EXHIBIT K – Description of Frequency Hopping System

FCC ID O2Z-BT2

The Equipment Under Test (EUT) is the Intel® Personal Wireless Module, a spread spectrum transmitter that uses frequency hopping modulation. This device is intended to be sold to Original Equipment Manufacturers (OEMs) for integration into laptop computers. This device will be integrated with one of five Intel sponsored antennas which are being recommended to be used with this device. The module will allow laptop computers to communicate with other consumer electronics containing Bluetooth® devices. This will allow a laptop computer to communicate to and share files and data with other devices such as digital cameras, cellular phones, wireless mice, wireless joysticks, wireless keyboards, etc.

Within the Bluetooth® protocol, frequency hopping is governed by one and only one Bluetooth® unit in any given communications group. The master unit determines the pseudo random hopping sequence and conveys this information to other “slave” units that are in the communications group with the master. Because the master unit generates the hopping sequence independently without any external information, there is no coordination with other FHSS systems. The Bluetooth® protocol relies on Forward Error Correction (FEC) along with re-transmissions to accommodate for multiple transmitters and interference on specific frequencies.

Under two specific modes (page mode and inquiry mode) of the Bluetooth® protocol, fewer than 75 hopping frequencies are used for a very short period of time. These two modes are used to search for and acquire new devices in the surrounding area. The amount of time that a Bluetooth® device spends in these two modes represents a very small portion of the overall communications time.

The data transmitted during these two modes is Direct Sequence modulated. Even though the transmitter is still hopping to a pseudo-random hopping sequence (less than 75 frequencies), the data transmitted at each frequency is Direct Sequence modulated. In this regard, the transceiver qualifies as a Hybrid System under the Part 15.247 rules.

Because the Bluetooth® protocol contains these modes, and because these modes do not meet the minimum number of hopping channels specified in Part 15.247, the Bluetooth® transmitter is categorized as a Hybrid system for these two modes and the hybrid-mode processing gain calculations apply.

Because the Bluetooth protocol contains these modes, and because these modes do not meet the minimum number of hopping channels specified in Part 15.247 for frequency hopping, the Bluetooth? transmitter is categorized as a hybrid system for these two modes and the hybrid-mode processing gain calculations apply.

2 FREQUENCY BANDS AND CHANNEL ARRANGEMENT

The Bluetooth system is operating in the 2.4 GHz ISM (Industrial Scientific Medicine) band. In a vast majority of countries around the world the range of this frequency band is 2400 - 2483.5 MHz. Some countries have however national limitations in the frequency range. In order to comply with these national limitations, special frequency hopping algorithms have been specified for these countries. It should be noted that products implementing the reduced frequency band will not work with products implementing the full band. The products implementing the reduced frequency band must therefore be considered as local versions for a single market. The Bluetooth SIG has launched a campaign to overcome these difficulties and reach total harmonization of the frequency band.

Geography	Regulatory Range	RF Channels
USA, Europe and most other countries[1)]	2.400-2.4835 GHz	f=2402+k MHz, k=0,…,78
Spain[2)]	2.445-2.475 GHz	f=2449+k MHz, k=0,…,22
France[3)]	2.4465-2.4835 GHz	f=2454+k MHz, k=0,…,22

Table 2.1: Operating frequency bands

Note 1. Japan, the MPT announced at the beginning of October 1999 that the Japanese frequency band would be extended to 2400-2483.5 MHz, effective immediately. Testing of devices by TELEC may however need some time to change. The previously specified special frequency-hopping algorithm covering 2471-2497 MHz remains as an option.

Note 2. There is a proposal in Spain to extend the national frequency band to 2403-2483.5 MHz. The Bluetooth SIG has approached the authorities in Spain to get a full harmonization. The outcome is expected by the beginning of year 2000.

Note 3. The Bluetooth SIG has established good contacts with the French authorities and are closely following the development of harmonization.

Channel spacing is 1 MHz. In order to comply with out-of-band regulations in each country, a guard band is used at the lower and upper band edge.

Geography	Lower Guard Band	Upper Guard Band
USA	2 MHz	3.5 MHz
Europe (except Spain and France)	2 MHz	3.5 MHz
Spain	4 MHz	26 MHz
France	7.5 MHz	7.5 MHz
Japan	2 MHz	2 MHz

Table 2.2: Guard Bands

2 PHYSICAL CHANNEL

2.1 FREQUENCY BAND AND RF CHANNELS

Bluetooth operates in the 2.4 GHz ISM band. Although globally available, the exact location and the width of the band may differ by country. In the US and Europe, a band of 83.5 MHz width is available; in this band, 79 RF channels spaced 1 MHz apart are defined. In Japan, Spain, and France, a smaller band is available; in this band, 23 RF channels spaced 1 MHz apart are defined.

