Section 15.247(a):

Describe how the EUT meets the definition of a frequency hopping spread spectrum system, found in Section 2.1, based on the technical description.

The Sensor is designed with a commercially available frequency-agile digitally modulated radio ASIC. This ASIC is designed to be capable of changing frequencies between packets. The device's firmware takes advantage of this capability by selecting a new operating frequency 100 times per second.

The ASIC uses GFSK modulation and is operated with carrier frequencies on 1 MHz steps from 2402 MHz to 2479 MHz, for a total of 78 channels. Output power is below 125 mW, so the maximum permissible 20 dB bandwidth by Section 15.247(a)(1) is 1.5 MHz. The system hopping rate is 100 Hz.

Link initialization uses a reduced hop set of 15 frequencies. This reduces the time spent in an unsynchronized state, while complying with the requirements of Section 15.247(a)(1)(iii).

The ASIC's digital modulation capabilities are used to provide enhanced robustness through interference detection due to redundant data transmission. The radio is never operated on a static carrier frequency, so the hybrid rules of Section 15.247(f) do not apply.

Pseudorandom Frequency Hopping Sequence

Describe how the hopping sequence is generated. Provide an example of the hopping sequence channels, in order to demonstrate that the sequence meets the requirement specified in the definition of a frequency hopping spread spectrum system, found in Section 2.1.

The hopping sequence is generated in a manner compatible with other Nomadio devices. Some remote devices, such as the GC-205 RCU, use a reduced frequency set. The Sensor adapts its hop sequence to match the capabilities of the linked device.

This is accomplished by adapting the basic Nomadio hop sequence to use only those frequencies available on the linked device. The basic hop set includes 79 channels from 2402 MHz to 2480 MHz. If the generated channel is enabled that channel is used for the current slot. If the channel is not enabled a replacement is selected from the list of enabled channels.

Basic Hop Sequence

The basic hop sequence selects frequencies from a 79-entry list. The list is ordered so that any 32-channel span in the list covers at least 64 MHz of spectrum. This is accomplished by listing all even channels (2402 MHz to 2480 MHz) followed by all odd channels (2403 MHz to 2479 MHz).

A 32-channel wide window is initialized to point into the list. The 32-selected channels are shuffled for the next 32 hops, so that each channel is used exactly once.

When all 32 entries from the current window have been used once, the window is advanced 16 entries in the table, in a circular fashion (the first table entry, 2402 MHz, is considered to immediately follow the last entry, 2479 MHz) and the control inputs to the shuffle stage are changed. After the window has been advanced 79 times it returns to the starting position. This occurs after $79 \times 32 = 2528$ hops.

There are 2^{14} possible shuffle patterns, used over the course of 2^{19} hops. When all patterns have been used, the phase of the 5-bit shuffle data input is changed. This increases the period of the shuffle output to 2^{24} hops. When this period expires, however, the sliding window will not be in the starting position. The two periods will not align until 79×2^{24} hops, at which point the pattern repeats. At 100 frames per second this is approximately 151 days of continuous operation, well in excess of the normal operational period of the system.

Because the base operation is a 32-channel shuffle, it is impossible for any single channel to be used on more than two consecutive slots, which only occurs if the channel is last in one shuffle and first in the next shuffle. Every channel is used 32 times in a 2528 hop cycle.

Each stage of calculation includes an exclusive-or with a portion of the link GUID. This ensures that two linked pairs will follow different hopping sequences, even if their positions in the hop sequence happen to be closely synchronized.

Limiting Channel Use

After a channel is generated by the basic sequence it is checked against the list of usable channels. If the channel is not usable a replacement is selected. The replacement is chosen using the shuffle output index (0-31) along with a sliding window into the list of used channels. The window is moved each time the base sequence window is moved. The used channel list is equivalent to the base channel list with unused channels removed. That is, all even used channels are listed followed by all used odd channels.

When the used channel set contains 32 or more channels, a given replacement channel can be used at most once for a given 32-channel shuffle. If fewer than 32 channels are in use (such as during rendezvous) a channel may be used as a substitute more than once in a 32-channel shuffle. Over time, as the selection window is moved through the hop set, each channel will be used the same number of times as any other.

