

How to Conduct a Drive Test Survey

Presented By:

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Outline

- **Reasons for Conducting a Survey**
- **Collecting the Measurements**
- **Analyzing the Measurements**
- **Uplink (Talk Back) Measurements**
- **Case Study: Newport News, Virginia**
- **Measurements at the Repeater Site**

Why Conduct a Survey?

Purpose of the Survey

- The Main Purpose of the Drive Test Survey is to Confirm that the Licensee has “Comparable” Radio Coverage.
- A Second Purpose is to Help Diagnose and Solve Problems Created by Rebanding

When Are Surveys Required?

Is It Always Required?

- No
- Mitigating Factors:
 - Complexity of the network
 - Which components have changed?
 - Can these components be isolated and tested?
- Complex Networks with New, Interdependent RF Components Require Drive Test Surveys
- Note that the Drive Test Survey Is Also a Check that You Did Everything Right
- Drive Testing is Not a Substitute for Thorough Subsystem Testing

Is Co-Channel Interference Included?

- **Generally, No**
 - FCC Co-Channel Separation Rules Apply (Part 90.621)
 - FCC says these rules are sufficient
 - Does not matter that the situation may have changed
- **Changes Occur in the Bands 851-861 MHz**
- **NPSPAC Usually Not a Problem**
 - Frequencies move in a block
 - The co-channel user has not changed
 - There are a few exceptions



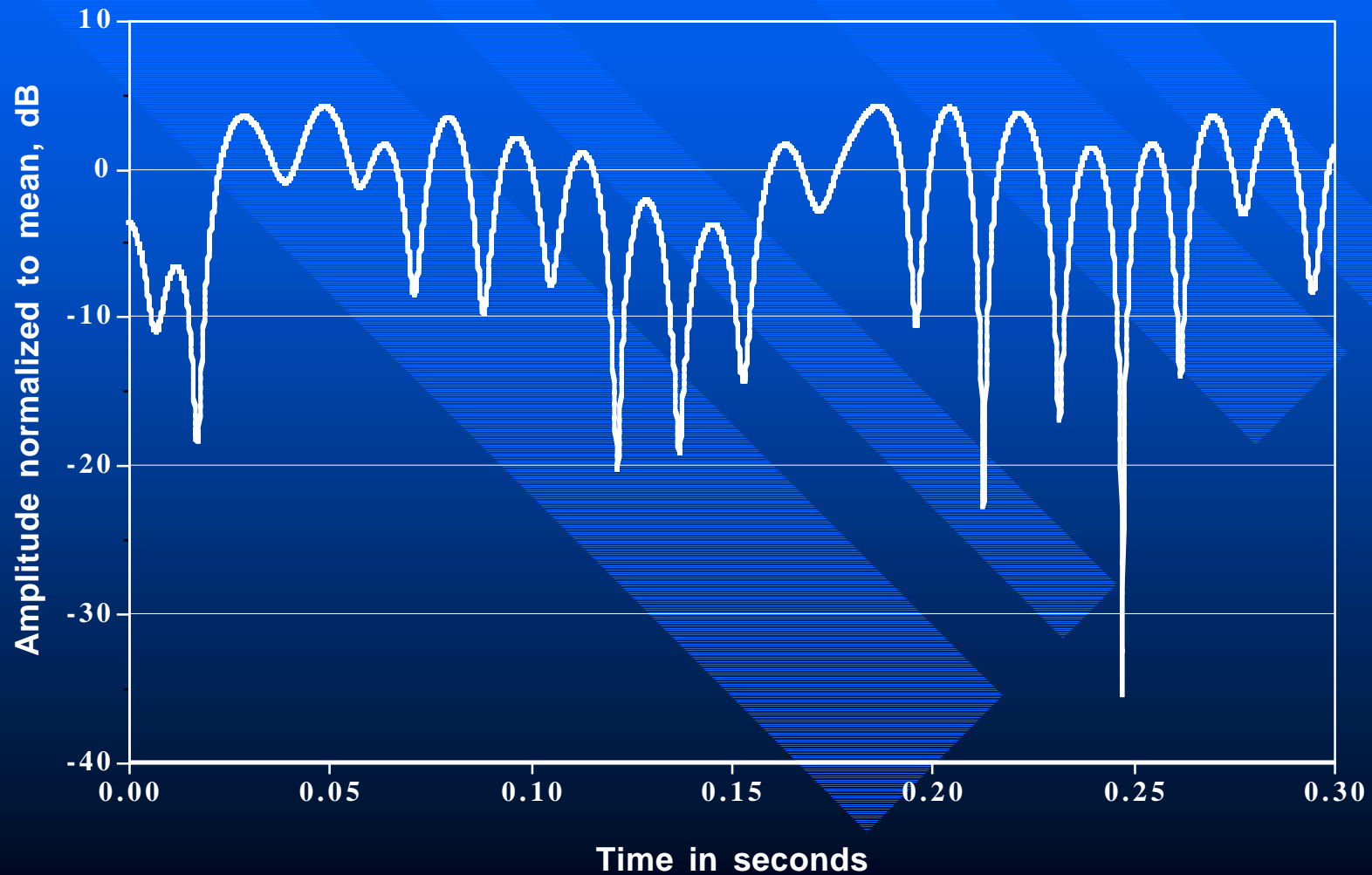
Collecting the Data

Characteristics of the Signal

- **Multipath Fading Dominates the Mobile Radio Channel**
 - Fade rate is a function of the doppler frequency, V/λ
 - E.g., for 860 MHz at 60 mph, fade rate is roughly 75 Hz
 - Amplitude is assumed to be Rayleigh-distributed
- **Radio Specifications are Typically for Mean Signal**
 - Corresponds to a particular delivered audio quality (DAQ)
 - Additional margin is needed to operate in fading
- **E.g., Analog FM Radio:**
 - 25 kHz channel
 - 5 kHz peak deviation
 - Static sensitivity = -118 dBm (12 dB SINAD)
 - Sensitivity in fading = -102 dBm (DAQ = 3.4)

Rayleigh Fading

($V = 30$ mph, $f = 850$ MHz)



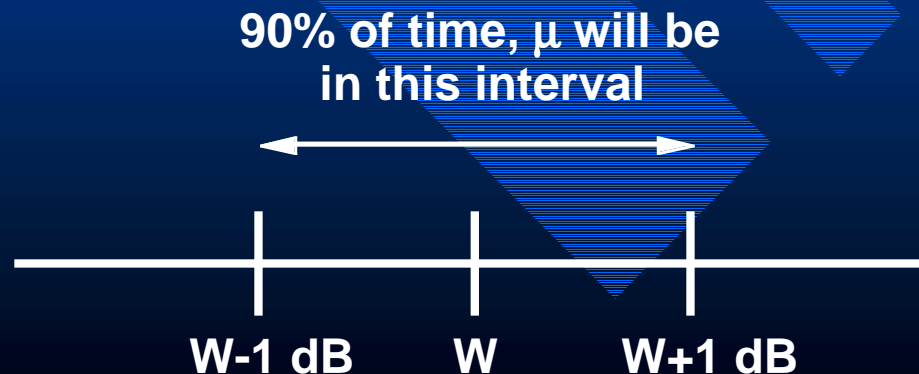
Estimating the Mean

- This is a Statistics Problem:
 - Find an unbiased estimator for the mean of a Rayleigh signal
- The typical estimator is the arithmetic average
- But a point estimate is only part of the story
- We want to know how accurate is this estimate
- We quantify accuracy by using the confidence level and the confidence interval

Confidence Intervals

■ Definitions:

- The value p is the probability that the interval $\pm d$, about the estimate contains the true value, μ . The value $\pm d$ is the confidence interval and the probability p is the confidence level.
- For example, if the confidence level is 90% and the confidence interval is ± 1 dB, then the probability that the interval of ± 1 dB about the estimate contains the actual value, μ , is 90%.