Country	Frequency Range	RF Channels	
Europe* & USA	2400 - 2483.5 MHz	f = 2402 + k MHz	k= 0,...,78
Japan	2471 - 2497 MHz	f = 2473 + k MHz	k= 0,...,22
Spain	2445 - 2475 MHz	f = 2449 + k MHz	k= 0,...,22
France	2446.5 - 2483.5 MHz	f = 2454 + k MHz	k= 0,...,22

Table 2.1: Available RF channels

*. except Spain and France

2.2 CHANNEL DEFINITION

The channel is represented by a pseudo-random hopping sequence hopping through the 79 or 23 RF channels. The hopping sequence is unique for the piconet and is determined by the Bluetooth device address of the master; the phase in the hopping sequence is determined by the Bluetooth clock of the master. The channel is divided into time slots where each slot corresponds to an RF hop frequency. Consecutive hops correspond to different RF hop frequencies. The nominal hop rate is 1600 hops/s. All Bluetooth units participating in the piconet are time- and hop-synchronized to the channel.

2.3 TIME SLOTS

The channel is divided into time slots, each 625 μs in length. The time slots are numbered according to the Bluetooth clock of the piconet master. The slot numbering ranges from 0 to 2^{27}-1 and is cyclic with a cycle length of 2^{27}.

In the time slots, master and slave can transmit packets.

A TDD scheme is used where master and slave alternatively transmit, see Figure 2.1 on page 44. The master shall start its transmission in even-numbered time slots only, and the slave shall start its transmission in odd-numbered time slots only. The packet start shall be aligned with the slot start. Packets transmitted by the master or the slave may extend over up to five time slots.

The RF hop frequency shall remain fixed for the duration of the packet. For a single packet, the RF hop frequency to be used is derived from the current Bluetooth clock value. For a multi-slot packet, the RF hop frequency to be used for the entire packet is derived from the Bluetooth clock value in the first slot of the packet. The RF hop frequency in the first slot after a multi-slot packet shall use the frequency as determined by the current Bluetooth clock value. Figure 2.2 on page 44 illustrates the hop definition on single- and multi-slot packets. If a packet occupies more than one time slot, the hop frequency applied shall be the hop frequency as applied in the time slot where the packet transmission was started.