Channel Set Selection

The Sensor can use four different hop sets, depending on device configuration and the nature of the linked device. These hop sets include a full-band 78 channel hop set, a full-band 15-channel hop set for rendezvous, a 32-channel hop limited to the upper portion of the band, and a 15-channel rendezvous hop set limited to the upper portion of the band.

The rendezvous hop set is set at system configuration time, depending on the nature of the intended remote device. Six channels are shared between the two rendezvous sets, allowing connections between GC-series devices and Sensor devices. When a connection is established, the remote device selects the hop set used for the connection.

Channel Sets

Full Band	Rendezvous	3, 8, 13, 18, 23, 28, 33, 38, 43, 48, 53, 58, 63, 68, 73
	Connected	0, 1, 2, ... 75, 76, 77
Reduced Band	Rendezvous	48, 53, 58, 63, 68, 73, 50, 54, 57, 61, 64, 67, 71, 74, 77
	Connected	45, 46, 47, ... 75, 76, 77

Frequency = channel + 2402 MHz

<u>Equal Hopping Frequency Use</u>

Describe how each individual EUT meets the requirement that each of its hopping channels is used equally on average (e.g., that each new transmission event begins on the next channel in the hopping sequence after the final channel used in the previous transmission event).

All messages are sent on the basis of a shared 100 Hz clock. On each timeslot, both devices in a linked pair generate a new frequency using the algorithm described above. Normally, the slave device will activate its receiver and the master device will transmit a message. The slave will respond with a short ACK message on the same channel.

If the master expects a response to a message (such as telemetry data) the response is sent from the slave in the next timeslot, using the frequency the request was received on. Both devices still execute the channel selection algorithm but discard the result. This ensures the devices remain synchronized if the slave device missed the request message, in which case both devices spend a timeslot receiving, likely on different frequencies.

All messages fit within a single timeslot, and a new frequency is selected for each timeslot. The hopping algorithm is guaranteed to return each channel equally on average (see description above).

Simulations of the hop algorithm over various length hop sequences (10,000 to over 300 million hops) and hop sets show no sustained bias toward or away from any channel.

<u>System Receiver Input Bandwidth</u>

Describe how the associated receiver(s) complies with the requirement that its input bandwidth (either RF or IF) matches the bandwidth of the transmitted signal.

The EUT is designed with a commercially available frequency-agile digitally modulated radio ASIC. This ASIC is used on both ends of the link, and is designed with matching transmitter and receiver bandwidths.

System Receiver Hopping Capability

Describe how the associated receiver(s) has the ability to shift frequencies in synchronization with the transmitted signals.

Each link consists of a master device and a slave device. Timeslot synchronization is maintained by tracking packet transmission and reception times. The master device internally generates a 100 Hz clock signal and sends packets on the basis of this clock. The slave records packet reception times and uses this timing information to adjust its 100 Hz clock to match the master clock's period and phase.

The hop algorithm on the slave device is initialized to match the master's during link initialization. Both devices step through the hop sequence on every timeslot.

Link initialization uses an unsynchronized hop sequence with a 15 channel hop set. The listening device hops at a reduced rate (typically 50 ms dwell time) to increase the odds of matching channels with the advertising device.

Section 15.247(g):

Describe how the EUT complies with the requirement that it be designed to be capable of operating as a true frequency hopping system.

All messages fit within a single timeslot, and a new frequency is selected for each timeslot. The hopping algorithm is guaranteed to return each channel equally (see description above).

This ensures that all enabled channels are used equally over a period of 32 hops times the number of used channels (32 × 32 = 1024 hops for an established connection to a GC-205 RCU, 32 × 32 = 2496 hops for a connection to a Sensor Car Transceiver, 15 × 32 = 480 hops for link establishment).

Section 15.247(h):

Describe how the EUT complies with the requirement that it not have the ability to be coordinated with other FHSS systems in an effort to avoid the simultaneous occupancy of individual hopping frequencies by multiple transmitters.

The link protocol only supports communication between a linked controller/remote transceiver pair. No mechanisms are provided for the inter-link communication necessary to synchronize hop sequences.