The Wireless Jungle

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Table of Contents

I. Introduction

a. Preface. This brief tutorial is intended to provide insight into the causes of interference in the 2.4 GHz band and describe steps that can be taken to avoid communication disruption. A basic overview of the technology used to send data over wireless channels is outlined. Common wireless devices are related to their spectral emissions: how their emitted power is spread over the frequencies of the 2.4 GHz band. Devices are presented that scan the 2.4 GHz band for WiFi only, and others that show emissions of any type within the band. By using these devices, offending equipment can be identified and clear channels can be chosen.

b. The ISM Bands. Those sections of the wireless spectrum which don't require a license are called the ISM (Industrial, Scientific, and Medical) bands. Originally the ISM bands were not allowed to be used for communication purposes. In 1985 the FCC lifted this prohibition and opened up the bands to data communication. At the same time the FCC in the U.S. and corresponding regulatory agencies in other countries required that ISM band data devices use spread spectrum technology. This had the effect of making them more tolerant of interference and thus would allow greater use of the ISM bands.

   The approval of ISM devices for communication came at a fortuitous time for the motion picture industry. Just as the Steadicam heralded the era of the mobile camera, ISM based data transmission devices made reliable wireless control of these cameras and lenses possible using a worldwide standard.

   There is a very important distinction that must be made between wireless devices destined for general data transfer (WiFi and Bluetooth devices)and those for camera and lens control. Whereas devices used for data transfer can tolerate occasional data loss (the missed data would simply be re-transmitted upon request), devices used for real time control like lens and camera controls must have substantially higher immunity to interference, or their utility would be severely compromised.

   Clearly the loss of a shot has a substantial cost, not only in the expenses associated with the interruption of production but also in the loss of a performance or opportunity that may not be possible to repeat. The discussion that follows will point out a number of actions that can be taken to minimize the possibilities of disruption.

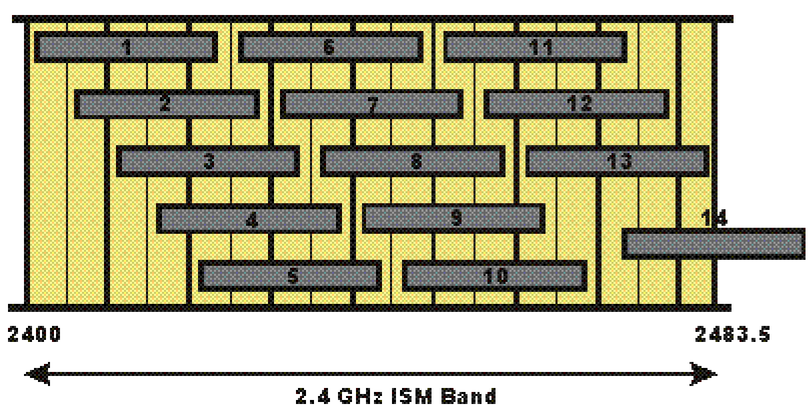
II. Microwave Devices

a. The following table lists some common microwave devices which use either the 2.4 GHz band or adjacent spectrum.

Name	Power (max allowed)	Modulation type	Band (if not 2.4 GHZ)
WiFi	1W	OFDM, DSSS	
Bluetooth type 1,2 or 3	.1W, ,0025W, .001W	FHSS	
Generic FH	1W	FHSS	
Generic DSSS	.1W	DSSS	
WiMAX-WCS	5 – 100W typ.	various	2.3 GHz
WiMAX -MMDS	20W uplink, .2W down	OFDM	2.5 – 2.7 GHz
Radar (airport ATC)	1kW -50kW+	High power pulses	L band (1 – 2 GHz), S band (2 – 4 GHz)
Microwave Oven	Typically 500 – 900W	Continuous	
Cell phones	1 – 3.6W	AMPS, GSM, CDMA	900 MHz, 1900 MHz