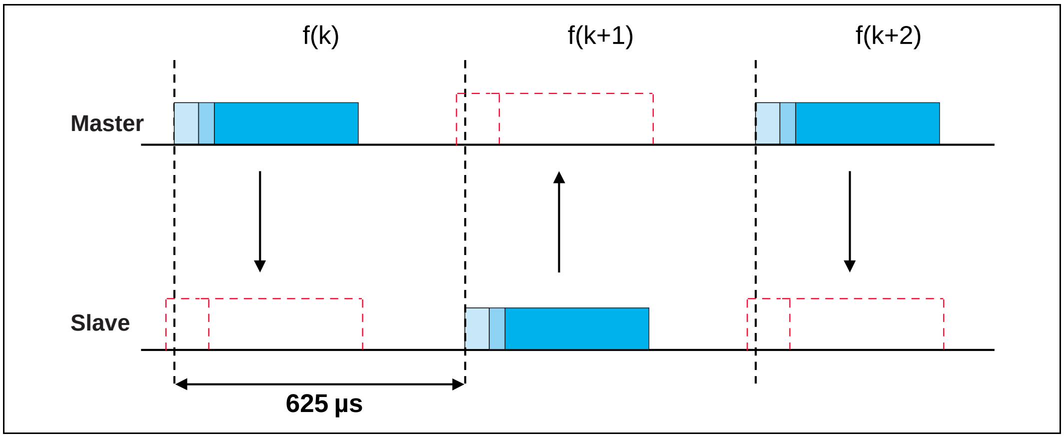

Figure 2.1: TDD and timing

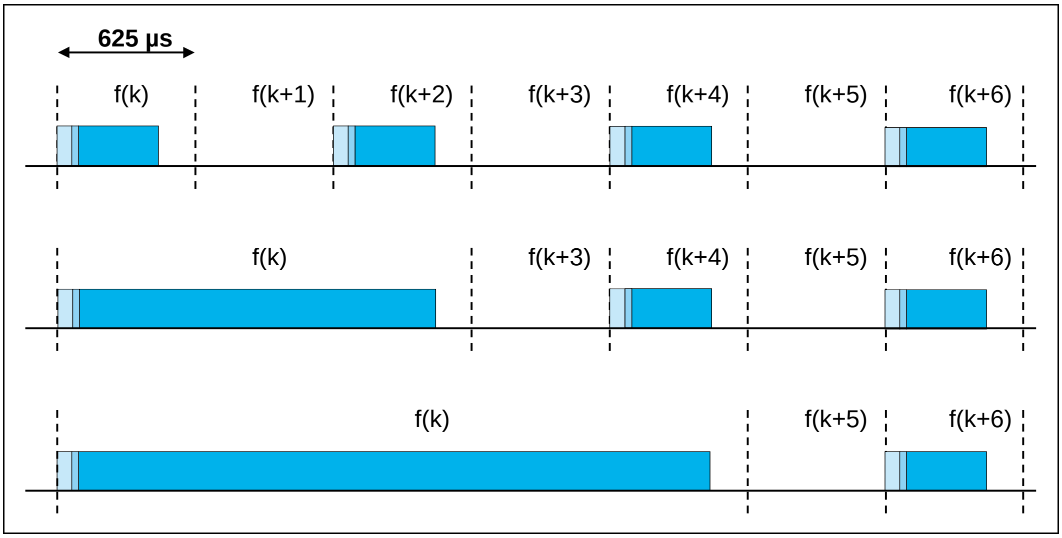

Figure 2.2: Multi-slot packets

2.4 MODULATION AND BIT RATE

The data transmitted has a symbol rate of 1 Ms/s. A Gaussian-shaped, binary FSK modulation is applied with a *BT* product of 0.5. A binary one is represented by a positive frequency deviation, a binary zero by a negative frequency deviation. The maximum frequency deviation shall be between 140 kHz and 175 kHz.

11 HOP SELECTION

In total, 10 types of hopping sequences are defined – five for the 79-hop and five for the 23-hop system, respectively. Using the notation of parentheses () for figures related to the 23-hop system, these sequences are:

- A **page hopping sequence** with 32 (16) unique wake-up frequencies distributed equally over the 79 (23) MHz, with a period length of 32 (16);
- A **page response sequence** covering 32 (16) unique response frequencies that all are in an one-to-one correspondence to the current page hopping sequence. The master and slave use different rules to obtain the same sequence;
- An **inquiry sequence** with 32 (16) unique wake-up frequencies distributed equally over the 79 (23) MHz, with a period length of 32 (16);
- A **inquiry response sequence** covering 32 (16) unique response frequencies that all are in an one-to-one correspondence to the current inquiry hopping sequence.
- A **channel hopping sequence** which has a very long period length, which does not show repetitive patterns over a short time interval, but which distributes the hop frequencies equally over the 79 (23) MHz during a short time interval;

For the page hopping sequence, it is important that we can easily shift the phase forward or backward, so we need a 1-1 mapping from a counter to the hop frequencies. For each case, both a hop sequence from master to slave and from slave to master are required.

The inquiry and inquiry response sequences always utilizes the GIAC LAP as lower address part and the DCI (Section 5.4 on page 73) as upper address part in deriving the hopping sequence, even if it concerns a DIAC inquiry.

11.1 GENERAL SELECTION SCHEME

The selection scheme consists of two parts:

- selecting a sequence;
- mapping this sequence on the hop frequencies;

The general block diagram of the hop selection scheme is shown in Figure 11.1 on page 128. The mapping from the input to a particular hop frequency is performed in the selection box. Basically, the input is the native clock and the current address. In **CONNECTION** state, the native clock (CLKN) is modified by an offset to equal the master clock (CLK). Only the 27 MSBs of the clock are used. In the **page** and **inquiry** substates, all 28 bits of the clock are used. However, in **page** substate the native clock will be modified to the master's estimate of the paged unit.

The address input consists of 28 bits, i.e., the entire LAP and the 4 LSBs of the UAP. In **CONNECTION** state, the address of the master is used. In **page** sub-state the address of the paged unit is used. When in **inquiry** substate, the UAP/LAP corresponding to the GIAC is used. The output constitutes a pseudo-random sequence, either covering 79 hop or 23 hops, depending on the state.

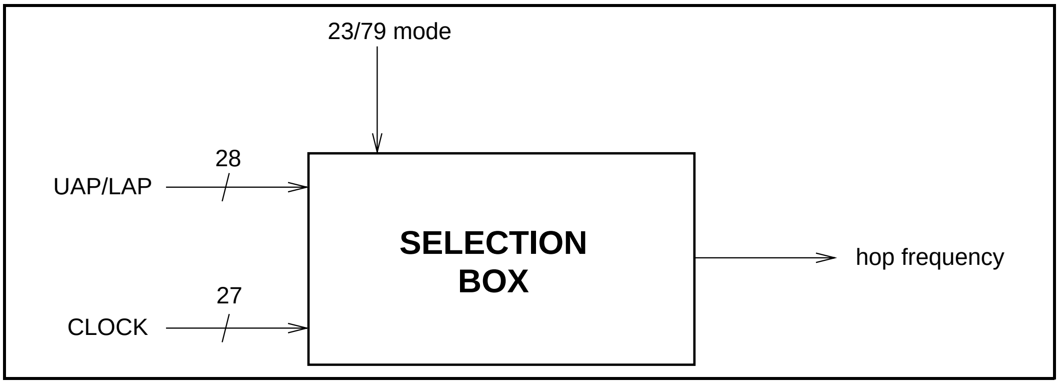

Figure 11.1: General block diagram of hop selection scheme.

