Using Spectrum Consumption Models to Specify Receiver Performance Interference Thresholds

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Background

- **Mistakes in spectrum management**
  - Nextel vs Public Safety
  - LightSquared vs GPS
- **Government Response**
  - HR 3609 requires GAO to undertake study on receiver performance and spectrum efficiency and published a report on options to improve receiver performance in Feb 2013
  - FCC Technological Advisory Council forms the Receivers and Spectrum Workgroup (2012) and publish a whitepaper on Harm Claims Thresholds in Feb 2013
- **Operator concerns about receiver standards**
  - Who benefits (Standards are developed for single industries)
  - Expense of transition and implementation
  - Exposure of capabilities, vulnerabilities, and operations
- **Receiver Performance Interference Thresholds (WINNF Top Ten Innovation)**
  - Defining receiver interference tolerance is necessary to coordinate spectrum sharing
  - Supports decisions in admitting new spectrum uses which consider in-band and out-of-band effects
    - In automated management
    - In regulation
  - Serves as a means to compare receiver designs

Problem

Options

Concerns

Innovation

FCC TAC Harm Claim Thresholds

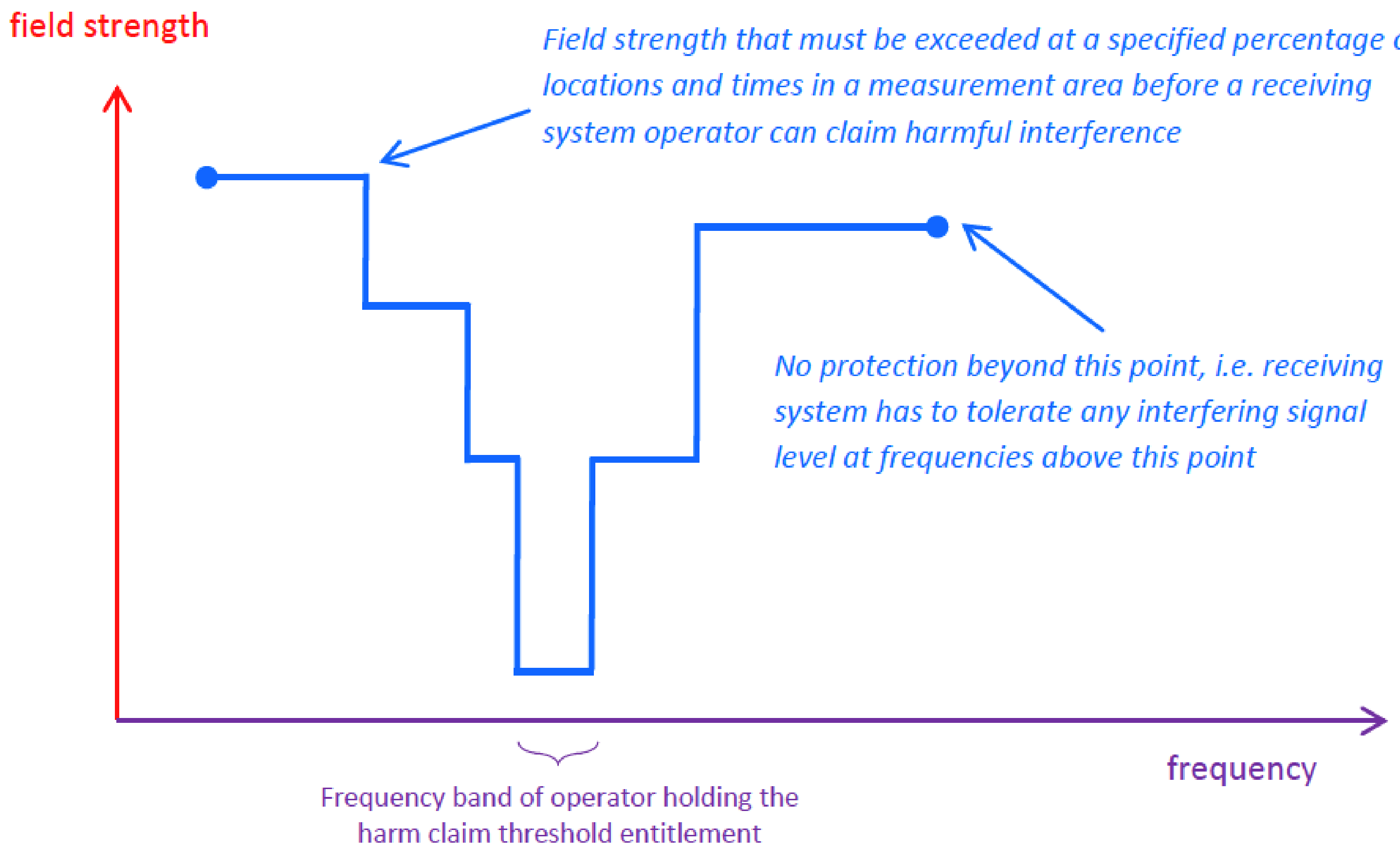
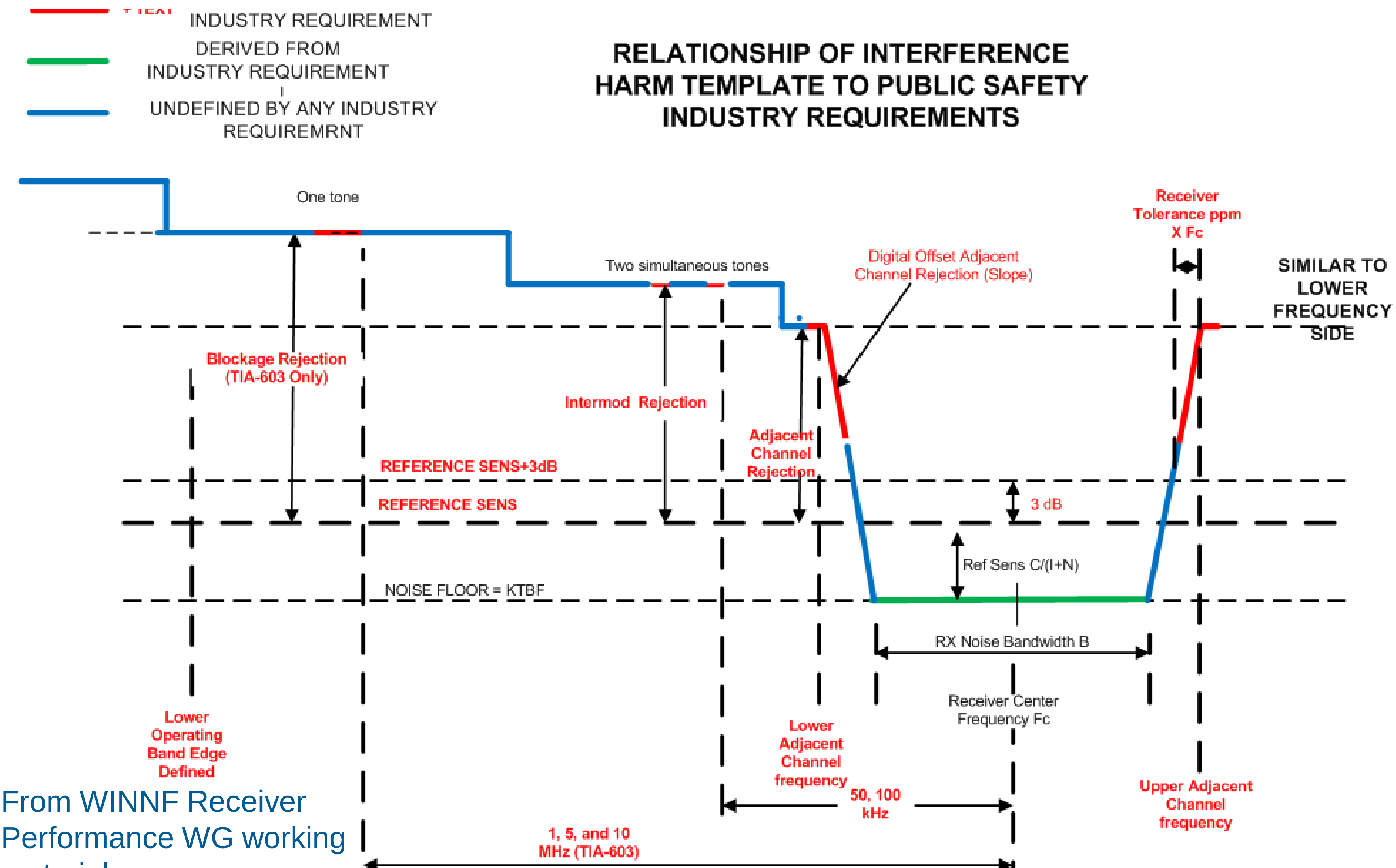


