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Monitoring & Measurements in Spectrum Management

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Frank Sanders, Senior Technical Fellow

Institute for Telecommunication Sciences (ITS)

National Telecommunications and Information Administration (NTIA)

fsanders@ntia.doc.gov

303-497-7600

Outline

- Part I: Purposes for Monitoring
  - Monitoring as a frequency management tool
  - Monitoring tradeoffs
  - Monitor when other approaches don’t work
  - (---break---)
- Part II: Types of Monitoring Systems
  - Types of monitoring systems
  - Mobile systems and remote DF sites
  - (---break; lunch---)

Monitoring Part I: Purposes

- Monitoring is the use of hardware and software to measure occupancy of radio spectrum at individual localities:
  - Monitoring can show patterns of spectrum usage.
  - Monitoring allows comparison of assignments in databases to actual spectrum use.
  - Monitoring can resolve some RF interference problems.
  - Monitoring should be one part of a larger spectrum management system.

Monitoring as a Support for Spectrum Management

- Monitoring supports spectrum management by:
  - Identifying unlicensed transmitters.
  - Demonstrating which transmitters are actually being used.
  - Helping to verify that technical emission standards are being met.
  - Indicating extent to which spectrum management policies are followed.
  - Indicating whether new policies might be needed to prevent interference.

Data Obtained from Monitoring

- Monitoring can provide information not otherwise available, including:

- Occupancy percentages by time of day and day of the week;
- Spectra of transmitters;
- Time-domain characteristics of transmitters;
- Some information on antenna performance and propagation;
- Information needed to resolve interference problems

Monitoring Limitations

- There are limits to the usefulness of monitoring:
- Well-designed hardware and software are costly;
- It is time-consuming and costly to properly train measurement personnel;
- Data only apply to the times & places where they have been acquired;
- Monitoring environments are uncontrolled;
- Nearby transmitters can overload receivers, extra (bogus) signals can appear;
- Monitoring stations have limited range;
- Equipment used to acquire data can generate misleading results

Monitoring for Spectrum Usage

- Can show how much frequency bands are used
- Can indicate crowding
- Can indicate that more/new frequency bands are available locally.
- May indicate a need for new regulations.

- Statistical sampling is needed for some services:
- Mobile - highly variable with time/location.
- Between 100-10,000 measurements needed per channel.
- Broadcast, fixed microwave - very stable: few measurements needed

- Many measurements can be (and probably should be) automated:
- Automation provides enough data for statistical reliability.
- Efficient comparisons possible with assignment data bases.

- Note: Usage data are *not* the same as license data. Propagation, duty-cycles,
- geographical distribution of mobile systems, etc. affect usage data

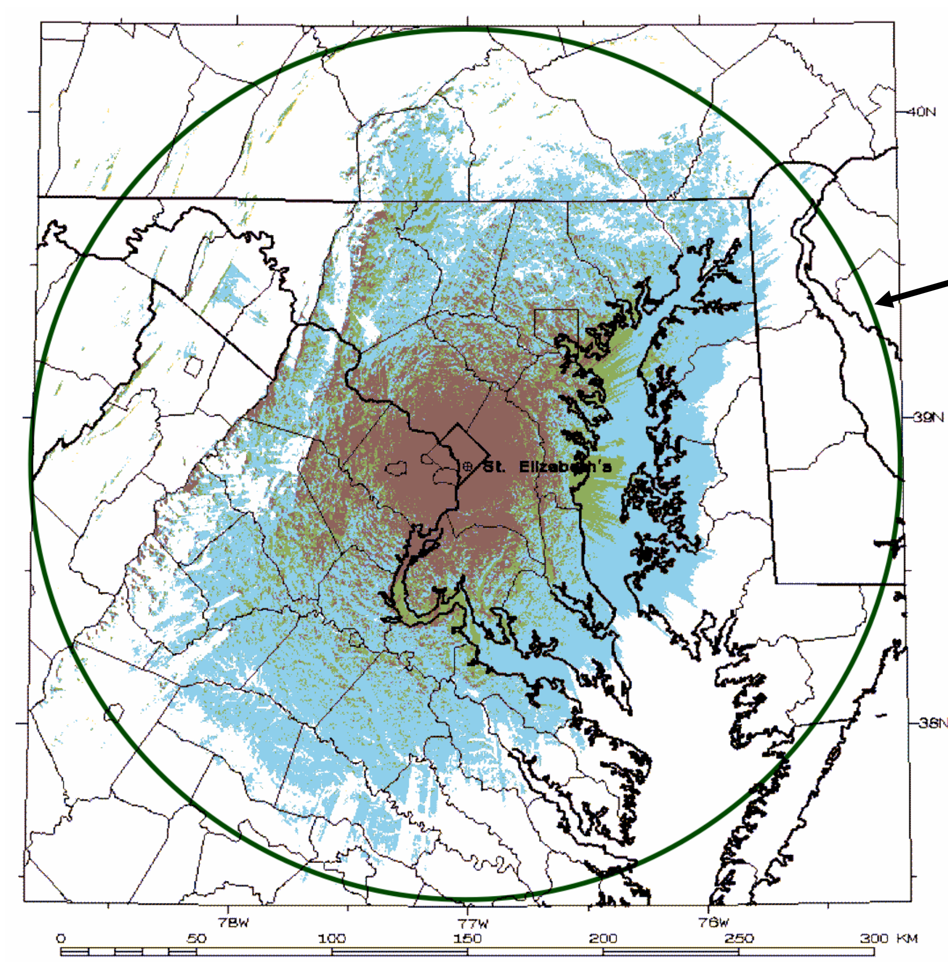
Finding Unused Frequencies

- May be needed when assignment/license database records lack information
  - Signals in unlicensed bands and assignments for large areas;
  - Monitoring might suggest unused assignments for further investigation.
- Automated monitoring equipment offers many advantages:
  - Cheaper, more unbiased and more reliable than manual checks;
  - More efficient: automation obtains more data faster than manual checks;
  - Statistically meaningful numbers of measurements can be made.
- Looking for unused frequencies is only the first step in determining whether some radio channels might be available because:
  - Some assignments might have very intermittent use;
  - Some assignments may not propagate well to monitoring location;
  - Emergency channels may be used little.

Signal Detectability

- Since spectrum survey measurements can only identify radio systems associated with transmitters, radio receivers and receive-only systems such as radio astronomy stations will not be observed in such measurements
- Signals arriving at a monitoring location will not be measurable if their signal power is much less than measurement system noise level:
  - $P_{received} \ll (kTB + NF)$
- where:
  - $P_{received}$ = signal power at the receiver input (dBm);
  - kTB = thermal noise in the receiver (= -174 dBm/Hz);
  - NF = noise figure of the receiver (dB).

Detectable Signals



Coverage Map
162-174 MHz

100 mile radius circle,
Centered on Washington,
Using RSMS-4 measurement
performance