For the 79-hop system, the selection scheme chooses a segment of 32 hop frequencies spanning about 64 MHz and visits these hops once in a random order. Next, a different 32-hop segment is chosen, etc. In case of the **page, page scan,** or **page response** substates, the same 32-hop segment is used all the time (the segment is selected by the address; different units will have different paging segments). In connection state, the output constitutes a pseudo-random sequence that slides through the 79 hops or 23 hops, depending on the selected hop system. For the 23-hop systems, the segment size is 16. The principle is depicted in Figure 11.2

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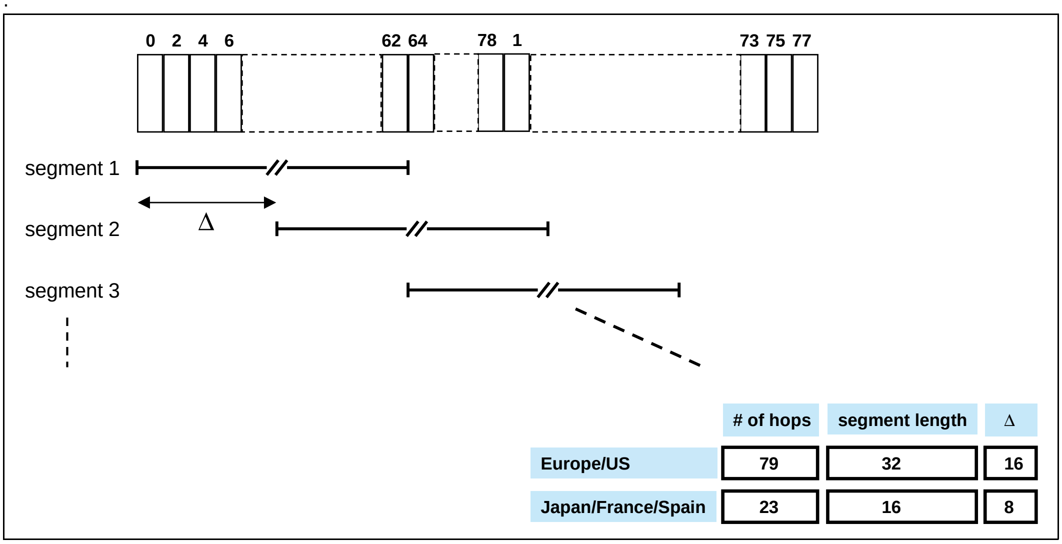

Figure 11.2: Hop selection scheme in CONNECTION state.

11.2 SELECTION KERNEL

The hop selection kernels for the 79 hop system and the 23 hop system are shown in Figure 11.3 on page 129 and Figure 11.4 on page 129, respectively. The X input determines the phase in the 32-hop segment, whereas Y1 and Y2 selects between master-to-slave and slave-to-master transmission. The inputs A to D determine the ordering within the segment, the inputs E and F determine the mapping onto the hop frequencies. The kernel addresses a register containing the hop frequencies. This list should be created such that first all even hop frequencies are listed and then all odd hop frequencies. In this way, a 32-hop segment spans about 64 MHz, whereas a 16-hop segment spans the entire 23-MHz.

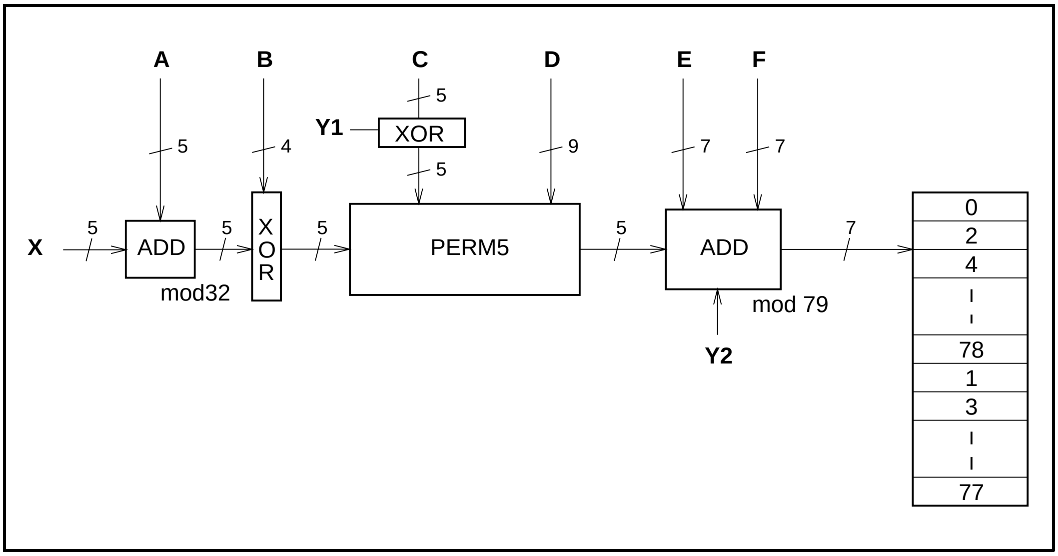

Figure 11.3: Block diagram of hop selection kernel for the 79-hop system.

