Agilent AN 1333

Performing Bluetooth RF Measurements Today

Application Note

Bluetooth™

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Introduction

Bluetooth is an open specification for a wireless personal area network. It provides limited range RF connectivity for voice and data transmissions between information appliances. The Bluetooth 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 Bluetooth is credited with uniting Denmark and Norway during his reign. Similarly today, Bluetooth unites technologies.

Bluetooth will allow seamless interconnectivity among devices. Computers and Personal Digital Assistants (PDAs) will be able to share files and synchronize databases remotely; laptop PCs will be able to 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 technology is in its early development stages, test methodologies will differ from those typically seen in mature technologies. Test procedures may require manual intervention or custom software control, as opposed to mature technologies in which easy-to-use, one-button measurements are available. 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.

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.

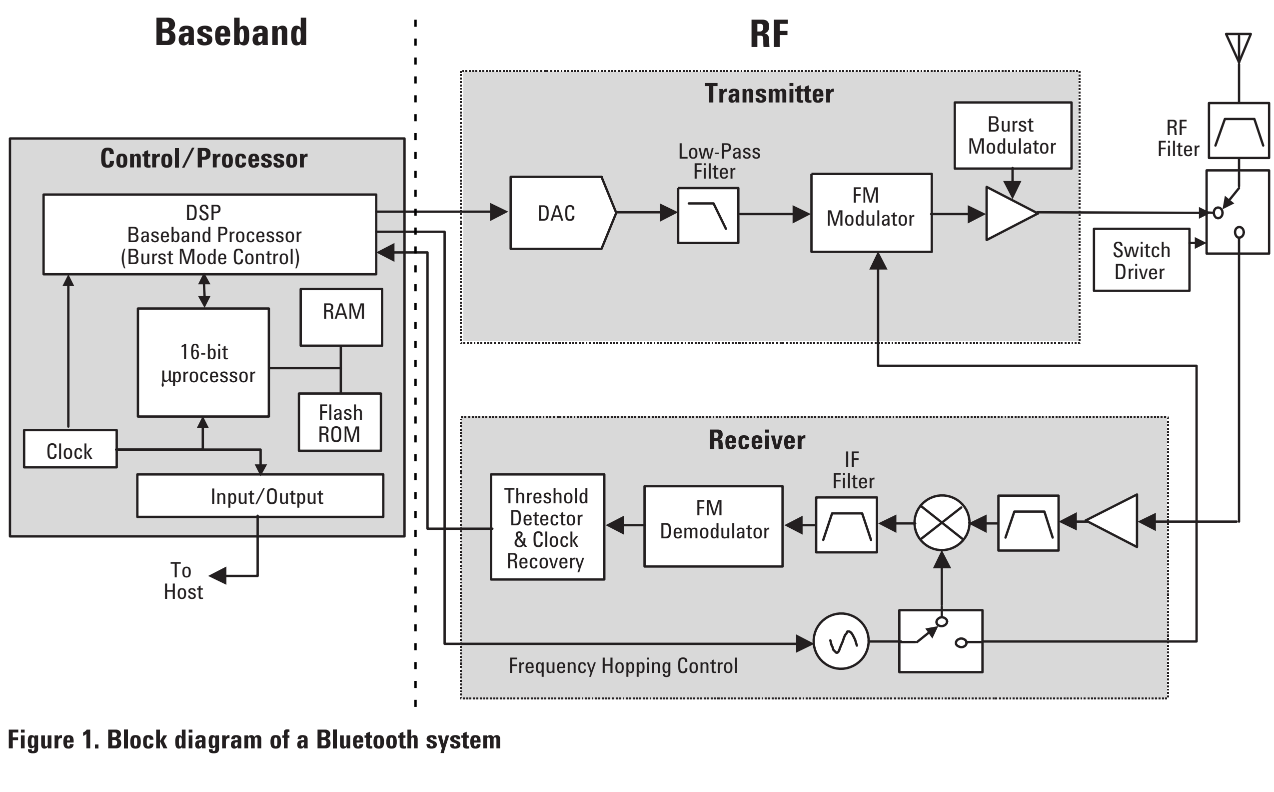


Figure 1. Block diagram of a Bluetooth system

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.[2] 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) exceptions: 2445 to 2475 MHz (Spain) 2446.5 to 2483.5 MHz (France) 2.471 to 2.497 MHz (Japan)	f=2402+k MHz, k=0,...,78 f=2449+k MHz, k=0,...,22 f=2454+k MHz, k=0,...,22 f=2473+k MHz, k=0,...,22
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 5 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.
2. Twenty-three channels in Spain, France, and Japan.

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.