The modulation types refer to different methods of transmitting information. Devices conforming to FCC rules are required to use modulation which spreads the signal out over a wider range of frequencies than required by amount of information alone. The type of modulation used in a radio device affects not only its ability to communicate information reliably but also its tendency to interfere with other devices in its vicinity. Basic aspects of a device's modulation can be seen in its **spectra**, a graphical representation of how the signal's power is distributed over the frequencies of the band. Some examples of device spectra are presented in the next section

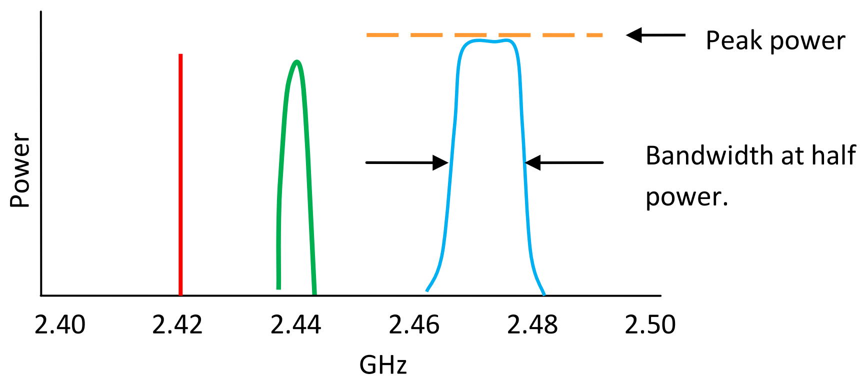
b. The following table shows the channel definitions for WiFI devices.



In the U.S, only channels only 1 – 11 are approved. Note that the channels overlap, so that devices operating on adjacent channels can interfere. The frequencies assigned to the WiFi channels are shown in the Appendix.

III. Wireless Spectra Primer

The spectrum of a signal refers to how its power is spread out in frequency. The simplest example is that of a signal of a single precise frequency. Like the sound of a tuning fork, the signal consists of a single tone. Such a “single tone” signal has a spectrum represented by the red vertical line (left below). This **red** line represents a signal at 2.42GHz (or 2420 MHz). As it is drawn, the <u>bandwidth</u> of this signal – corresponding to the width of the line –is too small to be resolved. The vertical height of the line is a measure of its power. For simplicity a linear power scale has been drawn in the figure below. In the examples of real spectra that follow the power scale is logarithmic, where each division of the vertical scale represents a factor of 10x in power.



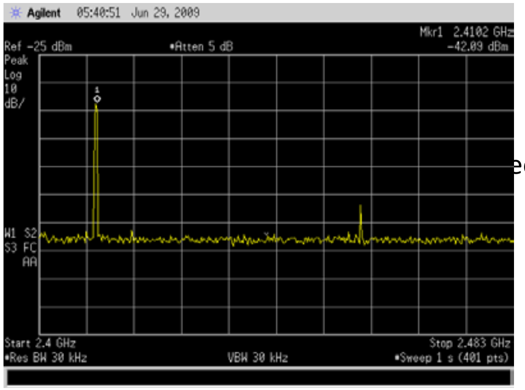
When information is added to a signal, it takes up more spectrum; the greater the amount of information carried by the signal, the more room it takes up. The **green** curve is centered on 2.44 GHz and takes up roughly .005 GHz, or 5 megahertz (MHz) of <u>bandwidth</u>. The **blue** curve on the right takes up approximately .02 GHz or 20 MHz of spectrum. In order to make the bandwidth measurement consistent for signals of differing power levels, the width of the signal is measured where the power has dropped a specified amount from its peak; in the example shown above at half of the signal’s peak power.

The term “spread spectrum” refers to the technology of increasing the bandwidth of a signal to enhance its resistance to interference. Graphically, spreading the signal is akin to transforming the narrow red or green curves shown above into the much wider blue curve.