Figure 1. Elements of a harm claim threshold

WG concerns about Harm Claim Thresholds

- **Does not account for the type of out-of-band energy from interference sources**
- **Derived thresholds are not based on integrated energy from possible interference sources (energy that passes the input filters of the receiver)**
  - Over protects from narrowband sources
  - Under protects from wideband sources
  - HCT based on statistical distribution not much help when you are at a poor location.
- **Confounds operational and environmental factors with the technical aspects of the receivers**

Receiver Performance WG Example



From WINNF Receiver Performance WG working materials

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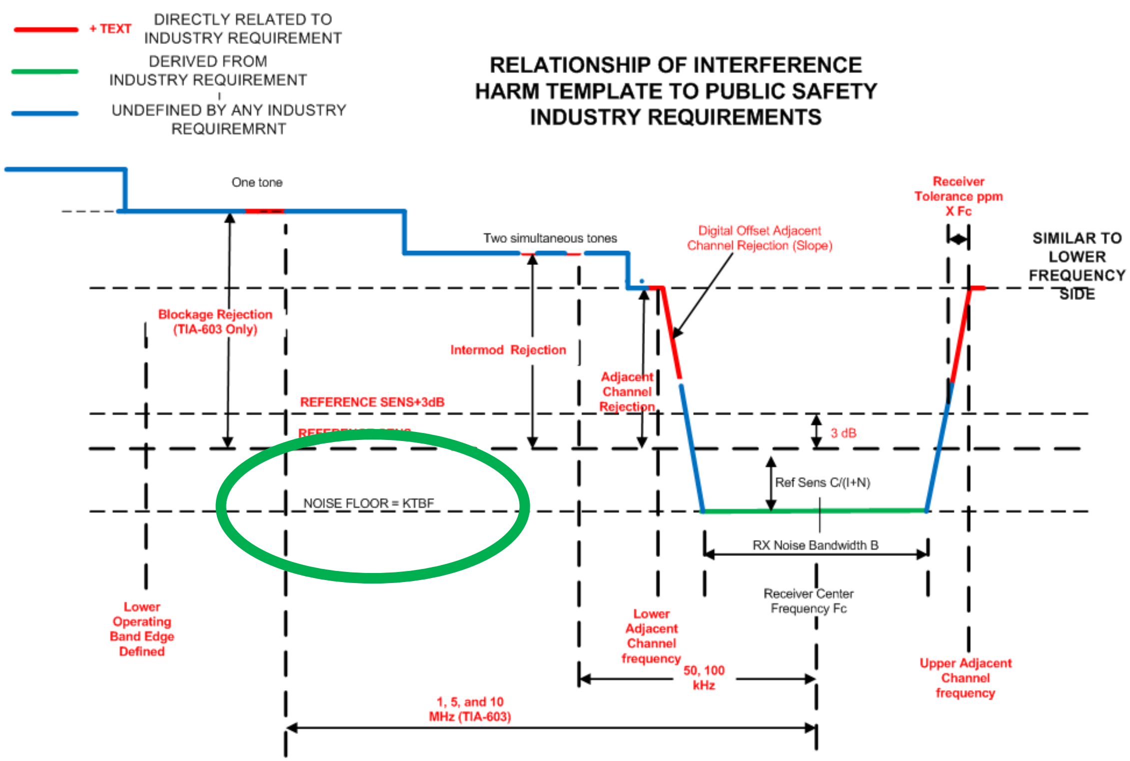
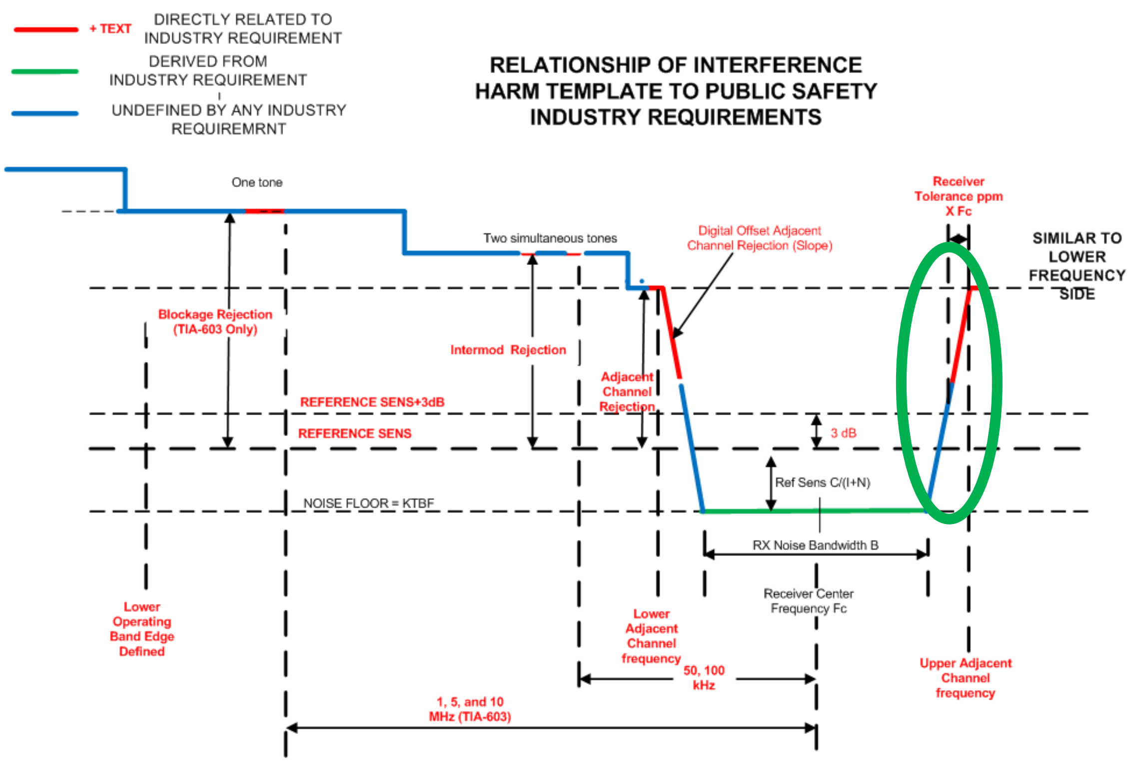
Reference Sensitivity



From WINNF Receiver Performance WG working materials

- **Reference Sensitivity is signal level where a min received signal quality is achieved (usually 5% BER or 12 dB SINAD)**
- **Ref Sens = Noise Floor+ C/N ref**
- **C/N ref varies with modulation (values in TSB-88)**
- **Noise Floor = KTBF**
- **B = RX Filter Noise Bandwidth Chosen to balance Adj Ch Rejection vs Sensitivity**

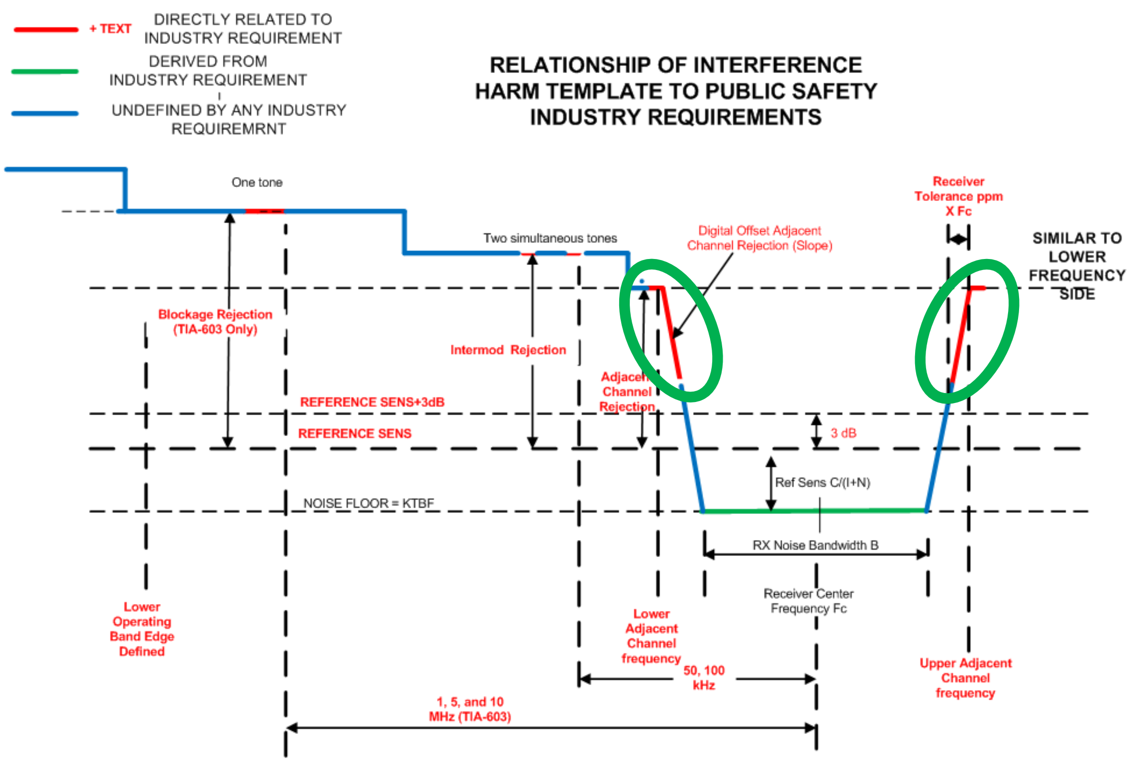
Adjacent Channel Rejection



- **Adjacent Channel Rejection (ACR) is Interference Level in the adjacent channel that results in 6 dB degradation in reference sensitivity**
- **Bandwidth B of receiver band limiting filter chosen to balance ACR against sensitivity**

