-20 dB Bandwidth	Off	Loopback [1]	DH5 [2,3]	PRBS 9	10kHz RBW 30kHz VBW
TX Output Spectrum-Adjacent Channel Power	Off	Loopback [1]	DH1	PRBS 9	100kHz RBW 300kHz VBW
Modulation Characteristics	Off	Loopback [1]	DH5 [2]	11110000 10101010	— —
Initial Carrier Frequency Tolerance	Off On	Loopback [1]	DH1	PRBS 9	—
Carrier Frequency Drift	Off	Loopback [1]	DH1 DH3 DH5 [2]	10101010	—

1. If Loopback is not available, the use of TX (transmitter mode) is allowed.

2. If DH5 is not supported, use the longest supported packets (with the longest supported payload length).

3. The original test specification required to perform this measurement with DH1 packets. However measurements on real DUTs have shown that the packet type has an impact on the test result, it is now required to perform this measurement with the longest supported packet type (See Reference 1).

Frequency Hopping

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 is not 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*.

Test Mode

The *Bluetooth* device can operate in different modes:

- Normal Mode
- Transmitter (TX) Test Mode
- Loopback Test Mode

“Normal mode” consists of having a standard *Bluetooth* communication. For instance, when the tester is acting as a master and the *Bluetooth* device as a slave, in normal mode the tester will send some POLL packets and the device will confirm the reception of these packets by sending back a NULL packet. The description of POLL and NULL packets can be found in Part B, “Baseband Specification,” in Specification of the *Bluetooth* System [Reference 2].

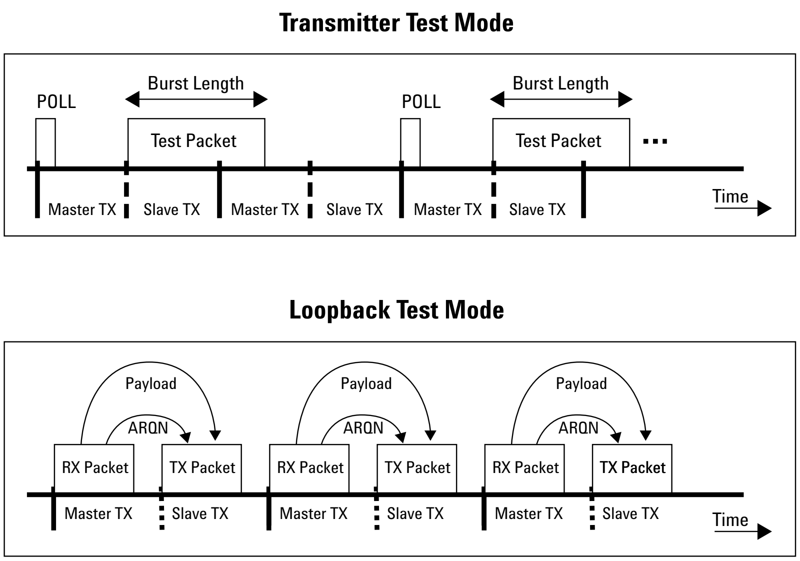
In Test mode, the *Bluetooth* device is operating in a specific state. In Loopback test mode, the *Bluetooth* device (slave) is asked to decode the packets sent by the tester (master) and send back the payload using the same packet type. While in Transmitter test mode, the *Bluetooth* device is simply asked to transmit a type of packet according to specific instructions sent by the tester (master) via POLL packets. An illustration of Loopback and Transmitter test mode is provided in **Figure 7**.

The implementation of Test mode in *Bluetooth* devices is required to facilitate testing of transmitter and receiver performance of a device. By putting the device into Test mode, different transmission and/or reception parameters can be controlled, such as frequency selection, TX frequency, packet type and length, bit pattern, poll period, and power level.

Note: To allow the tester (master) to put the device (slave) into Test mode, the host device will need to send a special command (LMP command) in order to prepare the device to enter Test mode. That is one of the reasons why in the different setups presented in the following sections, a DUT controller is included. The control could be performed either by protocol sent over an RF connection or by direct digital control of the device.

For more details on Test Mode and its activation, refer to Part I:1, "*Bluetooth* Test Mode," in Specification of the *Bluetooth* System [Reference 2].

Figure 7. Loopback and Transmitter Test Mode



2.1.2 Test Setup

Different setups may be used for *Bluetooth* transmitter tests, depending on whether you are testing a full functional *Bluetooth* device or just the RF transmitter, or even RF components of the transmitter. One way to test transmitter performance of a full functional *Bluetooth* device is to use a *Bluetooth* Test Set, such as the Agilent E1852A. The Test set and DUT form a piconet where the tester acts as master and the DUT acts as slave. The Test Set establishes a link (paged connection) with the device in either Normal or Test mode using the standard *Bluetooth* protocol. With the device in Test mode, the Test Set will have complete control of DUT operation. For instance, the Test set can put the device into Loopback mode or TX mode, disable frequency hopping, and ask the device to transmit at specific frequencies as required by the *Bluetooth RF Test Specification*.

Figure 8 shows this basic setup with the Agilent E1852A *Bluetooth* Test Set.

Three other types of transmitter measurement setups are illustrated in **Figure 9** on page 9. Setup 1 is an example of a setup to test transmitter performance of a full functional *Bluetooth* module, while Setup 2 is used for testing only a *Bluetooth* transmitter, and Setup 3 for testing RF components of a transmitter. Setup 1 differs from the setup of

Figure 8. Example of a setup to test transmitter performance of a full functional *Bluetooth* device. The Agilent E1852A *Bluetooth* Test Set is acting as a master, while the *Bluetooth* DUT is acting as a slave.

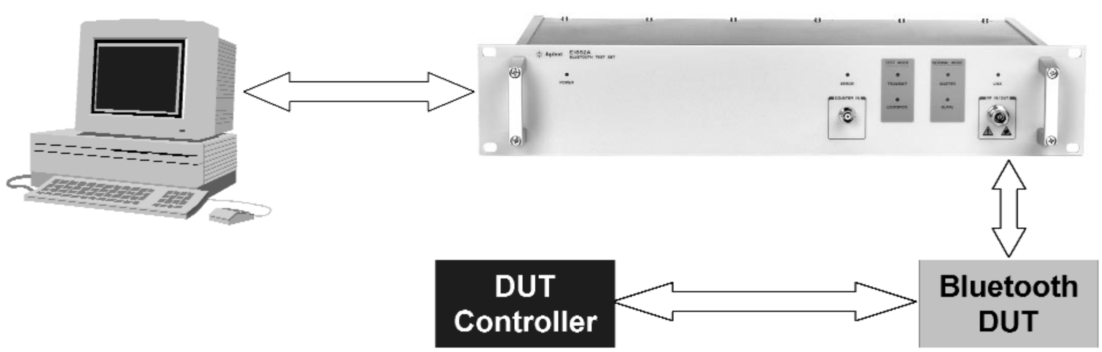
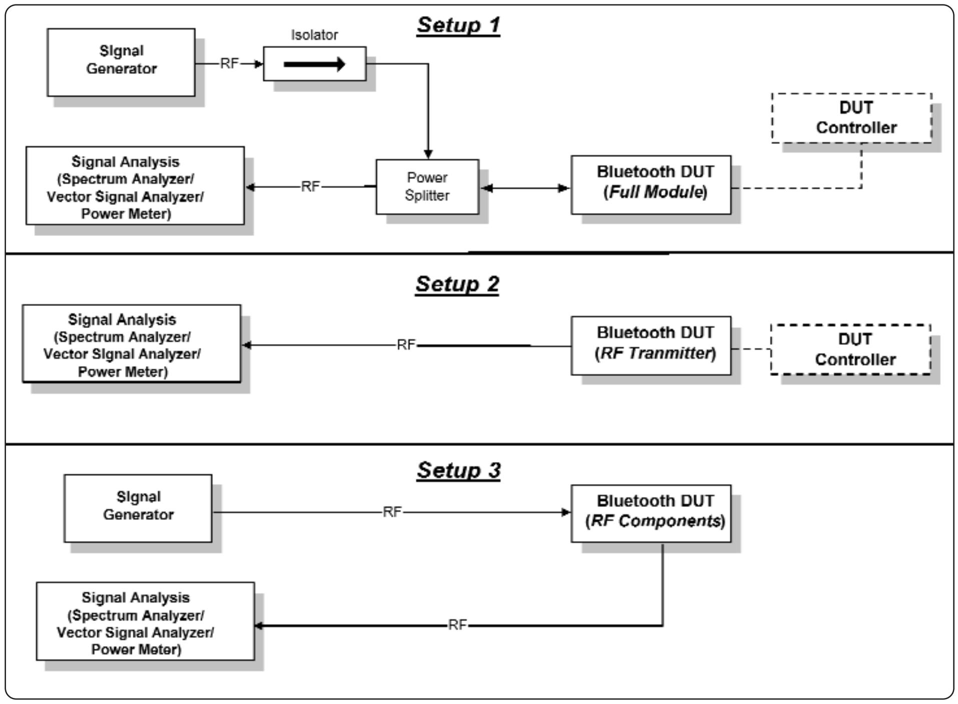


Figure 8 in that there is no *Bluetooth* communication established between the device and the test equipment, so the test equipment doesn't have any control of the DUT operation. For this setup, a special internal "Test Facilities" utility must be implemented in the device. This utility must have the ability to ask to the device to transmit the packets it receives. This will allow a *Bluetooth* signal from the digital signal generator to be transmitted into the device's receiver and looped back through its transmitter for analysis. For Setup 2, the utility must have the capability to control the type of transmission (frequency hopping on or off, different types of packets, etc.) in order to provide the right conditions to test the *Bluetooth* transmitter (see Table 4, page 7). Setup 3 could be used to test, for example, the amplifier of a *Bluetooth* transmitter, as well as a variety of other tests. These three setups require the use of a signal analyzer, which could be a spectrum analyzer or a vector signal analyzer. Additional equipment includes signal generators and possibly a power meter, power supply, oscilloscope, and network analyzer.

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 antennas should be accounted for in the calculations. This can be evaluated using a network analyzer.