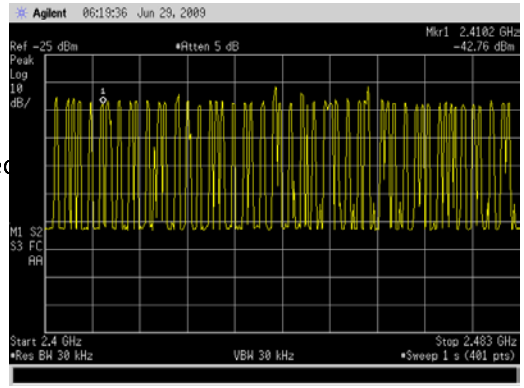
By spreading the signal in the right way, not only can communication can be made more immune to interference but more users can use a piece of radio spectrum than would be otherwise possible. For this reason, the FCC requires that communication devices which transmit on the 2.4 GHz band use a form of spread spectrum technology. However the specific method a device uses for spectrum spreading has important implications not only for its reliability, but also the reliability of other wireless devices working in the same area.

The next section relates some common spectrum spreading techniques with a graphical representation of their spectra captured by a **spectrum analyzer**.

IV. Typical Device Spectra



FHSS: snap-shot view



FHSS: time exposure view.

A. FHSS

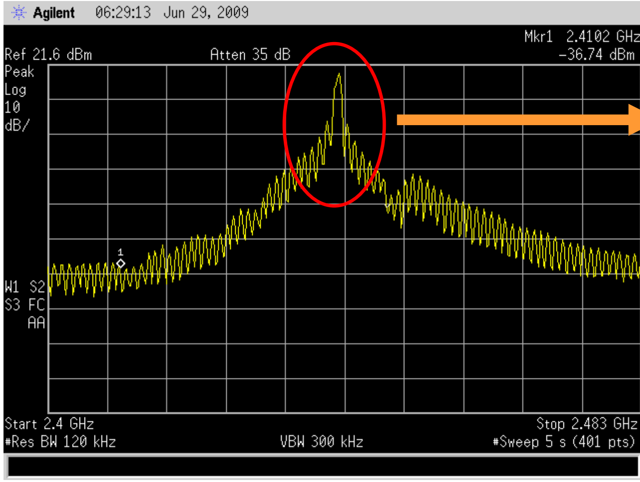
A frequency hopping device transmits data over a sequence of channels spread over the entire 2.4 GHz band. The maximum time allowed for transmitting on a channel before hopping is 0.4s. The pattern of channels is pre-determined and semi-random. Once all of the channels have been used, the sequence repeats. The snap-shot view, above left, shows the signal (very narrow) on a single frequency or channel. As the one minute time exposure view shows, the device will transmit over all of the available channels. When its transmissions overlap those of another user both in frequency and time, interference is likely.

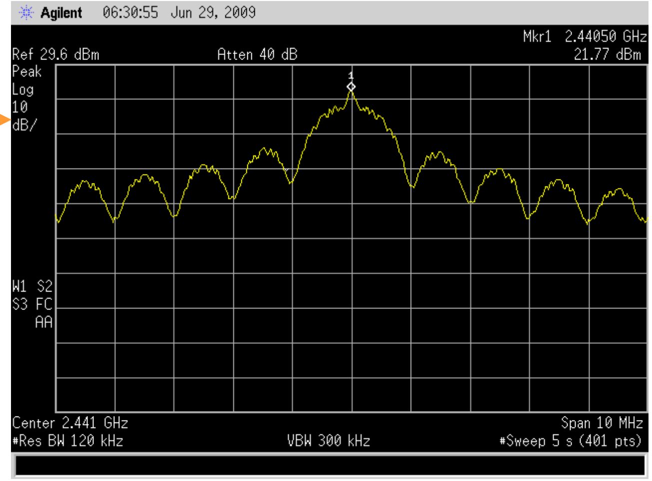
Bluetooth devices as well as some wireless microphones and remote camera and head control devices use this technology. Its main advantage is that the technology is inexpensive and very simple to implement. Its drawbacks include its susceptibility to data loss due to reflections and its disruption to other users in the band.

If another user is transmitting data in the same band, interference can occur when both transmitters are operating on the same or adjacent frequencies. Since the duration of each hop is short, normal transmission can be resumed so long as the next hop channel is clear of interference.