From WINNF Receiver Performance WG working materials

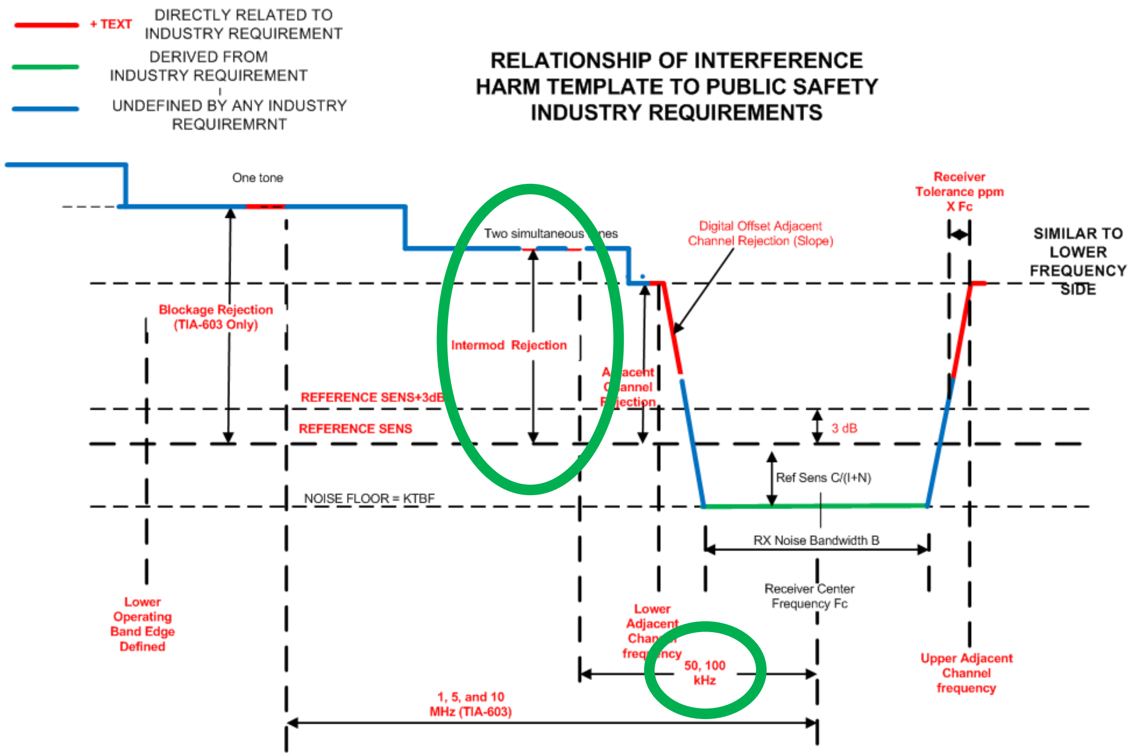
Digital Offset Rejection



- **Allowable degradation in adjacent channel rejection if interference happens to be slightly closer in frequency to receiver frequency than specified channel spacing**
- **Defined in terms of dB/kHz degradation over frequency tolerance of radio**

From WINNF Receiver Performance WG working materials

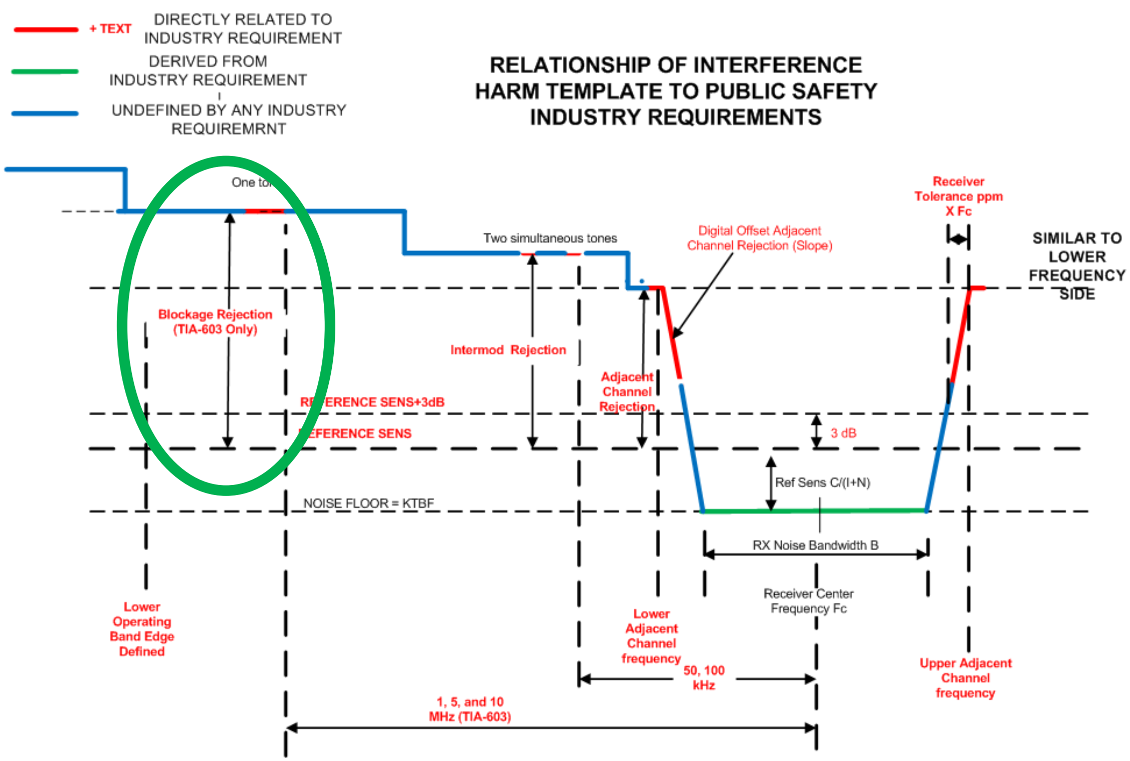
Intermodulation Rejection



- **Intermodulation Rejection is level of 2-tone interference above the reference sensitivity that results in 3 dB degradation of reference sensitivity**

From WINNF Receiver Performance WG working materials

Blockage Rejection



- **Blockage Rejection is level of 1-tone interference above reference sensitivity that results in 3 dB degradation of reference sensitivity**

From WINNF Receiver Performance WG working materials

Concerns about the example

- **Likely resisted because it is a specification**
- **Focused on the design and testing of receivers and not about arbitrating and managing interference**
  - How does location, propagation, antennas, etc. play
  - Other intermodulation effects
  - How is the interaction with special signals handled
    - Broadband vs narrowband
    - Frequency hopping
    - Pulsing

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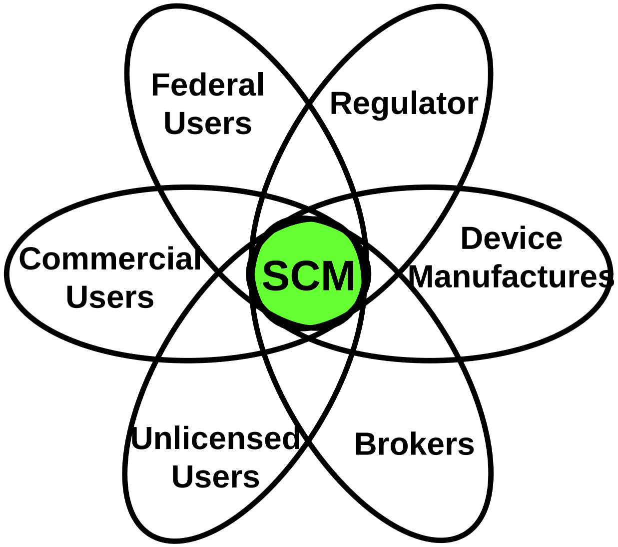
Motivation for Model-Based Spectrum Management

