The Usefulness of Frequency Coordination Versatility Factor

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Introduction

Frequency Coordination Versatility Factor is intended to be a value assigned to radio frequency transmitting/receiving equipment in respect of the equipment's ability to integrate into an existing RF Coordination scheme or *Band-Plan*. FCV is derived by quantitative analysis of the equipment's specifications and demonstrated performance to define a value used when making comparisons between different equipment. The ability to coordinate frequencies within the broadcast and Radio/TV/Film industries is evolving into a much more technically minded, scientific process which requires empirical data for proper results. The FCV factor is one such element which can be used to qualify equipment selection and purchasing decisions.

Frequency Coordination Background

Frequency coordination is a mathematical tool which analyses the inter-action of energy waves generated by radio transmitters used in proximity to each other. Proximity is defined as the ability of the multiple transmitters to interact based on power and radiator design/orientation. Examples of this are three 50,000 Watt commercial-band, FM radio stations covering the same metropolitan vicinity with a coverage area of several miles, or at the other end of the power scale, three 100 milliwatt transmitters used by musical performers in a concert stage. In either situation, the frequencies must be coordinated to allow satisfactory operation.

Scope

For the sake of brevity, the scope of this analysis will be limited to 470-698MHz, UHF low-power equipment.

Work-Flow

Several frequency coordination computer applications are available, some for purchase and some free, which have proven to be very valuable in the determination of potential interference as well as serving as overall management tools. These applications take into account the available band-width, frequency step, manufacturer's specifications and to a degree, the quality of the design of the transmitting and receiving equipment. The operational limits of each piece of equipment are entered into the database and then analyzed for which available frequencies can be used to function together without interference. Analytical consideration is also given to location-based RF sources such as commercial DTV transmitters, low power TV and other registered sources of radiation.

Explanation of Specifications

A Accessible Bandwidth

Equipment will always have a stated highest and lowest operational frequency. An example might be a receiver which can be tuned to a lowest frequency of 471.025 MHz and a highest of 494.000 MHz. These frequencies would be called the low and high limit which defines the *Accessible Bandwidth* (BW_A).

B Frequency Step

By design, a receiver might be manufactured to change its tuned frequency in increments of 25 KHz. This is called the *Frequency-Step*.

With the lowest frequency being 471.025 MHz, the next would be 471.050, then 471.075, 417.100, etc, stopping at the highest of 494.000 MHz. For this example, the receiver provides 919 frequency choices.

C Channels per Device

For a piece of equipment which houses multiple receivers in a single chassis, the number of choices is divided by the number of channels in the single chassis. Using our above example, the total quantity of frequencies, given that both receivers share the same specifications, would have access to 50% of the available 919 frequencies. For a unit which houses eight receivers, the number is divided by eight which would be approximately 114 choices for each channel.

D Maximum Density/Minimum Spacing

Manufacturer's stated maximum density is the number of matched transmitter/receiver pairs which the manufacturer claims to be possible when using their equipment in a controlled environment. This number is theoretical except under laboratory conditions as the environments and third party sources of radiation may exclude a user from experiencing satisfactory performance regardless of the manufacturer's proven design. For example, TV channel 37 in the US is reserved for radio astronomy. A manufacturer may rightfully claim that their equipment allows for 36 TX/RX pairs to work within their "block", but if that block includes TV channel 37, then the density will need to subtract that 6 MHz range belonging to TV channel 37. Regardless, the density is what is significant; how many carriers does the manufacture claim to be able to operate in a given block of spectrum. While this may seem like a duplication of the frequency step specification, it is significantly different; the steps may be as small as 5 KHz, but minimum spacing stated by the manufacturer may be 300 KHz.

E Transmitter Quality/SNR

The quality of the manufactured equipment must be a component of the total analysis. Lower-cost equipment may be more sensitive to and generate greater levels of unwanted RF energy than higher-quality offerings. This is included and discussed in much greater detail in the section titled *Inter-modulation Products Assessment* found at the end of this document.

