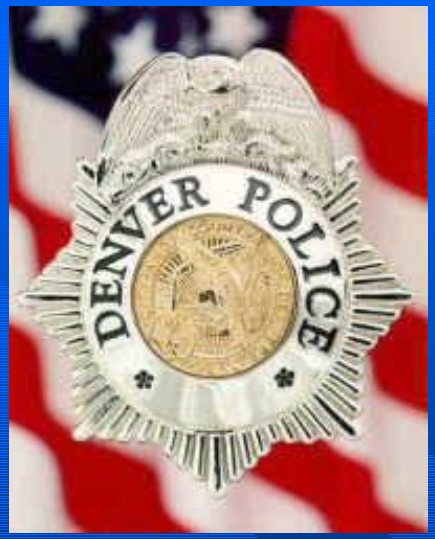
800 MHz Interference In Denver, CO

September 15, 2003



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For

The Federal Communications Commission
Office of Engineering & Technology

Outline

- The Denver/Nextel Problem
  - Nature of the interference
  - Techniques used to mitigate it
  - Relative success of the effort
- AT&T's Contribution to the Problem
  - Why it occurs
  - Extent of AT&T's contribution
- Why "Technical Toolbox" is Inadequate

The Denver Problem

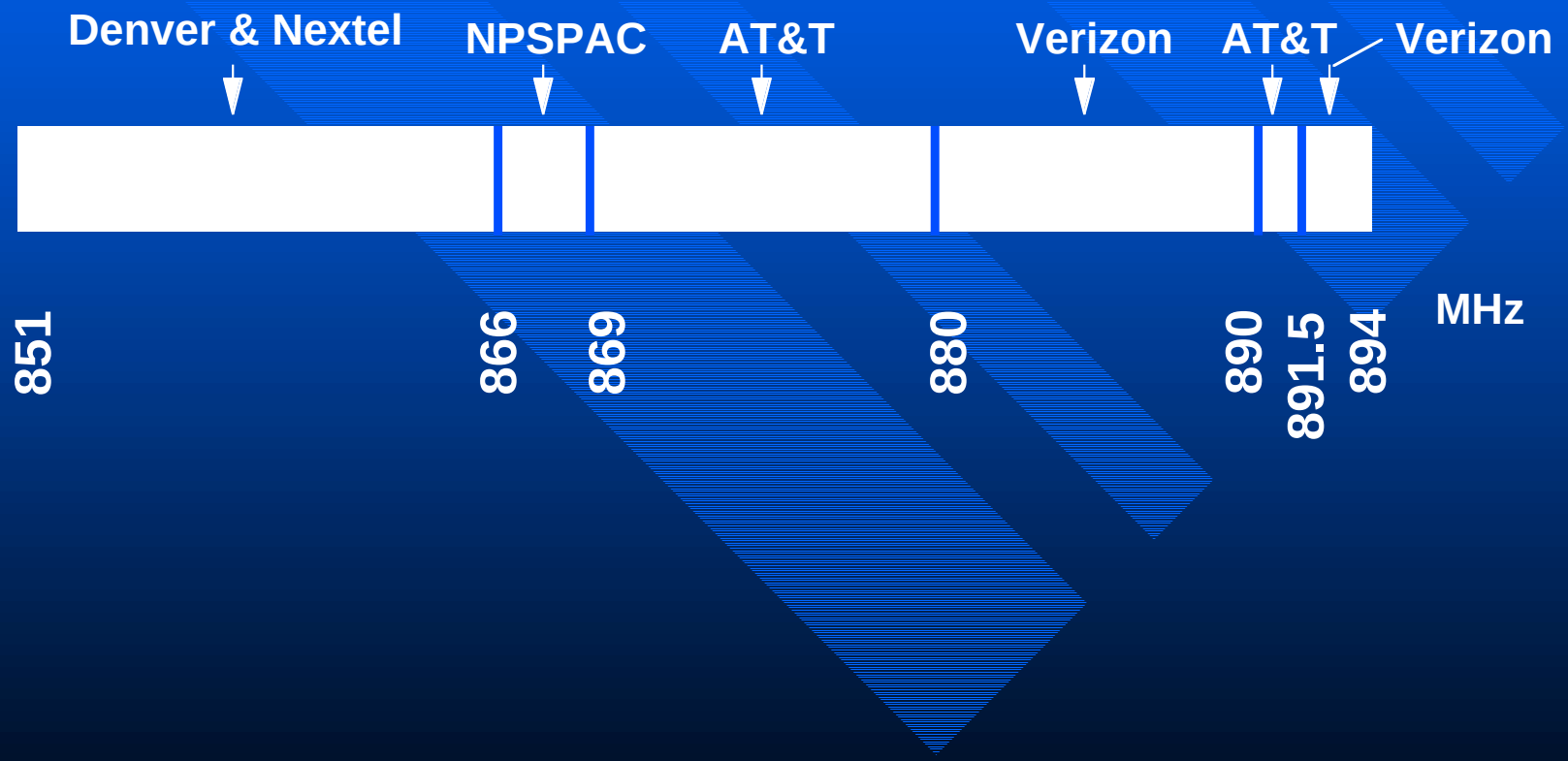
Denver Public Safety Radio

- **Frequencies**
  - Public Safety: 20 channels (25 kHz), 854-861 MHz
  - Public Safety: 13 NPSPAC channels (12.5 kHz), 866-869 MHz
  - Utilities: 15 channels (25 kHz), 854-861 MHz
- **Equipment**
  - MA/COM EDACS Trunked Radio System/Analog FM
  - Activated 1989
  - Directional 60° panel antennas
  - ERP = 600 Watts per channel
  - Channels combined in 10 channel combiners
- **Sites**
  - Main transmitter site on Mt. Morrison (7,750’ AMSL)
  - Backup site on Josephine Street in Denver
  - Four voting receiver sites

Status of Denver System

- **Maintenance**
  - Well maintained, operating near optimal levels
  - Also evaluated by Nextel at outset
- **Capacity**
  - Excellent at the moment, when interference is not present
  - Low call blocking
- **Signal on the Street**
  - Quite high and nearly uniform, -60 to -80 dBm mostly
  - Consequence of high site (2,500’ above city)
  - Some shadowing present, especially downtown
  - Problem areas usually have mean signal of -90 to -110 dBm
  - Note: Sensitivity in static environment ~ -116 dBm

