Buildwise Project Report

Report Editor:

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CHAPTER 1
Sensors Selection

1.1 Work Plan stages for Building Sensors Deployment

Figure.4 shows the overflow diagram for a general work plan to identify, interface and deploy sensors/meters in a building.

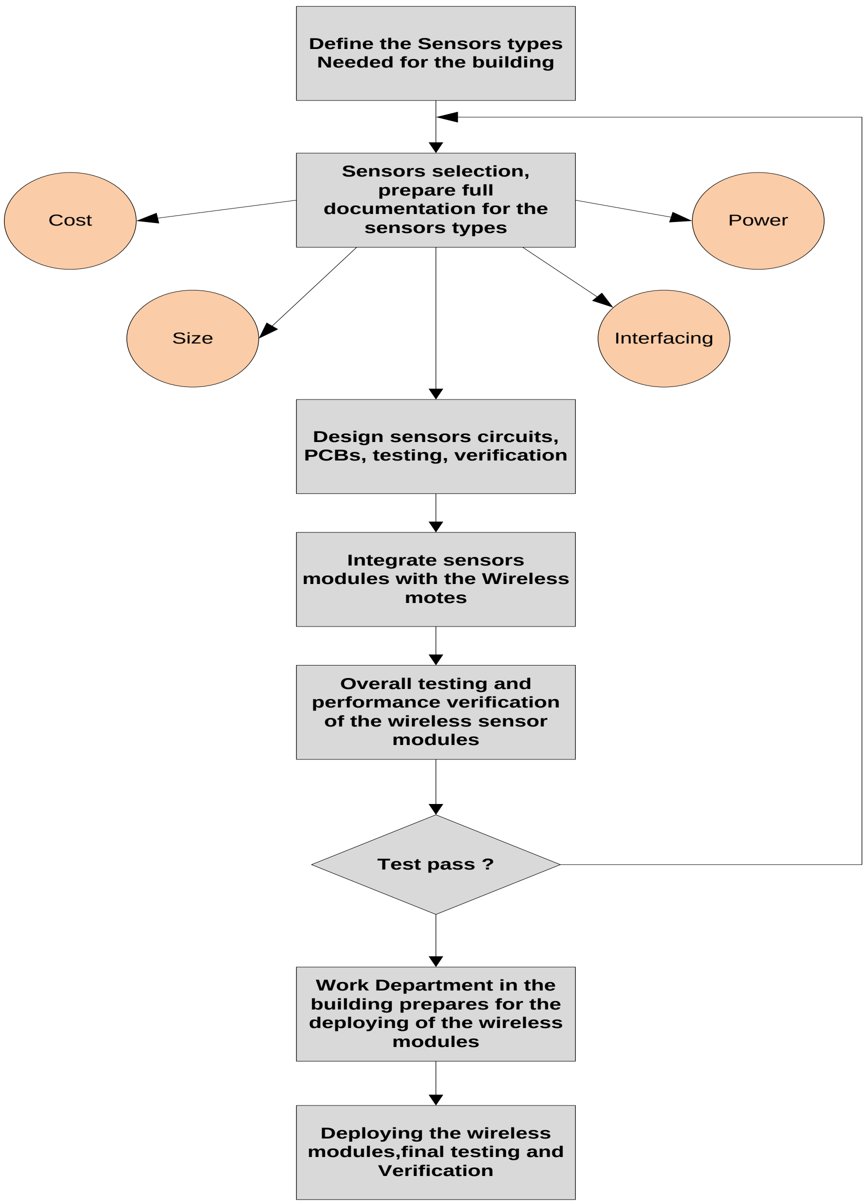


Figure 1. Work diagram of Building Sensors/Meters Deployment

1.2 Light Level (Lux sensor)

A light intensity sensor includes a variable-voltage opto-electronic generator adapted to deliver to the terminals of a load resistor a voltage varying as a function of the variable light intensity detected by the sensor. Some of highly advanced light sensors are integrated in mixed signal IC's to provide a digital output. The table below was made to shows part of the possible sensors to be selected based on different parameters

Device	Device Description	Peak Spectral Sensitivity (nm)	V_S (Min) (V)	V_S (Max) (V)	Supply Current @ E_V = 100Lux (µA)
EL7900	Ambient Light Photo Detect IC	540	2.5	5.5	62
ISL29000	Ambient Light Photo Detect IC	540	2.5	5.5	7.4

Device	Device Description	Peak Sensitivity (nm)	V_S (Min) (V)	V_S (Max) (V)	Supply Current (µA)
ISL29001	Light-to-Digital Sensor	550	2.25	3.63	280
ISL29002	Light-to-Digital I^2C Sensor	550	2.25	3.63	300
ISL29003	Light-to-Digital Output Sensor with High Sensitivity, Gain Selection, Interrupt Function and I^2C Interface	550	2.25	3.63	290
ISL29004	Light-to-Digital Output Sensor with Address Selection, High Sensitivity, Gain Selection, Interrupt Function and I^2C Interface	550	2.25	3.63	300
ISL29010	Light-to-Digital Output Sensor with High Sensitivity, Gain Selection, and I^2C Interface	540	2.5	3.3	250
ISL29013	Light-to-Digital Output Sensor with High Sensitivity, Gain Selection, Interrupt Function and I^2C Interface	540	2.5	3.3	250

TAOS Corporation

Device	Device Description	Peak Spectral Sensitivity (nm)	V_S (Min) (V)	V_S (Max) (V)	Supply Current (mA)
TSL12S	LIGHT-TO-VOLTAGE (LTV)	640	2.5	5.5	1.1
TSL2560/2561	LIGHT TO DIGITAL I2C Sensor	940	2.7	3.6	0.24 (Power down available)

1.3 Electricity Meters

1.3.1 Single Phase Meter

Single phase two tariff kWh Meter with RS-485 Interface

Features:

- Accuracy class 1
- kWh import
- Two tariff scheme
- Large 16 character Liquid Crystal Display with programmed reading sequence
- Pulse output to AMR system
- LEDs on front of meter indicate consumption of energy, low battery and incorrect RS-485 connection
- Internally wired current and voltage circuits
- Storage of all data in a non-volatile EEPROM memory
- Optically isolated RS-845 interface
- Control output for automatic connect/disconnect

1.3.2 Three Phase Meter

Three Phase Multi-tariff Kwh Meter RS-485 Interface

Features:

- Measuring energy of every phase separately, total energy is the summation of three phase's pulse with less inter-phase interference
- Reactive energy measurement via complementary passive phase circuit, accurate and reliable
- New design adopted, least influence from frequency, voltage and harmonics on measuring accuracy; no calibration needed within long working period
- Three phase power supply. Measurement accuracy won't be affected if one or two phase power supply were cut off
- Wide operating voltage range
- Remote test impulse output
- RS485 port

1.4 Windows Signal Sensors

1.4.1 Requirements

The sensors required for the doors/windows status detection are suppose to meet the following two objectives:

1- Detect if the door/window is open or closed.

2- How wide the door/window is opened.

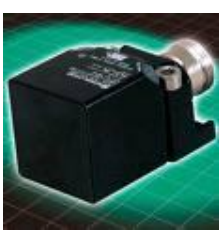
Beside that, the sensor has to be small in size, reliable and consumes low power to be used for long life application. The proximity sensors were selected for such application as they meet all the above requirements and easy to interface to any microprocessor based system. The following section will describe the main two types of the proximity sensors.

1.4.2 Inductive and Capacitive proximity sensors

Their operating principle is based on a high frequency oscillator that creates a field in the close surroundings of the sensing surface. The presence of a metallic object (inductive) or any material (capacitive) in the operating area causes a change of the oscillation amplitude. The rise or fall of such oscillation is identified by a threshold circuit that changes the output state of the sensor. The normal operating distance, or sensing range, is defined as the distance between the detector and the target when the change (switching) in the logic state of the proximity switch occurs. The operating distance of the sensor depends on the actuator's shape and size and is strictly linked to the nature of the material (Table 1 & Table 2).

Table 1: INDUCTIVE SENSORS

Sensitivity when different metals are present.
Sn = operating distance.



Fe37 (iron)	1 x Sn
Stainless steel	0.9 x Sn
Brass- bronze	0.5 x Sn
Aluminum	0.4 x Sn
Copper	0.4 x Sn

Table 2: CAPACITIVE SENSORS

Sensitivity when different materials are present.

Sn = operating distance.

Metal	1 x Sn
Water	1 x Sn
Plastic	0.5 x Sn
Glass	0.5 x Sn
Wood	0.4 x Sn

1.4.3 Photoelectric

These sensors use light sensitive elements to detect objects and are made up of an emitter (light source) and a receiver. Three types of photoelectric sensors are available. Direct Reflection - emitter and receiver are housed together and uses the light reflected directly off the object for detection. Reflection with Reflector - emitter and receiver are housed together and requires a reflector. An object is detected when it interrupts the light beam between the sensor and reflector. Thru Beam - emitter and receiver are housed separately and detect an object when it interrupts the light beam between the emitter and receiver.

1.4.4 Magnetic

Magnetic sensors are actuated by the presence of a permanent magnet. Their operating principle is based on the use of reed contacts, which consist of two low reluctance ferro-magnetic reeds enclosed in glass bulbs containing inert gas. The reciprocal attraction of both reeds in the presence of a magnetic field, due to magnetic induction, establishes an electrical contact.

1.5 Ultrasonic Flow Meters

1.5.1 Requirements

The ultrasonic non-introductive was found to be the optimal solution for measuring the water flow rate of the water on building pipes. It is required to get the flow rate measurements from different locations inside the building where pipes made from different materials and have wide scale diameter size. In order not to disturb the existing pipes installation and gives flexible testing option, the ultrasonic is quite suitable for such application.

1.5.2 Introduction

An ultrasonic flowmeter (non-intrusive Doppler flow meters) is a volumetric flow meter which requires particulates or bubbles in the flow. Ultrasonic flowmeters are ideal for wastewater applications or any dirty liquid which is conductive or water based. Ultrasonics flowmeters will generally not work with distilled water or drinking water. Aerations would be required in the clean liquid applications. Ultrasonic flowmeters are also ideal for applications where low pressure drop, chemical compatibility, and low maintenance are required.

The basic principle of operation employs the frequency shift (Doppler Effect) of an ultrasonic signal when it is reflected by suspended particles or gas bubbles (discontinuities) in motion. This metering technique utilizes the physical phenomenon of a sound wave that changes frequency when it is reflected by moving discontinuities in a flowing liquid. Ultrasonic sound is transmitted into a pipe with flowing liquids, and the discontinuities reflect the ultrasonic wave with a slightly different frequency that is directly proportional to the rate of flow of the liquid. Current technology requires that the liquid contain at least 100 parts per million (PPM) of 100 micron or larger suspended particles or bubbles.

1.5.3 Ultrasonic meters types

1.5.3.1 Doppler Flowmeters

To use the Doppler effect to measure flow in a pipe, one transducer transmits an ultrasonic beam of ~0.5 MHz into the flow stream. Liquid flowing through the pipe must contain sonically reflective materials such as solid particles or entrained air bubbles. The movement of these materials alters the frequency of the beam reflected onto a second, receiving transducer. The frequency shift is linearly proportional to the rate of flow of materials in the pipe and therefore can be used to develop an analog or digital signal proportional to flow rate.

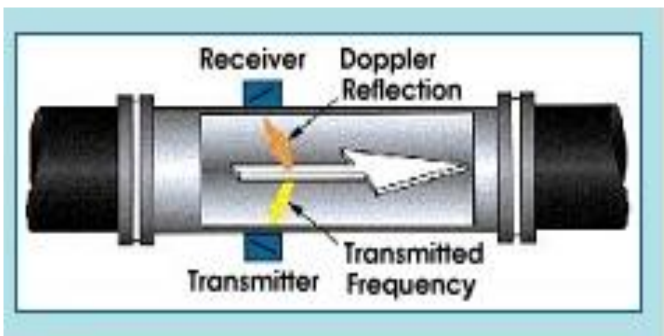


Figure 2. Doppler ultrasonic flowmeters operate on the Doppler effect, whereby the transmitted frequency is altered linearly by being reflected from particles and bubbles in the fluid. The net result is a frequency shift between transmitter and receiver frequencies that can be directly related to the flow rate.

1.5.3.2 Transit-Time Flowmeters

Transit-time meters, as the name implies, measure the difference in travel time between pulses transmitted in the direction of, and against, the flow. This type of meter is also called time of flight and time of travel.

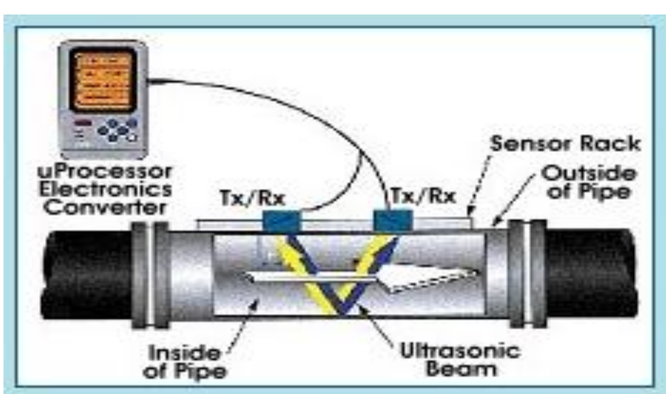


Figure 3. Transit-time flowmeters measure the difference in travel time between pulses transmitted in a single path along and against the flow. Two transducers are used, one upstream of the other. Each acts as both a transmitter and receiver for the ultrasonic beam.

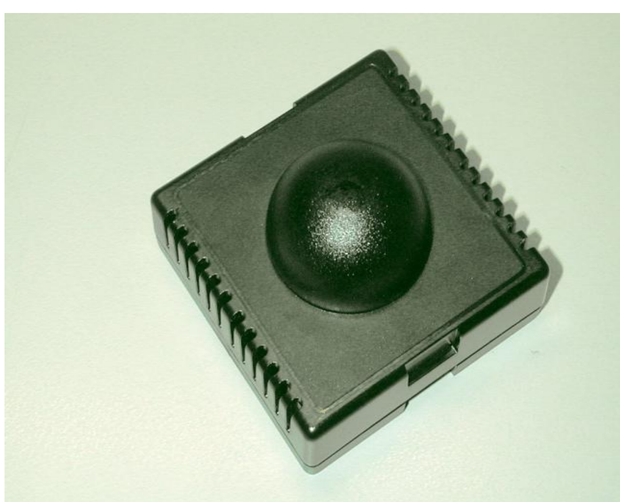
The key questions which need to be answered before selecting an ultrasonic flow meter or Doppler flowmeter are:

- Does the liquid have particulates of 100 ppm of 100 microns in size?
- Handheld or continuous process monitor is required?
- What is the minimum and maximum flow rate for the flow meter?
- What is the minimum and maximum process temperature?
- What is the minimum and maximum process pressure?
- The size of the pipe.
- Is the pipe always full?

1.6 Radiant Temperature Sensor

1.6.1 Introduction

The characteristics of the air-contact temperature sensor, point-measurement and dry-bulb temperature sensing, enable this type's sensor to measure only a spot air temperature of a 3 dimensional space where it is installed, and cannot measure the radiative heat transfer between the occupants and surroundings, just like a globe thermometer does.



The globe thermometer is designed to measure sensible heat transfer of a human body, but it also suffers from the same restriction of the location as the air-contact temperature sensor, so it has not been adopted by air-conditioning automatic control. The characteristics of the radiant temperature sensor, remote surface temperature sensing and zonal measurement, enable this type's sensor to do different measuring from the air-contact temperature sensor and globe thermometer. Therefore, it attracted attention as a new type of sensor for HVAC automatic control, and may replace the traditional sensors

1.6.2 Sensor Interfacing

The radiant temperature sensors with variable resistance can be easily interfaced to any microprocessor based system which has analog to digital conversion (ADC) unit. An interface circuit can be designed to interpret the change in capacitance to change in voltage or current.

1.7 Occupancy Detection

These systems use passive infrared (PIR) and/or ultrasonic technologies, signaling space occupancy based on changes in the temperature or sound profile of the space. Another sensor used for occupancy detection is CO2 sensor, since people exhale CO_2, the difference between the indoor CO_2 concentration and the level outside the building indicates the occupancy and/ or activity level in a space and thus its ventilation requirements. See section 2 for further information about CO2 sensors.

Below it is described several methods and sensors currently used in occupancy detection:

1.7.1 Occupancy Sensors: Technology Guide

There are mainly 3 types of occupancy sensors in terms of technology: Infrared sensors (PIR), ultrasonic sensors (US) and Dual technology (DT), ceiling and wall-mounted sensors are both available for the three of them.

1.7.2 Passive infrared (PIR)

PIR technology senses occupancy by detecting the difference between heat emitted from the human body and the background space. PIR sensors require an unobstructed line-of-sight for detection. These sensors utilize a segmented lens, which divides the coverage area into zones. Movement between these zones is interpreted as occupancy. PIR sensors are good at detecting major motion (e.g. walking) and work best in small, enclosed spaces with high levels of occupant movement.

1.7.3 Ultrasonic sensors (US)

Ultrasonic technology senses occupancy by bouncing ultrasonic sound waves (32kHz- 45kHz) off objects in a space and detecting a frequency shift between the emitted and reflected sound waves. Movement by a person or object within the space causes a shift in frequency, which is interpreted as occupancy. Ultrasonic occupancy sensors are good at detecting minor motion (e.g. typing, reading) and do not require an unobstructed line-of-sight, thus making them suitable for applications such as an office with cubicles or a restroom with stalls.

