

NOISE

ELECTROMAGNETIC, IMPULSIVE

A historically based tutorial by

Robert J. Matheson

Nov 14, 2013

BACKGROUND:

- The Nature of EM noise has changed over time, frequency, and technology.
- Some current questions about noise are partly historical. Therefore, a historical approach may help to enlighten the debate.
- Feel free to make comments or ask questions throughout the presentation

SPEAKER INTRO:

Robert J. Matheson –BA Physics, MS EE from CU

- ❑ 47 years at NTIA/ITS, retired 7 years ago.
- ❑ Began work in 1957 (summer job) with ARN-2 noise measurement program.
- ❑ Design of measurement system for ITS man-made noise program beginning in 1965.
- ❑ Radio Spectrum Measurement System program 1973-88, supporting NTIA frequency management.
- ❑ Deputy Director ITS Spectrum Division, 1988-91
- ❑ ITS research – spectrum efficiency, property rights, technical spectrum policy, etc. 1991-2006

TOPICS

- 1951-65. ARN-2 worldwide measurements of lightning noise. 0-20 MHz.
 - Impulsive noise, bandwidth effects, APDs, RMS, V_d , L_d .
- 1965-72. ITS Man-Made Noise program. .25-250 MHz.
 - MMN sources, criteria, measurement techniques
- Recent MMN measurements. 2000-2013
 - Wider bandwidths, statistical processing.
- Future questions: What is noise? Where & How to measure?

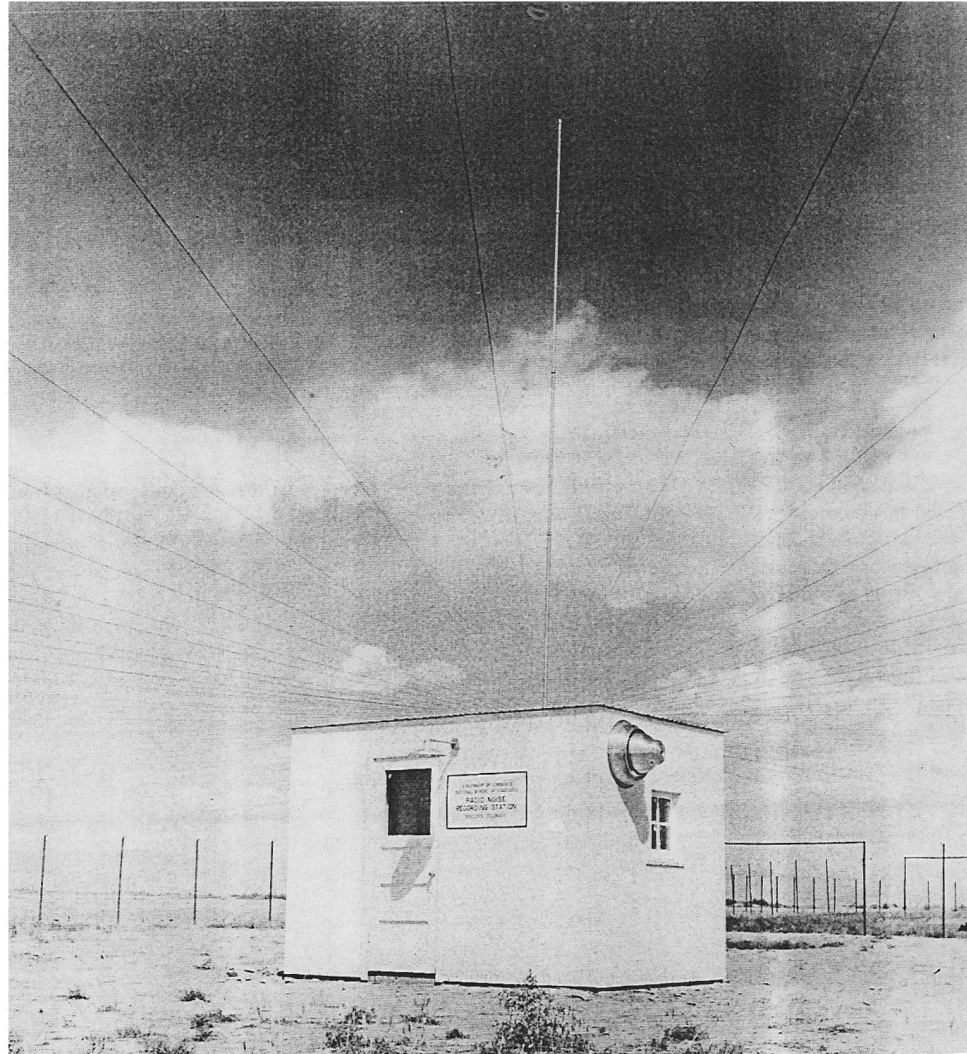
ARN-2 BACKGROUND:

- ❑ Atmospheric Radio Noise (ARN) measurements by NBS, 1956-65, at 8 frequencies (113 kHz – 20 MHz), 18 sites worldwide.
- ❑ Radio signals can be propagated (or not) around the world by multiple reflections off the ionosphere.
- ❑ Impulsive noise from lightning can also propagate worldwide, interfering with communications (60 dB change in average noise power).
- ❑ Received noise is dependent on global occurrence of thunderstorms and ionospheric propagation.
- ❑ Predicting hourly noise levels and noise statistics at any frequency and location is major goal.

ARN-2 STATION

- **ARN-2**
Station: 4-m
vertical whip
antenna,
surrounded by
100-ft diameter
ground-plane.

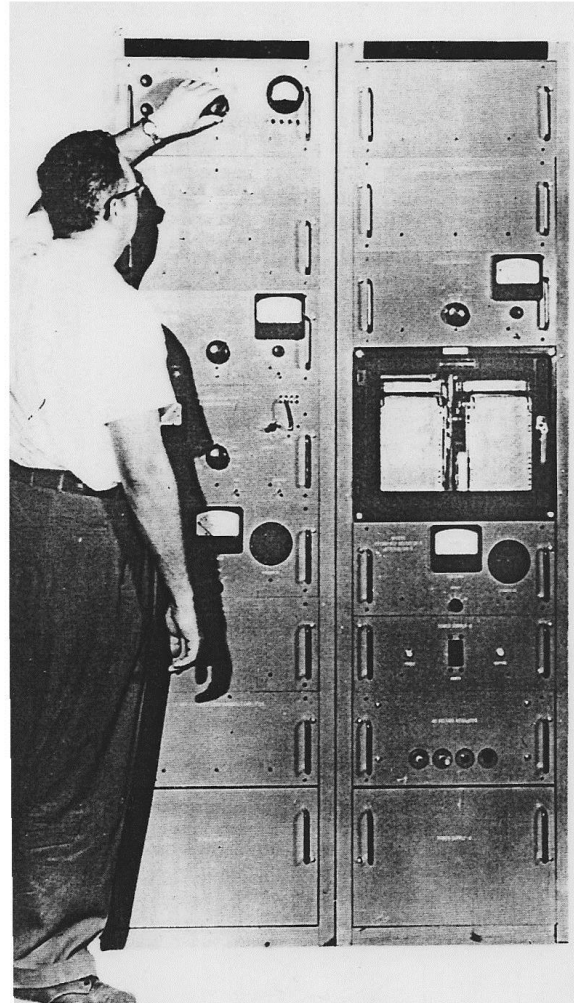
- **Frequencies:**
113 kHz – 20
MHz



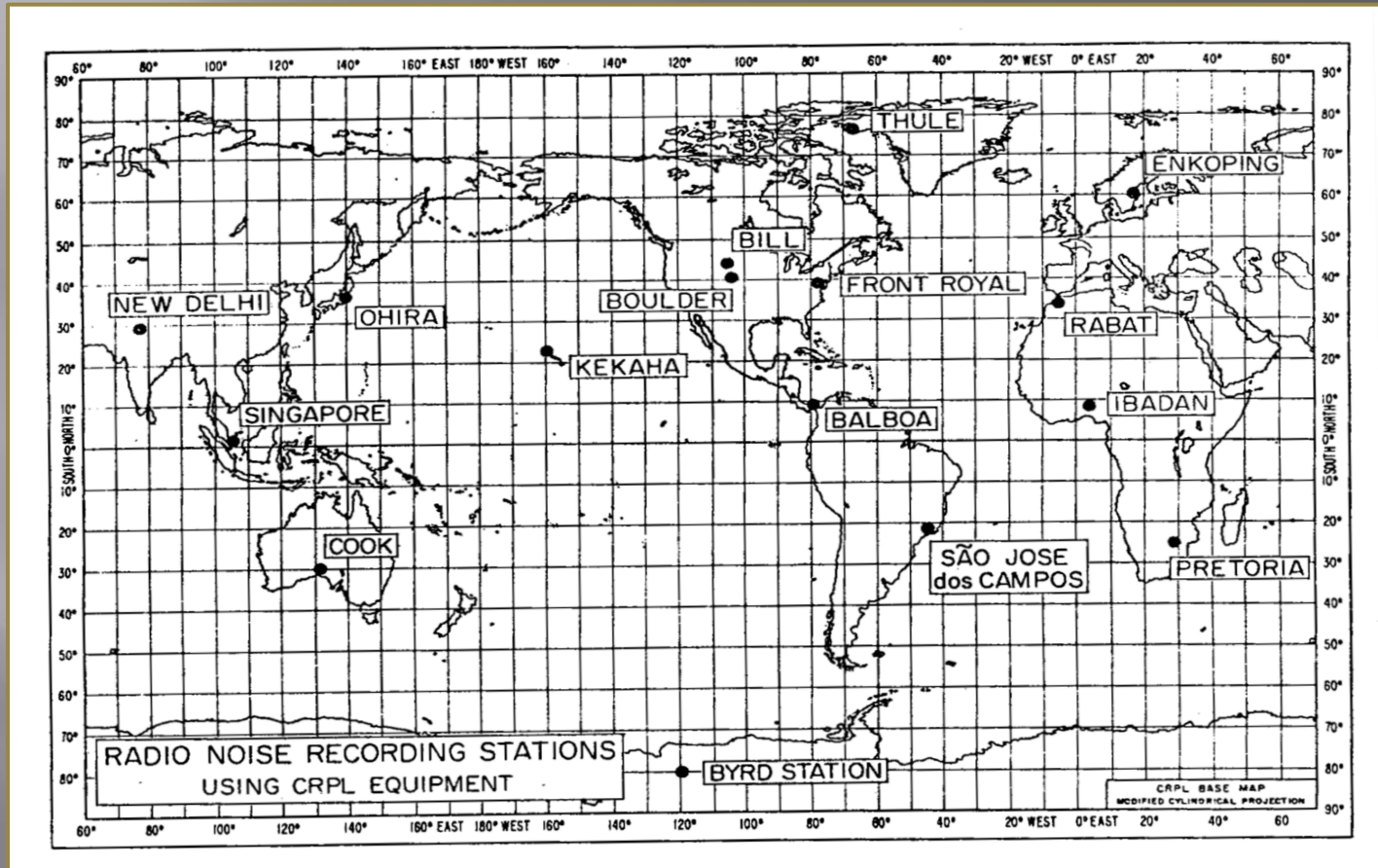
ARN-2 RECEIVER

- ❑ **ARN-2**
- ❑ **Noise Receiver**
- ❑ **8 frequencies**
- ❑ **(113 kHz-20 MHz)**

- ❑ **RMS and Vd**
recorded on EA
charts each hour.



GLOBAL ARN-2 NETWORK



ARN-2 Network: 16 stations operated by many nations 1956-1965. All personnel trained in Boulder, sites set up, EA chart records scaled and saved, equipment repaired in Boulder and returned to site.

ARN-2 NOISE MAPS

World noise maps:

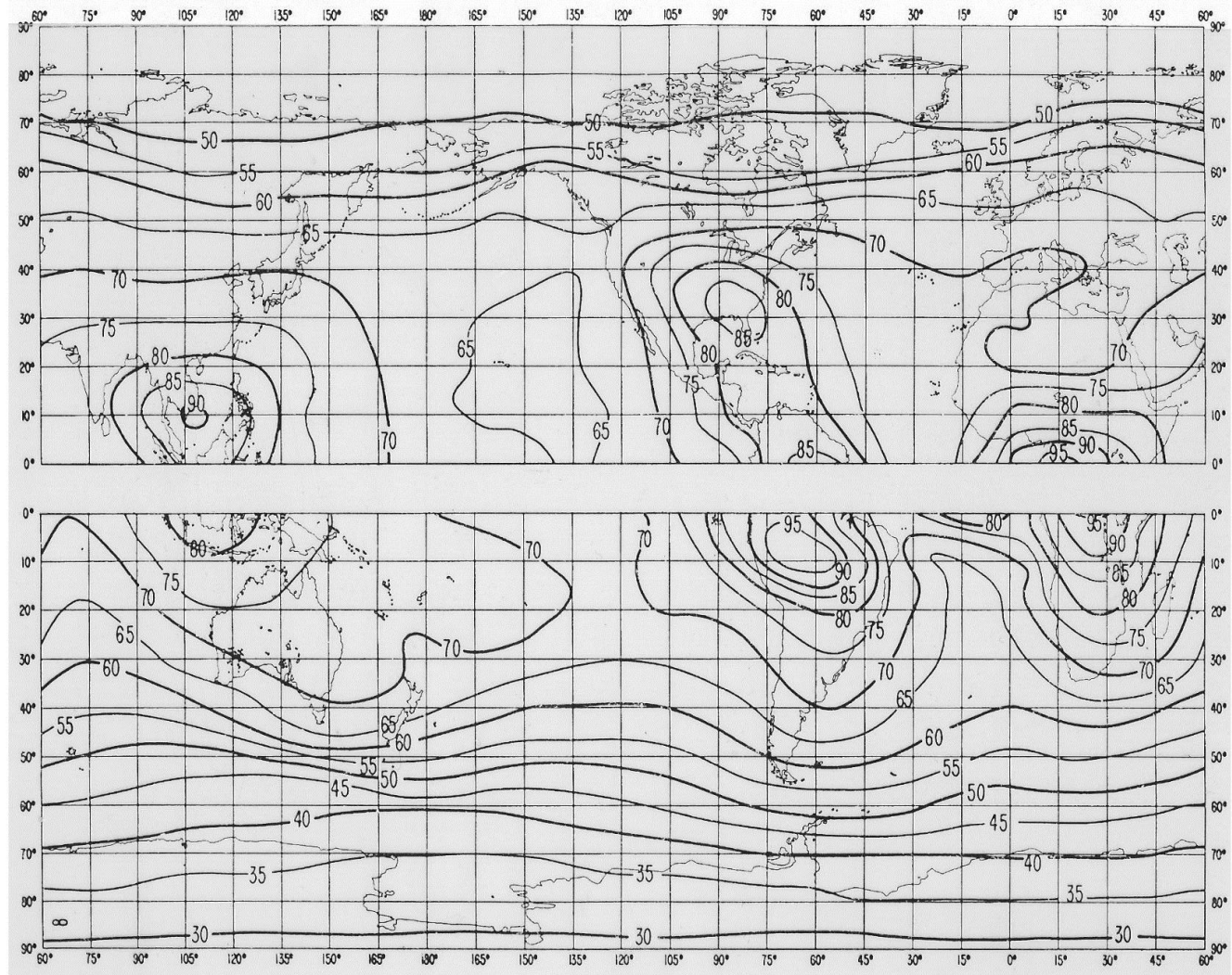
8 frequencies

Four seasons in a year.