The FCV value is determined by the simple equation below. This equation applies to basic equipment. More sophisticated equipment requires additional considerations.

$$\frac{[(F_{High} - F_{Low}) / \text{Channel Quantity}}{\text{Frequency Step}}$$

Described:

Highest Tunable Frequency – Lowest Tunable Frequency	=Accessible Bandwidth (BW_A)
BW_A / number of channels in the equipment	= Channel Bandwidth (BW_C)
BW_C /frequency step	= Simple Density Bandwidth (BW_{SD})
BW_{SD} analyzed against SNR	= FCV

The range of values is quite broad with some as low as 120 and others as high as 33000. In general terms, the higher the value, the greater the versatility; the lower the value, the less the versatility.

When designing a band-plan, the FCV factor determines which equipment should be coordinated first. Equipment with low versatility should be coordinated first; the most versatile will be coordinated last.

Additional Notes/Summary

1 Equipment with one channel, wide Accessible Bandwidth and small Frequency Steps will be the most versatile. Multi-channel, narrow bandwidth and large steps will be the least versatile.

2 The importance of the quality of the equipment being coordinated should not be overlooked. Lower cost and less sophisticated RF circuits can generate more *and* be more sensitive to spectrum density, de-sensing, signal propagation and proximity inter-modulation. One of the most important quality factors is inter-modulation.

3 Transmitters and receivers have polar opposite natures. The issues that affect receivers, such as diversity switching, de-sensing are not relevant to transmitters, such as power output, inter-modulation and deviation levels. These differences mandate that the criteria for FCV be independently addressed.

4 System design considerations can also impact the selection of equipment. If a single transmitter needs to be received by one channel of a dual receiver and picked up by a separate, portable (ENG style) receiver, the dual channel rack-mount receiver is the defining limitation as the ABW for each receiver may be different. Beyond the actual transmitters and receivers, other equipment such as multiple antenna locations, external preamplifiers and active antennas all contribute to overall performance. An improperly over-driven active antenna can severely reduce the quality of performance do to product generation.

Inter-modulation Products Assessment

Transmitters demonstrate proximity-based inter-modulation (IM) products. This can significantly affect the operational density; the lower the amplitude of the products, the greater possible density. This is measured on a spectrum analyzer with two frequencies and a 2x1 50-ohm signal combiner. Bear in mind that this test is only appropriate for transmitters with detachable antennas. Hand-held microphones and other forms of integrated antennas can't connect to the combiner so less consistent methods of proximity must be used such as mechanical jigs or in some cases, test cables connected to circuit boards. Two test conditions are used; (1) Highest/lowest and (2) Center/offset.

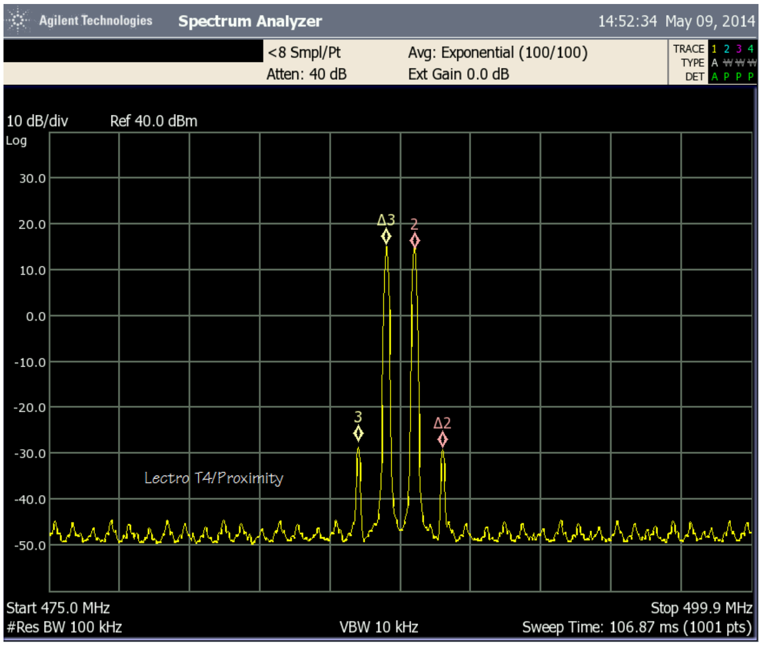


Image #1

This analyzer screen image shows the resultant products created when the two primary carriers combine in close proximity. F1 is 487MHz, F2 is 488MHz. The two products are mathematically located at 1MHz above the higher and 1MHz below the lower primary carriers. The mathematical relationship is unavoidable, but the amplitude can be minimized by careful system design. In this case, the difference between the primary carrier and the products is approximately -30 (3 and Δ2) and +15 (Δ3 and 2), an absolute distance of 45dB. The presence of the lower product at 486MHz and the higher product at 489MHz would exclude the use of those frequencies for other purposes.

