Methodologies & Results for Broadband Spectrum Surveys

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Background

- **Mid-1970s:** U.S. Dept. of Commerce decides to develop broadband, computer-controlled radio measurement systems
  - **Question:** Use capability for enforcement … or use capability as a research tool to improve Federal spectrum management?
  - **Answer:** From the very beginning, technical emphasis on computer-controlled measurements with well-designed RF front ends
- First Radio Spectrum Measurement System of the modern era built into a Travco motor home by HP (RSMS-1 and RSMS-2)
- Subsequent RSMS versions built on pickup truck body (RSMS-3), custom-built truck (RSMS-4), and various suitcase configurations

1927 Radio Car

This early system incorporated many features still needed today

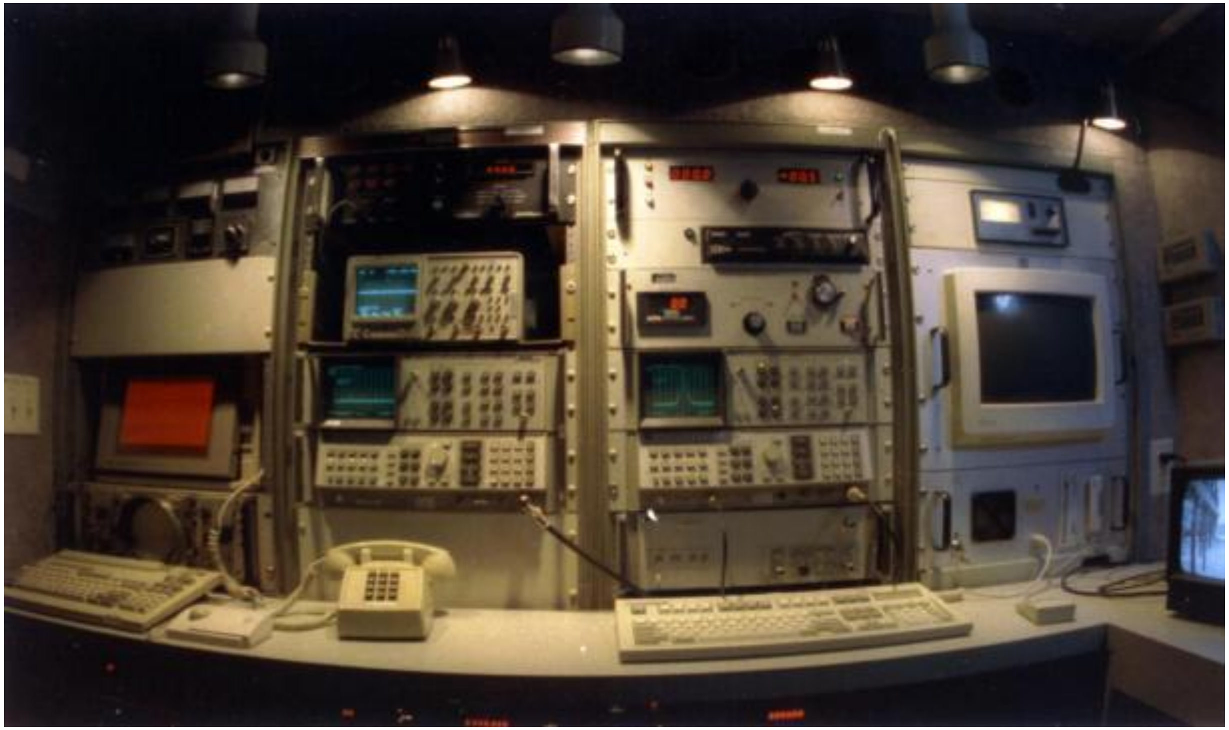
RSMS-1 and 2: 1974–1990

- ARS-400: 1st computer-controlled spectrum measurement system

- Custom-built hardware
- 8566A/B based on this design

RSMS-3: 1990 – present

Took advantage of more compact hardware but retained measurement features of 1 and 2



RSMS-4: 2002 – present

Continues to use specialized hardware and software to perform NTIA's spectrum management mission, including broadband spectrum surveys, interference analysis, and EMC studies

RSMS Suitcase Systems

- Shrinking hardware and computers →NTIA development of a wide variety of suitcase systems for surveys on rooftops, in deserts, and in small vehicles

Spectrum Survey Purposes

- Establish spectrum usage patterns — maximum / minimum / average
- Resolve ongoing RF interference problems at specific localities
- Identify unauthorized usage (now a rare event in the U.S.)
- Provide information for spectrum and new spectrum systems planners, via NTIA Technical Reports
  - Broadband survey results published for Denver, San Francisco, Los Angeles, and San Diego
  - Land mobile radio (LMR) and general survey results been published for Atlanta Olympics, Denver, and Washington, DC

Site Requirements for Spectrum Surveys

- Outdoor:
  - A good radio horizon — usually a site at the top of a high hill or mountain
  - Suitcase systems may be located on rooftops
  - Commercial power
  - No (or minimal) strong transmitted signals in the immediate vicinity to ameliorate RF front-end overload problems
  - Reasonably good security
- Indoor:
  - Commercial power

Indoor vs. Outdoor Surveys

Outdoor

- Shows patterns already known from allocation tables
- ISM band occupancy patterns are strongly dependent on exact location of the measurement system (e.g., San Francisco survey)
- Aside from ISM bands, one survey in a metro area probably shows representative patterns for entire area

Indoor

- Should show less of formal allocation patterns due to unlicensed and unintentional emissions indoors
- Important to understand environment for short-range wireless systems

Number of Locations Needed for Outdoor Surveys

- Based on past results, crowding might be a significant problem in only about 15 major U.S. metropolitan areas
- Uniform nation-wide allocations → usage patterns in cities tend to replicate from one to the next → fewer than 15 cities probably need to actually be measured
- 1 outdoor survey / city probably enough to characterize crowding in each metro area, barring very local variability in ISM patterns
- Highest usage and most crowding historically shown around coastal cities: Seattle, San Francisco, Los Angeles, San Diego, Boston, New York, Washington (DC), Philadelphia, Jacksonville

Number of Locations Needed for Indoor Surveys

- Geographic location or region not anticipated to be a significant factor for indoor spectrum behavior
- Indoor environments are what count for indoor surveys
- Distinguishable environments of interest probably fewer than 10, include:
  - High-rise office buildings
  - Low-rise office buildings
  - Warehouses
  - Light industrial areas
  - Office parks
  - Apartment buildings
  - Urban/suburban residential
- Number of surveys required to obtain representative data for each environment: still to be determined

Spectrum Measurement Survey Design Basics

- Spectrum surveys only show what they are designed to show
- What a measurement survey ***does not*** show can be more important than what it ***does*** show
- Survey design must take into account the characteristics of the signals that are intended to be observed
  - Usually these are the signals for which each band is allocated
  - Critical to match measurement parameters to signals to be observed, especially bandwidth and detection
- **Use the wrong bandwidth, detection technique or measurement algorithm and a band that's full of activity can be made to look "empty" or "fallow"**

Matching of Measurement Parameters to Signal Types

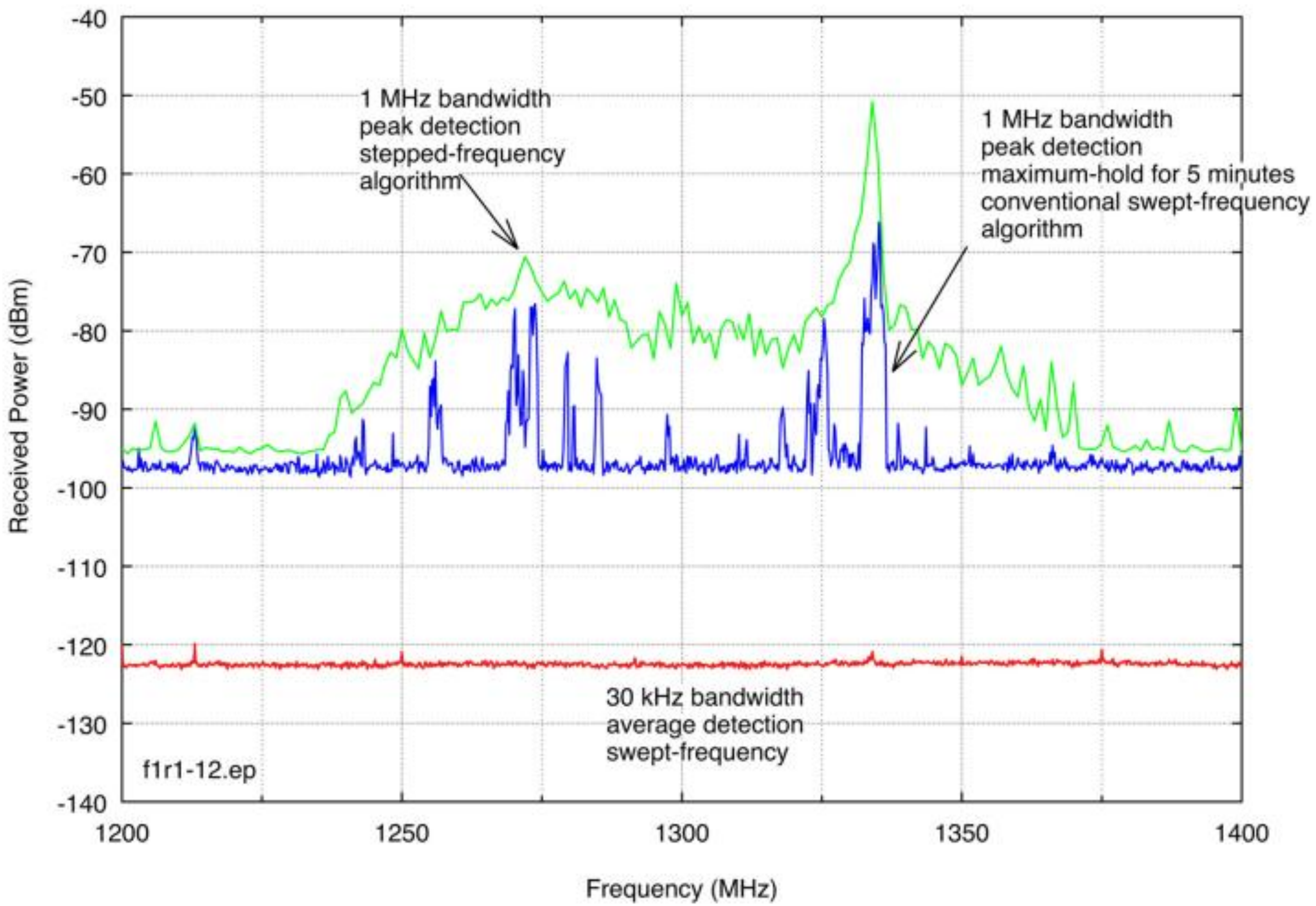
Signal Type	*Bandwidth*	*Detection*
LMR	about 10 kHz	Average with selection of median from multiple samples
Digital	about 1 MHz	Peak
Radar	100 kHz to 20 MHz, depending on radar	Peak
Noise	As wide as possible	Sample, to gather noise statistics