Denver 800 MHz Band



Background

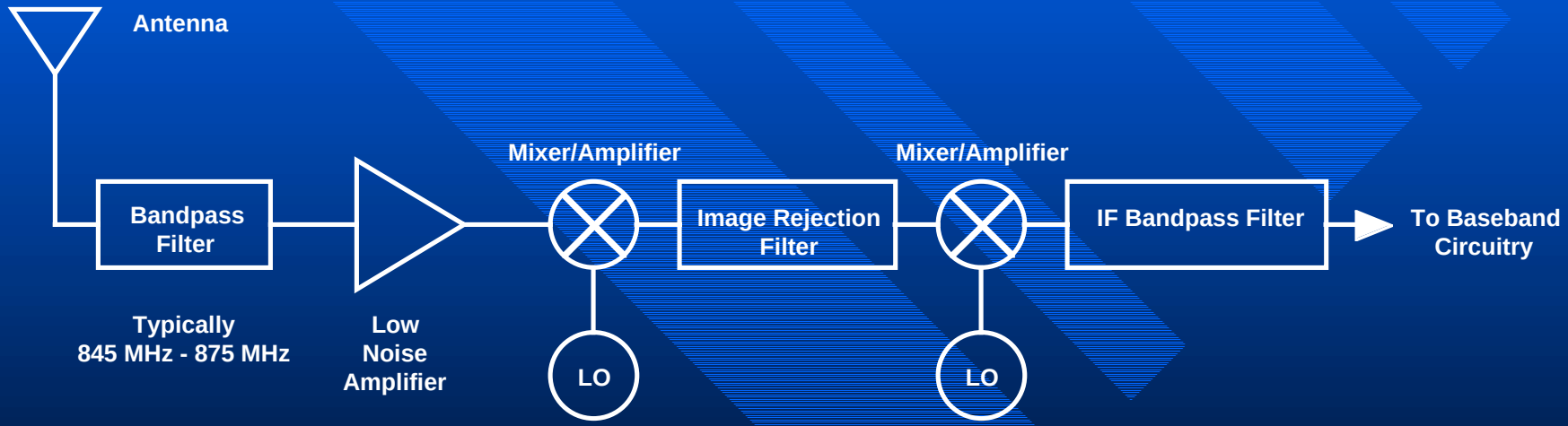
- Problem Discovered in Feb 2000 Following Officer Complaints
- Denver EEB Noticed Nextel Site Near Each Location
- Eventually 24 Sites Identified
- Actions Taken & Proposed
  - Near-term: mitigation
  - Long-term: a phased channel swap & re-banding

Problem Mitigation
Intermodulation Protection

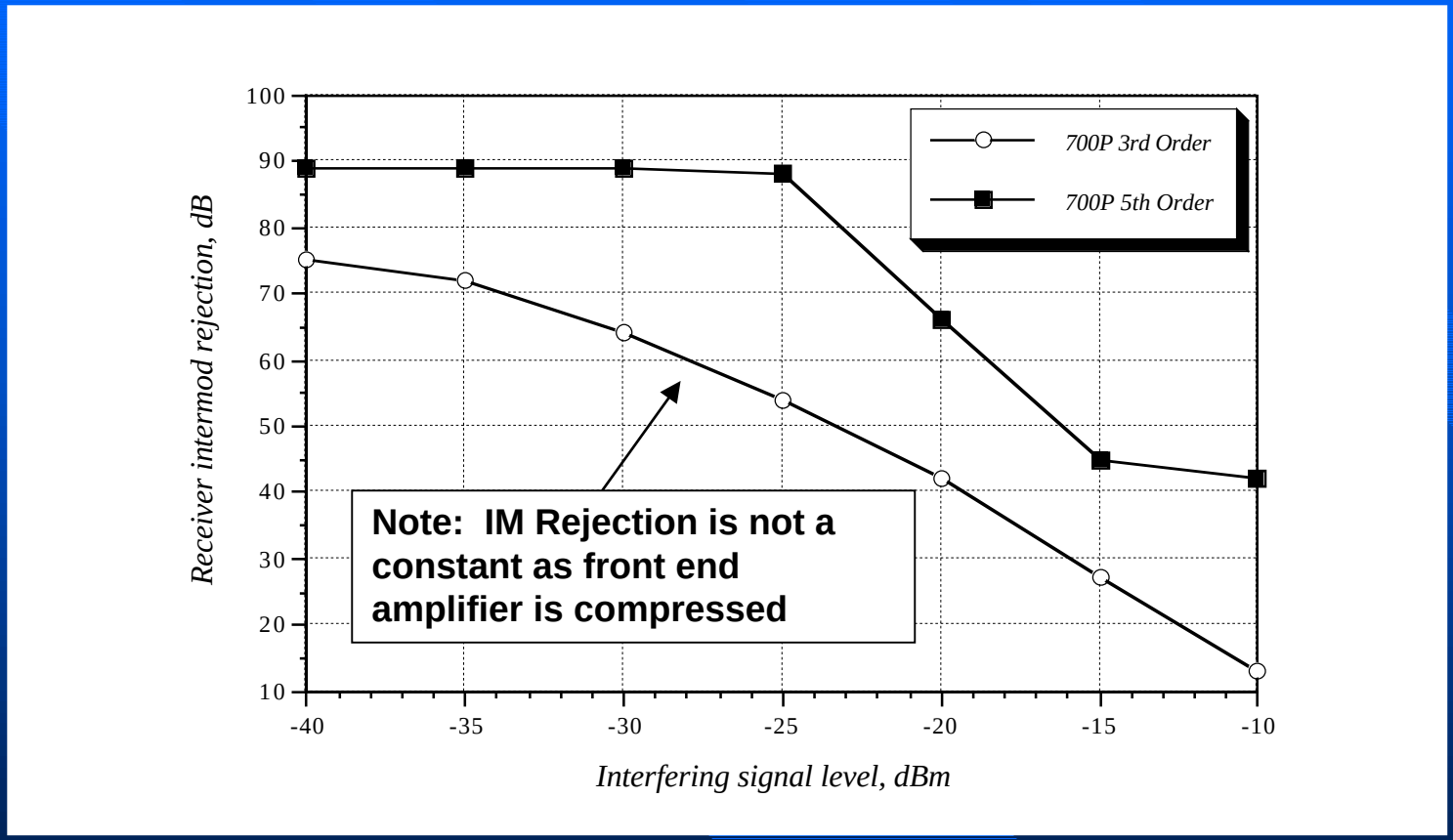
- **Actions**
  - Objective: Protect receivers from 3rd order products
  - Practically, only some Denver channels can be protected
  - Control channel is most important
  - Limit control channels to first five RF channels
  - Nextel protects just these five channels
- **Results**
  - Effective at roughly 18 of 24 problem sites
- **Limitations**
  - Only control channels are protected
  - Voice channels still experience interference
  - System often assigns user to a bad voice channel (one with IM)
  - Nextel limited in use of their spectrum

Public Safety Receiver

- At low levels, IM rejection driven by mixer performance
- At high levels (> -40 dBm), IM rejection driven by LNA
- Bandpass Filter Passes All of SMR, Most of A-Band Cellular



MA/COM 700P Typical IM Performance



Notes: Two-tone, equal amplitude, 1 kHz tone with 2.4 kHz deviation, 2 MHz (3rd order) & 4 MHz (5th order) separation, figure of merit = 12 dB SINAD, signal generators isolated from each other with cavity filters and ferrite isolators.