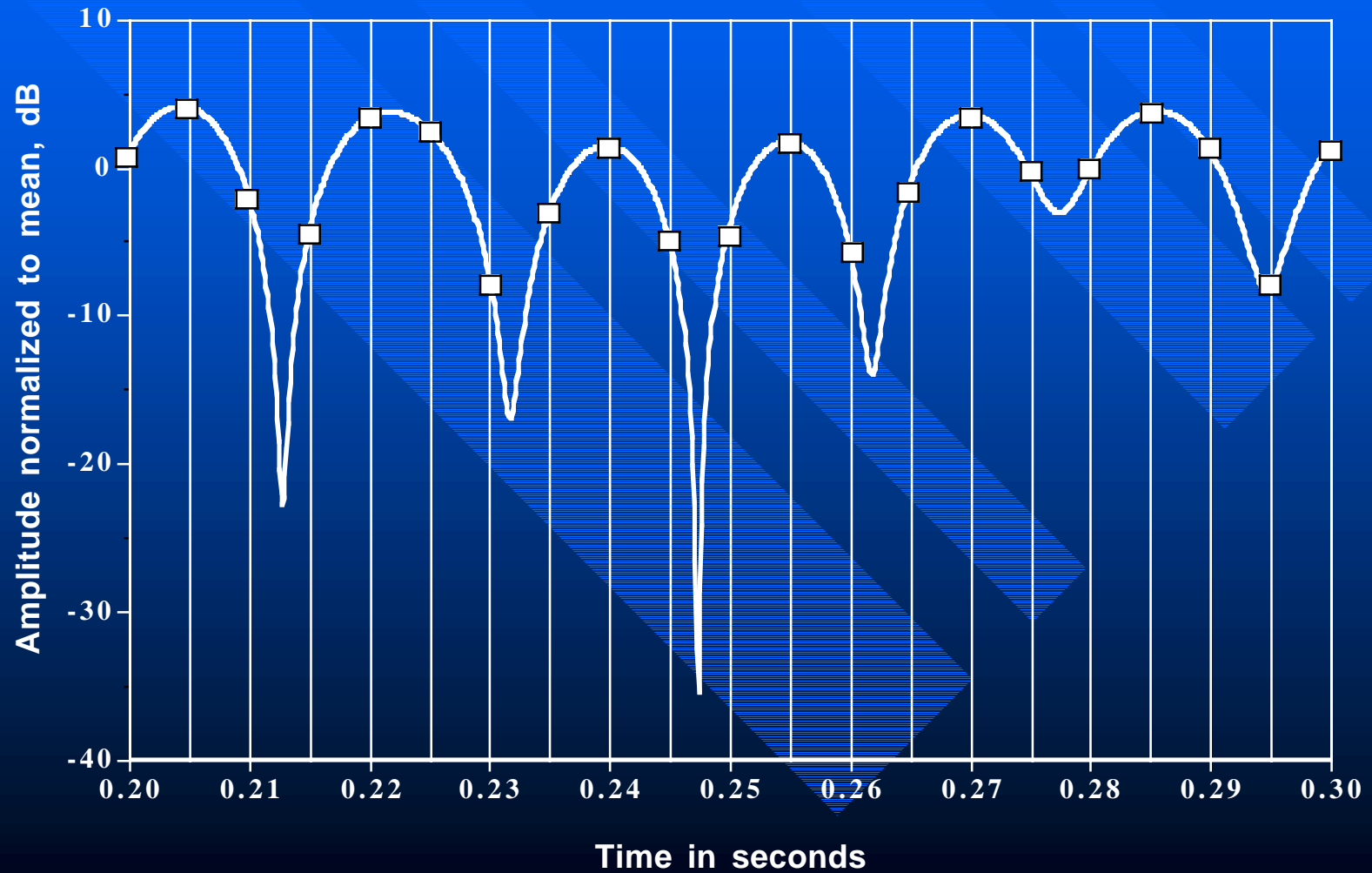
Estimating the Mean

- Our estimator is the arithmetic average, also called the sample mean:

$$W = \bar{X} = \sum_{i=1}^n x_i$$

- How many samples, n , are required to ensure a small confidence interval?

Sampling Rayleigh Signal



Sampling Rayleigh Signal

- Usually, receiver samples at a uniform rate
- One sample every 10 ms is typical
- I.e., 100 samples per second
- For mathematical convenience, the expressions for confidence level assume independent samples, which is not strictly true.
- However, common sense tells us more samples are better as long as we see a minimum number of wavelengths.

Subsamples Required

- From Lee [2]:

$$CI\left(\frac{\bar{X}}{\mu}\right) = \left(1 - \frac{z_{\alpha/2}}{\sqrt{n}} \sqrt{\frac{4 - \pi}{\pi}}, 1 + \frac{z_{\alpha/2}}{\sqrt{n}} \sqrt{\frac{4 - \pi}{\pi}} \right)$$

- Where μ is the mean value we are estimating and $z_{\alpha/2}$ is the argument of the unit normal distribution for a confidence level of $1-\alpha$. Values of $z_{\alpha/2} = 1.65, 1.96, 2.58$ for 90%, 95%, and 99%, respectively.

Subsamples Required

Full Confidence Interval	Confidence Level		
	90%	95%	99%
1.5 dB	91	129	222
1.75 dB	67	95	164
2.0 dB	52	73	126
2.5 dB	33	47	81
3.0 dB	23	33	56

Minimum Wavelengths

- Previous Expression Assumed Independent Samples
- In reality, Consecutive Samples are Correlated
- To Correctly Sample the Signal, a Minimum Number of Fades Must be Observed
- Minimum Fades Correspond to Minimum Wavelengths
- From Lee [2], Minimum Wavelengths = 40
 - At 150 MHz, 40 wavelengths = 262 feet
 - At 450 MHz, 40 wavelengths = 87 feet
 - At 850 MHz, 40 wavelengths = 46 feet
 - At 4.9 GHz, 40 wavelengths = 8 feet

Linear vs. Log Average

- Say we want at least 50 subsamples averaged over 40λ
 - Will give us 90% confidence interval of +/- 1 dB
 - Assumes Rayleigh-distributed amplitude
- Receiver Typically Records Levels in dBm
- Do we average the log values or linear (anti-log) values?
- Log Average Creates -2.5 dB error*
 - Assuming amplitude is Rayleigh-distributed
- Conclusion: Use Linear Average

*I.e., it is a biased estimator. See Hess [4], page 100.

Mean vs. Median

- **Some Prefer the Median over the Mean**
- **Why?**
 - Weak signals below the noise floor of the receiver will skew the mean to a higher level than reality
- **Problems with the Median**
 - More difficult to compute
 - Confidence intervals unknown
 - Radios are specified for a mean level in Rayleigh fading
 - Mean and median are not the same value in Rayleigh fading
- **Practical Advice**
 - For levels of -106 dBm and above, error is small if receiver noise floor is below -120 dBm
 - I.e., error is < 0.2 dB

Other Collection Issues

■ Where to Drive?

- Everywhere the user drives
- Do not limit survey to the highways
- Significant signal loss occurs on the side streets (more clutter)

■ When to Drive?

- For contract compliance, in the summer (foliage loss)

■ How Much to Drive?

- More is better
- Nominal grid size driven should match analytical grid size

Characteristics of Receiver

- Relatively fast (e.g., 100 samples per second)
- Good sensitivity (e.g., -118 dBm, match user radio)
- Accuracy: +/- 1.5 dB
- Good adjacent channel and intermod. rejection
- Computer-Controlled
- GPS compatible
- Linear averaging of at least n samples over 40 wavelengths



Analyzing the Data

Analysis Tasks

- **Remove Spatial Bias From Measurements**
- **Compute Service Area Reliability**
- **Compare Service Area Reliability to Contract Reqt.**
- **For Rebanding Surveys:**
 - Create intersection set
 - Compare pre and post service area reliabilities
 - Draw conclusion on equivalent coverage