Base only

Base and mobile

Base, mobile, handheld

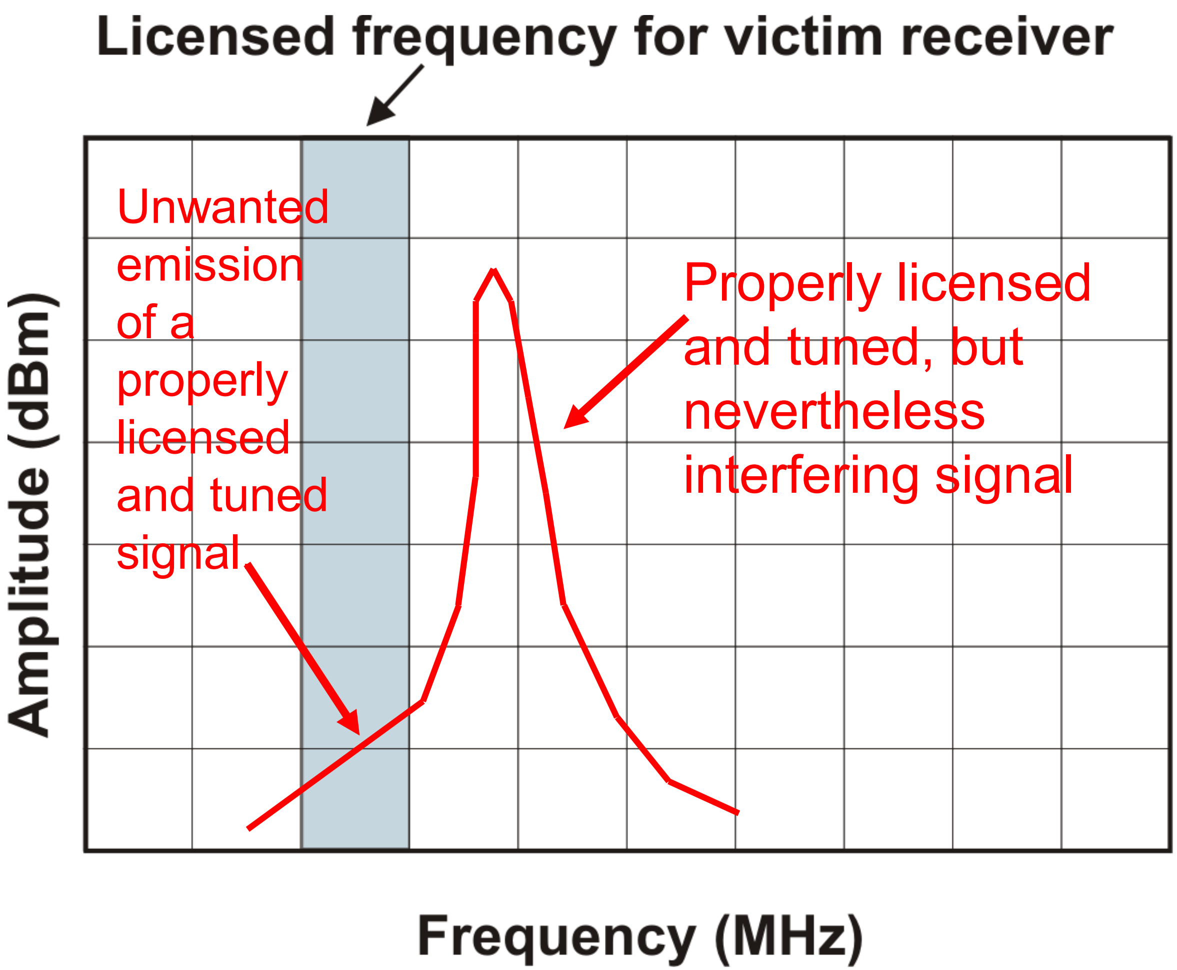
Solving Interference Problems

- In the experience of the NTIA Boulder labs personnel, *many reported interference problems turn out to not be radio interference at all.*
- When a radio system seems to fail:
  - people often jump to conclusion that interference is occurring; assumption of interference saves time and trouble of troubleshooting; *
  - assumption of interference causes finger-pointing:
  - a basis is created to request new systems to "solve" the interference.
- The first step in investigating an interference report is to be healthily skeptical:
  - Ask careful questions about when "interference" started;
  - Ask careful questions about the "interference" characteristics;
  - Example: "Was radio system "upgraded" when interference began?.
- Try to *eliminate other possibilities* before pursuing an assumption of interference.

Solving Interference Problems, continued

- If interference *is* occurring, the cause of problem must be identified next:
  - Co-channel interference (same frequency as victim receiver)
  - Unexpected legal signals, unlicensed signals,
  - Unexpected sidebands from licensed signals.
  - Out-of-band interference (different frequency from receiver):
  - Intermodulation from strong signals.
  - Inadequate receiver design (no front-end filtering).
- This process is difficult to automate:
  - There is no single technique for solution.
  - Careful on-site investigation is usually needed.
  - Intermittent problems, combinations of circumstances may complicate & extend the overall investigation.
- Good spectrum management should minimize interference.
  - Use realistic engineering models, conservative design, and accurate data bases.

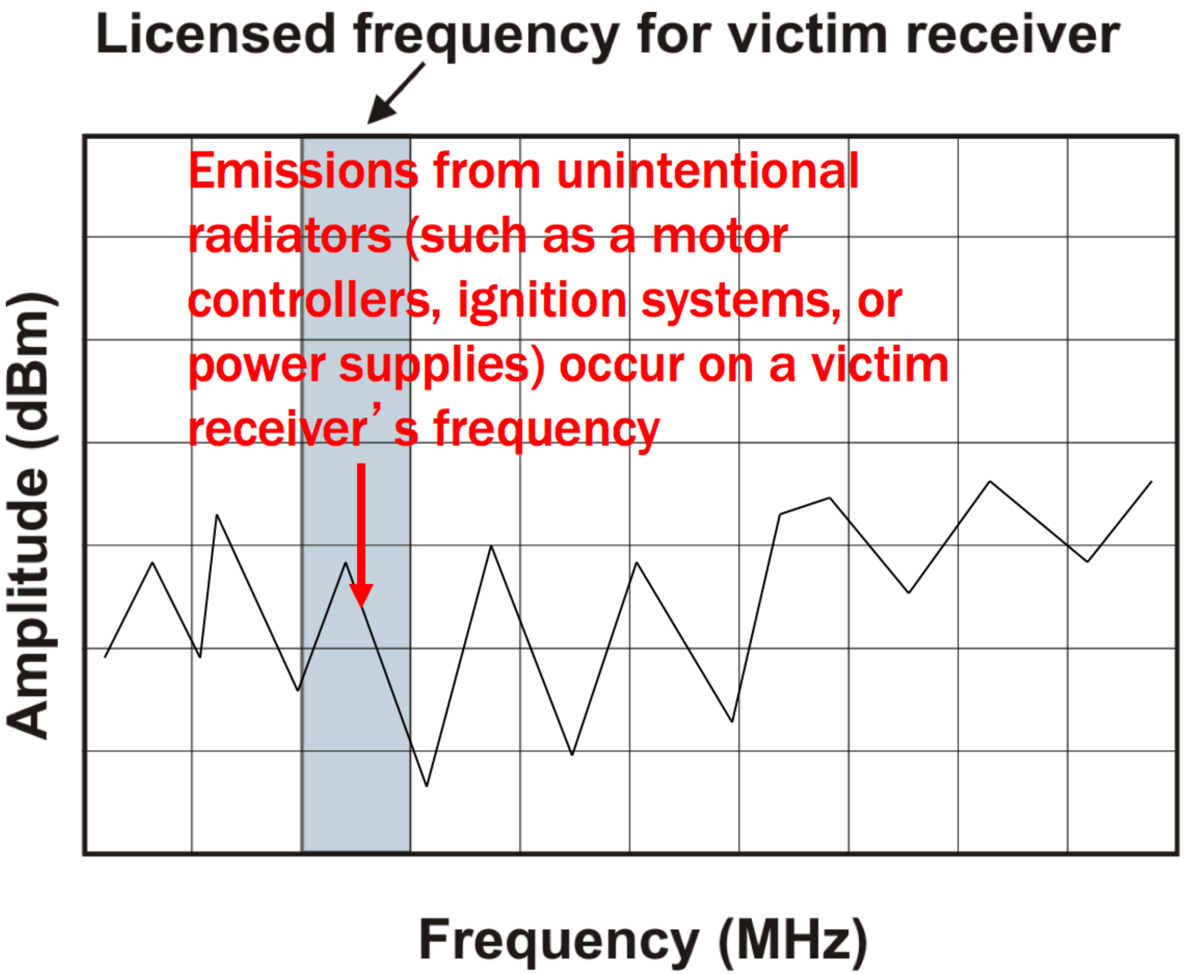
Co-Channel Interference



Co-channel interference may occur when a signal is mis-tuned, unlicensed (pirate), or generates high levels of unwanted emissions on a victim receiver's frequency.

Adherence to *emission masks* (e.g., the RSEC) controls unwanted emissions. But adherence to a mask does *not* guarantee that such emissions will never cause any interference.