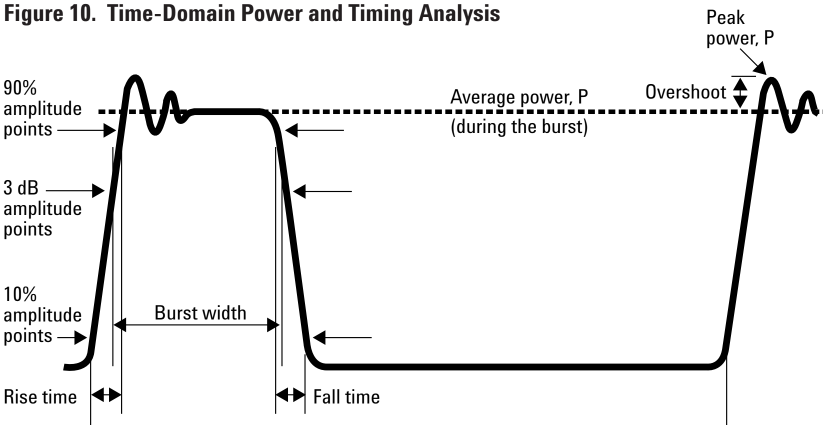
Figure 9.
Example of three other transmitter measurement setups:
Setup 1 : Transmitter performance test setup for a full functional *Bluetooth* device
Setup 2 : Setup to test performance of a complete *Bluetooth* transmitter
Setup 3: Setup to test performance of RF components of a *Bluetooth* transmitter



2.2 Power Tests

RF transmitter power measurements include output power (average power and maximum peak power in a burst), 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.

Figure 10. Time-Domain Power and Timing Analysis



2.2.1 Output Power

Output power measurements are performed in the time domain. Because the *Bluetooth* signal is a sequence of TDD bursts, it is necessary to trigger properly. Triggering occurs on the rising edge of the envelope to obtain a viewable signal.

Figure 10 illustrates power and timing characteristics of a signal burst in the time domain.

Average power and peak power measurements can be performed either by a *Bluetooth* Test Set, a power meter, a spectrum analyzer, or a vector signal analyzer. For any of these testers, the tester records the highest power value in the burst and calculates the average power from 20 to 80% of the duration of the burst. The duration of the burst (burst width) is the time between the leading and trailing 3dB points compared to the average power.

Figure 11a shows an output power measurement performed with a *Bluetooth* Test Set. The *Bluetooth* device has been put under the initial conditions required by the *Bluetooth RF Test Specification* for this output power transmitter test: the device is in test mode with frequency hopping, transmitting a DH5 packet with the longest payload length (339). Notice that this device is a Power Class 1 device (Pav<20dBm, Ppk<23dBm).

- 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 11b** shows a display of an average and peak power measurement on a swept-tuned spectrum 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 11c** 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.
- Power meters will be able to perform similar output power measurements for a lower cost. The Agilent power meter has a pre-defined *Bluetooth* setup stored in non-volatile memory, while its gate setup and control function allows closer analysis of the *Bluetooth* signal. **Figure 11d** on page 11 shows a power meter screen with the power trace in the upper window and a detailed analysis of the burst in the lower window.

Note: The output power results are to be expressed in EIRP (Equivalent Isotropically Radiated Power). Since EIRP is a measure of the radiated power of the system, it 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.

Figure 11a.
Agilent E1852A *Bluetooth* Test Set display showing an output power measurement (Device setup: Test mode, Frequency hopping ON, DH5 packet, maximum payload length, PRBS9 as payload)

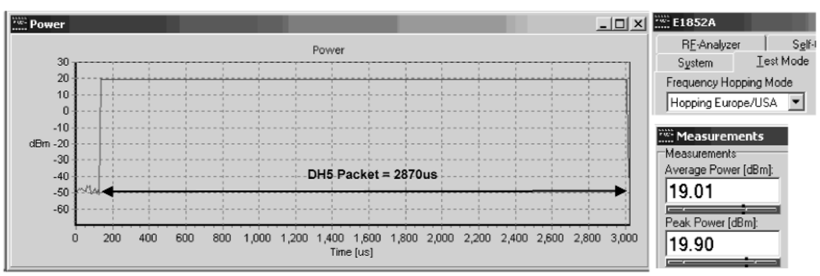


Figure 11b.
Agilent ESA-E series spectrum analyzer display of peak and average power measurement using the *Bluetooth* personality (CF=2.405GHz, sweep time 680µs, Triggering on IF ch3)

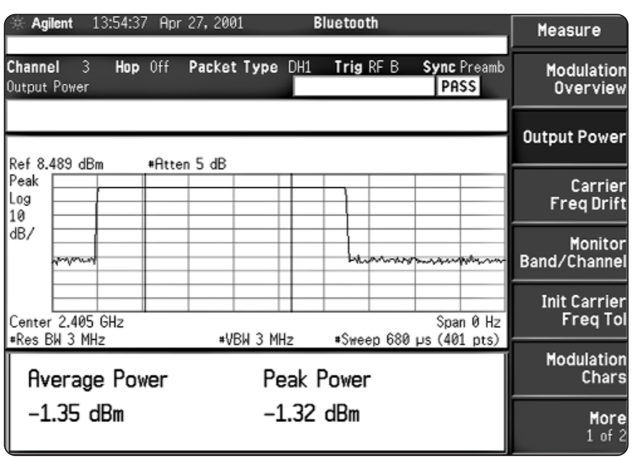


Figure 11c.
Agilent 89600 display of average and peak power measurement (CF = 2.402 GHz, 1 dB/div, sweep time 380 µs, triggering on IF ch 1, delay = 10µs)

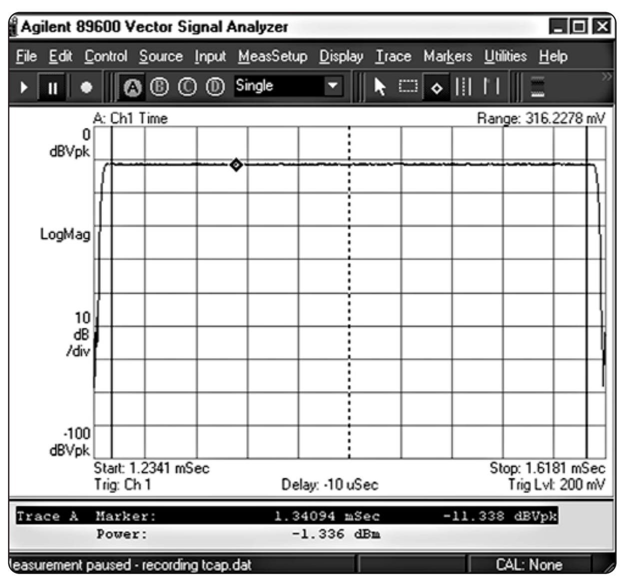
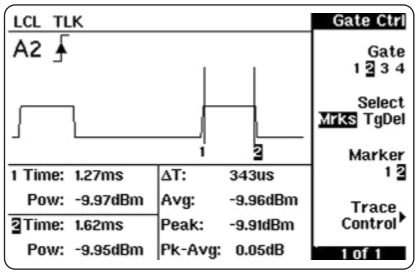


Figure 11d.
Agilent EPM-P series power meter display showing the power trace, delta time, delta average, delta peak, and delta peak-to-average ratio for the selected gate (Gate 2, previously configured in the *Bluetooth* pre-defined setup.)



2.2.2 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 12a**[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 12b**. 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.

2.2.3 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 (lowest, mid, highest operating frequency). The power control test verifies power levels and power control step sizes to ensure that they are within the specified range. With a link established, the Agilent E1852A *Bluetooth* Test Set can adjust the power level of the DUT.

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 12a.
Agilent ESA-E display of power density measurement (CF = 2441 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)

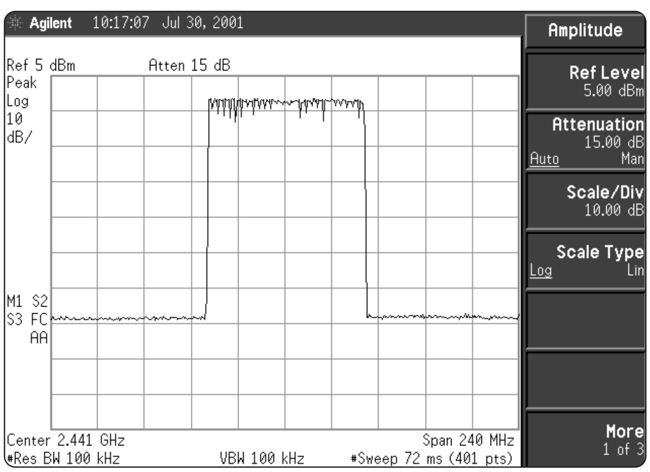
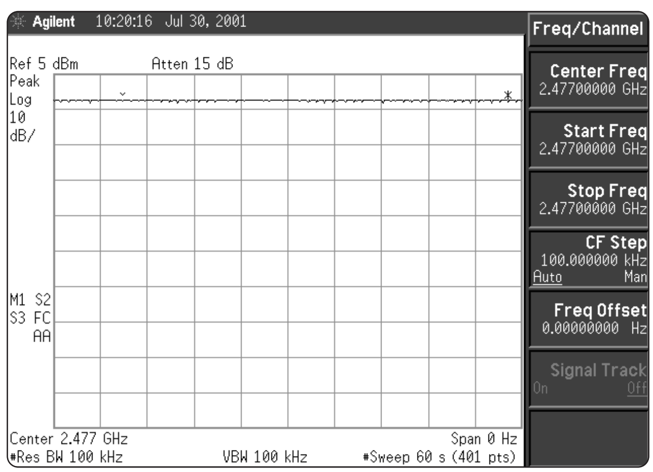


Figure 12b.
Agilent ESA-E display of power density measurement in zero span (CF = 2477 MHz, span = 0 Hz, RBW = 100 kHz, VBW = 100 kHz, peak detector, trigger free run, trace on Max Hold, sweep time = 60 s, continuous sweep)



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).

2.3 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 5**.