Six 4-hr blocks in each day.

5-dB contour spacing

CCIR Report 322 (1964) and future upgrades



ARN-2 NOISE MAPS

ARN-2 Noise Program mission was largely completed with CCIR Report 322 in 1964.

After “Cold War” ended, Russians and Chinese released compatible noise measurements and a revised report was created using the new data – NTIA TR-85-173.

New radio technology has made these measurements less valuable.

1. Satellites, undersea optical fiber, higher radio frequencies have greatly eclipsed HF importance.
2. Automatic Link Establishment (ALE) continuously monitors several frequencies and chooses best.

NOISE MEASUREMENT

- ARN is impulsive noise produced by numerous, random (time and amplitude) lightning strokes.
- How can a bunch of random impulses be measured in a meaningful way?

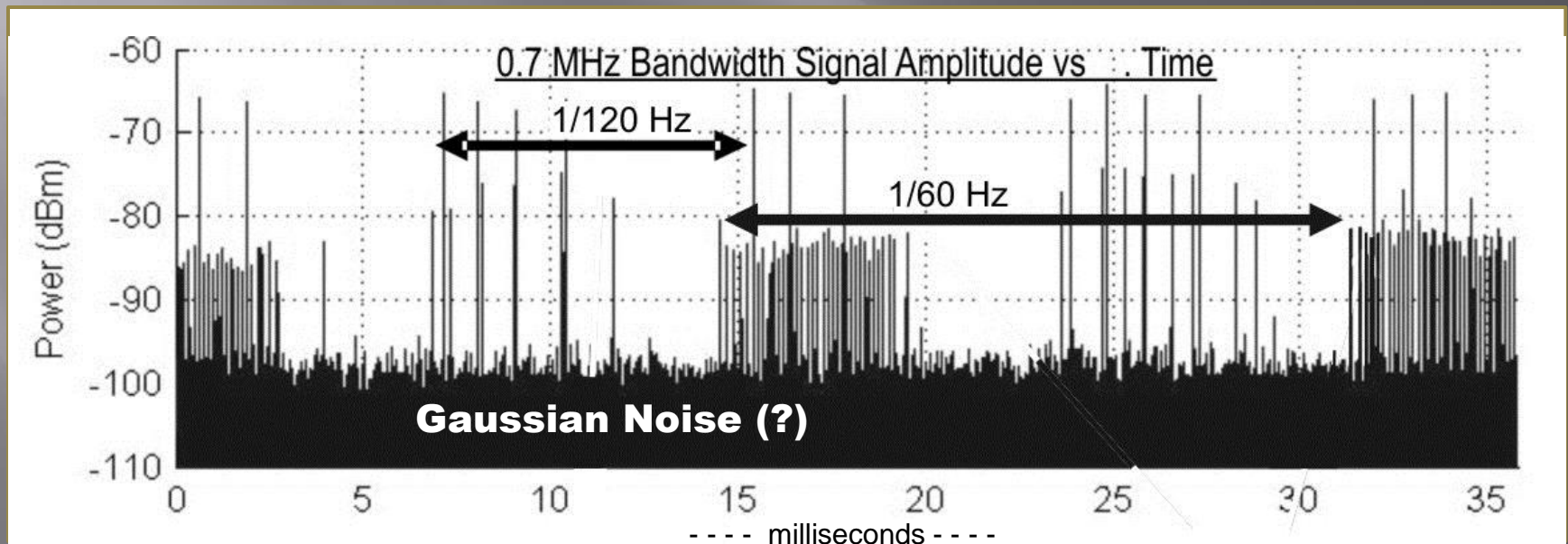
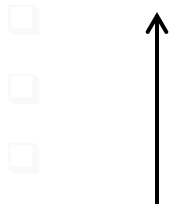


Figure from Mark McHenry's 2013 Powerline noise measurements - 2013. (67 MHz, 700 kHz BW)

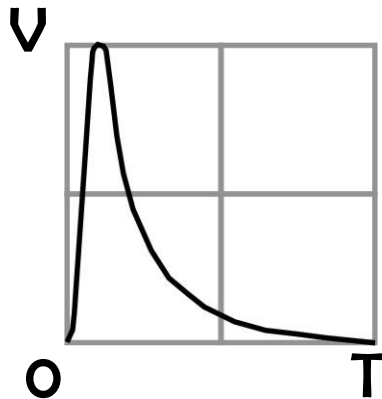
MEASURING EM IMPULSES

Impulse = finite total energy
infinite peak power
zero time duration
very wide uniform spectrum

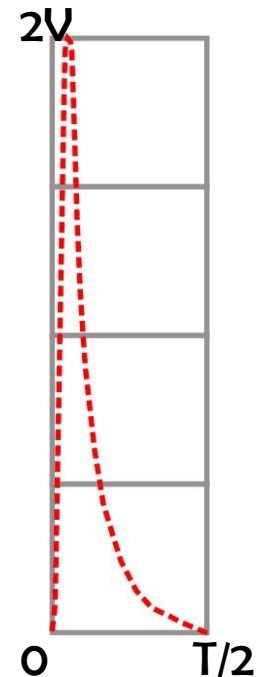
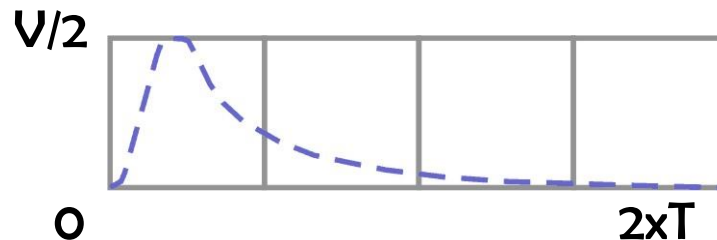


Bandwidth = $2B$

Bandwidth = B



Bandwidth = $B/2$



LARGER BANDWIDTH?

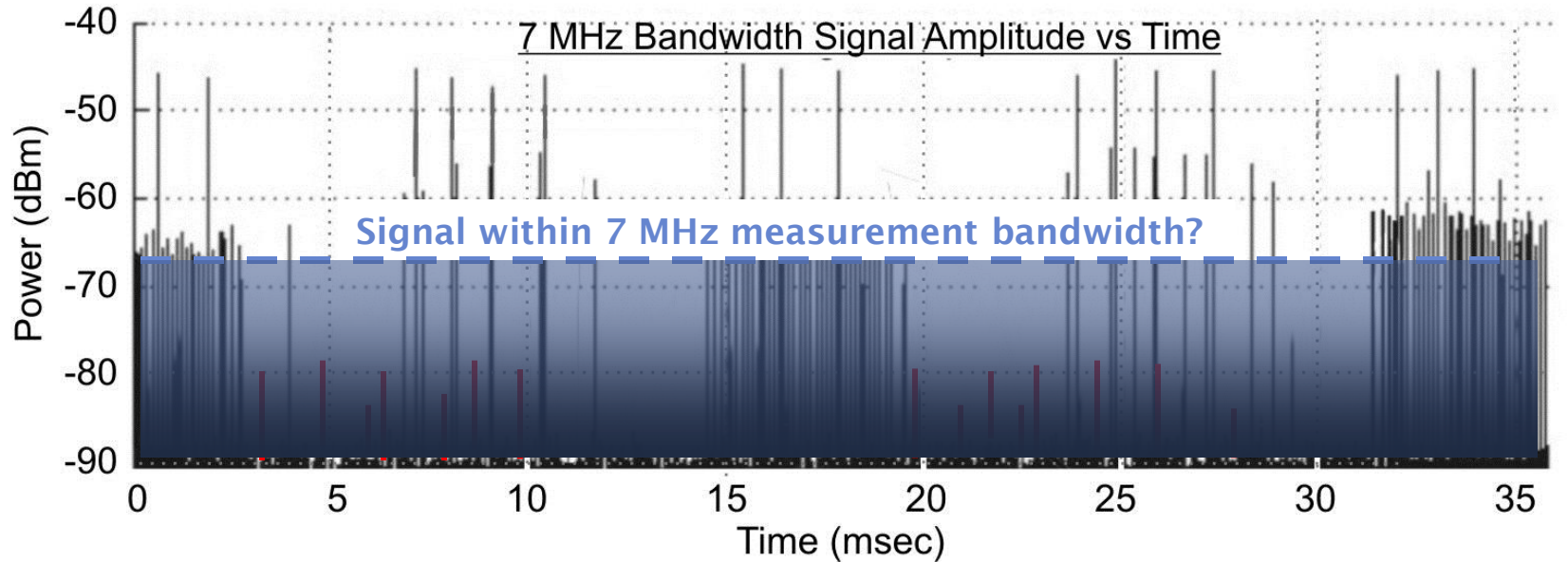
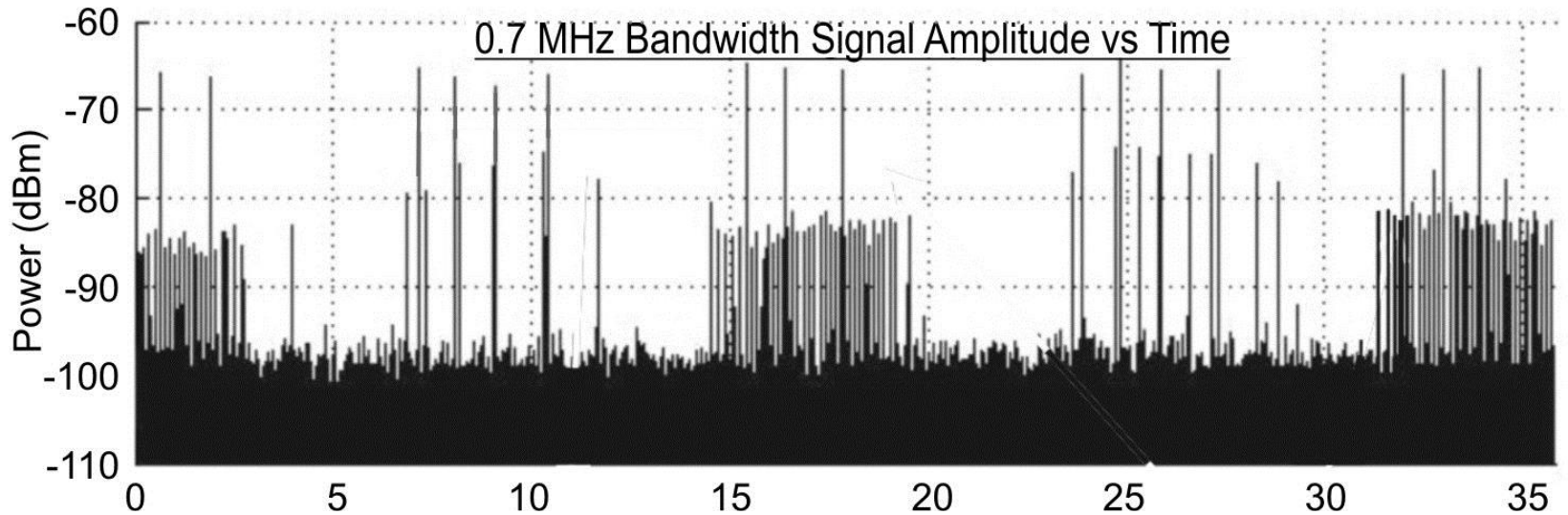
- Suppose the previous 700 kHz powerline noise were measured in a larger bandwidth? Perhaps 7 MHz BW (i.e., $10 \times B$) ...