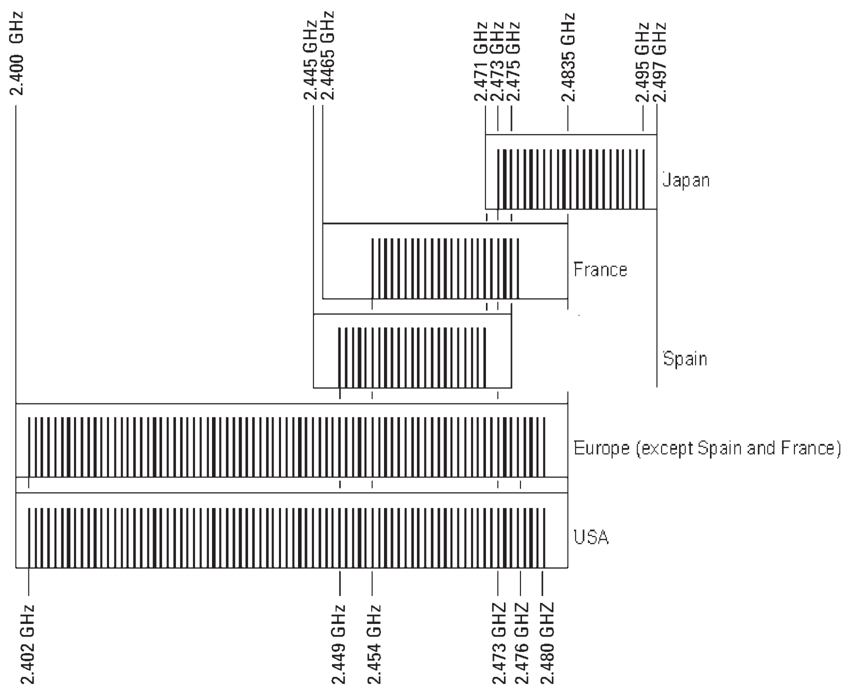


Figure 2. Bluetooth frequency channels

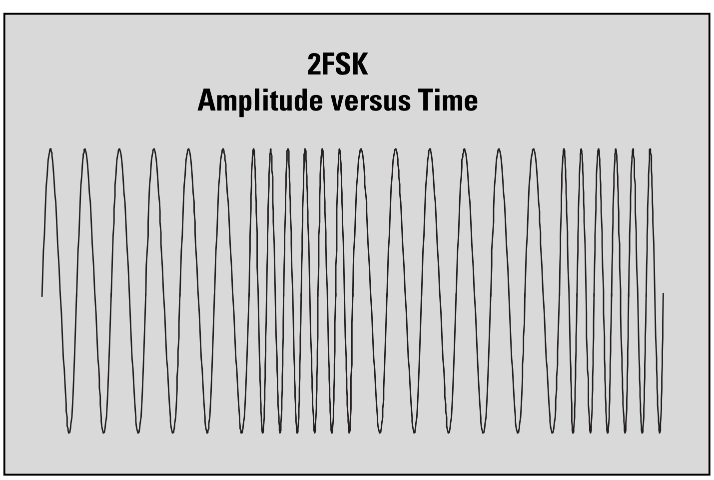


Figure 3. 2FSK modulation

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 Forward Error Correction (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.

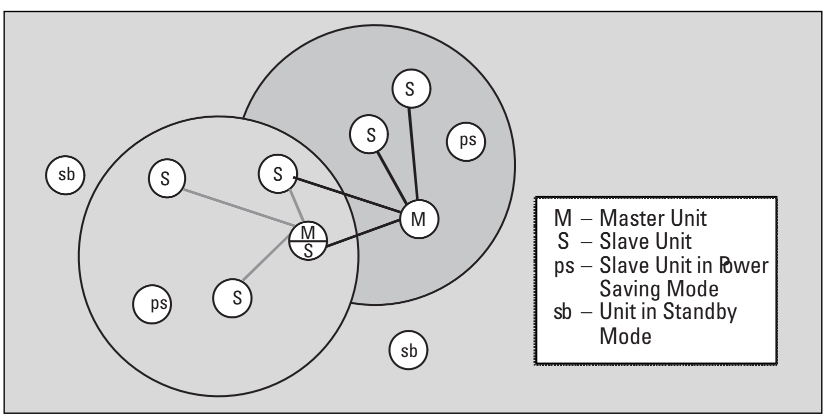


Figure 4. Network topology

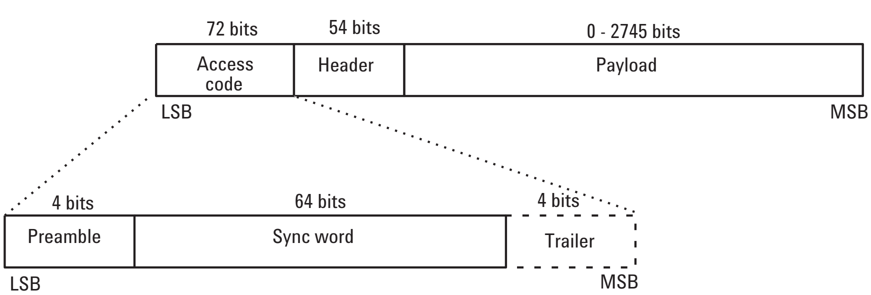


Figure 5. Bluetooth general packet format

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.

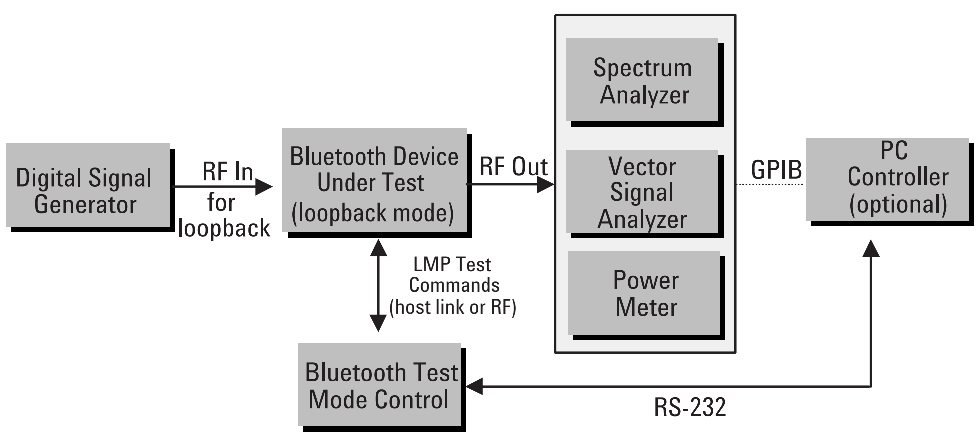


Figure 6. Transmitter measurement setup

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 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 out 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 1's or four 0's, the output should have reached its fully settled condition.