- If a band contains multiple signal types, a survey may need to run through the band multiple times, with different sets of measurement parameters on each run
- Apparent band activity varies dramatically as measurement parameters vary

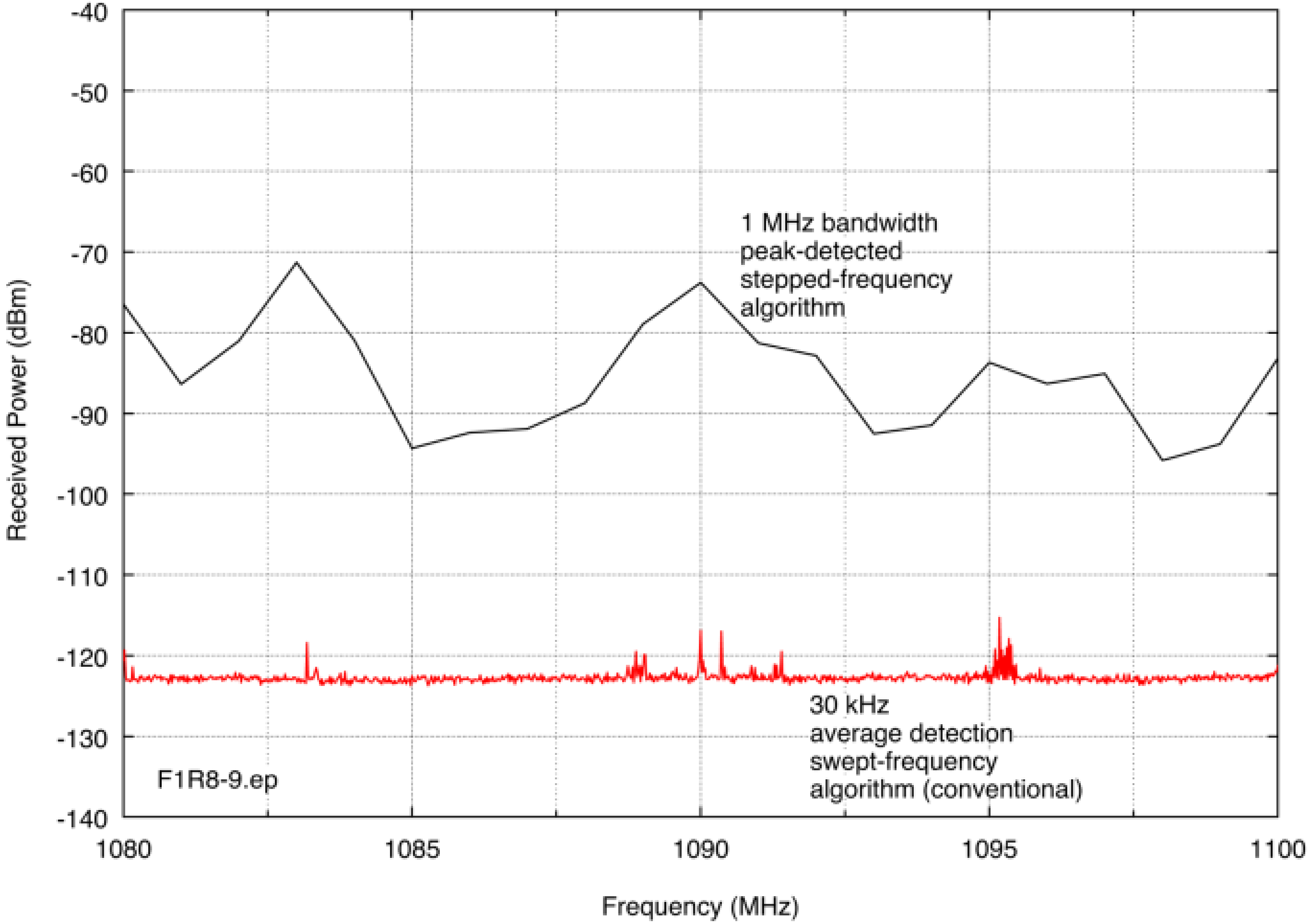
Matching Measurement Algorithms to Signal Types

- Algorithms used to examine each band are just as important as measurement parameters
- The most conventional algorithm:
  - Rooted in the original hardware design of swept-LO analog spectrum analyzers
  - Sweeps frequencies across each measurement band
  - Successive sweeps are either recorded in clear-write modes or in maximum-hold modes.
  - Max-hold mode is not the same as peak detection!
- Even modern vector signal analyzers behave as if they are frequency-sweeping — but really doing FFTs on fast time-domain samples
- Some signals will not show up this way
  - Example: to see radar signals, need to step from one measured frequency to the next, dwelling for many seconds at each frequency and recording and storing the single highest power that occurs during each frequency step otherwise, radar bands will be mis-measured and look empty

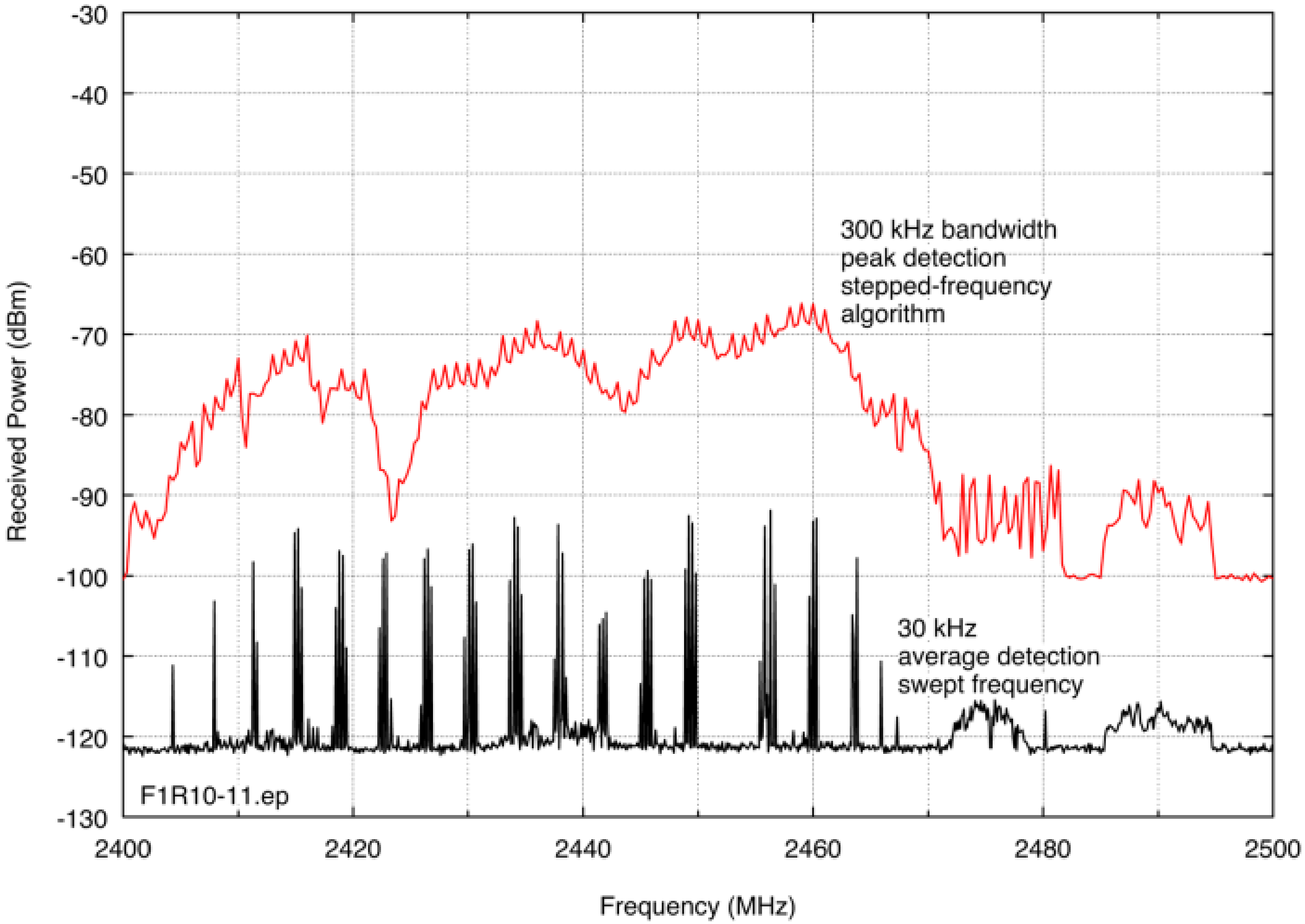
Different Ways to See a Radar Band (Right vs. Wrong?)