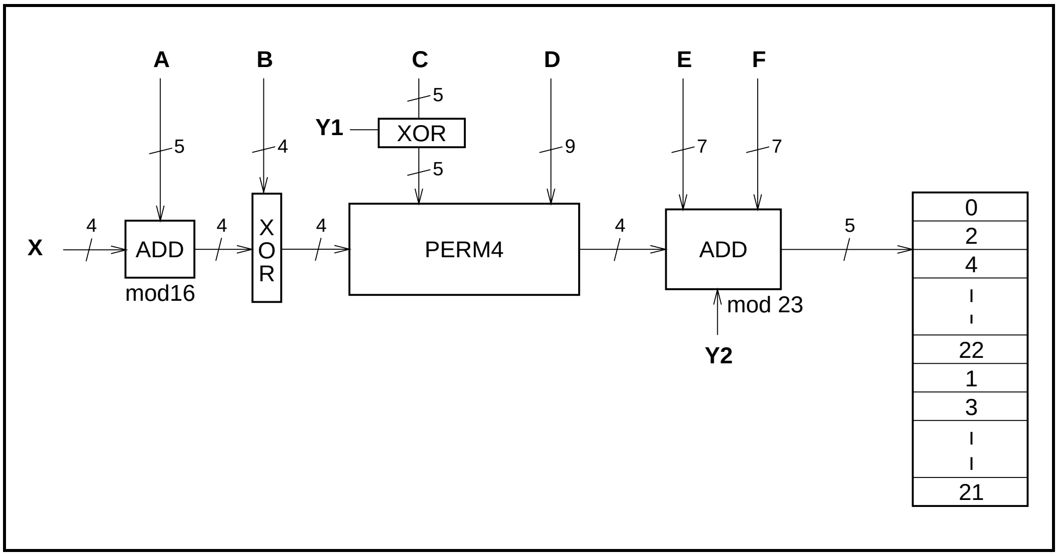

Figure 11.4: Block diagram of hop selection kernel for the 23-hop system.

The selection procedure consists of an addition, an XOR operation, a permutation operation, an addition, and finally a register selection. In the remainder of this chapter, the notation A_i is used for bit i of the BD_ADDR.

11.2.1 First addition operation

The first addition operation only adds a constant to the phase and applies a modulo 32 or a modulo 16 operation. For the page hopping sequence, the first addition is redundant since it only changes the phase within the segment. However, when different segments are concatenated (as in the channel hopping sequence), the first addition operation will have an impact on the resulting sequence.

11.2.2 XOR operation

Let Z' denote the output of the first addition. In the XOR operation, the four LSBs of Z' are modulo-2 added to the address bits A_{22-19}. The operation is illustrated in Figure 11.5 on page 130.

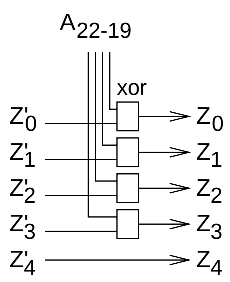

Figure 11.5: XOR operation for the 79-hop system. The 23-hop system is the same except for the Z'_4/Z_4 wire that does not exist.

11.2.3 Permutation operation

The permutation operation involves the switching from 5 inputs to 5 outputs for the 79 hop system and from 4 inputs to 4 outputs for 23 hop system, in a manner controlled by the control word. In Figure 11.6 on page 132 and Figure 11.7 on page 132 the permutation or switching box is shown. It consists of 7 stages of butterfly operations. Table 11.1 and Table 11.2 shows the control of the butterflies by the control signals P. Note that $P_{0\text{-}8}$ corresponds to $D_{0\text{-}8}$, and, P_{i+9} corresponds to $C_i \oplus Y1$ for $i = 0 \ldots 4$ in Figure 11.3 and Figure 11.4.

Control signal	Butterfly		Control signal	Butterfly
P_0	$\{Z_0,Z_1\}$		P_8	{Z1,Z4}
P_1	$\{Z_2,Z_3\}$		P_9	$\{Z_0,Z_3\}$
P_2	$\{Z_1,Z_2\}$		P_{10}	$\{Z_2,Z_4\}$
P_3	$\{Z_3,Z_4\}$		P_{11}	$\{Z_1,Z_3\}$
P_4	$\{Z_0,Z_4\}$		P_{12}	$\{Z_0,Z_3\}$
P_5	$\{Z_1,Z_3\}$		P_{13}	$\{Z_1,Z_2\}$
P_6	$\{Z_0,Z_2\}$			
P_7	$\{Z_3,Z_4\}$			

Table 11.1: Control of the butterflies for the 79 hop system

Control signal	Butterfly		Control signal	Butterfly
P_0	$\{Z_0,Z_1\}$		P_8	$\{Z_0,Z_2\}$
P_1	$\{Z_2,Z_3\}$		P_9	$\{Z_1,Z_3\}$
P_2	$\{Z_0,Z_3\}$		P_{10}	$\{Z_0,Z_3\}$
P_3	$\{Z_1,Z_2\}$		P_{11}	$\{Z_1,Z_2\}$
P_4	$\{Z_0,Z_2\}$		P_{12}	$\{Z_0,Z_1\}$
P_5	$\{Z_1,Z_3\}$		P_{13}	$\{Z_2,Z_3\}$
P_6	$\{Z_0,Z_1\}$			
P_7	$\{Z_2,Z_3\}$			

Table 11.2: Control of the butterflies for the 23 hop system

The Z input is the output of the XOR operation as described in the previous section. The butterfly operation can be implemented with multiplexers as depicted in Figure 11.8 on page 132.