B. DSSS (Direct Sequence Spread Spectrum)

A device using direct sequence technology spreads the signal by adding a sequence of bits ("the code sequence") to each bit of transmitted data. The code can be as short as 8 bits in WiFi applications or as long as thousands or even millions of bits when applied to NASA planetary probes or military applications. Because of the additional code information this signal occupies much greater bandwidth than it would if it were only carrying the raw data. However the receiver contains a special type of filter that enables it to distinguish signals containing the correct code from other signals. The selectivity provided by the receiving filter enables direct sequence devices to have enhanced capability to operate in the presence of interference.





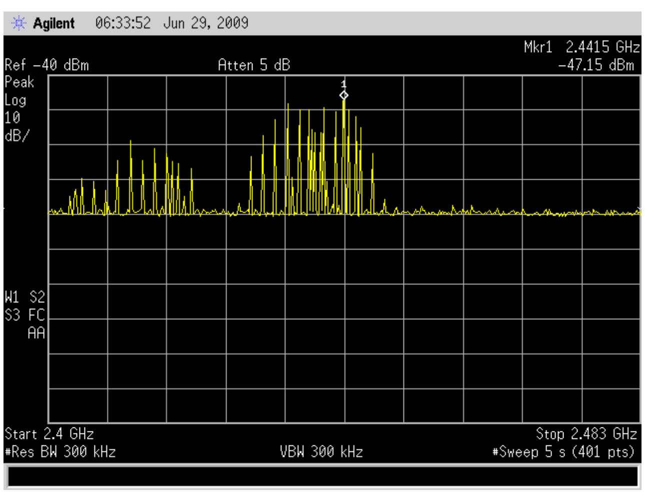
DSSS: wide shot of entire 2.4 GHz band

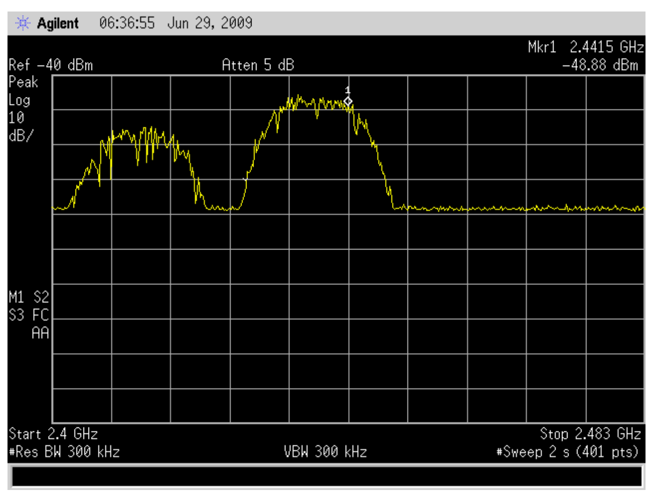
DSSS: close-up on 10MHz section

Unlike frequency hopping devices, DSSS devices operate on an <u>assigned channel</u>. This enables them to operate reliably with other fixed channel devices in the same location little chance of interference. DSSS devices work very well in low to medium data rate systems like the FI+Z and Zigbee based industrial devices. They are also used in applications up to 11 Mbs, such as the wireless network cards used in many computers.

C. OFDM Modulation.

For applications requiring data rates greater than 11 Mbs another type of modulation called OFDM is used. OFDM modulation splits the information to be transmitted into a large number of signals called <u>subcarriers</u>, each of which carries only a small fraction of the data. Some additional information is added to the signals to enable the contents to be recovered if some of the subcarriers are lost due to interference or environmental effects such as reflections. Wireless modems with maximum data rates greater than 11Mbs use OFDM. Typical OFDM spectra are shown below.





OFDM: snap-shot view showing subcarriers

OFDM: time exposure view.

es.