Table 3. Transmitter test parameters

	Test parameters				
Transmitter test	**Frequency hopping**	**Test mode**	**Packet type**	**Payload data**	**Measurement bandwidths**
Output power • Average power • Peak power	On	Loopback	Longest Supported	PRBS 9	3 MHz RBW 3 MHz VBW
Power density	On	Loopback	Longest Supported	PRBS 9	100 kHz RBW 100 kHz VBW
Power control	Off	Loopback	DH1	PRBS 9	3 MHz RBW 3 MHz VBW
Transmit output spectrum	Off	Loopback	DH1	PRBS 9	100 kHz RBW 300 kHz VBW
Modulation characteristics	Off	Loopback	Longest Supported	11110000, 10101010	not specified
Initial carrier frequency tolerance	On & Off	Loopback	DH1	PRBS 9	not specified
Carrier frequency drift	On & Off	Loopback	Longest Supported	10101010	not specified
Burst profile[1]	Off	Loopback	not specified	not specified	not specified

1. Not a specified test, but useful in troubleshooting.

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. 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% to 80% 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.

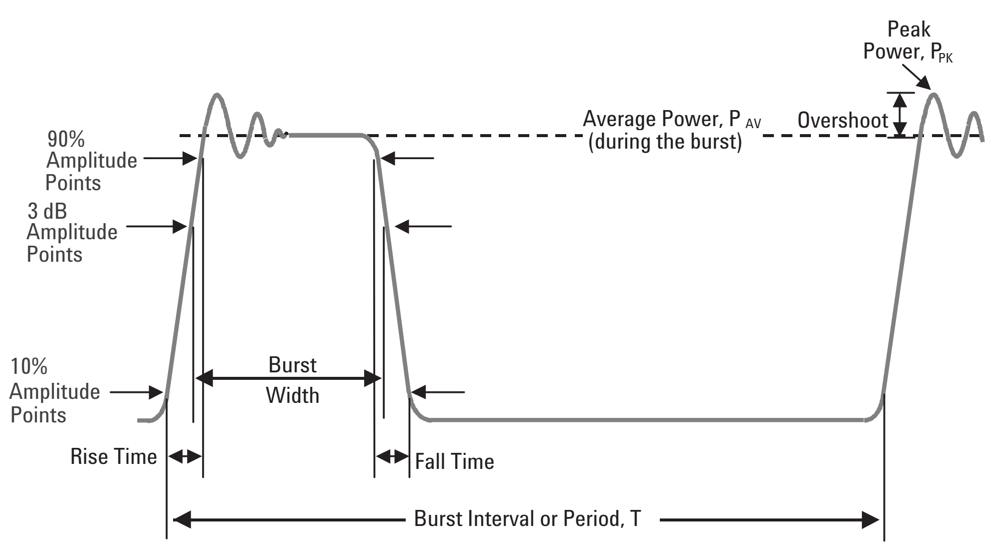


Figure 7. Time-domain power and timing analysis

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 8 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.

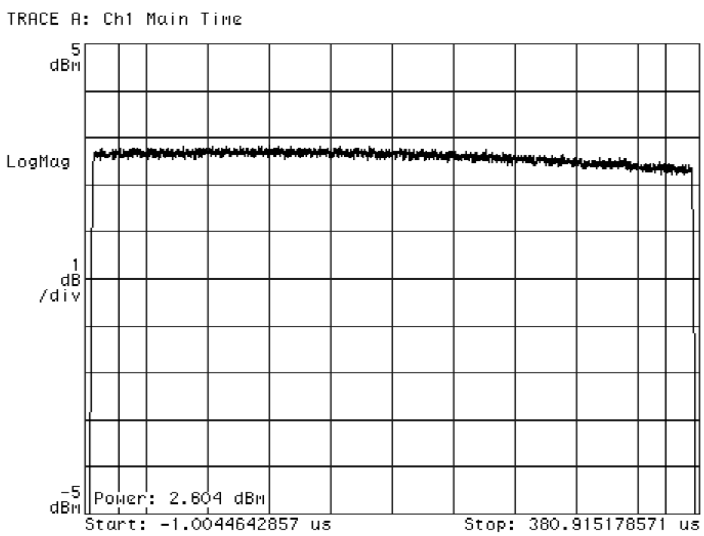


Figure 8. Agilent 89441A display of average and peak power measurement
(CF=2.402 GHz, 1dB/div, sweep time=380μs, triggering on IF ch 1, delay=1μs)

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 one-minute single sweep is performed with the trace in Max Hold with peak detection. The peak value of the trace is found; this frequency becomes the analyzer's new center frequency. Figure 9a[1] illustrates this portion of the measurement, in which the peak power point is identified.

For the second part of the measurement, the analyzer is changed to the time domain and a one-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.

(a) (b)

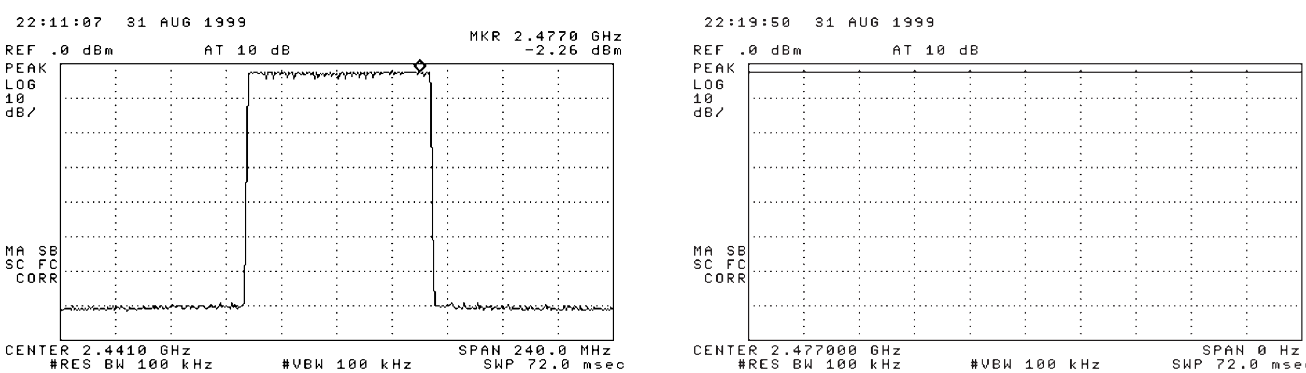


Figure 9. Agilent 8594E display of power density measurement
(CF=2.441 MHz (a) and 2.477 MHz (b), Span=240 MHz (a) and 0 Hz (b), RBW=100 kHz, VBW=100 kHz, Peak Detector, Trigger Free Run, Trace on Max Hold, Sweep Time=72 ms, Continuous Sweep)