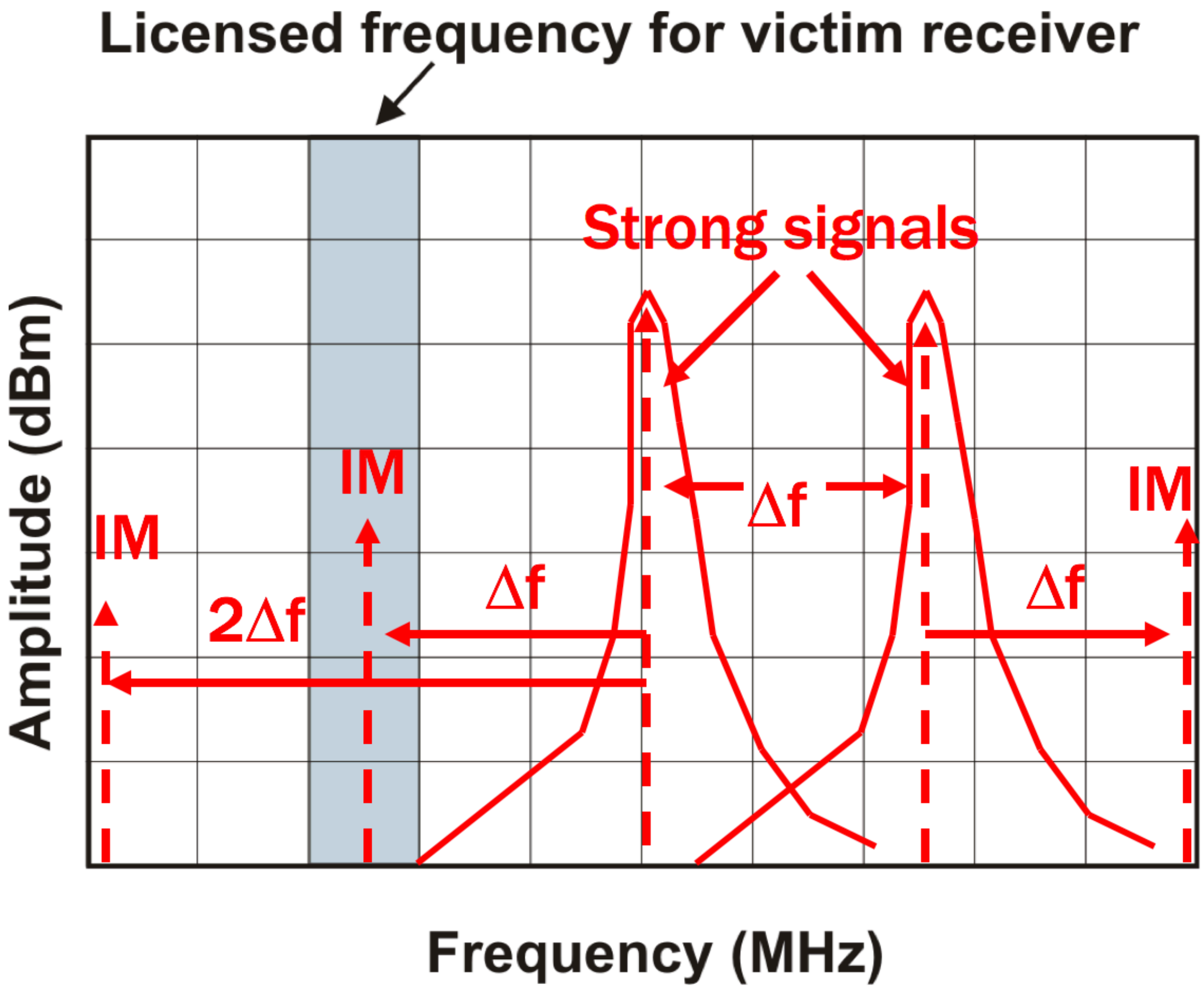
Co-Channel Interference, continued



Unintentional radiators (such as power supplies, motor controllers, and ignition systems) may cause co-channel interference. Such emissions are often impulsive and broadband.

Industrial, scientific, and medical (ISM) gear, producing radiation that is intentional but unlicensed (e.g., cordless phones) may also be sources of co-channel interference.

Intermodulation Interference

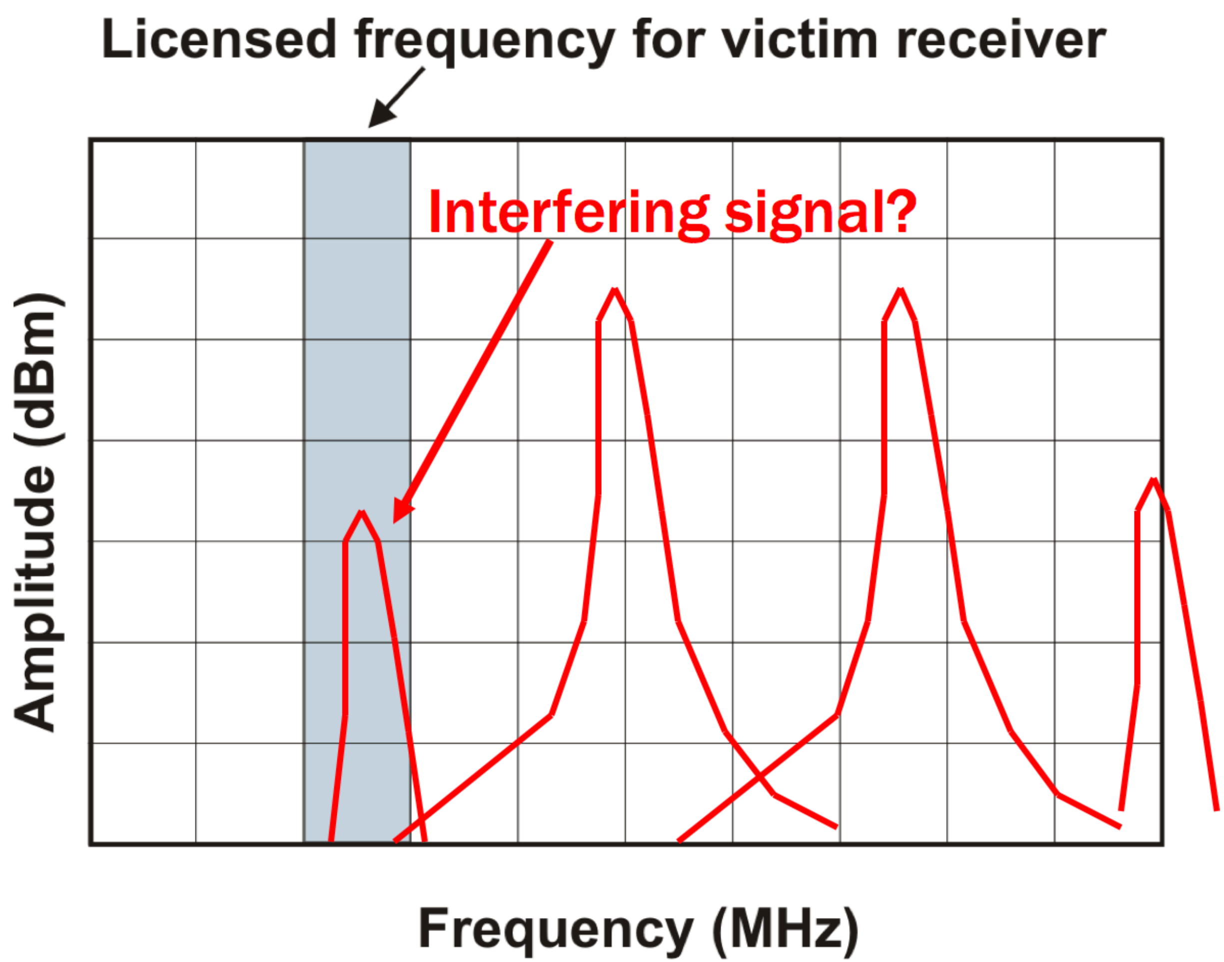


Intermodulation (IM) products generated in the victim receiver by multiple strong signals at multiples of the freq difference between the strong signals.

Who is held responsible for IM interference? Depends on the rules.

Typically, site management must resolve this.

Intermodulation Interference, continued



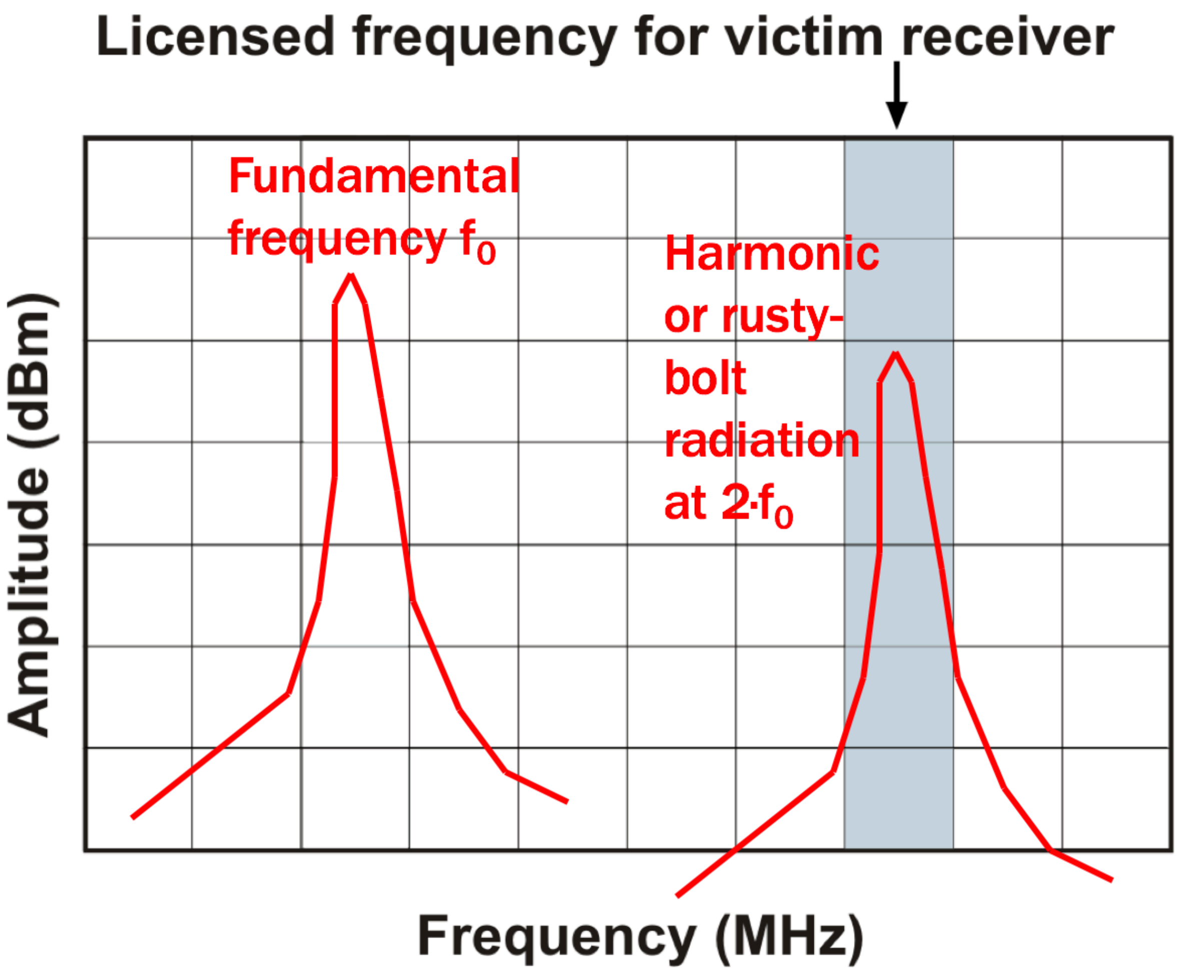
Suppose that your monitoring receiver shows a signal on the victim receiver channel.