1.7.4 Dual technology (DT)

Dual technology occupancy sensors use both passive infrared and ultrasonic technologies for maximum reliability. These sensors also minimize the risk of false triggering (lights coming on when the space is unoccupied). Both US and PIR technologies must detect occupancy to turn lighting on, while continued detection by only one technology will keep lighting on. The dual technology sensors are the best performing sensor for most applications.

Note1: The PIR sensors cannot differentiate at all between one or more occupants in a monitored space; it is required additional algorithms to determine the number of occupants.

Note2: The PIR sensors as based on Motion Detection and therefore if motion activity ceases for a period of time, how do you know what happened? Are the occupants gone? Is someone there who is simply inactive? , for instance, extra sensors & algorithms are required.

Note3: A simple Occupancy Detector system that not only detects whether the room is empty but also differentiates between one or more occupants is described in the following Final Design Project: http://instruct1.cit.cornell.edu/courses/ee476/FinalProjects/s2006/aa338_mg266_emo29/aa338_mg266_emo29/index.htm#IRSensors

Occupancy Detection

(top)

An occupancy detector circuit was built using a pair of infrared transceivers (Receiver: LTR-4206E; Transmitter: LTE-4208). When an opaque object is put in between the aligned transceiver current flows through the receiver. Putting one transceiver on a door could be used to determine whether someone crossed the door, however, two are needed to determine the direction of the person crossing the door.

The voltage that develops across the receiver is dependent on the opaqueness of the object and the distance between the transmitter and receiver. To deal with this, two inverting Schmitt Triggers were designed using a LMC7111 Operational Amplifier. Each Schmitt Trigger was designed to have a low threshold of 1.55 V and high threshold of 2.08 V. This design permits easy interfacing with the microcontroller as it provides an active-low signal to indicate a specific sensor has toggled.

The transmitter/receiver pair has an active range of detection of about 10° and were tested for acceptable operation of 2m. The actual circuits were mounted on the frame for demonstration purposes, as the picture on the right shows.

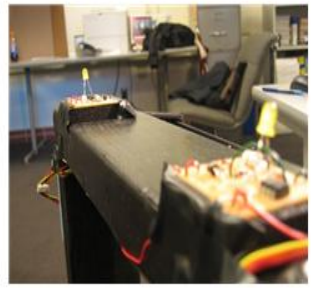


Figure 2: Occupancy Detector Circuit mounted on frame.

The diagram below illustrates the Occupancy Detector Circuit, and the image to the right of that shows a receiver and a transmitter circuit (which do not communicate with each other).

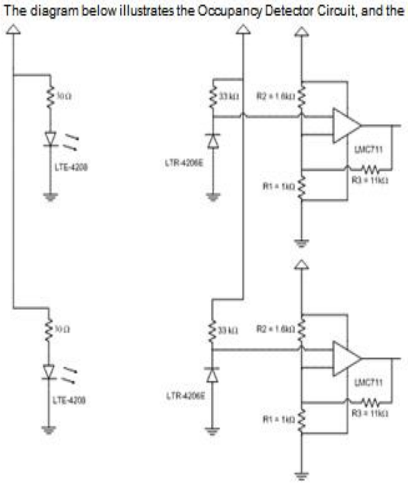


Figure 3: Infrared Occupancy Detection Circuit

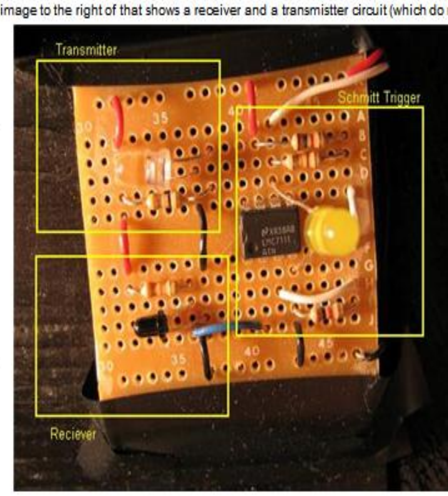


Figure 4: Actual Transmitter, Reciever and Schmitt Trigger.

The circuit feeds information to the microcontroller, so an appropriate algorithm needed to be developed. Conceptually, when a person walks into the room through a door with the sensors, Sensor A is toggled first followed by Sensor B. Similarly, when a person leaves the room, Sensor B is toggled before Sensor A. In order to account for cases when a person walks half-way through the door (toggling only Sensor A) and decides to reverse direction and leave never entering the room, the following algorithm was implemented:

The number of people in the room will only be increased if the sensors are toggled in the following specific order:

1. Sensor A
2. Sensor A and Sensor B
3. Sensor B

In an analogous manner, the number of people will only be decreased if the following sensors are toggled in order:

1. Sensor B
2. Sensor B and Sensor A
3. Sensor A

All other combinations are ignored

The actual code developed for this circuit is listed below.

```
if (sensorA && !sensorB) {
if((traffic == NONE)||(traffic == IN_M)) traffic = IN;
}
else if (!sensorA && sensorB) {
if((traffic == NONE)||(traffic == OUT_M)) traffic = OUT;
}
else if (sensorA && sensorB) {
if(traffic == IN) traffic = IN_M;
else if (traffic == OUT) traffic = OUT_M;
}
else if (!sensorA && !sensorB) {
if(traffic == OUT_M) {
if(num_people != 0) num_people--;
PORTB = ~num_people;
}
else if(traffic == IN_M) {
num_people++;
PORTB = ~num_people;
}
traffic = NONE;
}
```

1.7.5 Wireless integrated occupancy sensor

The application relates to an occupancy sensor for a room and, in particular, to an occupancy sensor that integrates a passive infrared ("PIR") motion detector and a magnetic door switch in one wireless, battery-powered unit.As in section 1.7.4, it says that the use of a PIR motion detector as an occupancy sensor does not produce an accurate indication of a room being occupied in situations in which an occupant remains motionless for an extended period of time, such as in sleeping, reading or watching television and that the PIR motion detector is also not accurate in rooms in which the geometry of the room includes blind spots to the PIR motion detector such as alcoves or bathrooms and it establishes that the accuracy of occupancy information can be improved by using both a PIR motion detector and a magnetic door switch, which provides status information as to whether the access door to a room is open or closed.

http://www.patentstorm.us/patents/7123139-description.html

1.8 CO2 Sensors

1.8.1 CO2 Sensors focused on Building automation

The Carbon Dioxide (CO2) sensor measures and records carbon dioxide in parts per million (ppm) in occupied building spaces. These carbon dioxide measurements are typically used in Demand-controlled ventilation (DCV) method.

CO2-based DCV has the most energy savings potential in buildings where occupancy fluctuates during a 24-hour period, is unpredictable, and peaks at high level, for example, office buildings, government facilities, retail stores and shopping malls, movie theaters, auditoriums, schools, entertainment clubs and night clubs.

Since people exhale CO_2, the difference between the indoor CO_2 concentration and the level outside the building indicates the occupancy and/ or activity level in a space and thus its ventilation requirements.

Demand-controlled ventilation (DCV) using carbon dioxide (CO_2) sensing is a combination of two technologies: CO_2 sensors that monitor CO_2 levels in the air inside a building, and an air-handling system that uses data from the sensors to regulate the amount of ventilation air admitted. CO_2 sensors continually monitor the air in a conditioned space. Given a predictable activity level, such as might occur in an office, people will exhale CO_2 at a predictable level. Thus CO_2 production in the space will very closely track occupancy. Outside CO_2 levels are typically at low concentrations of around 400 to 450 ppm. Given these two characteristics of CO_2, an indoor CO_2 measurement can be used to measure and control the amount of outside air at a low CO_2 concentration that is being introduced to dilute the CO_2 generated by building occupants. The result is that ventilation rates can be measured and controlled to a specific cfm/person based on actual occupancy. This is in contrast to the traditional method of ventilating at a fixed rate regardless of occupancy.

Building codes require that a minimum amount of fresh air be provided to ensure adequate air quality. To comply, ventilation systems often operate at a fixed rate based on an assumed occupancy (e.g., 15 cfm per person multiplied by the maximum design occupancy). The result is there often is much more fresh air coming into buildings than is necessary. That air must be conditioned, resulting in higher energy consumption and costs than is necessary with appropriate ventilation. In humid climates, excess ventilation also can result in uncomfortable humidity and mold and mildew growth, making the indoor air quality (IAQ) worse rather than better.

A lack of adequate fresh air, on the other hand, can make building occupants drowsy and uncomfortable. To avoid the problems of too much or too little fresh air, the heating, ventilation, and air-conditioning (HVAC) system can use DCV to tailor the amount of ventilation air to the occupancy level. CO_2 sensors have emerged as the primary technology for monitoring occupancy and implementing DCV. Energy savings come from controlling ventilation based on actual occupancy versus whatever the original design assumed.

1.8.2 CO2 Sensors: Technology Guide

Cost

Costs for CO2 sensors have dropped by about 50% over the last several years as the technology has matured and become more widely used. Sensors typically cost between 200 to 300 Euros each.

Power Requirements

CO_2 sensing is a fairly simple technology, and installation of the sensors themselves is not complicated. Sensor voltage, power, and control output requirements are similar to those used commonly by thermostats.

Electronic signals from 2 to 10 V DC, 0 to 10 V DC, 4 to 20 mA are the most common.

Wired CO2 sensors considerations

Wired sensor installations, the type of wire used for the signal wiring is often critical; some controls manufacturers specify the wire gauge, type, and shielding/ grounding requirements to prevent signal irregularities and errors.

Wireless CO2 sensors

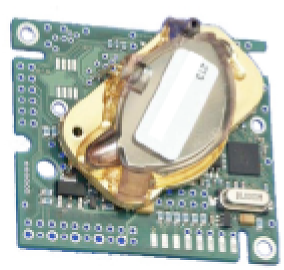
With wireless sensors, the considerations made in section 2.2.3 are not a concern, as data are transmitted over a Federal Communications Commission-approved frequency. The wireless sensors are mounted on a self-powered board and use on-board power management to alert the building operator when the battery needs to be changed.

Data from the sensors are fed to the building's control system or to an actuator (that controls the amount of ventilation air that is admitted for example).

Maintenance

Maintenance of the sensors themselves is not reported to be a problem. Although earlier sensor models had reliability problems, the literature generally reports that newer models typically are reliable and accurate. Manufacturers offer sensors that recalibrate themselves automatically and that are guaranteed not to need calibration for up to 5 years. However, it is recommended that calibration be checked periodically by comparing sensor readings during a several-hour period when the building is unoccupied with readings from the outdoor air. Many sensor models are able to sense calibration problems and alert maintenance personnel if they are malfunctioning.

CO_2 Engine™ - Default Technical Specification



General Performance:

Storage Temperature Range	-30 to +70 °C
Sensor Life Expectancy	> 15 years
Maintenance Interval	no maintenance required [1]
Self-Diagnostics	complete function check of the sensor module
Operating Temperature Range	0 - 50 °C
Operating Humidity Range	0 to 95% RH (non-condensing)
Operating Environment	Residential, commercial, industrial spaces and Potentially dusty air ducts used in HVAC (Heating Ventilation and Air-Conditioning) systems. [2]
Warm-up Time	<1 min. (@ full specs <15 minutes)
Conformance with the standards	Emission: EN61000-6-3:2001, EN55011B Immunity: EN61000-4-3, -4-11

Electrical / Mechanical:

Power Input	5,7-7,5 VDC, stabilized to within 10% (external protection circuits required) [3]
Current Consumption	40 mA average < 150 mA peak current (averaged during IR lamp ON, 100 msec) < 400 mA peak power (during IR lamp start-up, the first 25 msec)
Electrical Connections [4]	terminals not mounted (G+, G0, OUT1, OUT2, ErrStat, TxD, RxD, R/T)
Dimensions	5,1 x 5,7 x 2 cm (Length x Width x approximate Height)

1.9 HUMIDITY SENSOR

1.9.1 Humidity Sensors focused on Building automation

Relative humidity (RH) is an important indicator of air quality in buildings. Extremely low or high humidity levels (the comfort range is (30 - 70% RH)) can cause discomfort to workers and can reduce building longevity. Humidity control also dictates building energy consumption during heating seasons.

The market offers a wide variety of these sensors, particularly interesting are those which use digital technology (CMOS chip technology instead of the traditional capacitive analogue technology) as they require no calibration or adjustment, and their digital outputs allow using them with embedded microprocessor the sensor's digital signal to a continuous DC voltage which corresponds to 0-100% relative humidity as well as wireless approach. Most of these sensors also provide temperature measurement as it is an important part of controlling relative humidity and needed to convert the voltage output to relative humidity.

1.9.2 Humidity Sensors: Technology Guide

Conventional sensors determine relative air humidity using capacitive measurement technology. For this principle, the sensor element is built out of a film capacitor on different substrates (glass, ceramic, etc.). The dielectric is a polymer which absorbs or releases water proportional to the relative environmental humidity, and thus changes the capacitance of the capacitor, which is measured by an onboard electronic circuit. These are the analogue humidity sensors which presents several disadvantages against the newer generation of integrated, digital, and calibrated humidity and temperature sensors using CMOS "micro-machined" chip technology:

- Poor long-term stability: Due to the relatively large dimensions of the sensor elements (10-20 mm2), as well as the aging of the polymer layer, current capacitive sensors on the market exhibit varying degrees of sensitivity to the same external influences. Therefore, the drift per year, i.e., the yearly change in error tolerance of the sensor, is becoming an important criterion for quality. The aging of the metallic layer electrodes can also lead to errors in the humidity signal.

- Complicated calibration: Before use, capacitive humidity sensors must undergo a complicated calibration process. For this purpose, the end user must have complex and expensive calibration and reference systems, as well as external electronic components, such as memory components.

- Analogue technology: Additional problems arise directly from the analogue measurement principle, which links the stability of the operating voltage inseparably to the sensor accuracy. This problem can only be counteracted by increased spending on electronics and inevitably leads to higher integration costs.

1.9.3 Example of humidity sensor based on digital technology: SHT11

Combining CMOS and sensor technologies leads to a highly integrated and small humidity sensor. These devices often includes two calibrated micro sensors for relative humidity and temperature which are coupled to an amplification, analogue-to-digital (ND) conversion and serial interface circuit on the same chip. The temperature sensor and the humidity sensor together form a single unit, which enables a precise determination of the dew point without incurring errors due to temperature gradients between the two sensor elements.

Cost

~14 Euro

Precision

High precision (±2% to ±5% according to configuration)

Size

Small footprint (7x5x3 mm)

Power Requirements

Low power consumption (<3µA standby)

Wireless

These sensors chip can be connected directly to any microprocessor system by means of the digital 2-wire interface.

Maintenance

They require no calibration or adjustment

CHAPTER 2
ERI RF Measurements

2.1 Introduction and Objectives

The radio Frequency (RF) Monitoring and Measurement of the Environmental Research Institute (ERI) was tasked by the Buildwise project team to carry out a RF survey in both the Zigbee (2.44 GHz) and the industrial, scientific and medical (ISM 433MHz). The main objective of this survey is to confirm what the noise and interferences threat signals exist in these bands. As it is planed for the next two stages of the project to deploy a determined scale Wireless Sensors network (WSN), it is crucial at this stage to have a clear idea about the RF activity of the Building for the 24 hours period.

It was agreed that the surveys would be carried out in 5 different rooms and areas that are candidates for the Wireless Sensors deployments, these are:

1- Plant Room (Ground Floor)

2- Immunology Lab (First Floor)

3- Open Office Area (Second Floor)

4- Seminar Room (Second Floor)

5- Seminar Room Corridor (Second Floor)

The method used in this survey was represented by an integrated hardware/Software system as shown in Figure 4. In the Hardware side, a handheld spectrum analyzer (SA) of frequency range 100 kHz to 3.0 GHz was used. Suitable band antennas with SMA connectors were fixed at the top of the device to receive the RF signals. The SA is connected to a laptop through RS232. A Labview program was written to control the operation of the SA in two single sweep (for the 24 hours survey) and max hold (for detecting noise signals) modes.

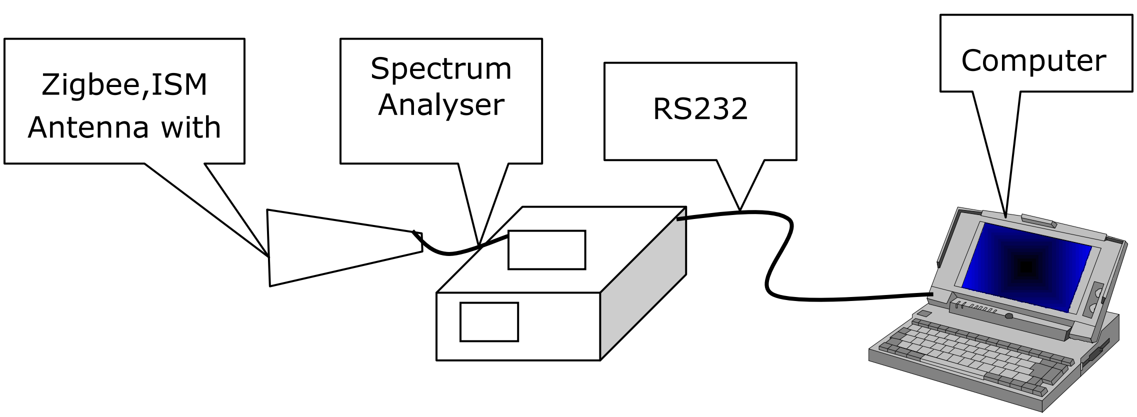


Figure 4: Survey Equipment Configuration

2.2 Hardware and Software Tools Used

2.2.1 Handheld Spectrum Analyzer

Covering the 100 kHz to 3.0 GHz frequency range, the MS2711D handheld spectrum analyzer is the proven solution for installing, provisioning, maintaining and troubleshooting wireless systems and RF frequency spectrum interference issues. This portable spectrum analyzer features a built-in standard preamplifier in a compact, handheld design that can go anywhere, anytime with no backpack required. The MS2711D is ideal for field environments and applications that require mobility, such as site surveys and on-site system testing.