V. Interference.

A. Overview.

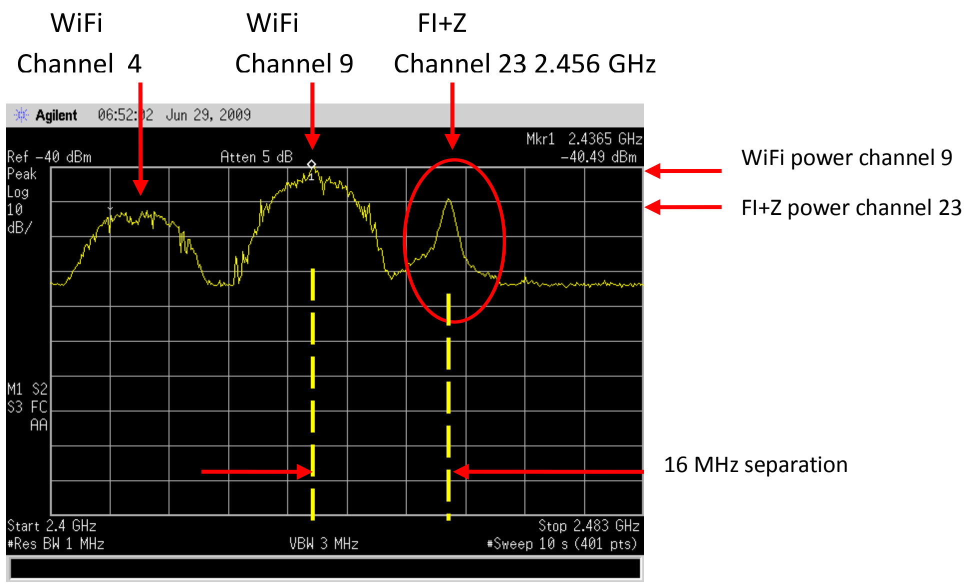
Every wireless device has only a finite ability to reject interfering signals. This means that in the presence of a sufficiently strong interfering signal, the wireless device will be unable to function. Interfering signals can be broadly categorized as:

- Co-channel: devices operating on the same or overlapping frequencies.
- Adjacent Channel: devices operating in the same band but on non-overlapping frequencies.
- Out of band

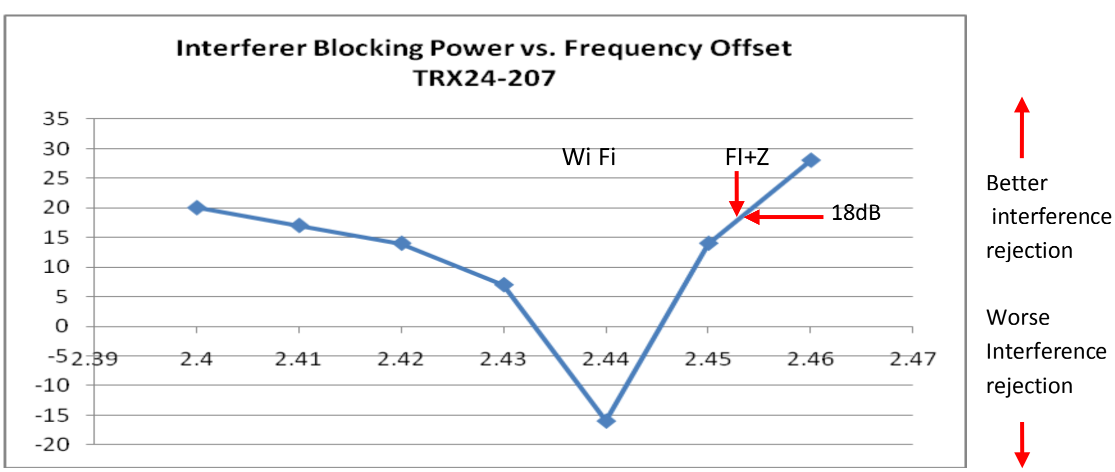
B. WiFi Interference.

To illustrate co-channel interference, the spectrum of two WiFi routers and a FI+Z system was recorded. All of the units were operating on different channels.

The WiFi unit on channel 9 is separated by approximately 16 MHz from the FI+Z unit on channel 23. The peak power received by the MDR from the FI+Z unit is about **<u>10x</u>** less (one vertical division) than the peak power from the channel 9 WiFi.