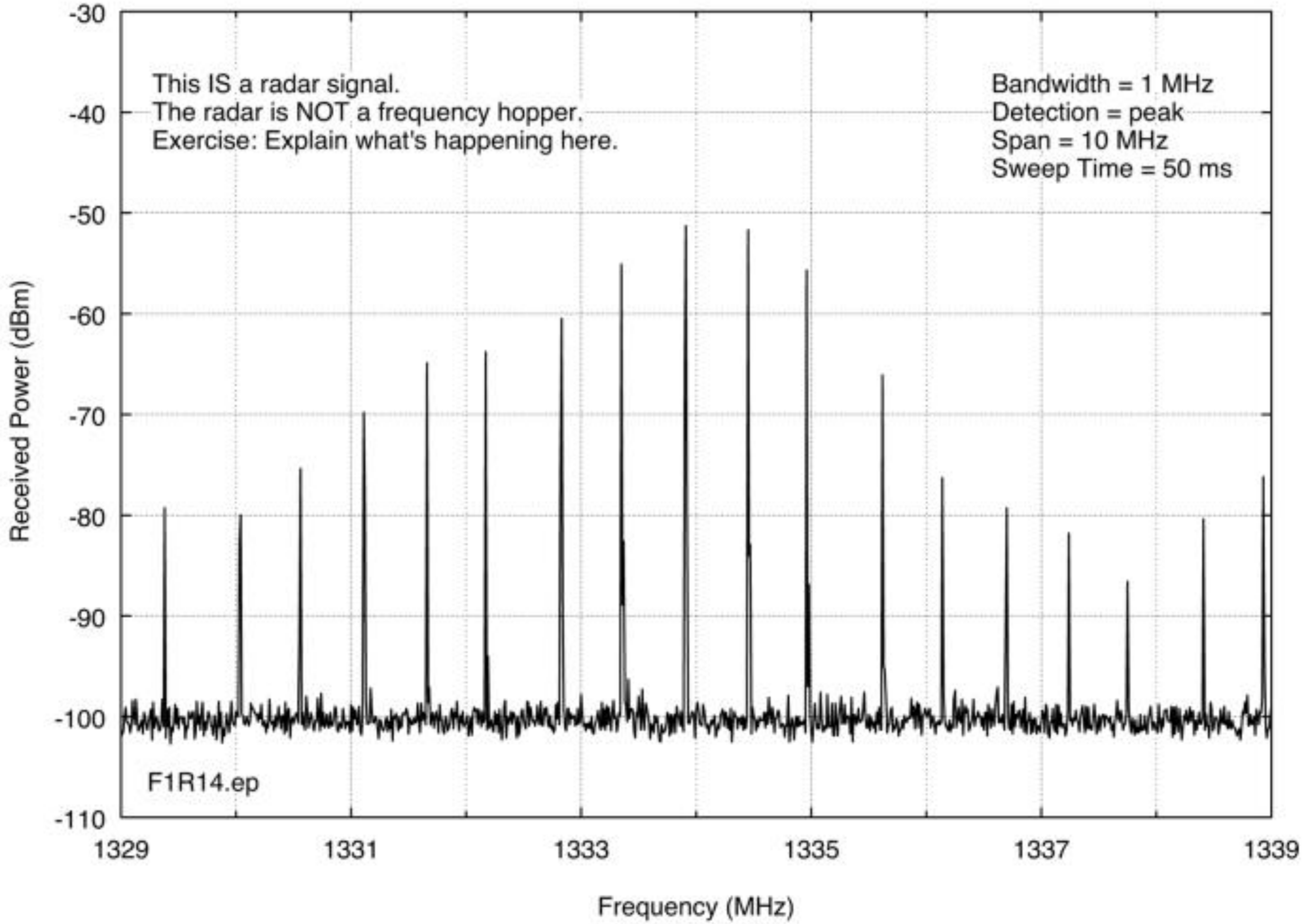
Different Ways to See Air Traffic Control Beacon Signals



Different Ways to See an ISM Band



Example of a Misleading "Spectrum" Picture

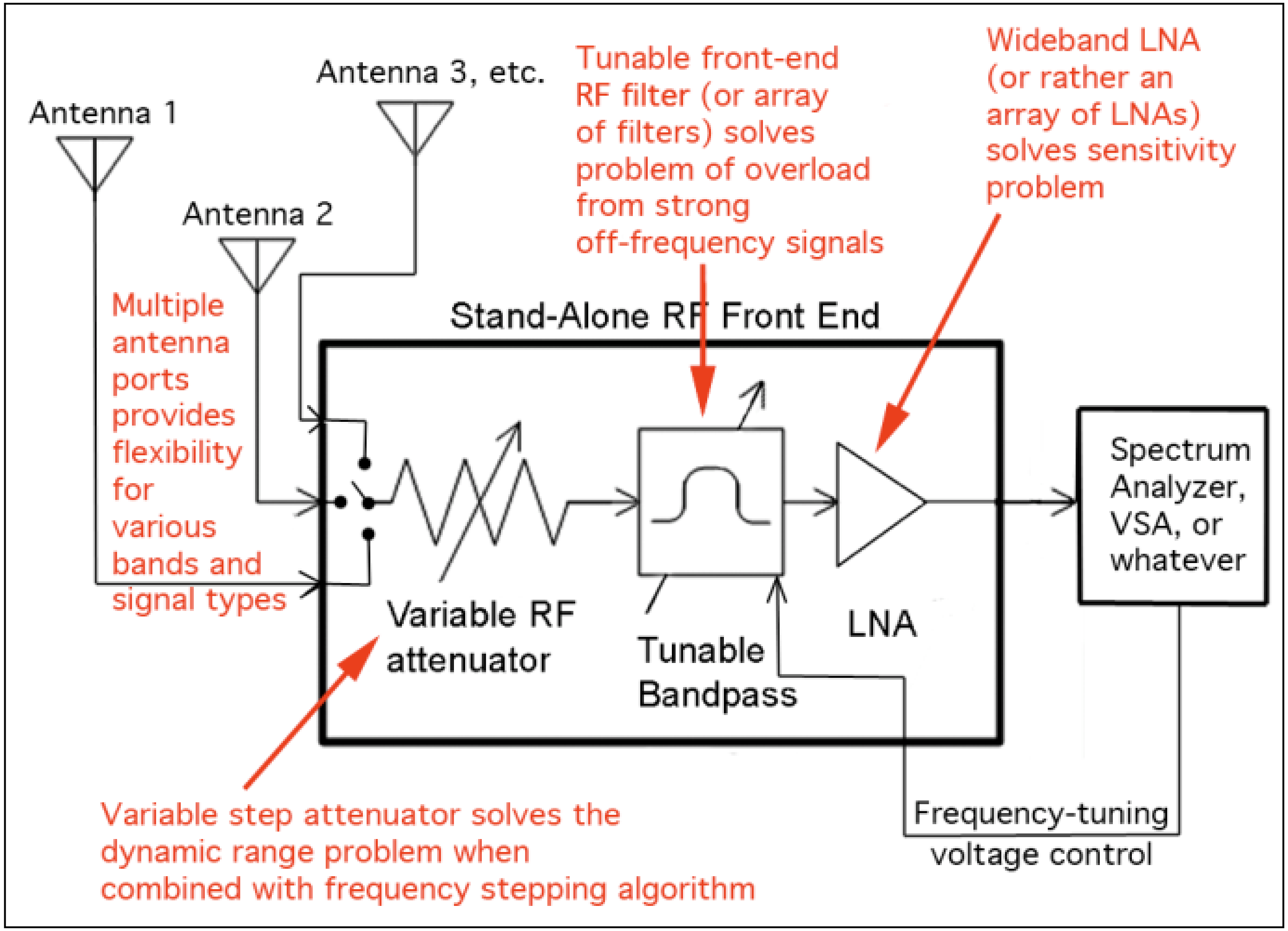


Hardware Requirements: Off-the-Shelf Analyzers?

- Inherent limitations of off-the-shelf analog spectrum analyzers, digital spectrum analyzers, real-time spectrum analyzers, vector signal analyzers, etc. used for spectrum survey measurements:
  - Poor sensitivity (high noise figures);
  - Limited dynamic range (usually about 60-70 dB);
  - Little or no front-end RF filtering to reject strong off-frequency signals.
- Most off-the-shelf analyzers have modes that can overcome some of these problems some of the time — we have yet to find one that solves all of these problems all of the time
  - Some have good, tunable RF front-end filtering — but only across limited frequency ranges (e.g., above 3 GHz)
  - Some have built-in low noise amplification for good sensitivity — but only across other frequencies (e.g., below 3 GHz)
  - None give more than ≈ 60 dB of instantaneous dynamic range — inadequate for measurements of many transmitters, including radars, where 100 dB to 120 dB may be required for interference assessment and EMC studies

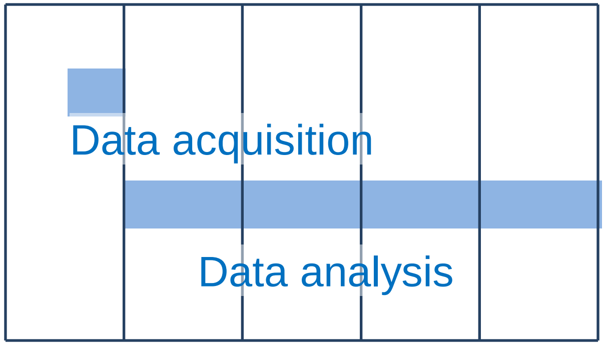
Hardware Requirements: Custom RF Front Ends are Necessary

Special RF front-ends between the measurement antenna(s) and the analyzer overcome the limitations of off-the-shelf analyzers



Data Analysis Requirements

- Post-data-collection analysis of results for ultimate report preparation and perhaps on-line data dissemination — a factor that is consistently forgotten
- Substantive thought needs to go into data structures, analysis procedures and algorithms before a survey
  - It takes about 10 times longer to analyze recorded data than it does to acquire it
  - Data needs to be recorded so as to allow fast review of results and prep for analysis
  - Bad data records (inevitable!) must be quickly and easily identified and discarded