- Bandwidth = $10 \times B$
dB to impulse amplitudes
dB to system noise

Add 20
Add 10

- Note: 10 dB greater impulse-to-system noise ratio

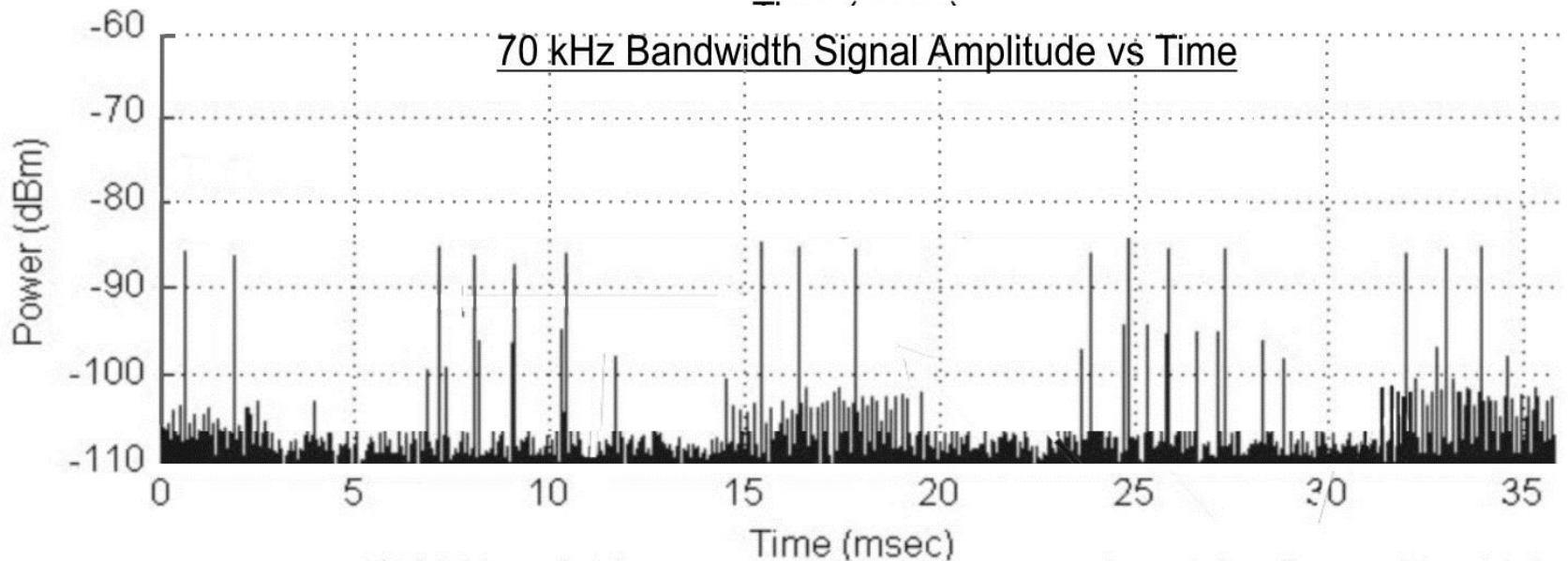
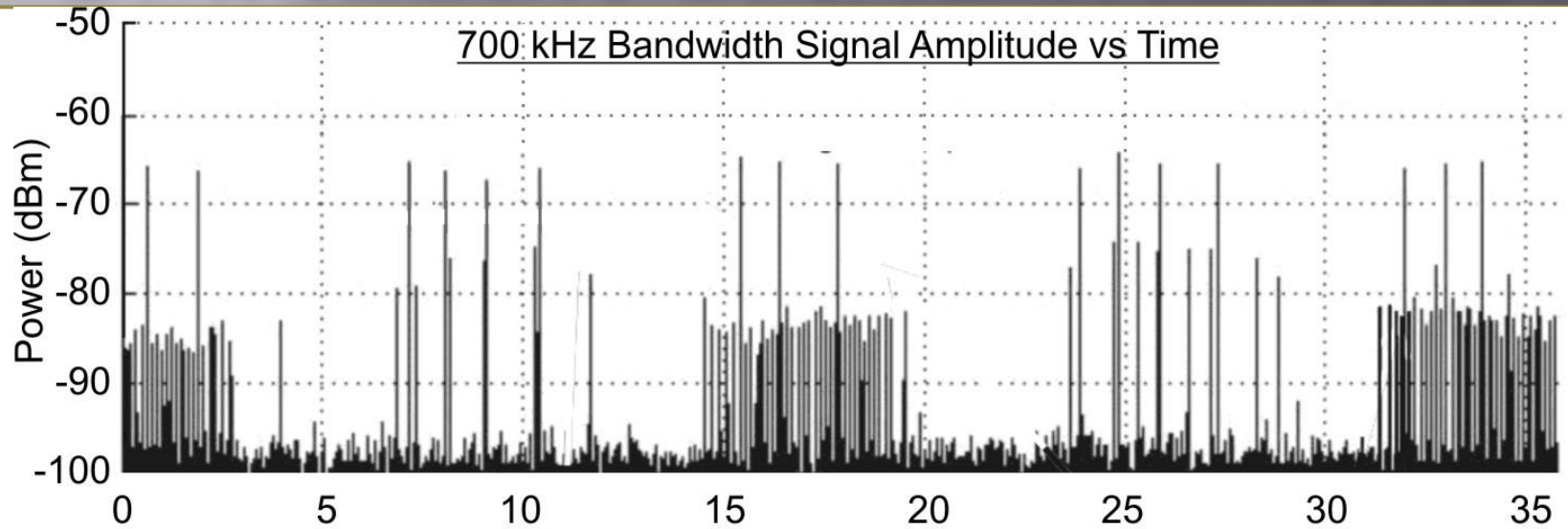
LARGER BANDWIDTH?



SMALLER BANDWIDTH?

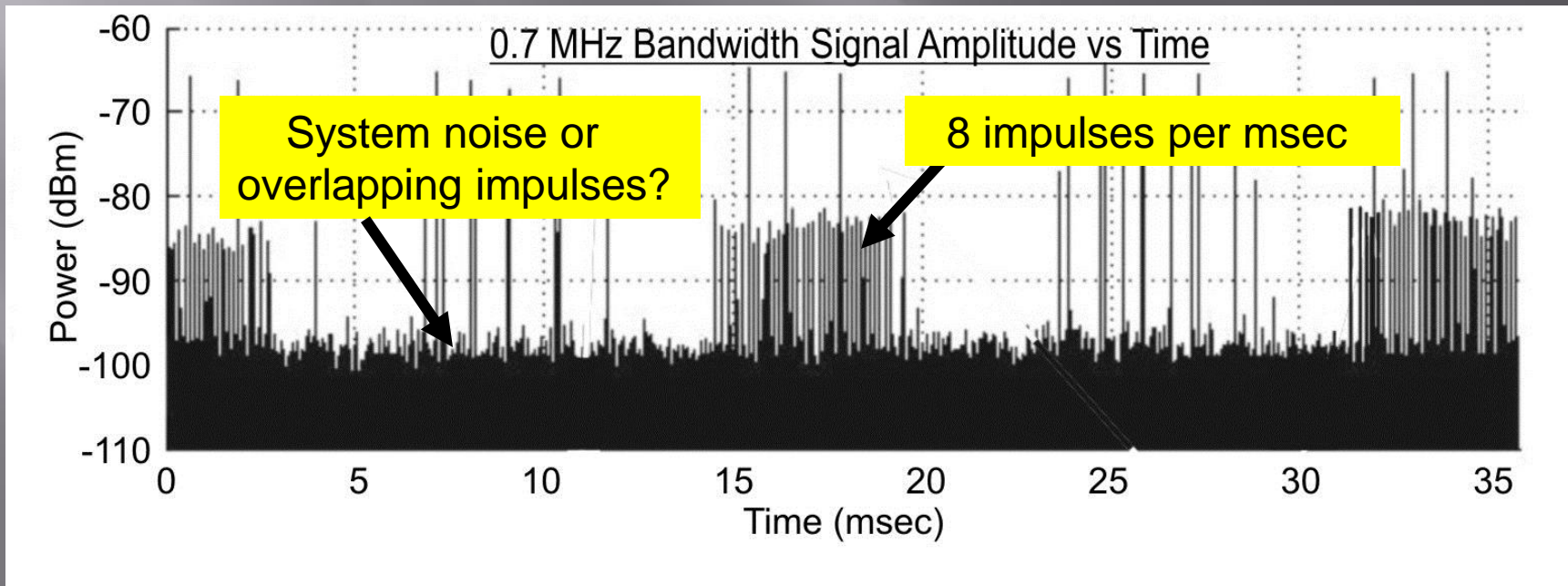
- Suppose the previous 700-kHz powerline noise were measured in a smaller bandwidth?
Perhaps 70 kHz BW (i.e., $0.1 \times B$)?
- Bandwidth = $0.1 \times B$:
Subtract 20 dB from impulses
Subtract 10 dB from system noise
- Note: 10 dB smaller impulse-to-SN ratio

SMALLER BANDWIDTHS?

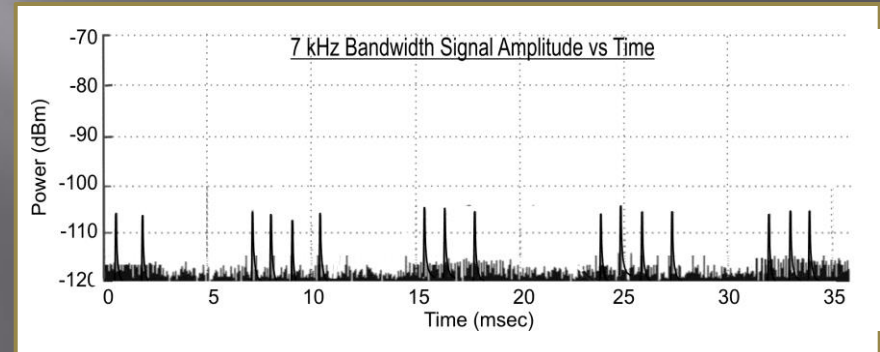
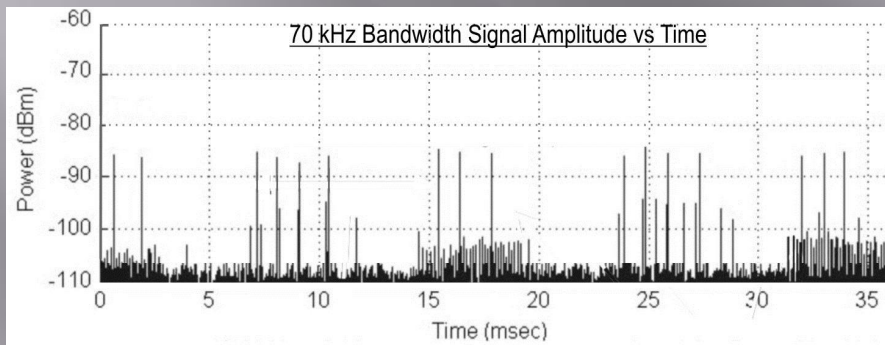
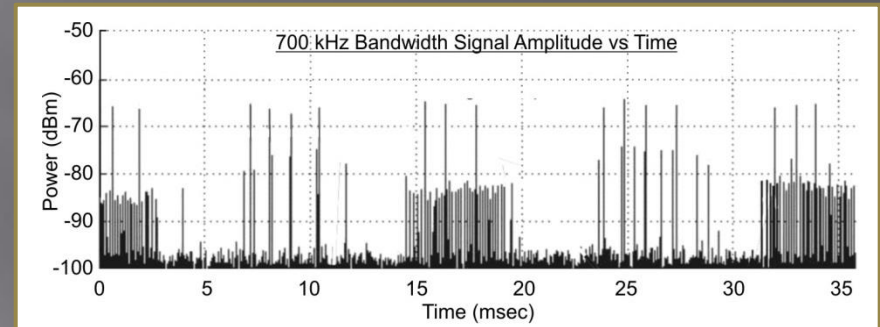
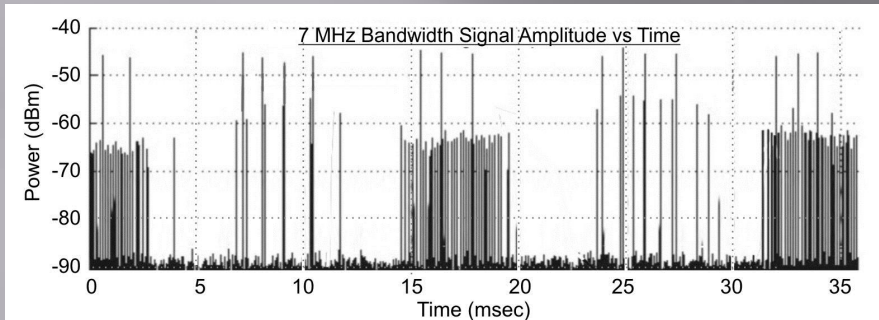


VERY SMALL BANDWIDTH?

- Suppose the previous powerline noise had been measured in a very small bandwidth? Perhaps 200 Hz ? (ARN-2) 4 kHz? (MMN) Pulses overlap, adding together in random phases, giving Gaussian-like noise.



VARIOUS BANDWIDTHS?



- ❑ Question: Which bandwidth gives the “right” answer to “show” the amount of noise?
- ❑ Answer: Wider BW impulses are higher, but possibly too fast (short duration) to see.

CHOOSING BANDWIDTHS

- How do you choose a measurement bandwidth?
 - Choose bandwidth of prospective system, if known.
 - Larger bandwidth data can be reduced to smaller BW easier than smaller BW can be changed to larger BW.
- Problems with larger bandwidth measurements:
 - Need wider signal-free spectrum (signals contaminate noise measurements). Digitally excise signals?
 - Larger bandwidth requires wider dynamic range and faster amplitude changes.
 - Collect and process larger amounts of data if sampling based on X hours/min/sec to get statistical reliability.

HISTORIC BANDWIDTHS

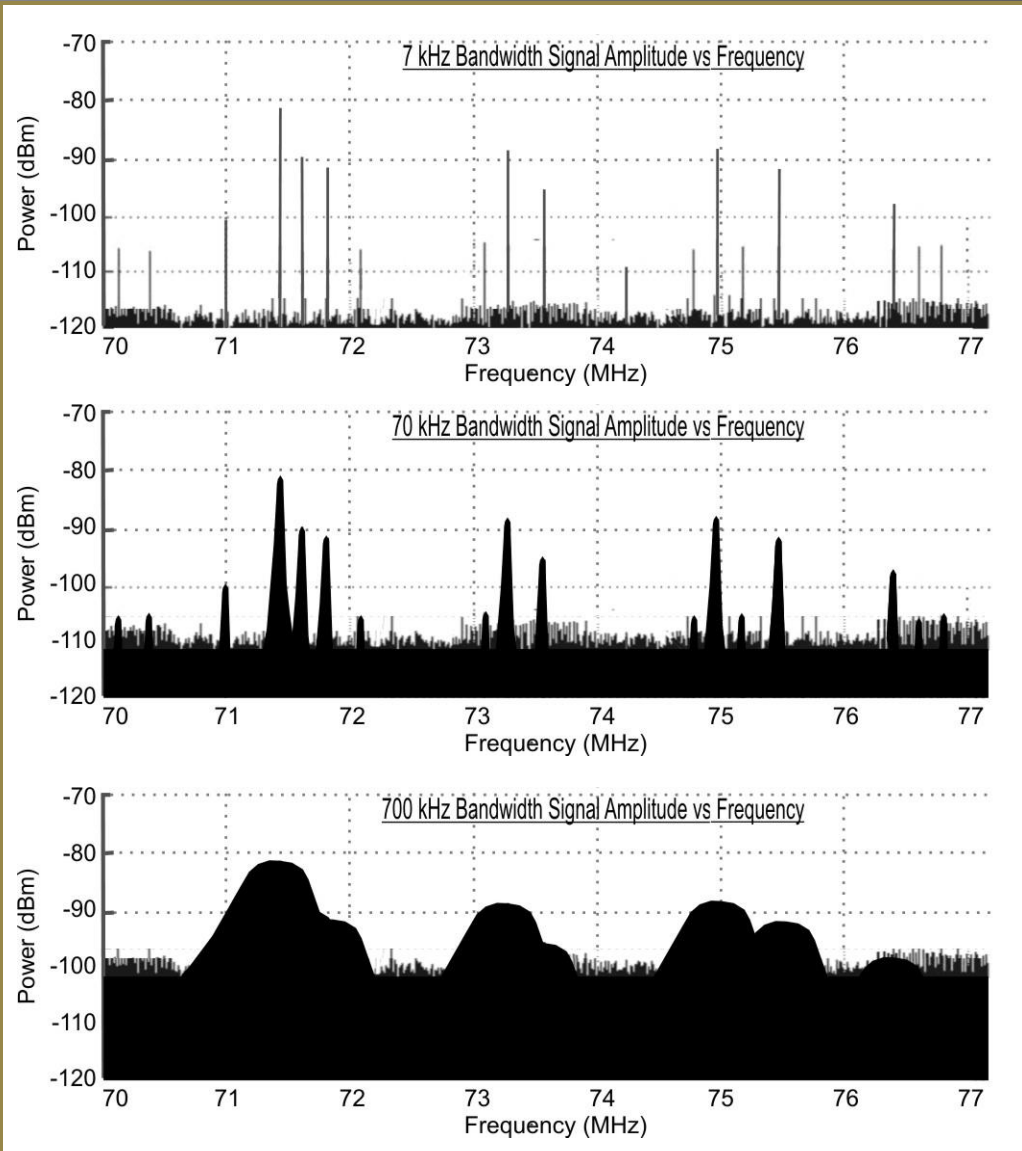
- ARN-2 program: 200 Hz BW – dense signal environment over whole 0-20 MHz range. Used narrow guard-bands around WWV standard time signals (2.5, 5, 10, 20 MHz) + 13, 51, 160, 495 kHz.
- Limited dynamic range RMS detector (30-40 dB)
- ITS Man-Made Noise (MMN) measurements, 1965-75, .25-250 MHz, 4-kHz or 10-kHz BW, 60-dB RMS detector
- ITS 2001 MMN: 30 kHz, 2009 MMN: 1 MHz BW

SIGNALS VS BANDWIDTH

In a typical frequency scan of narrowband signals, 10 x wider bandwidth raises system noise 10 dB, while signal amplitude remains same, hiding weaker signals below system noise.