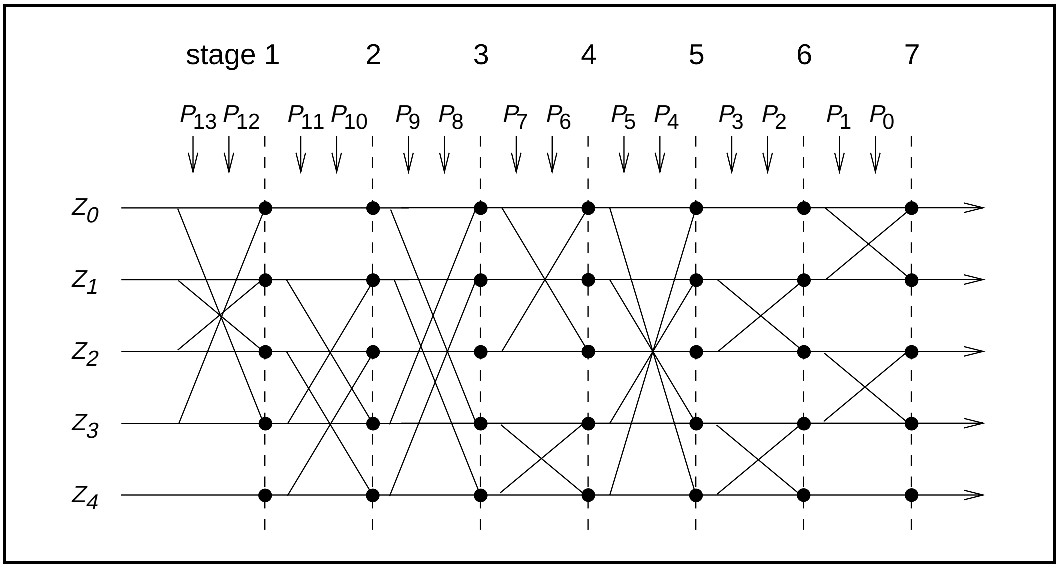

Figure 11.6: Permutation operation for the 79 hop system.

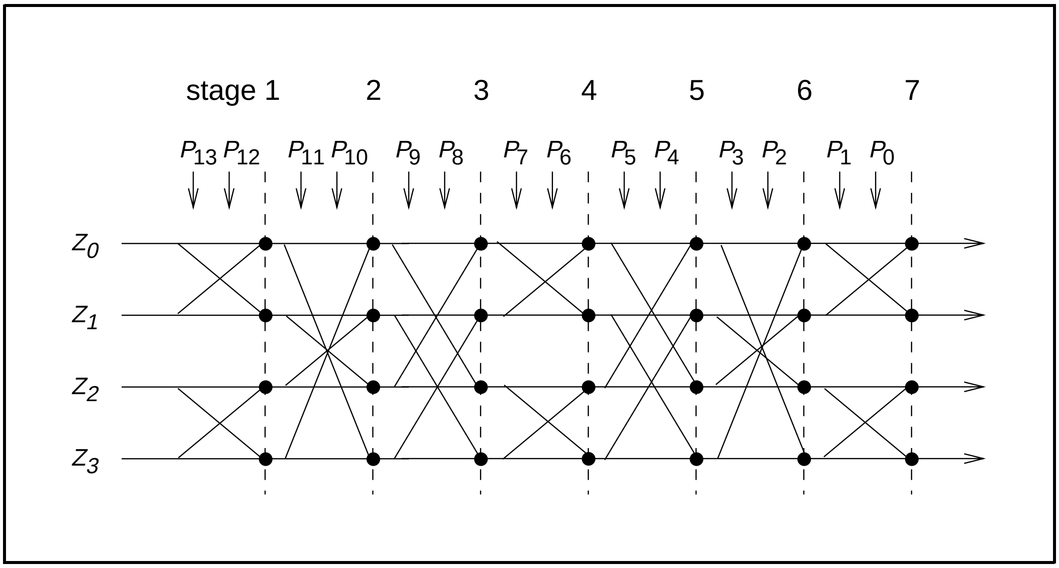

Figure 11.7: Permutation operation for the 23 hop system.