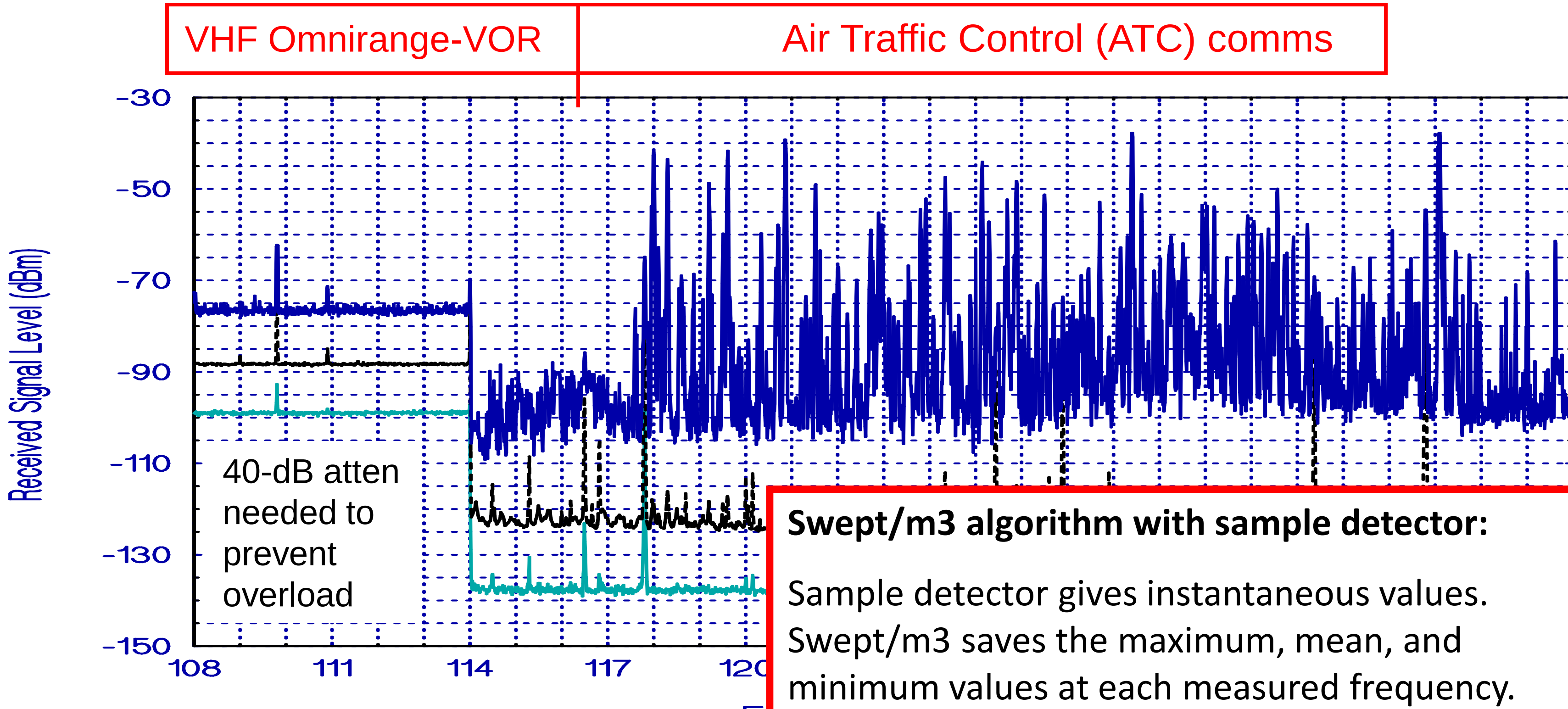


- Survey data doesn't benefit taxpayers if it's not published: analysis needs to lead to report publication and on-line data dissemination

Design Requirements for Spectrum Survey Measurements

- Any and all spectrum survey measurements are very costly in time, personnel, hardware and financial resources
- A badly-performed survey will cost about as much as a well-performed survey
- For proper and effective performance, before a survey marshal and verify:
  - hardware (commercial / custom-built)
  - band-specific algorithms
  - automated computer routines scripted for data acquisition
  - analysis software and algorithms
  - plan for report prep and on-line data dissemination

Example: 108-138 MHz Band

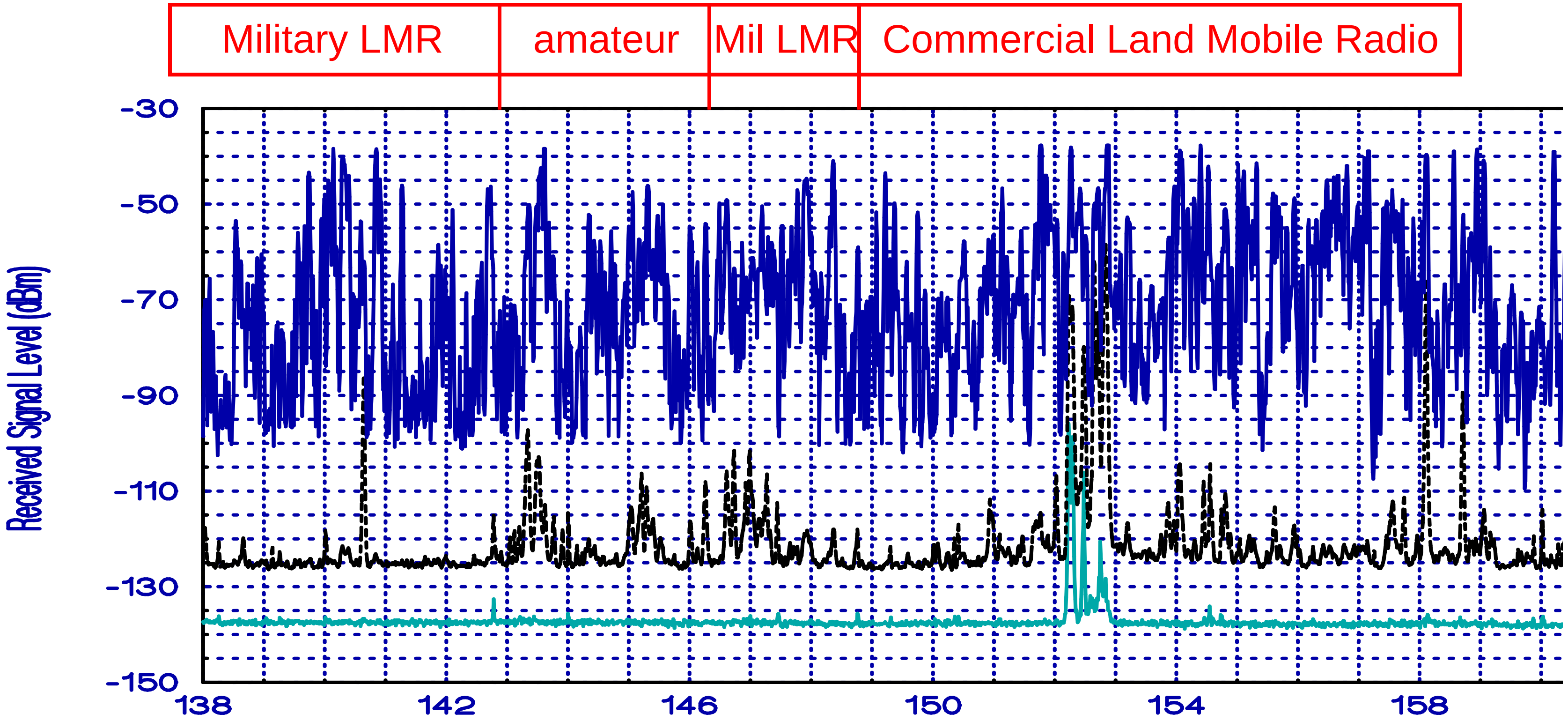


Swept/m3 algorithm with sample detector:

Sample detector gives instantaneous values. Swept/m3 saves the maximum, mean, and minimum values at each measured frequency.

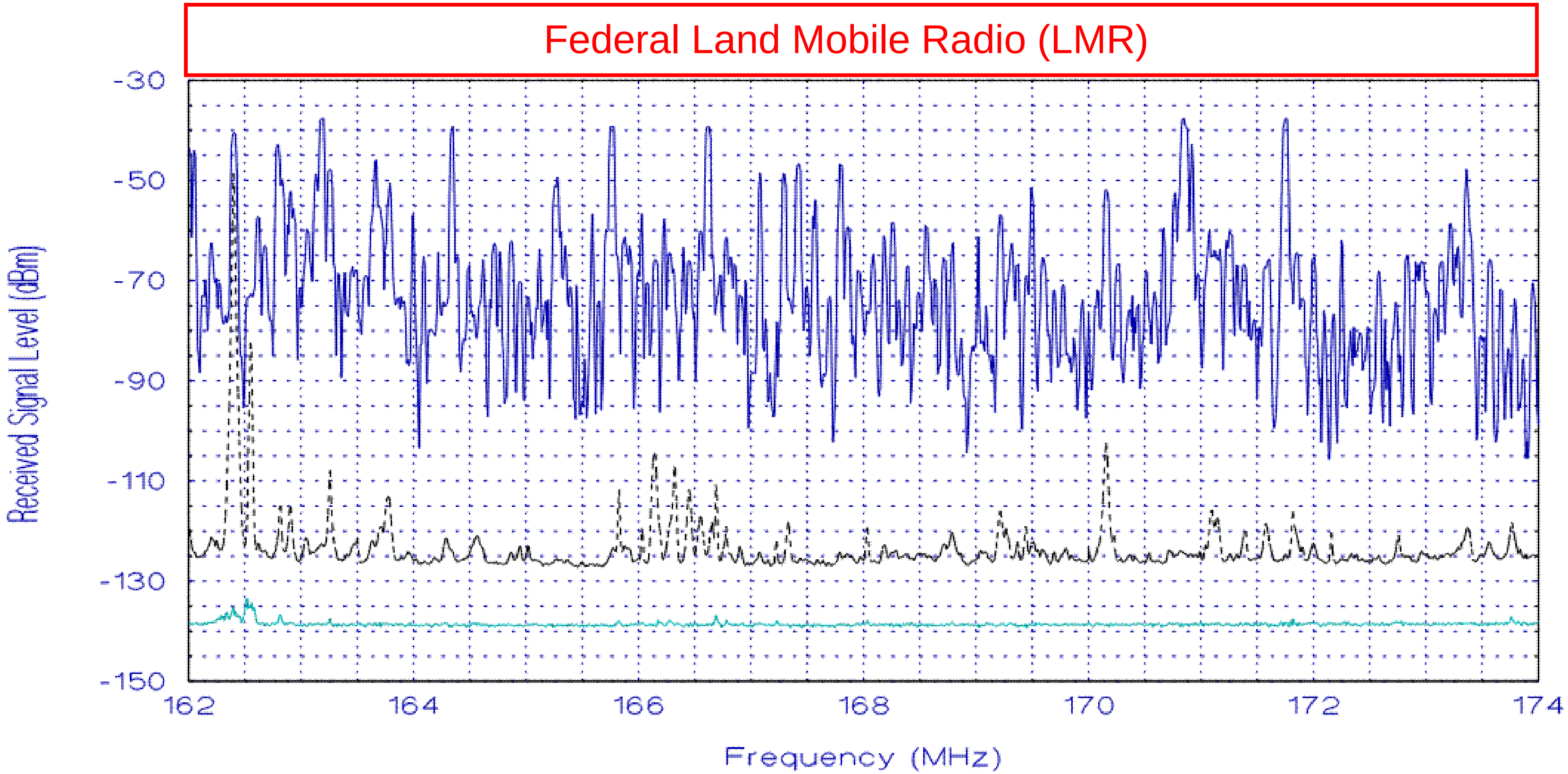
7,000 sweeps across the 108-138 MHz range at San Diego, CA, 1995
Band event 11, swept/m3 algorithm, sample detector, 10-kHz bandwidth