In order to quantify the effect of adjacent channel interference, a measurement was made to determine the amount of interferer power that would cause a specific amount of data loss – in this case 0.1% - as a function of the frequency spacing between the WiFi interferer on channel 9 and the FI+Z system. The chart below shows the result for the current transceiver TRX24-207.



The chart indicates that for the 16 MHz separation used in our example, the FI+Z can operate without disruption, provided that the power received from the WiFi device is no more than 18dB greater than the signal from the FI+Z transmitter. The 18dB (decibel) is a logarithmic measure of the power difference which corresponds to a factor of 63x in power.

Although the factor of 63x sounds like a lot, if the WiFi and FI+Z transmitters had the same power, the WiFi located at 10' from the MDR receiver would disrupt the FI+Z at 80'distance. As the separation in frequency becomes less, the susceptibility to interference gets substantially worse. At a frequency separation of 5 MHz or less, the WiFi will disrupt FI+Z communication when the units are roughly equidistant from the MDR receiver.

Because WiFi signals take up substantial bandwidth – greater than 16 MHz – it's clear that they should be kept as far away from the set as possible. Personal communication devices which have both cellular and WiFi capability should be restricted to cellular use. Furthermore, a site survey should be made before filming commences to determine the channels any nearby WiFi are operating on, so that non-interfering FI+Z channels can be chosen.

C. Frequency Hopper Interference

Frequency hopping devices are allowed to operate with up to 1W peak power. Since the FI+Z transmitter is limited to one tenth of that power, frequency hopping devices can easily disrupt communication not only with the FI+Z, but any other device using the 2.4 GHz band.

D. Airport Radar.

Airport radar equipment can disrupt 2.4 GHz wireless transmission. Although their operating frequencies are normally outside the 2.4 GHz band, the high power levels employed (up to 100,000 Watts) can saturate the sensitive amplifiers used in the FI+Z transceivers and block reception. The interference will coincide with the radar beam sweeping past the FI+Z system. A Command cable should be kept in the kit for this eventuality.

VI. How to detect avoid interference.

a. Check for the presence of any devices using the 2.4 GHz band including:

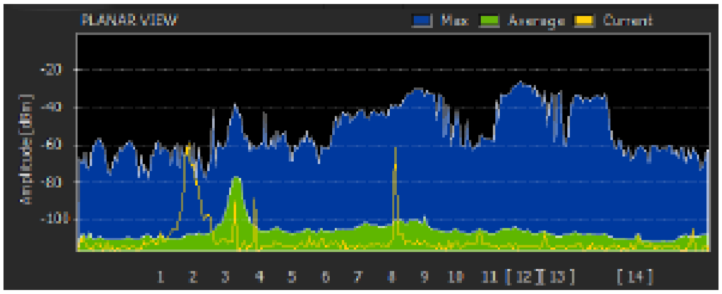
- Other FI+Z units
- Other wireless camera/lens controls
- Wireless Boom mikes
- Wireless video assists
- Bluetooth devices
- Wireless controls for remote heads
- Microwave ovens

Useful tools for conducting site surveys are described in the following sections.

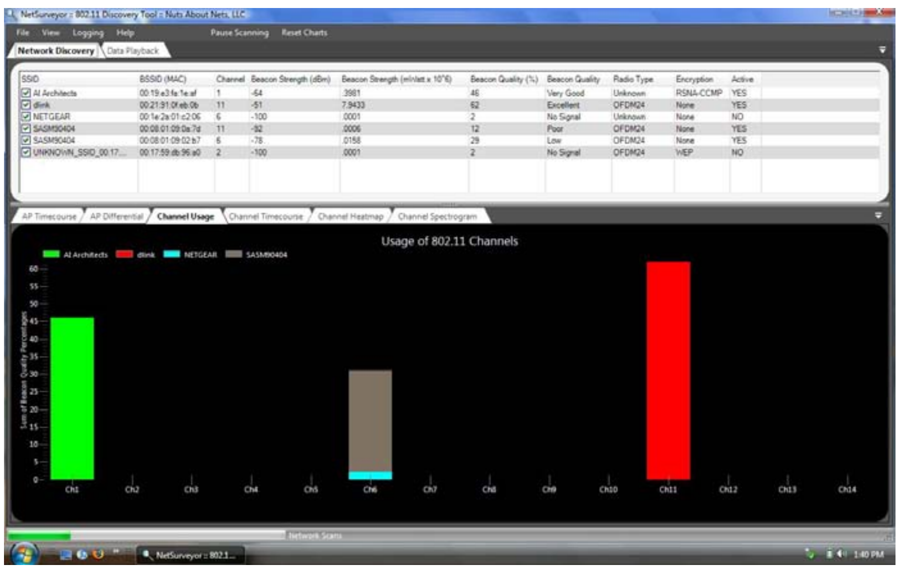
b. Site Survey Tools.