Is it a co-channel spur of an emitter, or IM, or something else?

Monitoring receivers can generate IM also.

This is why monitoring receivers need to be very carefully designed, with good RF front-end filters.

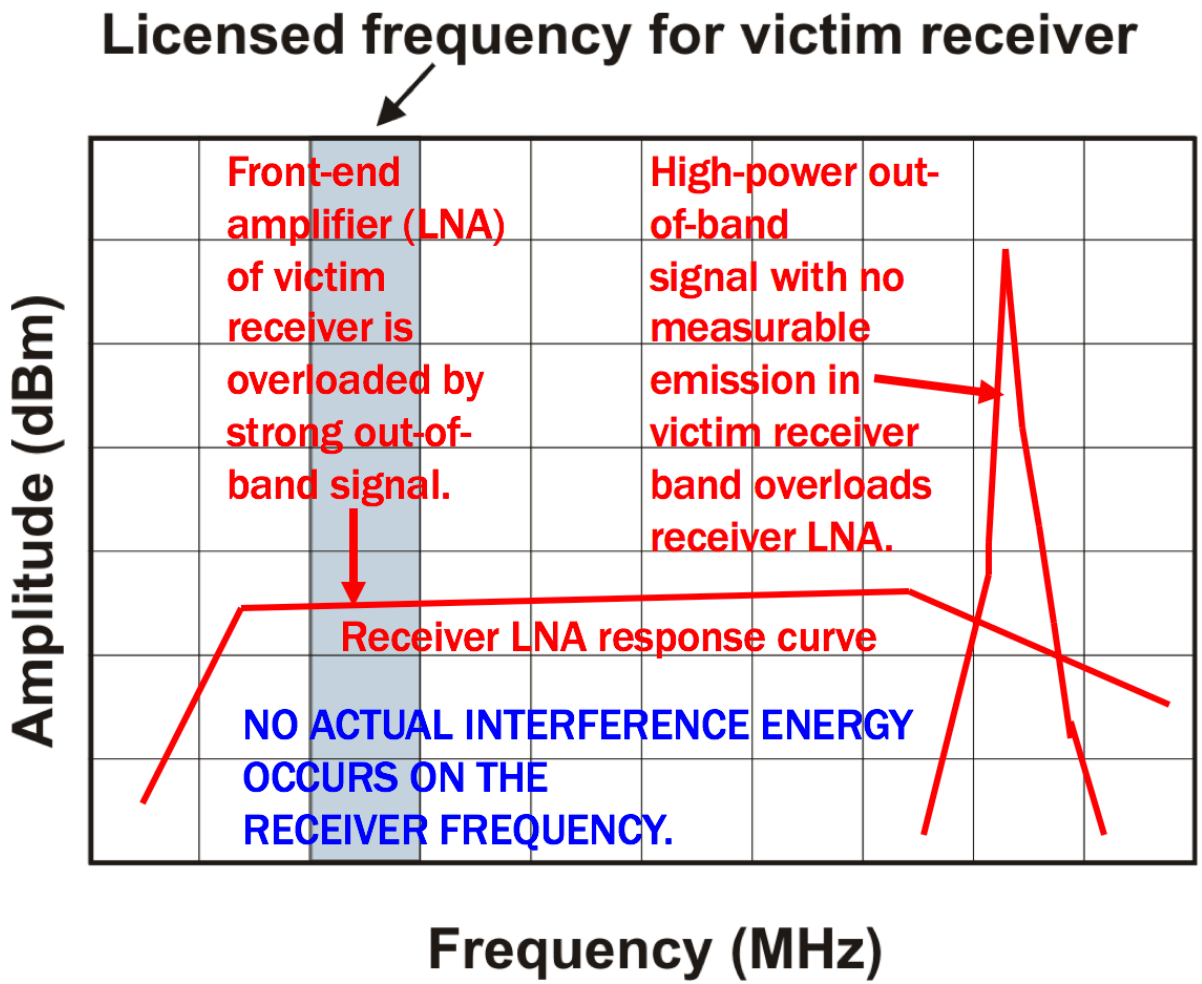
Harmonic Radiation versus Rusty-Bolt Interference



Corrosion (rust) on towers, fences, and other metal fittings can pick up radiation from a properly licensed, properly operating transmitter, and then re-radiate an image of that transmitter's signal on a harmonic ($2f_0$, $3f_0$, etc.) frequency.

The trick is to distinguish between rusty-bolt radiation and a harmonic radiated by the transmitter. How?

RF Front End Overload Interference



Sometimes victim receivers do not have any filter in front of their low-noise amplifier (LNA). *These LNAs have wider response ranges than the bands for which they are specified.* They will be overloaded by strong signals that are hundreds of megahertz from the frequency of the “victim” receiver.

The out-of-band transmitter is NOT at fault and the “victim” receiver needs a front-end filter

Compatibility Measurements

- Non-routine special measurements for:
  - Development of new types of systems.
  - Proposed new uses of existing systems.
  - Proposed new technical standards.

- Check whether new systems work as planned:
  - Will they cause interference to existing systems?

- Laboratory measurements are needed for:
  - Compliance testing for new products.
  - Engineering data for development and regulation.

Identifying Interfering Signals

- It is difficult and expensive to identify unknown signals.
  - Unlicensed transmitters have no call signs or ID.
  - Mobile users change location and are intermittent.
  - Tunable radios often change frequency.
  - Many signals on the same frequency.
  - Monitoring only as a last resort.
  - Multiple (fixed or mobile) DF sites are very useful.

- Better to control transmitters with frequency management.
  - Keep accurate license database information.
  - Use good technical models and rules to license.
  - Control transmitter sales (type acceptance).

Break and Questions

- Questions and Discussion
- 10-minute Break

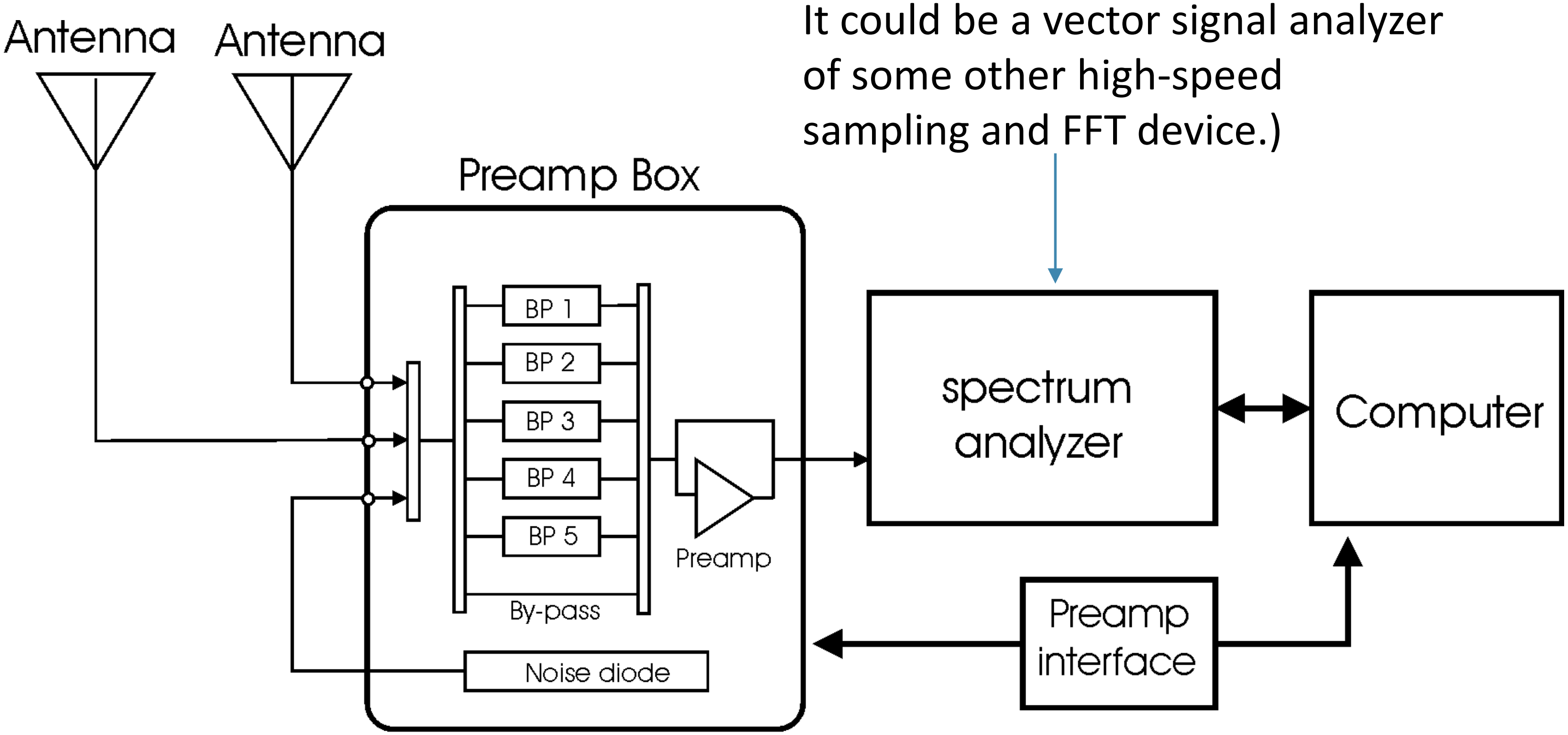
Monitoring Part II: Types of Monitoring Systems