Example: 138-162 MHz Band



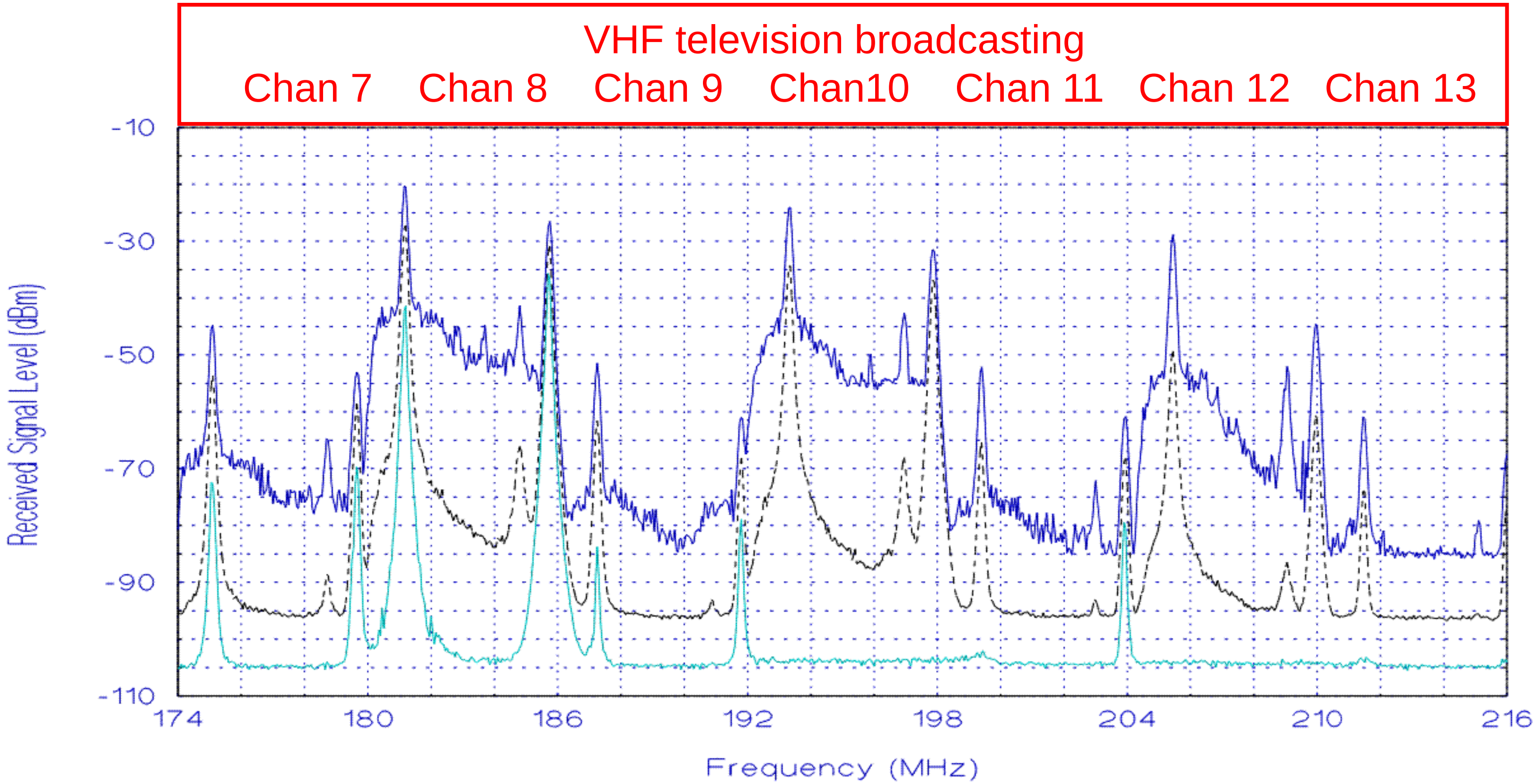
7,000 sweeps across the 138-162 MHz range at San Diego, CA, 1995
Band event 11, swept/m3, sample detector, 10-kHz bandwidth

Example: 162-174 MHz Band



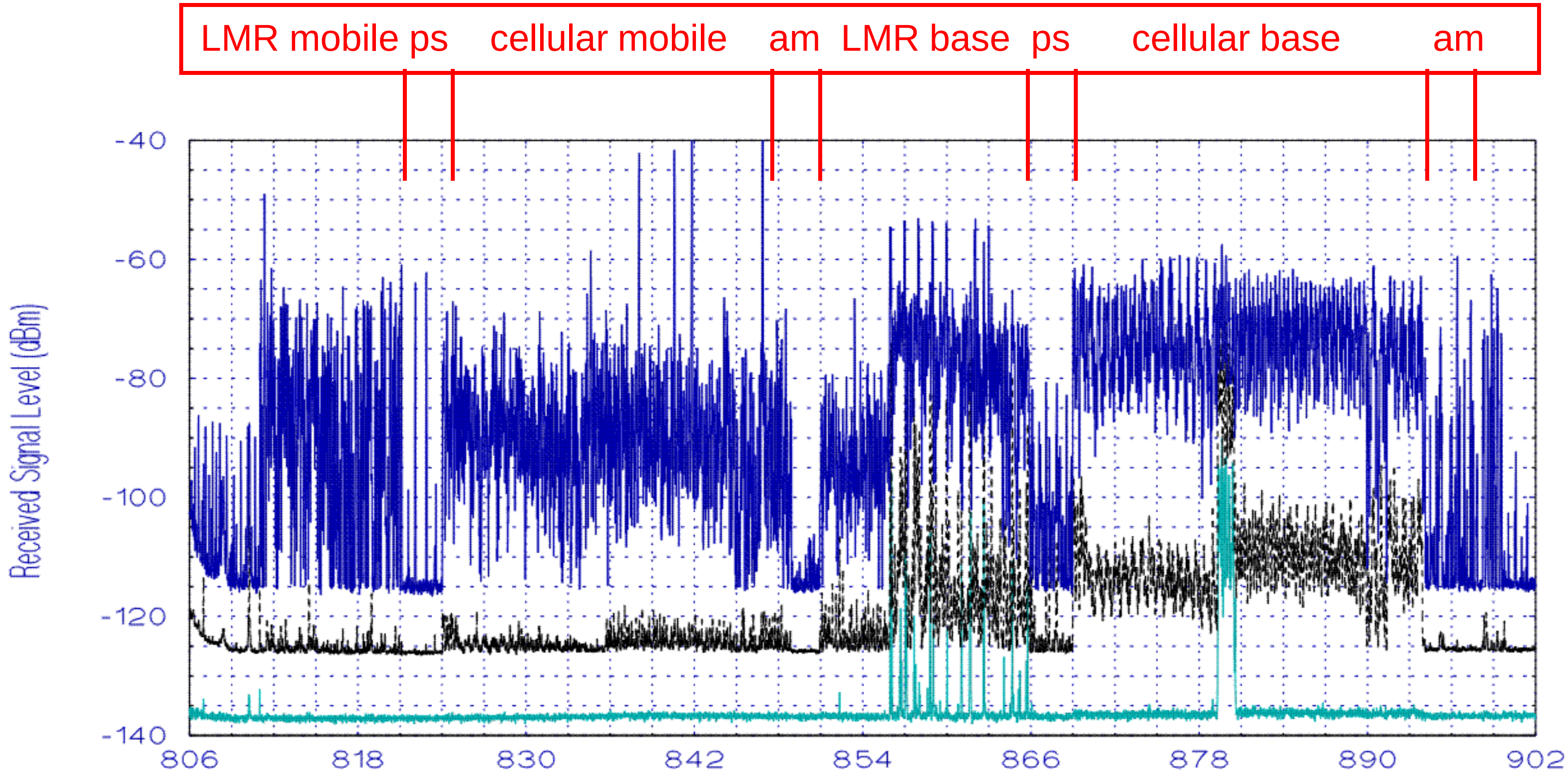
52,500 sweeps across the 162-174 MHz range at San Diego, CA, 1995
Band Event 12, swept/m3 algorithm, sample detector, 10-kHz bandwidth

Example: 174-216 MHz Band



18,500 sweeps across the 174-216 MHz range at San Diego, CA, 1995
Band event 13, swept/m3 algorithm, sample detector, 100-kHz bandwidth

Example: 806-902 MHz Band



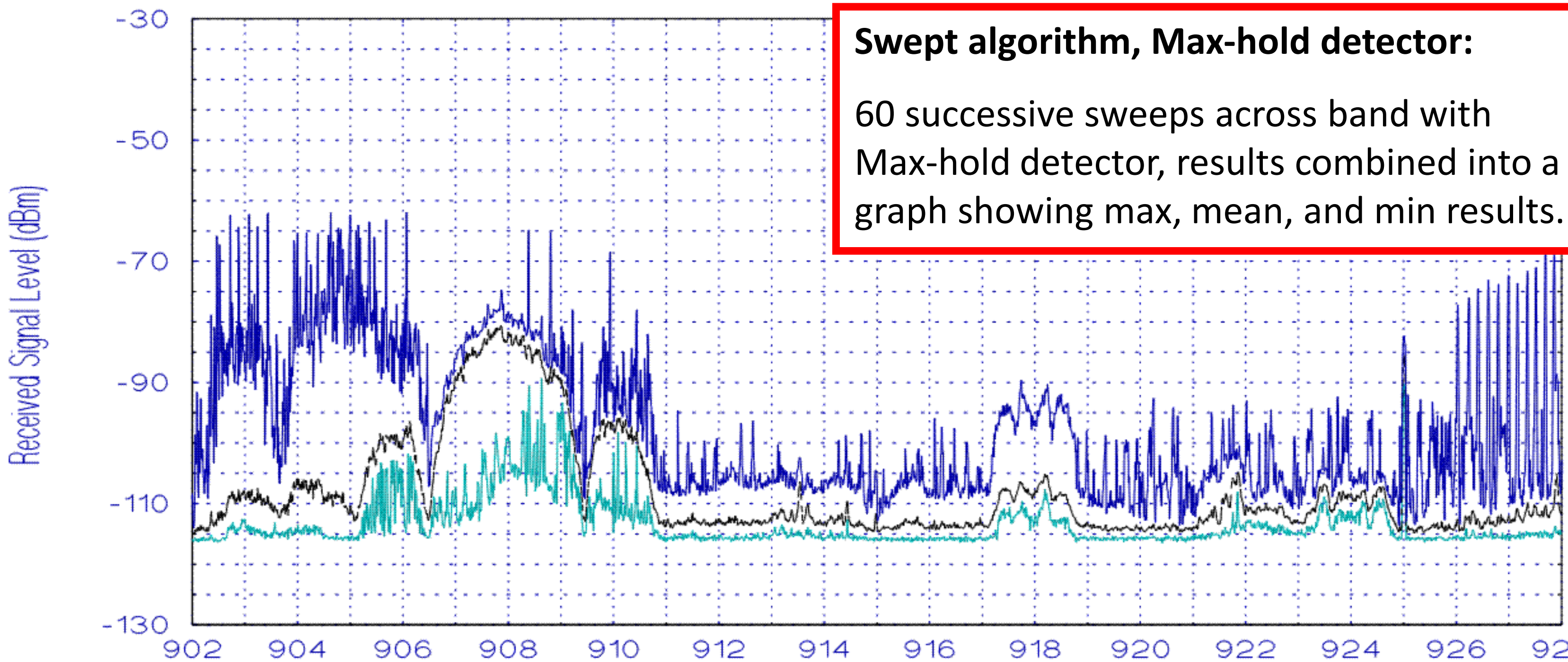
4,020 sweeps across the 806-902 MHz range at San Diego, CA, 1995
Band event 22, swept/m3 algorithm, sample detector, 10-kHz bandwidth