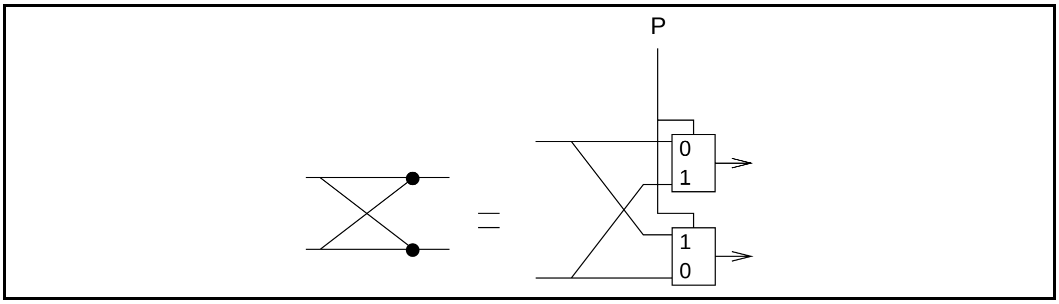

Figure 11.8: Butterfly implementation.

11.2.4 Second addition operation

The addition operation only adds a constant to the output of the permutation operation. As a result, the 16-hop or 32-hop segment is mapped differently on the hop frequencies. The addition is applied modulo 79 or modulo 23 depending on the system type (Europe/US vs. others).

11.2.5 Register bank

The output of the adder addresses a bank of 79 or 23 registers. The registers are loaded with the synthesizer code words corresponding to the hop frequencies 0 to 78 or 0 to 22. Note that the upper half of the bank contains the even hop frequencies, whereas the lower half of the bank contains the odd hop frequencies.

11.3 CONTROL WORD

In the following section $X_{j\text{-}i}$, $i<j$, will denote bits i, i+1,...,j of the bit vector X. By convention, X_0 is the least significant bit of the vector X.

The control word P of the kernel is controlled by the overall control signals X, Y1, Y2, and A to F as illustrated in Figure 11.3 on page 129 and Figure 11.4 on page 129. During paging and inquiry, the inputs A to E use the address values as given in the corresponding columns of Table 11.3 on page 134 and Table 11.4 on page 134. In addition, the inputs X, Y1 and Y2 are used. The F input is unused. In the 79-hop system, the clock bits $CLK_{6\text{-}2}$ (i.e., input X) specifies the phase within the length 32 sequence, while for the 23-hop system, $CLK_{5\text{-}2}$ specifies the phase within the length 16 sequence. For both systems, CLK_1 (i.e., inputs Y1 and Y2) is used to select between TX and RX. The address inputs determine the sequence order within segments. The final mapping onto the hop frequencies is determined by the register contents.

In the following we will distinguish between three types of clocks: the piconet's master clock, the Bluetooth unit's native clock, and the clock estimate of a paged Bluetooth unit. These types are marked in the following way:

1. $CLK_{27\text{-}0}$: Master clock of the current piconet.
2. $CLKN_{27\text{-}0}$: Native clock of the unit.
3. $CLKE_{27\text{-}0}$: The paging unit's estimate of the paged unit's native clock.

During the **CONNECTION** state, the inputs A, C and D result from the address bits being bit-wise XORed with the clock bits as shown in the "Connection state" column of Table 11.3 on page 134 and Table 11.4 on page 134 (the two MSBs are XORed together, the two second MSBs are XORed together, etc.). Consequently, after every 32 (16) time slots, a new length 32 (16) segment is selected in the 79-hop (23-hop) system. The sequence order within a specific

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Dear Application Examiner:

The following information serves to augment the information provided in Exhibit K, "Description of Frequency Hopping System.pdf"

Part I. Acquisition mode Requirements

With the device in the acquisition mode, it is a Hybrid transmitter. Sections a through g below address the requirements of Part 15, Section 15.247(a)1. These include dwell times, channel separation, derivation of the hop mode, derivation of the hop sequence, and examples thereof. In addition this section addresses requirements of equal frequency usage, receiver input bandwidth, and receiver synchronization to the acquisition signal.

a) Dwell time in the acquisition mode:

Please refer to Exhibit S, "Dwell Time.pdf" for dwell time measurements in both Page Mode operation and Inquiry mode operation. An individual transmission on a channel in page mode is 77 microseconds long. In inquiry mode, an individual transmission on a channel is also 77 microseconds long. Per the requirements of 15.247(f) the maximum dwell time cannot exceed 0.4 seconds within a time period in seconds equal to the number of hopping frequencies multiplied by .4 (in this case 32 x.4 =12.8). During a 12.8 sec time period, the total dwell time in both page and inquiry modes is 98.6 milliseconds (77 uS duration, 10mS period) therefore the requirement is met.