Monitoring System Components

- Major components of any monitoring system include:
  - Good Location
  - Proper antennas
  - Adequate preselector filters/preamplifiers
  - Receiver (spectrum analyzer, etc)
  - Signal processing - voice, video, technical data, ID
  - Databases - licenses, previous measurements

Block Diagram of a Good Monitoring System

(This does not have to be a spectrum analyzer.
It could be a vector signal analyzer of some other high-speed sampling and FFT device.)

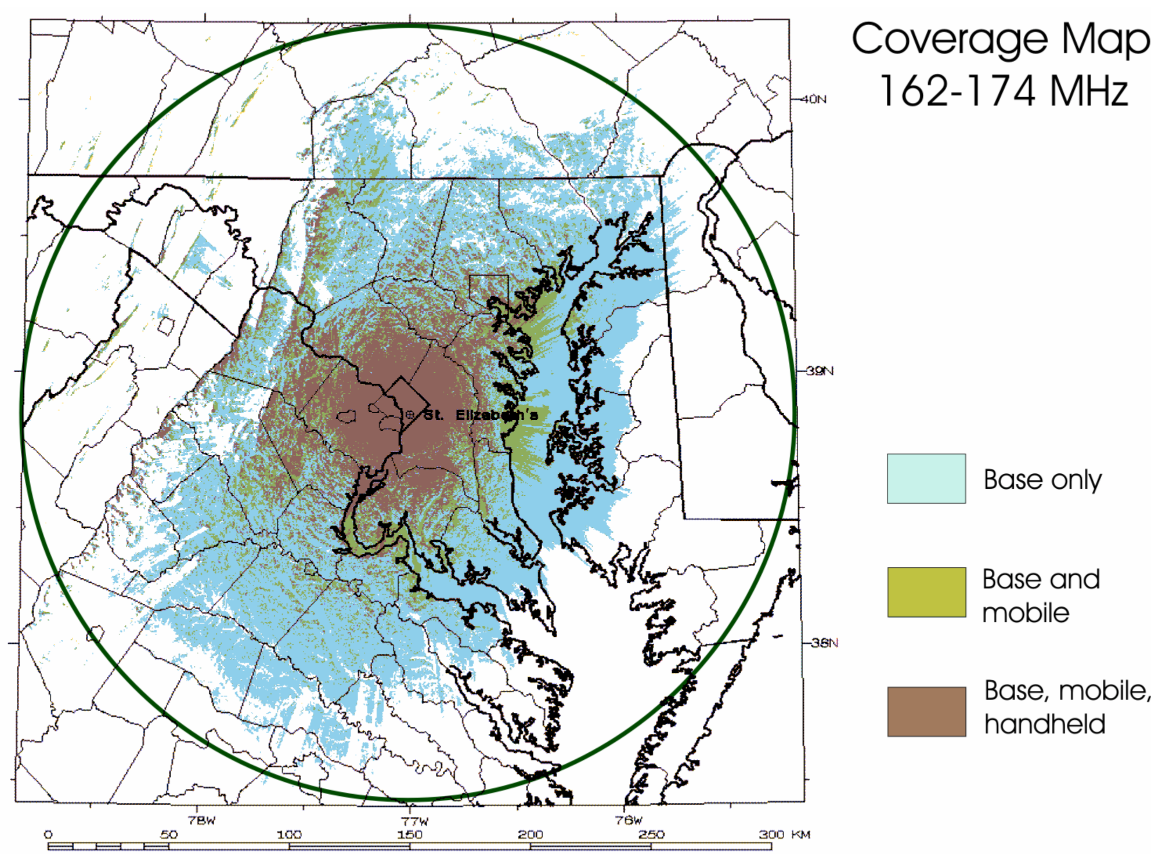


Locating a Monitoring System: Single High Point

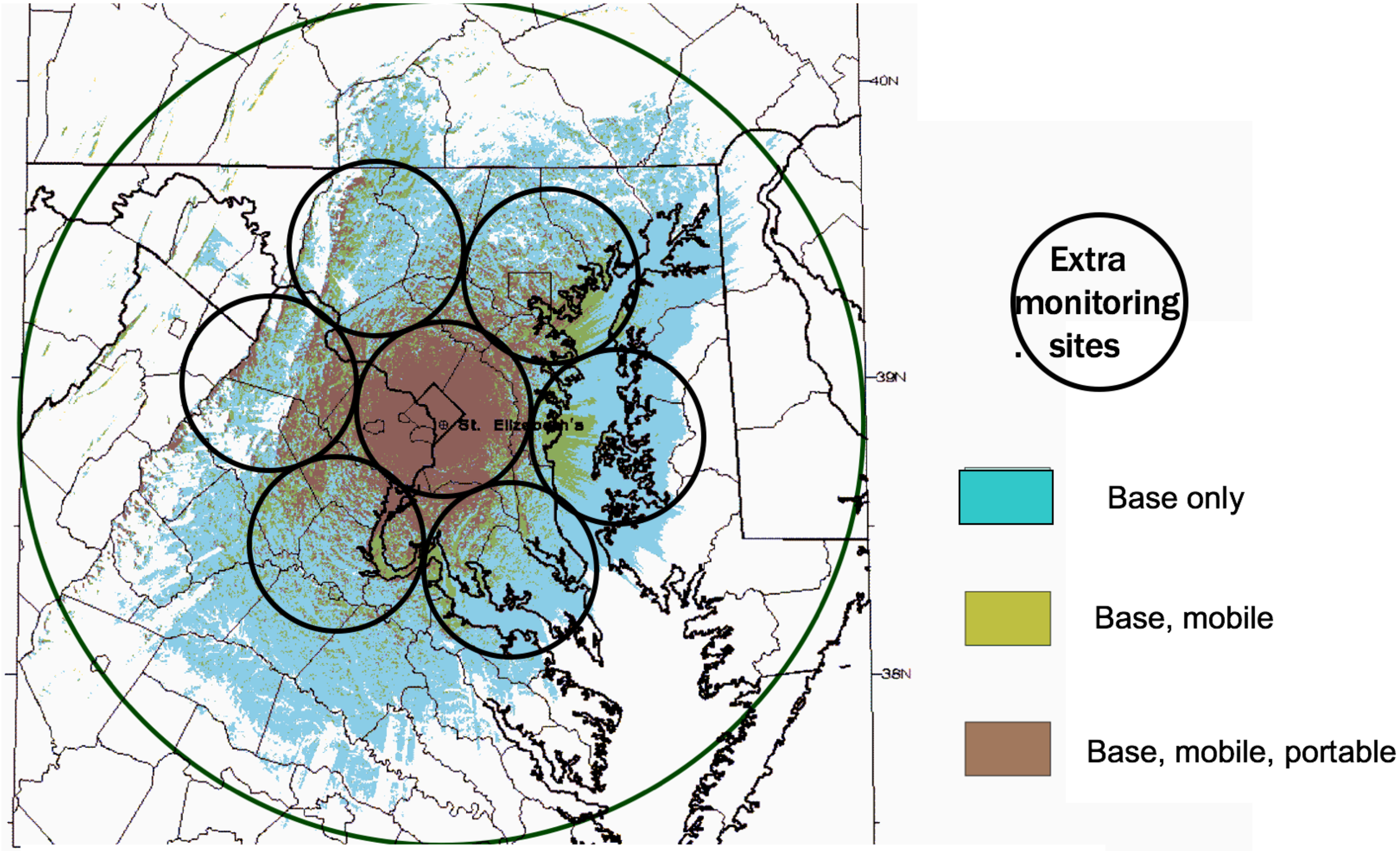
Location: Can't measure a signal if it isn't above monitoring receiver noise.

How close do you need to get? High-gain antennas and line-of-sight can be traded-off for being closer. Which is best?

Interference measurements need to be made at the receiver (sometimes inside).



But Several Separate Locations May be Better



Antenna Types and Patterns

Omnidirectional - monopole, dipole, stacked-dipole, discone*, biconical*, slant-polarized biconical*

Quadrant - Approximately 90° beamwidth, 3-6 dB gain. log periodic*, conical helix*, cavity-backed spiral*.