The main features of the MS2711D handheld SA are as follow:

- Handheld, battery-operated design
- Lightweight at only 4.9 lbs
- Noise Level < -135 dBm typical (preamp on)
- Quick Zoom-in, Zoom-out display in 1-2-5 sequence
- RBWs (Radio Bandwidths): 100 Hz to 1 MHz in 1-3 sequence
- VBWs (Video Bandwidths): 3 Hz to 1 MHz in 1-3 sequence
- Automatic, manual, and dynamic attenuator control
- Amplitude Accuracy +/- 0.5 dB typical
- Dedicated smart measurements
- Trace Averaging
- Reference Level Offset
- 50-ohm Interface standard (75-ohm interface capability - instrument internally corrects for adapter loss)
- RS232 Interface

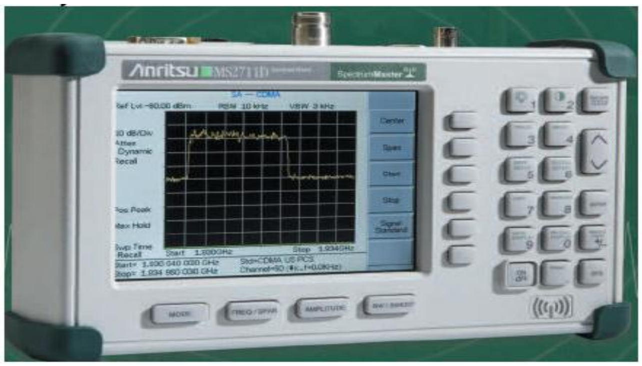


Figure 5: MS2711D handheld Spectrum Analyzer

2.2.2 LABVIEW Program for data logging

A Labview program was set to run on a laptop, and this was attached to the MS2711D via RS232 cable. The main units of this program were developed to communicate, select parameters, control data flow and store readings from the SA as shown in Figure 6.

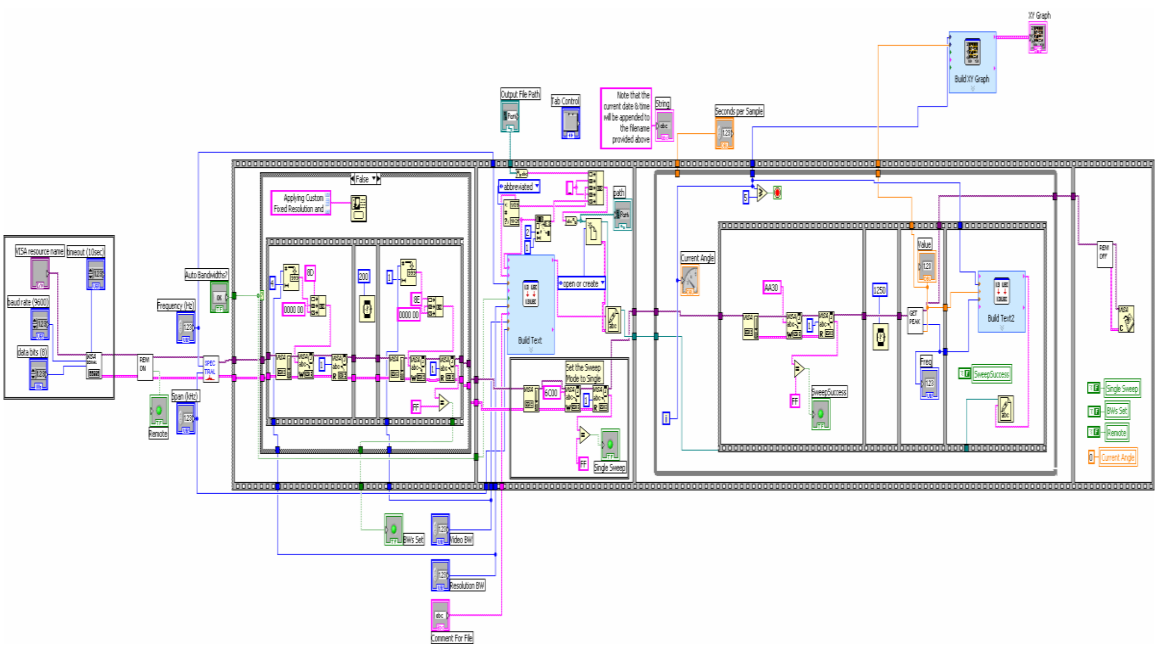


Figure 6: Main LABVIEW developed program

The front panel of the program is designed for easy user interactive. The main panel is containing 4 branched windows for SA, Port, File and rate settings as given by Figure 7. In the SA settings, user can select the centre frequency and the span frequency besides setting both the RBW and VBW. The data are stored in an Excel file after being attached with the data and time. The file will be located through the path entered on the File setting Window.

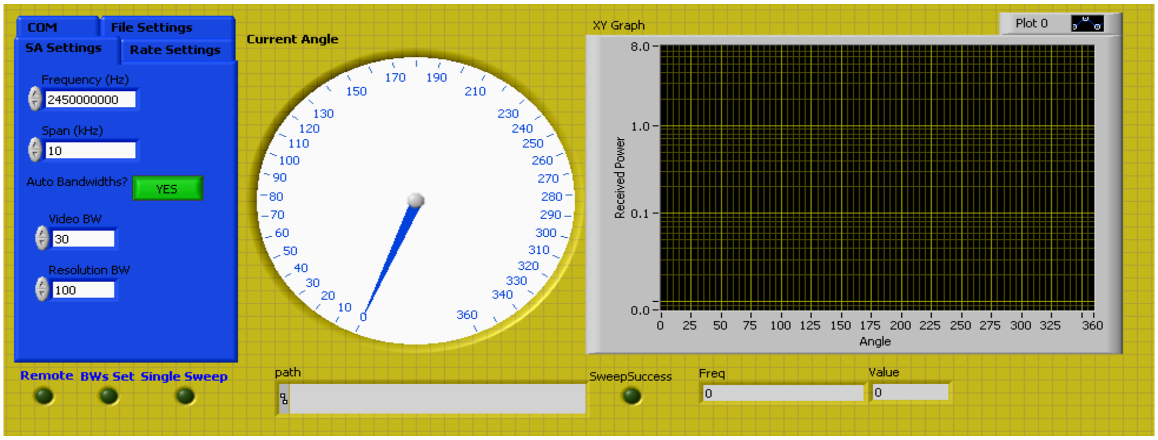


Figure 7: Front Panel of Labview program

2.2.3 Zigbee and ISM Antennas

The selected Zigbee antenna utilizes a helical element to greatly reduce the physical length of the antenna housing. The antenna is attached via a Part 15 compliant RP-SMA connector. The main features of this antenna are:

Center Freq 2.45GHz

Bandwidth 80MHz

Wavelength 1/4-wave

VSWR <1.9 typ. at center

Impedance 50 ohms

On the other hand, the specifications of the ISM band (monopole) antenna are:

Center Freq 433.92MHz

Bandwidth 20MHz

Wavelength 1/4-wave

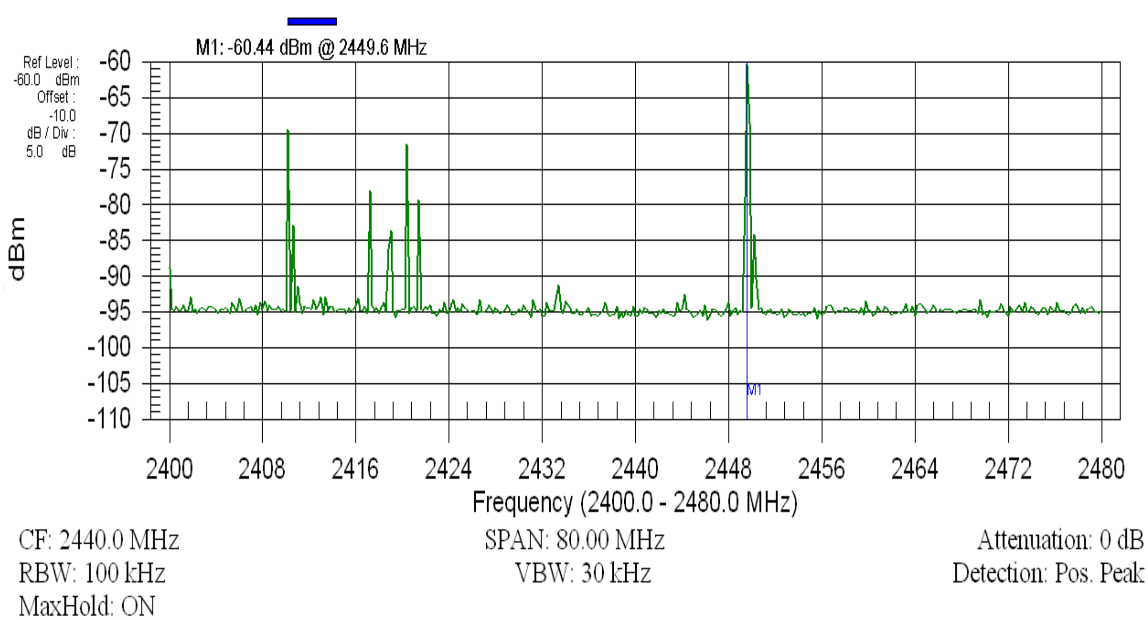
VSWR <2.0 typ. at center

Impedance 50 ohms

2.3 RF noise peaks captured in Zigbee and ISM bands

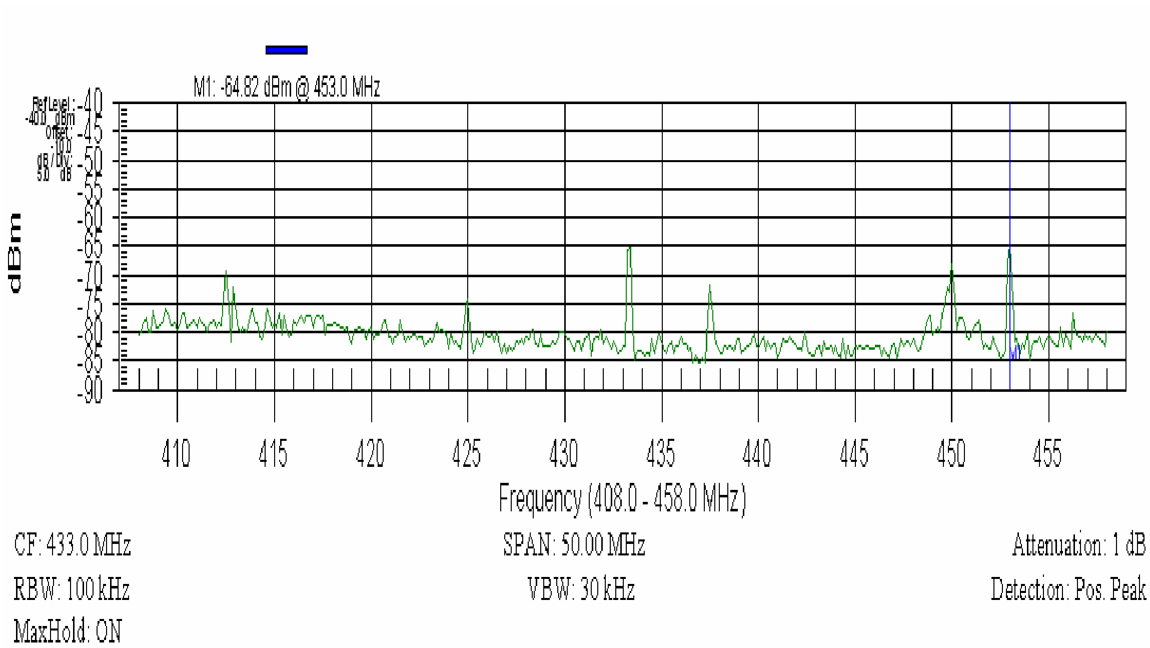
2.3.1 Seminar Room

Noise detection using Max hold mode (Zigbee) at 11.30AM



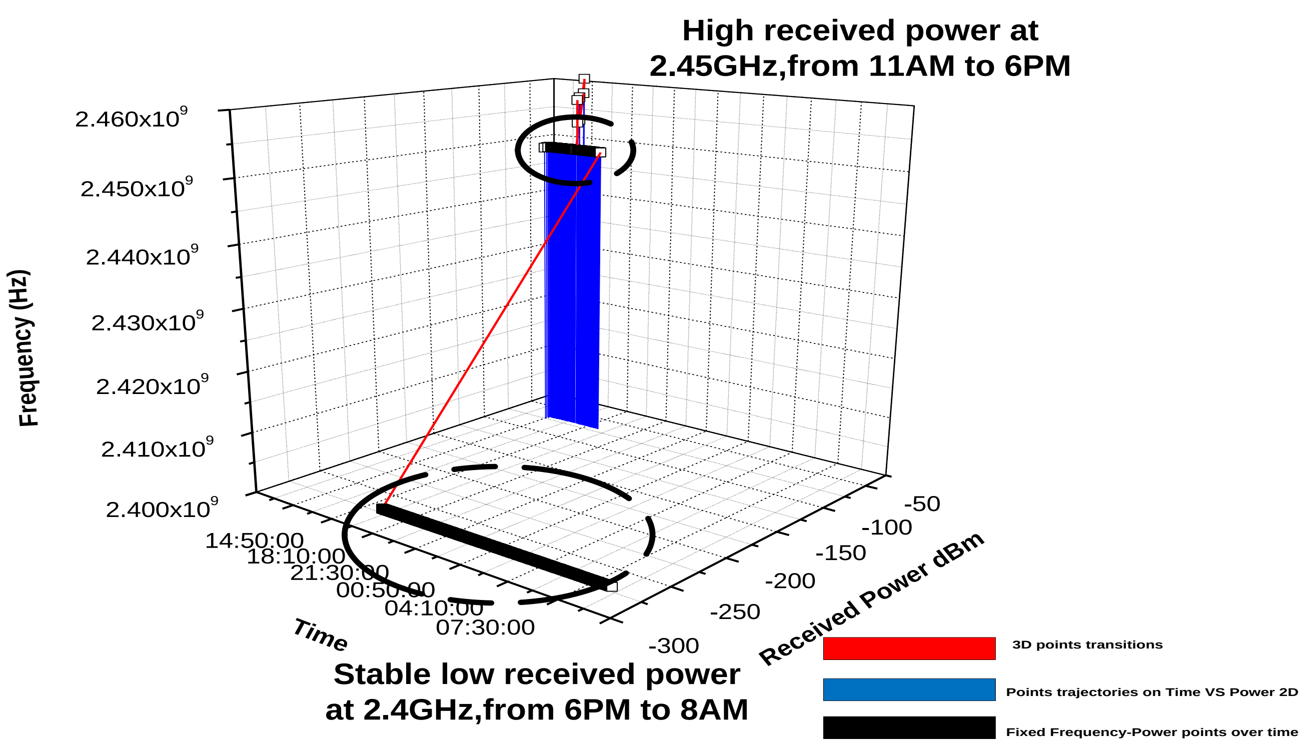
From the above figure, number of noise peaks was detected, where the max recorded amplitude was 2.4496 GHz of -60.44 dBm amplitude. Other peaks with less amplitude were recorded at frequency band (2.41 – 2.424 GHz).

Noise detection using Max hold mode (ISM) at 11.30AM

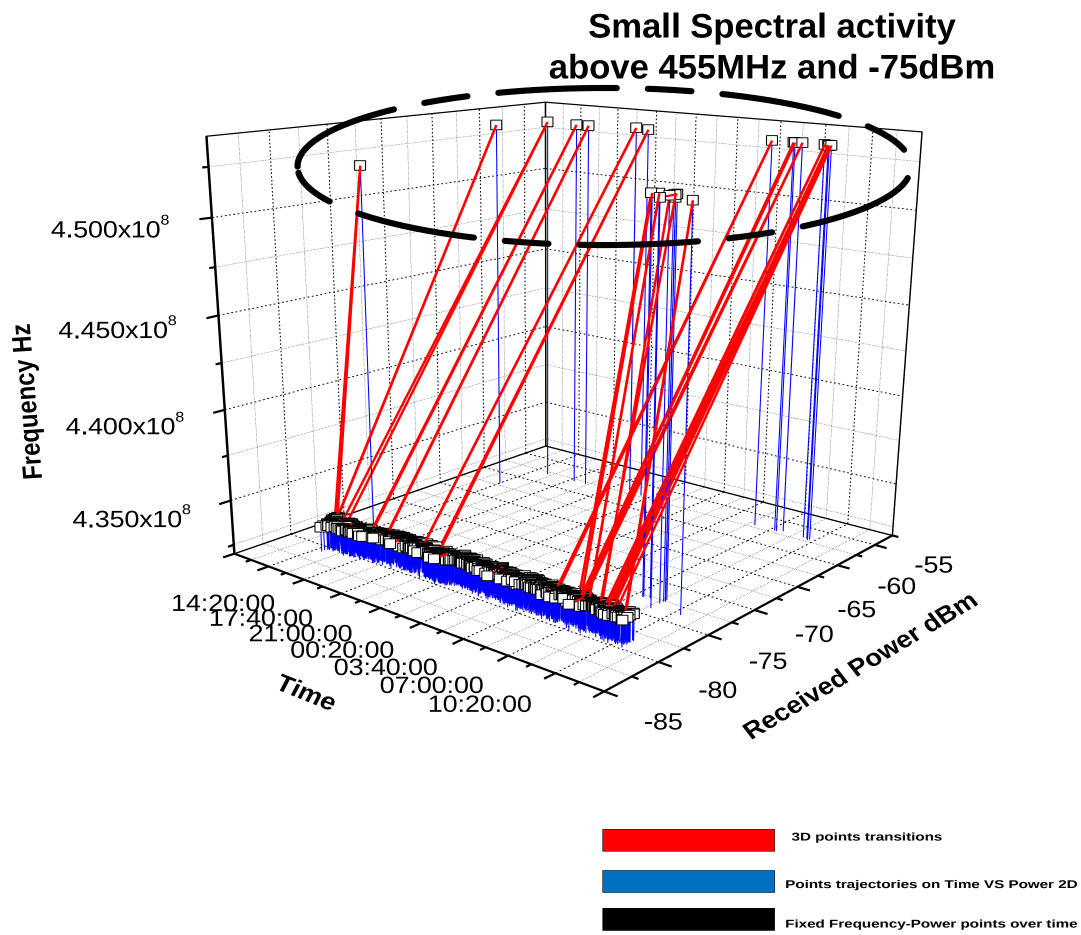


The figure above shows scattered noise acitivity distributed at different frequencies. The max recorded peak was at 453 MHz with -64.82 dBm amplitude.