- **Dynamically sharing spectrum requires defining the boundaries of spectrum use**
- **Defining boundaries of spectrum use requires**
  - Defining how systems emit EM radiation
  - Defining what is interference to a system
  - Defining how these qualities of systems are different in time and space
  - Identifying behaviors that allow sharing
- **All spectrum communities should use a common means to define spectrum use**



Resulted in our proposing Model-Based Spectrum Management and Spectrum Consumption Modeling

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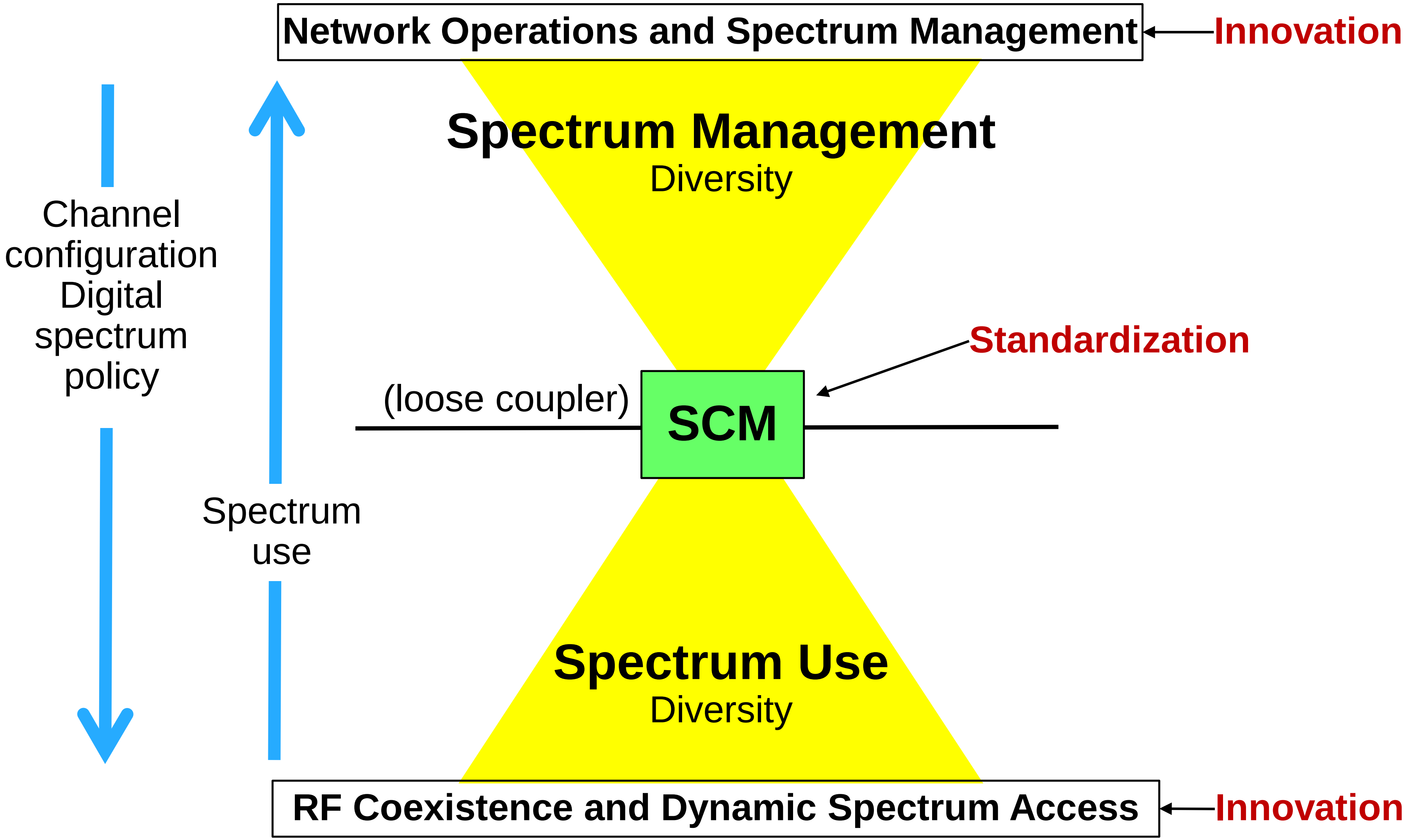
Spectrum Consumption Modeling as a Loose Coupler



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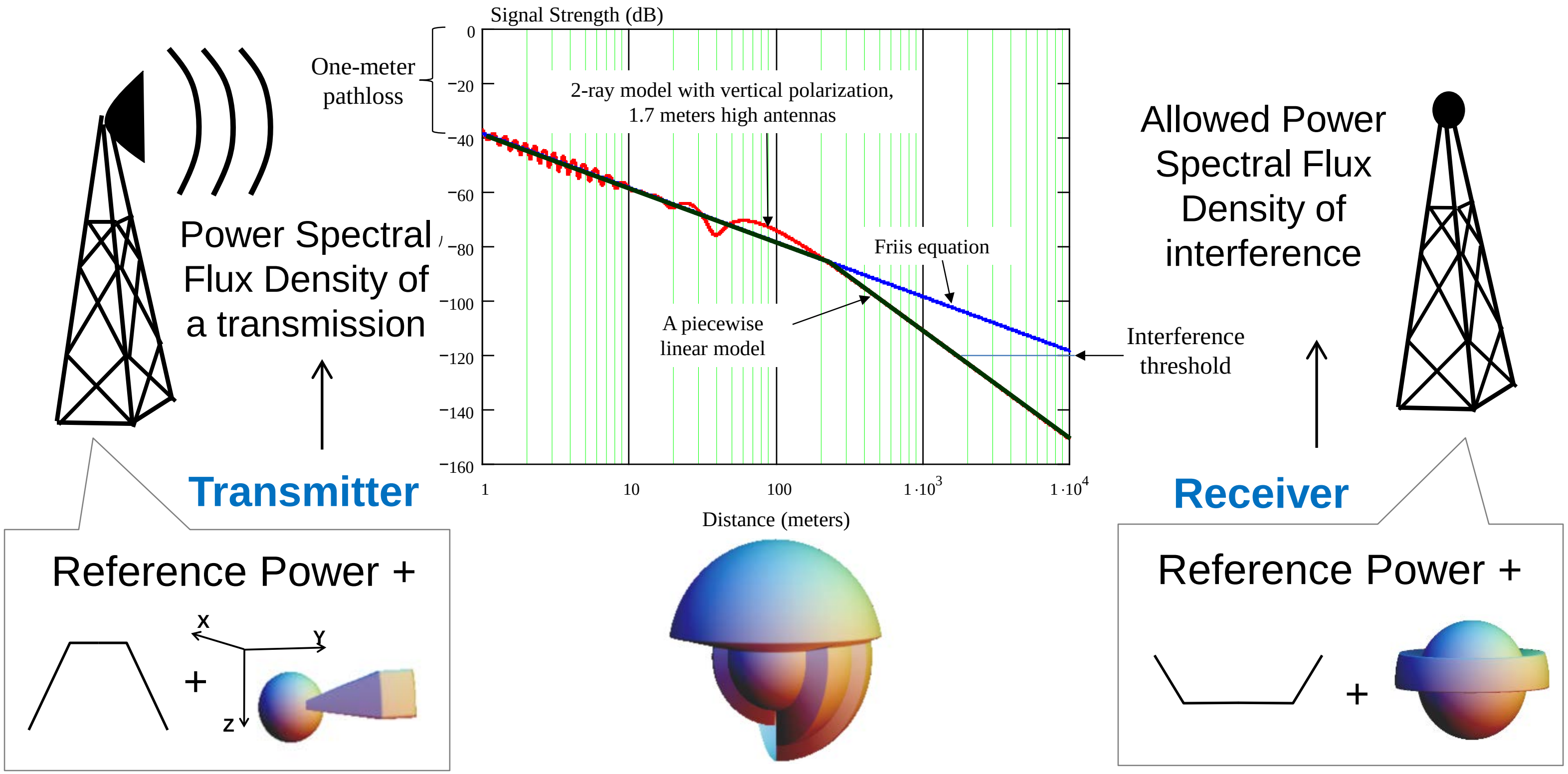
Using SCM to Determine Compatibility



- **Constructs are provided to capture the phenomenology of spectrum use**
- **The methods of modeling are complemented with methods to compute the compatibility of spectrum uses**

SCMs are built to protect not to predict!