Directional - Yagi, parabolic dish* (gain ≈ 20 log F, beamwidth ≈ 1/F)

* Indicates very wide frequency range (usually 10:1)

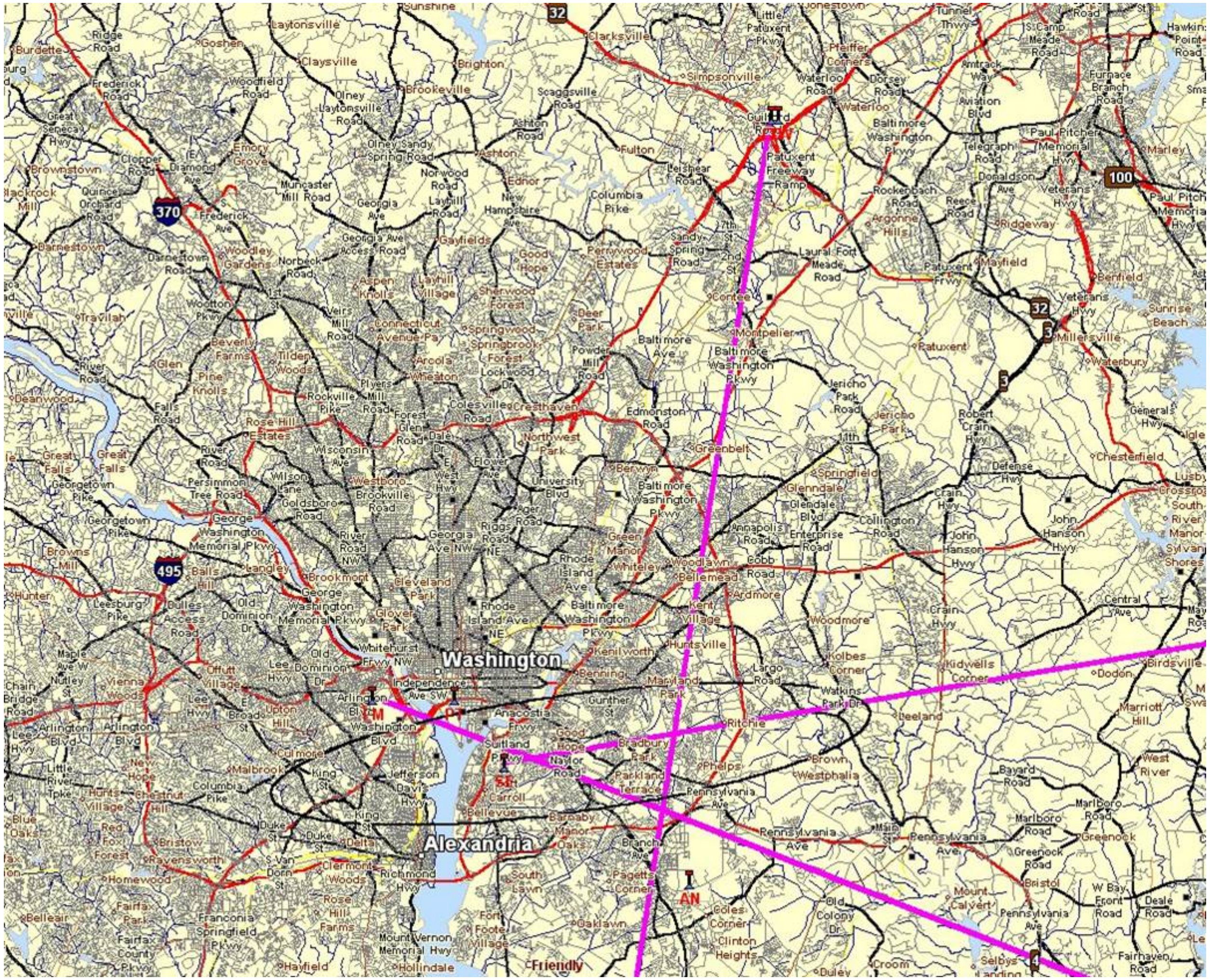
Direction-Finding

- Direction-of-Arrival: Helpful to identify and locate unknown or interfering signals. Methods include:
  - Maximum response on high-gain directional antenna (excellent for weak signals, but hard to get into beamwidth).
  - Comparison of signals received on multiple antennas - esp. 4-sided and 6-sided arrays of quadrant antennas.
  - Phased relationships on broadband dipoles - esp. 4-dipoles.
  - Nulled response of two identical antennas - Nulls are much sharper than high-gain beamwidth, but may require stronger signals.
  - Even a single, simple, inexpensive dipole antenna makes an excellent DF antenna for VHF-UHF frequencies. Again, the trick is to DF on antenna pattern *nulls* instead of peaks (see example two slides forward).

Triangulating (DFing) on a Signal

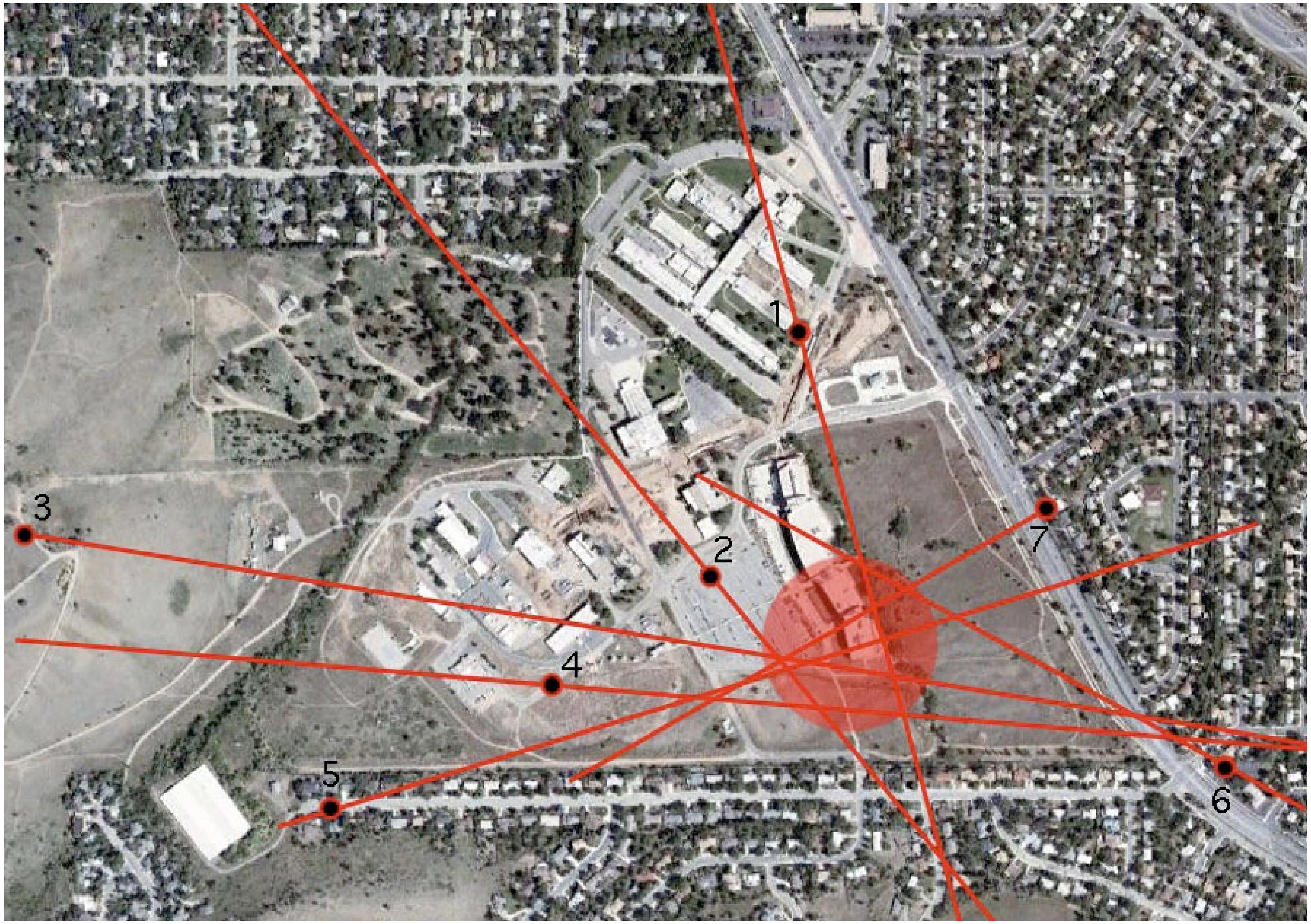
Multiple DF sites allow triangulation to find approximate location of a transmitter.

Major accuracy problems from a distance; usually drive closer to get better estimates.



Triangulation Example: DFing with a Small Dipole

Actual case: The presenters recently DF'ed a broadband interference source (200-600 MHz with emission lines spaced 100 kHz apart) to the rooftop of a large building. The emitter was a noisy stepper-motor controller for a sun tracker. (A different model of controller that cost an extra $50 was radio-quiet.)