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 measurement analyzes 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 measurement compares the device's output power spectrum to a predefined mask that has the characteristics shown in Table 4.

Table 4. Output 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.

Figure 10 shows an output spectrum display of a Bluetooth signal with a 5 dBm carrier in swept mode. The span in this illustration is set to 10 MHz to show the whole output spectrum mask. The test should normally be performed with a span of 1.5 MHz, requiring several measurements to view the complete region of interest. Figure 10 also shows an interpretation of the mask using the limit line feature of spectrum analyzers such as the Agilent 8590 E-series analyzers, which can be customized to provide a mask that automatically determines pass or fail results. The display in Figure 10 was created with a signal generator and may look cleaner than that of an actual Bluetooth device. When viewing an output spectrum, some asymmetry on the spectral display may be noticed due to the content of the data transmission.

The output spectrum provides a combined view of the effects of modulation and power switching. There may be overlap, but failures at offsets greater than 500 kHz from the carrier frequency are likely to be due to switching transients. Comparing results with the burst profile will confirm this. Unlike some other time-division systems, like GSM and DECT, which have both gated and non-gated measurements, Bluetooth's output spectrum measurement is not gated. Spectrum measurements need to capture the entire period of the burst and the space between bursts to include both modulation and transient effects.

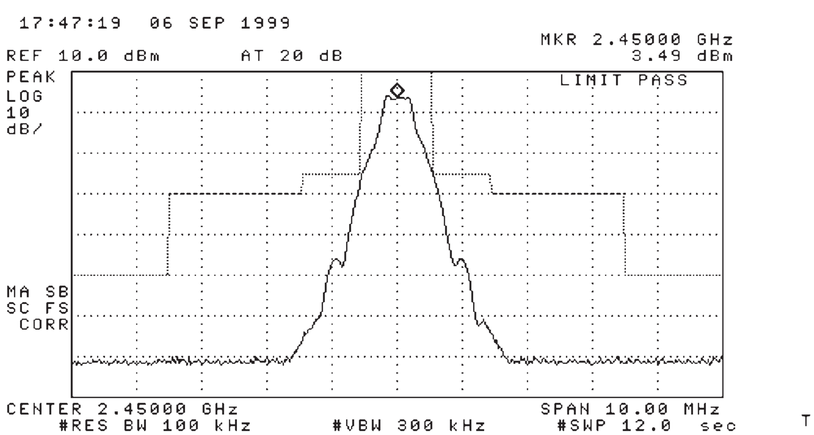


Figure 10. Agilent 8594E display of output spectrum measurement (CF=2.45 GHz, Span=10 MHz, RBW=100 kHz, VBW=300 kHz, Sweep Time=12 s, Detector Sample Mode, Trace Max Hold, Limit Line Mask)

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 Voltage-Controlled Oscillator (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 each bit in the 8-bit sequence are measured and averaged together. Then, the maximum deviation from the average for each of the 8 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. An example of a demodulated burst is shown in Figure 11. The example uses a repeating 00001111 payload sequence with no access code or header. The marker indicates the frequency deviation of one bit.

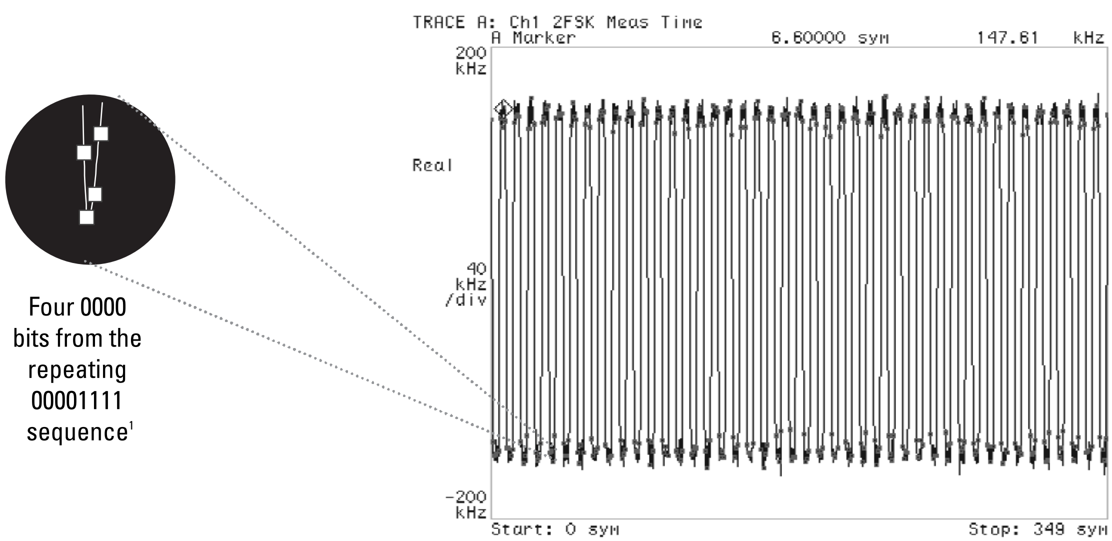


Figure 11. Agilent 89441A display showing modulation characteristics measurement
(CF=2.45 GHz, Demodulation mode, 2FSK, symbol rate=1 MHz, triggering on IF channel 1, FSK measured time, part real (I), result length=350 symbols)

