THE CHALLENGES OF RF MEASUREMENTS IN A BLUETOOTH FREQUENCY HOPPING SYSTEM.

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Background to Bluetooth

Bluetooth products are specified by a series of open, royalty-free standards that are maintained by the Bluetooth Special Interest Group (SIG). These specifications define all aspects of commercial unit design, including the RF conformance tests, and protocol stack. The current Bluetooth radio and core SIG specification are freely available on the Bluetooth web site at www.Bluetooth.com. Compliance with the RF test specification is critical if the regulatory requirements of the European Union and the United States are to be met. Conformance to the Bluetooth specification more importantly permits the use of the Bluetooth trademark and ensures Bluetooth device interoperability.

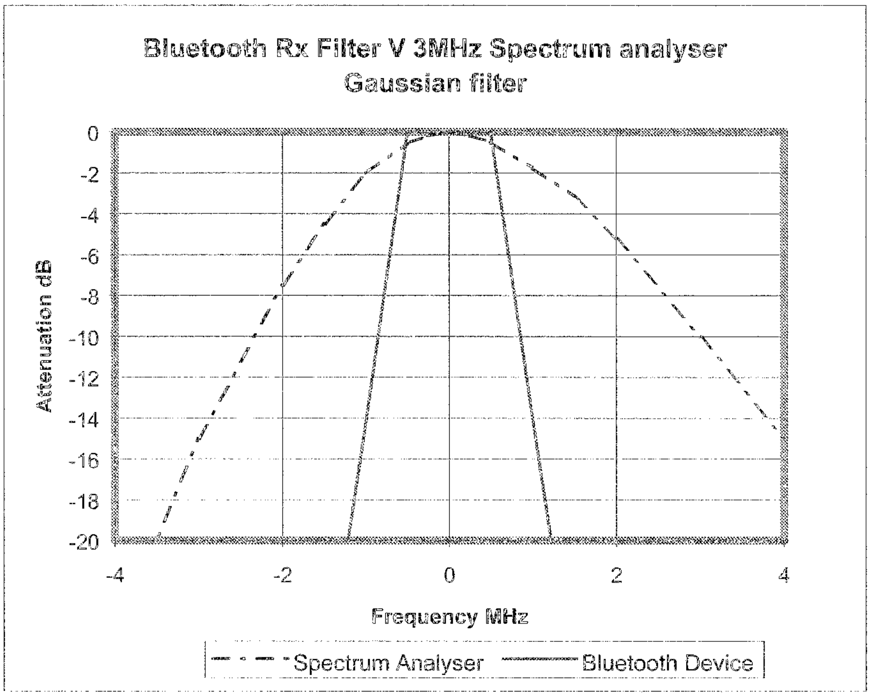
Problems with making compliant measurements

Using many pieces of general-purpose test equipment an engineer could theoretically perform Bluetooth testing according to the 0.91 issue of the RF specification. However when so many instruments are combined, not only is the solution expensive, but a great deal of instrument interconnection and GPIB automation is required. The instruments used in such an implementation will have their own limitations for Bluetooth testing. A detailed investigation of some of the pitfalls of using a spectrum analyser illustrates effectively the type of limitations encountered when using general-purpose test equipment.

When the Bluetooth specification was originally agreed, the spectrum analyser was the primary instrument available for testing modulation characteristics. Bluetooth errata number 277 clearly highlights some spectrum analyser measurement inadequacy.

- To perform optimum Bluetooth testing, the measurement bandwidth must be set in the vicinity of 1.3 MHz. This setting is not possible on a spectrum analyzer due to the limited predefined bandwidths. Tests have also shown that this can result in the inclusion of noise and residual emissions from other channels.
- The Gaussian filter used within a spectrum analyser has a non-ideal shape factor. A practical Bluetooth channel filter is implemented with a flat top resulting in a measurement error by the non-inclusion of spectrum.
- A further problem associated with the bandwidth settings is that the spectrum analyser filter characteristics often differ between manufacturers

The figure below shows graphically the disparity between a typical commercial Bluetooth unit and a spectrum analyser.



There are other drawbacks associated with the spectrum analyser implementation.

- The spectrum analyser has no information about the frequency and timing relationship of the hopping packet. Without protocol information and specialised triggering, the measurement time is forced to become relatively slow. Thus to guarantee the capture of a particular packet, the operator must set the spectrum analyser to maximum hold for a period of time sufficient to encompass a complete hopping cycle. Another problem associated with not having protocol checking of individual Bluetooth packets is that any corrupted packets are included in the measurements, ultimately leading to a greater deviation in the results.