Also, 10 x wider bandwidth widens the spectral response, causing stronger signals to hide weaker signals.

Therefore, wider measurement bandwidth generally hides information on details of signal population, but improves details on impulsive noise populations.



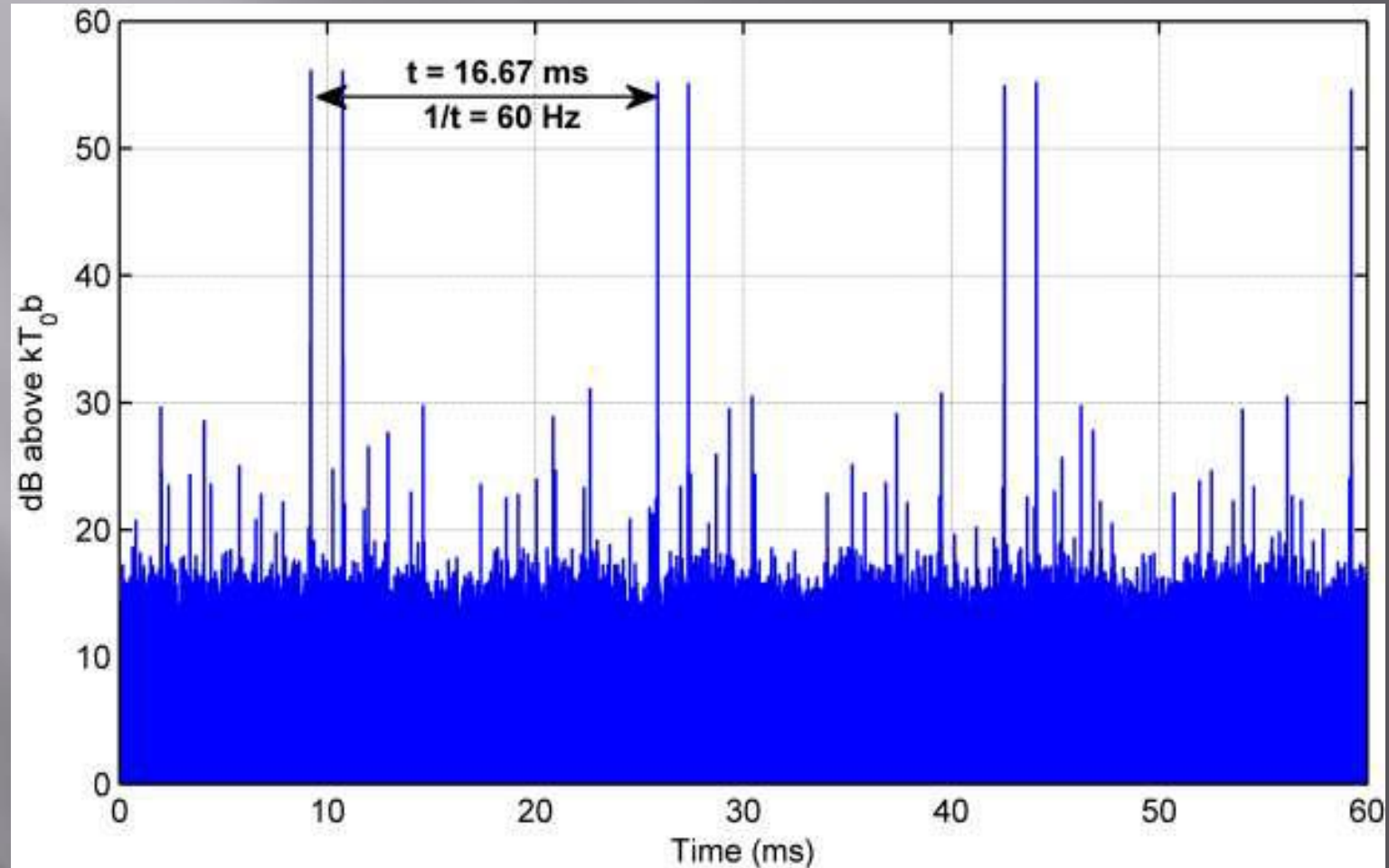
SIGNALS VS IMPULSES:

- Note that measurement bandwidth typically affects signals and impulses in “opposite” ways.
- Impulsive noise: Increasing bandwidth **increases** the distance above internal system noise, makes more noise impulses appear.
- Signals: Increasing bandwidth **decreases** the distance above system noise for CW/modulated signals, signals overlap, makes fewer signals less visible.

STATISTICAL NOISE DATA

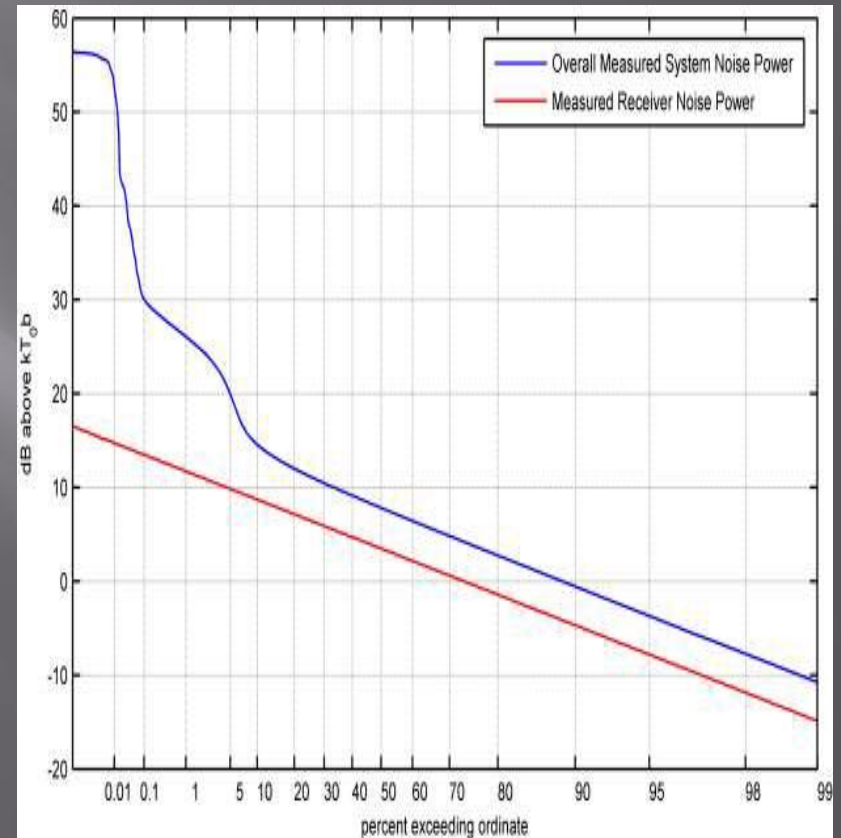
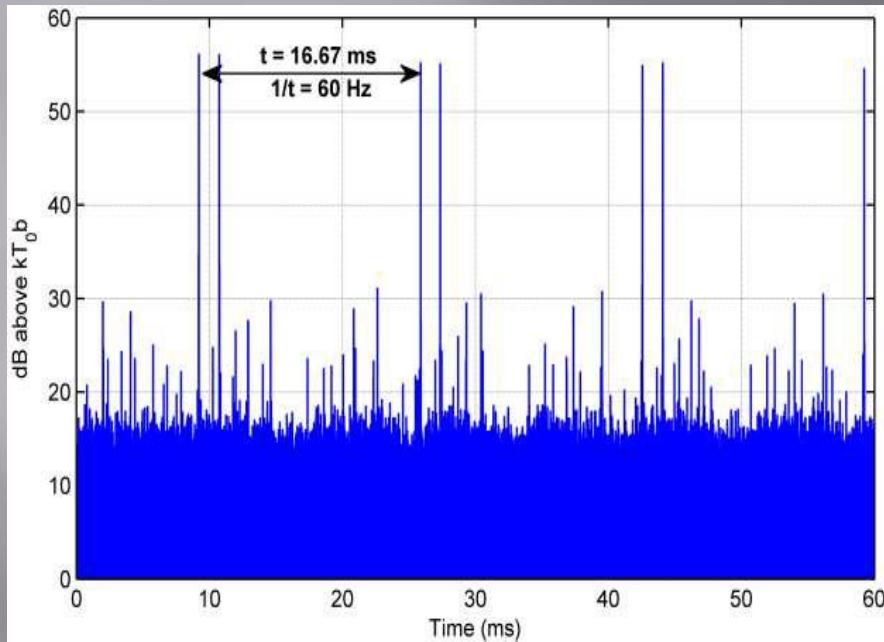
- Question: How Can Statistical Noise Data Be Easily Summarized?
- Raw data - Highly detailed, but much more complex than for most needs.
- APDs (Amplitude probability distributions) - Good summary of amplitude statistics, but no time statistics.
- Various weighted averages –
 - RMS - Average noise power/Hz - power per unit BW
 - V_d – dB ratio between RMS and average voltage
 - L_d – dB ratio between RMS and average log voltage
 - Quasipeak – traditional, interference to AM voice

STATISTICAL NOISE DATA



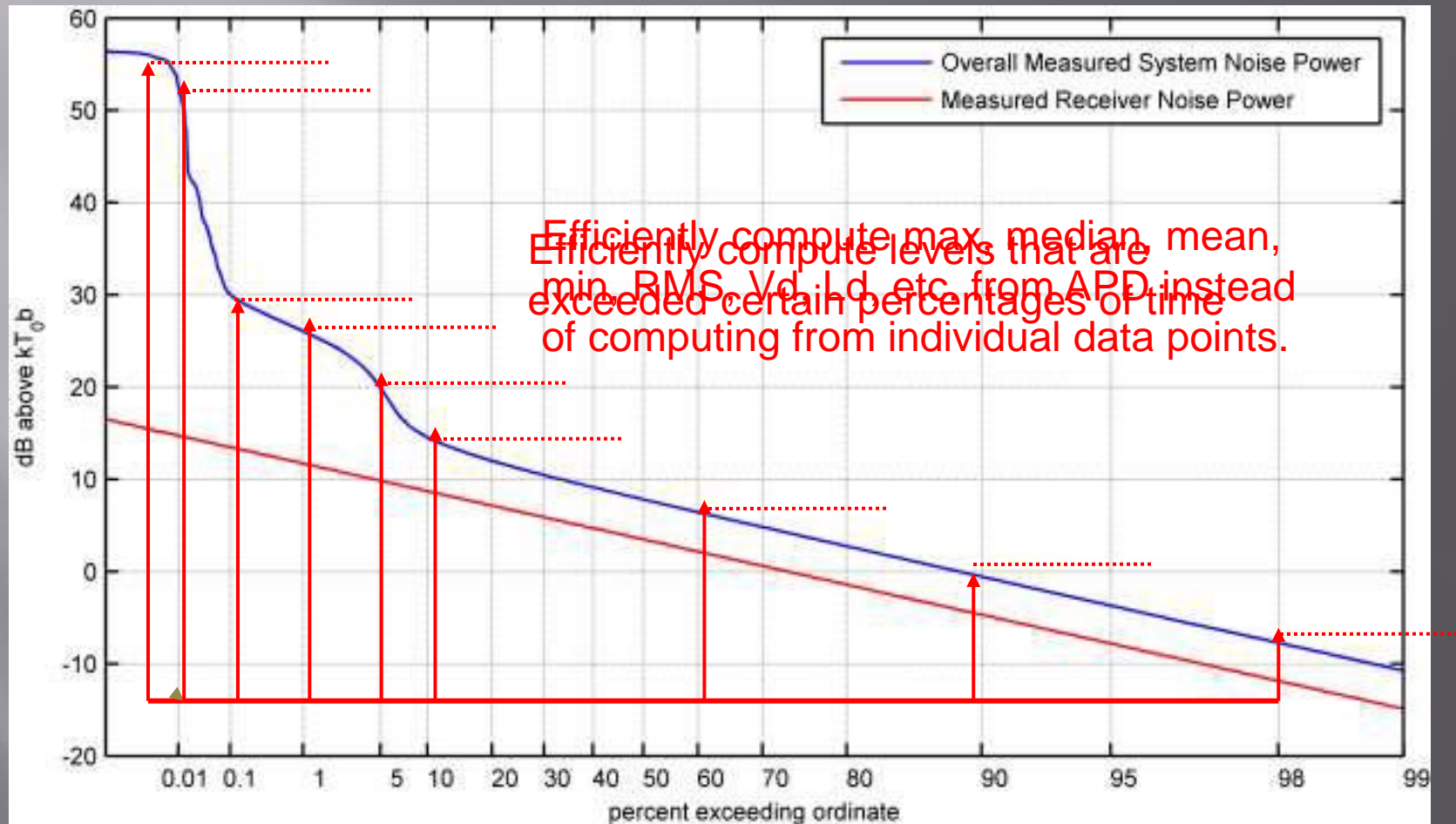
Wepman, Figure 14. Noise time sample, 112.5 MHz, residential, 0349 AM.

STATISTICAL NOISE DATA



Summarizing data samples in APD or similar forms give an easy way to see impulsiveness of noise, detect low-level signals, identify independent noise sources, etc.