The following analyzer settings were used.
Span = 0 centered on hopping channel
Resolution Bandwidth = 1 MHz
Video Bandwidth =Resolution Bandwidth
Sweep = as necessary to capture the entire dwell time per hopping channel
Detector = peak
Trace = max hold

b) Channel Separation: Response: By system architecture channels are 1 MHz apart

c) Derivation of Hop Sequence:

Response: The pseudorandom sequence is generated in a nine-stage shift register whose 5th and 9th stage outputs are added in a modulo-two addition stage with the result fed back to the input of the first stage. This produces a pseudorandom sequence length of 31 bits for page and inquiry modes and provides for transition to a 511 bit pseudorandom sequence length for data mode of operation.

d) An Example of the Hop Sequence in the hybrid mode:

Sequence example a:
5,72,13,48,14,39,54,23,7,46,62,30,3,8,55,10,63,12,16,37,11,43,66,25,51,58,24,17,47,9,29,65
Sequence example b:
41,38,63,14,31,59,40,13,6,25,65,15,61,67,58,47,19,28,54,55,8,48,52,11,5,42,64,17,62,51,20,30

e) Equal Use of Frequencies:

The FHS (frequency hop selection) packet is transmitted by a sending unit. It contains UAP (upper address part)/LAP (lower address part) as well as clock information which is updated before retransmission in the inquiry state. When in hybrid state, the UAP/LAP is used together with the clock to select the sequence. The output from the selection box constitutes a pseudo-random sequence covering 79 hops for US operation. For inquiry mode, the selection scheme chooses a segment of 32 hop frequencies from the 79 hops spanning about 64 MHz and visits these hops once in a random order. Next, a different 32-hop segment is chosen, etc. Refer to chapter 11 of the Bluetooth specification for a more through explanation of the hopping structure.

f) Receiver input bandwidth:

Response: The receiver bandwidth in hybrid mode (32 hopping channels) is equal to the receiver bandwidth in the 79 hopping channel mode which is 1 MHz.

g) Receiver Synchronization with the acquisition signal:

Response: Synchronization within a piconet uses a system of beacon channels generated by the master unit with the remaining slave units periodically waking up and listening on a beacon channel. Beacon channels are designated by the master unit in page mode to identify channels for slave units to listen to. The beacon channel packet also contains the synchronization information required for the slave to sync with the master unit. In page mode the same 32-hop segment is used all the time and the segment is selected by the address with different units having different paging segments. Although they are referred to as beacon channels, they are designated as beacons only for purpose of assisting the listening function for establishing a connection. The master unit is continually hopping through all 32 channels in the page mode. When two Bluetooth devices establish contact for the first time, one of the devices is sending out an inquiry access code, and the other party is scanning for this inquiry access code. If the two devices have been connected previously, and want to start a new session, a similar procedure takes place. The only difference being that instead of the inquiry access code, an access code derived from the paged unit's address is used. If the two Bluetooth devices have exchanged information during the last five hours, the typical time it takes to establish the connection is reduced considerably due to the ability of the paging unit to estimate at what frequency the other unit will perform the page scan. For further information see chapter 10 of the Bluetooth specification.

Part II. Data mode Requirements

With the device in the data mode it must meet the requirements of an FHSS transmitter per Part 15. The following section addresses the derivation of the hopping sequence, a list of channel frequencies, and a sample of a few sequences.

a) Derivation of the hopping sequence: The derivation of the hopping sequence is described in **Part Ic** above.

b) List of Channel Frequencies: Seventy nine frequencies from 2400 MHz through 2483.5 MHz are available in the data mode.

c) Sample Hop Sequences: The following are two examples of possible 79 channel hopping sequences with channels identified as 1 through 79. The channel numbering scheme starts with channel 2 at 2402 MHz with the 79th channel then appearing at 2480 MHz as channel 80.

Sequence a:
2,17,68,55,4,77,56,27,70,80,22,33,57,34,29,79,44,50,3,71,66,36,78,20,67,30,24,11,37,69,23,7,41,38,63,14,31,59,40,13,6,25,65,15,61,73,58,47,19,28,54,76,74,48,52,75,5,42,64,72,62,51,60,18,45,53,16,39,46,32,49,43,8,21,9,12,10,26,35

Sequence b:
50,6,41,57,64,14,42,33,79,3,20,38,56,69,75,21,80,23,31,40,45,68,32,28,4,15,34,59,71,61,70,5,72,13,48,70,39,54,78,7,77,62,30,2,8,55,10,63,12,16,37,11,43,66,25,51,58,74,17,47,9,29,65,19,53,18,52,36,27,26,44,22,49,24,35,60,73,76,67

Part III. Equal Frequency Usage

To meet the requirements of Part 15.247, each frequency must be used equally on the average by each transmitter.

This requirement is guaranteed in all modes by the Bluetooth design specification. The only case that the frequency band usage would not be uniform would be if the transmission was periodic with a period exactly equal to (a multiple of) the size of the Bluetooth clock (i.e. transmission every N*2^^27 slot), in which case only one frequency would be used. However, this is impossible since Bluetooth requires that transmissions take place much more often. Since the random sequence continues for each transmission (whether it is repeated or not) uniform usage of the band is ensured under any transmission scenario.