Table 5.
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 4 on page 7, the *Bluetooth* specification splits the test into three parts:

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

The first two tests use peak detection, while adjacent channel power uses average detection. The last two tests use a Max hold mode, while frequency range uses an averaging mode.

2.3.1 Frequency Range

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 (or 2446.5 MHz for France) and at 2483.5 MHz.

2.3.2 –20dB Bandwidth

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 13a** 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.

Note: The original test specification required the signal analyzer be set to a sweep time of "Auto," meaning that the sweep time was dependent on type and manufacturer of the signal analyzer. However, if the sweep time was too short (< 1 sec, which can happen because of the bursted signal), the measured spectrum had gaps and did not represent the correct values. For this reason, the *Bluetooth* SIG decided to require that this measurement use a sweep time higher than 1 sec.

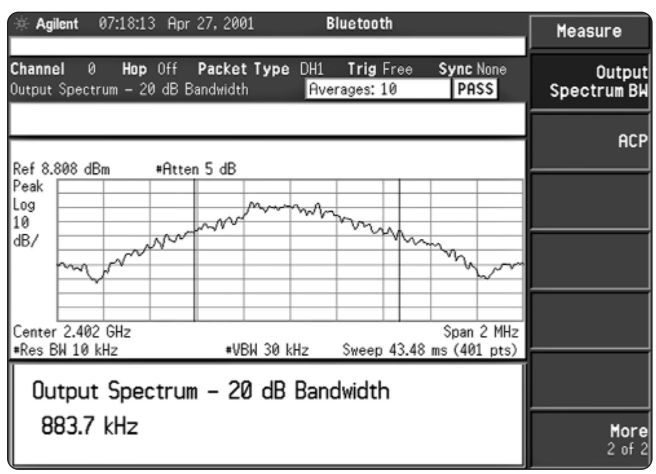
2.3.3 Adjacent Channel Power

The adjacent channel power (ACP) 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. The results are summed. The measurement channel is incremented by 1 MHz and the process repeated until the top of the band is reached. As mentioned in Table 5, with the DUT transmitting on channel M and the adjacent power measured on channel N, the following conditions must be verified for compliance:

$P_{TX}(f) \leq -20dBm$ for $|M-N| = 2$
$P_{TX}(f) \leq -40dBm$ for $|M-N| \geq 3$

Figure 13a.

–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[1] 43.48 ms (401 pt), markers automatically set to –20 dB points by measurement personality)



1. The new requirement for sweep time (>1sec) will be implemented in the next release of the *Bluetooth* measurement personality of the Agilent ESA-E spectrum analyzer. The personality will still provide the flexibility to set the sweep time to "Auto" or to decrease the sweep time from the User Interface if the measurement time has to be reduced.

With a proprietary algorithm, the Agilent ESA-E spectrum analyzer provides an ACP measurement solution by pressing a single button. It makes the complex ACP measurement easy and provides an ideal tool for pre-compliance tests.

Figure 13b shows an ACP measurement performed for channel 3 (M=3). The condition P_{TX} (f) ≤ -20dBm is checked for channel 1 and 5 (N=1,5) and the condition P_{TX} (f) ≤ -40dBm is verified for the rest of the channels (N=0,6,7,...78). The validation of this test is notified by a flag "PASS."

2.4 Modulation Tests

Bluetooth modulation measurements consist of modulation characteristics, initial carrier frequency tolerance (ICFT), 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 requires the ability to demodulate the *Bluetooth* signal so that the frequency of each bit can be determined.

2.4.1 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. More detail can be found in the introduction of this section (Transmitter Measurements on page 7) concerning the kind of stress mechanisms provided by different types of patterns.

Modulation Characteristics Process
This test procedure requires using the longest supported packets (using the longest supported payload length) and running the measurement at the lowest, middle, and highest operating frequency. For each of these three frequencies, the following process is performed for the 00001111 payload sequence and repeated for the 01010101 payload sequence:

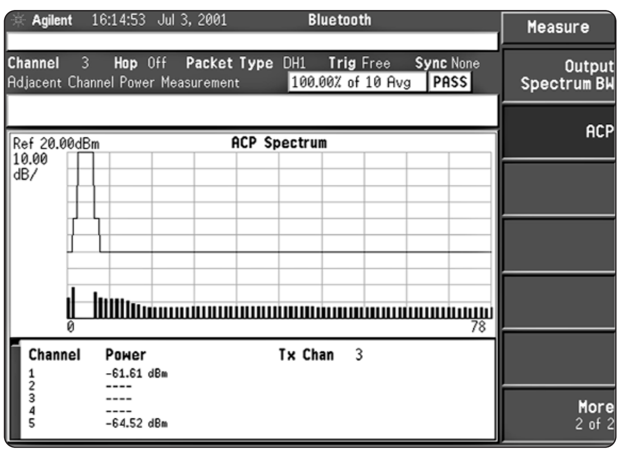
> The frequencies of each 8 bit sequence in the payload are measured and averaged together. Then the maximum deviation from the average for these bits is recorded as $\Delta F1_{max}$ for the pattern 00001111 and as $\Delta F2_{max}$ for the pattern 01010101. Finally, an average of the maximum deviation values is computed and recorded as $\Delta F1_{avg}$ for the pattern 00001111 and as $\Delta F2_{avg}$ for the pattern 01010101. Both the maximum deviations and the average of the maximum deviations are used in the result. This procedure is performed over a period of at least 10 packets.

Then the following measurement conditions are verified to ensure the validation of the modulation characteristics:

1. 140 kHz ≤ $\Delta f1_{avg}$ ≤175 kHz
2. $\Delta f2_{max}$ ≥ 115 kHz
3. $\Delta f2_{avg}/\Delta f1_{avg}$ ≥ 0.8

The Agilent E1852A Bluetooth Test Set provides the ability to perform this test automatically. An example of a modulation characteristics measurement is shown in **Figure 14a** on page 14. The upper part displays a modulation graph for the payload sequence 1111000 with a calculation of $\Delta F1_{max}$ ($\Delta F1_{max}$; see squared rectangle) and $\Delta F1_{avg}$ (see rounded rectangle). The lower part displays identical results for the sequence 10101010. The validation of this test is noted by a green bar under the calculated values in the measurement window.

Figure 13b.



Agilent ESA-E Series Spectrum Analyzer showing an ACP measurement performed on channel 3. The upper window provides an ACP spectrum (measured power versus channel) and the lower window an ACP numeric summary table listing. The latter can be extended to see the complete list of channels.

Similarly, by using the *Bluetooth* measurement personality for the Agilent ESA-E spectrum analyzer, this measurement can be performed in a few keystrokes. Presented with a 10101010 [F2] payload, both the maximum deviation $\Delta F2_{max}$ and the average of the maximum deviations $\Delta F2_{avg}$ are displayed on the screen.

The result can then be stored and a burst with the 11110000 pattern can be presented to the analyzer. The measurement process is repeated with this new 11110000 [F1] payload sequence. $\Delta F1_{max}$ and $\Delta F1_{avg}$ are computed and displayed. Then the ratio $\Delta F2_{avg} / \Delta F1_{avg}$ is generated using the stored $\Delta F2_{avg}$. If this ratio is below 80%, a "FAIL" flag is displayed.

Figure 14b shows a display of the Agilent ESA-E spectrum analyzer performing this modulation characteristics measurement. The ESA-E is measuring the 11110000 pattern and comparing it with the (previously stored; see "Hold result" menu) 10101010 pattern.

Figure 14a.

Modulation characteristics measurement using Agilent E1852A *Bluetooth* Test Set [1]. Setup: Test mode (Transmitter mode), frequency hopping OFF, channel 0, DH5 packet, maximum payload length (339), payload pattern (00001111 for upper part and 10101010 for lower part.). A change of the type of payload can be done without breaking the connection with the *Bluetooth* DUT.

1. The new release of the Agilent E1852A *Bluetooth* Test Set provides an automatic calculation of $\Delta f2_{avg}/\Delta f1_{avg}$.

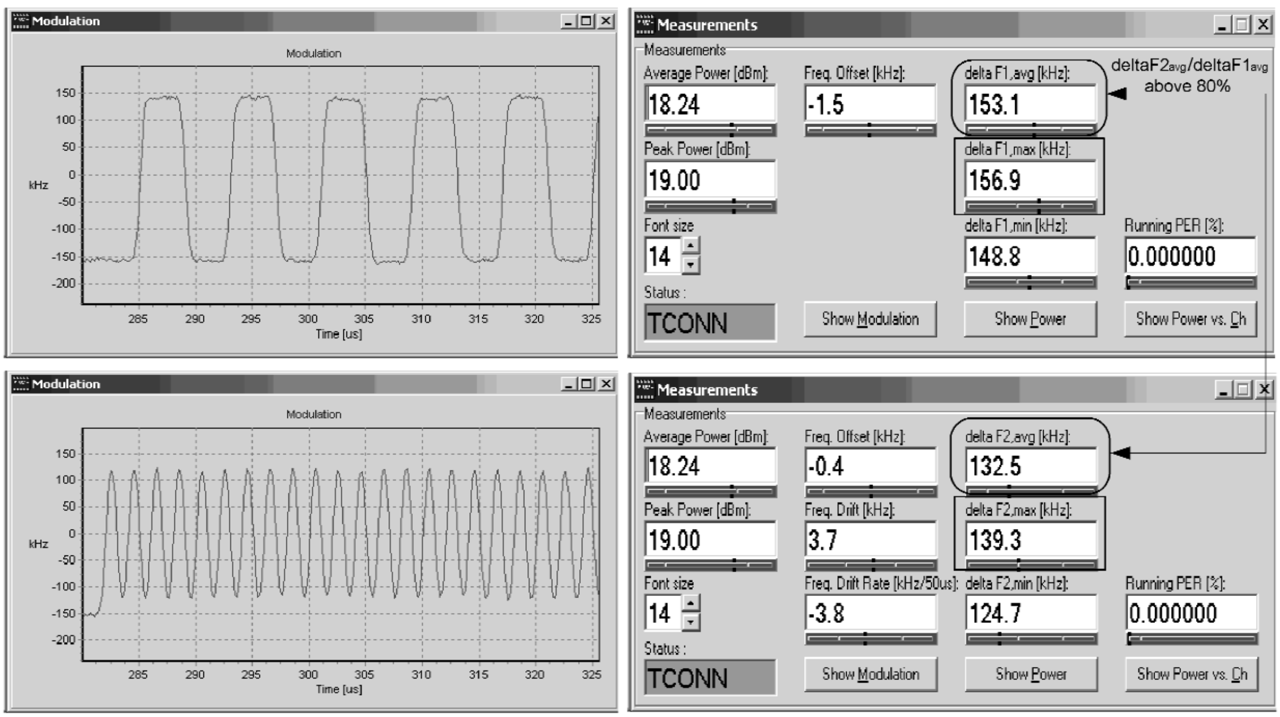
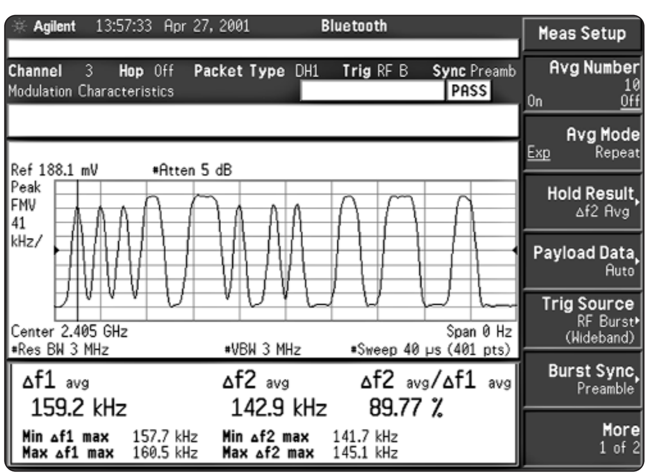