24 Hours RF Spectral Monitoring using Single Mode Sweep (Zigbee)



24 Hours RF Spectral Monitoring using Single Mode Sweep (ISM)

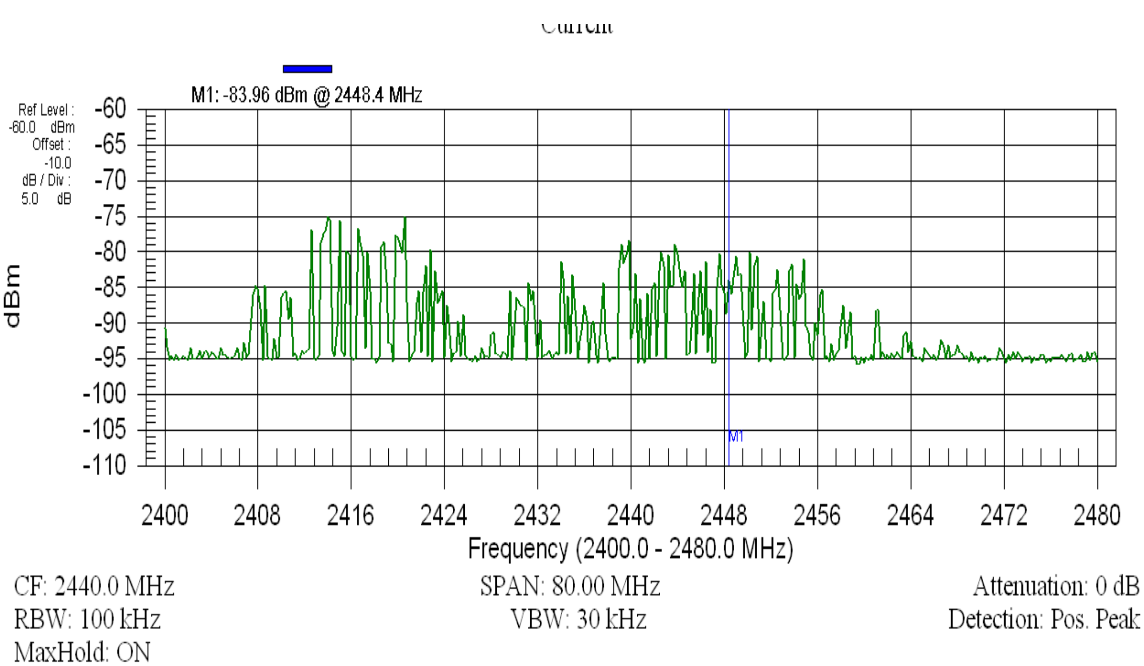


The 24 hours spectral sweep in Zigbee band shows auniform activity at 2.45 GHz with -75 dBm amplitude most of the day. During evening and night, the RF spectral activity is recorded at 2.4 GHz with constant power magnitude at -275 dBm.

For the ISM band, small scattered RF activity was recorded at frequencies above 455 MHz and power magnitude -75 dBm.

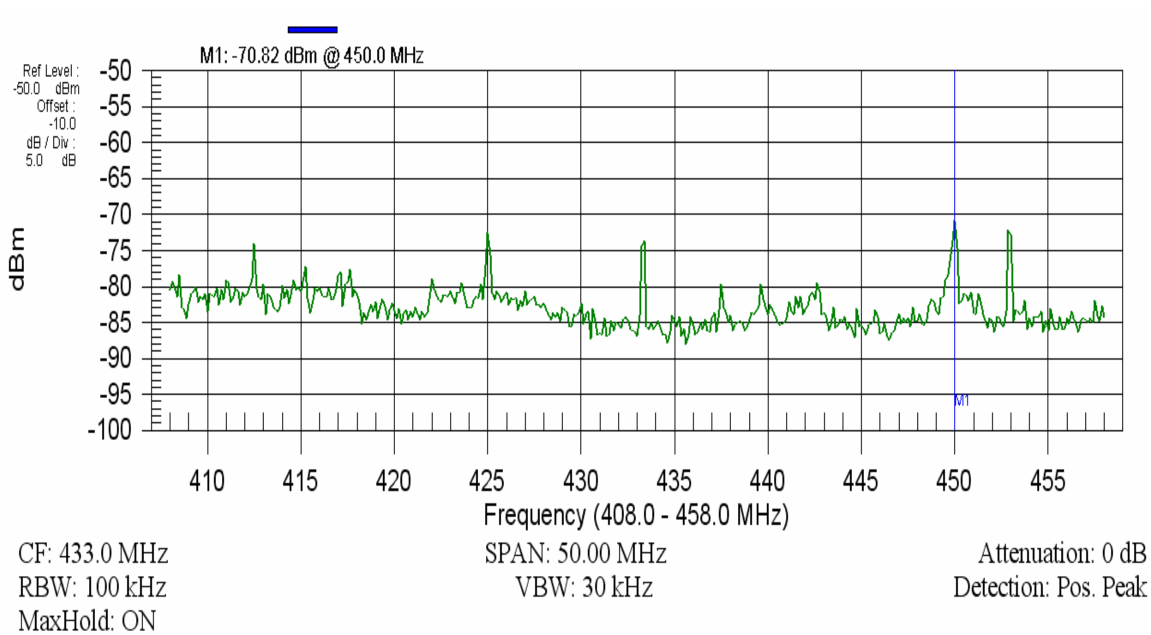
2.3.2 Immunology Lab

<u>Noise detection using Max hold mode (Zigbee) at 16.10PM</u>

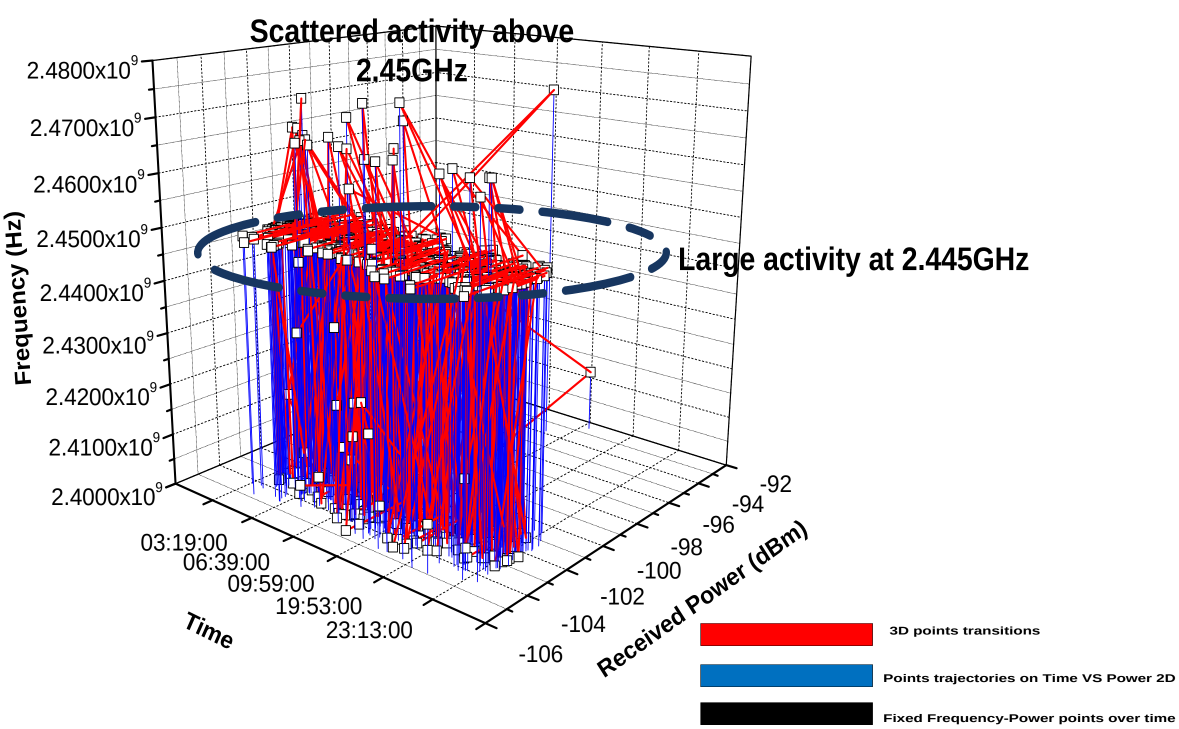


The immunology lab is displaying a high noise activity in Zigbee band. The max detected peak was at 2.4484 GHz with -83.96 dBm power magnitude. This is can be due to the existed equipments and devices that may generate such Inband noise peaks.

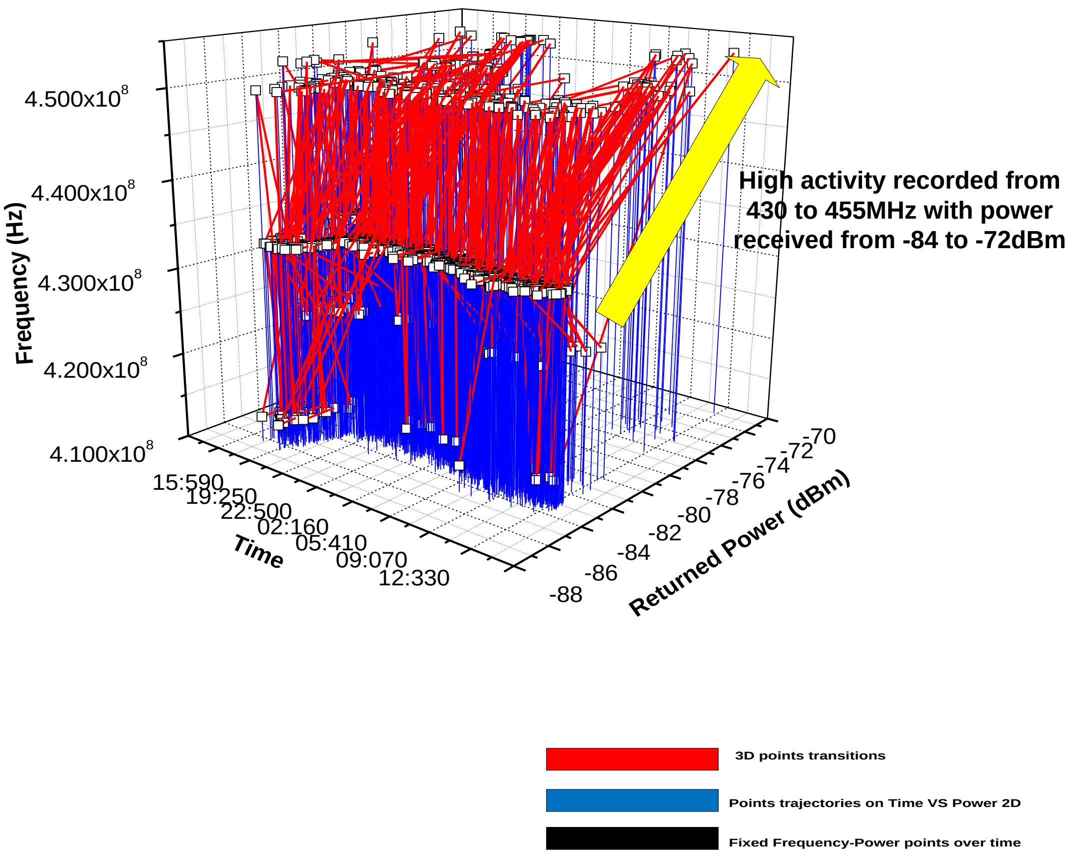
Noise detection using Max hold mode (ISM) at 17.00PM



24 Hours RF Spectral Monitoring using Single Mode Sweep (Zigbee)

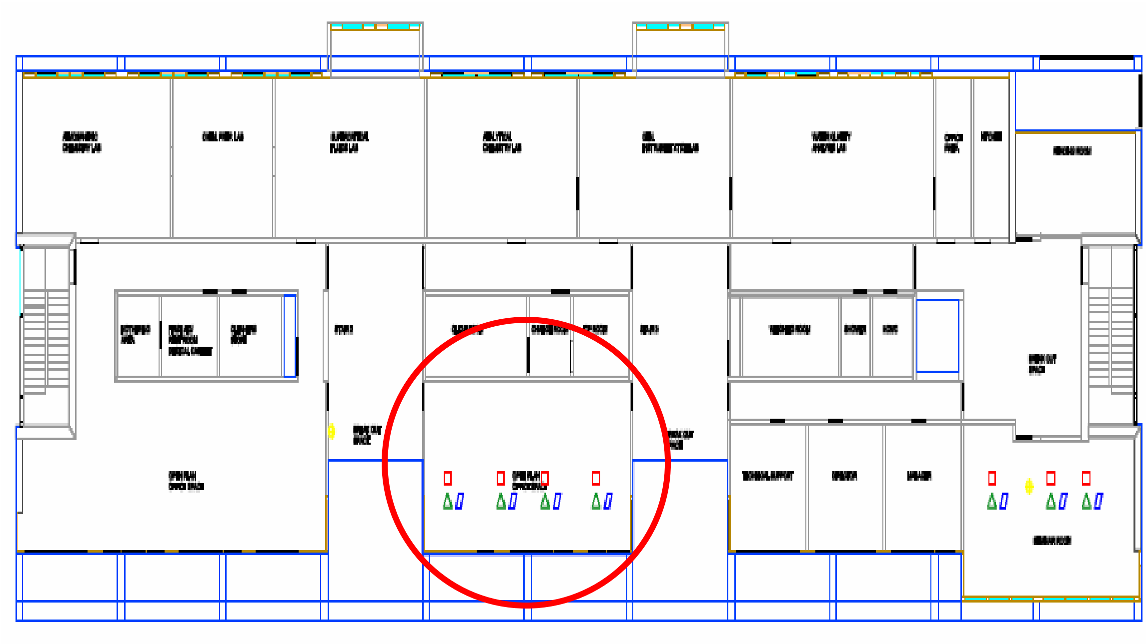


24 Hours RF Spectral Monitoring using Single Mode Sweep (ISM)

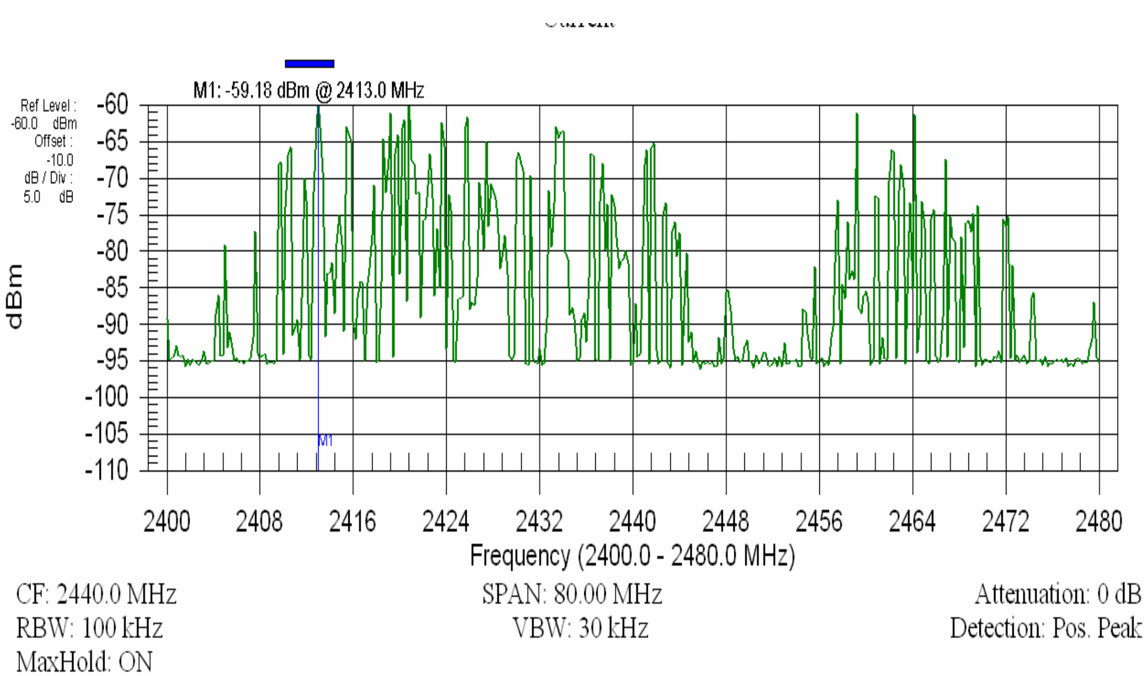


The 24 hours RF survey in Zigbee band displays a large activity at 2.445 GHz and other scattered components with similar power magnitudes at 2.45 GHz. In the ISM band, high RF activity was monitored in the frequency band 430-455 MHz with received RF power from -84 to -72 dBm.