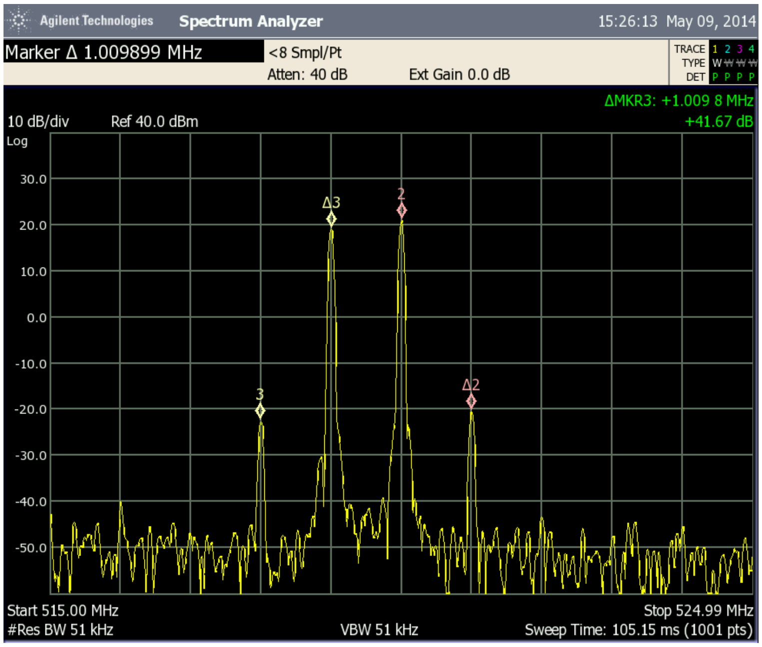
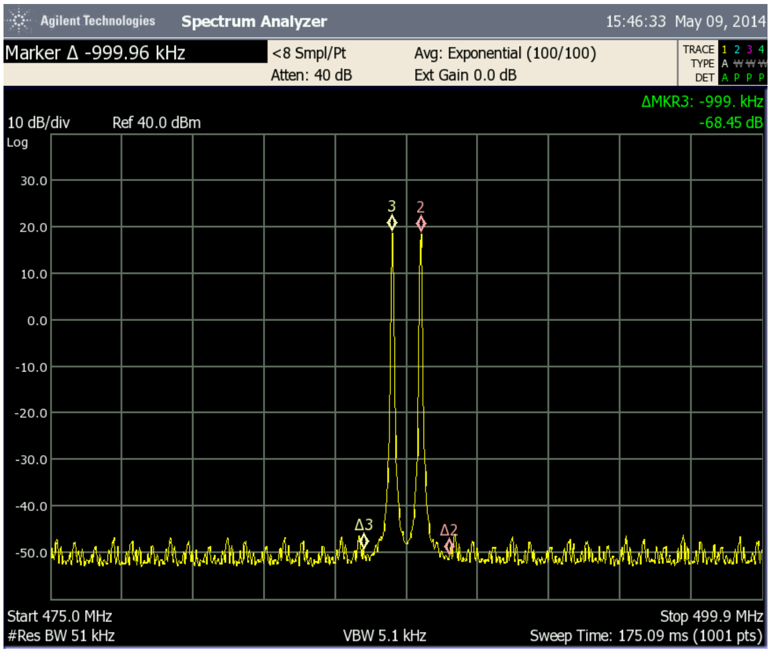