Figure 14b.

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



2.4.2 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*, modulation quality measurements such as FSK error, magnitude error, and the eye diagram are valuable troubleshooting tools. **Figure 15** 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.

2.4.3 Initial Carrier Frequency Tolerance

The initial carrier frequency tolerance test (also called frequency offset 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.

Figure 16a 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.

Figure 15.
Agilent 89600 display of demodulation quality test

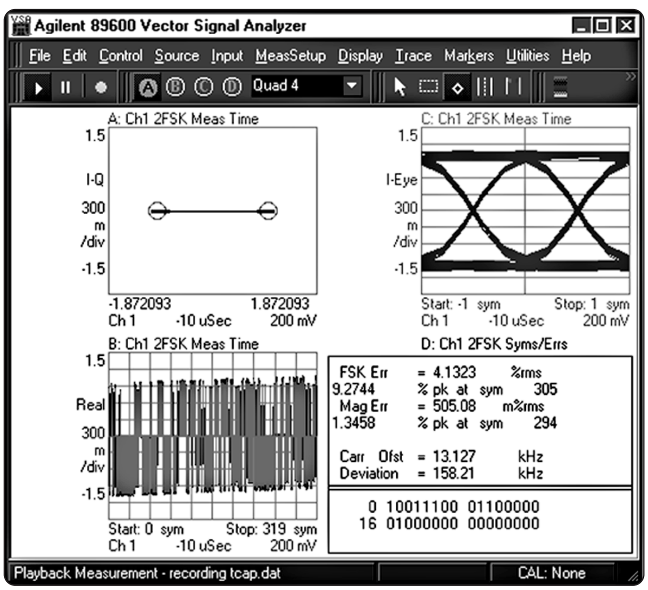


Figure 16a.
Agilent ESA-E series spectrum analyzer display showing a 482.7Hz offset modulation characteristic measurement (First 16 bits of burst displayed, 100 ns sample rate, analyzer triggering on p0 bit)

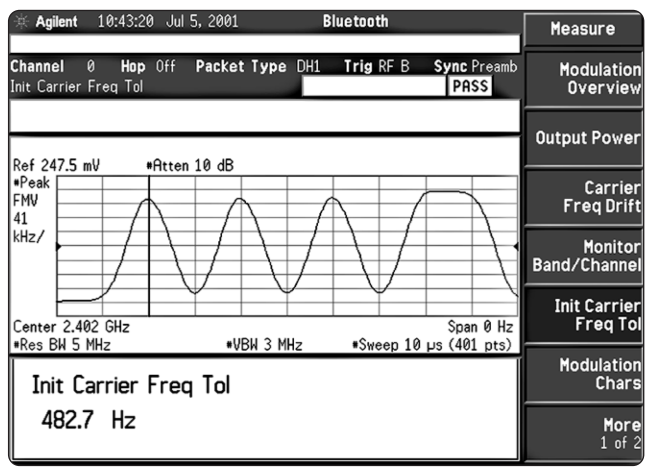


Figure 16b shows an ICFT measurement performed with the Agilent E1852A *Bluetooth* Test Set with frequency hopping on. The lower part of this figure is not part of this measurement, but shows an "Average power versus channel," showing that the signal is hopping. A similar graph with frequency hopping off will display just a power bar at the selected channel.

Both the *Bluetooth* Test Set and the spectrum analyzer use the same algorithm to calculate initial carrier frequency tolerance. An alternative method of measuring ICFT is available using Agilent 89400 and 89600 series vector signal analyzers in demodulation mode. This is a more generic method. With their result length set to the minimum number of symbols (10), these analyzers provide the carrier offset at a glance in their 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 15 on page 15, provides an example of this initial carrier offset measurement.

2.4.4 Carrier Frequency Drift

Carrier frequency drift consists of verification of the transmitter center frequency drift with a packet. As the two previous tests, modulation characteristics and initial carrier frequency tolerance, carrier frequency drift is also measured as a demodulated signal (frequency versus time).

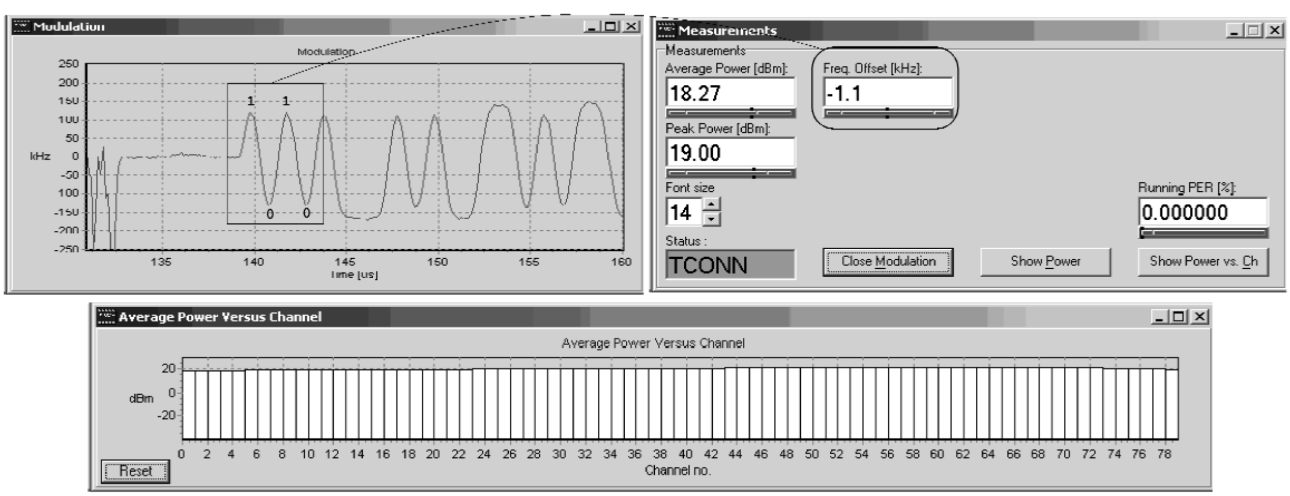
The payload data consists of a repeating 4-bit 1010 sequence. To perform the measurement, the absolute frequencies of the 4 preamble bits are measured and integrated; this provides the initial carrier frequency. Then the absolute frequencies of each successive 10-bit part in the payload are measured 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: one-slot packet (DH1), three-slot packet (DH3), and five-slot packet (DH5).

Software control makes this repetitive measurement easier. **Figure 17a** on page 17 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 30 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.

As mentioned before, this carrier frequency drift test is required for three types of packets (DH1, DH3, DH5) with frequency hopping on and frequency hopping off (at the lowest, middle, and highest frequency channel). In total, the number of measurements required is 12. Obviously, this can be time-consuming. If this is an issue, "test sequencer" software may be the tool to use.

The Agilent E1852A *Bluetooth* Test Set is provided with such a "test sequencer". **Figure 17b** on page 17 shows how the test sequencer could be used for carrier frequency drift test. The 12 measurements are performed in less than 5 seconds and each measurement is validated according to the following *Bluetooth* test specification limits:

Figure 16b.
Agilent E1852A *Bluetooth* Test Set display showing an ICFT measurement with frequency hopping on. The "Average power versus channel" graph shows how the signal is hopping over 78 channels. Setup: Test mode (Transmitter mode), frequency hopping on, DH1 packet with pseudorandom bit sequence (PRBS) as payload.



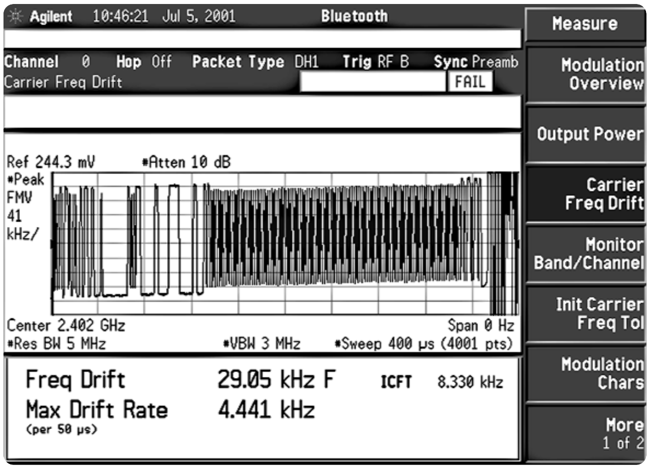


Figure 17a.
Agilent ESA-E spectrum analyzer display of frequency drift showing an initial carrier frequency (ICFT) of 8.330 kHz, 29.05 kHz drift across the burst and 4.441 kHz maximum drift rate. (CF=2.402 GHz, triggered on p0 bit; F indicates maximum frequency drift limit exceeded).