Gridding

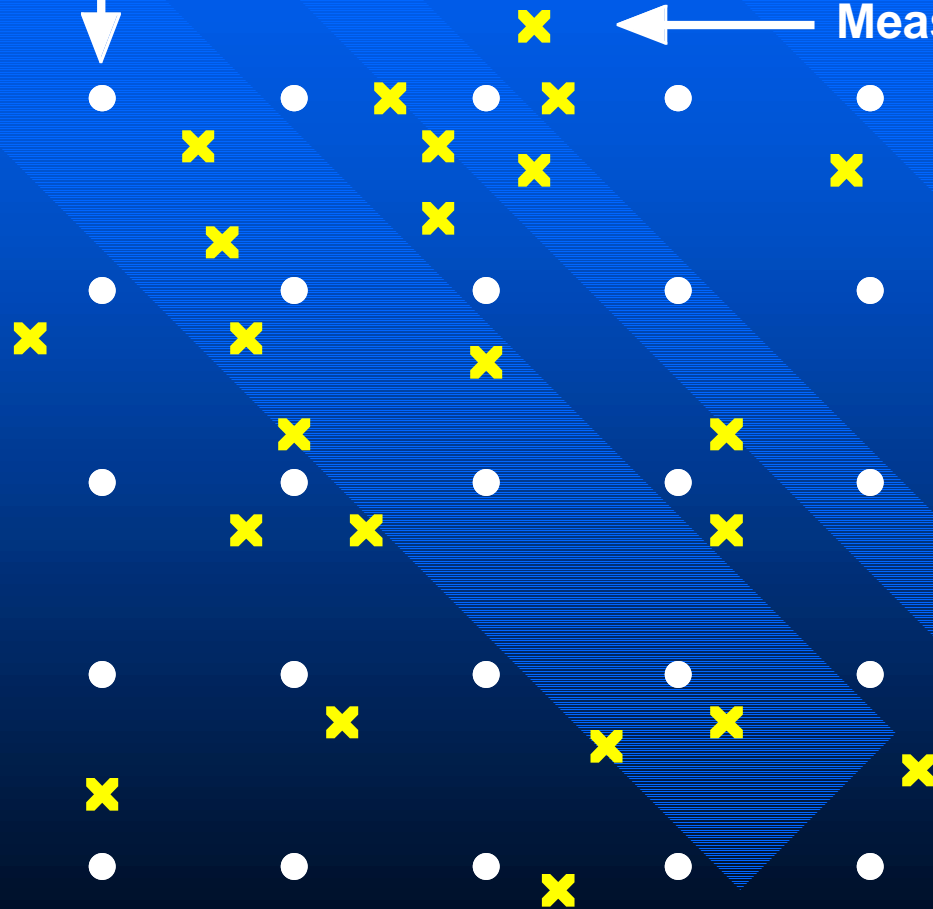
- **In Practice, Uniform Spatial Sampling is Difficult**
 - I.e., some spatial bias exists in the data
- **Gridding Solves This Problem**
- **What is Gridding?**
 - Gridding interpolates randomly distributed data to a uniform, two-dimensional grid
- **SAR Computed from Gridded Data**

Gridding

Grid Point

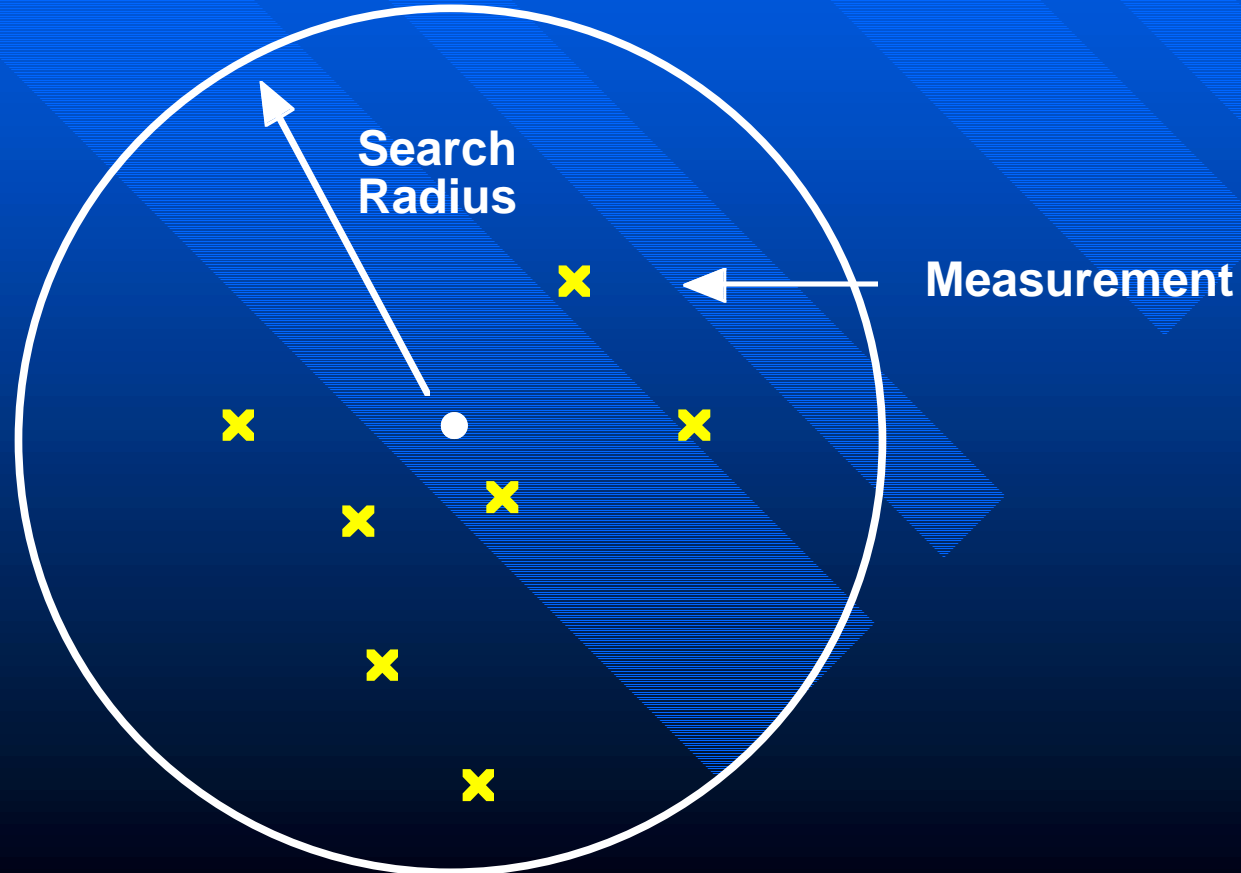


Measurement



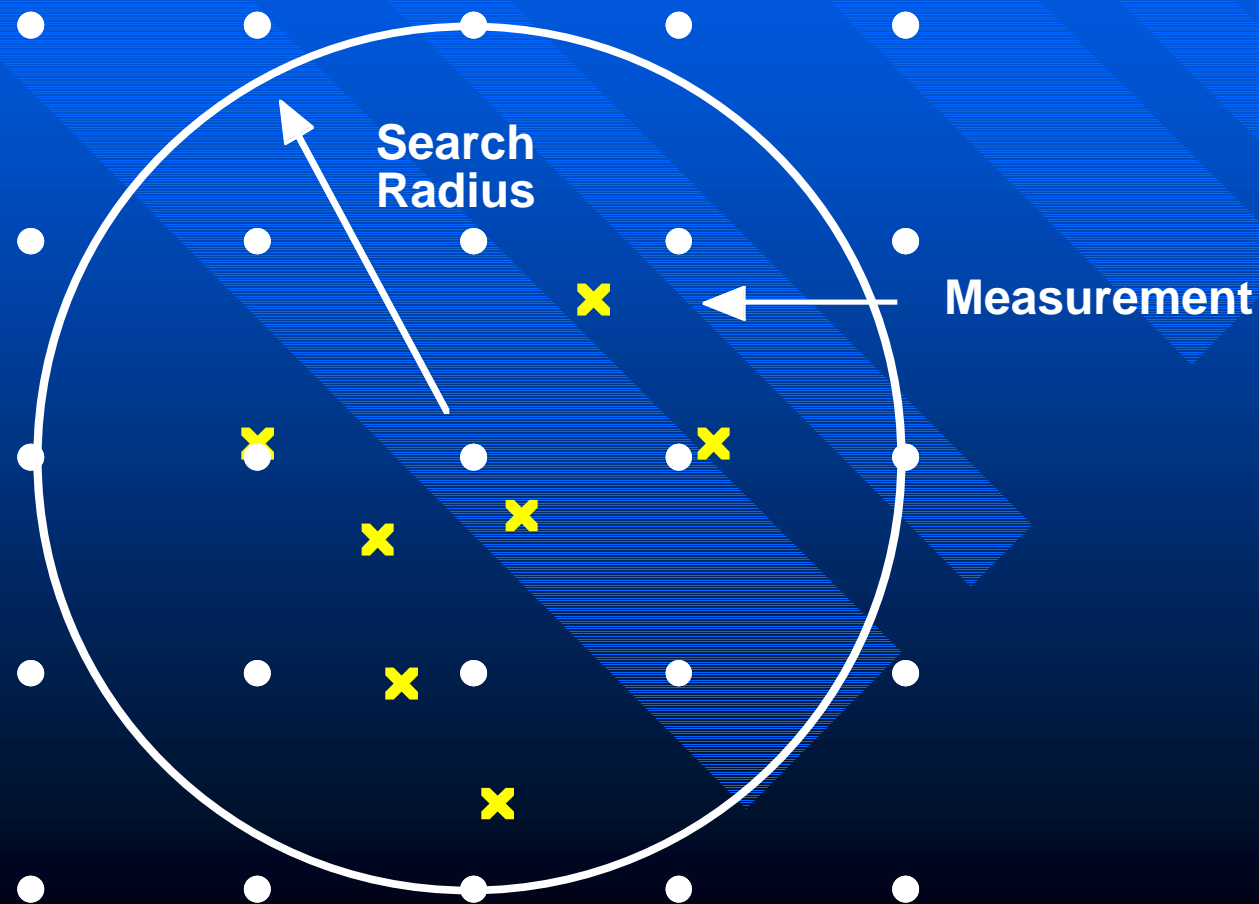
Gridding

- Gridding is 2-D Interpolation
 - Key elements are search radius and interpolation algorithm



Search Radius

- Search Radius Should Be Relatively Small
 - Twice the nominal collection grid size is appropriate



Interpolation Algorithm

- Weight by Distance
- Nearby Measurements Weighted More Heavily
- Inverse-Distance-Squared is One Algorithm
- No Universally Accepted Algorithm

A Word About Independence

- **Mathematical Models Usually Assume Independence**
- **Measurements Collected Close in Time or Space are Likely to be Somewhat Correlated.**
- **Some Suggest that Data be Purged to Approximate Independence.**
- **Is this a Good Idea?**
 - Generally, no because the purged data are still good data
- **Advantage of interpolation is that all data within the search radius is used to estimate the signal level inside that tile.**

Service Area Reliability (SAR)

- Definition:

“Service area reliability is the probability that a point, selected at random inside the service area, has a measured level above the service level.”