Image #2

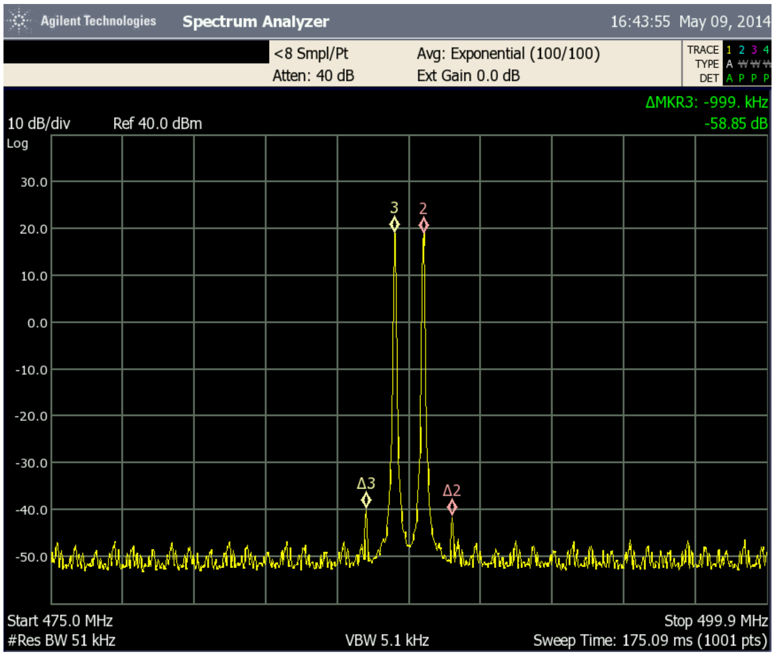
The second image shows a similar, directly connected dual-carrier transmitter with a +20 and -20dBm, or 40dBm total SNR between the primary carriers and the products. Again, the two carriers were set at 1MHz apart and the resultant products conform to the mathematically ordered 1MHz below and 1 MHz above spacing. This situation has a poorer SNR than the image above. The equipment used in this test is a dual-transmit device with an internal 2x1 combiner. This output is native to an original, unmodified, factory produced unit.



15:46:33 May 09, 2014
Marker Δ -999.96 kHz
<8 Smpl/Pt
Atten: 40 dB
Avg: Exponential (100/100)
Ext Gain 0.0 dB
ΔMKR3: -999. kHz
-68.45 dB
Ref 40.0 dBm
Start 475.0 MHz
#Res BW 51 kHz
VBW 5.1 kHz
Stop 499.9 MHz
Sweep Time: 175.09 ms (1001 pts)

Image #3

This image is a duplicate set of frequencies from Image #1. This version has the two transmitters running through an active transmitter combiner. The high isolation of the active amplified inputs of the combiner minimizes the amplitude of the products. This is an example of an improvement in system design allowing for greater density of carriers due to the severe reduction of inter-modulation products.



16:43:55 May 09, 2014
<8 Smpl/Pt
Atten: 40 dB
Avg: Exponential (100/100)
Ext Gain 0.0 dB
ΔMKR3: -999. kHz
-58.85 dB
Ref 40.0 dBm
Start 475.0 MHz
#Res BW 51 kHz
VBW 5.1 kHz
Stop 499.9 MHz
Sweep Time: 175.09 ms (1001 pts)

Image #4

This image is a duplicate set of frequencies from Image #1, as well but this configuration uses a 2x1 passive signal combiner. While not supplying as severe a reduction in product amplitude, there is a 5dBm improvement as compared to the antenna radiated scenario in the first image. Also important to note is the 3-dBm loss of energy due to the passive combiner. While manufactured to deliver a maximum output of +20dBm, the same as shown here, the active combiner could accommodate up to eight inputs. To do the same with a passive combiner would result in a 9dBm drop in carrier amplitude.

1.1 Test Condition #1 (Highest/Lowest)

Tests for inter-modulation when using the maximum separation between the two frequencies

F_1 = lowest possible tunable frequency

F_2 = Highest possible tunable frequency

1.2 Test Condition #2 (Center/Off-set)

Tests for inter-modulation with minimum separation between two frequencies at the center of the accessible bandwidth

F_1 = Center frequency – ½ minimum separation

F_2 = Center frequency + ½ minimum separation

Use the manufacturer's stated maximum number of operational units within a stated bandwidth to determine the *Manufacturer's Stated Operational Density* (MSOD). This number is divided into the total bandwidth to determine the minimum spacing to achieve MSOD. One-half the minimum spacing value is added to the center frequency and one-half is subtracted from the center frequency to generate F1 and F2.