The transmitter center frequency is not allowed to drift more than ±25 kHz for a one-slot packet, ±40 kHz for a three- to five-slot packet, and the maximum drift rate must be ±20kHz/50µs.

The calculation of the latter figure has not been included in the test sequencer program but can easily be implemented by inserting the command requesting this calculation into the original program. The command can be read from the Communications window of the *Bluetooth* Test Set. See **Figure 17c**.

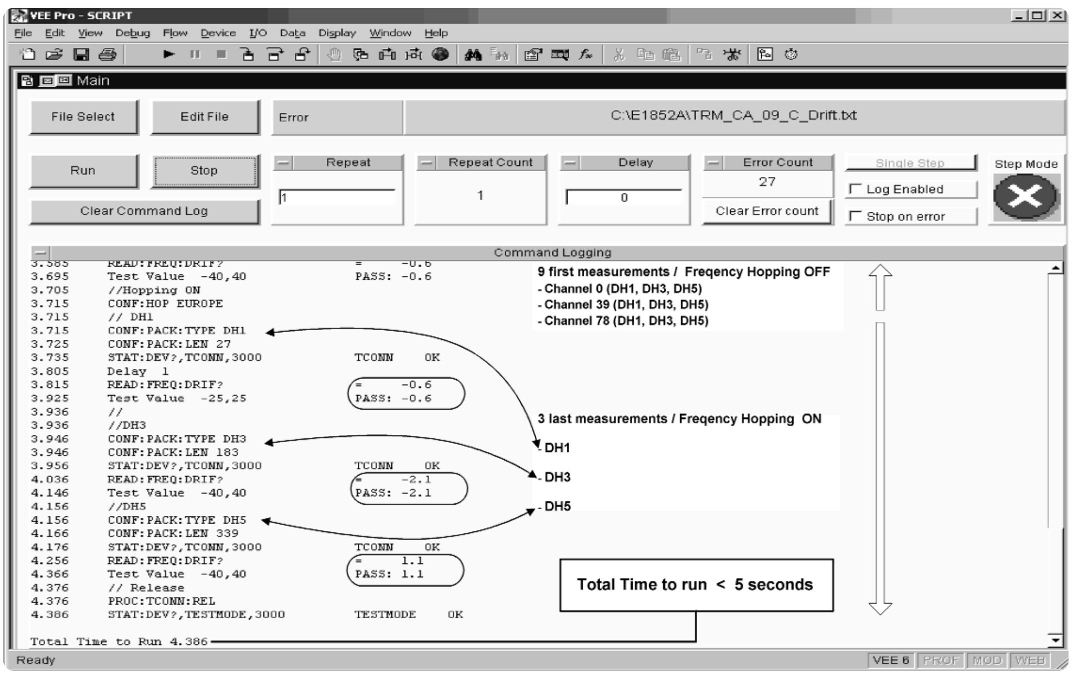


Figure 17b.
Interface of the "Test sequencer" provided with the Agilent E1852A *Bluetooth* Test Set showing the performance of the 12 measurements requested for the carrier frequency drift test.

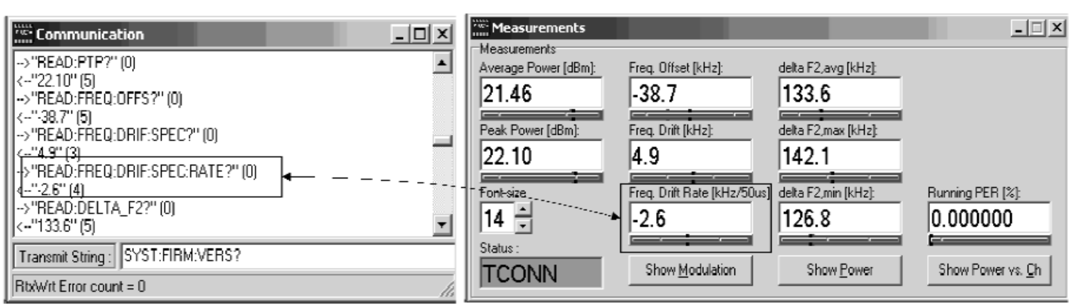


Figure 17c.
Measurement and communications window of the Agilent E1852A *Bluetooth* Test Set showing a maximum drift rate measurement and the control command associated with its calculation.

2.5 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.

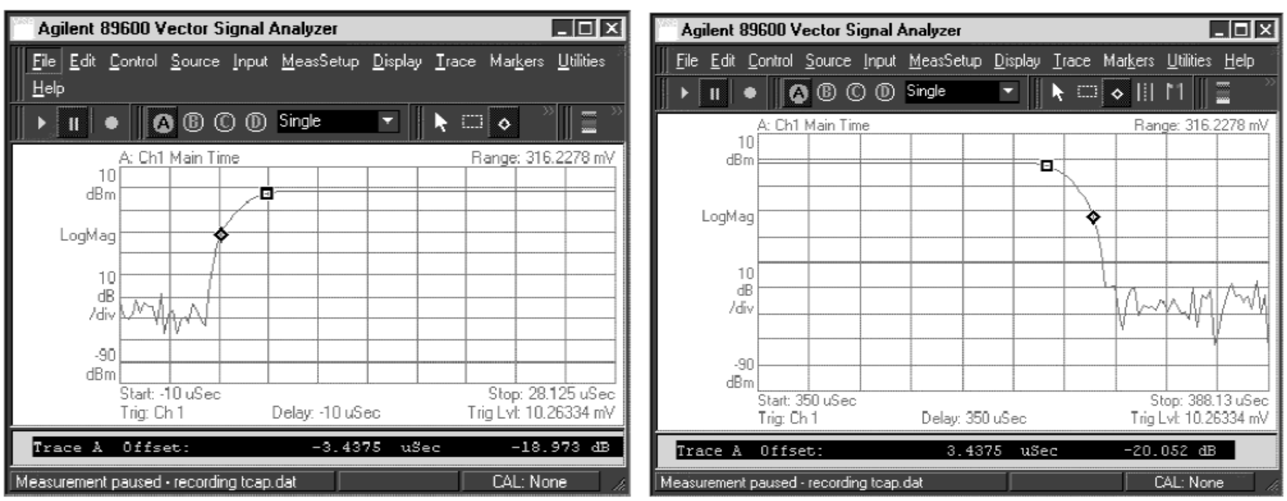
2.5.1 Burst Profile

Burst rise and fall time can be measured in the time domain using a signal analyzer or a power meter. 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% (–20 dB) amplitude point to the 90% (–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 18** provides a measurement example of a burst rise time and a burst fall time. Additional burst profile characteristics include on/off ratio of burst, overshoot, burst interval, and burst repetition frequency (see Figure 10 on page 9). These characteristics can be seen in detail using the Agilent power meter analyzer software.

2.5.2 Spectrogram Measurements

Figure 19a on page 19 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 indicating higher amplitudes.

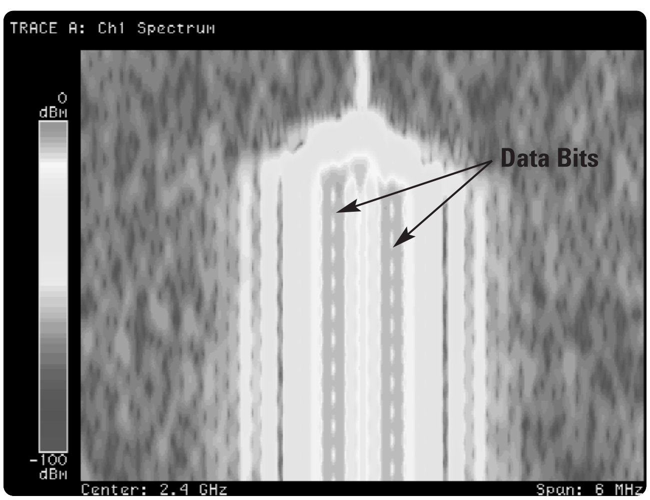
Figure 18.
Agilent 89600 displays showing burst rise and burst fall times (CF=2.45 GHz, Span=3MHz, vector mode, triggering on IF, main time ch1, magnitude log (dB), main length=20µs)



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 19b** 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 19a.
Agilent 89441A spectrogram display for PLL settling time

Figure 19b.
Agilent 89441A spectrogram display for symbol timing and rate



3. Transceiver Measurements

The transceiver measurements consist of performing some out-of-band spurious emissions tests.

These out-of-band spurious emissions tests verify 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 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 can be 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*. 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 with 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

In this section, the various receiver measurements required for *Bluetooth* modules are discussed. These measurements are intended to ensure the integrity of the *Bluetooth* receiver's performance characteristics. Further detail regarding the conditions under which the receiver measurements are performed can be found in the *Bluetooth RF Test Specification*. 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

Bit error rate (BER) is the criterion used to evaluate receiver performance. BER is determined by comparing transmitted and received payload data and noting the difference in bits. The ratio of the erroneous bits to the total number of bits received is the BER.

4.1 Test Conditions and Setup

4.1.1 Test Conditions

Table 6 is a summary of the test conditions under which receiver measurements have to be performed.

4.1.2 BER Test Setup

Different measurement setups can be used to perform a BER measurement. Similar to the transmitter measurement setup, a BER measurement can be performed using a *Bluetooth* standalone tester (see Figure 8 on page 8), or with a test system.

A BER measurement performed with the Agilent E1852A *Bluetooth* Test Set is shown in **Figure 20a**. A link has been established between the standalone tester and the *Bluetooth* DUT. The DUT, operating in loopback test mode, receives, demodulates, and decodes the incoming signal. It then re-packets the recovered payload data in the same packet type as it received and re-transmits the packet. The returned packet is then received by the *Bluetooth* Test Set, which performs a BER measurement. The *Bluetooth RF Test Specification* specifies a minimum of 1,600,000 returned payload bits to be analyzed in performing a receiver measurement.