- For Mathematical Convenience, Each Sample of the Service Area is Assumed to be an Independent Trial.
- With This Assumption, the SAR is the Parameter, p , for a Binomial Random Variable
- Typical Contract SAR is 95%

Estimate for SAR (From Drive Test Survey)

$$SAR(\%) = \frac{T_p}{T_t} 100\%$$

where

T_p is the number of tiles passed

T_t is the total number of tiles

How Accurate is the Estimate? (More Confidence Intervals)

$$n = \frac{z_{\alpha/2}^2 p(1-p)}{d^2}$$

Where p is the value of the SAR, $z_{\alpha/2}$ is the argument of the unit normal distribution for a confidence of $1-\alpha$ and d is one-half of the confidence interval [5]. For example, for 90% confidence, $z_{\alpha/2} = 1.65$.

Worst Case

($p = 1/2$)

$$n = \frac{z_{\alpha/2}^2}{4 d^2}$$

Confidence Level	$z_{\alpha/2}$	d	n
90%	1.65	+/- .02	1,702
95%	1.96	+/- .02	2,401
99%	2.58	+/- .02	4,160

Proving Equivalent Coverage

- **Attention to Detail is Paramount**
 - Use the same receiver, vehicle, antenna, coaxial cable, drive route, time of day, day of the week, season, etc.
- **Despite Best Efforts, Before & After will Vary**
 - Some variation is normal
 - Systems may still be equivalent

Equivalent Coverage Rule

“If the post-rebanding service area reliability estimate falls inside a range equal to twice the 90% confidence interval of the pre-rebanding service area reliability estimate, the two systems have equivalent coverage.”

Equivalent Coverage Example

■ Test Parameters:

- 1750 gridded samples
 - 90% confidence interval = $\pm .02$
 - Pre-rebanding SAR = 97%
 - Post-rebanding SAR = 93%
 - Actual SAR = 95% (known only to the omniscient)
- Pass or Fail?
- Pass because the range is less than twice the confidence interval

Uplink Drive Tests

The background features a blue gradient that transitions from a lighter blue at the top to a darker blue at the bottom. Overlaid on this gradient are several diagonal lines that create a sense of depth and movement, resembling a stylized staircase or a series of parallel paths.

Uplink vs. Downlink

- Drive Test Surveys are Usually Downlink (Talk Out)
- Should We Measure Uplink (Talk Back) Also?
- Maybe
 - Antenna reciprocity means we can deduce uplink from downlink
 - But only if same antennas are used
 - Frequency separation effects usually negligible
- Example:
 - Four-site simulcast system with voting receivers
 - Transmit antennas are directional
 - Receive antennas are omnidirectional
 - Antenna reciprocity does not apply to talk out/talk back

Uplink From Downlink

- **Antenna Reciprocity May Apply, But**
 - Transmit power levels are different
 - Sensitivities are different
 - Amplifiers on uplink amplify noise and signal
- **For These Reasons, Must Compare on Basis of Common Metric Such as Signal-to-Noise Ratio**

Uplink Measurements

■ Issues with Uplink Measurements

- Need one receiver at each repeater site
- To discriminate sites, will need one mobile TX for each site
- Transmitter is mobile, receiver is stationary
- Receiver does not know location of transmitter
- Post-Processing of RX and TX files is necessary
- If conducting downlink survey simultaneously, mobile transmit may desense receiver(s)
- To compare apples to apples, need to scale uplink measurements for gain and noise figure of uplink path

The background is a blue gradient, transitioning from a lighter blue at the top to a darker blue at the bottom. Several diagonal lines, also in shades of blue, run from the top-left towards the bottom-right, creating a sense of movement or depth.

Case Study

Newport News, VA

Newport News

■ System Description

- Three site, 800 MHz mobile data system
- Multiple repeaters at each site

■ Rebanding Impact

- Two of three sites were affected by rebanding
- One frequency affected at each site

■ Objectives

- Conduct pre and post rebanding surveys
- Compare pre and post results
- Verify equivalent coverage

Test Setup

■ Measurements:

- 90% confidence level
- +/- 1 dB confidence interval
- Required subsamples = 50 (over 40 wavelengths)

■ Service Area Reliability:

- 90% confidence level
- +/- 2% confidence interval
- Required grid points = 1702

■ Drive Route

- Newport News is roughly 50 square miles
- 1702 grid points = 905 feet = 275 meter square tiles

Test Setup (cont'd)

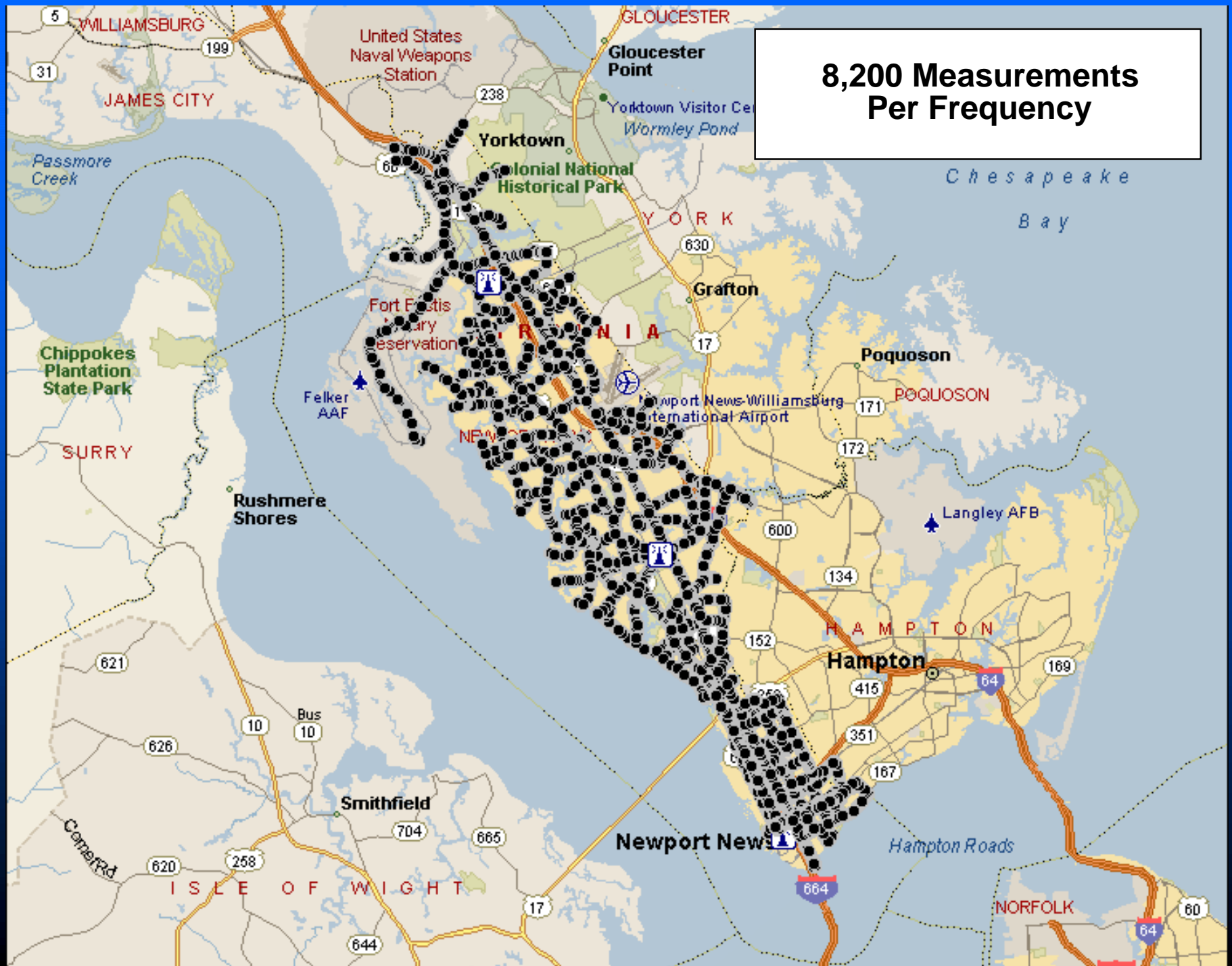
■ Actual Measurements:

- Three Sites Measured
- Four frequencies measured:
 - » Lee Hall #1 (affected by rebanding)
 - » Station 8 # 1 (affected by rebanding)
 - » Station 8 #2 (not affected by rebanding)
 - » City Hall (not affected by rebanding)
- 8,200 measurements collected (each 40λ , 50 subsamples)

■ Analysis

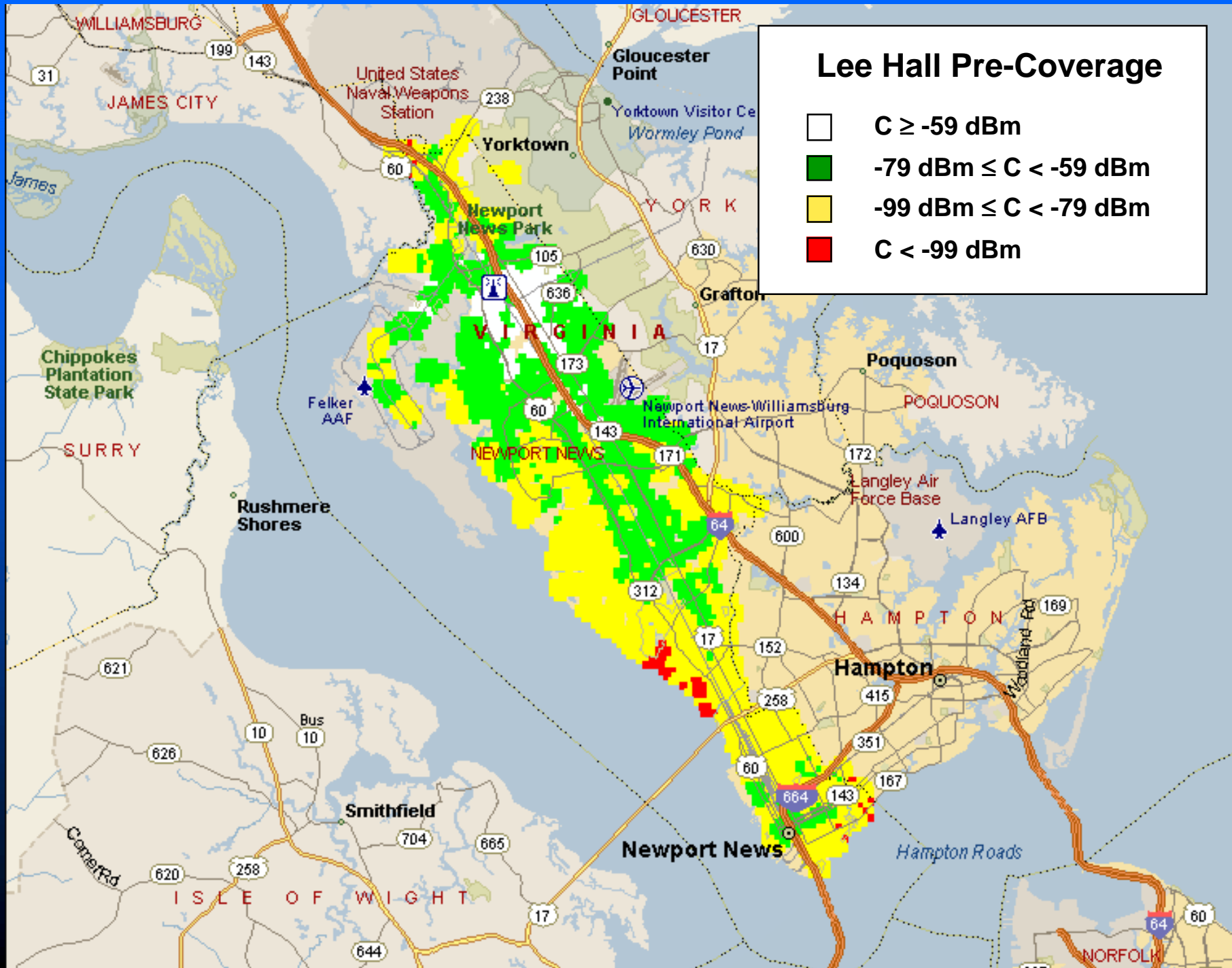
- 200 meter square tiles
- 400 meter search radius
- Inverse distance squared interpolation
- Results in 3,571 uniformly spaced points

8,200 Measurements
Per Frequency



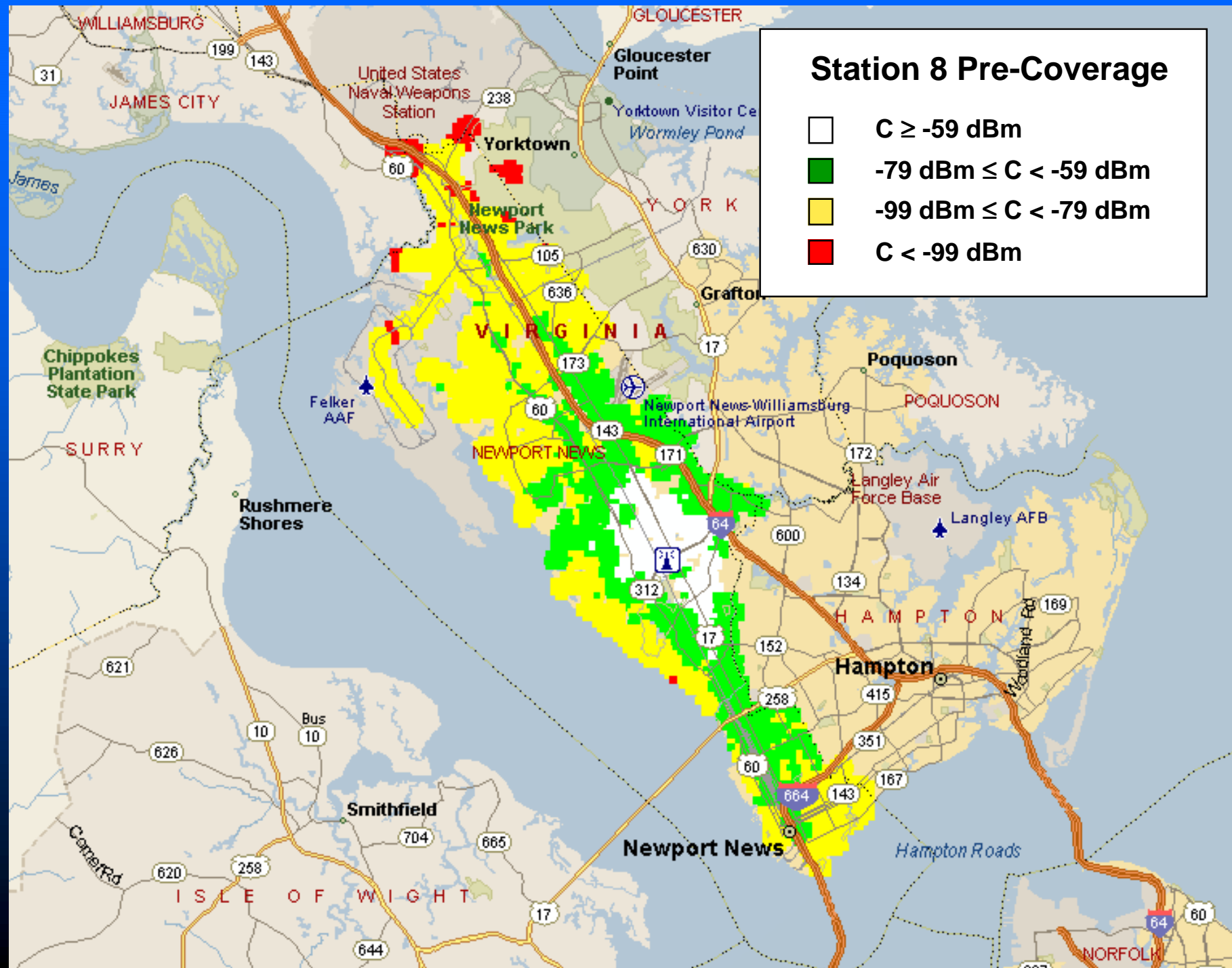
Lee Hall Pre-Coverage

- $C \geq -59$ dBm
- -79 dBm $\leq C < -59$ dBm
- -99 dBm $\leq C < -79$ dBm
- $C < -99$ dBm