1. Noise on the measurement with these analyzer settings affects the result.

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 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. For example, to perform the measurement shown in Figure 13, a 5 MHz span was used. Also, ensure that the auto correction of

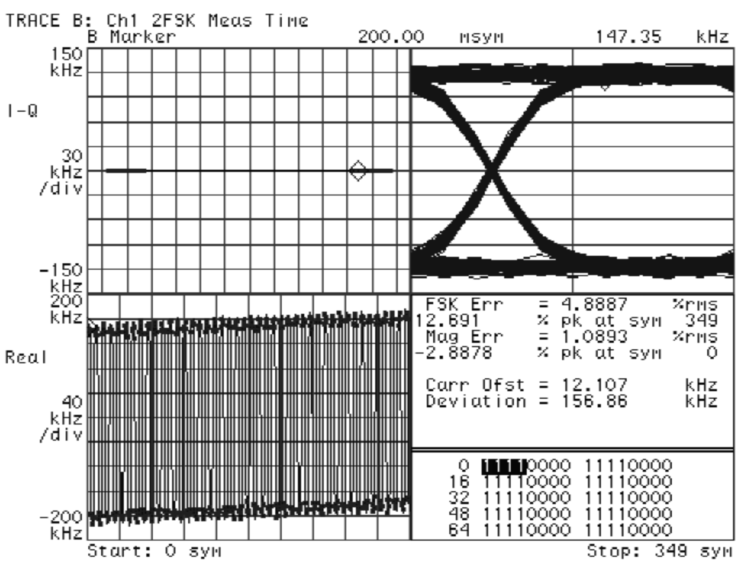


Figure 12. Agilent 89441A display of demodulation quality test

the carrier center frequency is disabled on the analyzer. Figure 13 shows an example of the measurement in which the first 10 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 vector 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, more convenient 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 4, 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.

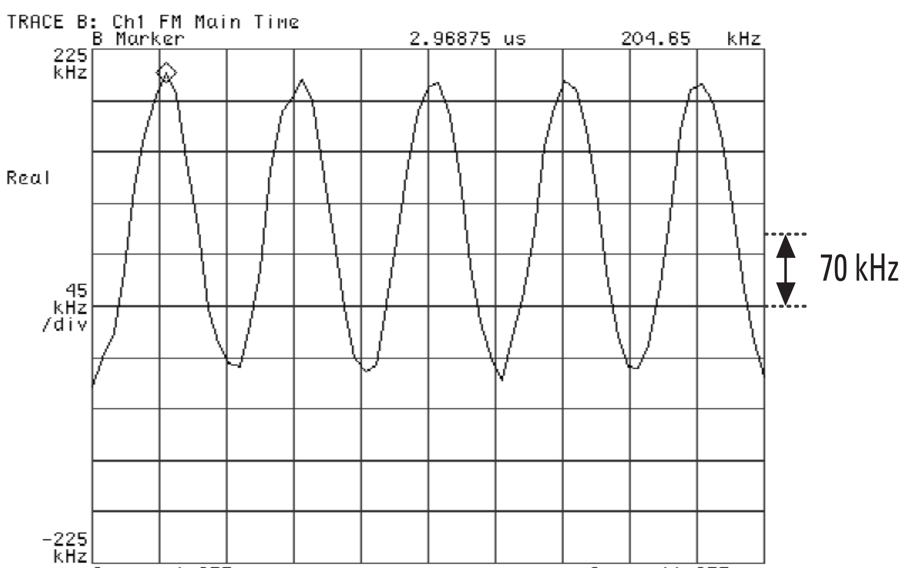


Figure 13. Agilent 89441A display of initial carrier frequency tolerance measurement with a 70 kHz frequency offset
(CF=2.45 GHz, Span=5 MHz, Demodulation mode, FM, symbol rate=1 MHz, triggering on IF channel 1, FM Main Time, part real (I), result length=10 μs)

2.3.4 Carrier frequency drift

Carrier frequency drift is also measured as a demodulated signal using 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 4-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 4 bits in the payload field. The maximum drift rate is also checked, and is defined as the difference between any two adjacent 4-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. A vector signal analyzer is the instrument of choice for this task. Software control makes this repetitive measurement more straightforward. Figure 14 provides an example of a carrier frequency drift measurement using an impaired Bluetooth-modulated signal with a 00001111 repeating sequence and 25 kHz of frequency drift.