STATISTICAL NOISE DATA

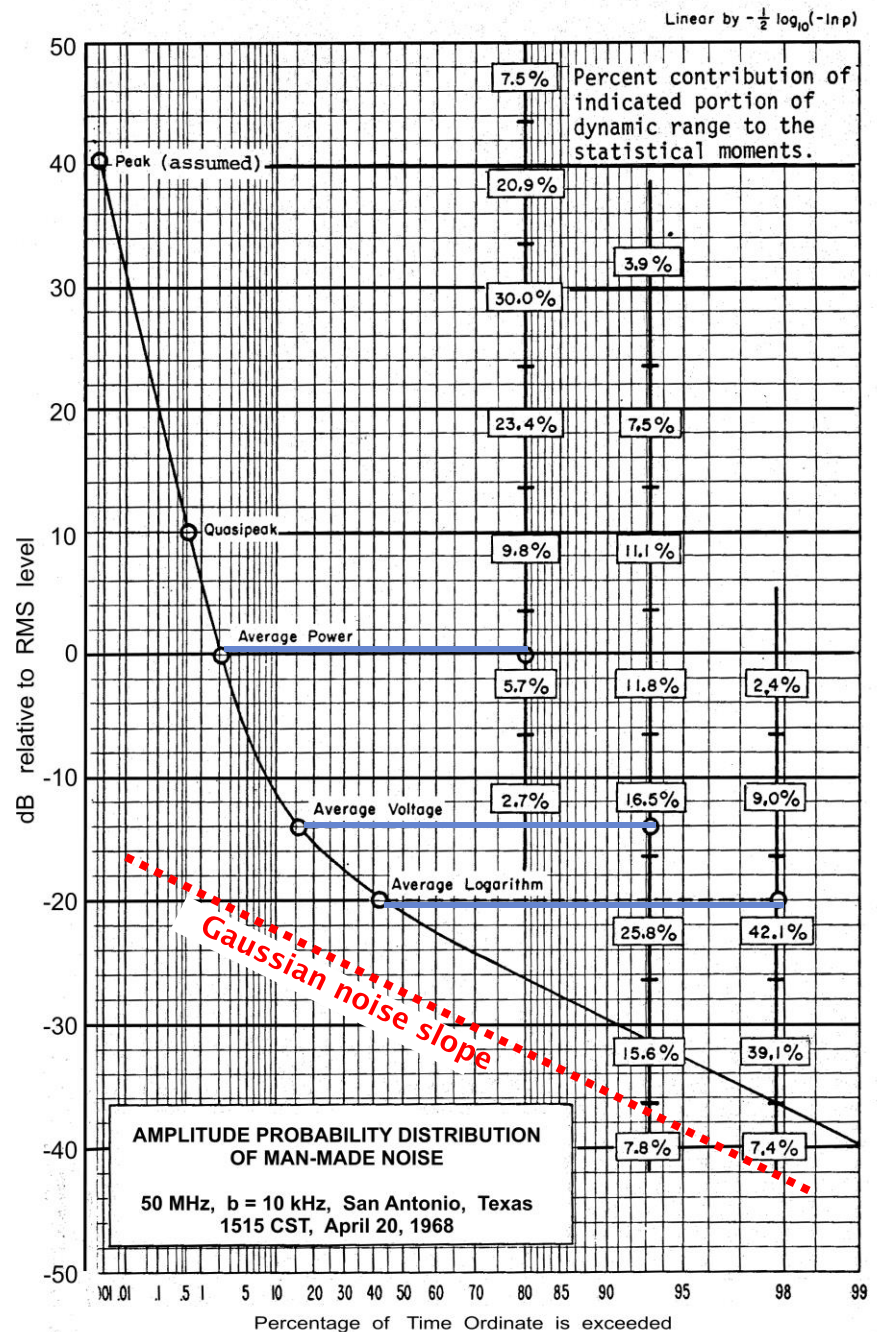


APD is an efficient form of data summary, representing possibly 100's of millions of data points, but stored as 200-300 points

ITS MOBILE NOISE APD

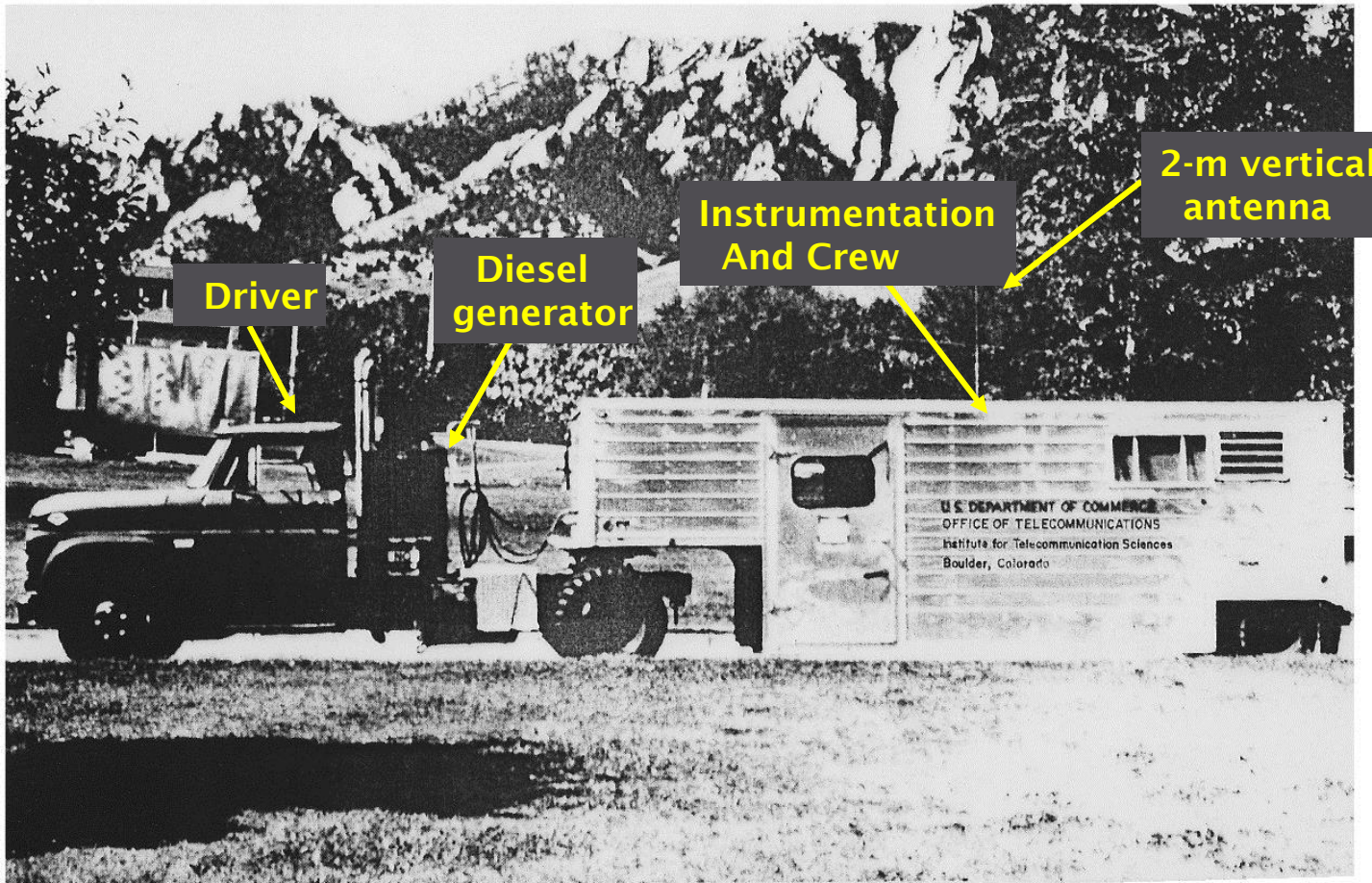
APDs contain a statistical summary of data used to calculate various detector modes.

Or, data can be processed real-time by various detectors and used to infer APDs.
ARN, but less MMN



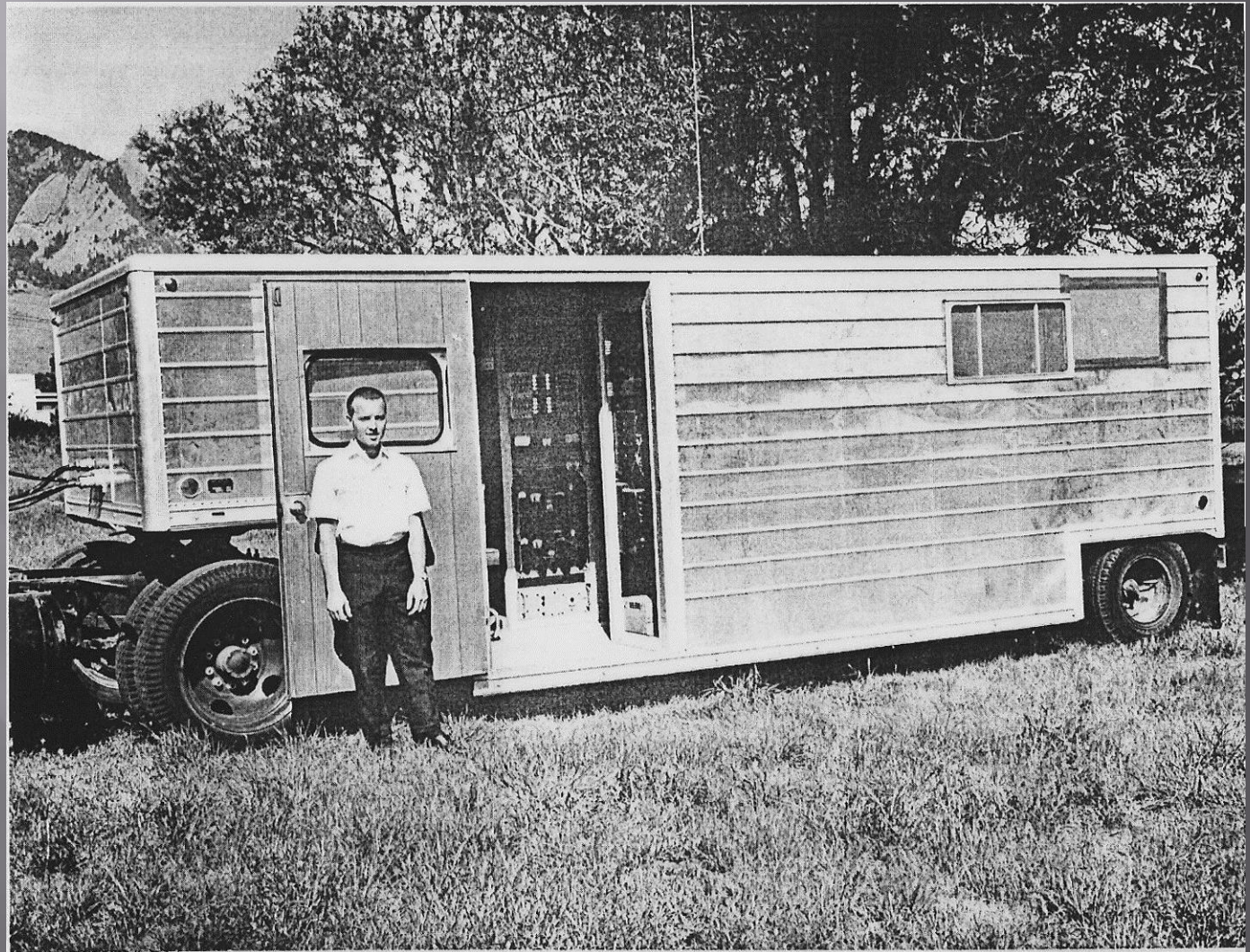
ITS MOBILE NOISE LAB

1966 -1971 - ITS MMN measurement program.



ITS MOBILE NOISE LAB

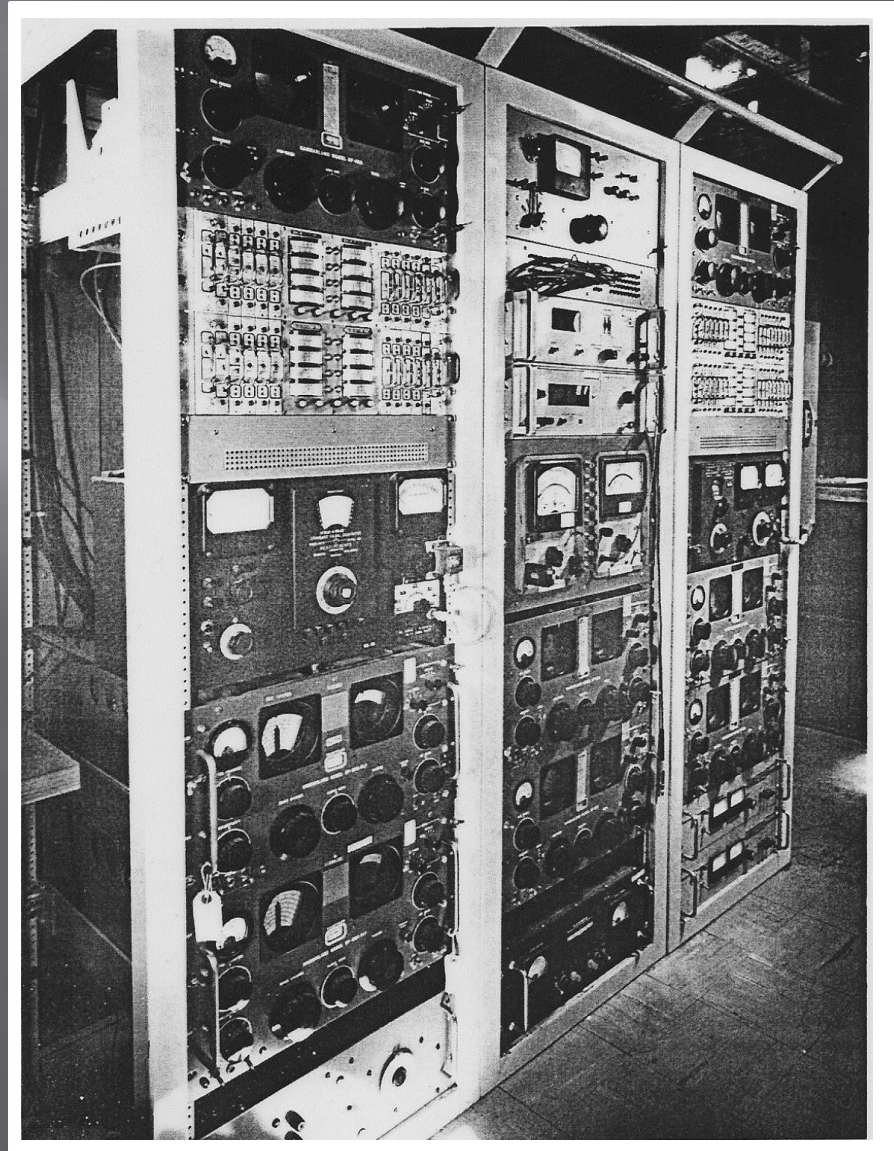
□ 1966-71



ITS MOBILE NOISE LAB

- ❑ Eight frequencies –
250 kHz to 250 MHz
- ❑ 4 kHz or 10 kHz
Bandwidth
- ❑ RMS, V_d , L_d , Q_d
- ❑ Sampled every 10 sec