Problem Mitigation
Transmitter Out of Band Emissions (OOBE)

- **Actions**
  - Nextel installed auto-tune cavity combiners
  - Greater filter selectivity reduces out-of-band emissions
- **Results**
  - Effective when channel separation is wide enough
- **Limitations**
  - Not effective for closely spaced frequencies (< 150 kHz)

Problem Mitigation
Antenna Patterns

- **Actions**
  - Nextel installed antennas with reduced downward radiation
- **Results**
  - Reduces Nextel signal level on the street
  - IM products reduced by roughly 3 to 1 ratio in dB
- **Limitations**
  - Signal still too strong at some locations
  - Some loss of indoor coverage close-in for Nextel
  - Note: Wireless operators often do the opposite & use null fill

AT&T Wireless

Problem Statement

- **After Mitigation, Six Sites Remained a Serious Problem***
  - Five of the six were co-located Nextel/AT&T Wireless
  - Mathematically, AT&T can contribute to receiver IM
  - IM can be AT&T alone (NPSPAC mostly) or with Nextel
  - Verizon also in theory, but to lesser extent
- **Task: Determine if AT&T is Contributing to Problem**

*These are the red sites. Denver also has lesser problems at several yellow sites.

Cellular Operators in Denver

- **AT&T Wireless**
  - Cellular A band, 869 - 880 MHz, 890 - 891.5 MHz
  - AMPS, TDMA, CDPD (GSM in the future)
  - 30 kHz channels
  - Dynamic Channel Allocation
  - Lucent base station with linear amplifier combiners
- **Verizon Wireless**
  - Cellular B band, 880 - 890 MHz, 891.5 - 894 MHz
  - AMPS, CDMA
  - 30 kHz, 1.25 MHz channels
  - Virtually all traffic carried on 1.25 MHz channels

Observations - AT&T

- **Factors Contributing to Interference**
  - AT&T is adjacent to NPSPAC band (869-880, 890-891.5 MHz)
  - Numerous theoretical “hits” on Denver NPSPAC channels
  - Numerous “hits” with Nextel frequencies in 855 MHz region
  - Denver receivers do not attenuate below 875 MHz
  - AT&T base stations pass transmitter noise below 869 MHz
- **Mitigating Factors**
  - Signal levels on street are lower than Nextel (in general)
  - Location in 800 MHz band limits AT&T 3rd order products
  - Most likely products are combinations with Nextel
  - Frequencies above 875 MHz attenuated (for some radios)
  - Transmitters not keyed continuously

Observations - Verizon

- **Factors Contributing to Interference**
  - **Some theoretical hits with AT&T Wireless**
  - **Wideband CDMA signal affects many channels**
- **Mitigating Factors**
  - **Transmitters tend to be low power & low power density**
  - **Most Denver portables do not pass freqs. above 880 MHz**
  - **Base stations do not pass transmitter noise below 869 MHz**
  - **Verizon not contributor at known problem sites**

Known Problem Sites
(Co-Located with AT&T)

- 48th & Elm
- Colorado & Colfax
- 1st & University
- Yale & Colorado
- 14th and Market

Approach

- **Verify AT&T is Contributing to Problem**
  - **Measure receiver IM performance in lab**
  - **Drive test each site**
  - **Predict & plot areas of poor *C/I***
  - **Conduct desktop intermodulation study**
  - **Conduct on-off tests to verify predictions**
- **Investigate Potential Solutions**

Methods

- **Test Instrument: Grayson WMS**
  - Verified test receiver IM occurs at signals > -40 dBm
  - Eliminated test receiver IM through filtering & attenuators
- **Data Collection**
  - Linear average at least 50 subsamples over > 100 feet
  - Ensures high confidence level, narrow confidence interval
- **Analysis**
  - Predict receiver *C/I* caused by receiver IM
  - Use receiver IM curves from lab measurements
  - Apply measured signal amplitudes to predict *C/I*
- **Plot Data on Digital Maps for Display**
  - *C/I* > 20 dB = Green, 17 dB < *C/I* ≤ 20 dB = Yellow, *C/I* ≤ 17 dB = Red

Example

- Yale & Colorado, 39.6659° N, 104.9406° W
  - Suburban commercial with Denver Firehouse
  - Nextel Across Street from AT&T Wireless
  - Nextel Site is IM-Free on Denver Control Channels
- Mean Signal Levels
  - Denver Control Channel: 854.9875 MHz, -97 dBm
  - Nextel: 865.4375 MHz, -27 dBm
  - AT&T: 870.210 MHz, -38 dBm
- From Rx IM Curve for 700P (Referenced to Strongest Signal),
  - Predicted IM inside receiver = -85 dBm (58 dB IM rejection)
- Predicted C/I = -97 - (-85) = -12 dB