Example: 902-928 MHz Band (ISM and radar)

Military radars, ISM devices, automatic vehicle monitoring (AVM), spread spectrum devices, amateur, microwave ovens

Swept algorithm, Max-hold detector:

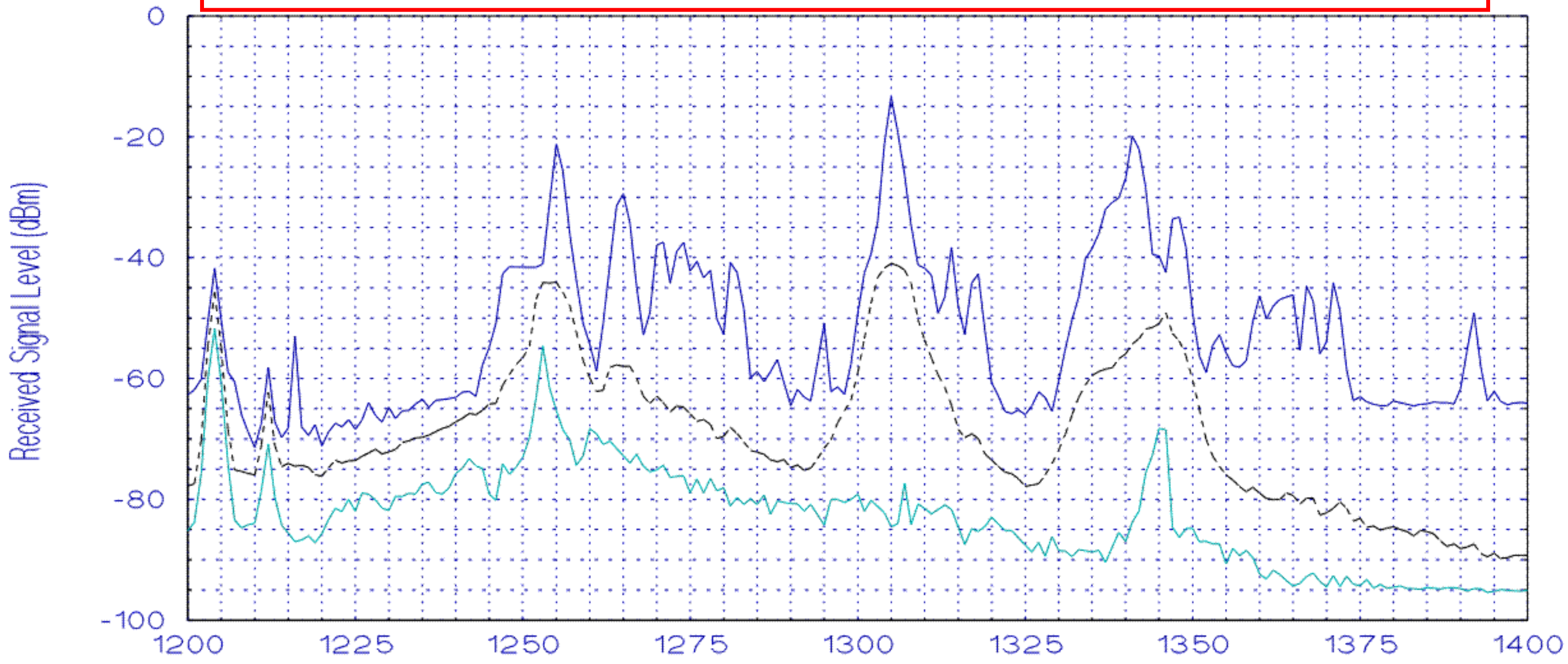
60 successive sweeps across band with Max-hold detector, results combined into a graph showing max, mean, and min results.



16,800 sweeps across the 902-928 MHz range at San Diego, CA, 1995
Band event 23, swept algorithm, maximum-hold detector, 10-kHz bandwidth

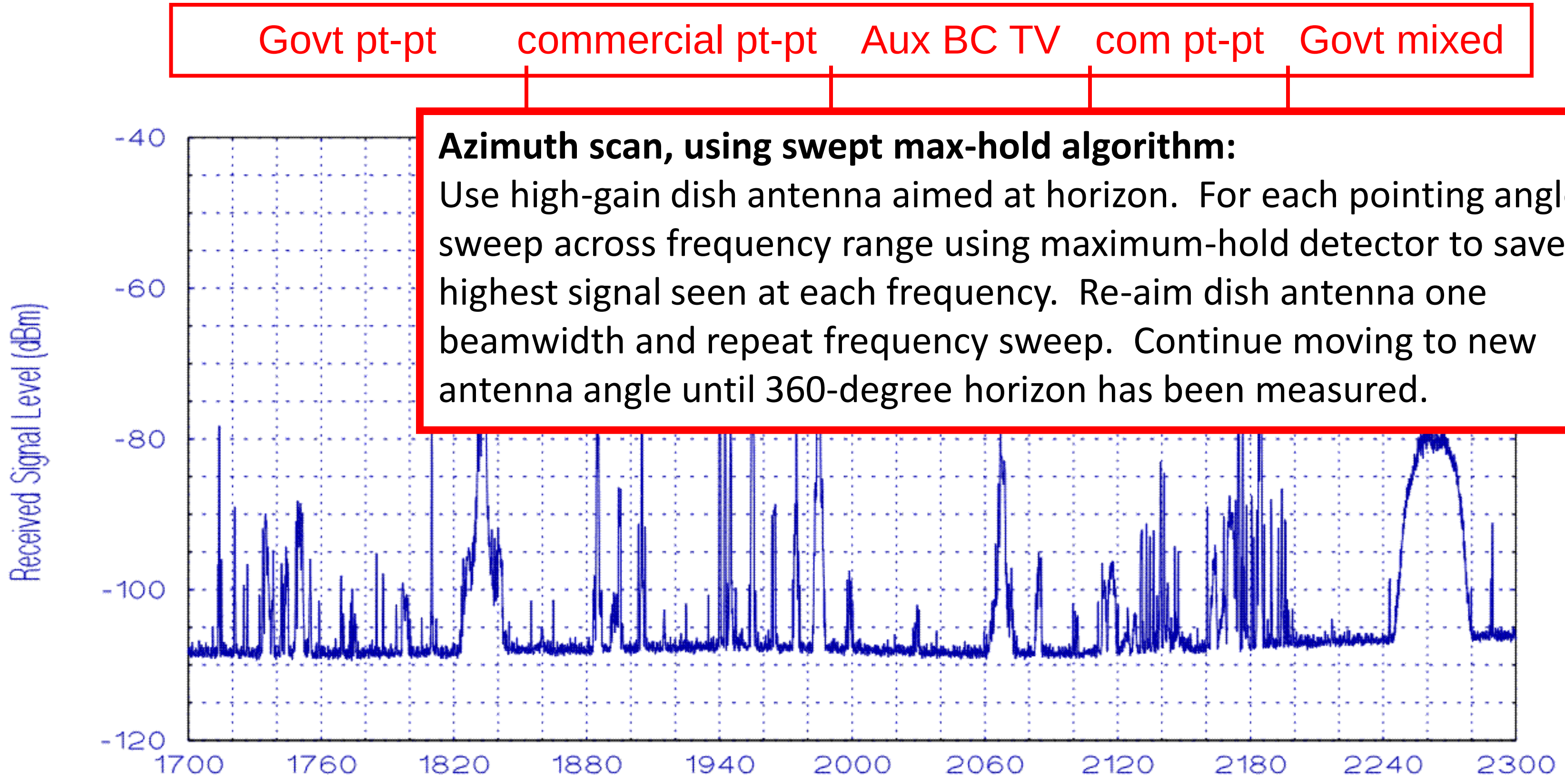
Example: 1215-1400 MHz Band

Long range L-band search radars, fixed & mobile above 1350



28 scans across the 1215-1400 MHz range at San Diego, CA, 1995
Band event 06, stepped algorithm, +peak detector, 1000-kHz bandwidth