- ❑ Vacuum tube receivers
- ❑ Transistor metering strips



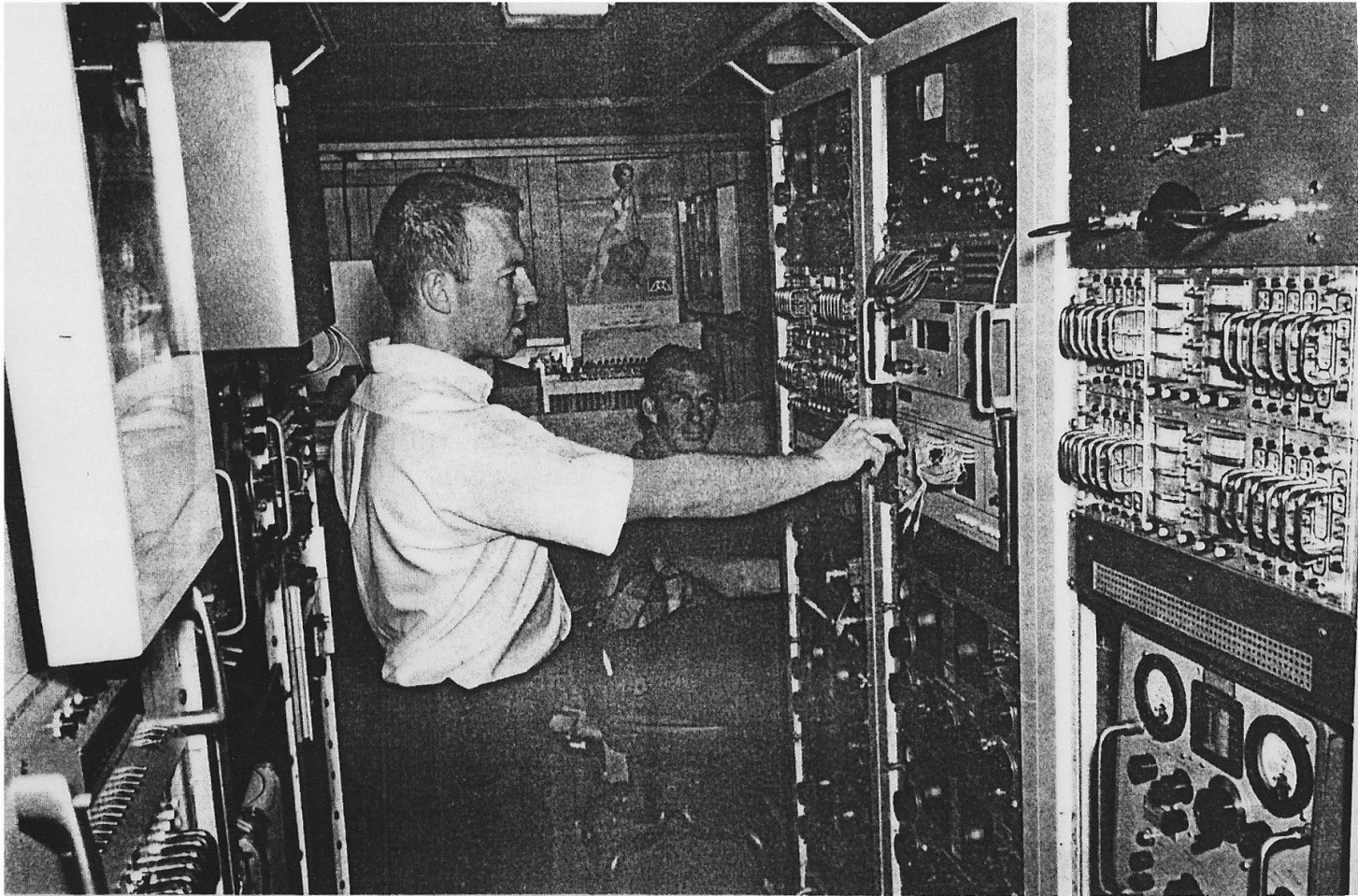
ITS MOBILE NOISE LAB

- ❑ 8 receivers, 4 outputs digitized and recorded on digital mag tape every 10 sec.
- ❑ Mileage (0.01 mi res), time, and log event #.
- ❑ EA chart backup
- ❑ Optional printer output
- ❑ DM-2 gives 15-level APD for one channel.



ITS MOBILE NOISE LAB

Typical operational configuration



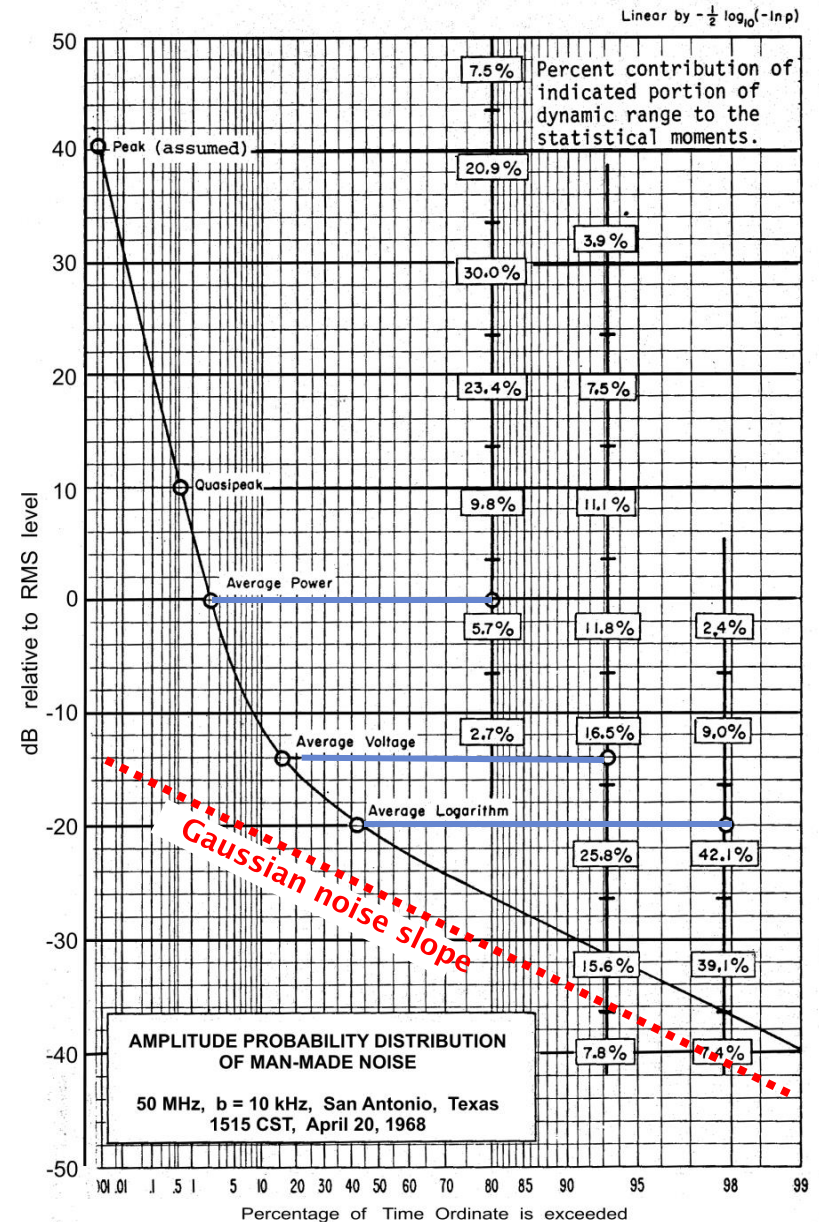
ITS MOBILE NOISE LAB

Three major measurement modes:

- ▣ Parked in various types of neighborhoods – residential, business, industrial, powerlines, highways, etc.
- ▣ Driving through traffic, to measure ignition noise in typical LMR environments.
- ▣ Multiple drives over fixed course to get average noise level contour maps of an area.

ITS MOBILE NOISE APD

- 8 channels of RMS, Vd, Ld, Qd detectors.
- 1 channel of APD
- Correlate APD & dets so that detector read-ings provided likely APDs.
- Large dynamic range needed for various detectors.

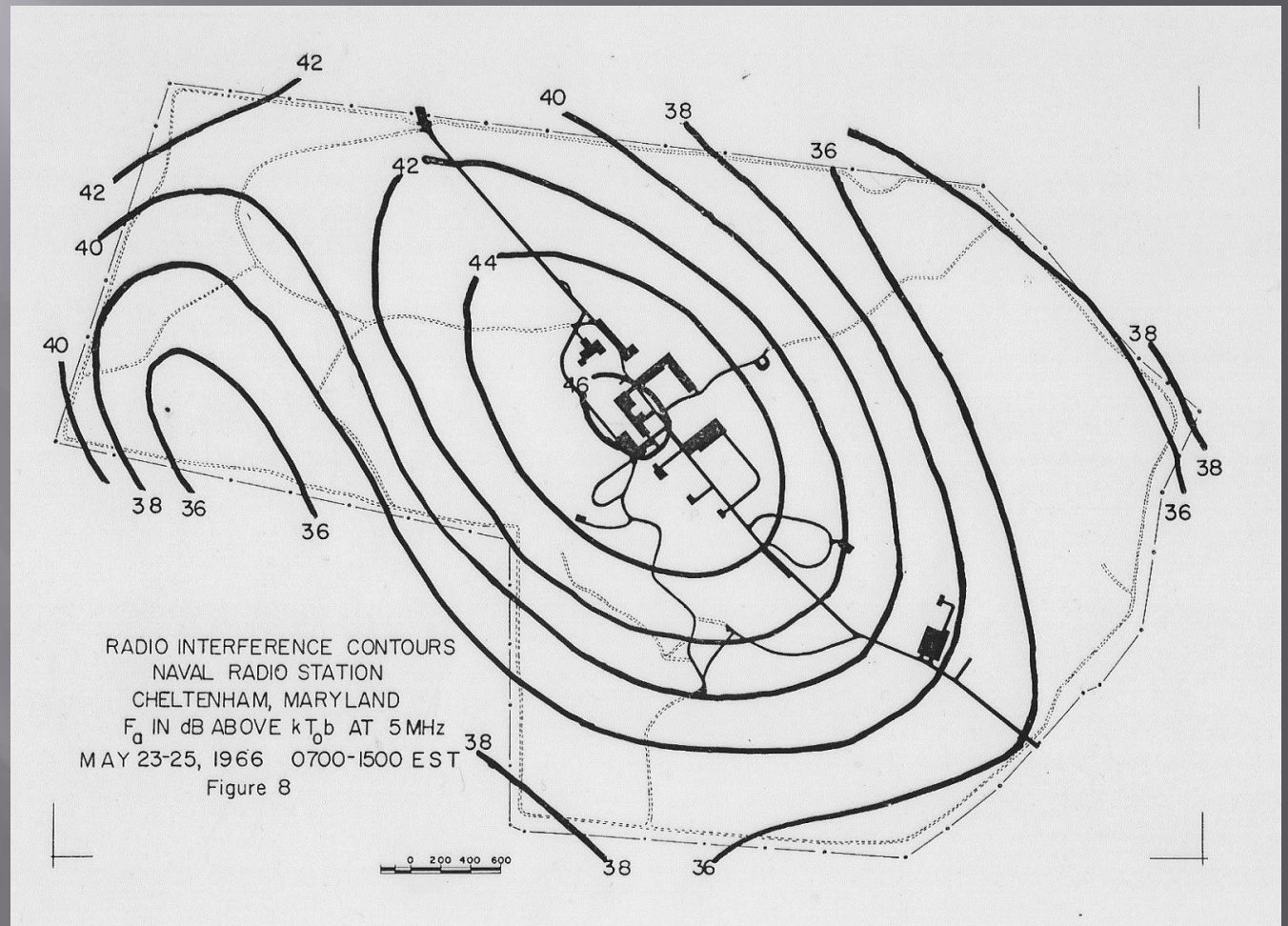


NOISE CONTOUR MAP

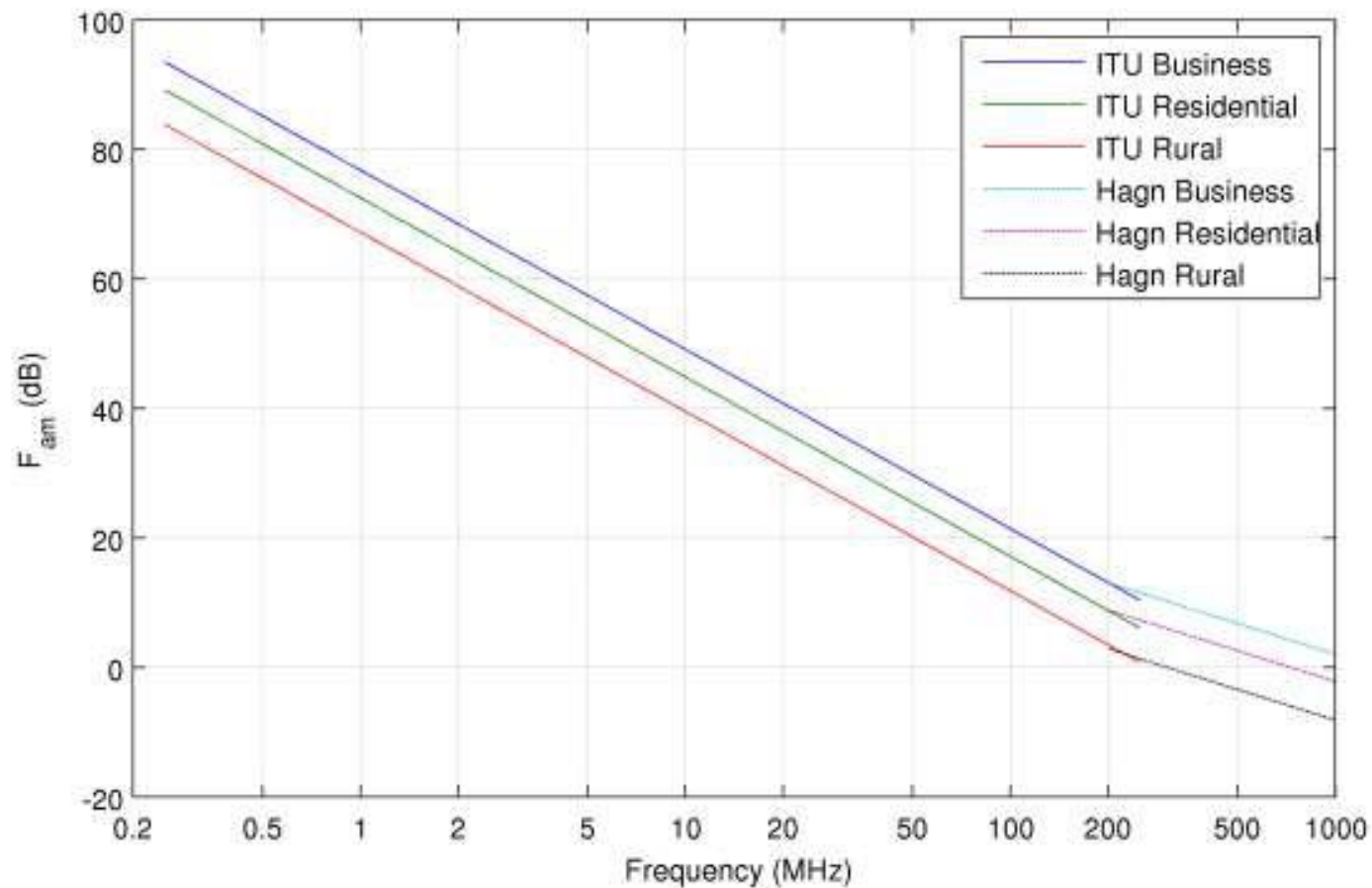
Geographical markers and mileage give location info.