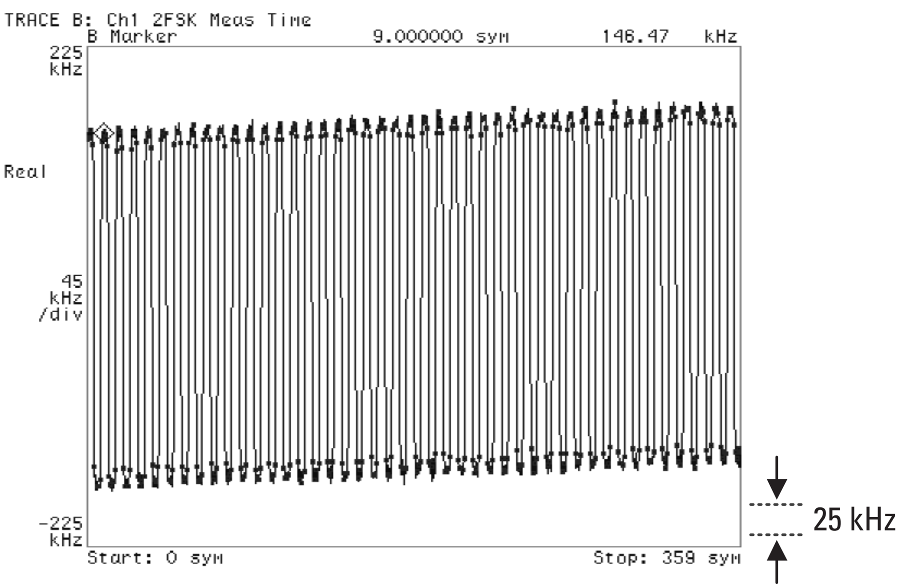


Figure 14. Agilent 89441A display of carrier frequency drift measurement
(CF=2.45 GHz, Span=5 MHz, Demodulation mode, 2FSK, symbol rate=1 MHz, triggering on IF channel 1, FSK measured time, part real (I), result length=360 symbols)

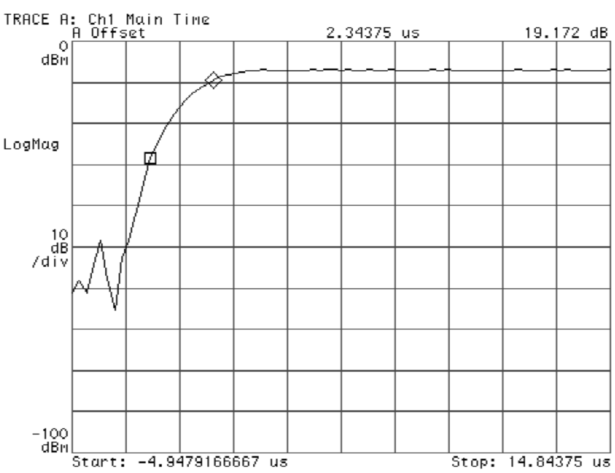
2.4 Timing tests

Timing tests may be performed on Bluetooth signals; these tests include analysis of the burst profile, PLL settling time, and other timing characteristics. These tests, although not part of the specifications, help R&D engineers to 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. 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. 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).

(a)



(b)

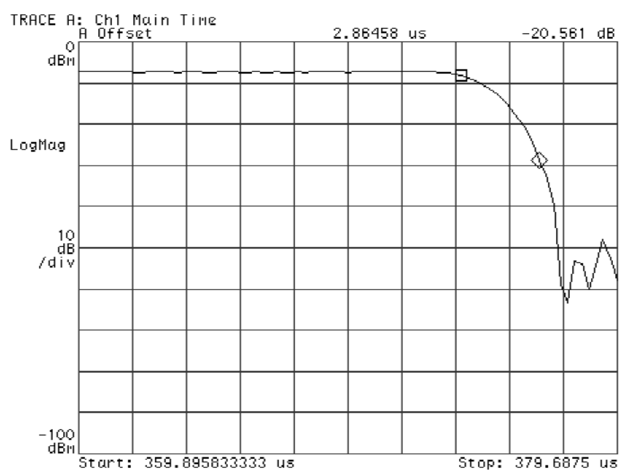


Figure 15. Agilent 89441A display showing burst (a) rise and (b) fall times
(CF=2.45 GHz, Span=3 MHz, Vector mode, triggering on IF channel 1, main time ch1, magnitude log(dB), main length=20 µs)

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

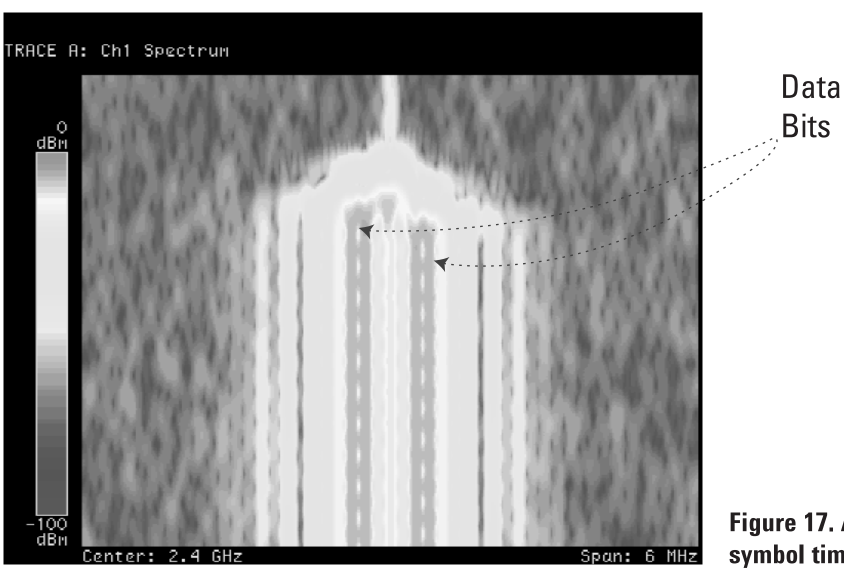


Figure 17. Agilent 89441A spectrogram display for symbol timing and rate

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 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 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 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

	Test parameters				
Receiver tests	**Frequency hopping**	**Test mode**	**Packet type**	**Payload data**	**Measurement BER**
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

Carrier-to-interference (C/I) performance is measured by sending co-channel or adjacent channel Bluetooth-modulated 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.

4.1.4 Blocking performance

The blocking performance test specifies a transmit and receive frequency of 2460 MHz. The tester continuously sends a Bluetooth modulated signal which is 3 dB over the reference sensitivity level.[1] 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 amplitudes associated with each frequency range are provided in the specification.

4.1.5 Intermodulation performance

Intermodulation performance measures unwanted frequency components resulting from the interaction of two or more signals passing through a nonlinear device. The test is performed by the tester continuously sending a Bluetooth-modulated 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.