Example: 1710-2300 MHz Band

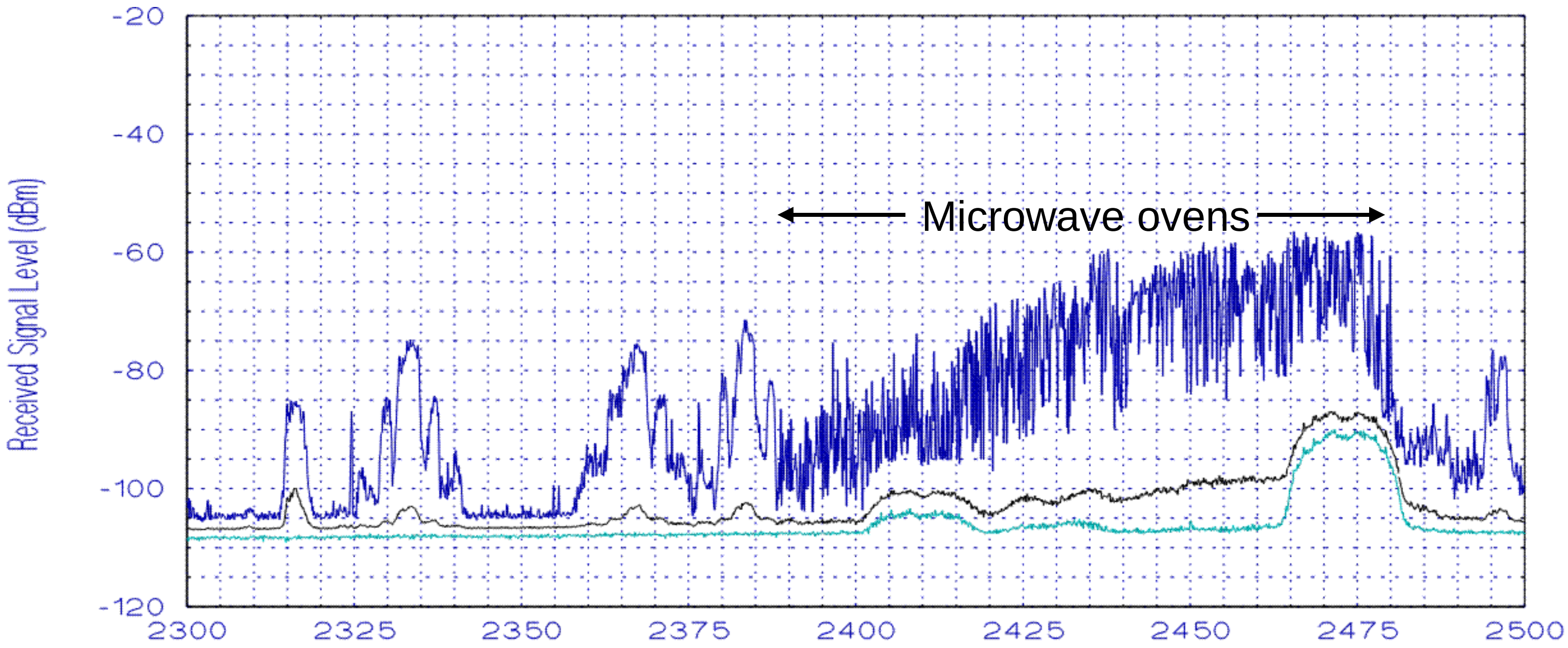


Azimuth scan, using swept max-hold algorithm:
Use high-gain dish antenna aimed at horizon. For each pointing angle, sweep across frequency range using maximum-hold detector to save highest signal seen at each frequency. Re-aim dish antenna one beamwidth and repeat frequency sweep. Continue moving to new antenna angle until 360-degree horizon has been measured.

Azimuth-scan graph of the 1710-2300 MHz range at San Diego, CA, 1995
Band event 10, swept algorithm, maximum-hold detector, 100-kHz bandwidth