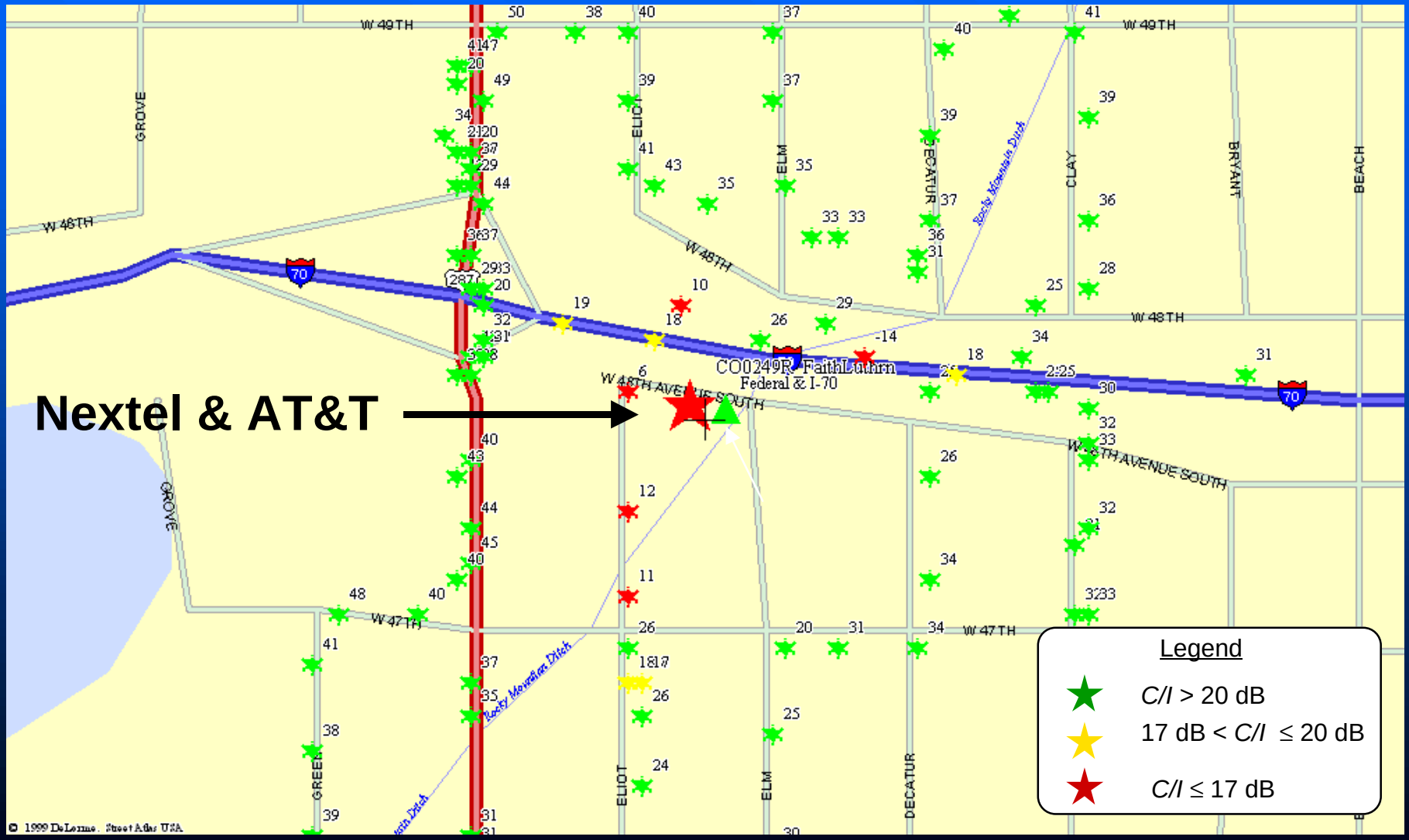
Yale & Colorado

Nextel Site
(East Side)

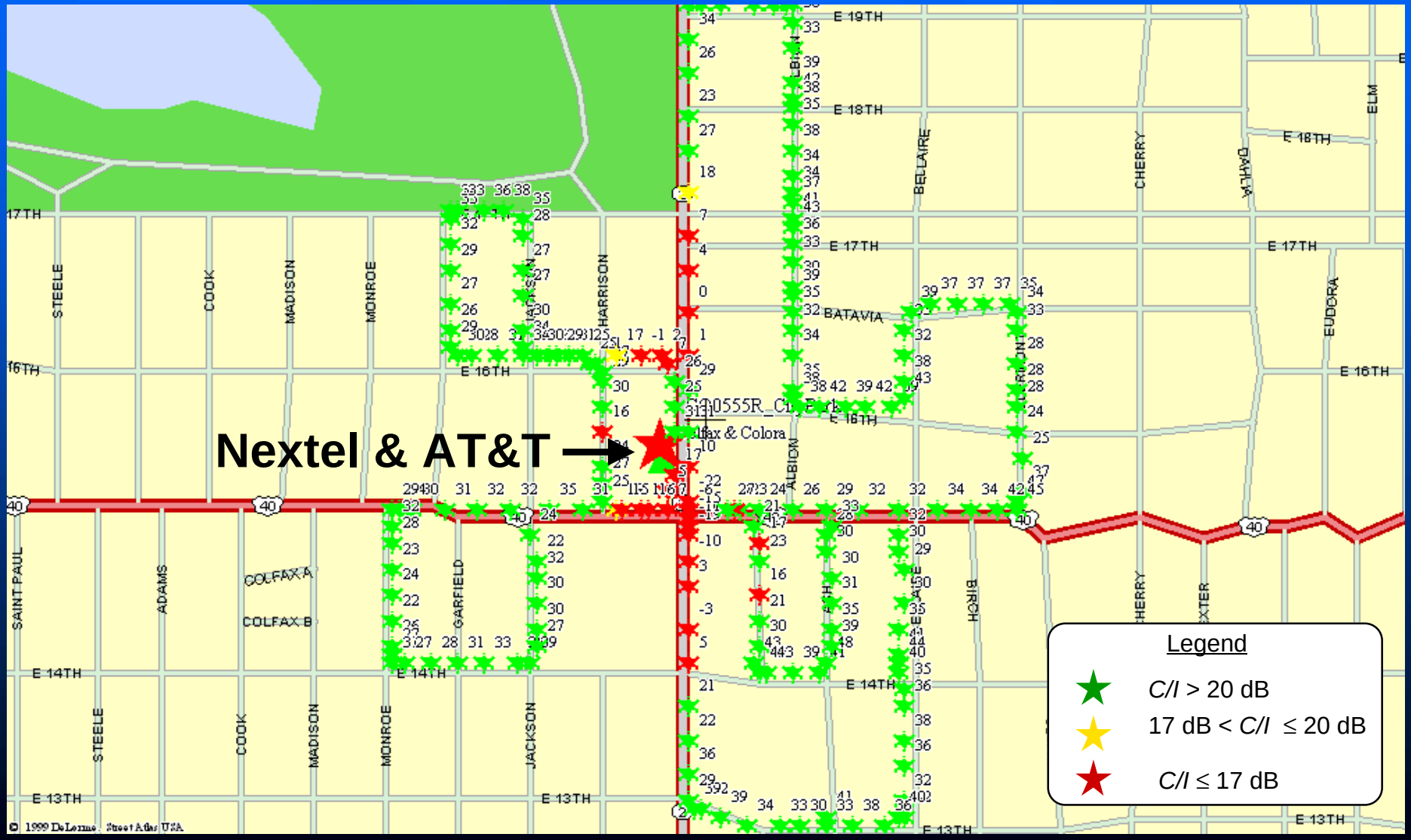
AT&T Site
(West Side, north
of Fire House)

Denver Fire House
(West Side)