A BER measurement can also be performed using a basic test system consisting of a signal generator with BER analysis capability and a signal analyzer with FM demodulation capability. The measurement setup is illustrated in **Figure 20b** on page 21. For this setup, a special internal "Test Facilities" utility must be implemented in the device. This utility must have the ability to ask to the device to retransmit the packets it receives. This will allow a *Bluetooth* signal from the digital signal generator to be received, demodulated by the device's receiver, looped back through its transmitter and sent back to the spectrum analyzer. This signal will then be demodulated by the spectrum analyzer and resent to the signal generator to perform the BER measurement.

Table 6. 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%

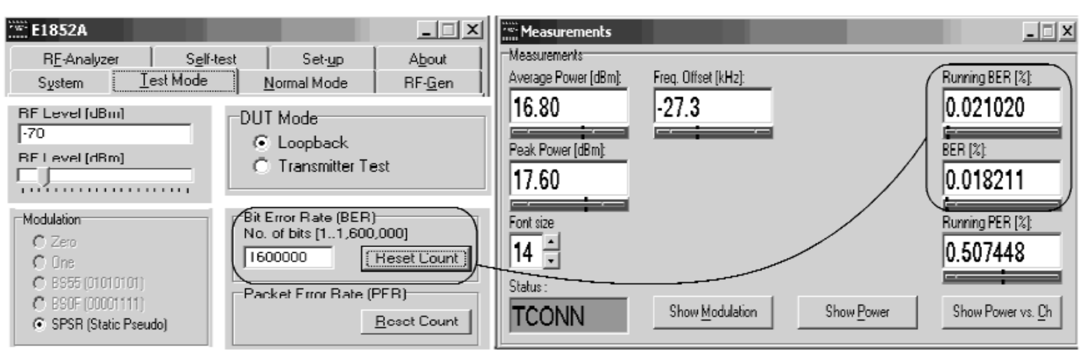


Figure 20a.
Agilent E1852A *Bluetooth* Test Set performing a BER measurement. With an input power level of –70dBm, the BER of the DUT receiver is equal to 0.018. Setup: Loopback mode, frequency hopping off, DH1 packet with pseudorandom bit sequence (PRBS) as payload.

In both of the previous measurement setups, the *Bluetooth* device must have the ability to retransmit the recovered data from the received signal. It must support loopback test mode (setup used in Figure 20a) or have a "loopback test facility" internally implemented (setup of Figure 20b). If this is not the case, a different setup must be used.

Figures 20c and 20d provide two examples of BER measurement setups in which the *Bluetooth* DUT is simply acting as a standard receiver. No loopback is performed between its receiver and its transmitter. The BER measurement is performed using the Agilent ESG-D signal generator series' internal BER analyzer (Option UN7).

As shown in Figure 20c, the *Bluetooth* DUT receives and demodulates the signal from the ESG-D, providing access at the FM discriminator output. The demodulated packets are then fed to the data input of the signal generator's BER analyzer. A TTL converter is required for signal conditioning between the FM discriminator output and the BER analyzer input.

Using the measurement setup shown in Figure 20d, the *Bluetooth* DUT receives and demodulates the signal, then provides access to the *Bluetooth* Baseband signal at the Baseband Processor. Similar to the previous setup, the *Bluetooth* packets at the output of the Baseband Processor are fed to the data input of the ESG-D's internal BER analyzer. For additional details on BER analysis using the Agilent ESG-D series digital signal generator, refer to the Agilent Product Note, *Agilent Technologies Signal Studio–Bluetooth for the ESG, Option 406*.

Figure 20b.
Example of BER measurement setup using a basic test system consisting of an Agilent ESG digital series signal generator and an ESA-E spectrum analyzer. The *Bluetooth* DUT provides an RF loopback signal.

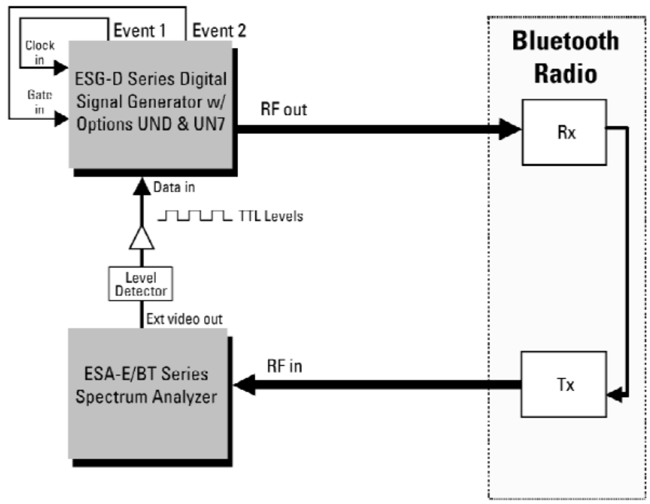


Figure 20c.
Example 1: Measurement setup illustrating how a BER measurement can be performed when the *Bluetooth* DUT receiver provides access to the demodulated *Bluetooth* signal at the FM discriminator output.

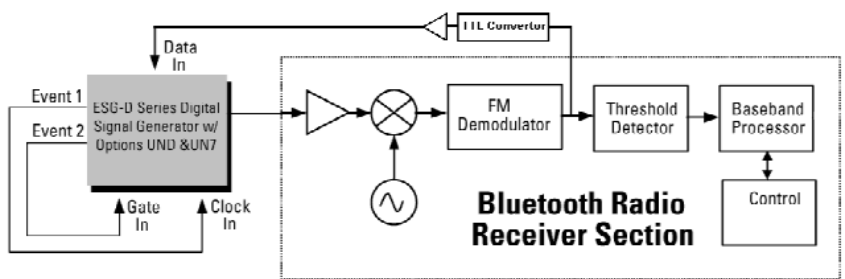
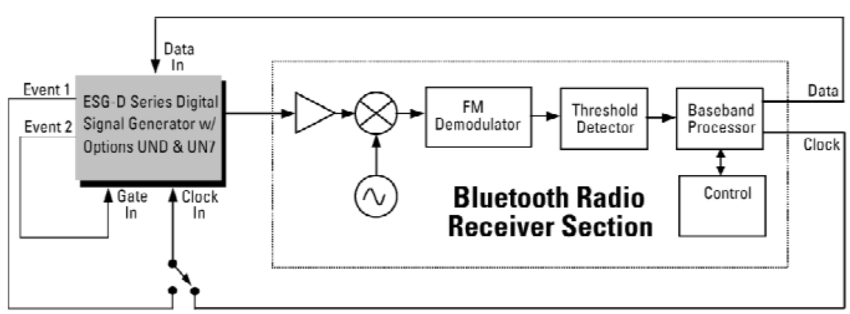


Figure 20d.
Example 2: Measurement setup showing how a BER measurement can be performed when the *Bluetooth* DUT receiver provides access to the *Bluetooth* Baseband signal at the Baseband Processor output.



As an alternative, Packet Error Rate (PER) measurements instead of BER measurements can be made when the *Bluetooth* device does not support Loopback mode. Because PER measurements do not require the *Bluetooth* DUT to operate in Loopback mode, they can be performed using the *Bluetooth* Test Set operating in either Transmitter test mode or in Normal mode. Although the PER measurement is not part of the *Bluetooth RF Test Specification*, it still provides insight into the performance of the *Bluetooth* receiver. PER measurement is performed by the *Bluetooth* Test Set as follows: In transmitter (TX) Test mode, the *Bluetooth* DUT is instructed by the *Bluetooth* Test Set to transmit specific packet types. This instruction is sent by the *Bluetooth* Test Set via POLL packets. A POLL packet has no payload and therefore consists of the channel access code and packet header only. Two situations have to be taken into account. The first one is the DUT does not receive the POLL packet (power level too low); in this case the DUT may just not transmit any TX packet. The second situation is the DUT receives the POLL packet but does not read it correctly. For instance, it does not detect the access code of the POLL packet. In this case, the DUT will send back the corresponding TX packet but with the ARQN bit (acknowledgment indication bit) set to NAK (Negative acknowledge, ARQN = 0). As a result, the *Bluetooth* Test Set will determine the PER by comparing the number of POLL packets sent with the number of TX packets received from the DUT, and by analyzing how many TX packets have a ARQN bit equal to 0 (NAK).

$$\text{PER\%}_{\text{(In TX Mode)}} = \frac{100 \times [\text{Number of TX packets missing} + \text{Number of TX packets with a ARQN} = 0]}{\text{Number of POLL Packets sent}}$$

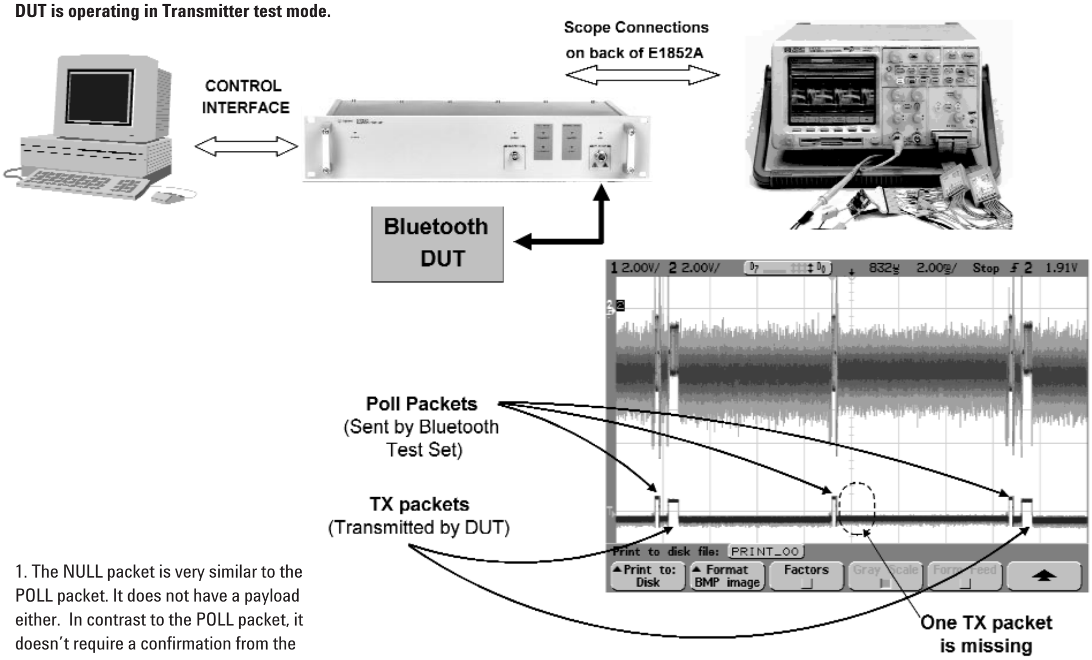
A similar calculation can be performed in Normal mode. In Normal mode, the Test Set sends some POLL packets. If the DUT receives them and reads them correctly, it will send back a NULL[1] packet for each good reading. The PER calculation will be performed by the Test Set in Normal mode by comparing the number of POLL packets sent with the number of NULL packets received.

$$\text{PER\%}_{\text{(In Normal Mode)}} = \frac{100 \times [\text{Number of POLL packets sent} - \text{Number of NULL packet received}]}{\text{Number of POLL Packets sent}}$$

To help understand PER measurements, an oscilloscope, such the Agilent 54620 Series Mixed Signal Oscilloscope, can be used to visualize the transmitted packets and determine when one is missing. See **Figure 21**.