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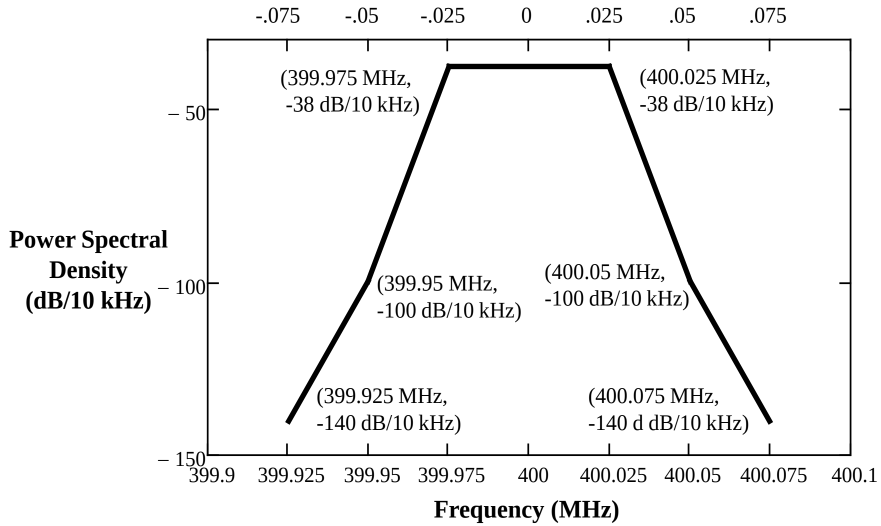
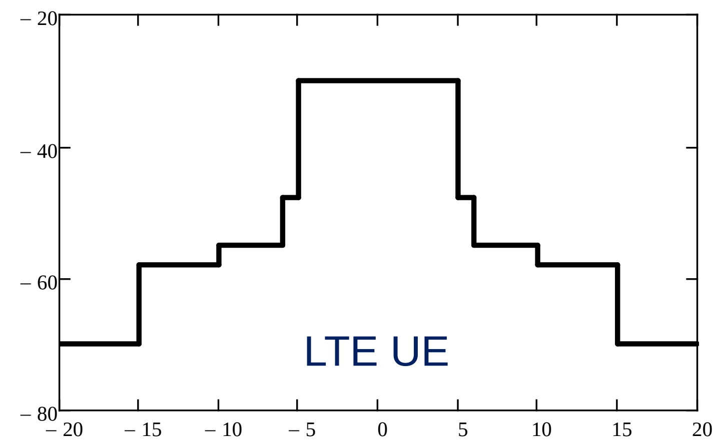
Spectrum Mask





A list of inflection points that form a mask. Each point consists of a frequency and relative power. A resolution bandwidth conveys the spectral density of the power terms, i.e. dB/BW.

Specifies the power-density spectrum of a signal

Spectrum Mask Versions

- **Continuous signal**
  - A single mask
  - Assume the transmission is on at any time
- **Hopped or pulsed signal**
  - A mask for the signal
  - A range of frequency over which it may occur
  - A dwell time
  - A revisit period
- **Example: A radar**
  - A mask for the signal
  - The center frequency of the signal
  - The dwell time = duration of a pulse
  - The revisit period = pulse rate

$$Duty\ Cycle = \frac{Dwell\ Time}{Revisit\ Period}$$

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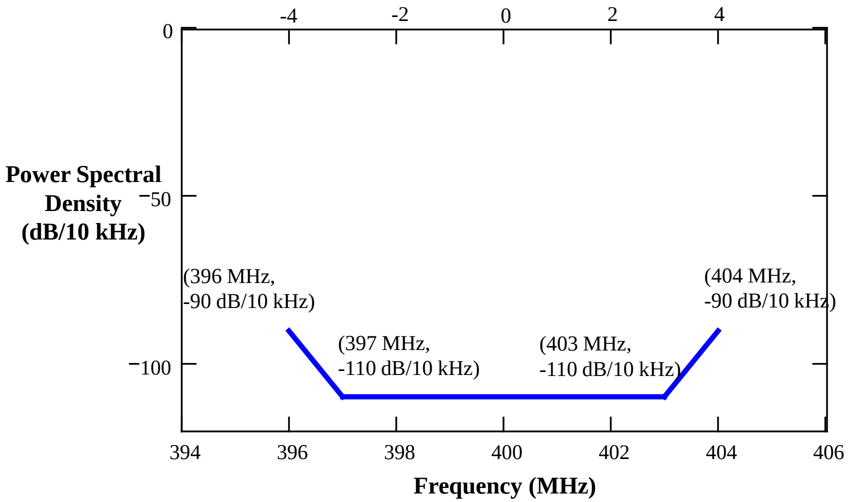
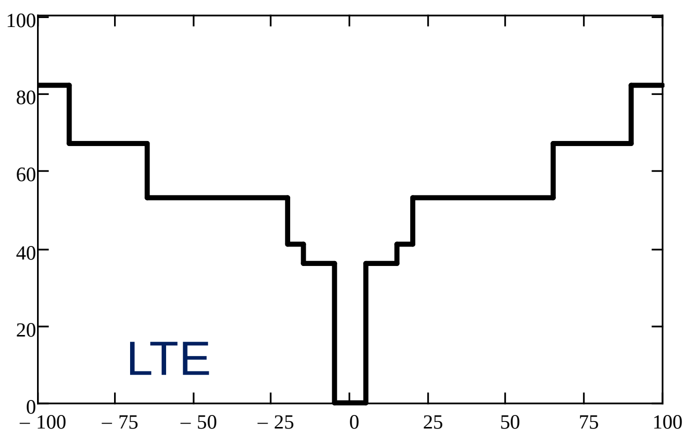
Underlay Mask



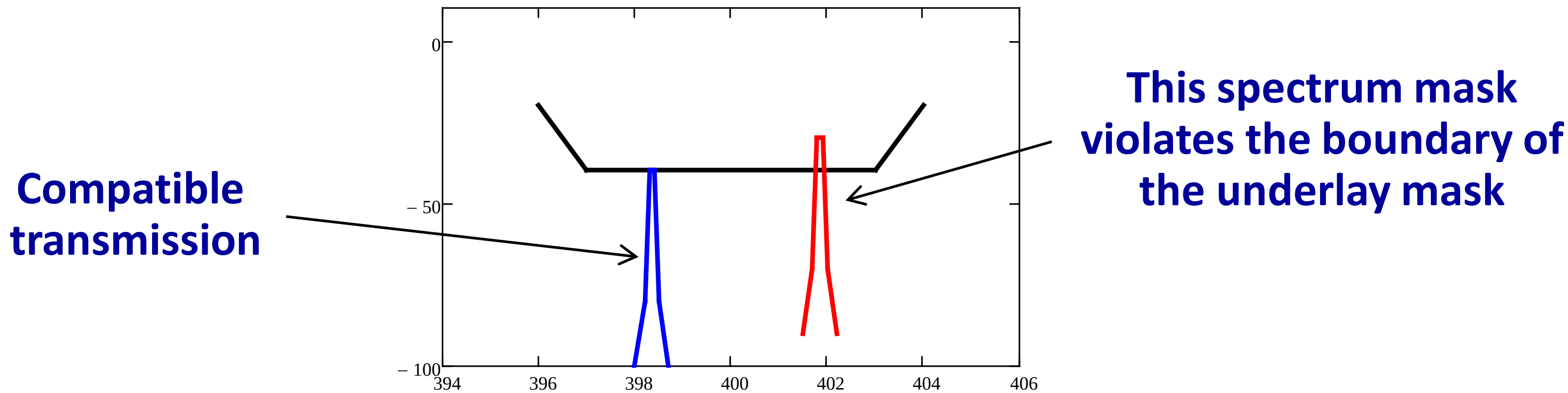


A list of inflection points that form a mask. Each point consists of a frequency and relative power. A resolution bandwidth conveys the spectral density of the power terms.

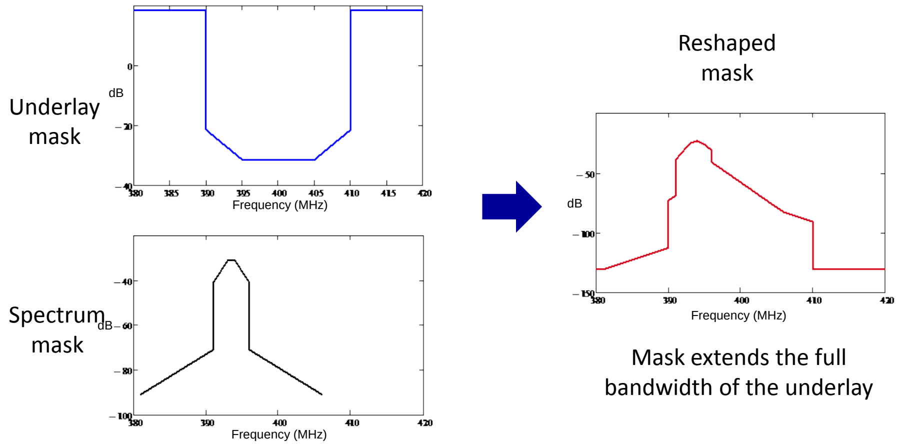
Specifies limit to the allowed interference by frequency