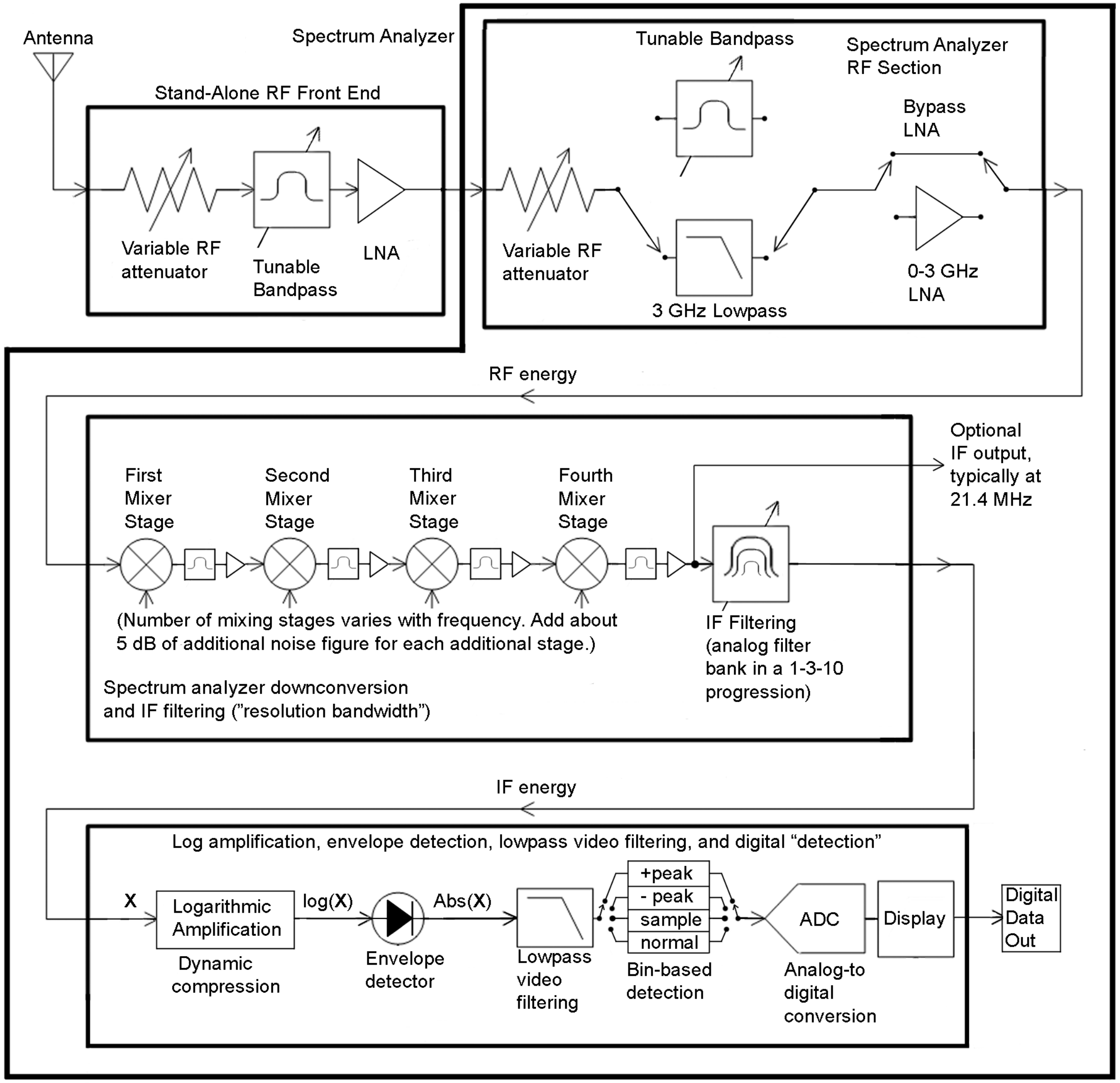


Receiver Designs for Monitoring & Measurements

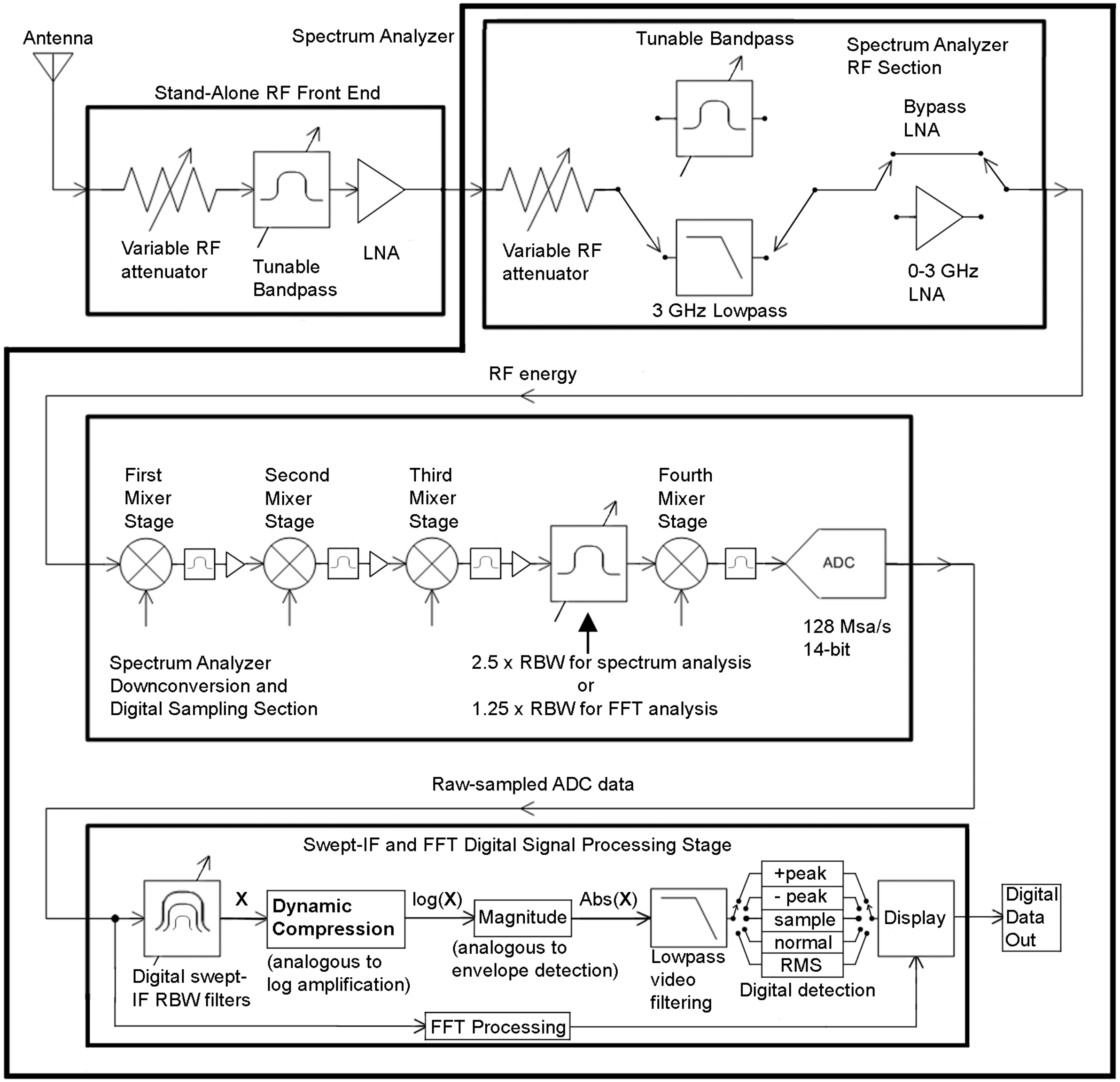
- Tune to the signals of interest, measure their power, frequency, modulation, etc.
- Frequency range, bandwidths, detectors and demodulators, signal processing
- Noise figure – sensitivity for very small signals
- Dynamic range (internal noise to overload) - IM3, TOI, IP1
- LO Sideband noise, digitizer jitter
- Accuracy - measured power and frequency

- Packages:
- Field Intensity Meter (FIM) - single frequency, power of single channel on meter
- Analog spectrum analyzer –
  - Sweep LO across a frequency band giving power in IF bandwidth display.
- Digital spectrum analyzer –
  - Digitize whole IF (5-10 MHz) and compute to give multiple narrow bandwidths
- Vector signal analyzer - I and Q channels because many signals are QAM