Multiple passes over fixed route gives data for noise contour map.

Noise from base activities.



STATISTICAL NOISE DATA



PROGRAM:

- Following the 1965-1972 ITS MMN program, results were summarized by Spaulding “Man-Made Radio Noise – Part 1: Estimates for Business, Residential, and Rural Areas” NTIA Report OT-74-38.
- Measurements made occasionally to see if anything had changed significantly.
- Achatz & Dalke – “Man-made noise power measurements at VHF and UHF frequencies,” NTIA Report TR-02-390
- Wepman – “Wideband man-made radio noise measurements in the VHF and low VHF bands,” NTIA Report TR-11-478.
- Decisions against need for larger noise program to thoroughly upgrade results.

24-HR NOISE DATA

Wepman report “Wideband Man-made Radio Noise Measurements in the VHF and low UHF Bands,” NTIA Report TR-11-478 includes a number of 24-hr measurements at a number of different types of locations at 112 MHz, 220 MHz, and 401 MHz.

Note: Previous extensive spectrum scans to find frequencies without signals.

Some following examples

24-HR NOISE DATA

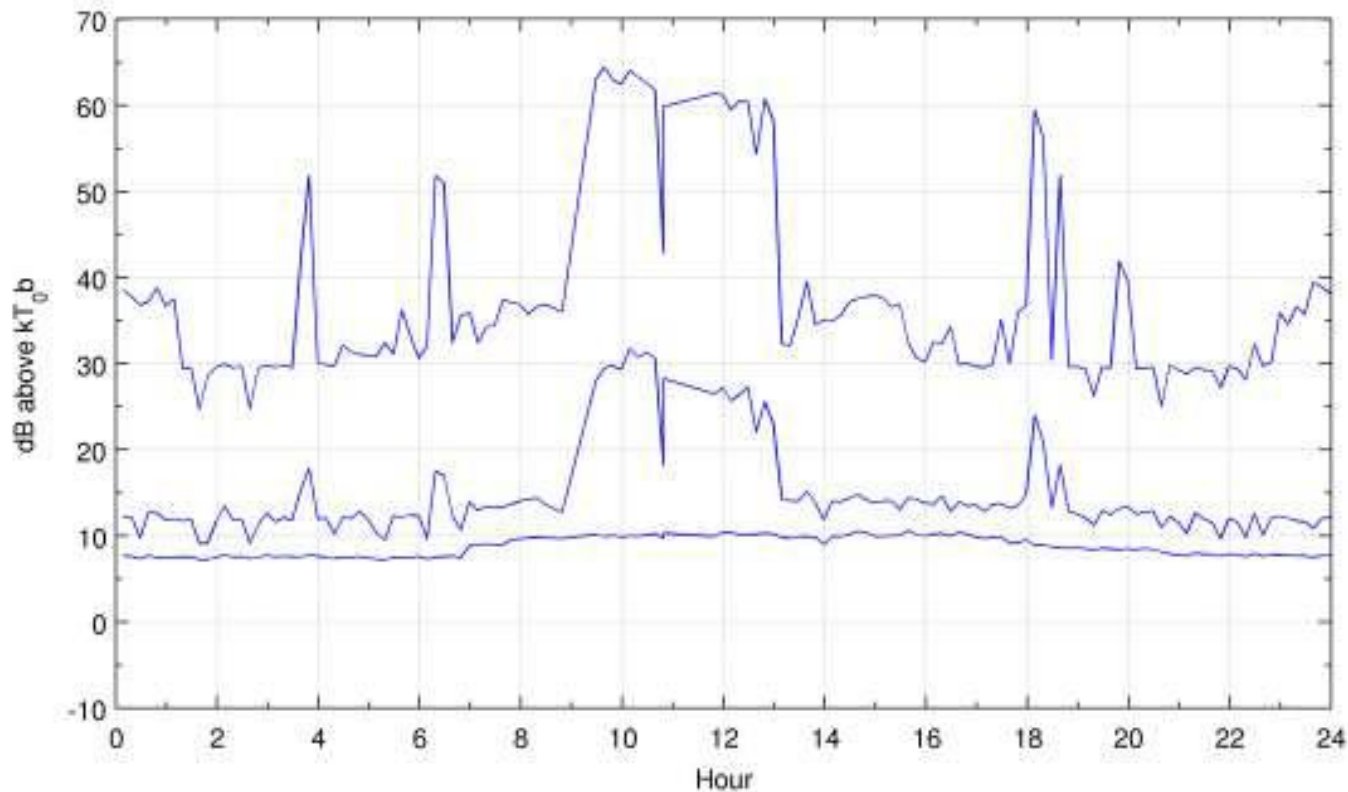


Figure 19. Median, mean, and peak measured noise power in a 1-MHz bandwidth at a center frequency of 112.5 MHz at the Boulder residential location (August 31-September 1, 2009).

24-HR NOISE DATA

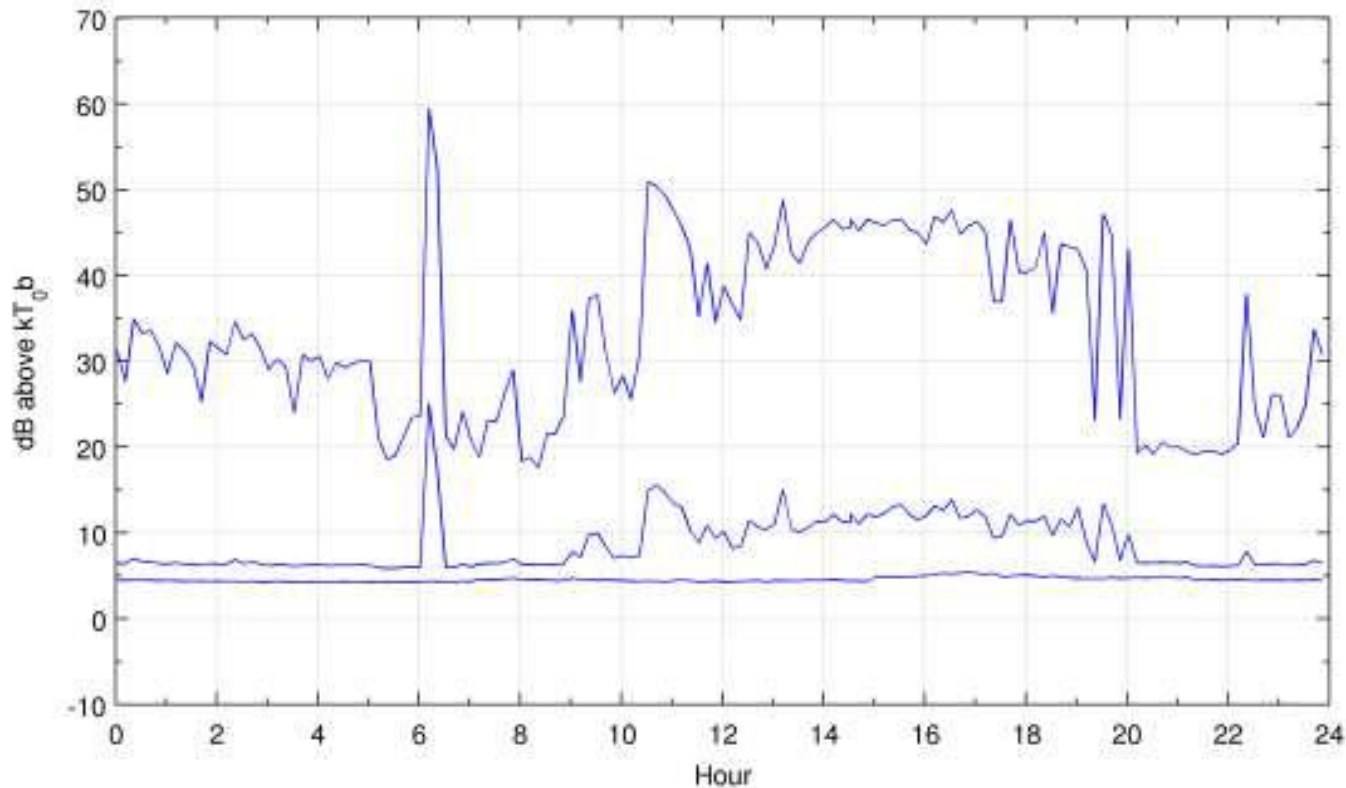


Figure 20. Median, mean, and peak measured noise power in a 1-MHz bandwidth at a center frequency of 221.5 MHz at the Boulder residential location (September 3–4, 2009).

24-HR NOISE DATA

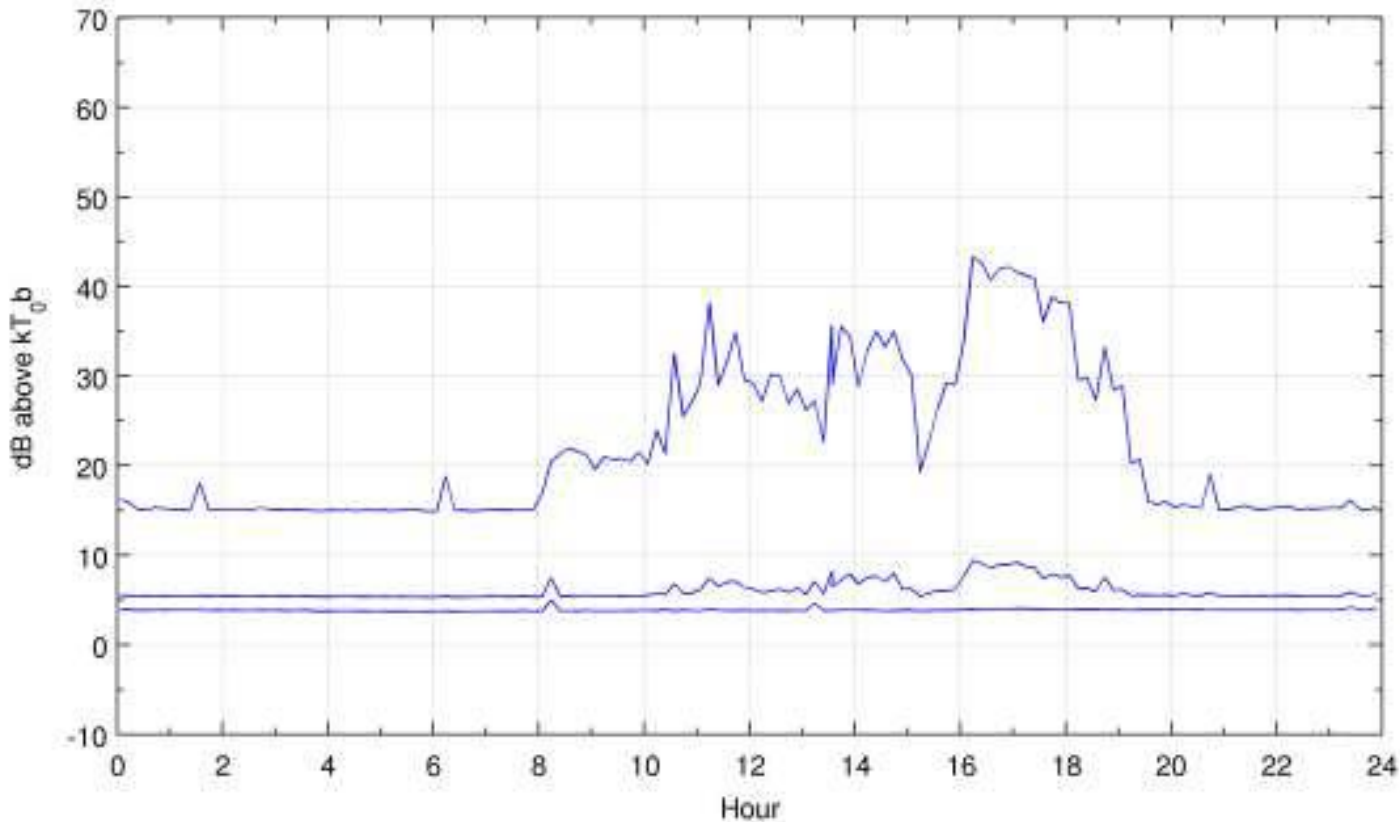


Figure 21. Median, mean, and peak measured noise power in a 1-MHz bandwidth at a center frequency of 401 MHz at the Boulder residential location (September 2-3, 2009).

24-HR NOISE DATA

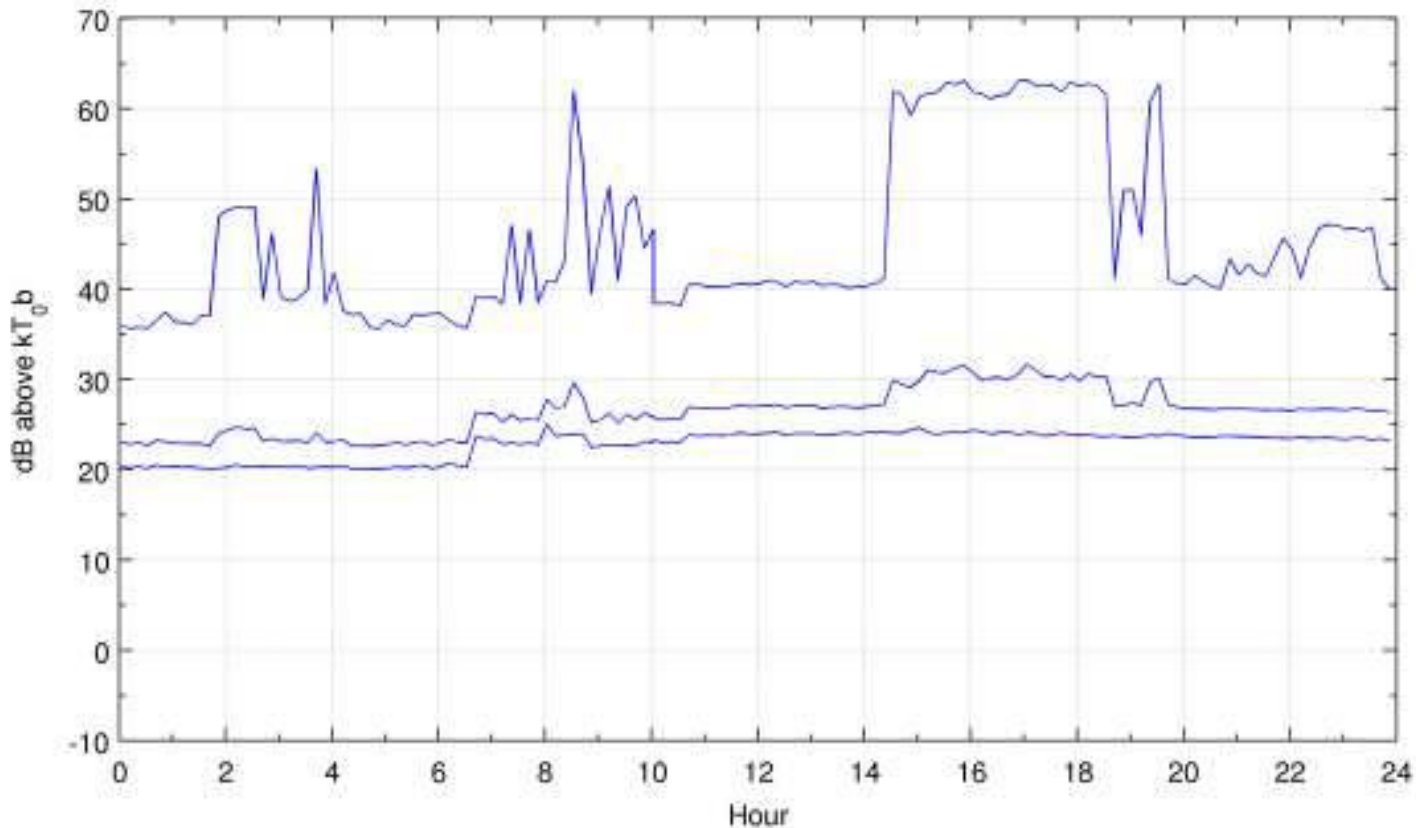


Figure 22. Median, mean, and peak measured noise power in a 1-MHz bandwidth at a center frequency of 112.5 MHz at the Boulder business location (July 21–22, 2009).