2.3.3. Open office Area

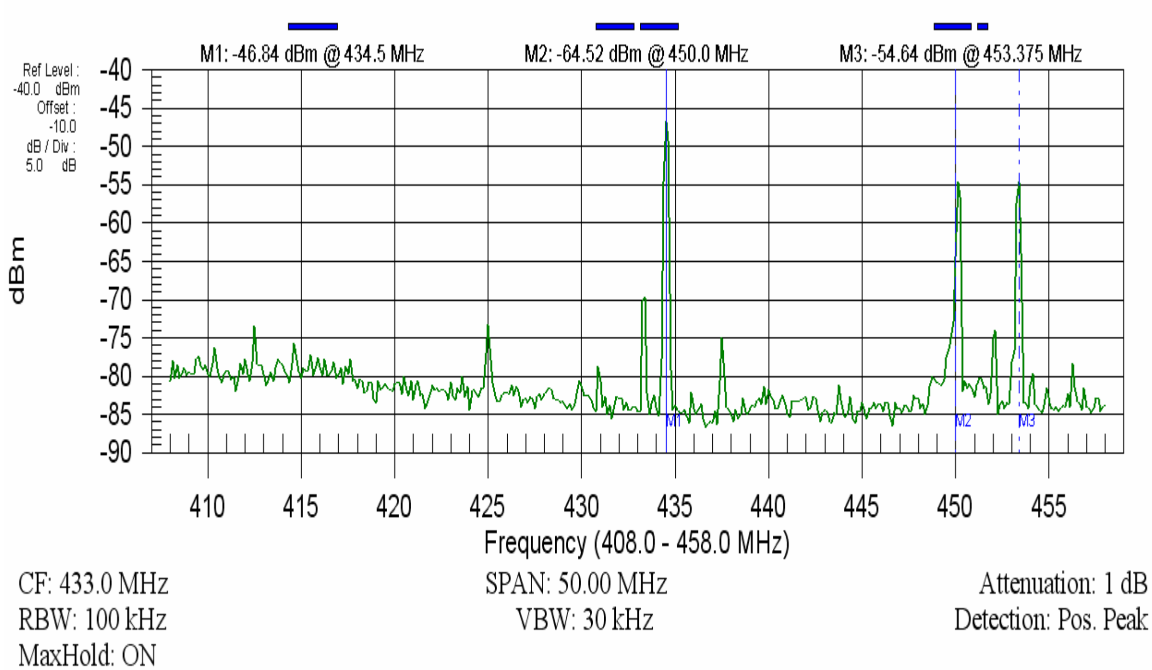


Noise detection using Max hold mode (Zigbee) at 11.00AM



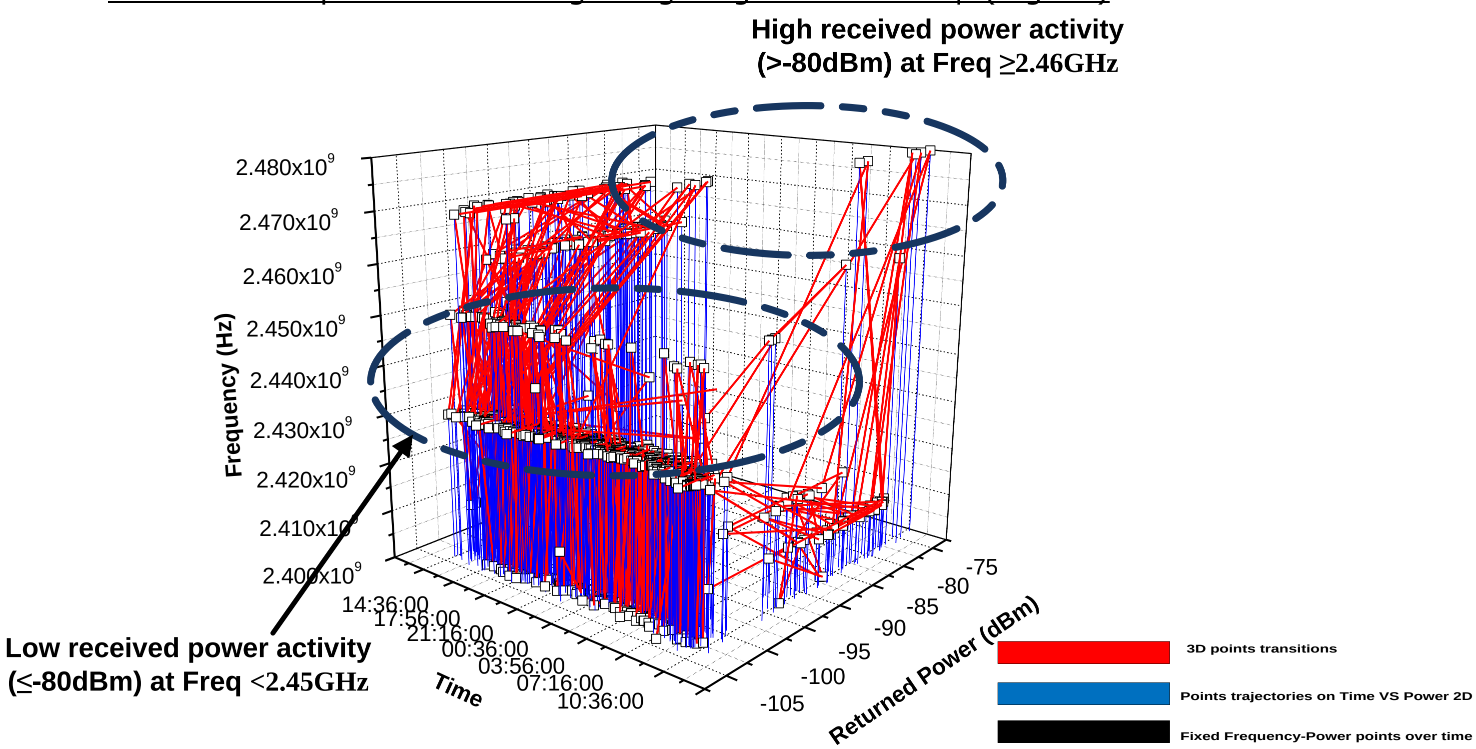
The figure above shows a high noise peaks captured along the considered band. The least noise activity is occurring in the band 2.448 – 2.456 GHz. The max recorded noise peak was at 2.413 GHz with -59.18 dBm power magnitude

Noise detection using Max hold mode (ISM) at 10.15AM

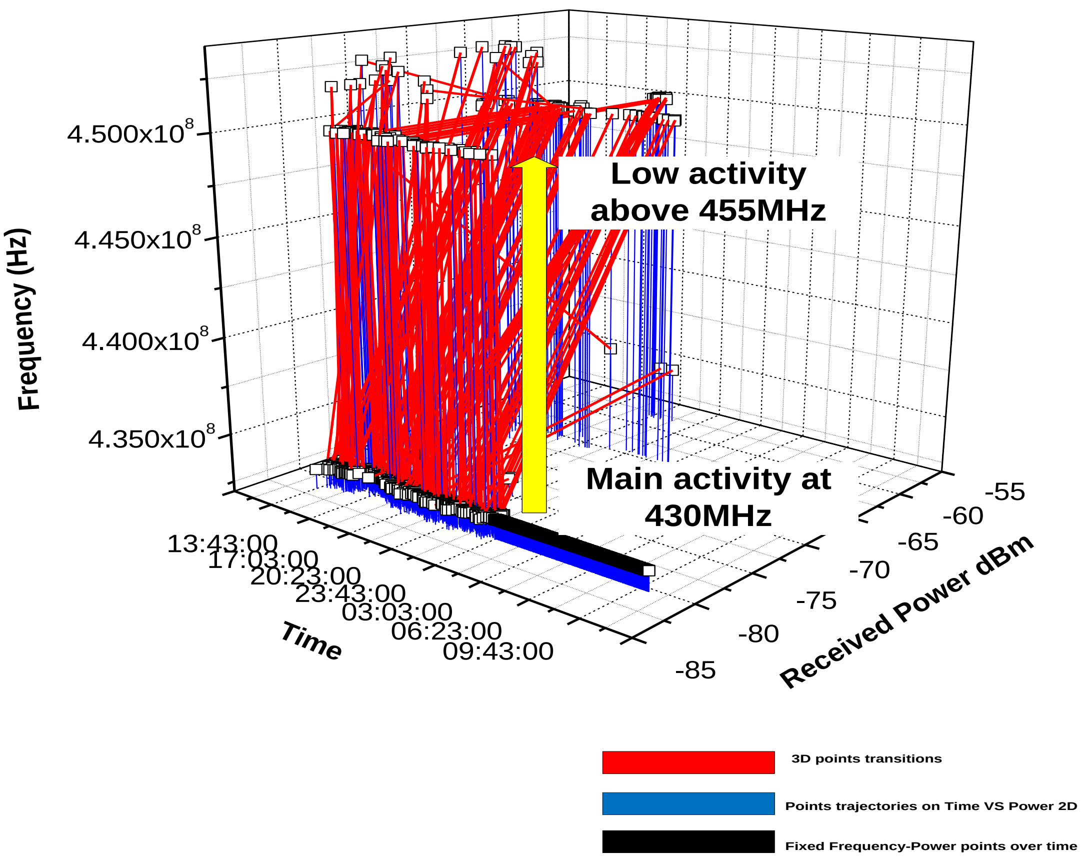


Few noise peaks were detected at frequencies > 434 MHz with max amplitude of -64.52 dBm.

24 Hours RF Spectral Monitoring using Single Mode Sweep (Zigbee)



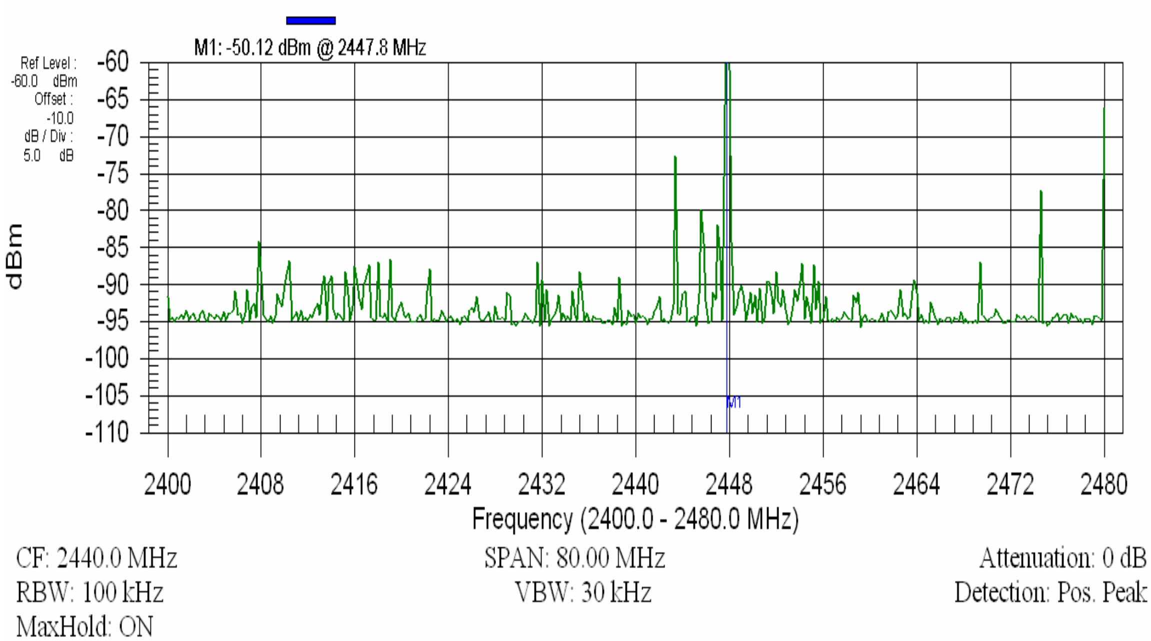
24 Hours RF Spectral Monitoring using Single Mode Sweep (ISM)



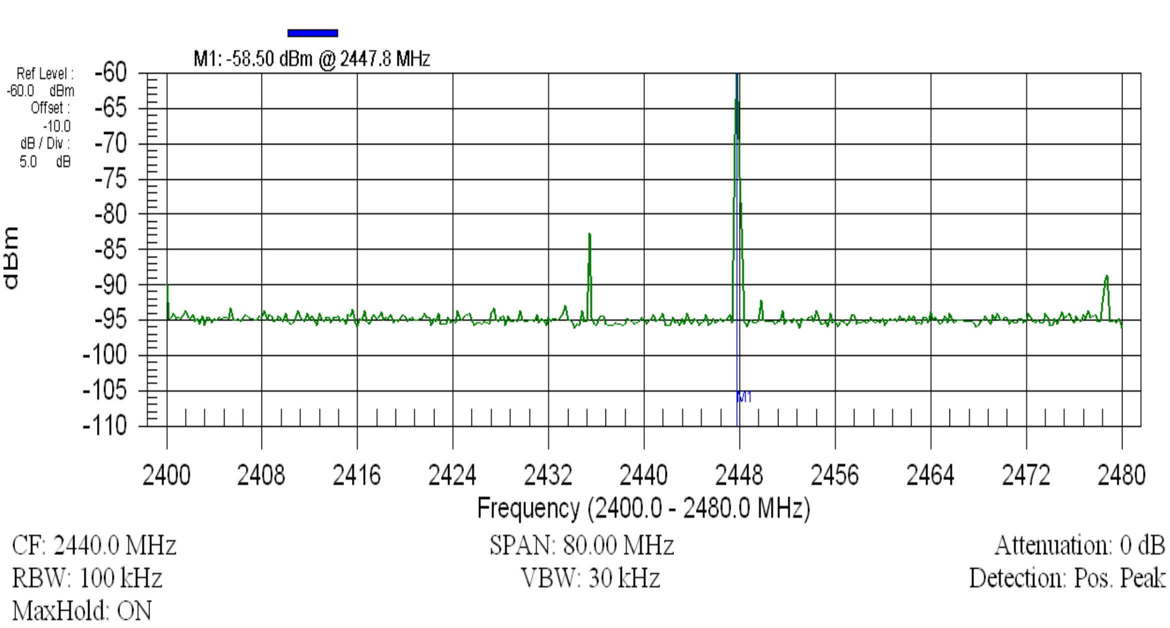
The Zigbee RF survey can be presented by two regions, high received power region at frequencies ≥ 2.46 GHz and low received power region at frequencies < 2.45 GHz. On the other hand, the main RF activity in the ISM band was monitored at 430 MHz with power magnitude around -80 dBm

2.3.4 Plant Room

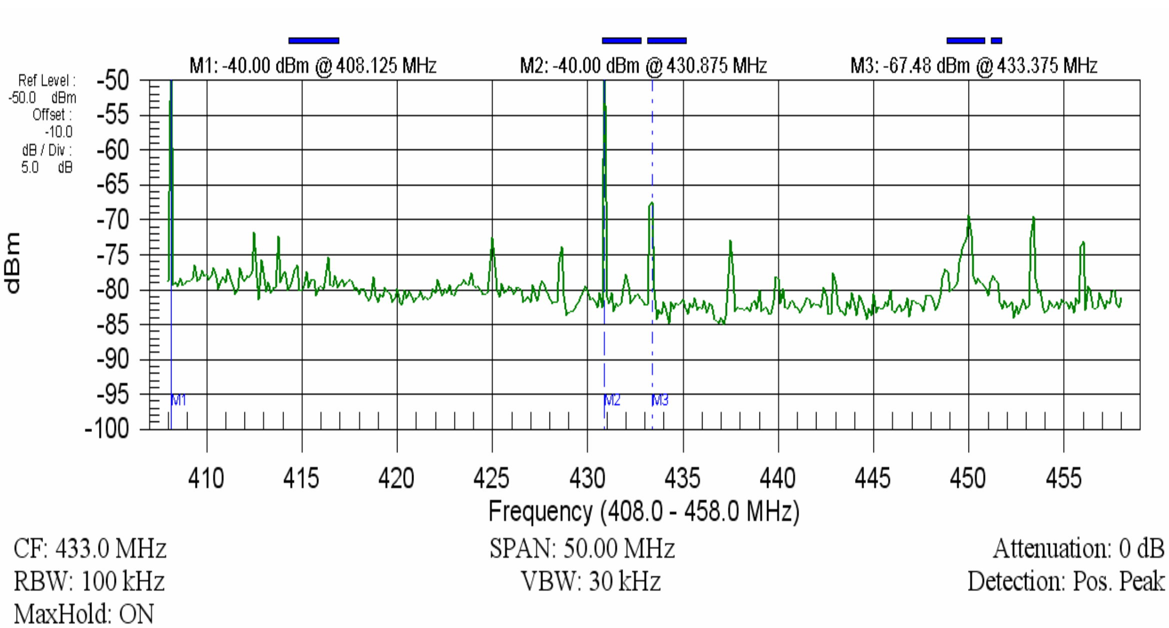
Noise detection using Max hold mode (Zigbee) at 11.15AM