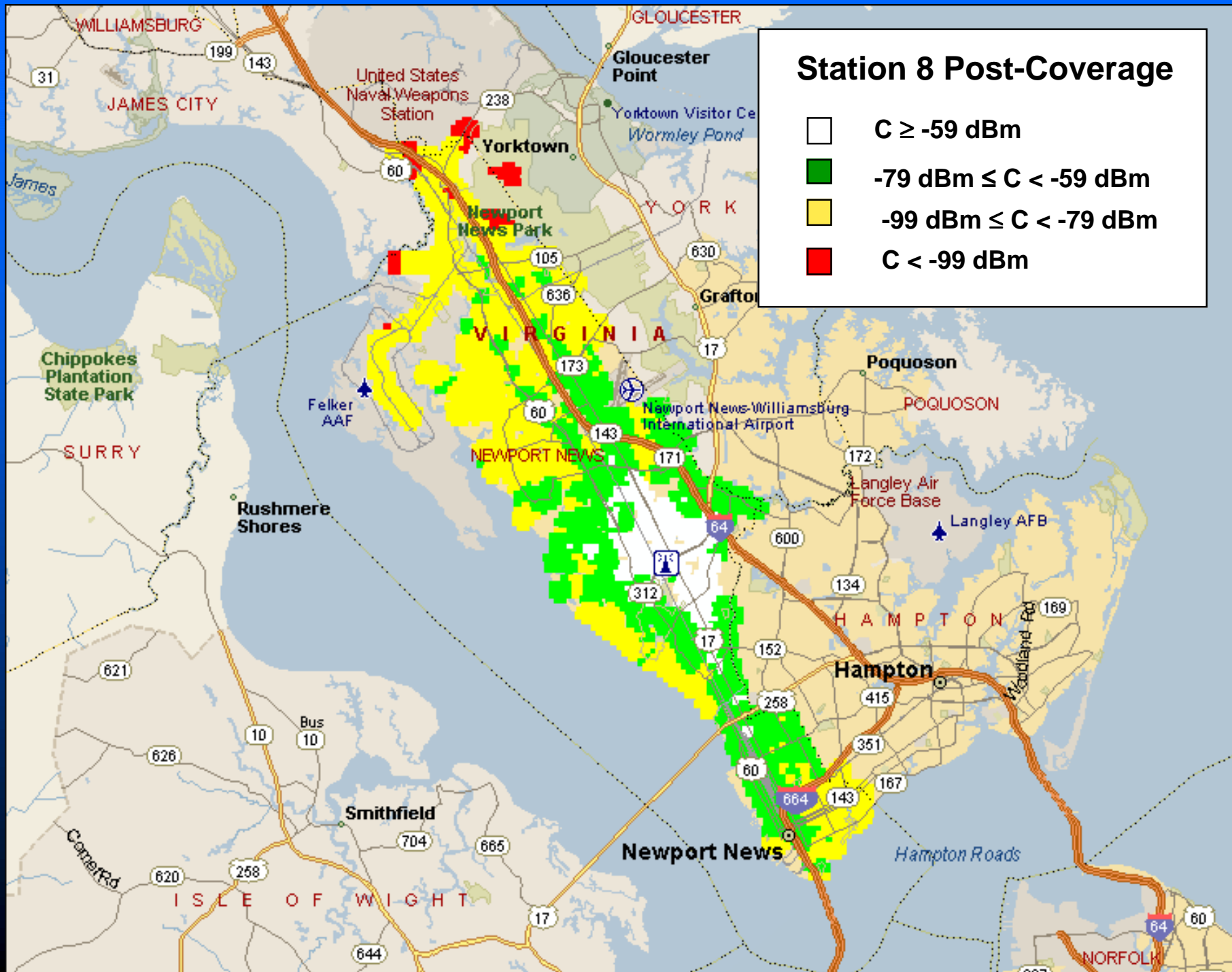
Station 8 Pre-Coverage

- $C \geq -59$ dBm
- -79 dBm $\leq C < -59$ dBm
- -99 dBm $\leq C < -79$ dBm
- $C < -99$ dBm







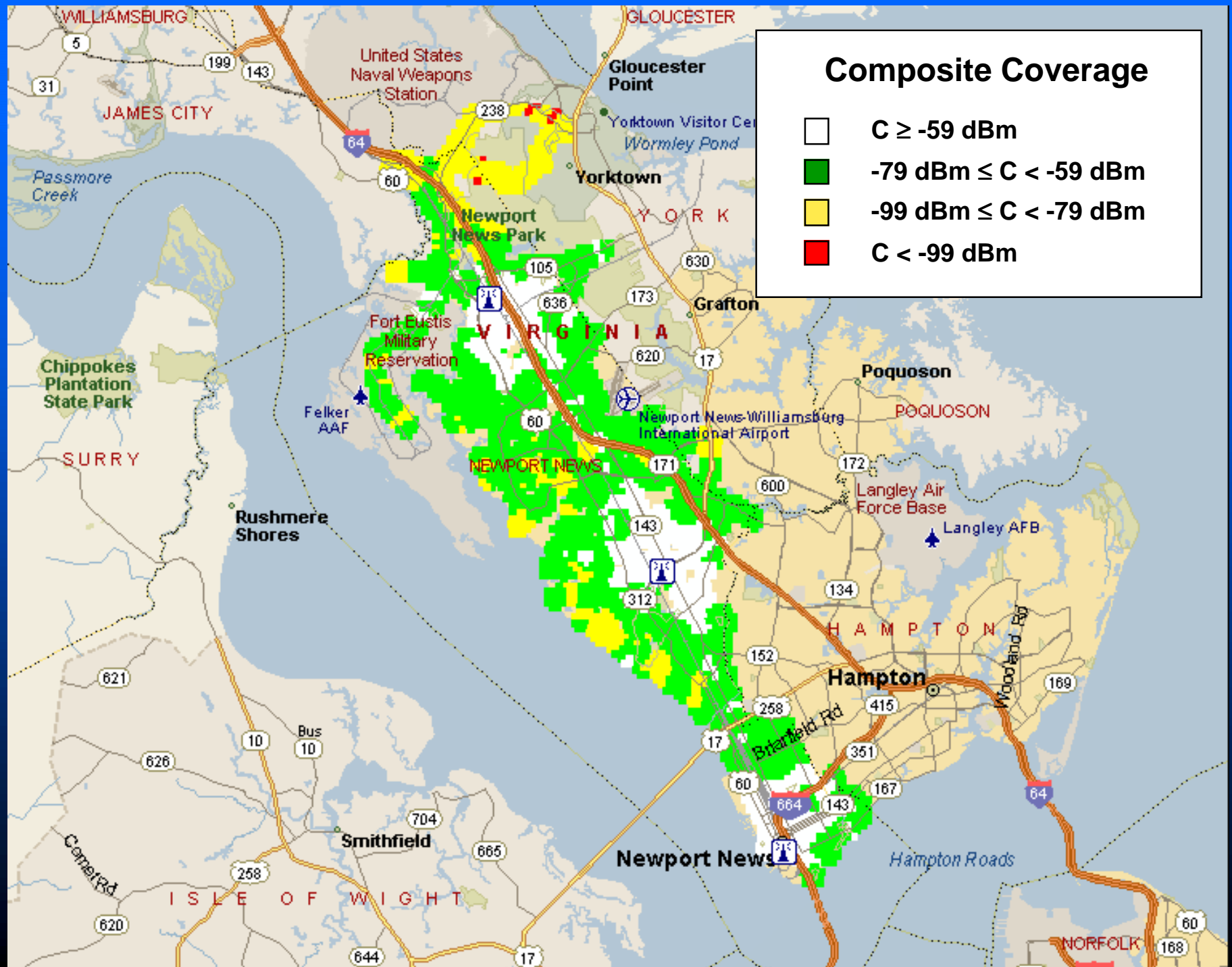
Station 8 Post-Coverage

- $C \geq -59$ dBm
- -79 dBm $\leq C < -59$ dBm
- -99 dBm $\leq C < -79$ dBm
- $C < -99$ dBm



Composite Coverage

-  $C \geq -59$ dBm
-  -79 dBm $\leq C < -59$ dBm
-  -99 dBm $\leq C < -79$ dBm
-  $C < -99$ dBm