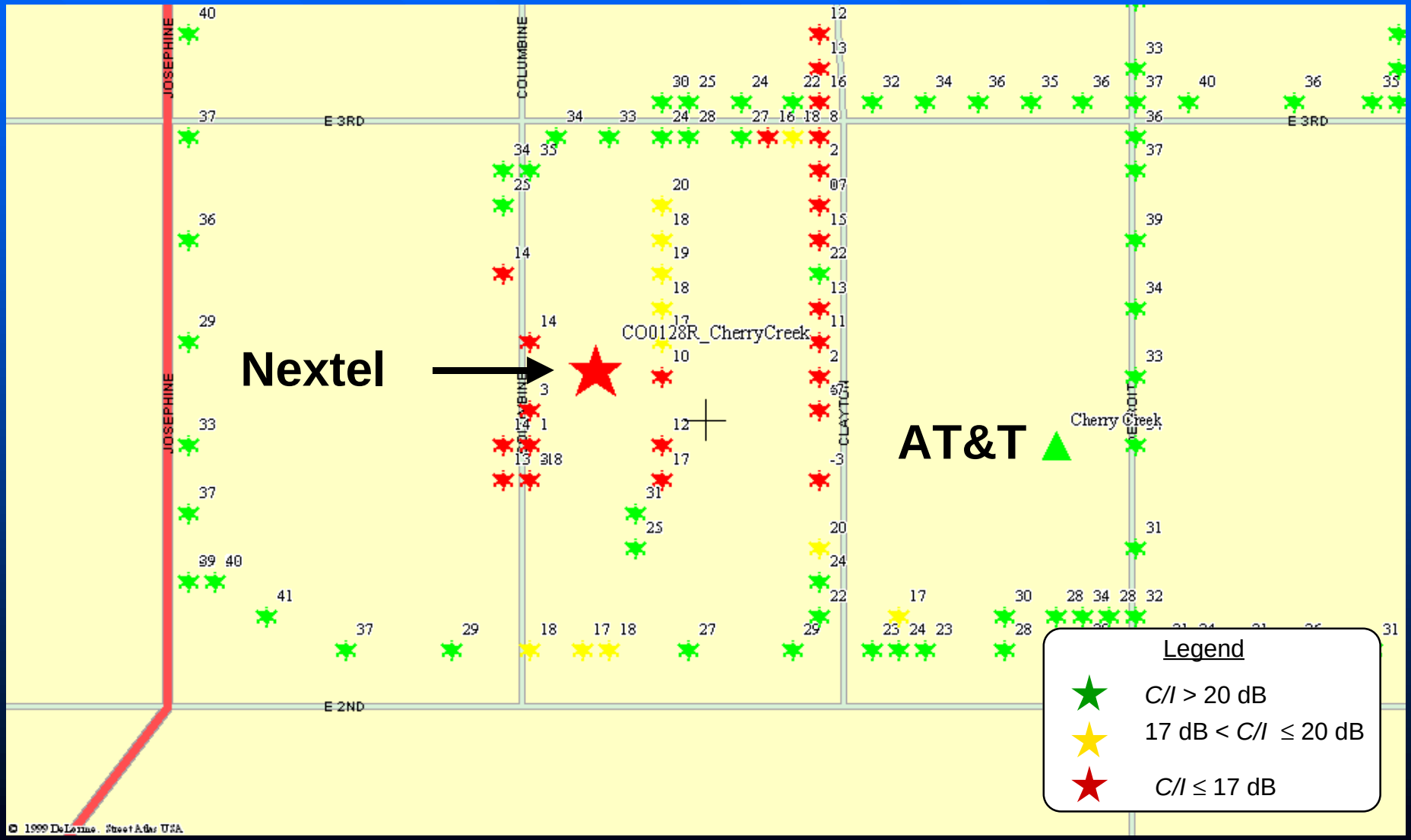
48th & Elm


Nextel & AT&T
W 49TH
W 48TH
W 47TH
W 48TH AVENUE SOUTH
GROVE
ELIOT
ELM
DECATUR
CLAY
BRYANT
BEACH
Federal & I-70
Legend
C/I > 20 dB
17 dB < C/I ≤ 20 dB
C/I ≤ 17 dB