Problems with utilising a production chip set design

In designing a solution to Bluetooth testing, the simplest approach would be to build the test instrument based around a production chip set. However, as detailed below, a number of factors would compromise the solution.

<u>Updates to the Bluetooth specification</u>

The Bluetooth specification continues to evolve to keep pace with newly discovered interoperability issues, specification errata, and advancing technology. Control of the protocol is vital. Changes in protocol would certainly not be viable in a commercially available chip set requiring a rerun of the ASIC design. A flexible and incremental solution for the test instrument could be achieved by the use of FPGA (Field Programmable Gate Array) technology.

Frequency hopping time restrictions

For a Bluetooth chip set, a time period of 180 μs has been allocated for the synthesiser to go to a new hop frequency. This timing imposes a limit to the synthesiser's settling time, which directly translates to frequency resolution. A solution to obtain more time and guarantee a much greater synthesiser frequency resolution can be achieved by allocating dedicated synthesisers for the transmit and receive paths. Within such a test instrument the transmitter synthesiser can be initialised to the next hopping frequency at the end of the current Bluetooth transmit packet, giving 884 μs to settle. However, this limitation has other implications, as special non-standard Bluetooth timing is required to support half slot packets during the paging sequence.

The "dirty transmitter" factor

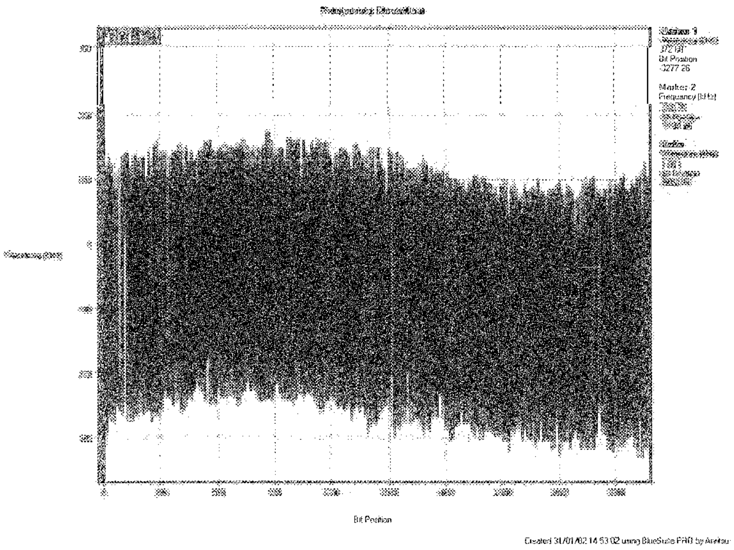
For a normal Bluetooth operation communication with the production chip set is the primary requirement. However, a test instrument must also be able to fully exercise the device and guarantee the interoperability with other devices. These production devices could individually pass a specification limit but not interoperate because each device is at opposite test limit extremes. The Bluetooth SIG adopted the concept of the 'Dirty Transmitter'. The dirty transmitter specification ensures that when the equipment under test receiver threshold tests are performed, the transmitter is cycled between known extreme limits of acceptable performance.

Instrument Traceability

The dirty transmitter requirements impose a need for good frequency accuracy and stability on the test instrument transmitter. In order to achieve the accuracy required, all of the transmitter synthesisers must be locked to a high stability reference (normally at the test industry standard frequency of 10 MHz). To obtain the fine offset frequency resolution, a synthesiser with a large division ratio is required, which is not normally available on a high frequency fast hopping synthesiser without using advanced synthesis techniques.