For example:

First, determine minimum spacing for maximum density: BW is 470-495MHz, (example: MSOD is 16) units.

$$(494\text{-}470)/16 = 1.5625\text{MHz}$$

Then figure the center frequency

$$(494\text{-}470)/2 = 482.500\text{MHz}$$

Next figure one-half the minimum spacing

$$1.5625/2 = .78125\text{MHz}$$

Finally add and subtract one-half the spacing from the center frequency

$$482.500 + .78125 = 483.28125 \text{ and } 482.5 - .78125 = 481.71875$$

These values need to round to the nearest tunable frequency. For a typical .025MHz step, those values would be:

$$F_1 = 481.725$$
$$F_2 = 483.275$$

In each test condition #1 and #2:

Measure the lower primary carrier (F_1)
Measure the higher primary carrier (F_2)
Measure the lower frequency product (F_{PL})
Measure the higher frequency product (F_{PH})

Average the F_1/F_2 measurement by:

$$(F_1 + F_2)/2$$

Average the F_{PL}/F_{PH} measurement by:

$$(F_{PL} + F_{PH})/2$$

The F_1/F_2 Average is the desirable energy which should be as close to the manufacturer's specification as possible allowing for ~ -4dBm for the losses of the combiner and connecting cables; the higher the value the stronger the transmitter.

The F_{PL}/F_{PH} Average is the undesirable energy; the lower the value or even non-existent, the better.

It is the ratio between these numbers that is most significant. The higher the primary carriers and the lower the products, the better the equipment and the more density can be attained. The greater the absolute amplitude difference, the better. This is commonly referred to as a signal-to-noise (SNR).

Test #1: $[(F_1 + F_2)/2] + [(F_{PL} + F_{PH})/2]$ = Test1 Average

Test #2: $[(F_1 + F_2)/2] + [(F_{PL} + F_{PH})/2]$ = Test2 Average

Finally, average the Test1 result and Test2 result to determine the over-all average IM-SNR.

SNR Factor Relevance

In determining the FCV-Factor, if the average SNR is greater than 75, the equipment is assigned a value of one (1). If it is less than 75 and greater than 50, it is assigned a value of two (2). If it is less than 50 it is assigned a value of three (3). This figure is divided into the FCV factor to diminish its versatility due to its poor SNR value. It is only applicable to transmitters as only transmitters can inter-modulate on the carrier frequency. Note that when dividing by one (1) the net effect is no change since the products are not sufficiently strong to impact the analysis.

This SNR factor is the most challenging to quantify in the scope of determining FCV for several reasons; (1) The passive 2x1 combiner is the least forgiving method of combining, (2) it is only a small percentage of the time that transmitters are in close enough proximity to affect each other and (3) the use of active transmitter combiners for fixed-base-transmitters can provide high isolation through amplification and isolator circuits to minimize the generation of these products.

Example Equipment #1 (Fixed Base Transmitter)

Test #1 Example Data: (See image #2)
F_1 = 519.000MHz @ +20.5dBm
F_2 = 520.000MHz @ +19.5dBm
F_{PL} = 518MHz @ -20dBm
F_{PH} = 521MHz @ -20dBm

$$(20.5 + 19.75)/2 = 20.5$$
$$(-20 + -20)/2 = -20$$

Next:

$$(+20.5 - -20) = 40.5 \textbf{ SNR}$$

Test #2 Example Data:
F_1 = 481.725 MHz @ +22.5dBm
F_2 = 483.275MHz @ +23.5dBm
F_{PL} = 480.175 MHz @ -35dBm
F_{PH} = 484.825 MHz @ -50dBm

(22.5 +23.5)/2 = 23
(-35 + -50)/2 =-42.5

Next:

(23 - -42.5) = **65.5 SNR**

These two SNR values are then averaged and rounded to a whole number:

(57 + 65.5)/2 = **61dBm** average SNR

Example Equipment #2 (High Quality Analog Microphone)

Test #1 Example Data:
F_1 = 470.000MHz @ +14dBm
F_2 = 506.000MHz @ +13.5dBm
F_{PL} = 452MHz @ -70dBm
F_{PH} = 524MHz @ -80dBm

(14 +13.5)/2 = 13.75
(-70 + -80)/2 =-75

Next:

(13.75 - -75) = **88.75 SNR**

Test #2 Example Data:
F_1 = 481.725 MHz @ +14.5dBm
F_2 = 483.275MHz @ +14dBm
F_{PL} = 480.175 MHz @ -60dBm
F_{PH} = 484.825 MHz @ -65dBm