Service Area Reliability (SAR)

Site	-99 dBm		-79 dBm	
	Before	After	Before	After
Lee Hall	98.8%	99.9%	49.7%	57.9%
Station 8	97.3%	97.7%	47.2%	52.0%
Station 8 (Reference)	97.2%	97.6%	47.1%	51.7%

Difference Statistics

(Compared at Identical Grid Points)

Site	Mean	Median	Std. Dev.
Lee Hall	2.4 dB	2.5 dB	3.8 dB
Station 8	1.3 dB	1.2 dB	2.7 dB
Station 8 (Reference)	1.3 dB	1.2 dB	2.5 dB
City Hall	1.6 dB	1.5 dB	3.2 dB

Lessons Learned

- **Attention to Detail is Important**
 - Pre-rebanding survey done on weekend
 - Post-rebanding survey done on weekdays
 - Might account for 1.5 dB Difference
- **Include a Reference Signal**
 - Helps Troubleshoot Problems
- **Is the Nextel Frequency Really Turned Off?**

Conclusions

- Drive Test Surveys are Powerful Tools
- Usually More Accurate than Computer Model
- Automation Makes Them Cost-Effective
- Not for the Faint-Hearted
 - Attention to detail is important
 - Interpretation of results requires specialized knowledge

Repeater Site Measurements

Why Repeater Site Measurements?

- Especially Important for Proving Equivalency
 - A 1 dB loss in transmitter power is easy to detect at the repeater site, hard to detect in drive test survey.
- Do Measurements Immediately Before and After Retuning
- Site Tests are required with or without drive testing

Why Repeater Site Measurements?

- Per the FCC's R&O, comparable facilities are those that will provide the same level of service as the incumbent's existing facilities, including:
 - Equivalent channel capacity
 - Equivalent signaling capability, baud rate and access time
 - Coextensive geographic coverage
 - Equivalent operating costs
- Licensees that upgrade frequency-dependent infrastructure must certify that the upgraded facilities are comparable.

Why Repeater Site Measurements?

- **Do Measurements Before and After Retuning**
- **Measurements Required To:**
 - **Establish the Parameters for the Outbound Drive Test**
 - » **Initial Power Source being Measured**
 - **Establish the Parameters for the Inbound Drive Test**
 - » **Signal Level Requirements Above Total Noise**
 - **Provide Source of Information to Make**
 - » **Comparable Facilities Determination**
 - » **If No Drive Test Required**

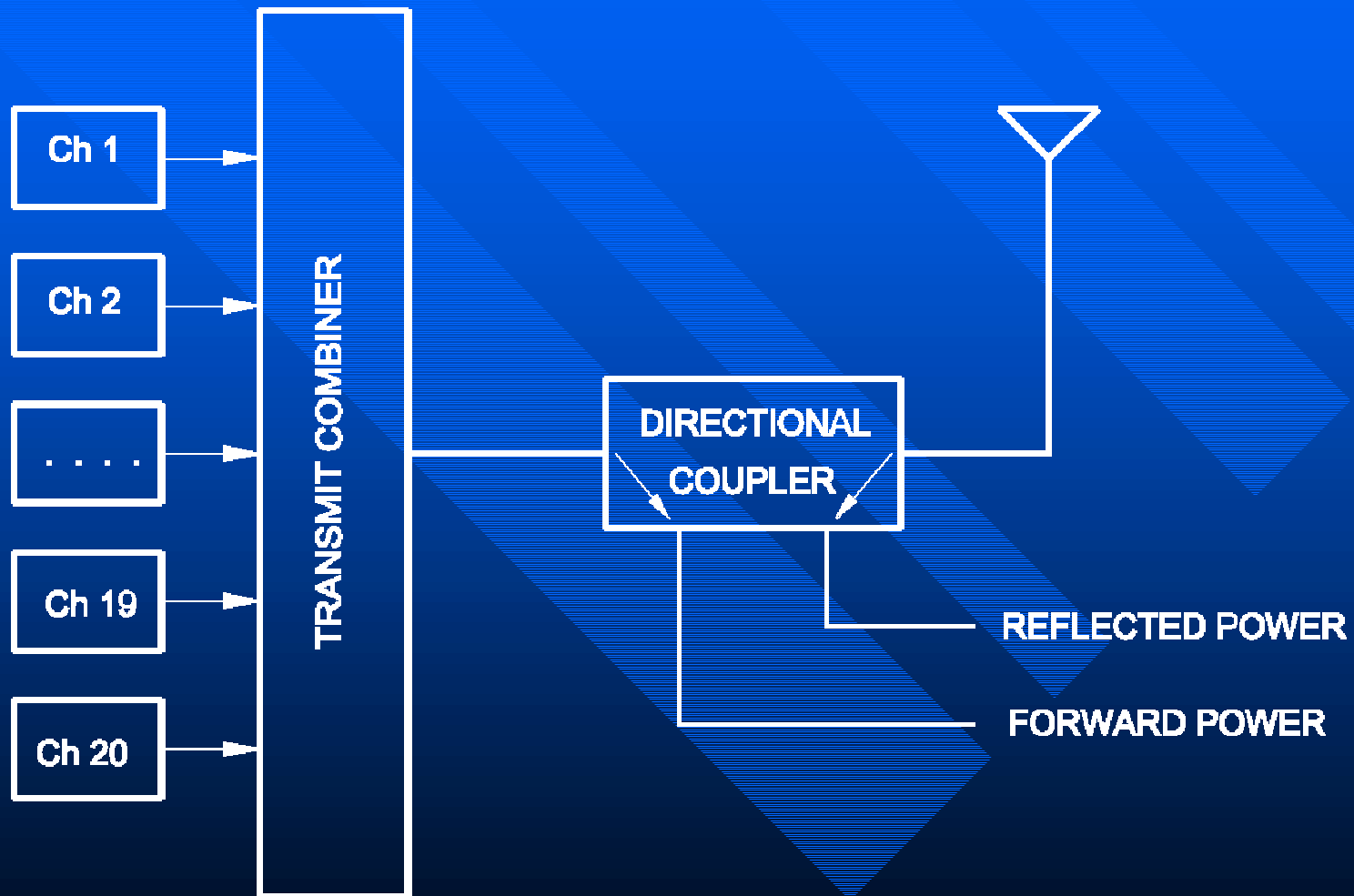
What Repeater Site Measurements?

- **Do Measurements Before and After Retuning**
- **Measurements Required:**
 - **Transmitter Performance Measurements at ALL Tx Sites**
 - **Receiver Performance Measurements at ALL Rx Sites**
 - **Antenna System Measurements at ALL RF Sites**

Transmit Site Measurements

- **Do Measurements Before and After Retuning**
- **Transmit Site Measurements Required:**
 - Output power of each transmitter at combiner output
 - Return loss of all antennas (at old and new frequencies)
 - Insertion loss of all antenna system components
 - » (coaxial cable, surge arrester, duplexer, external cavity filter, etc.)