Noise detection using Max hold mode (Zigbee) at 15.00PM



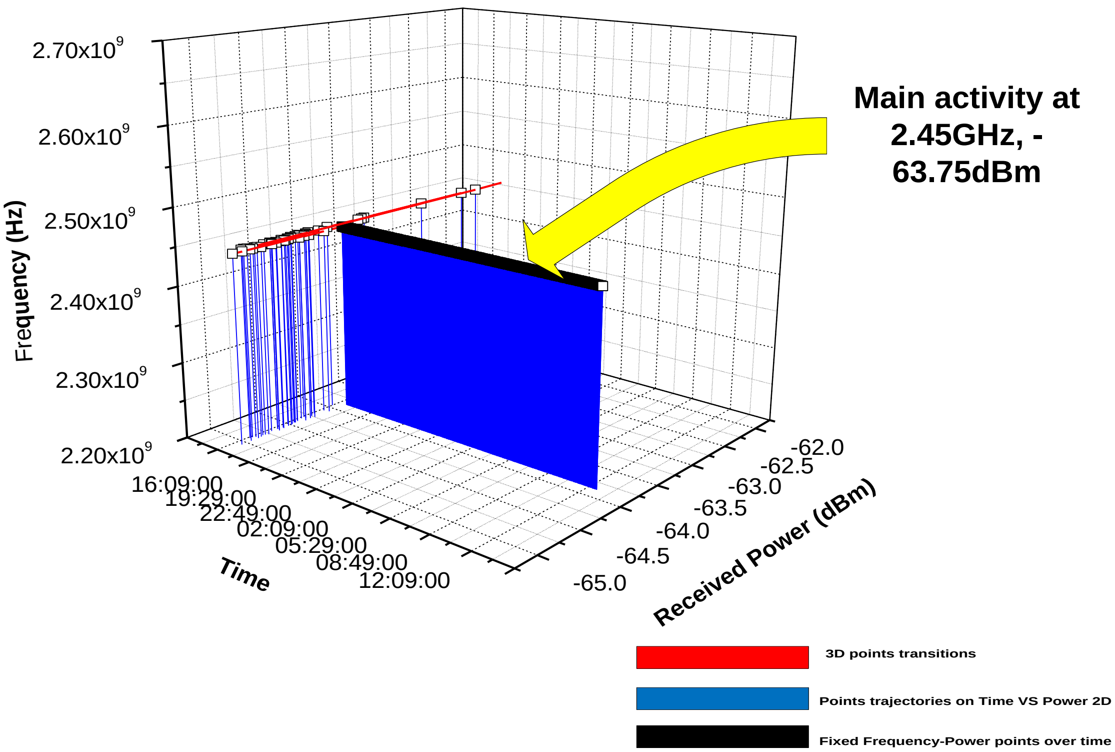
Noise detection using Max hold mode (ISM) at 17.30PM



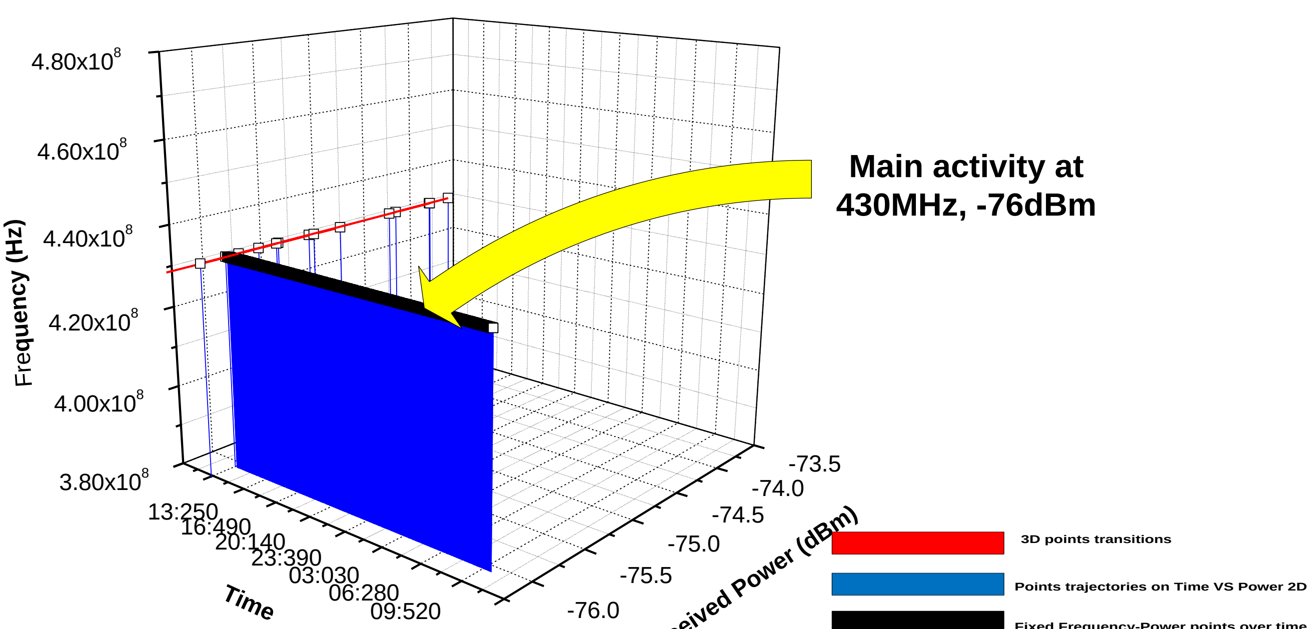
The Zigbee RF noise detected was recorded at two different times. First during the day, where an unexpected low noise activity was noticed with max peak at 2.4478

GHz and -50.12 dBm magnitude. The noise activity has been decreased at 15.00 PM with the same detected max power peak. In the ISM band, the recorded two main noise peaks were at 408.125 and 430.875 MHz with power magnitudes of -40 dBm.

4 Hours RF Spectral Monitoring using Single Mode Sweep (Zigbee)

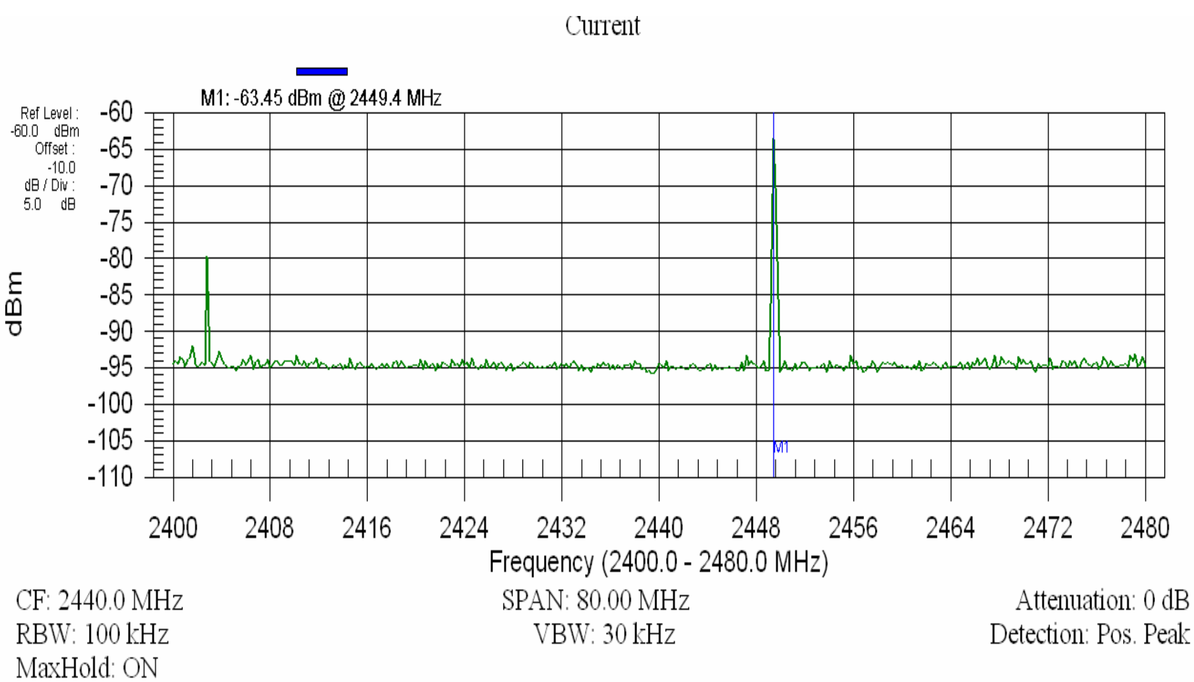


24 Hours RF Spectral Monitoring using Single Mode Sweep (ISM)



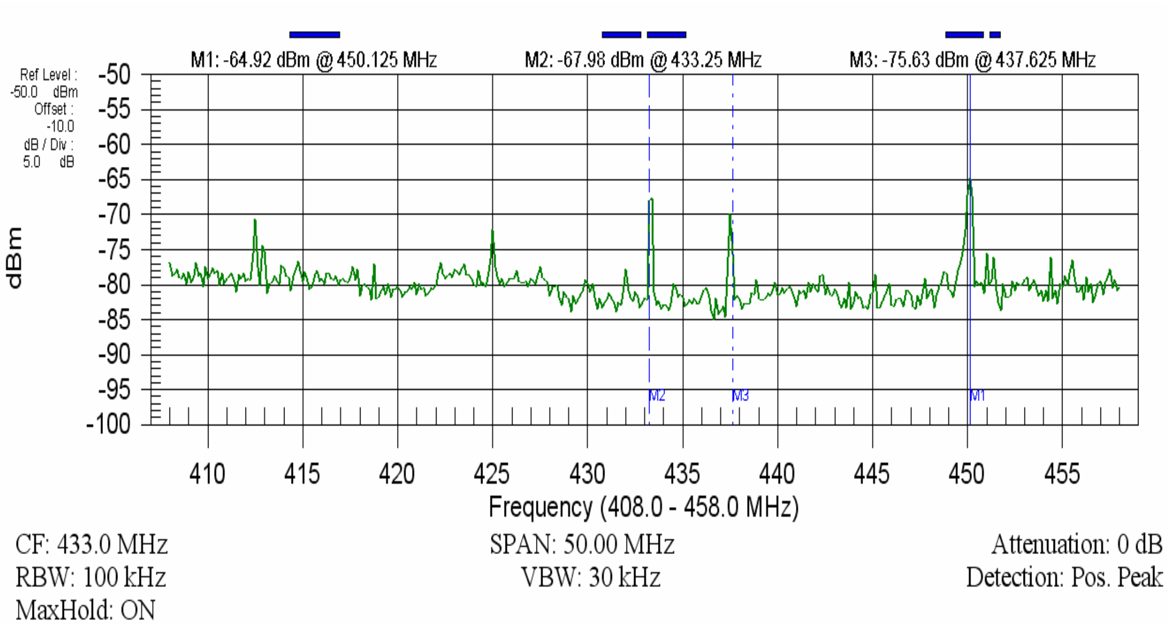
2.3.5 Seminar Room Corridor

<u>Noise detection using Max hold mode (Zigbee) at 16.00PM</u>

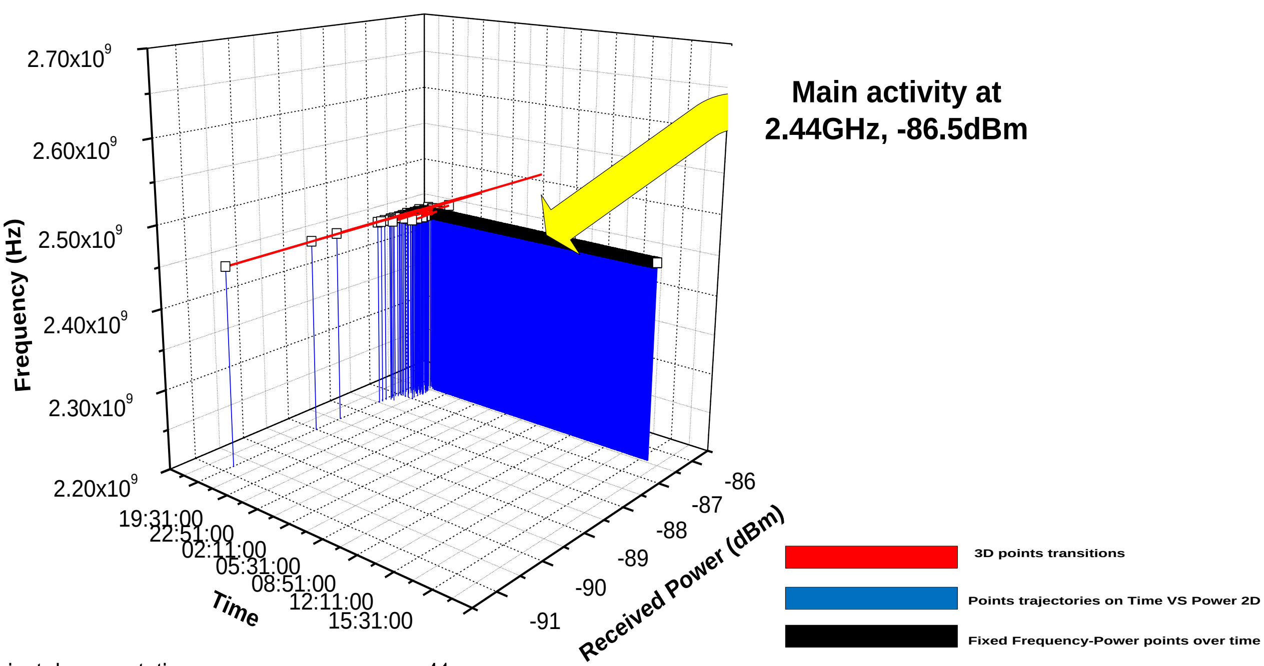


The noise activity is very low in this area for the Zigbee and relatively higher for the ISM band (refer to the next page). In Zigbee band, the max recorded peak was recorded at 2.4494 GHz with -63.45 dBm power magnitude.

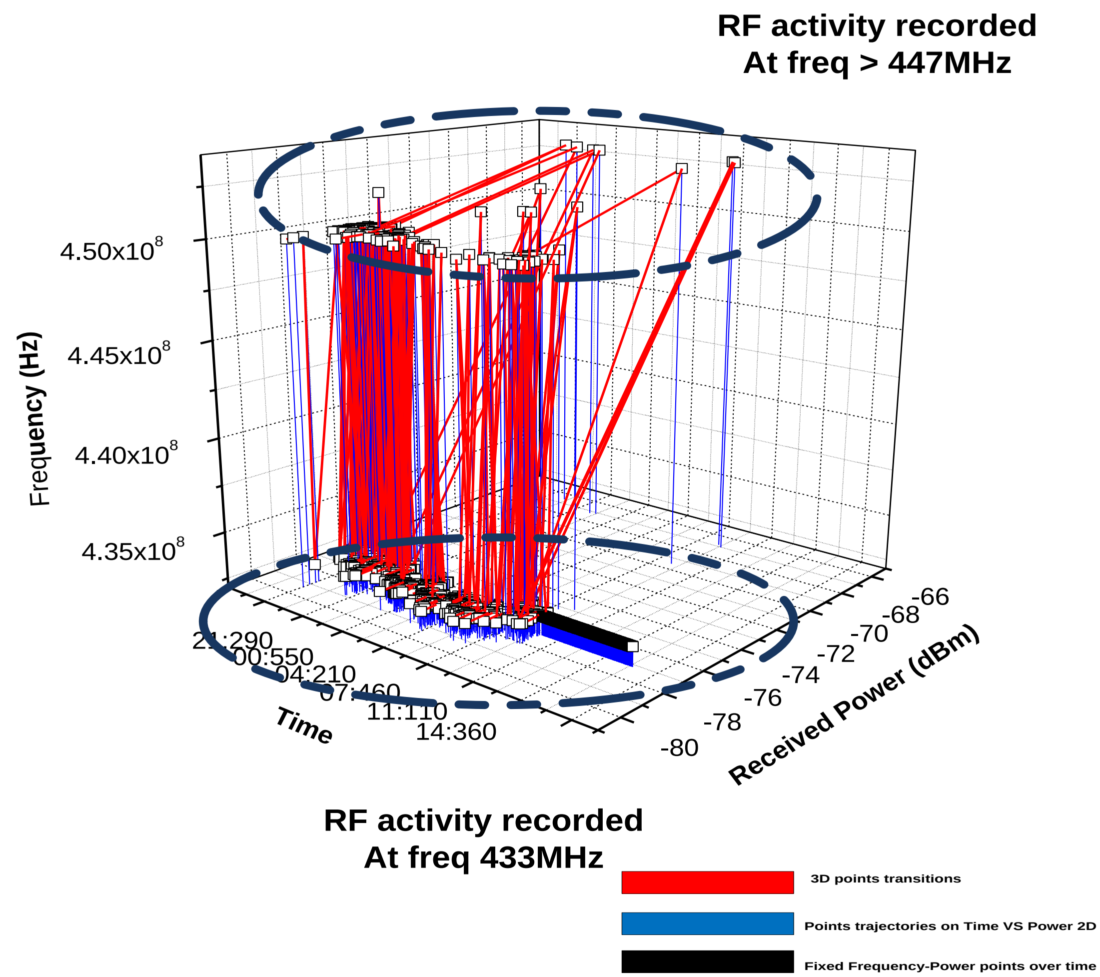
Noise detection using Max hold mode (ISM) at 17.30PM