Two Methods of Mask Interaction

- **Maximum power density method (graphical)**



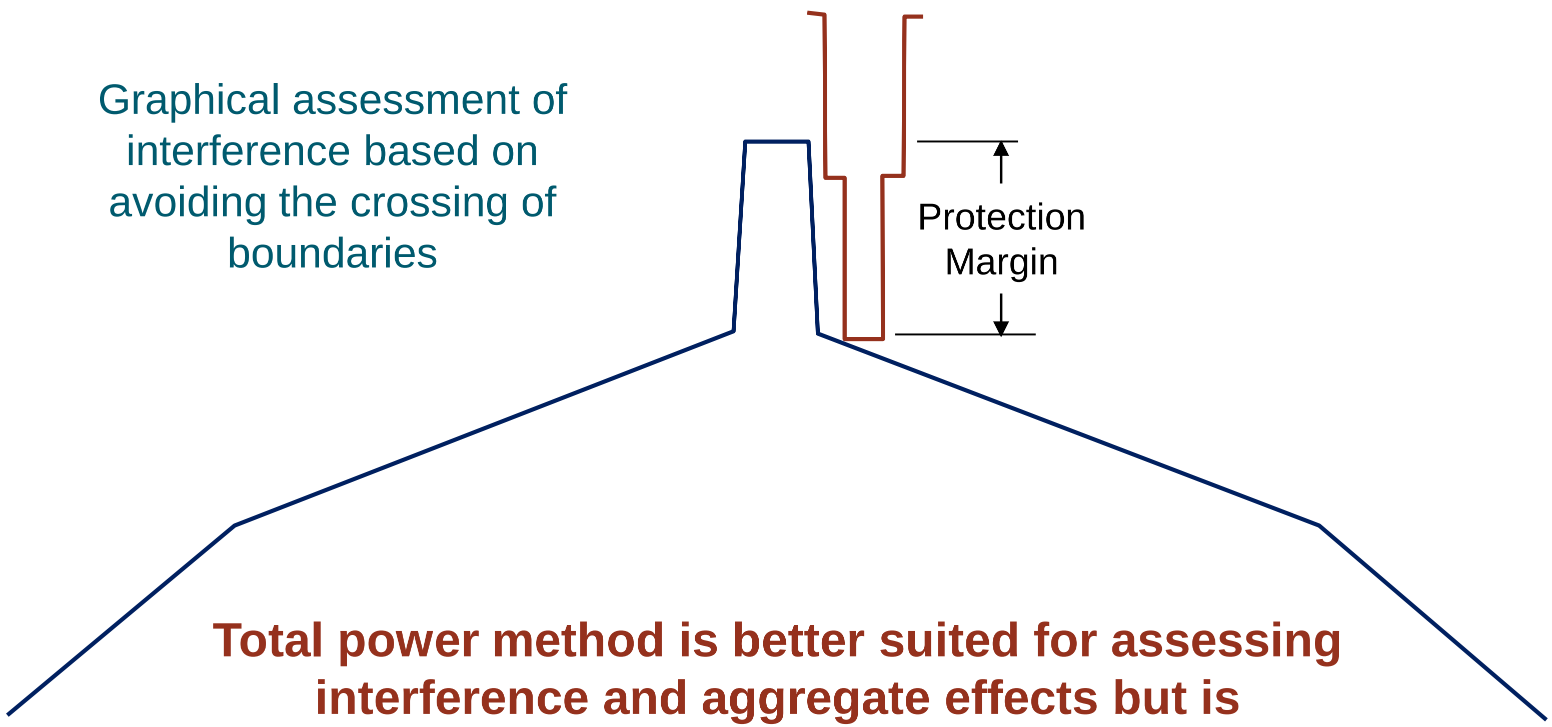
- **Total power method**
  - Underlay masks defines a filter which operates on the spectrum masks to determine the total energy that enters a receiver
  - Compatible if below a threshold



Limitation of Maximum Power Density Computation

- **Anticipates aggregate interference and simplifies admission of new uses**
- **Underestimates Frequency Dependent Rejection (FDR)**

Graphical assessment of interference based on avoiding the crossing of boundaries



Total power method is better suited for assessing interference and aggregate effects but is computationally more demanding

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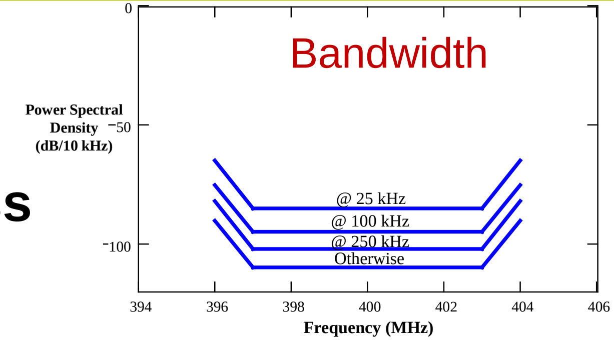
Underlay Mask Variants

- Variants of the underlay mask allow identifying differences in robustness to interference based on bandwidth, frequency hopping, and duty cycle of interfering signals
- In compatibility computations the spectrum masks are mapped to the least restrictive underlay mask for which they meet the criteria of use



Multiple Mask Structure

(396, −65, 397, −85, 403, −85, 404, −65) @ 25 kHz

(396, −75, 397, −95, 403, −95, 404, −75) @ 100 kHz

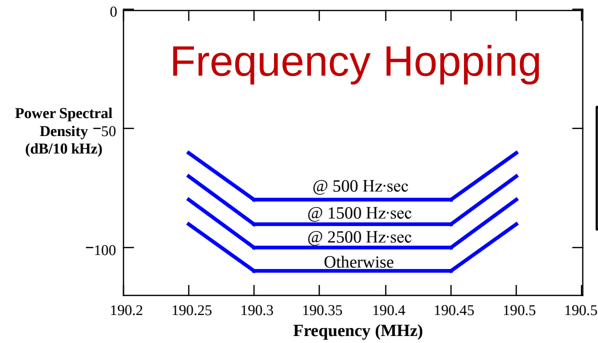
(396, −82, 397, −102, 403, −102, 404, −82) @ 250 kHz

(396, −90, 397, −110, 403, −100, 404, −90)

Single Mask with Offset Data Structure

(396, −90, 397, −110, 403, −100, 404, −90)

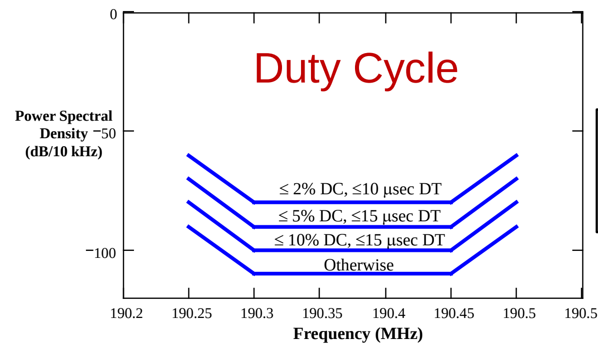
(25, 25, 100, 15, 250, 8)



Data Structure with Bandwidth-Time Product Ratings

(190.25, −90, 190.3, −110, 190.45, −100, 190.5, −90)

(500, 30, 1500, 20, 2500, 10)

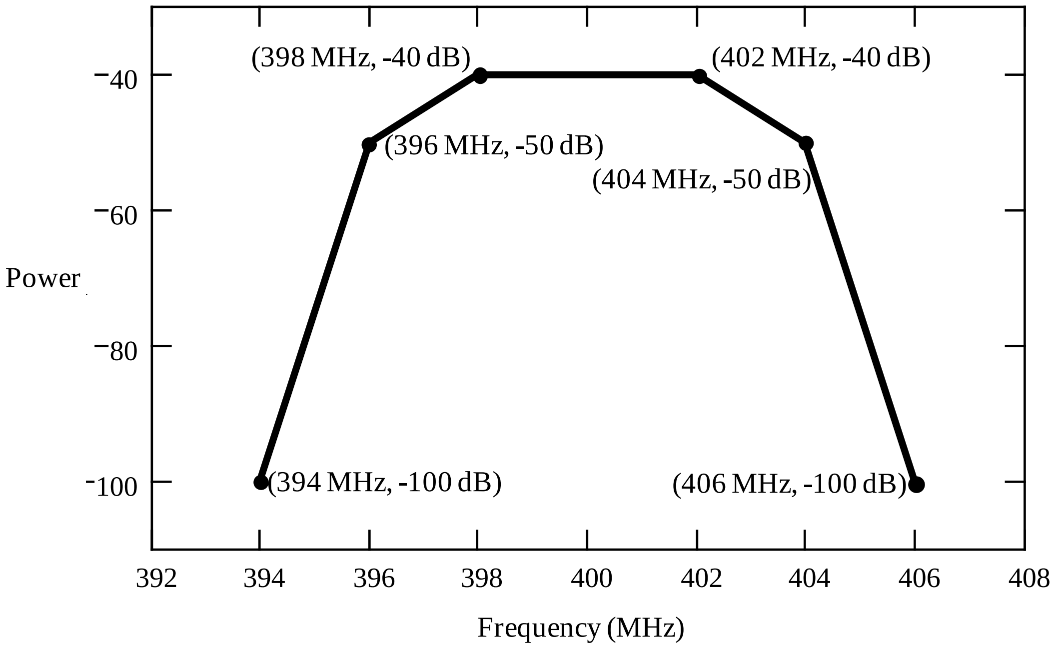


Data Structure with Duty Cycle Ratings

(190.25, −90, 190.3, −110, 190.45, −100, 190.5, −90)