Figure 21.

Setup with an Agilent E1852A *Bluetooth* Test Set and an Agilent 54620 Series Mixed Signal Oscilloscope to visualize packet error. The *Bluetooth* DUT is operating in Transmitter test mode.

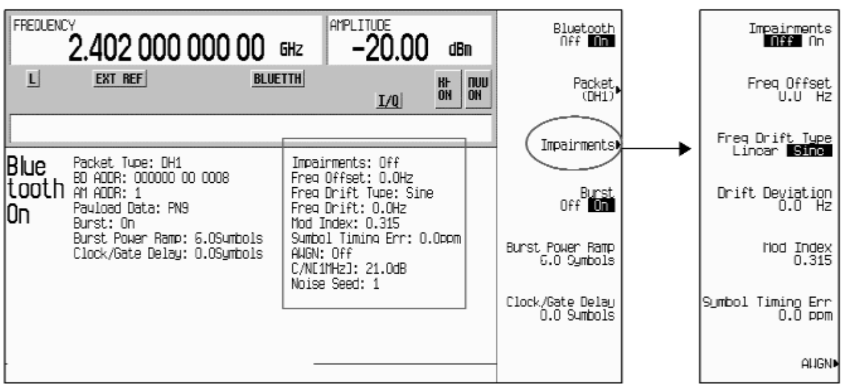


1. The NULL packet is very similar to the POLL packet. It does not have a payload either. In contrast to the POLL packet, it doesn't require a confirmation from the recipient.

4.2 Sensitivity—Single-slot Packets

Bluetooth receiver sensitivity is a measure of the minimum signal level required by the receiver to produce a maximum allowed BER. Sensitivity is tested by sending a *Bluetooth* signal with various impairments to the receiver and measuring the BER of the recovered payload data. A set of 10 different “dirty” transmitter packets are defined by the *Bluetooth RF Test Specification*, with impairments including carrier frequency offset, carrier frequency drift, modulation index, and symbol timing drift. The Agilent ESG-D digital series of signal generators provides a simple menu for adding these impairments to a *Bluetooth* signal. (See **Figure 22**.) To meet the specifications, the receiver’s BER must not exceed 0.1% when the transmit power is such that the signal level at the receiver input is -70 dBm. This is referred to as the reference sensitivity level and all *Bluetooth* receivers must meet this specification. The actual sensitivity of a *Bluetooth* receiver is the signal level required by the receiver to produce a 0.1% BER. The test is performed at the lowest, middle, and highest operating frequencies of the DUT.

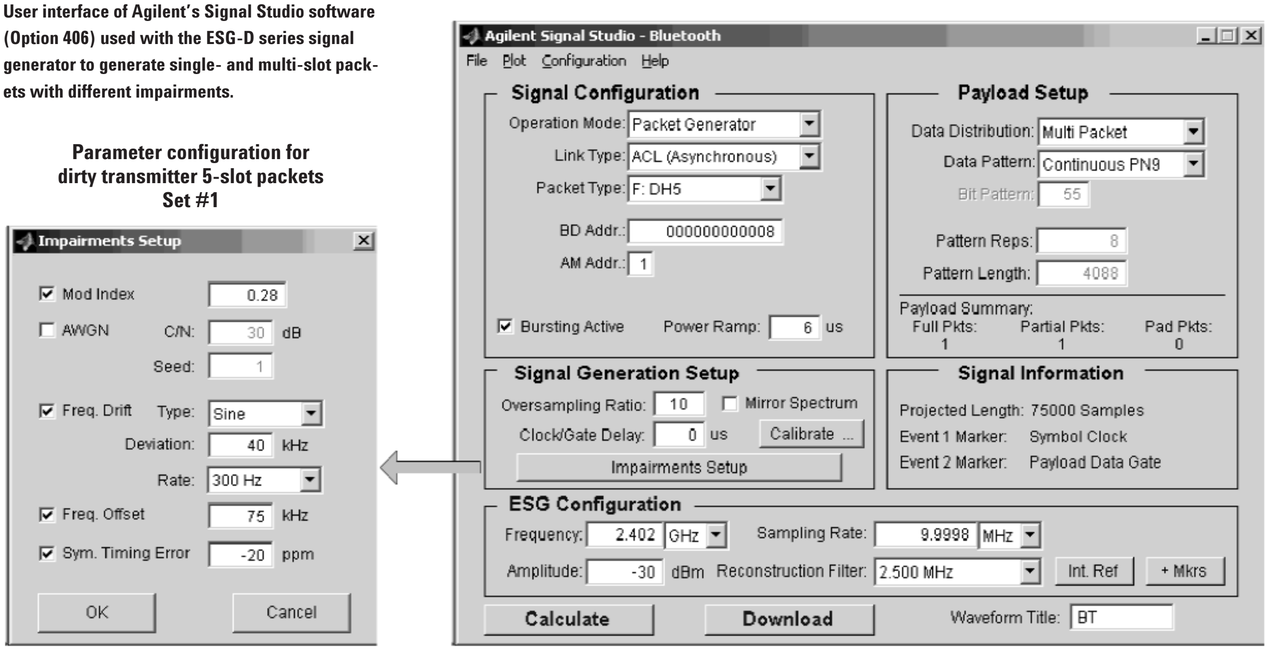
Figure 22.
The ESG-D digital series signal generator user interface (Option UND), showing the different impairment that can be generated with this signal source.



4.3 Sensitivity—Multi-slot Packets

Multi-slot packet sensitivity measurement is very similar to that of single-slot packets. The key difference is that the multi-slot packet sensitivity measurement is performed using impaired DH3 or DH5 packets rather than impaired DH1 packets, as is the case with the single-slot sensitivity measurement. The longest packet type supported by the device under test is used to measure multi-slot packet sensitivity. As shown in **Figure 23**, a software personality is available for use with the Agilent ESG-D signal generator to simplify the creation of impaired *Bluetooth* packets.

Figure 23.
User interface of Agilent’s Signal Studio software (Option 406) used with the ESG-D series signal generator to generate single- and multi-slot packets with different impairments.



4.4 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 interference performance on co-channel and adjacent 1 MHz and 2 MHz channels is measured with the desired signal 10dB over the reference sensitivity level. On all other frequencies, the desired signal must be 3dB over the reference sensitivity level.[1] Additional details on the structure of the interference signal are given in the *Bluetooth RF Test Specification*. The test is performed at the lowest, middle, and highest operating frequencies of the receiver, with the interfering signals at all operating frequencies within the band. The BER must be ≤ 0.1%.

Notes: The original *Bluetooth RF Test Specification* required the wanted and interference signals to be bursted. However, problems arose because both signals were bursted and not synchronized. As a result, overlap of the desired signal and interference signal bursts could differ from 0 to 100%. In the worst case (0%), the *Bluetooth* device receiver did not experience any interfering signal. On the other hand, in the best case there was 100% overlap. The lack of a synchronization definition inherently leads to a situation in which test results cannot be reproduced. Consequently, the *Bluetooth* SIG requested that the original test specification be replaced with the following requirement: The modulated interfering signal shall be continuously modulated (not bursted). This ensures 100% overlap of the interference and wanted signal.

Figure 24 shows an example of a setup that could be used to perform this carrier-to-interference performance test. The Agilent E1852A *Bluetooth* Test Set establishes communication with the *Bluetooth* DUT and provides the wanted signal, while the ESG-D digital signal generator produces a *Bluetooth* modulated interfering signal. The returned packets from the *Bluetooth* DUT are received by the *Bluetooth* Test Set and the BER is measured.

4.5 Blocking Performance

The receiver blocking performance is measured by sending a continuous wave (CW) interfering signal with the desired signal and then measuring the receiver's BER. The desired signal is transmitted at 3dB over the reference sensitivity level[1] at a frequency of 2460 MHz. The CW interfering signal (blocking signal) ranges from 30 MHz to 12.75 GHz in 1 MHz increments. Within this frequency band, different power levels for the interfering signal have been defined in the *Bluetooth RF Test Specification*. The BER measurement, performed under the conditions described above, must be ≤ 0.1% to validate the receiver's performance in the presence of a blocking signal.

The blocking performance measurement can be performed with a similar setup (see **Figure 24**) by replacing the ESG-D signal generator with an analog source. The new Agilent Microwave Performance Signal Generator (E8241A) is ideal for this application. Its features include a step/list sweep at the frequencies and power levels required for the blocking signal.