i. A number of companies offer devices which add spectrum analysis capability to laptop computers. A site survey using this equipment will show the types of 2.4 GHz band microwave emissions present in the environment. For example, see: http://www.nutsaboutnets.com/performance-wifi/main/purchase-wifi-spectrum-analyzer.htm#airsleuth-lite and http://www.metageek.net/products/wi-spy-24i .

The WiSpy devices from Metageek are noteworthy for their low cost. They offer displays of the 2.4GHz spectrum which show signals in three different colors to indicate their current strength; their strength averaged over time, and their maximum values. The display software runs on both Mac and PC platforms.



ii. Laptops having WiFi cards can be used to survey sites for WiFi activity. **Net Surveyor** is a free software program for the PC platform. It displays the occupied channels, signal strength, activity and type of modulation (screenshot below). It can be downloaded here: [http://www.nutsaboutnets.com/performance- wifi/products/netsurveyor-network-discovery.htm](http://www.nutsaboutnets.com/performance-wifi/products/netsurveyor-network-discovery.htm)



c. An inexpensive , handheld WiFi survey device called the Canary Wireless HS-20 Digital Hotspotter is available from http://www.canarywireless.com/canary/ The unit identifies occupied WiFi channels, shows their SSID, and displays signal strength.

d. HU3 Scan Function

The HU3 Scan Function can display the channels used by other HU2 and HU3 units. This function is located in the System menu (Menu →System). Once in the System menu choose Network. The display shows occupied FI+Z channels and their signal strengths.

VII. Appendix

i. WiFi Channels

Channel Number	Lower Frequency MHz	Center Frequency MHz	Upper Frequency MHz
1	2 401	2 412	2 423
2	2 404	2 417	2 428
3	2 411	2 422	2 433
4	2 416	2 427	2 438
5	2 421	2 432	2 443
6	2 426	2 437	2 448
7	2 431	2 442	2 453
8	2 436	2 447	2 458
9	2 441	2 452	2 463
10	2 451	2 457	2 468
11	2 451	2 462	2 473
12	2 456	2 467	2 478
13	2 461	2 472	2 483
14	2 473	2 484	2 495

ii. FI+Z Channels

1. Hand Unit1 / MDR1 channels

Channel#	GHz	Channel#	GHz	Channel	GHz
0	2.4120	**10**	2.4320	**20**	2.4520
1	2.4140	**11**	2.4340	**21**	2.4540
2	2.4160	**12**	2.4360	**22**	2.4560
3	2.4180	**13**	2.4380	**23**	2.4580
4	2.4200	**14**	2.4400	**24**	2.4600
5	2.4220	**15**	2.4420	**25**	2.4620
6	2.4240	**16**	2.4440	**26**	2.4640
7	2.4260	**17**	2.4460	**27**	2.4660
8	2.4280	**18**	2.4480	**28**	2.4680
9	2.4300	**19**	2.4500	**29**	2.4700

2. Hand Unit 2/ MDR2 Channels

Channel#	GHz	Channel#	GHz	Channel	GHz
0	2.4120	**10**	2.4310	**20**	2.4500
1	2.4139	**11**	2.4329	**21**	2.4519
2	2.4158	**12**	2.4348	**22**	2.4539
3	2.4177	**13**	2.4367	**23**	2.4559
4	2.4196	**14**	2.4386	**24**	2.4579
5	2.4215	**15**	2.4405	**25**	2.4599
6	2.4234	**16**	2.4424	**26**	2.4619
7	2.4253	**17**	2.4443	**27**	2.4639
8	2.4272	**18**	2.4462	**28**	2.4659
9	2.4291	**19**	2.4481	**29**	2.4679