(0.02, 10 μsec, 30, 0.05, 15 μsec, 20, 0.1, 15 μsec, 10)

Intermodulation (IM) Mask



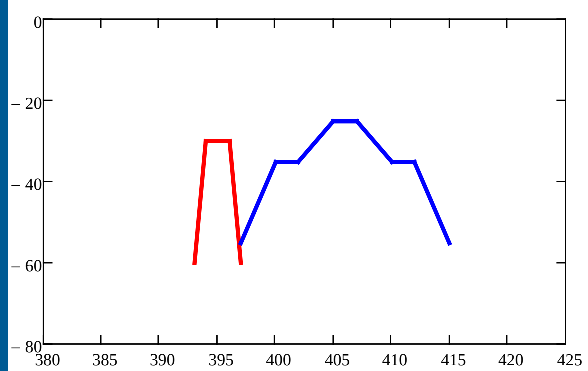
A list of inflection points, frequency and relative power, that form a filter mask

Specifies how signals amplitudes are combined for a particular order of IM distortion

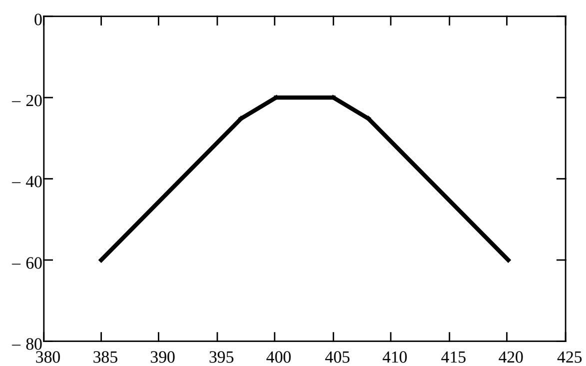
May be associated with a receiver or a transmitter

Using an IM Combining (IMC) Mask

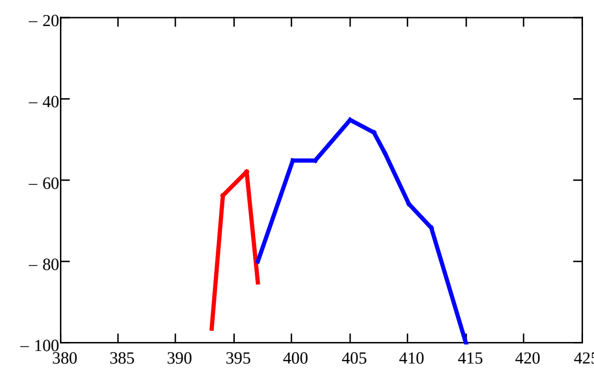
- **The IMC mask specifies how signals that are inputs are shaped and amplified before combining by the characteristics of the device**
  - The portion of the input mask that falls within the bandwidth of the IMC mask is scaled by the power level of the IMC mask



Input signals



IMC Mask



Scaled outputs

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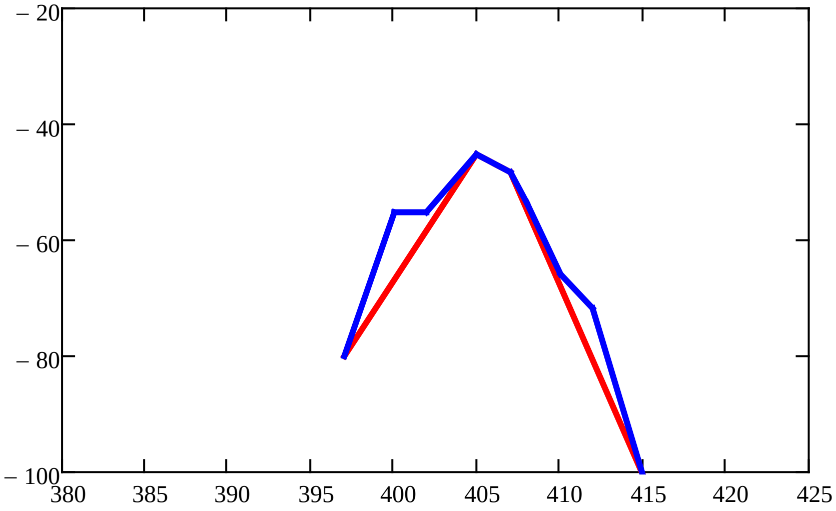
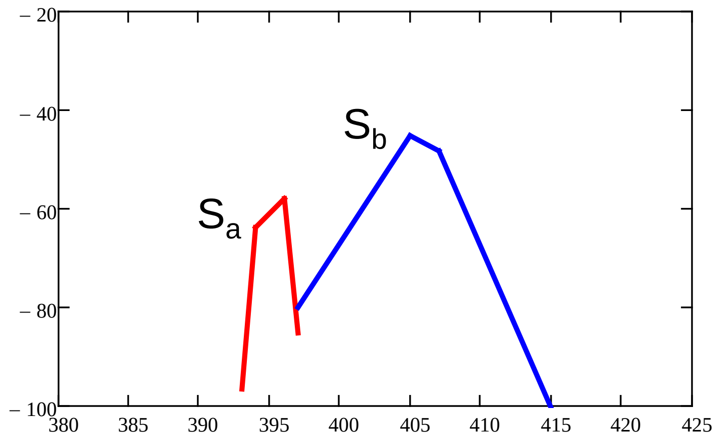
Using an IMC Mask - 2

- **The shaped signals are reduced to four points prior to combining them, the end points to maintain bandwidth and the two highest power points to capture amplitude**