4.6 Intermodulation Performance

Intermodulation performance measures unwanted frequency components resulting from the interaction of two or more signals passing through a non-linear device. The desired signal is transmitted at frequency f_0 with a power level 6dB above the reference sensitivity level[1]. In order to create intermodulation products (3rd, 4th, and 5th order), two types of signals with power levels of –39dBm are generated. The first is a static sine wave signal at frequency f_1, while the second is a *Bluetooth* modulated signal at frequency f_2. Both signals must fulfill the following conditions:

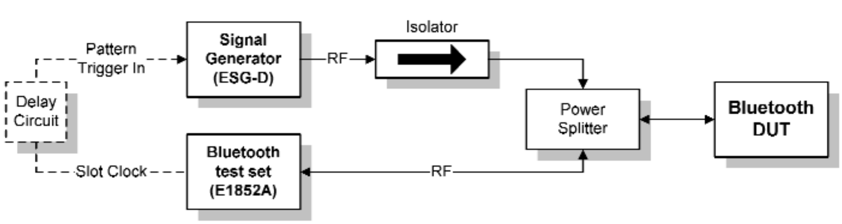
$f_0 = 2f_1 - f_2$ and
$|f_2 - f_1| = n * 1\text{MHz}$,
where n can be 3, 4, or 5.

The BER is then measured; any BER > 0.1% indicates a problem in the performance of the receiver in the presence of intermodulation distortion. The setup of **Figure 24** can be reused to perform the intermodulation performance measurement by adding an additional interference source to provide the static sine wave signal.

4.7 Maximum Input Level

The maximum input level test measures the receiver's 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.

Figure 24.
Example setup used to perform the carrier-to-interference (C/I) performance test. The part within the dotted line does not need to be implemented with the new revision of the *Bluetooth RF Test Specification* (the interfering signal is continuous and not bursted, so no synchronization is needed).



1. The reference sensitivity level is -70 dBm.

5. Power Supply Measurements

The Bluetooth RF Test Specification 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. More details on these measurements can be found in the "Pre-integration Factors" section of the Agilent application note, *Investigating Bluetooth Modules* (literature number 5988-2417EN) Application Note #AN 1333-2.

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: 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 –all of which puts the slave unit in varying states 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–A net formed be multiple independent and nonsynchronized piconets. 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 B: 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

DUT Device Under Test

EIRP Equivalent Isotropically Radiated Power (Effective Isotropic Radiated Power)

EMC Electromagnetic Compatibility

ETSI European Technical Standards Institute

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

RSSI Receiver Signal Strength Indicator

RF Radio Frequency

SCO Synchronous Connection-Oriented link

SIG *Bluetooth* Special Interest Group

TDD Time Division Duplex

VBW Video Bandwidth

VSA Vector Signal Analyzer

Appendix C: Recommended Reading for *Bluetooth*

The following documents are accessible via the Agilent *Bluetooth* website:
www.agilent.com/find/bluetooth

Application Notes

Investigating Bluetooth Modules: The First Step in Enabling Your Device with a Wireless Link, Application Note AN 1333-2, lit. no. 5988-2417EN

Verifying Bluetooth Baseband Signals using Mixed Signal Oscilloscopes, Application Note AN 1333-3, lit. no. 5988-2181EN

Bluetooth RF Testing—The Right Test for the Radio Design, Agilent Article, web only

Product Overviews

Agilent Technologies Solutions for Bluetooth Wireless Technology, brochure, lit. no. 5980-3032EN

Agilent E1852A Bluetooth Test Set Data Sheet, lit. no. 5988-1978EN

Agilent Bluetooth Measurement Solution for the ESA-E Series Spectrum Analyzers Product Overview, lit. no. 5980-2786EN

Agilent ESA-E Series Spectrum Analyzer Bluetooth™ Measurement Option, Self-Guided Demo, Product Note, lit. no. 5980-2577EN

Agilent Technologies Signal Studio—Bluetooth for the ESG, Option 406, Product Note, web only

Agilent EPM-P Series Single- and Dual-Channel Power Meters Demo Guide, lit. no. 5988-1605EN

New Design and Test Solution for W-CDMA/EDGE/Bluetooth in the 89400 Series Vector Signal Analyzer, lit. no. 5968-7347E

Agilent EEs of EDA E5616A/AN Bluetooth DesignGuide, lit. no. 5988-0701EN

Generic RF Recommended Reading

Application Notes

8 Hints for Making Better Measurements Using RF Signal Generators, Application Note 1306-1, lit. no. 5967-5661E

8 Hints for Making Better Spectrum Analyzer Measurements, Application Note 1286-1, lit. no. 5965-7009E

Cookbook for EMC Precompliance Measurements, Application Note 1290-1, lit. no. 5964-2151E

Measuring Bit Error Rate using the Agilent ESG-D Series RF Signal Generators Option UN7, lit. no. 5966-4098E.

Spectrum Analysis, Application Note 150, lit. no. 5952-0292.

Testing and Troubleshooting Digital RF Communications Receiver Designs, Application Note 1314, lit. no. 5968-3579E

Testing and Troubleshooting Digital RF Communications Transmitter Designs, Application Note 1313, lit. no. 5968-3578E

Product Notes

Agilent 89600 Series Wide Bandwidth Vector Signal Analyzers, lit. no. 5980-0723E

Using Vector Modulation Analysis in the Integration, Troubleshooting, and Design of Digital RF Communications Systems, Product Note 89400-8, lit. no. 5091-8687E

10 Steps to a Perfect Digital Demodulation Measurement, Product Note 89400-14A, lit. no. 5966-0444E

Customizing Digital Modulation with the Agilent ESG-D Series Real-Time I/Q Baseband Generator, Option UN8, lit. no. 5966-4096E

Generating and Downloading Data to the Agilent ESG-D RF Signal Generator for Digital Modulation, lit. no. 5966-1010E

Generating Digital Modulation with the Agilent ESG-D Series Dual Arbitrary Waveform Generator, Option UND, lit. no. 5966-4097E

Appendix D: Agilent Solutions for *Bluetooth* Wireless Technology

Agilent Equipment for *Bluetooth* testing

● = Meets fully specified *Bluetooth* test requirements
◆ = Not fully compliant to *Bluetooth test* requirements; pre-compliance testing only

***Bluetooth* RF Layer Test Cases**	**E1852A *Bluetooth* Test Set**	**ESA-E Series Spectrum Analyzers [1]**	**ESG-D Series Signal Generators [2]**	**EPM-P Series Power Meters [3]**	**89400/600 Series E4406A Series Vector Signal Analyzers [4]**
Transmitter Tests					
Output Power [TRM/CA/01/C]	●	●		●	●
Power Density [TRM/CA/02/C]		●			●
Power Control [TRM/CA/03/C]	●	●		●	●
TX Output Spectrum-Frequency Range [TRM/CA/04/C]		●			●
TX Output Spectrum-20 dB Bandwidth [TRM/CA/05/C]		●			●
TX Output Spectrum-Adjacent Channel Power [TRM/CA/06/C]		◆			●
Modulation characteristics [TRM/CA/07/C]	●	●			●
Initial carrier frequency tolerance [TRM/CA/08/C]	●	●			●
Carrier frequency drift [TRM/CA/09/C]	●	●			●
Transceiver Tests					
Out-of-Band Spurious Emission [TRC/CA/01/C]		●			◆
Receiver Tests					
Sensitivity/single-slot packets [RCV/CA/01/C]	◆		●		
Sensitivity/multi-slot packets [RCV/CA/02/C]	◆		●		
C/I performance [RCV/CA/03/C]	● [5]		● [5]		
Blocking performance [RCV/CA/04/C]	● [6]		● [6]		
Intermodulation performance [RCV/CA/05/C]	● [7]		● [7]		
Maximum input level [RCV/CA/06/C]			●		

1. Requires Options 303 or 304 (General Purpose Bundle for *Bluetooth* wireless technology).

2. Requires Option UND (Dual Arbitrary Waveform Generator), Option UN8 (I/Q Baseband Generator), Option UN7 (Baseband BER Analyzer), and Option 406 (Signal Studio-*Bluetooth* software).

3. Requires Agilent E9322A/E9326A sensors with a minimum of 1.5 MHz bandwidth

4. Agilent 89400 Series requires Options AYA (Vector Modulation Analysis) and AY9 (Extended Time Capture). Agilent 89600 Series requires Options AYA (Vector Modulation Analysis) and 288 (288MB Time Capture RAM). Option AYB (Waterfall and Spectrogram) is required for spectrograms. Agilent E4406A Series, for *Bluetooth* testing, must be used with Agilent 89601A vector signal analysis software.

5. Requires an additional signal source with *Bluetooth* capability for the interfering signal.

6. Requires Agilent E8241A Microwave Performance Signal Generator to generate the CW interfering signal (30MHz-12.75GHz).

7. Requires two additional signal sources (one standard and one with *Bluetooth* capability) to generate intermodulation.

Appendix E: References

1. *Bluetooth Test Specification*–RF, Part A, First revision for Specification 1.1, Revision 0.91, July 2, 2001–*Bluetooth* SIG
2. *Specification of the Bluetooth System*–Version 1.1, Volume 1 "Core", February 22, 2001–*Bluetooth* SIG
3. The Official **Bluetooth** Website, **www.bluetooth.com**. Includes information on *Bluetooth* history, technology, news, specifications, applications, products, events, and *Bluetooth* Special Interest Group (SIG). The *Bluetooth* SIG–Members area web site, **www.bluetooth.org** provides access to *Bluetooth Test Specification*, announcements and pre-release specifications. This website is password protected.

For More Information

For information on how Agilent Technologies' products, services, and training can help you in *Bluetooth* testing, please contact us in any of the following ways:

Go to **www.agilent.com/find/bluetooth** for online assistance.

Agilent Technologies' Test and Measurement Support, Services, and Assistance
Agilent Technologies aims to maximize the value you receive, while minimizing your risk and problems. We strive to ensure that you get the test and measurement capabilities you paid for and obtain the support you need. Our extensive support resources and services can help you choose the right Agilent products for your applications and apply them successfully. Every instrument and system we sell has a global warranty. Support is available for at least five years beyond the production life of the product. Two concepts underlie Agilent's overall support policy: "Our Promise" and "Your Advantage.

Our Promise
Our Promise means your Agilent test and measurement equipment will meet its advertised performance and functionality. When you are choosing new equipment, we will help you with product information, including realistic performance specifications and practical recommendations from experienced test engineers. When you use Agilent equipment, we can verify that it works properly, help with product operation, and provide basic measurement assistance for the use of specified capabilities, at no extra cost upon request. Many self-help tools are available.

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