(14.5 +14)/2 = 14.25
(-60 + -65)/2 =-62.5

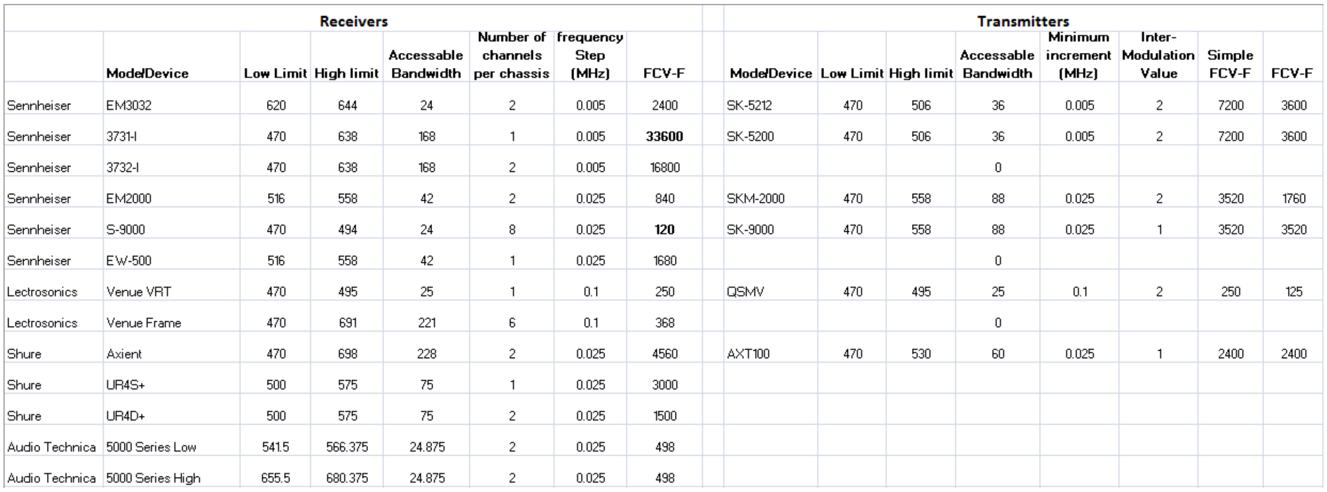
Next:

(14.25 - -62.5) = **76.75 SNR**

These two SNR values are then averaged and rounded to a whole number:

(88.75 + 76.75)/2 = **82.75dBm** average SNR spread.

Equipment Comparison



Receivers									Transmitters								
	Model/Device	**Low Limit**	**High limit**	**Accessable Bandwidth**	**Number of channels per chassis**	**frequency Step (MHz)**	**FCV-F**		**Model/Device**	**Low Limit**	**High limit**	**Accessable Bandwidth**	**Minimum increment (MHz)**	**Inter-Modulation Value**	**Simple FCV-F**	**FCV-F**
Sennheiser	EM3032	620	644	24	2	0.005	2400		SK-5212	470	506	36	0.005	2	7200	3600
Sennheiser	3731-I	470	638	168	1	0.005	**33600**		SK-5200	470	506	36	0.005	2	7200	3600
Sennheiser	3732-I	470	638	168	2	0.005	16800					0				
Sennheiser	EM2000	516	558	42	2	0.025	840		SKM-2000	470	558	88	0.025	2	3520	1760
Sennheiser	S-9000	470	494	24	8	0.025	**120**		SK-9000	470	558	88	0.025	1	3520	3520
Sennheiser	EW-500	516	558	42	1	0.025	1680					0				
Lectrosonics	Venue VRT	470	495	25	1	0.1	250		QSMV	470	495	25	0.1	2	250	125
Lectrosonics	Venue Frame	470	691	221	6	0.1	368					0				
Shure	Axient	470	698	228	2	0.025	4560		AXT100	470	530	60	0.025	1	2400	2400
Shure	UR4S+	500	575	75	1	0.025	3000									
Shure	UR4D+	500	575	75	2	0.025	1500									
Audio Technica	5000 Series Low	541.5	566.375	24.875	2	0.025	498									
Audio Technica	5000 Series High	655.5	680.375	24.875	2	0.025	498									