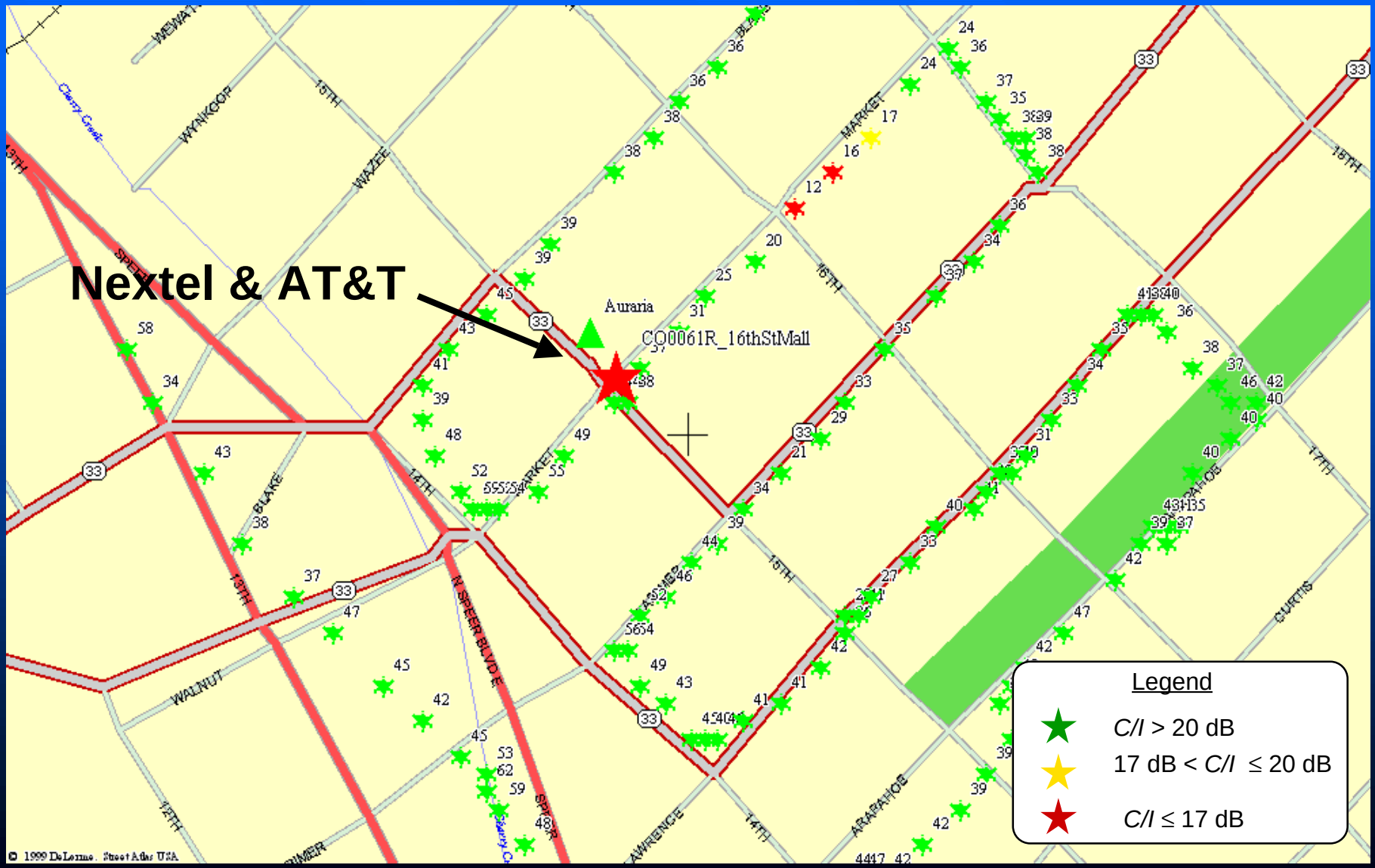
Colorado and Colfax



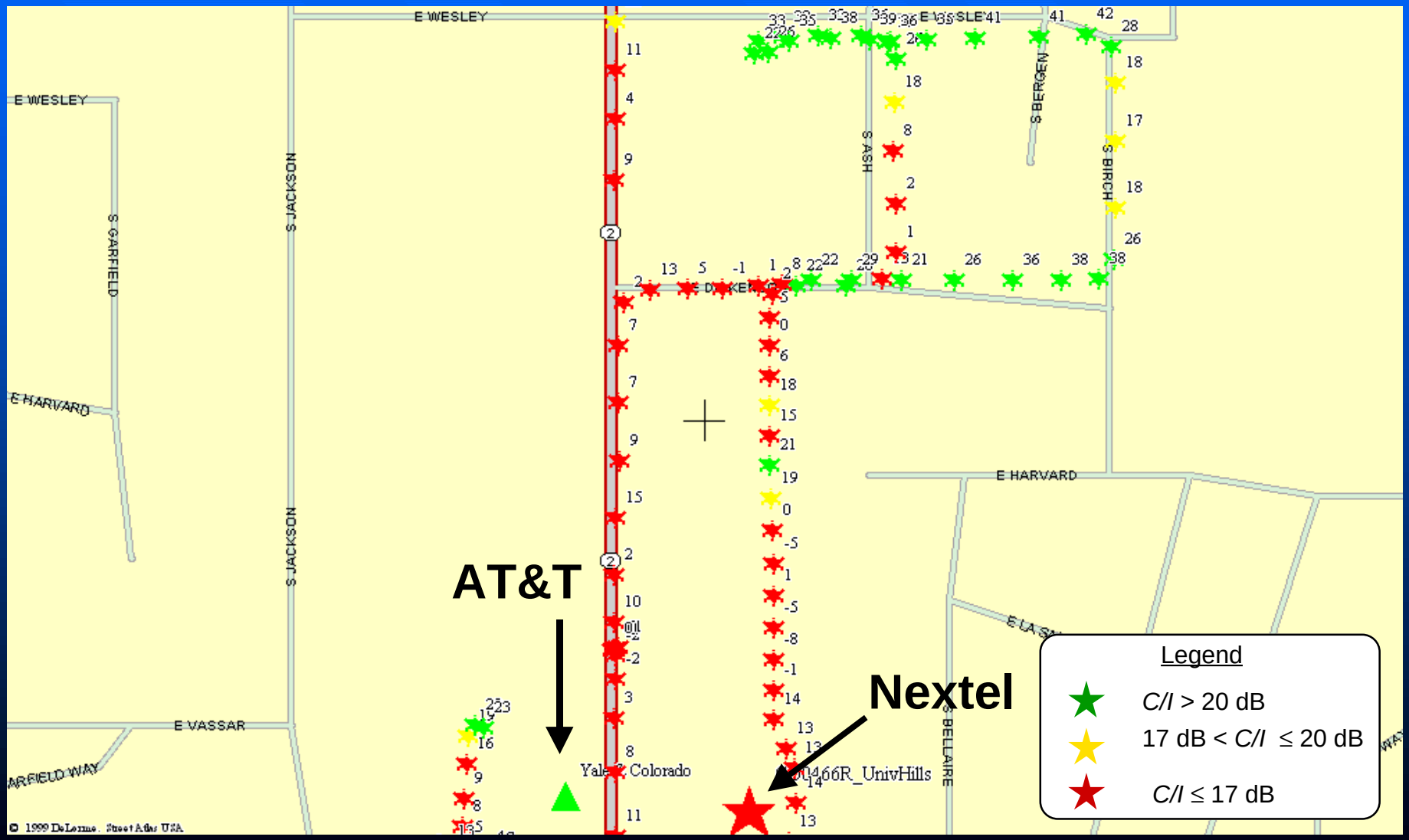
1st and University



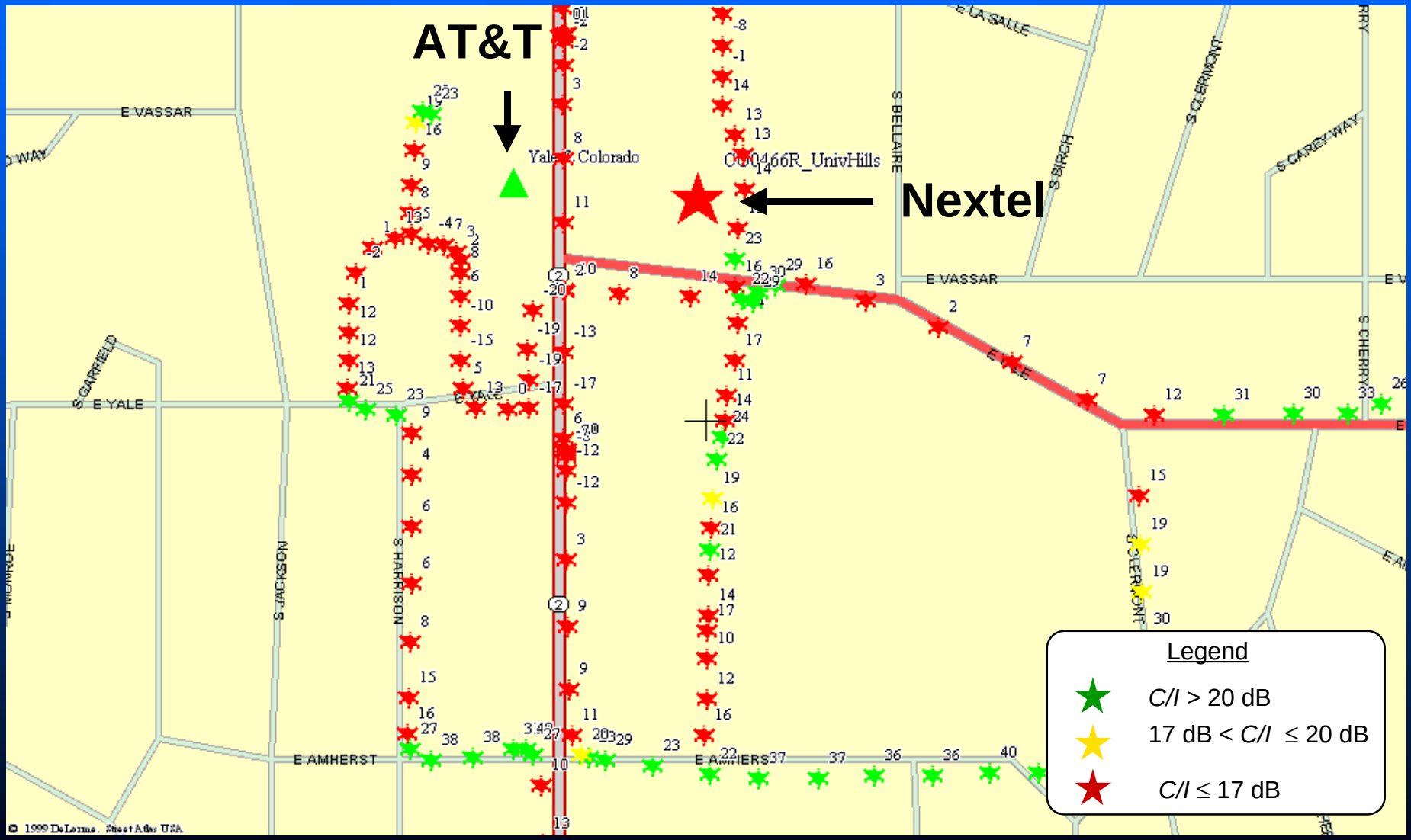
14th and Market



Yale and Colorado (North)



Yale & Colorado (South)



On-Off Testing

- First, Conduct Intermodulation (IM) Study
  - Consider all 3rd order products with AT&T & Nextel
  - Complicated by fact that AT&T has large set of potential freqs.
  - Only first five Denver channels considered (control channels)
- Second, Use IM Study to Configure On-Off Test
  - Limit keyed AT&T frequencies so only known IM products occur
  - I.e., assures cause and effect conclusion is correct
- Finally, Walk the Area Under On and Off Conditions
  - Verifies that AT&T is or is not a contributor