24 Hours RF Spectral Monitoring using Single Mode Sweep (Zigbee)



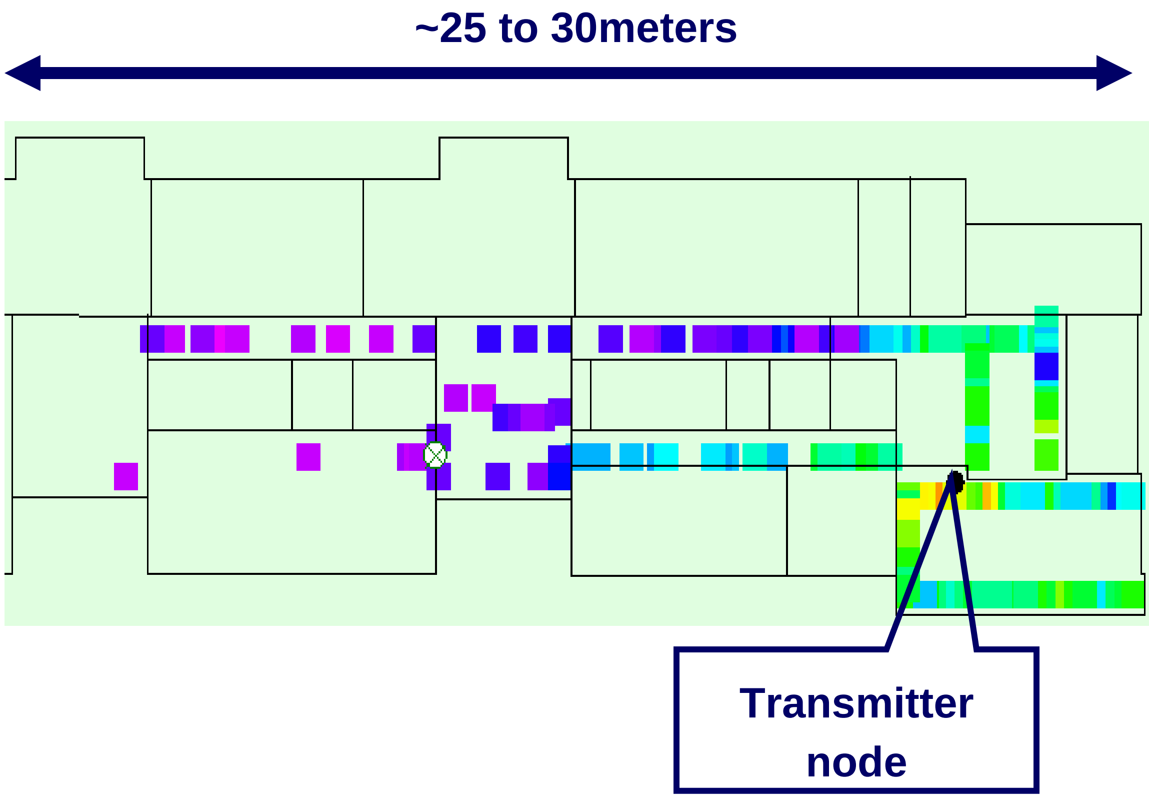
24 Hours RF Spectral Monitoring using Single Mode Sweep (ISM)



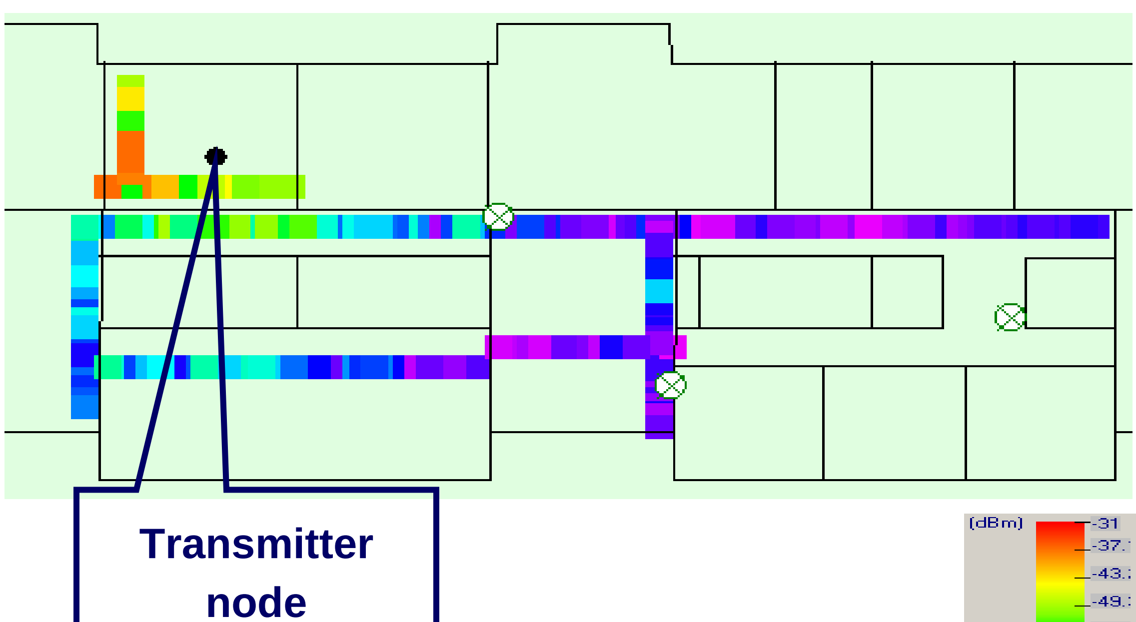
The RF surveys show a uniform activity in the Zigbee band at the centre frequency 2.44 GHz with -86.5 dBm received power magnitude. In the ISM band, two activities were monitored, one at frequency 433 MHz and other one at frequencies > 447 MHz with higher received power magnitudes.

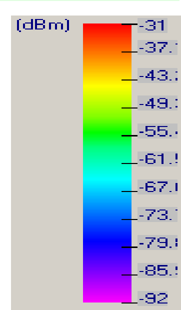
2.4 RSSI Tests using Zigbee Tyndall 25mm mote

Ground Floor



First Floor





2.5 Glossary

In conclusion, RF noise and 24 hours spectral activity were measured for 5 different places at the ERI building to get a clear image about the building RF noise and interferences that might disturb any future deployed wireless sensor network (WSN). The rooms are distributed as follows: one in the ground floor, one in the first floor, and three in the second floor.

Noise activity was noticed to be higher in Zigbee than ISM band especially in the Immunology Lab and the Open office area. The plant room, that contains the main electrical board and other pipes meters, has relatively lower noise components at Zigbee and some higher peaks in the ISM bands.

The 24 hours RF surveys were graphed in 3D scattered plots to visualize the actually daily activity. Generally two behaviours were noticed, uniform at a certain frequency or/and scattered at different frequency regions.

CHAPTER 3 Wireless Sensors Deployment Plan and HW Shopping List

3.1 Wireless Sensor and Meter Deployment

The following images give a brief overview of the **wireless** sensors/meters placement.

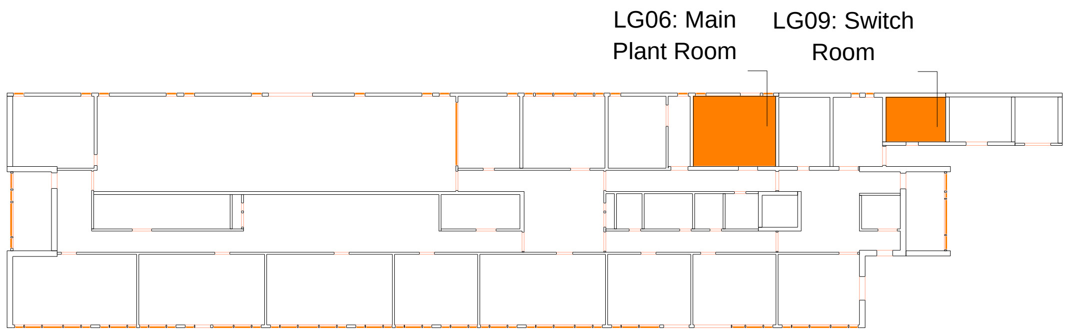


Figure 8 - Lower ground floor sensor/meters placement overview

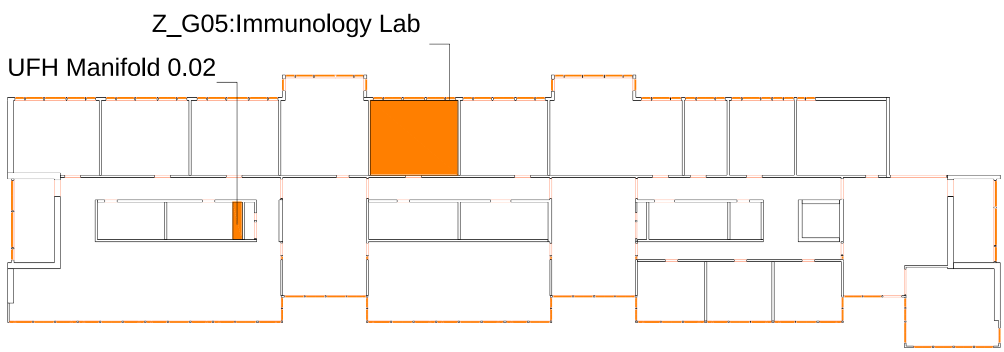


Figure 9 - Ground floor sensor/meters placement overview

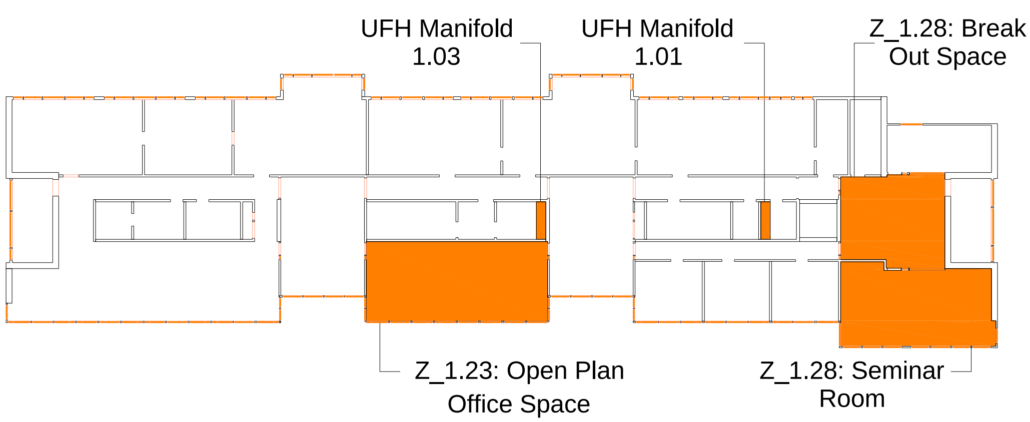


Figure 10 - First floor sensor/meters placement overview

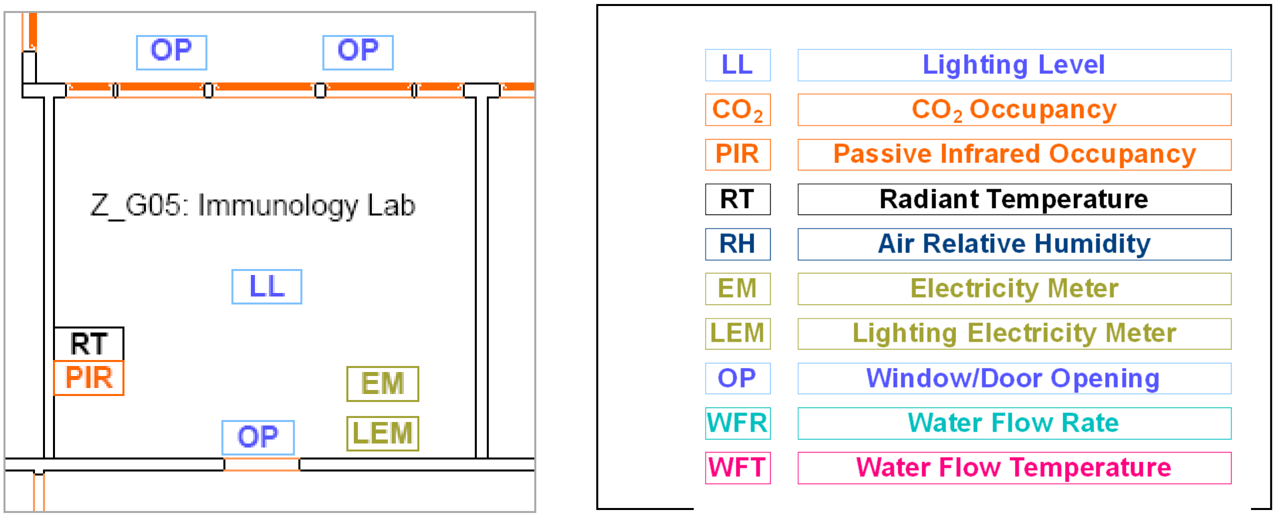


Figure 11 - Detail Z_G05: Immunology Lab

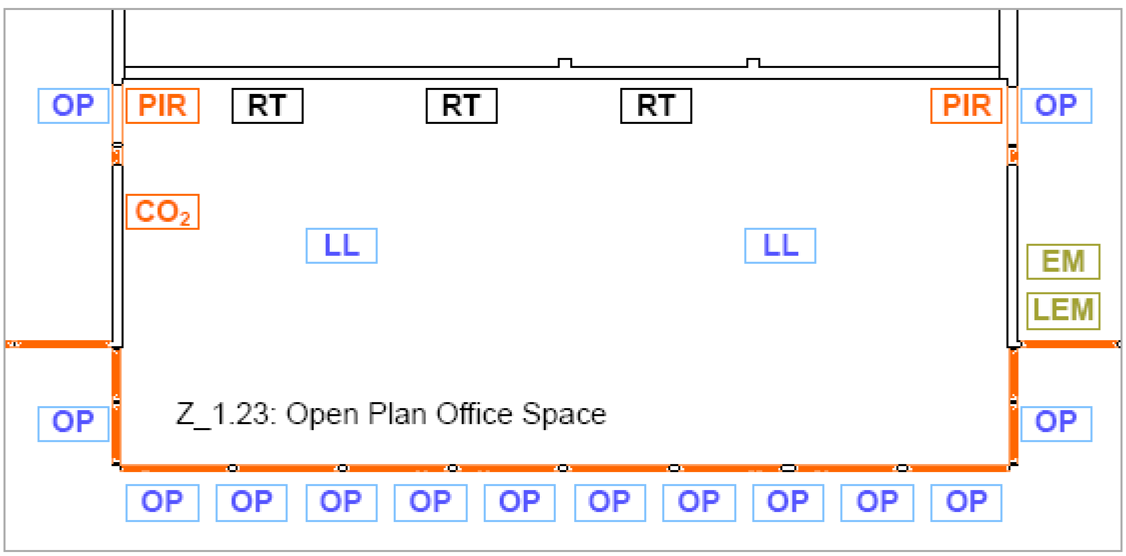
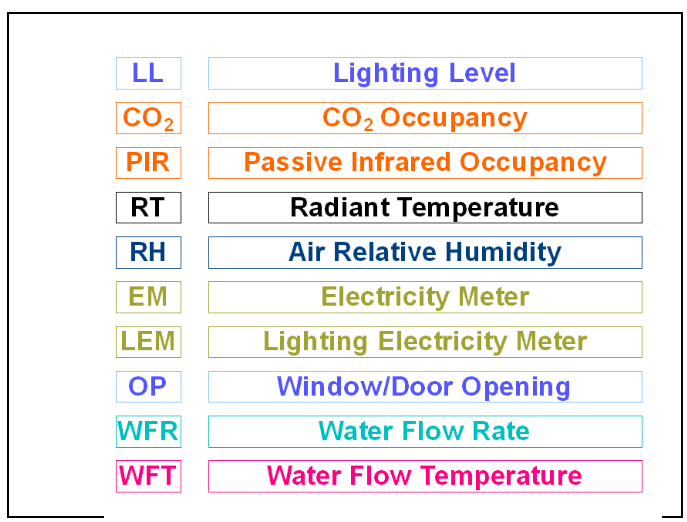