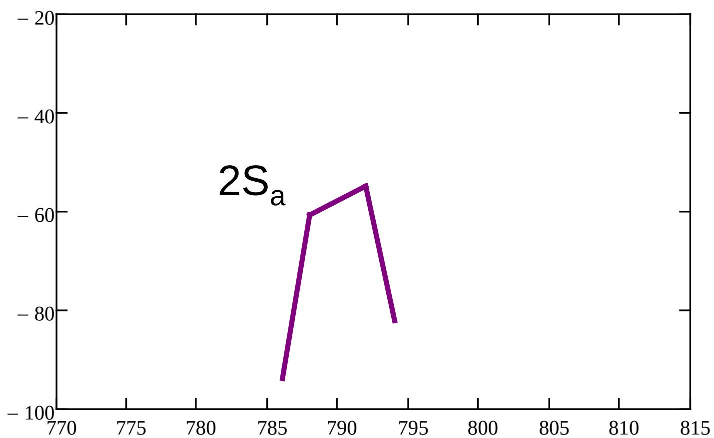


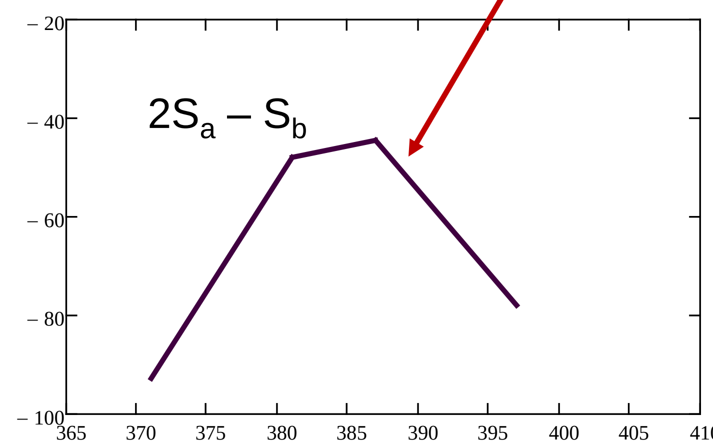
Using IMC Mask - 3

- **Consider the intermodulation product ($2S_a – S_b$)**



Use this mask of the product with the underlay mask to determine interference





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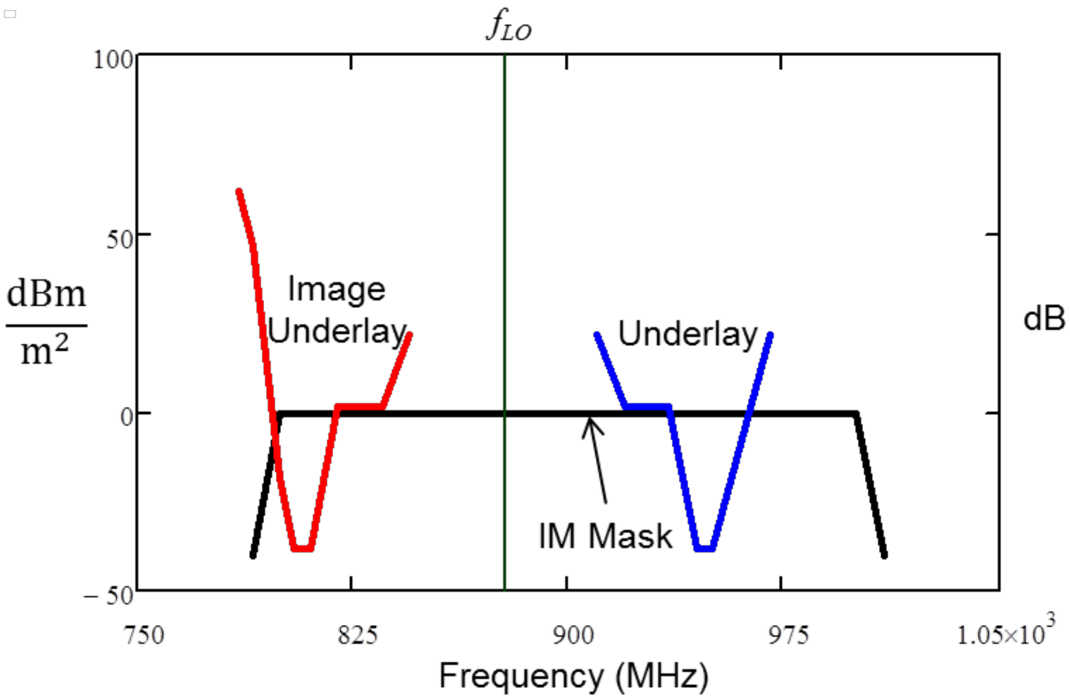
IM Masks and Image Frequencies

- The IM Mask construct is also used to convey susceptibility to image frequencies
- Preferred analysis finds the image underlay mask

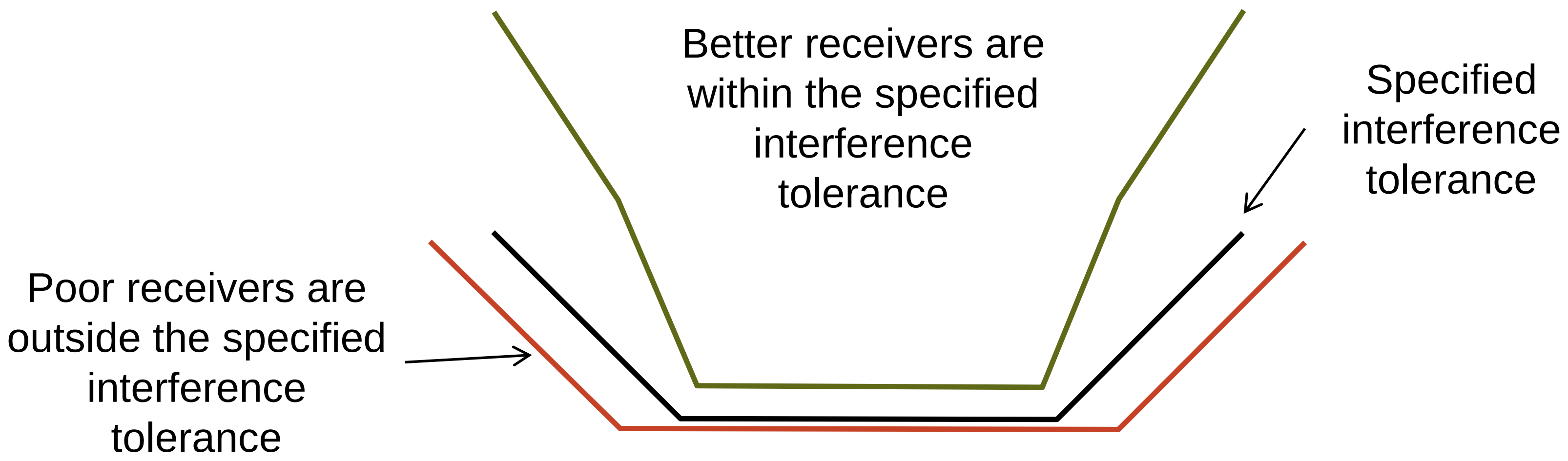


The image underlay mask is a reflection of the underlay mask about the local oscillator frequency further shaped by the IM mask

Use it as any other mask to determine interference

Conclusions

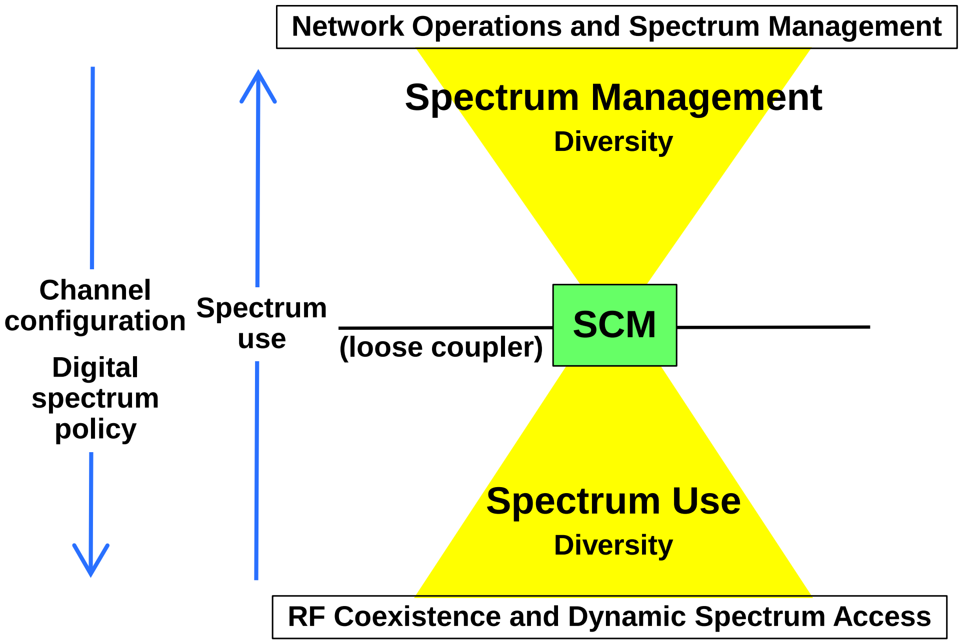
- **Receiver performance factors can be captured using SCM**
- **SCM provide the additional features of**
  - Capturing all factors (location, time, antenna gain, propagation, and behaviors) that affect spectrum use
  - Methods for arbitrating compatibility
- **Underlay masks can be used to indicate the quality of receivers**



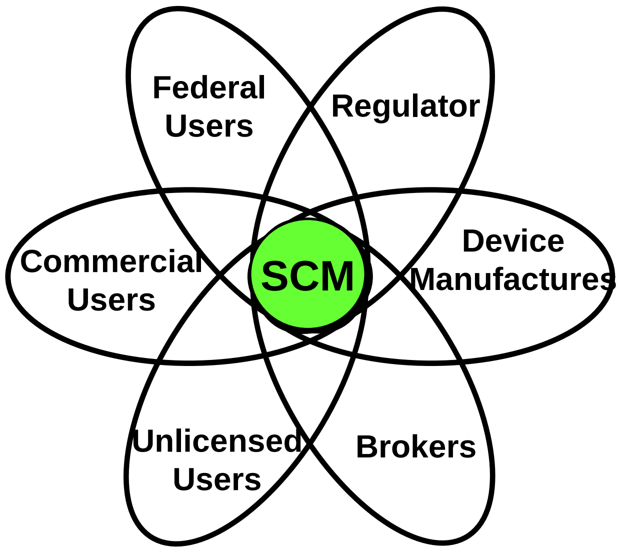
A Central Role for Models

- **SCM capture the minimum common set of data on spectrum use that is shared among machines, systems, processes, and organizations**

A loose coupler for spectrum management systems that provides a machine readable means to communicate spectrum use and DSA policy



A common means for the communities of the spectrum management enterprise to communicate spectrum use and collaborate in spectrum sharing



Opportunities to Learn More

- **IEEE DySPAN Standards Committee Working Group 1900.5 is standardizing the Methods to Model Spectrum Consumption**
  - Meeting this week on Wednesday (10:35 – 17:00) and Thursday (9:00 – 12:00) to develop the standard
  - We will be discussing these very constructs of modeling
- **WINNF Receiver Guidelines Group**
  - Meets 1400 Thursday afternoon
  - Discussing relevance and role of SCM constructs for the role of specifying receiver performance guidelines

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