Example

- **Yale & Colorado:**

2 (863.0375 MHz) - 871.080 MHz = 854.9950 MHz

2 (Nextel) - AT&T = Denver Channel 1 (control channel)*

- **Turn off 871.080 MHz and interference effects disappear**

***Offset by 7.5 kHz**

AT&T Results

- AT&T Wireless Contributes to Receiver IM
  - Predicted mathematically, confirmed by On-Off tests
  - Good correlation between predictions and on-street experience
- Most 3rd Order Products Require Nextel Also
  - Mathematically, frequencies between 869 and 880 cannot do it alone
  - 2A - B products can only reach to 858 MHz, above first five channels
  - But 2A - B with A = Nextel, B = AT&T, does occur
  - Similarly, A + B - C with A,B = Nextel, C = AT&T does occur
  - Extended band frequencies (890-891.5 MHz) often attenuated by front-end
- Nextel Levels on the Street Stronger than AT&T in General
- Lab Test Results:
  - IM product more sensitive to amplitude of “A” than “B”
  - Consequence of second harmonic generation (2A-B)
  - Thus, Nextel amplitude has stronger effect for most products
  - Also, 5th order products much lower than 3rd order (helpful result)

Potential Solutions

- **Restrict AT&T Frequency Sets at Problem Sites**
  - **Eliminate 3rd order products alone and with Nextel**
- **Reduce Interference Power on the Street**
  - **Replace Nextel antennas (less downward radiation)**
  - **Replace AT&T antennas (less downward radiation)**
  - **Lower Nextel transmitter power**
  - **Lower AT&T transmitter power**
  - **Different sector orientation/split sectors/move site(s)**
- **Increase Desired Signal Power on the Street**
  - **Booster amplifiers**
- **Each of These Has Pros & Cons**
  - **Sorry, no painless solution**

Why The “Technical Toolbox” is Inadequate

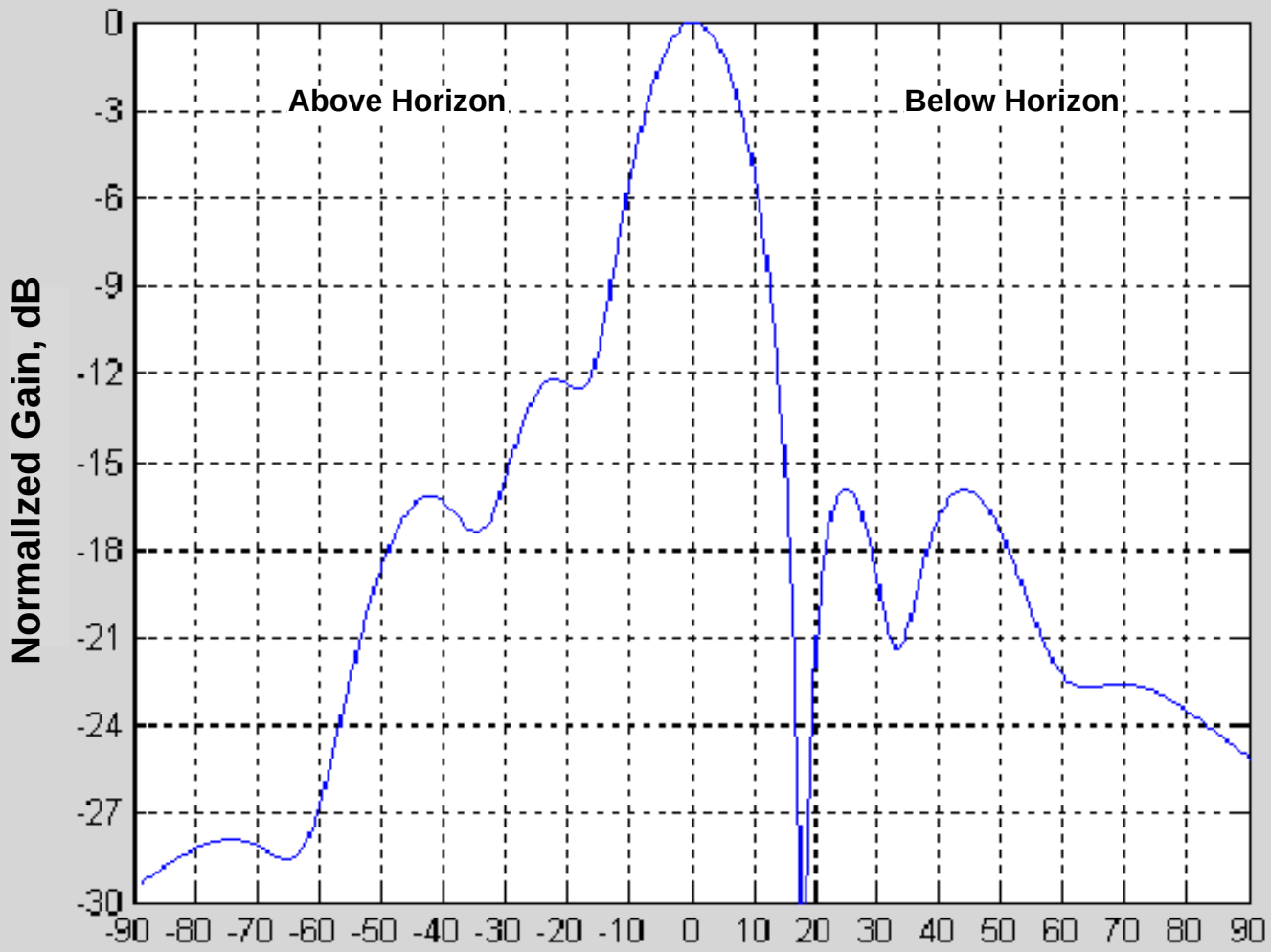
The “Technical Toolbox”

- Tools Already In Service in Denver:
  - IM Tuning at Nextel Sites
  - Auto-tune cavity combiners
  - Antennas with less downward radiation
  - Booster amplifiers
  - Reduced Nextel transmitter power
- Varactor Bandpass Filters
  - Addresses “wide open” receiver problem
  - Provides isolation for users of a specific band
- Switchable Attenuator
  - Assuming 3rd order products, reduces IM by 3:1
  - I.e., 3 dB attenuator reduces IM product by 9 dB
- Why Can’t These Tools Do the Job Without Re-banding?