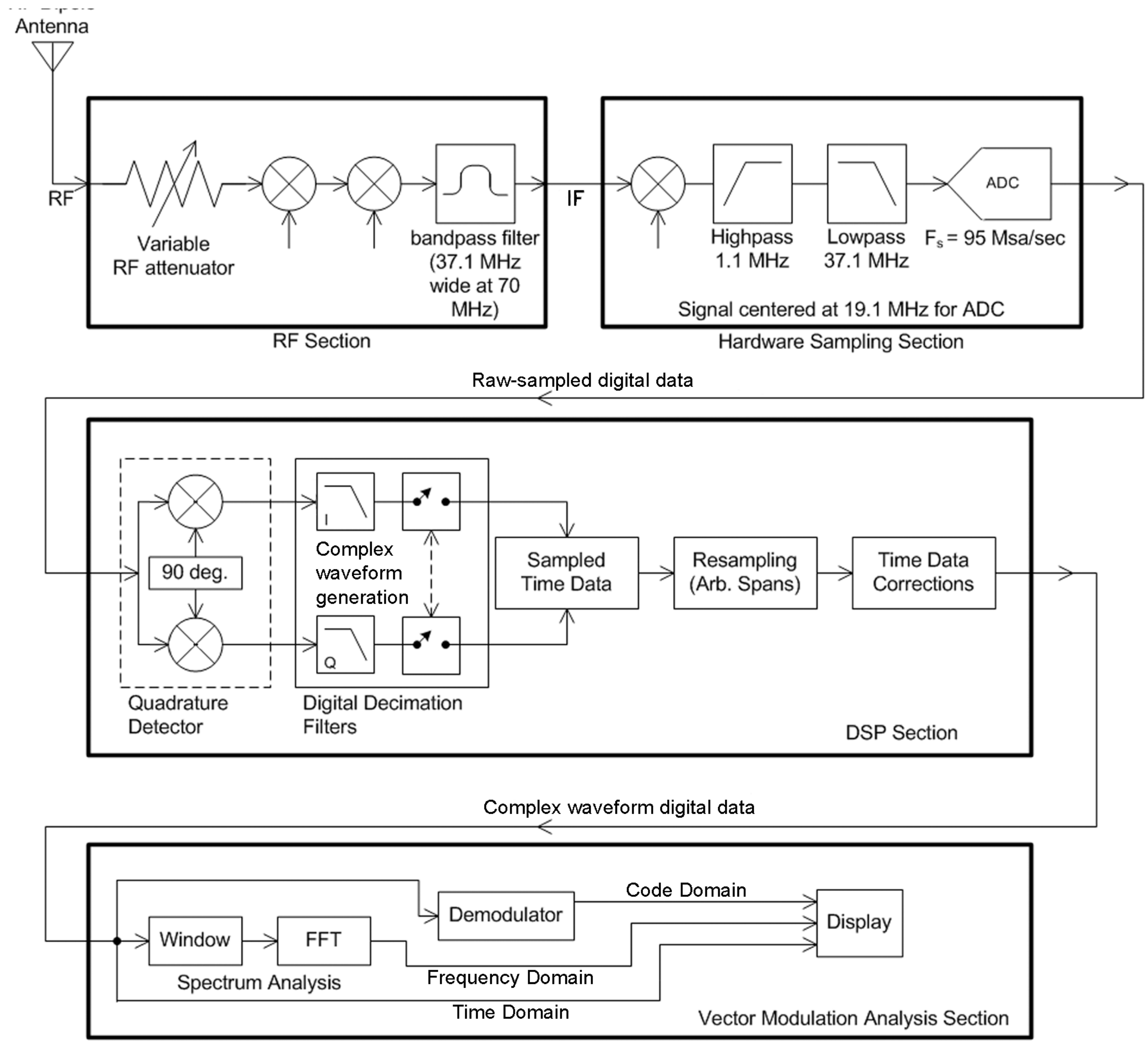
Typical analog spectrum analyzer (with custom RF front-end)



Typical digital spectrum analyzer (with custom RF front-end)



Typical vector signal analyzer (VSA)



Noise Figure

- kT = -174 dBm/Hz = -204 dBW/Hz (assuming T = about 300°K)

- Noise power = kTB. In dBm, P = -174 + 10 log B (dBm)
- B = 1 Hz, 10 log B = 0, Noise power = - 174 dBm
- B = 1 kHz, 10 log B = 30, Noise power = - 144 dBm
- B = 1 MHz, 10 log B = 60, Noise power = - 114 dBm

- Noise figure (NF) = X dB means that a device appears to have at its input a noise source of [X + (-174) dBm/Hz]
- Gain stages (amplifiers) *amplify system noise along with signal*. Improvement in signal-to-noise ratio only happens if the amplifier's own noise figure is less than the noise figure of the system to which it is attached, with just enough gain to overdrive receiver's own noise figure.
- Best amplifier choice: $(G_{amp} + NF_{amp})$ = (approx.) $G_{receiver}$

Noise Figure, continued

- Here's where we look at an LNA on the front end of a spectrum analyzer.
- And we do some LNA gain and noise figure examples as a group, for the right amplifier choices to make for various types of receiver noise figure

Preselector (Front End) RF Filters

- **Preselector (front end) RF filters** are used to block out most frequencies, so that strong signals at those frequencies cannot cause IM products.
- **Fixed-frequency bandpass filters** have lowest insertion loss.
  - But you need to think about:
    - Using narrower bandwidth filters (best at eliminating more unwanted signals),
    - Versus: the narrower the filters the more you my have to use in your receiver to cover a given frequency range.
- **Tracking bandpass filters** - These are narrowband filters that can be made to automatically follow the frequency that the spectrum analyzer(or VSA or whatever) is measuring. Use yttrium-iron-garnet (YIG) filters for frequencies above 500 MHz; and varactor filters for frequencies below 500 MHz.

Computer Control

- Computer control can be extremely valuable, if used properly.
- Control your SA (or VSA or whatever) with measurement and analysis programs, precisely directing complex measurements, saving data in printed or electronic form, adding calibrations and various other analysis, remote data collection via Internet, etc.
- But, not all computer-control software for monitoring matches users' needs. Computer control can be complex, and hard to learn and use. Good software engineers and custom software are needed for some jobs.

Portable Remote Site

Portable Remote Site Suitcase-Type System

Examples of Mobile DF Systems

Examples of FCC vehicles used to track down interference. DF antennas are usually inside vehicle roof. These vehicles are made to look ordinary.

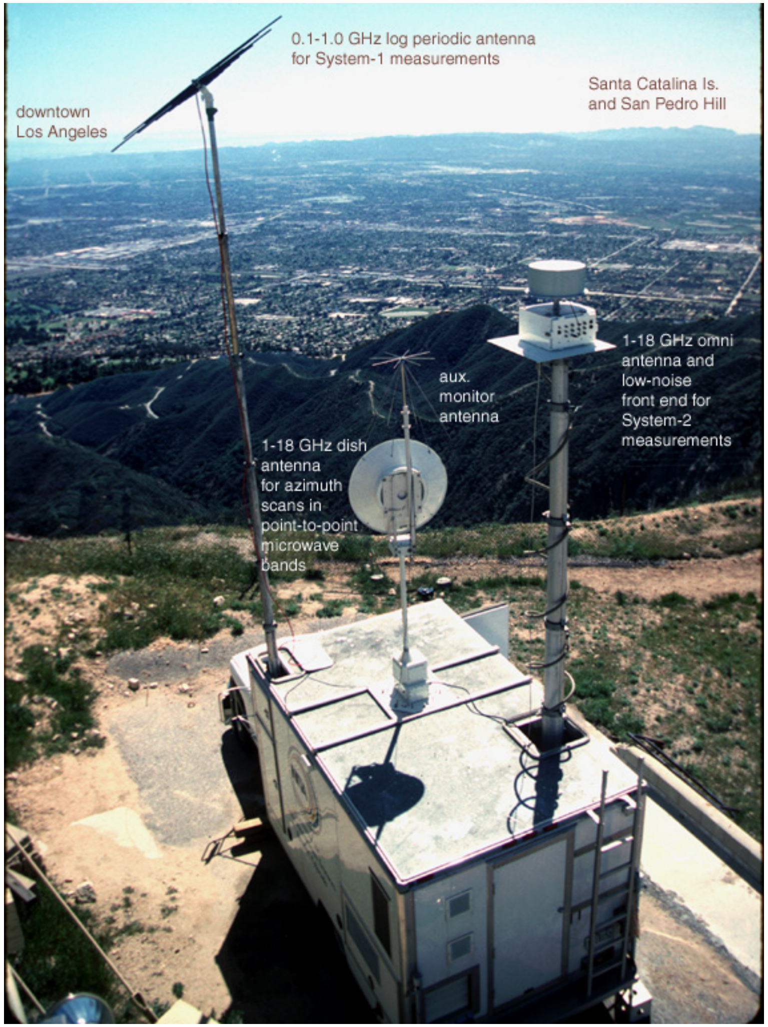
Hilltop Mobile Monitoring and Measurement

Example of an NTIA self-contained wide-band mobile measurement system on a hilltop. Two computer-controlled systems.

Remote monitoring by phone or cell-phone.

Good for site surveys or spectrum usage measurements 100 MHz -18 GHz.

Shown here for spectrum usage measurements in the Los Angeles area



Fixed versus Mobile Monitoring & Measurement Sites

- Fixed monitoring sites can be permanently located on hilltops to give large field of view, to help see signals in large cities and cover large areas with high-gain antennas. These may be somewhat expensive.
- However, many interference problems need to be investigated locally. For example, a strong transmitter close to a receiver, causing receiver overload or intermodulation. Direction-of-arrival very inaccurate at a distance.
- Smaller mobile systems can go much closer to the situation where interference is occurring, seeing much more. Less expensive. Always need mobiles. Move between cities

Break and Questions

- Questions and Discussion