Figure 12 - Detail Z_1.23: Open Plan Office Space



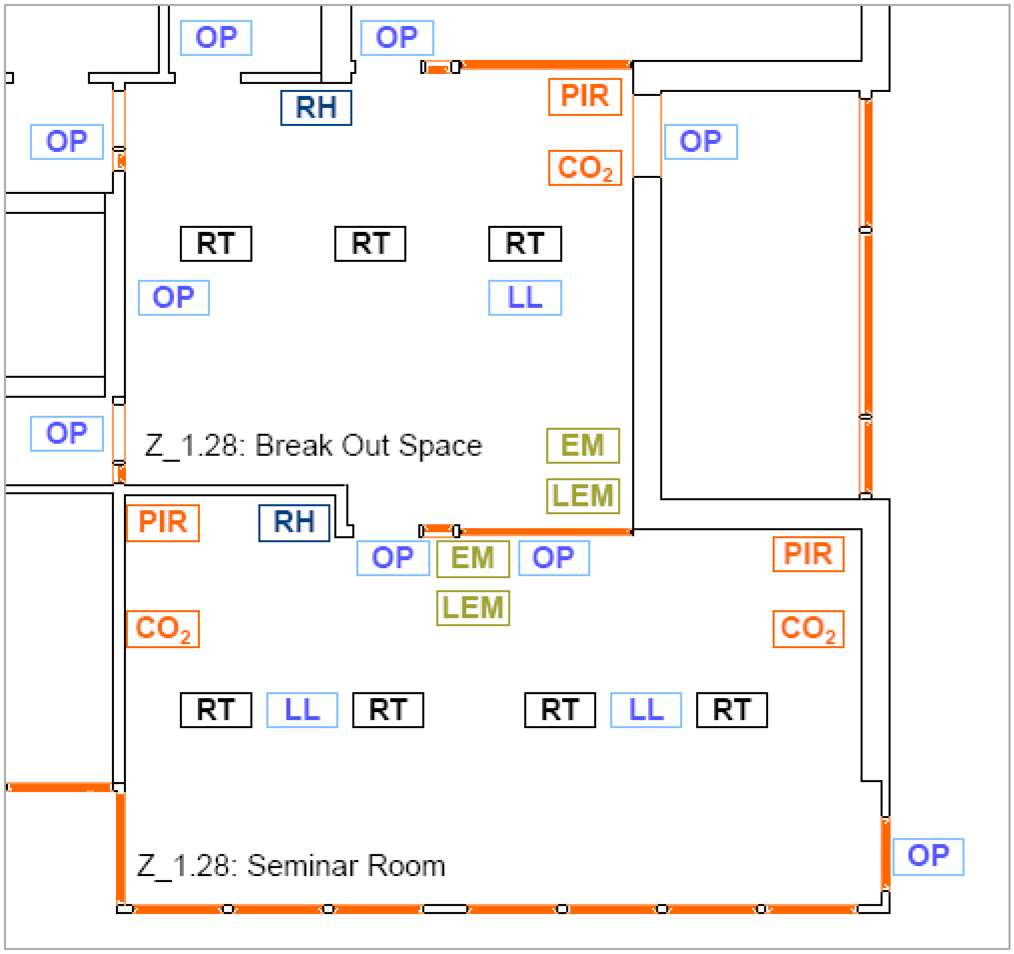


Figure 13 - Detail Z_1.28: Break Out Space and Z_1.28: Seminar Room

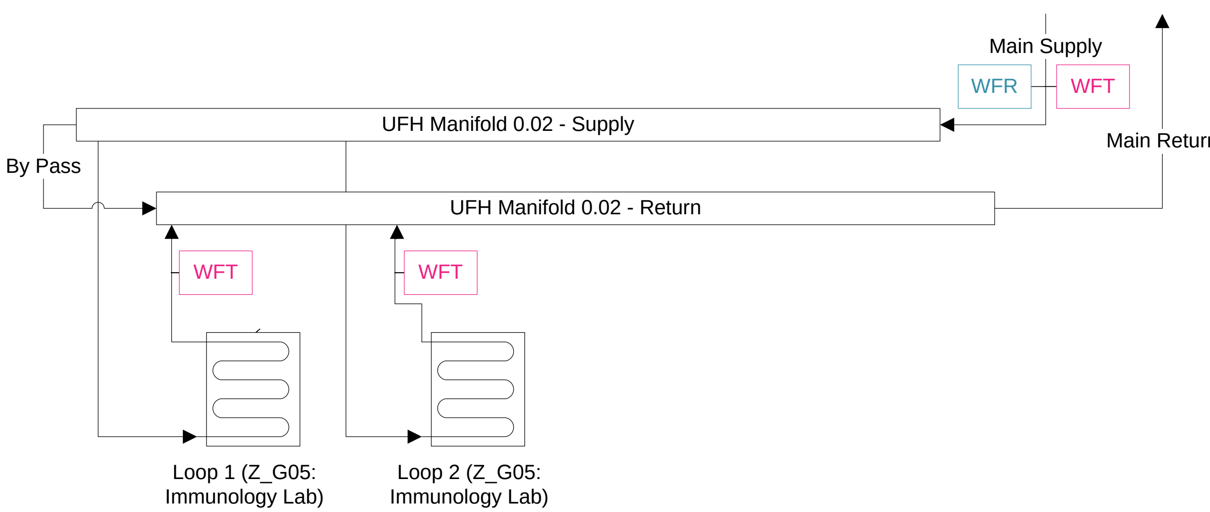


Figure 14 - Detail UFH Manifold 0.02

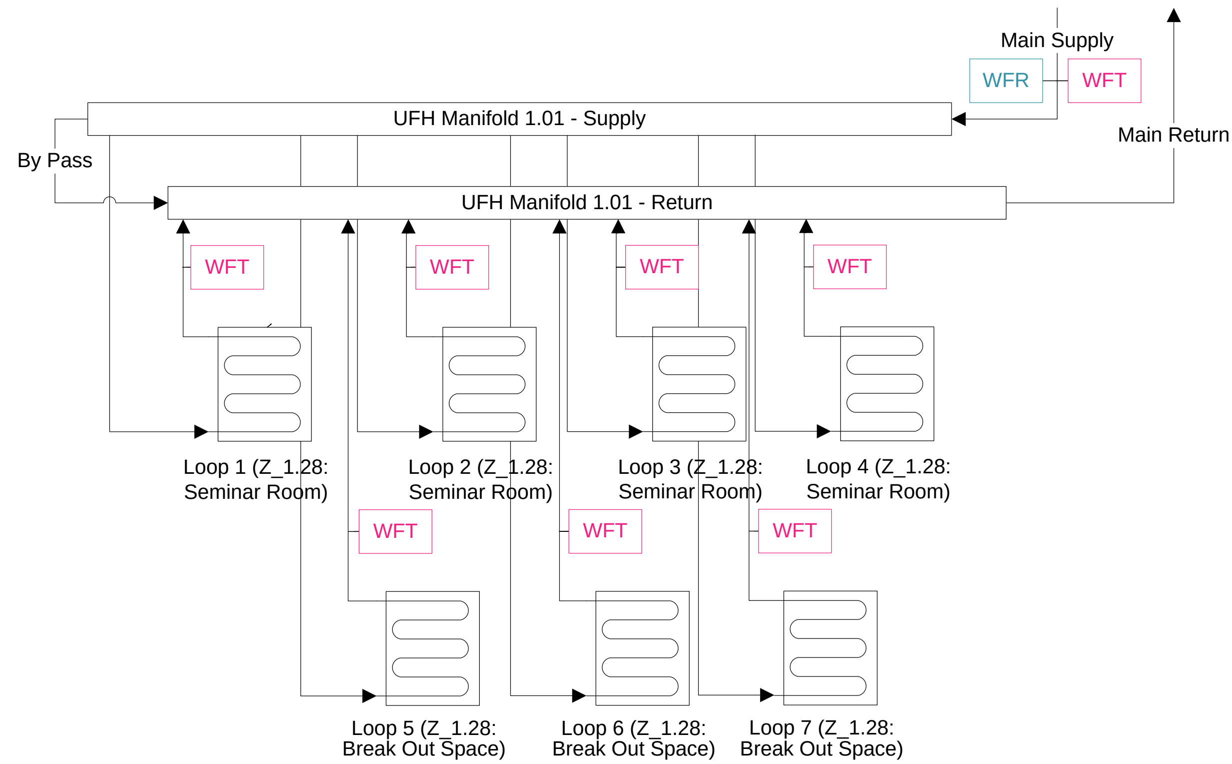
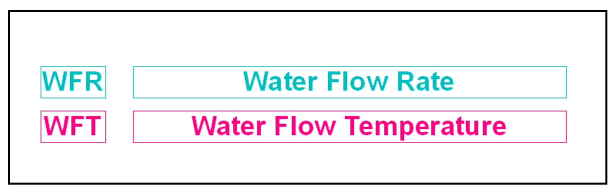


Figure 15 - Detail UFH Manifold 1.01



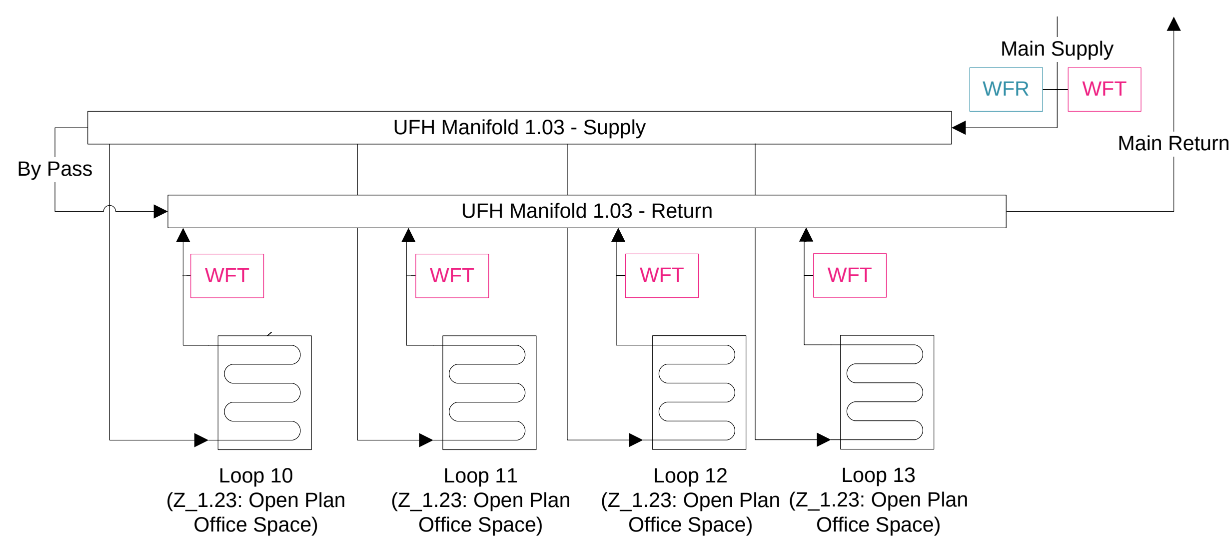


Figure 16 - Detail UFH Manifold 1.03

Other than the sensors/meters specified in the details there are 5 others:

- Outside Wind Direction (on the roof)
- Total Lighting Electricity Meter (LG09: Switch Room)
- Total Domestic Hot Water Meter (LG06: Main Plant Room)
- Aquifer Loop Outlet Water Flow (LG06: Main Plant Room)
- UFH Pump P8A Electricity Meter (LG06: Main Plant Room)
- UFH Pump P8B Electricity Meter (LG06: Main Plant Room)

3.2 Table of costs

Product type	Product description	Unit	Manufacturer ID	Unit Price	Quantity	Total Price($)	Total Price(€)	Reference
S/M	Ambient Miniature Light Sensor (Lighting level)	Lux	N5AC501085	$1.45	6	$8.70		http://www.chartlandelectronics.co.uk, Farnell Distributor-Ireland
S/M	CO2 Sensor (Occupancy)	CO2	Engine™ K30	$150.55	4	$602.20		http://www.senseair.com
S/M	PIR Sensor (Occupancy)	IR	AMN44122	$37.55	6	$225.30		http://pewa.panasonic.com/, Mouser Distributor-USA
S/M	Radiant Temperature Sensor (Air temp)	°C	B57861S103F40	€4.19	11		€46.09	http://www.epcos.com/, Farnell Distributor-Ireland
S/M	Relative Humidity Sensor	% RH	SHT11	€16.63	2		€33.26	http://www.sensirion.com, Farnell Distributor-Ireland
S/M	Single/Three Phase Meter (Electricity consumption)	kWh	PM3000	$2,661.00	11	$29,271.00		http://www.archmeter.com/eng/downloads.htm
S/M	Capacitive and Inductive Proximity Sensors (Windows and door opening)	%			26			
S/M	Ultrasonic Flow Meter (Water flow rate)	l/s	300MB	$400.55	5	$2,002.75		http://www.shenitech.com/
S/M	Temperature Sensor (mounted on pipes)	°C	QAD22	€42.63	16		€672.00	http://www.buildingtechnologies.siemens.co.uk, Building Automation Ltd-UK
S/M	Wind Direction Meter	Degree	ADXL330KCPZ	$13.75	1	$13.75		http://www.analog.com/ , Farnell Distributor-Ireland
				Total Motes	**88**			

Legend product type: S/M - Sensor or Meter ACT - Actuators WD - Wireless Device HHD - Hand Held Device

WD	Motes		€120.55	88		€10,608.40	
WD	USB Boards		€150.55	88		€13,248.40	
HHD	Hobo - 4 channels (temperature, humidity, lighint level, ext) with datalogging + Software kit (99 US $)	U12-012	$224.00	1	$224.00		http://www.onsetcomp.com/products/data-loggers/u12-012#tabs-tabs1-1
HHD	Handheld Hygrometer Humidity and Temperature Meter	RH85	$95.00	1	$95.00		http://www.omega.com/ppt/pptsc.asp?ref=RH85&Nav=temhu02
HHD	Auto Ranging Clamp type AC Power Meter	MDT6052	$229.00	1	$229.00		http://www.multimeterwarehouse.com/DT6052f.htm
HHD	e-Tracker Portable Energy Monitor	E-Tracker	€2,250.00	1		€2,250.00	http://www.transtest.com http://www.sinergy-meters.com/e-Tracker_A4_4_page_19_01_06.pdf
HHD	HD 50 Handheld Distance Meter	HD150	$104.99	1	$104.99		http://www.amazon.com/gp/product/B000Q5U9JG?tag=particculturf-20/hd50.shtml http://www.trimble.com
HHD	Thermal Imager Includes camera	Flir InfraCAM SD	€4,995.00	1		€4,995.00	http://www.transtest.com
HHD	Set of 3 Clothes Peg CT’s (0.5A – 100A)	Hi-Sensitivity Clip on CT’s	€360.00	1		€360.00	http://www.transtest.com
					$32,776.69	**€32,213.15**	
			Exchange rate €/$		1.41		
				Total (€)	**€55,459.03**		

Legend product type: S/M - Sensor or Meter ACT - Actuators WD - Wireless Device HHD - Hand Held Device

CHAPTER 4
Buildwise
Prototype 1
Sensor Board

4.1 Sensors Layer design

A multi-sensor interface layerlayer was deigned to interface with the afore mentioned sensors as well as incorporating additional capability for use within buildwise, Double actuation capabilities for any AC/DC with up to 280 V and 25 A (to turn on and off appliances) as well as additional RS485 capability to interface with any device using the protocol

This multisensory interface layer was also designed to incorporate externa flash memory (Atmel AT45DB041): The layer features a 4-Mbit serial flash for storing data, measurements, and other user-defined information. It is connected to one of the USART on the ATMega128L. This chip is supported in TinyOS which uses this chip as micro file system. This device consumes 15 mA of current when writing data.

Additional feature interfaced in this layer include a Miniaturized Low Power Light Sensor and a Smart digital output (MEMS) accelerometer to enable further sensor fusion and data aggregation.

A system block diagram is given below.

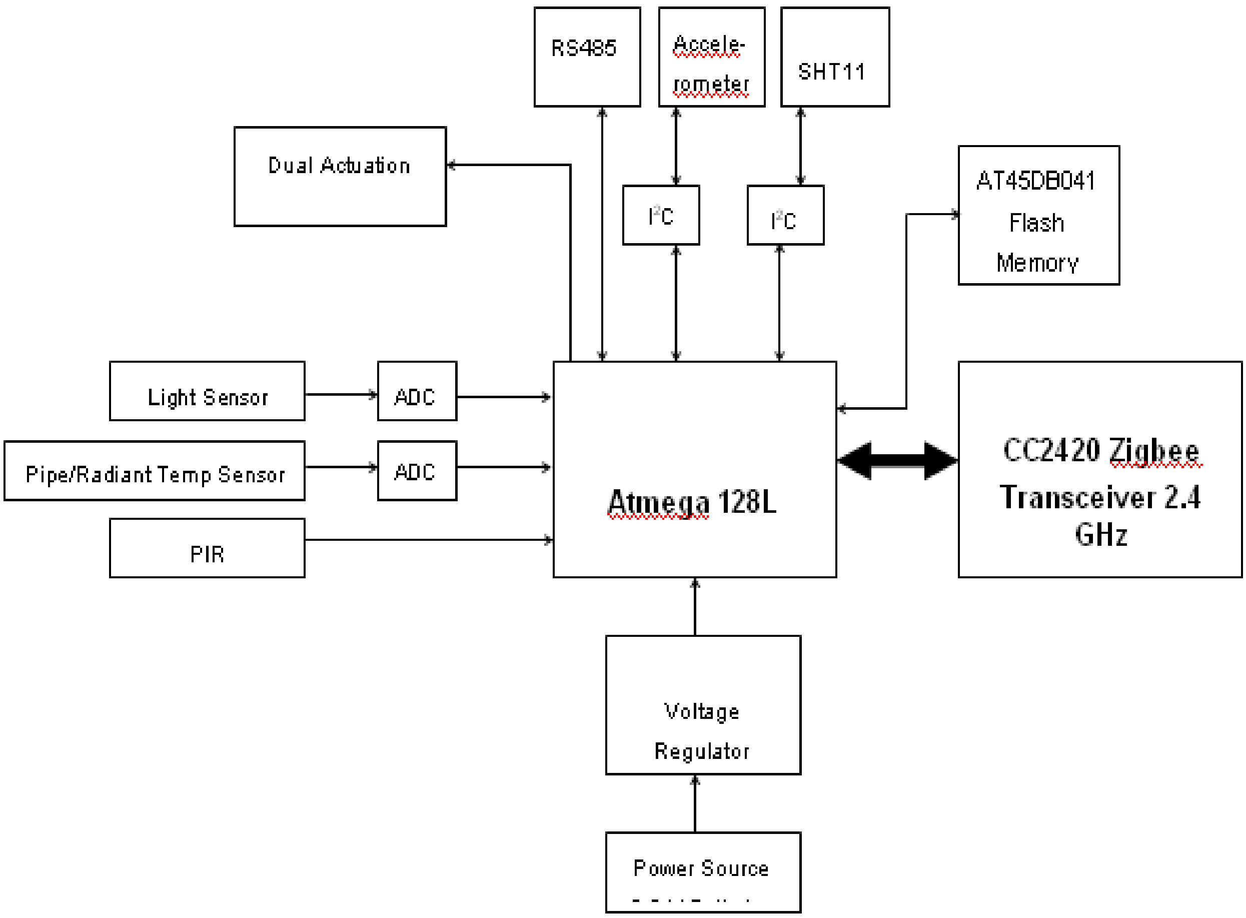


Figure 1: Multi Sensor System Block Diagram