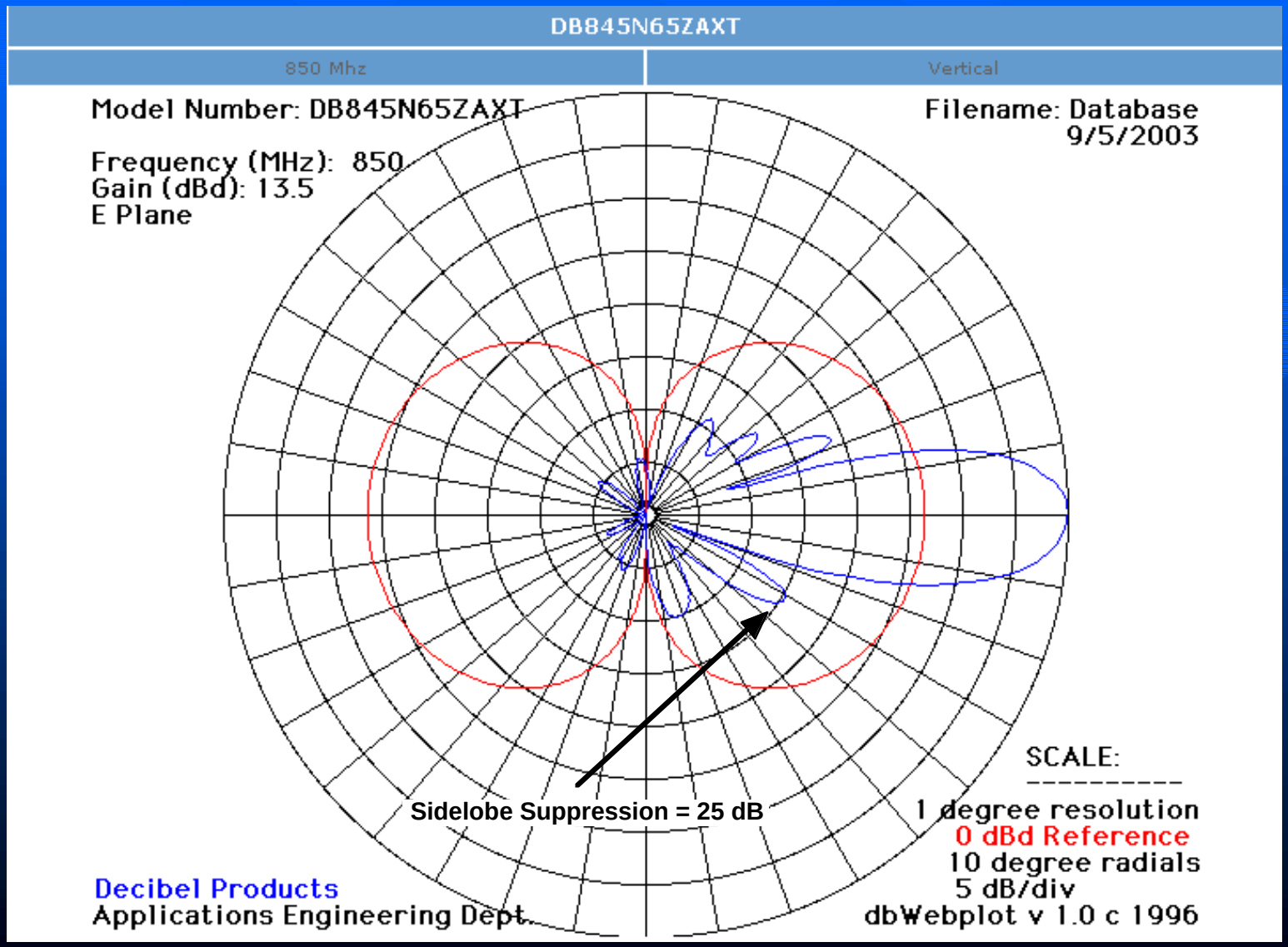
The “Technical Toolbox”

- IM Tuning
  - Limits Nextel’s frequency choices too much
  - Only practical to protect a handful of frequencies (control ch’s)
  - At congested sites, we still have strong IM on traffic channels
  - Nextel alone can’t control the Nextel/AT&T mixes
- Auto-Tune Cavity Combiners
  - Cavities have finite isolation
  - Not good for close-in channels (< 150 kHz)
  - Further limits Nextel’s frequency choices
- Antenna Patterns
  - See REMEC FCC comments
  - They have right idea, but we are already doing this

REMEC Pattern



Antenna Used in Denver



Antenna Issues

- Tried Sidelobe Suppression at Two Sites:
  - City Bank, 8-10 stories high, good results
  - 14th & Market, ~ 3 stories high, not effective
- Only works on relatively high sites (look down angle issue)
- Lose close-in, indoor coverage
- Scattering limits isolation regardless of theoretical pattern
  - Might contribute to problem at 14th & Market
- Higher gain, narrower beamwidth antennas best
  - High gain antennas are taller
  - But zoning restrictions limit antenna height

It’s Usually the Low Site

(Alameda & Federal)

Another Low Site

(48th & Elm)

The “Technical Toolbox”

- **Booster Amplifiers**
  - Several already in use at indoor locations
  - Wideband outdoor amplifiers rejected for Nextel or AT&T Problem
    - » Outdoor isolation between input and output difficult to achieve
    - » Amplifies OOBE from other Nextel sites
    - » Creates more intermodulation interference
    - » Only appropriate for very small areas
    - » Adds maintenance costs to the overall system
  - Better suited for post re-banding when filters could help
  - Channelized amplifiers prohibitively expensive (48 channels)
- **Reduce Nextel Transmitter Power**
  - Limited effectiveness
  - Reduced power means reduced coverage and more sites

The “Technical Toolbox”

- Varactor-Tuned Bandpass Filters
  - Motorola suggestion
  - Good idea, but cannot help if channels are interleaved
  - Better for switching between 700 & 800MHz systems
- Switchable Attenuator
  - Motorola suggestion
  - Detects strong signals, switches in 15 dB attenuator
  - But cannot distinguish between IM and receiver overload
  - In most cases, will unnecessarily degrade sensitivity by 15 dB
  - But the problem occurs at -90 to -110 dBm
  - Cannot afford a 15 dB hit in sensitivity at these levels*

*Note: Motorola might use RSSI to determine desired signal level and attenuate or not depending on the measured level. However, the C/(I+N) still may not be sufficient if broadband OOBE are present, effectively raising the noise floor. Also, the energy at the desired channel frequency may actually be IM. It is a difficult estimation problem.

Why Denver Needs Re-Banding

- **Denver Has Tried the "Technical Toolbox" for 3 Years**
  - **Only partial improvements**
  - **These are stop-gap measures**
- **The Problem Will Only Get Worse**
  - **Nextel & AT&T will continue to build sites with low antenna heights**
- **Only Re-Banding will Solve the OOBE Issue**
- **Receiver Technology Will Not Save Us**
  - **Amplifier & mixer technology is mature**
  - **No significant advances on the horizon**
- **Filtering at Receivers & Transmitters Only Effective w/Re-Banding**

Conclusions

- City and County of Denver has 3 years experience
  - We've tried all practical solutions
  - Problem is still not solved
- Long Term Solution Should be Re-Banding
  - Dissimilar technologies should not share band
  - Otherwise, near-far problem will always be present
- Separating Bands Helps in Several Ways:
  - Moves NPSPAC channels away from A-Band operator (AT&T)
  - Allows vendors to put useful bandpass filters at front-end
  - Creates guard band to minimize number of harmful IM products
  - Makes IM tuning at Nextel sites feasible & practical
  - Makes filtering of OOBE at Nextel sites feasible

Points of Contact

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