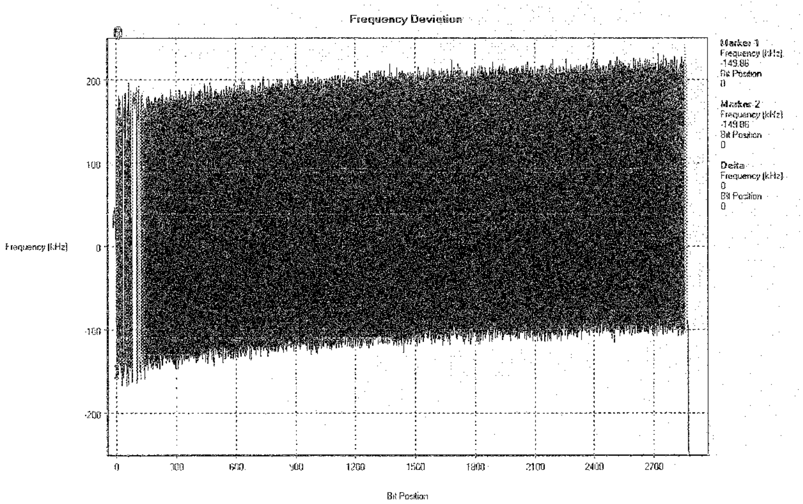
Packet drift

A second Dirty transmitter requirement is the need for a sinusoidal frequency offset varying over the whole packet length. A dirty packet is illustrated in the figure below.



Note: Packet length DH5 with –75 kHz offset, 0.35 mod index and 300Hz sine wave at +/- 40 kHz deviation.

This introduced initial carrier offset and sinusoidal packet drift anomaly simulates the settling characteristic of the production Bluetooth device. An implementation of a commercial chip set that shows the synthesiser settling and drift over a DH5 packet is shown below.



This sinusoidal dirty transmitter drift impediment is required to be precisely generated with the appropriate test instrument traceability. An ideal solution for the test instrument would be to incorporate this function within the fast hopping transmitter synthesiser. This synthesiser will be designed to follow the Bluetooth spreading sequence and so possess a fast loop response. If a relatively slow modulating sinusoidal signal is applied to this loop, the synthesiser output frequency will track this error signal and generate the modulation required.

Adjustable modulation

Another requirement for the dirty transmitter is the generation of a guaranteed, accurate, and variable modulation index which can be set to extreme limits and again this may be difficult to access or not available with a standard production chip set. A simple implementation of this function would be to use a similar approach as for the drift sinusoid and incorporate this function into the transmitter synthesiser. However the transfer characteristic of the VCO used within the synthesiser is not linear with frequency and this would result in the modulation index changing with channel. This would require costly characterisation. To overcome this calibration difficulty, the addition of a fixed frequency synthesiser can be considered. The advantage of this approach would be that the new synthesiser could be designed with loop characteristics that are not susceptible to a data sequence containing a large string of consecutive ones or zeros. Normal Bluetooth operation however requires that the payload data is scrambled with a pseudo random binary sequence (PRBS 9) such that large strings of unchanging data are never encountered.

The receiver side of the equation

The same constraints as for the transmitter synthesiser settling time also hold true for the receiver. To get greater frequency resolution for measurement of a Bluetooth packet, the larger settling time offered by separate transmitter and receiver synthesiser topology is advantageous.

The two separate conflicting functions within a Bluetooth test instrument receiver are data discrimination and packet parameter measurement. So a dual channel receiver, one optimised for real time data demodulation, and the other for accurate frequency and power measurement could be an effective solution. The measurement channel has no real time requirement, as every Bluetooth test requires the result to be averaged over one or more packets. This mathematical averaging function is ideally performed digitally with samples stored for later processing. A DSP and an IQ demodulator would be a suitable architecture to implement such a function. This topology can derive both power and frequency from the stored samples. The power profile can be directly derived from the sample IQ vector magnitude whilst the frequency deviation and offset can be derived from the IQ vector phase and the relationship rate of change of phase is equal to frequency. The instantaneous absolute frequency can be monitored over time to determine frequency deviation and drift. Such a sampling topology also lends itself to digital filtering and has the dual advantage of decimation, reducing the original high sample rate and filter flexibility in determining the receiver measurement bandwidth.

Conclusion

As this article has highlighted, there are key attributes that go into making an accurate production measurement instrument that guarantee interoperability of all Bluetooth devices. The dirty transmitter concept of fully exercising a Bluetooth device is at the heart of the specification, and a challenge for test equipment manufacturers. The One box tester (OBT) is the common solution for manufacturing test that has been widely adopted in mobile phone testing. The key element of such a tester is the marriage of test instrument hardware and protocol to enable full real-time control of the equipment under test. Such instruments provide a cost-effective solution where the difficulties of integrating many general-purpose test instruments are avoided. The Anritsu MT8850A with its 4 individual synthesisers accurately generating the dirty transmitter parameters is an instrument that addresses the issues to provide an integrated solution for production Bluetooth testing.