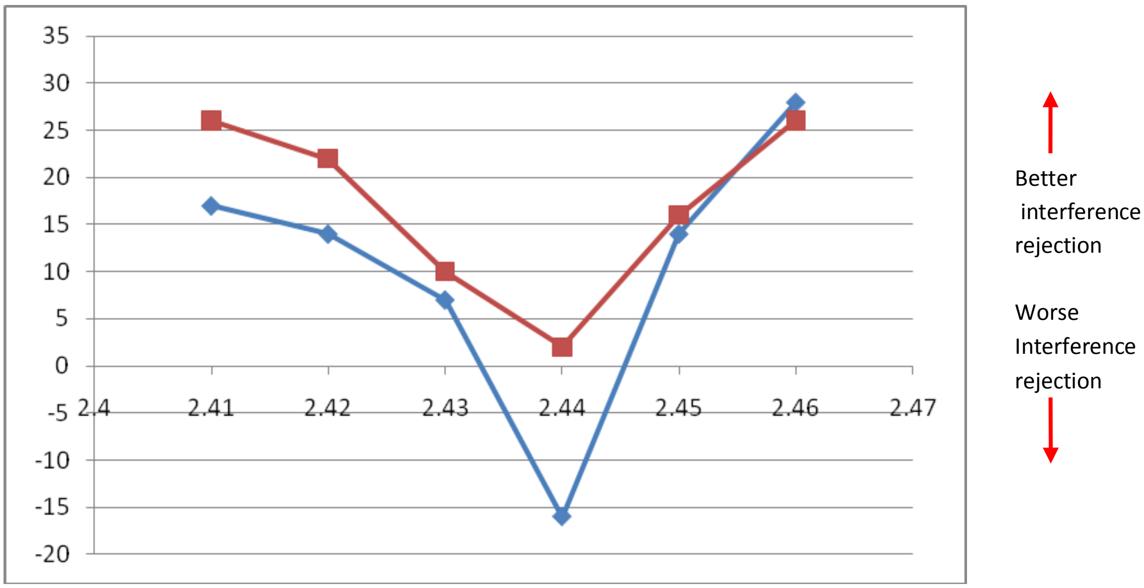
3. TR4 (new generation) channels

Channel#	GHz	Channel#	GHz	Channel#	GHz
0	2.4020	**10**	2.4270	**20**	2.4570
1	2.4040	**11**	2.4300	**21**	2.4600
2	2.4060	**12**	2.4330	**22**	2.4630
3	2.4080	**13**	2.4360	**23**	2.4660
4	2.4100	**14**	2.4390	**24**	2.4690
5	2.4120	**15**	2.4420	**25**	2.4720
6	2.4150	**16**	2.4450	**26**	2.4740
7	2.4180	**17**	2.4480	**27**	2.4760
8	2.4210	**18**	2.4510	**28**	2.4780
9	2.4240	**19**	2.4540	**29**	2.4800

VIII. New Generation Transceivers.

New generation transceivers will become available in fall, 2009. These new transceivers can be used as drop-in replacements for earlier generation devices in the HU3, MDR2, Focus-Iris, and Radio Micro Force modules. They are not compatible with the Microwave Transmitter module used in the HU1 and HU2.

These new transceivers offer a significant improvement in interference rejection, much lower power consumption, and lower part count = higher reliability. When used in the HU3, battery life is expected to double.



The above graph shows the co-channel and adjacent channel WiFi interference rejection for the current FI+Z Transceiver (Blue line) and the next generation TRX4 transceiver TR4 (Red Line).

The new TR4 transceiver improves on the co-channel interference rejection of its predecessor by 18 decibels or a factor of 63x. Adjacent channel interference is improved from 3dB to 10dB over most of the 2.4 GHz band.