Example: 2300-2500 MHz Band

Mobile/TM 2.3-2.4, Govt radar 2.3-2.45, ISM 2.4-2.5, pt-pt 2.45-2.5

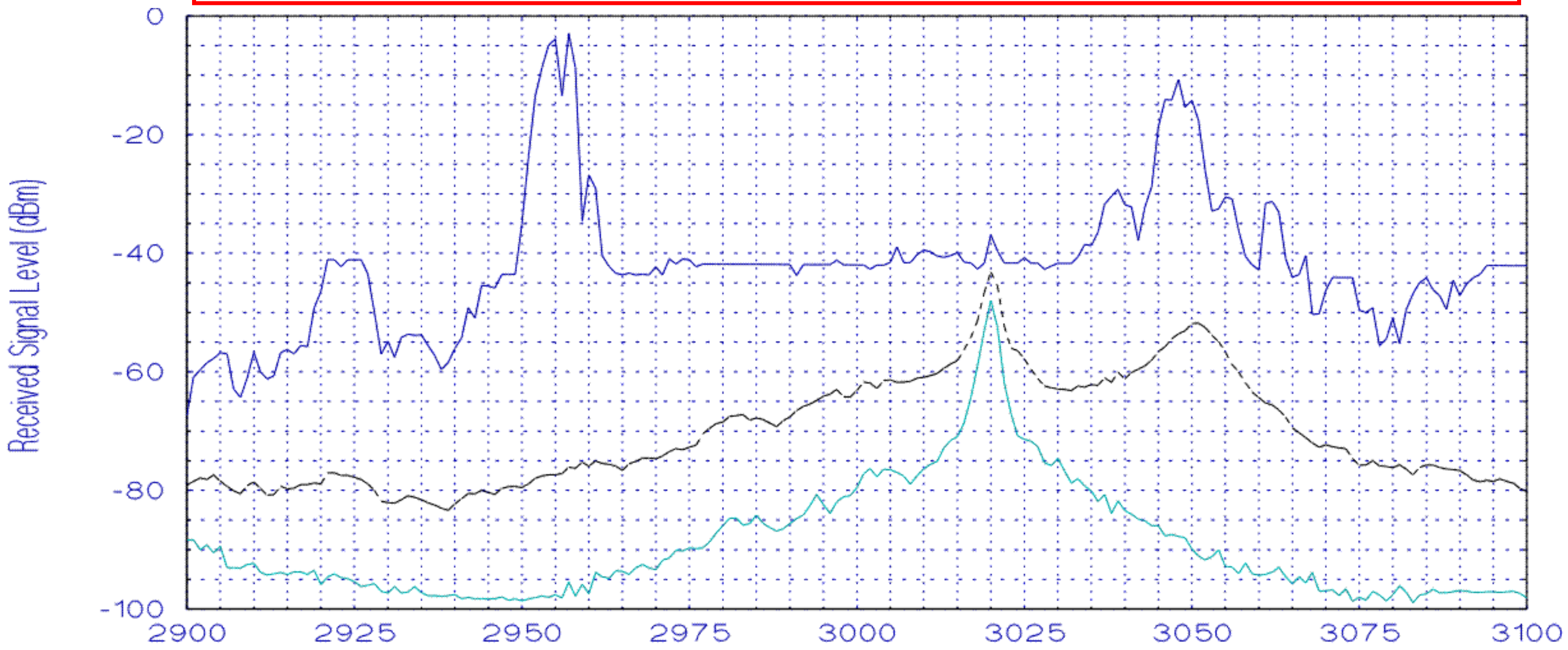


28,800 sweeps across the 2300-2500 MHz range at San Diego, CA, 1995

Band event 11, swept algorithm, maximum-hold detector, 100-kHz bandwidth

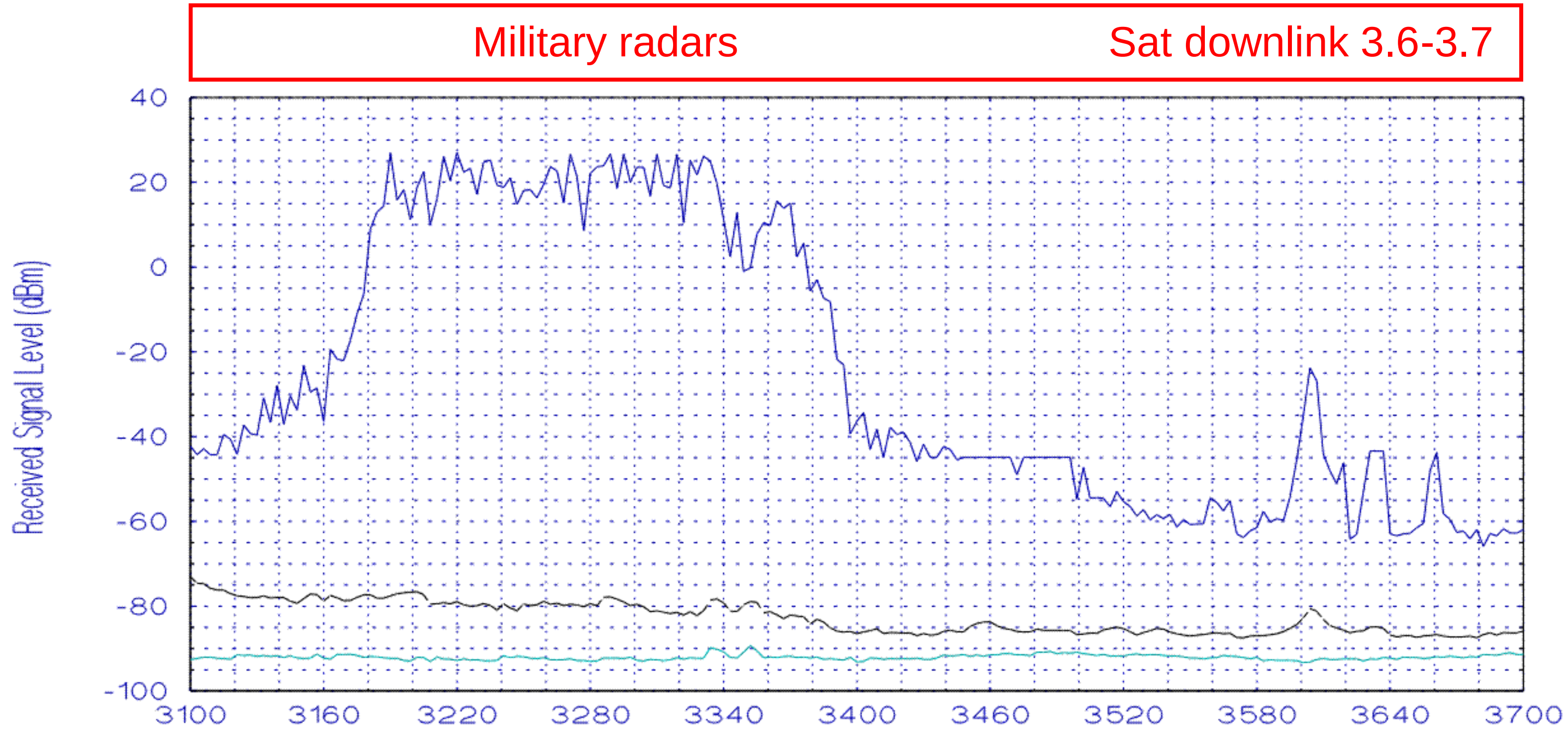
Example: 2900-3100 MHz Band

Maritime and military radars



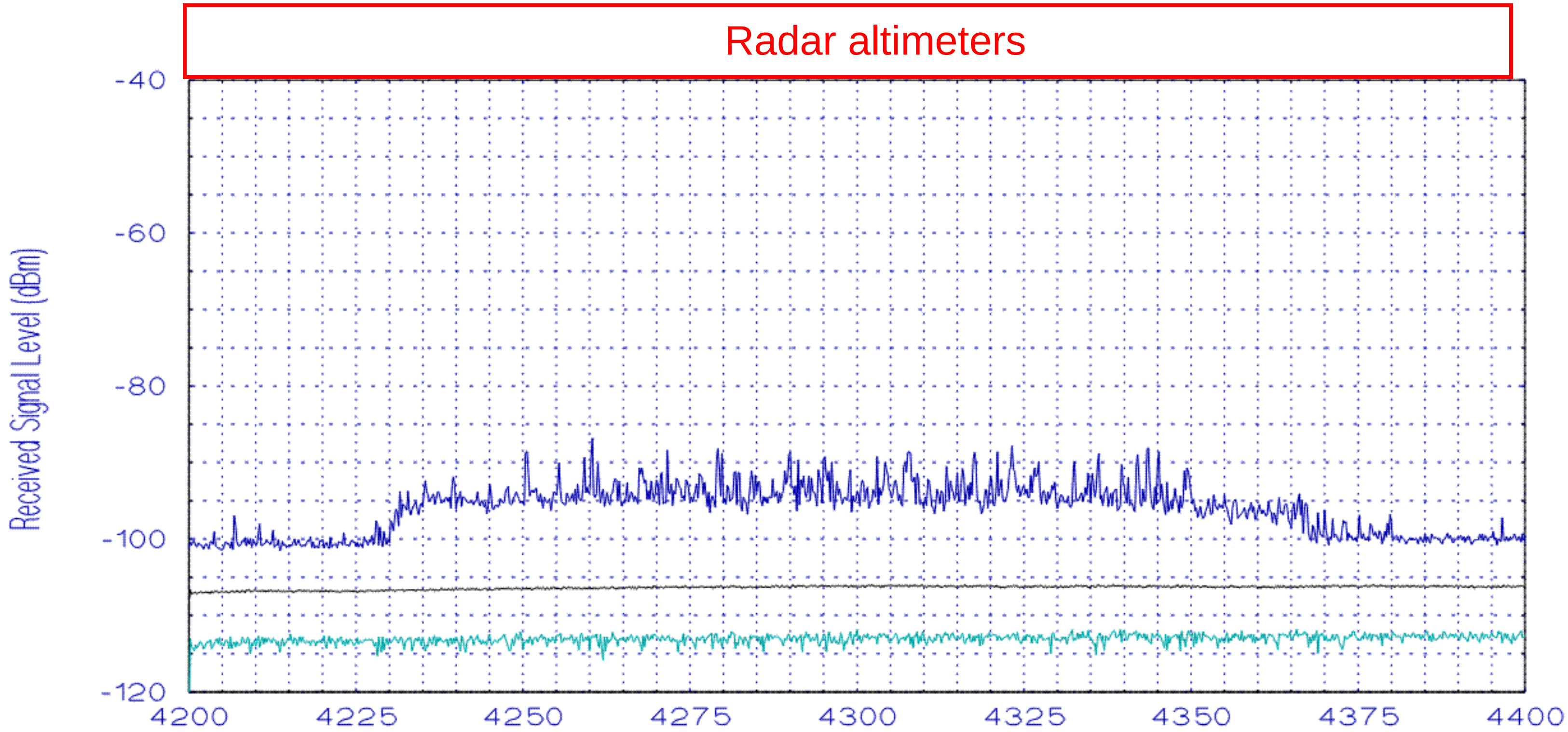
48 scans across the 2900-3100 MHz range) at San Diego, CA, 1995
Band event 14, stepped algorithm, +peak detector, 1000-kHz bandwidth

Example: 3100-3700 MHz Band



46 scans across the 3100-3700 MHz range at San Diego, CA, 1995
Band event 15, stepped algorithm, +peak detector, 3000-kHz bandwidth

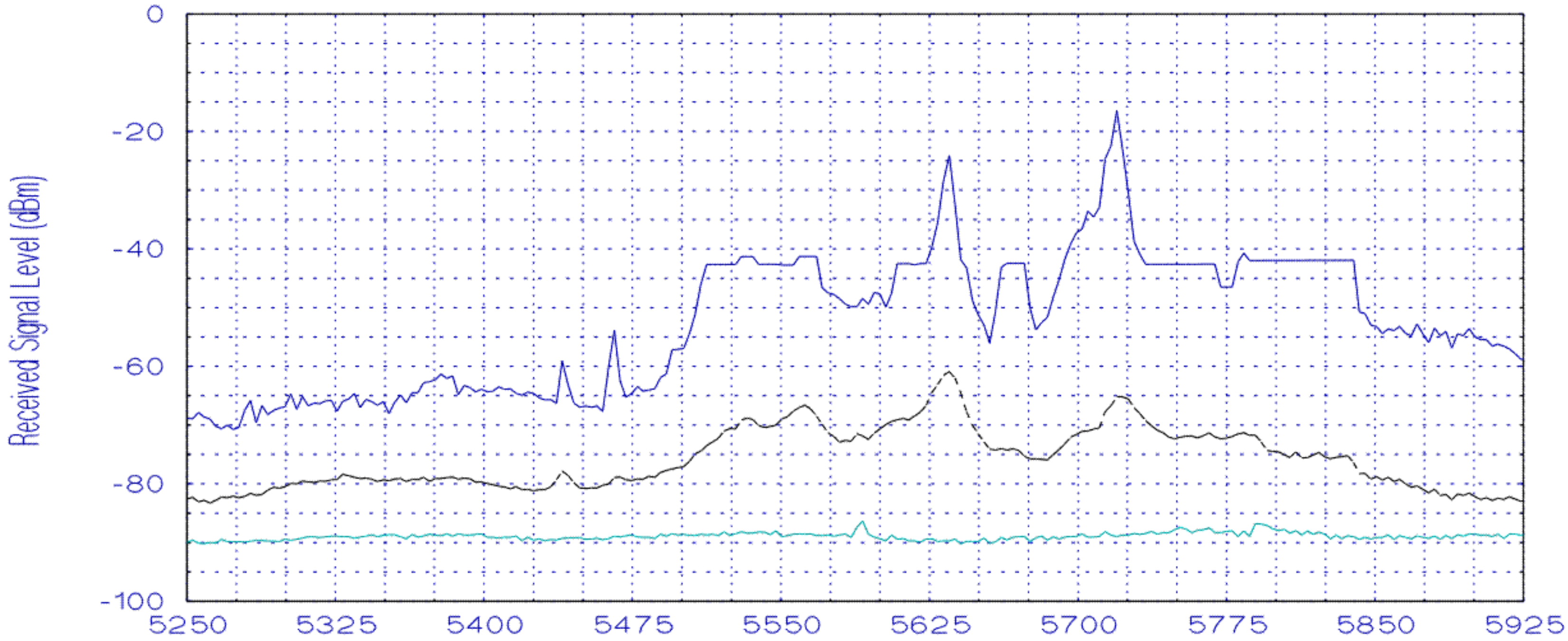
Example: 4200-4400 MHz Band



32,500 sweeps across the 4200-4400 MHz range at San Diego, CA, 1995
Band event 17, swept/m3 algorithm, +peak detector, 300-kHz bandwidth

Example: 5250-5925 MHz Band

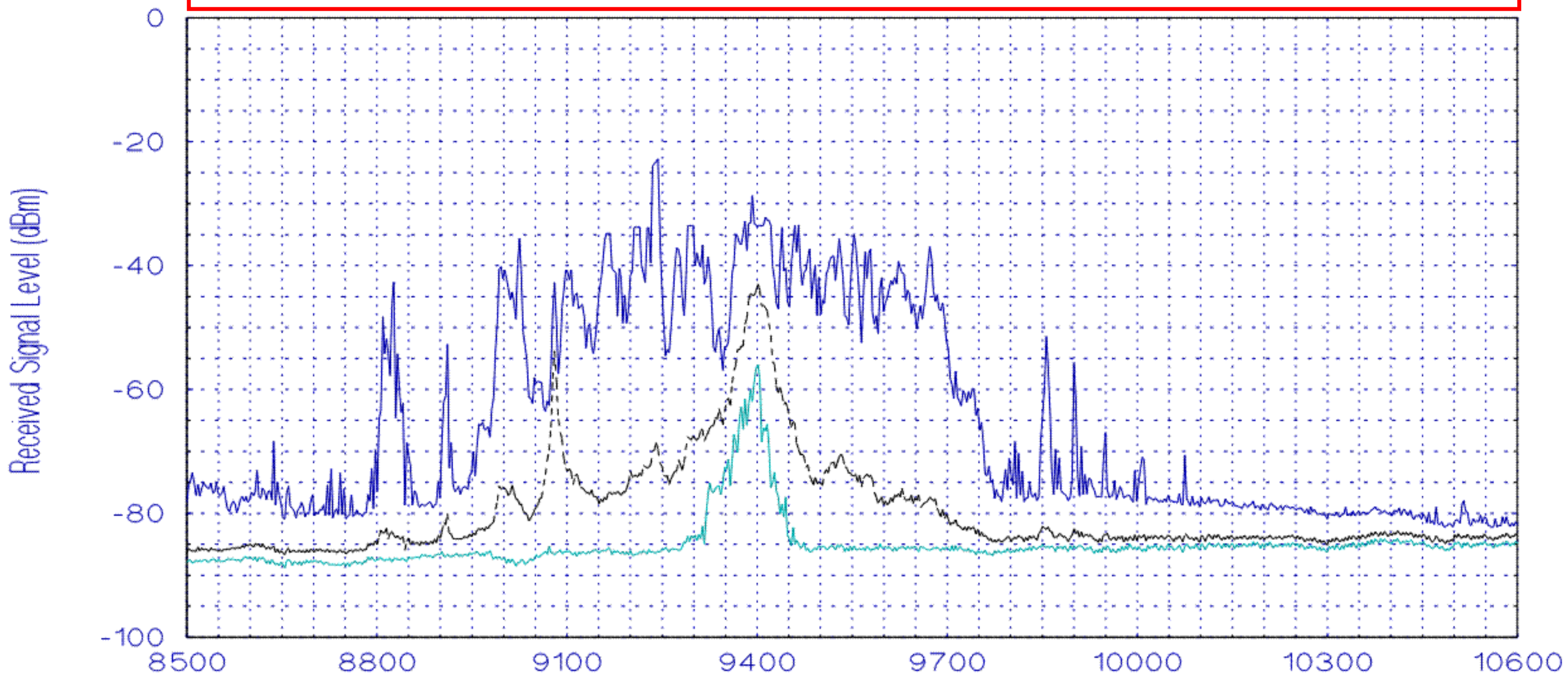
C-band radars: maritime, weather, military. ISM: 5725-5875



22 scans across the 5250-5925 MHz range at San Diego, CA, 1995
Band event 20, stepped algorithm, +peak detector, 3000-kHz bandwidth

Example: 8.5-10.5 GHz Band

X-band radars: maritime, airborne, airborne weather, racons, etc.



23 scans across the 8500-10550 MHz range) at San Diego, CA, 1995
Band event 23, stepped algorithm, +peak detector, 3000-kHz bandwidth

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