24-HR NOISE DATA

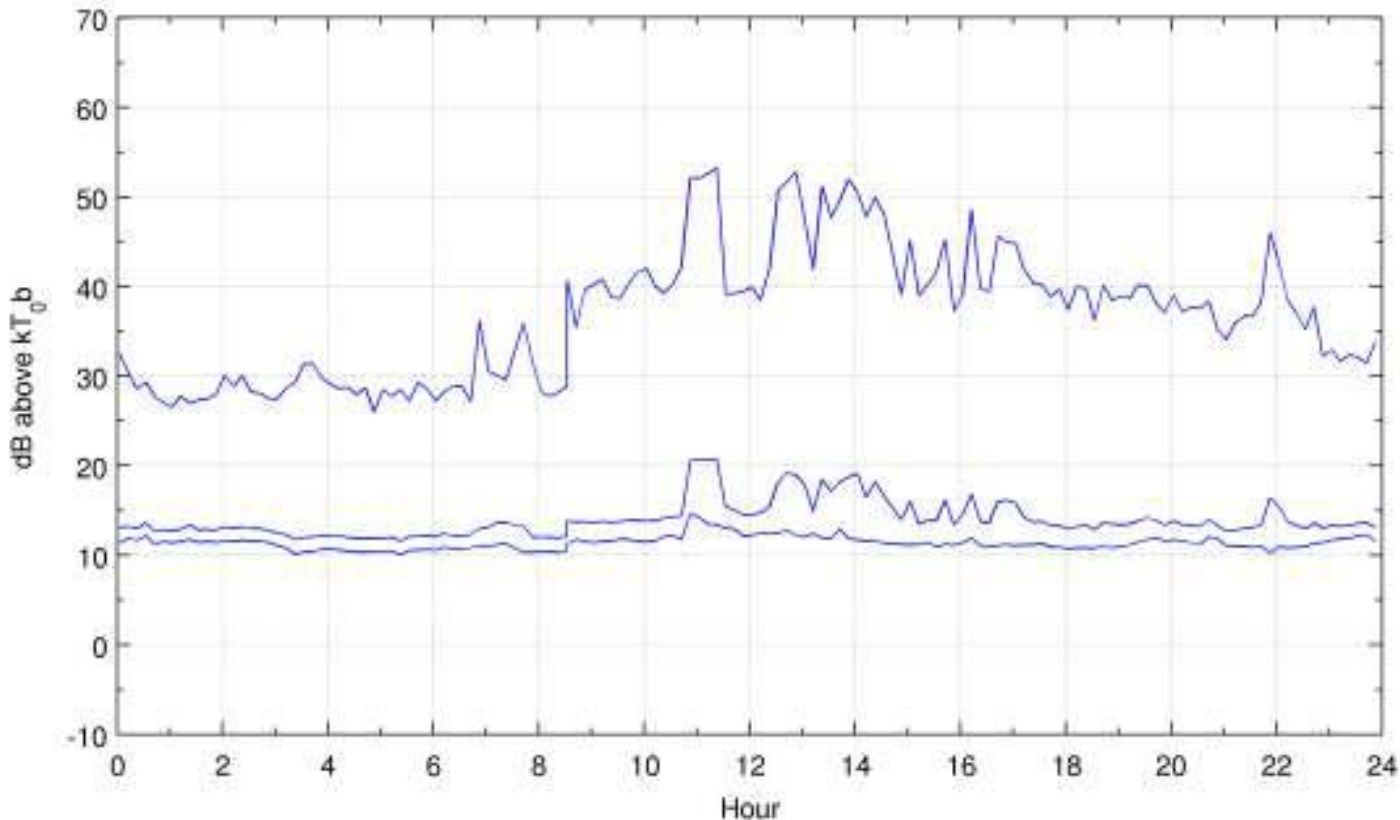


Figure 23. Median, mean, and peak measured noise power in a 1-MHz bandwidth at a center frequency of 221.5 MHz at the Boulder business location (July 20–21, 2009).

24-HR NOISE DATA

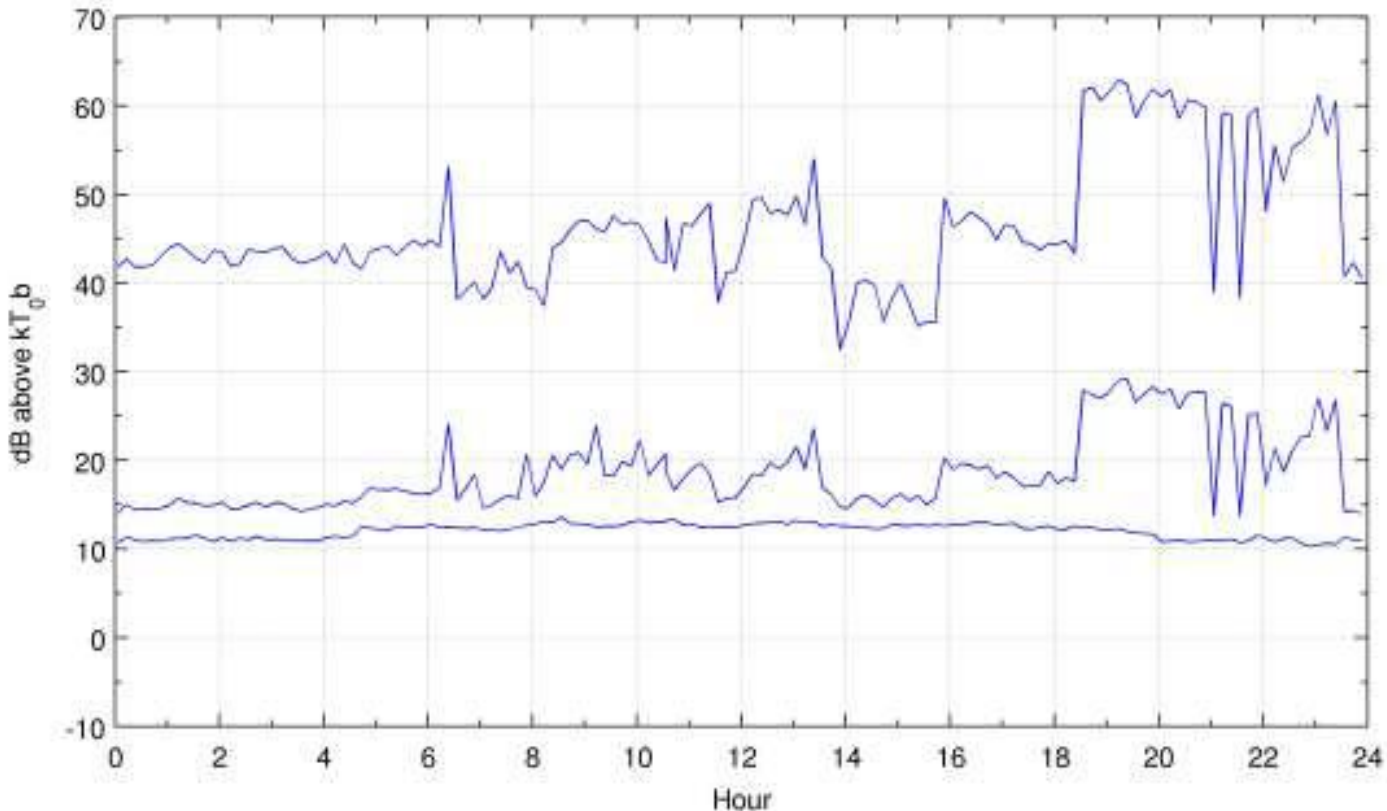


Figure 29. Median, mean, and peak measured noise power in a 1-MHz bandwidth at a center frequency of 221.5 MHz at the Denver business location (August 18-19, 2009).

24-HR NOISE DATA

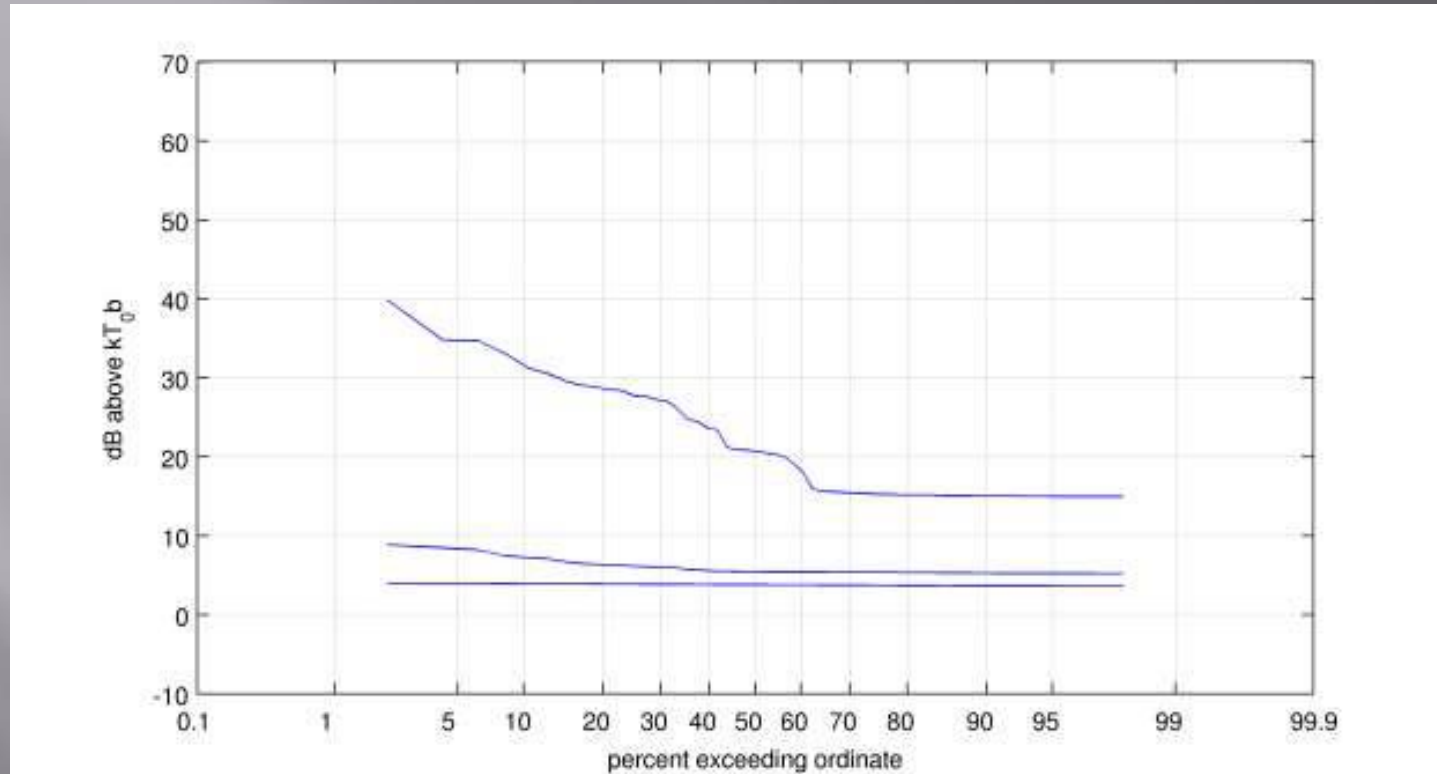


Figure 34. Complementary cumulative distribution of the hourly median values of the median, mean, and peak powers in a 1-MHz bandwidth at a center frequency of approximately 112.5 MHz over both business locations.

PROGRAM:

The changing nature of noise:

ARN : Noise is strictly impulsive, natural. Any man-made energy (signals or impulses) is rejected.

MMN: Some ARN at lower frequencies (<20 MHz) cannot be avoided. MMN sources include powerlines, auto ignition, fluorescent lamps, electrical machinery, light dimmers, computers, switching power supplies, etc. Intentionally radiated (NB carrier) RF rejected/avoided. Note: Some noise looks like NB (dithered to widen).

Today/tomorrow: Many “Gaussian noise-like” wideband signals, possible UWB impulse-like signals, many nonlicensed low-power, intermittent signals.

PROGRAM:

Where, when, how often to measure?

1. ARN - 18 stations worldwide, 5 years. Very long range noise transmission, weather & solar cycles.
2. MMN - Mobile radio used outdoors, highways. Noise measurements outdoors, highways.
3. Today - Wireless, WiFi, nonlicensed used everywhere. Unlicensed low-powered signals play similar interference role as noise. Indoors, outdoors, vehicles, special events, office/business, houses, apartments, stores, malls, rooftops, trains, factories, power lines, rural, suburban, urban, etc. ID major sources?

PROGRAM:

What to do about noise-like signals?

1. Measure everything, don't try to discriminate.
2. Extract/avoid known signals. Rest is "noise".
3. Use wider bandwidths to divide into "impulsive" noise and Gaussian floor (inc LP signals). This works until UWB.
4. ITU-R Recommendation SM.1753-2 (2012) Methods for Measurements of Radio Noise.
5. Intelligently excise known signal types; rest is noise.
6. Et cetera???

THE END

Questions? Comments?

Robert Matheson

November 14, 2013