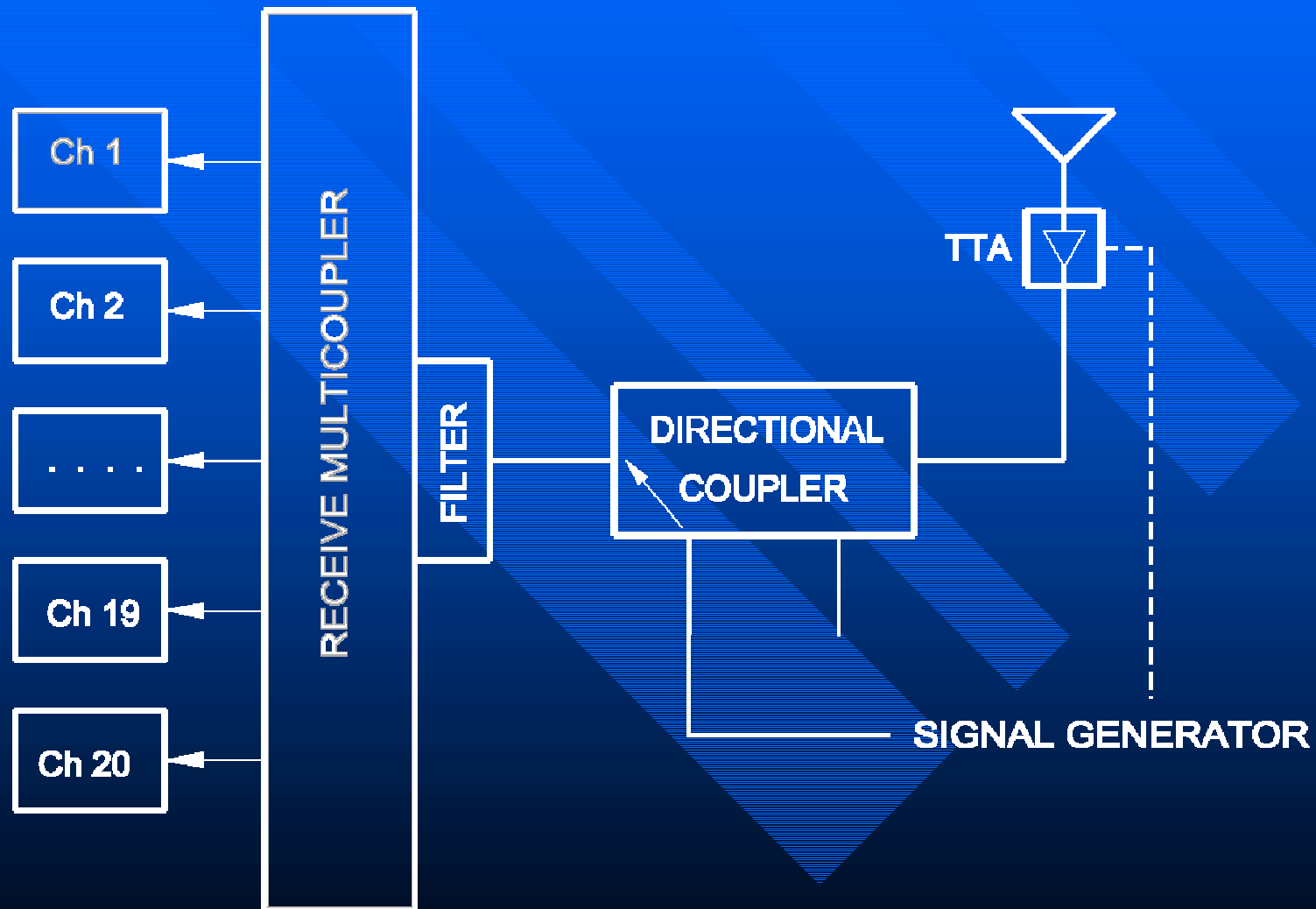
Transmit Site Measurements



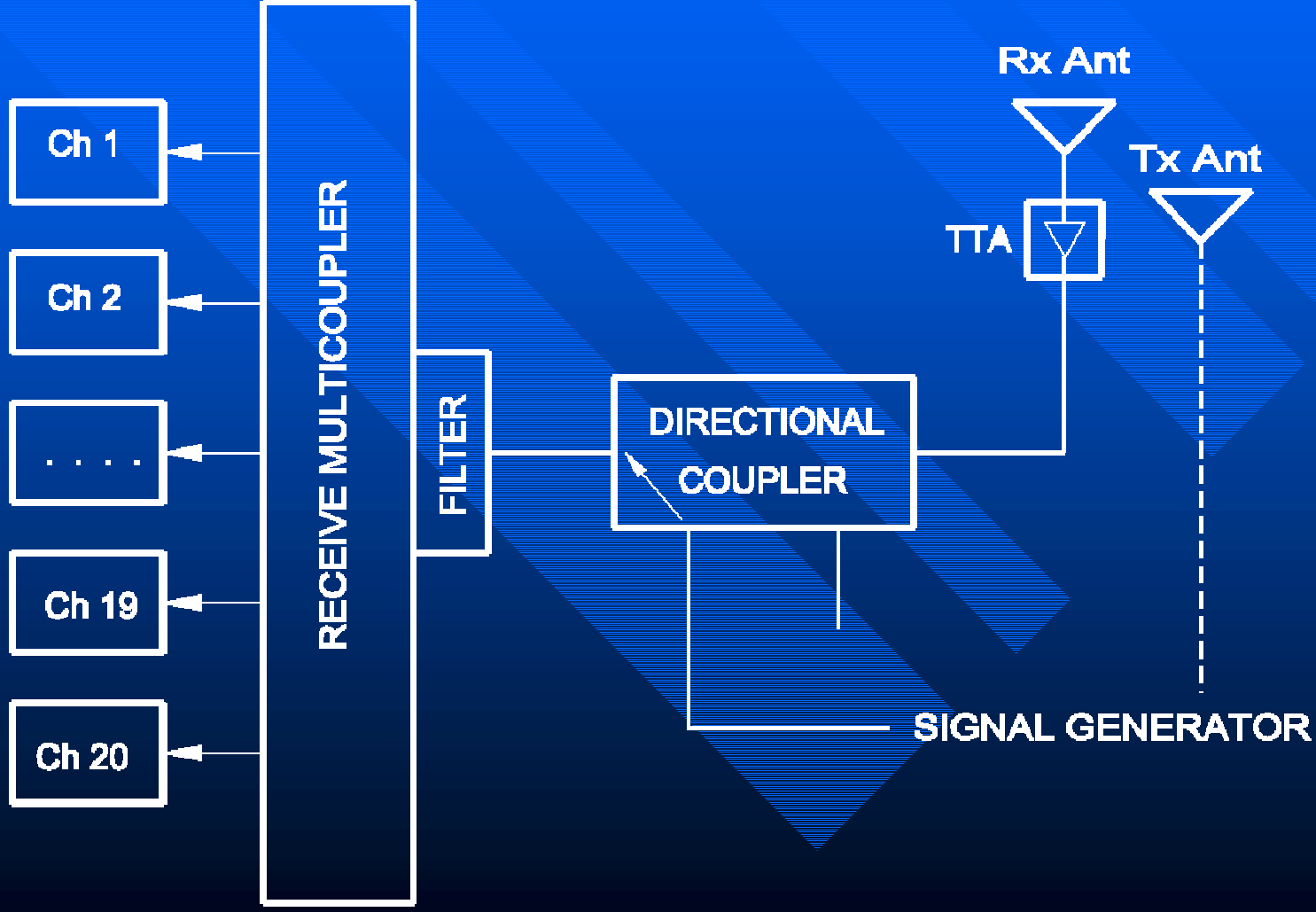
Receiver Site Measurements

- **Do Measurements Before and After Retuning**
- **Receive Site Measurements Required:**
 - **Receiver effective sensitivity**
 - » Evaluates receiver performance and TOTAL noise
 - **Insertion loss of receive system components**
 - » (Preselect Filter, TTA, Rx Multicoupler, etc.)
 - **Receive system noise performance**
 - » Internal and External noise

Receiver Site Measurements



Receiver Site Measurements



Receiver Site Measurements

- Effective Sensitivity Measurement Required:
 - Receiver 12dB SINAD (or BER) RF directly into receiver
 - Receiver 12dB SINAD (or BER) RF thru directional coupler
 - » With Dummy Load (No Antenna)
 - Receiver 12dB SINAD (or BER) RF thru directional coupler
 - » With Antenna (No Dummy Load)

■ Calculate Signal Level Required to Overcome Noise

Total Noise: Rx Thermal Noise
TTA & Multicoupler Amplifier Noise
Noise Sources After Gain Components
External Noise entering Antenna

Note: 12dB SINAD \approx 4-5dB C/(N+I) 5% BER \approx 5-7dB C/(N+I)

Other Considerations

- **Licensee or Contractor-Installed BDA's**
 - May be configured for a specific portion of the Band
 - May not work properly or may cause interference/noise
- **External In-Building Receiver/Voter Equipment**
 - Evaluate / Locate Inventory before Start of Retuning
- **Verify ALL Programmed / Adjustable Parameters**
 - Voice / Data Deviation, Tone / Digital Squelch, etc.
- **Operational Test of ALL Features and Functions**
 - Backup / Fallback modes of operation

References

- [1] W.C.Y. Lee, Mobile Communications Design Fundamentals, 2nd Ed., Wiley, 1993.
- [2] W.C.Y. Lee, “Estimate of Local Average Power of a Mobile Radio Signal,” *IEEE Transactions on Vehicular Technology*, February, 1985, pp. 22-27.
- [3] M. M. Peritsky, “Statistical Estimation of Mean Signal Strength in a Rayleigh Fading Environment,” *IEEE Transactions on Communications*, November, 1973, pp. 1207-1213.
- [4] G. C. Hess, Land Mobile Radio System Engineering, Artech House, 1993.
- [5] R. J. Larsen, M. L. Marx, An Introduction to Mathematical Statistics and its Applications, Prentice-Hall, 1986, pp. 281.
- [6] EIA-TSB-88-B, “Wireless Communications Systems – Performance in Noise and Interference-Limited Situations, etc.” May 1, 2005.

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Questions?