When performing the carrier-to-interference test, blocking performance test, and the intermodulation performance test, multiple signal generators may be required.

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. The reference sensitivity level is defined as the power level at the receiver input at which the BER is 0.1%. The reference sensitivity shall be –70 dBm (± 1 dB) or better.

4.1.7 BER test setup

To perform the BER tests, a signal generator can be used to generate a Bluetooth-modulated signal and transmit this signal to the unit under test. The signal is then routed through the device and demodulated. The data is then returned to a BER tester for analysis. Figures 18 and 19 provide examples of two possible setups for testing baseband BER. Figure 18 shows an example in which the clock, data, and gate outputs of the baseband processor are routed to the BER tester. The gate signal is optional. This method is straightforward if these signals are available. If they are not available, the setup in Figure 19 can be used. In this setup, the output of the device's FM demodulator is routed to a signal generator's BER tester inputs after the signal has been digitized and the clock has been recovered. Alternatively, the digitized output of the threshold detector may be looped back directly to the BER tester along with a clock signal. Both of these examples are ideal for R&D work in which direct access to the device's circuitry is available.

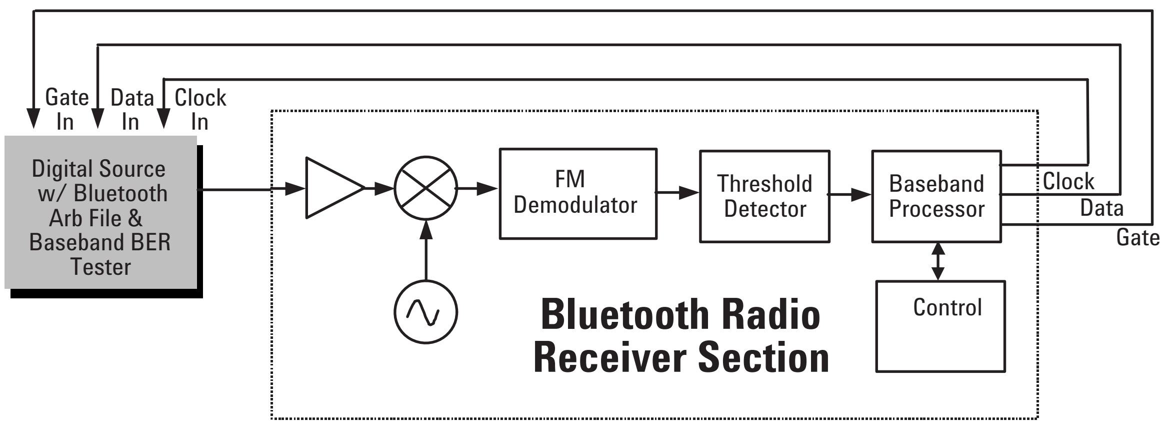


Figure 18. BER test setup using output of baseband processor

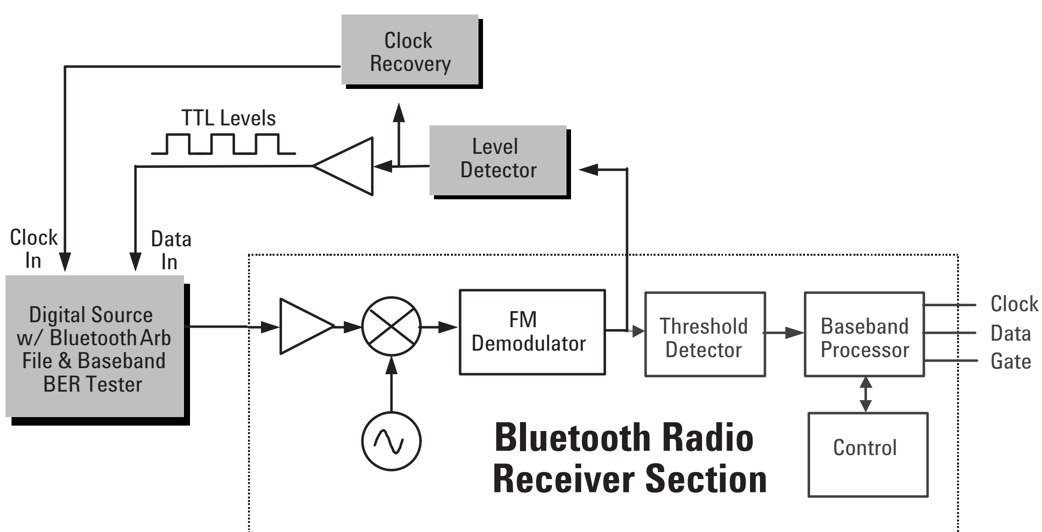


Figure 19. BER test setup using output of Bluetooth receiver's FM demodulator

A third method requires a BER tester that has the capability of demodulating a Bluetooth signal. Given this information, the Bluetooth device must be instructed to loopback its receive signal using test mode commands. These commands may be either sent over the RF link or through direct digital control to the device under test. The output of the device under test's transmitter can then be routed back to the BER tester for analysis. Given a PRBS9 payload, the BER tester can determine the expected bit sequence from any 9 bits and determine the BER. Figure 20 provides an example of this configuration.

4.1.8 Signal generation for receiver BER tests

For non-frequency-hopping applications, there are several ways of creating a Bluetooth signal from a signal generator. The Agilent ESG-D series signal generators offer a built-in Bluetooth signal selection, available with Option UND (Internal Dual Arbitrary Waveform Generator). This feature provides the ability to define a Bluetooth signal and offers several user-defined impairments.

