Radio System

The radio operates in the worldwide 2.4-GHz Industrial, Scientific, and Medical (ISM) frequency band (2.400 GHz–2.4835 GHz). It divides the ISM band into 26 channels, each of which are 3 MHz wide. The device generates a redundant bit pattern, known as a Pseudo Noise (PN) code for each bit to be transmitted. The receiver utilizes a copy of the same PN code as the transmitter (the system for synchronizing PN codes at connection time is described below in the Rendezvous Hopping section) and a matched filter to find signals on the same frequency which are transmitted using the same PN code. The filter will not respond to either random noise (except in very unlikely events) or signals transmitted using other PN codes. Using the DSSS radio transceiver as a base band radio, the radio system implements a frequency hopping spread spectrum (FHSS) system in software by shifting frequencies between every transmitted DSSS packet according to an agree upon pseudo-random pattern.

Theory of Operation

The React transmitter is the link master. The vehicle transceiver (separate certification) is the link slave. At startup, the slave advertises its availability by transmitting a Service message. If the slave is bound to a master, the master's Global Unique Identifier (GUID) is included in the Service message. During this time the master and slave are unsynchronized. Each device hops through the rendezvous channel set at its own rate and offset. When the desired master (or any unbound master if the slave is unbound) detects the Service message, it replies with a Connect message containing various link parameters, including the master's clock. The slave synchronizes its clock value to the master's and synchronizes the start of its clock periods to the timing carried in the Connect message. From this point forward the devices hop on a synchronized basis 136 times per second. All data transmission is initiated by the master. During most timeslots, the master sends a packet of command data to the slave, and the slave responds with an Ack message on the same channel. If the master is ready for new telemetry information it sends a request as part of its command packet. The slave then sends a data packet on the following timeslot, using the channel the request was received on.

15.247 (a) (1) Statement

1. Pseudorandom hop selection

The generation of the hopping sequence in connection mode depends essentially on two input values:

1 LAP/UAP of the master of the connection
2 Internal master clock

The LAP (lower address part) are the 24 LSB's of the 48 BD_ADDRESS. The BD_ADDRESS is an unambiguous number of every Bluetooth unit. The UAP (upper address part) are the 24 MSB's of the 48 BD_ADDRESS.

The internal clock of a unit is derived from a free running clock which is never adjusted and is never turned off. For synchronization with other units only offset are used. It has no relation to the time of the day. In most case it is implemented as 28 bit counter. For the deriving of the hopping sequence the entire LAP (24 bits), 4 LSB's (4 bits) (Input 1) and the 27 MSB's of the clock (Input 2) are used.

With this input values different mathematical procedures (permutations, additions, XOR-operations) are performed to generate the sequence. This will be done at the beginning of every new transmission. The output constitutes a pseudorandom sequence covering 26 hop channels.

The following is a sample of a pseudorandom hopping sequence of 1 sec. 136 hops):

06	11	08	20	07	09	21	23	17	15	16	24	02	14	01
18	03	25	26	04	10	05	12	19	21	13	22	05	09	

2. Equally average use of frequencies

The product channel hopping sequence which has a very long period length does not show repetitive patterns over a short time interval, but distributes the hop frequencies equally over the 26 hopping channels during a short time interval.

3. Receiver input bandwidth

The ML2724 used in RF module is a dual conversion Low IF receiver. The integrated image reject mixer gives sufficient rejection in this channel. All channel filtering and demodulation is performed using active filters, which are automatically aligned. A matched bit rate filter and a data slicer follow the demodulator.

The transceiver automatically tunes all the internal filters using the reference frequency from the FREF pin. When the chip is powered up (VDD first applied), the tuning information is reset to mid-range. This self-calibration sets:

- Discriminator center frequency
- IF filter center frequency and bandwidth

- Receiver data low-pass filter bandwidth
- Transmit data low-pass filter bandwidth

The receiver input bandwidth match the transmitter output bandwidth. Both of them is 3 MHz width.

4. Synchronization of the receiver with the transmitted signals

The RF mixer down-converts the 2.4GHz RF input signal to the first intermediate frequency (IF), where it is filtered to remove adjacent channel signals. An active image reject mixer converts this signal down to a Low IF frequency, where the data is limited, filtered, and demodulated. This architecture provides all the benefits of direct conversion to baseband while maintaining the stability and robustness of a traditional super-heterodyne.

A single synthesizer is used for both the receiver and the transmitter. The phase locked loop (PLL) is completely integrated, including the voltage controlled oscillator (VCO), tuning circuits, and VCO resonator.

The ML2724 PLL is programmed via control register 2 to the set RF center frequency of operation of the radio. The PLL does not need to be (though it can be) reprogrammed between RECEIVE and TRANSMIT modes. With careful planning, channels can be programmed in 1024 KHz steps as long as care is exercised to insure that two radio links will not share spectrum at any one time.

15.247 (g) Statement

The product channel hopping sequence which has a very long period length does not show repetitive patterns over a short time interval, but distributes the hop frequencies equally over the 26 hopping channels during a short time interval.
The generation of the hopping sequence in connection mode depends essentially on two input values:
1 LAP/UAP of the master of the connection
2 Internal master clock

The LAP (lower address part) are the 24 LSB's of the 48 BD_ADDRESS. The BD_ADDRESS is an unambiguous number of every unit. The UAP (upper address part) are the 24 MSB's of the 48 BD_ADDRESS.
The internal clock of the product unit is derived from a free running clock which is never adjusted and is never turned off. For synchronization with other units only offset are used. It has no relation to the time of the day. In most case it is implemented as 28 bit counter.
For the deriving of the hopping sequence the entire LAP (24 bits), 4 LSB's (4 bits) (Input 1) and the 27 MSB's of the clock (Input 2) are used.
With this input values different mathematical procedures (permutations, additions, XOR-operations) are performed to generate the sequence. This will be done at the beginning of every new transmission. The output constitutes a pseudorandom sequence covering 26 hop channels.
For short transmissions the systems have the following behaviour:
When the first connection between two devices is established, a hopping sequence is generated. If for transmitting the wanted data the complete hopping sequence is not used,

the connection is ended.
When a second connection is established. A new hopping sequence is generated. Due to the fact that the clock has a different value, because the period between the two transmission is longer (it cannot be shorter) than the minimum resolution of the clock. The hopping sequence will always differ from the first one.

15.247 (h) Statement

The device units which want to communicate with other units must be organized in an structure called piconet. This piconet consist of max. 8 units. One unit it the master of the other seven are the slaves. The master co-ordinates frequency occupation in this piconet for all units, the master determines the hopping sequence and the slave follows this sequence. Both devices shift between RX and TX time slot according to the clock of the master.

As the master hop sequence is derived from its BD address which is unique for the device, additional masters intending to establish new piconets will always use different hop sequence.