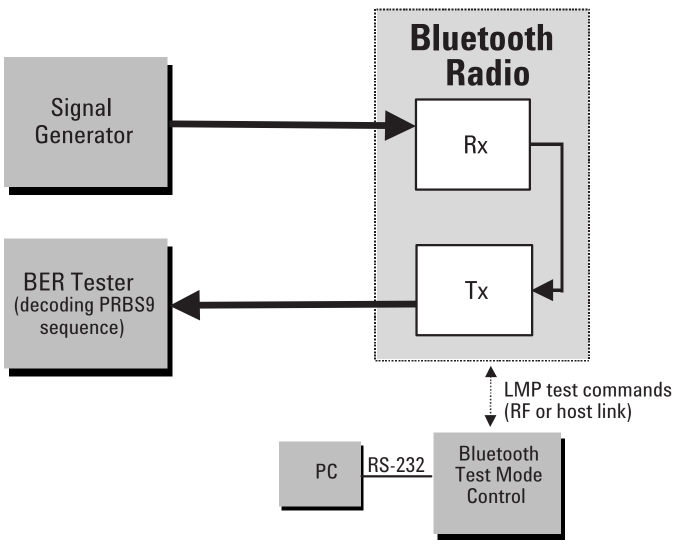


Figure 20. BER test setup using BER tester with Bluetooth device in test loopback mode

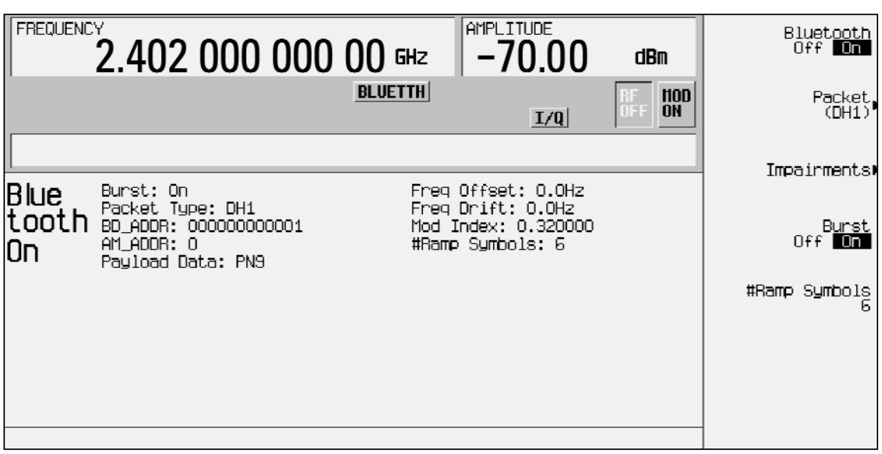


Figure 21. Agilent ESG-D series Option UND display of Bluetooth configuration menu

Option UN8 (Real Time I/Q Baseband Generator with TDMA Standards) also allows the manual creation of pulsed 2FSK signals with Gaussian filtering and customizable payloads to simulate Bluetooth. Table 6 provides a step-by-step example of this manual configuration.

Table 6. 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	4 "1's" and 4 "0's"
Pulse	
Pulse width	366 µs
Pulse period	1.25 ms[1]
Pulse on/off	On

Furthermore, customized arbitrary waveform files for the Agilent ESG-D series signal generators have been created to simulate normal and impaired Bluetooth signals. These files require the dual arbitrary waveform generator, Option UND. The impaired Bluetooth signals allow advanced analysis of Bluetooth receivers by stressing the reception and demodulation capabilities of the device. To access these files online, go to: www.tmo.agilent.com/tmo/datasheets/English/E4433B.html and select *E4433B Technical Support*.

4.2 Supplementary receiver tests

Although frequency hopping is not required by the *Bluetooth RF Test Specification* [1] for receiver tests, it is listed as an option for more in-depth testing. Fast frequency hopping may be performed using the Agilent E6432A VXI microwave synthesizer with an 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.

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.

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 Technologies 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.

6. Appendix A: Agilent Solutions for Bluetooth

●= Meets fully specified test requirements

❍= Not fully compliant to test requirements; characteristics only

	Agilent Instruments				
	Vector signal analyzers		Spectrum analyzers		Sources
Bluetooth measurements	**89400 series vector signal analyzers[1]**	**E4406A VSA series transmitter tester**	**8590 E series spectrum analyzers[2]**	**ESA-E series spectrum analyzers[3]**	**ESG-D series signal generators[4]**
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					●
Out-of-band blocking performance					●
Intermodulation performance					●
Maximum input level					●
Receiver tests with frequency hopping					●[5]

1. Requires Options AYA (Vector Modulation Analysis) and AY9 (Extended Time Capture). Option AYB (Waterfall and Spectrogram) is required for spectrograms.
2. Requires Options 101 (Fast Time Domain Sweep) and 102 (AM/FM Demodulation).
3. Requires Options AYX (Fast Time Domain Sweeps) and BAA (FM Demodulation).
4. 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.
5. Requires Agilent E6432A VXI microwave synthesizer to perform hopping.

7. Appendix B: Recommended Reading

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

2. *8 Hints for Making Better Spectrum Analyzer Measurements,* Agilent Application Note 1286-1, literature number 5965-7009E.

3. *10 Steps to a Perfect Digital Demodulation Measurement,* Agilent Product Note 89400-14A, literature number 5966-0444E.

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

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

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

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

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

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

8. 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.

9. 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 ElectoMagnetic 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
PRBS 9 (PN9) PseudoRandom Bit Sequence or Pseudorandom Noise of period 2^9-1 bits
PSD Power Spectral Density
RBW Resolution Bandwidth
RF Radio Frequency
SCO Synchronous Connection-Oriented link
SIG Bluetooth Special Interest Group
TDD Time Division Duplex
VBW Video Bandwidth
VSA Vector Signal Analyzer

10. References
11. Related Literature

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.

Related literature

Official Bluetooth Web site, www.bluetooth.com, 8/99.

Bluetooth '99 Conference Presentations, Queen Elizabeth II Conference Centre, London, June 9–10, 1999.

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