Interference Rejection Thresholds of DTV Receivers

National Translator Convention

May 2007

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(Research Study by Steve Martin)
FCC Office of Engineering and Technology

DTV Receiver Test Program

- **TV Receiver Performance:**
  - Threshold reception performance (ability to receive service)
  - Interference rejection capabilities (immunity from interference on adjacent channels)

- **FCC Has Now Conducted Studies of Both Aspects:**
  - "Tests of ATSC 8-VSB Reception Performance of Consumer Digital Television Receivers Available in 2005", Report FCC/OET TR 05-1017 (SHVERA Study (www.fcc.gov/oet/info/documents/reports/TR-05-1017-ATSC-reception-testing.pdf)
  - "Interference Rejection Thresholds Of Consumer Digital Television Receivers Available in 2005 and 2006," Report FCC/OET 07-TR-1003 (www.fcc.gov/oet/info/documents/reportsDTV_Interference_Rejection_Thresholds-03-30-07.doc)

Review of Reception Performance Study

- Questions addressed- Among reasonably-priced consumer DTVs,
  - Is there a wide variation in reception performance?
  - Is such variation related to price?
  - Should such variation be factored into setting a standard for whether a household is unserved by a digital signal?

- DTV receiver model- Predicts required signal level at the TV input
  - ***Noise figure =*** ***10 dB (VHF) or 7 dB (UHF)***
  - ***Required Carrier-to-Noise Ratio (CNR) =*** ***15.2 dB***
  - ***Min. Threshold for Reception-*** ***84 dBm (UHF)***

    (Them. Noise + Noise Figure + C/I) ***81 dBm (VHF)***
  - ***Multipath handling capability***- Ability to demodulate in various multipath conditions

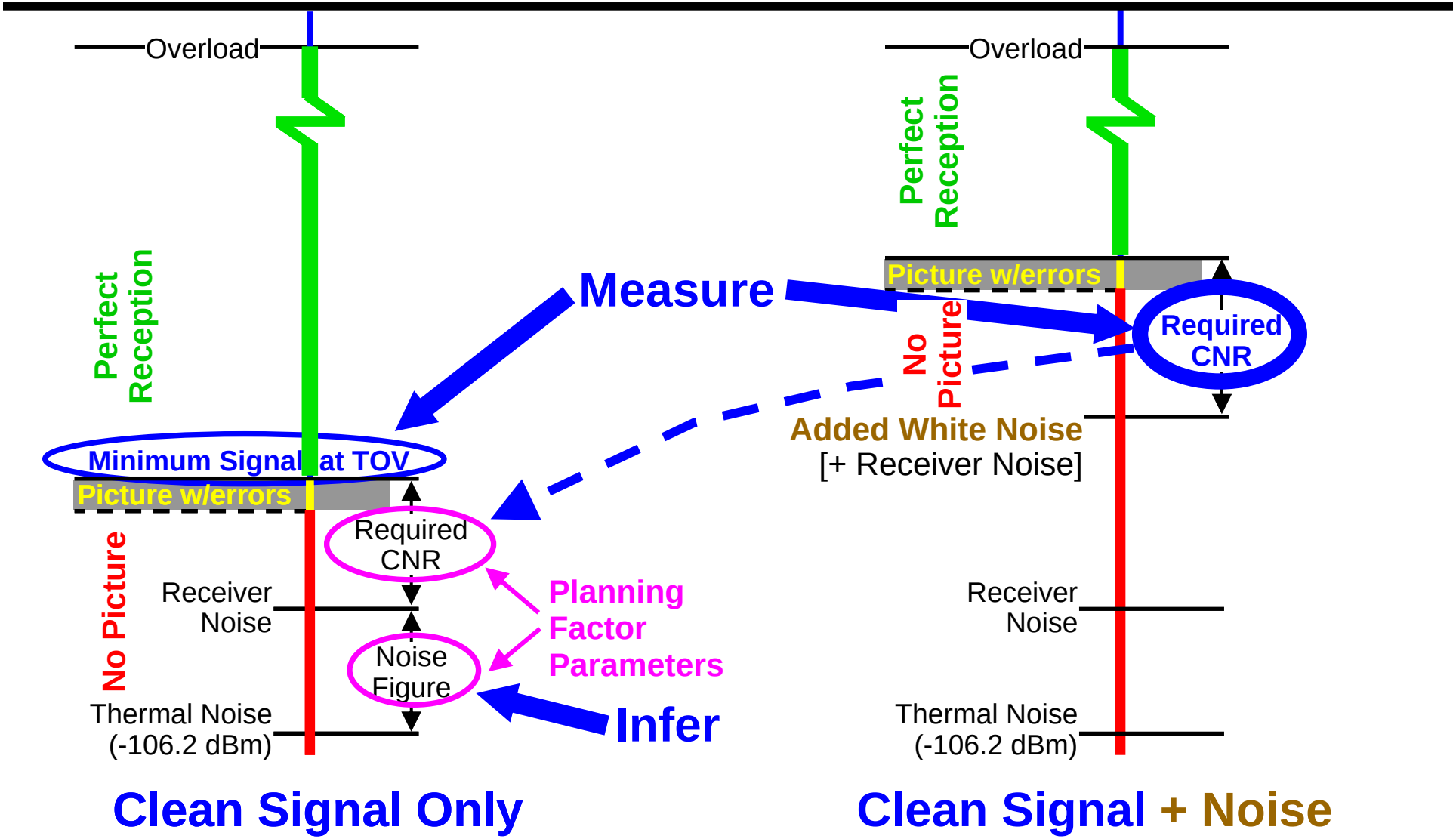
DTV Receiver Samples

Sample Type	Number of Samples	Display Size	Display Aspect Ratio	Display Technology
Set-Top Box (STB)	5	N/A	N/A	N/A
DTV with Integrated ATSC Digital Tuner:				
• $370 - $1000	6	26” – 36”	4:3 or 16:9	Direct-View CRT
• $1001 - $2000	8	26” – 52”	16:9	Direct-View LCD, Plasma, CRT Rear Projection, DLP Rear Projection, LCD Rear Projection
• $2001 - $4200	9	32” – 62”	16:9	Direct-View LCD, Plasma, DLP Rear Projection, LCD Rear Projection
TOTAL	**28**			

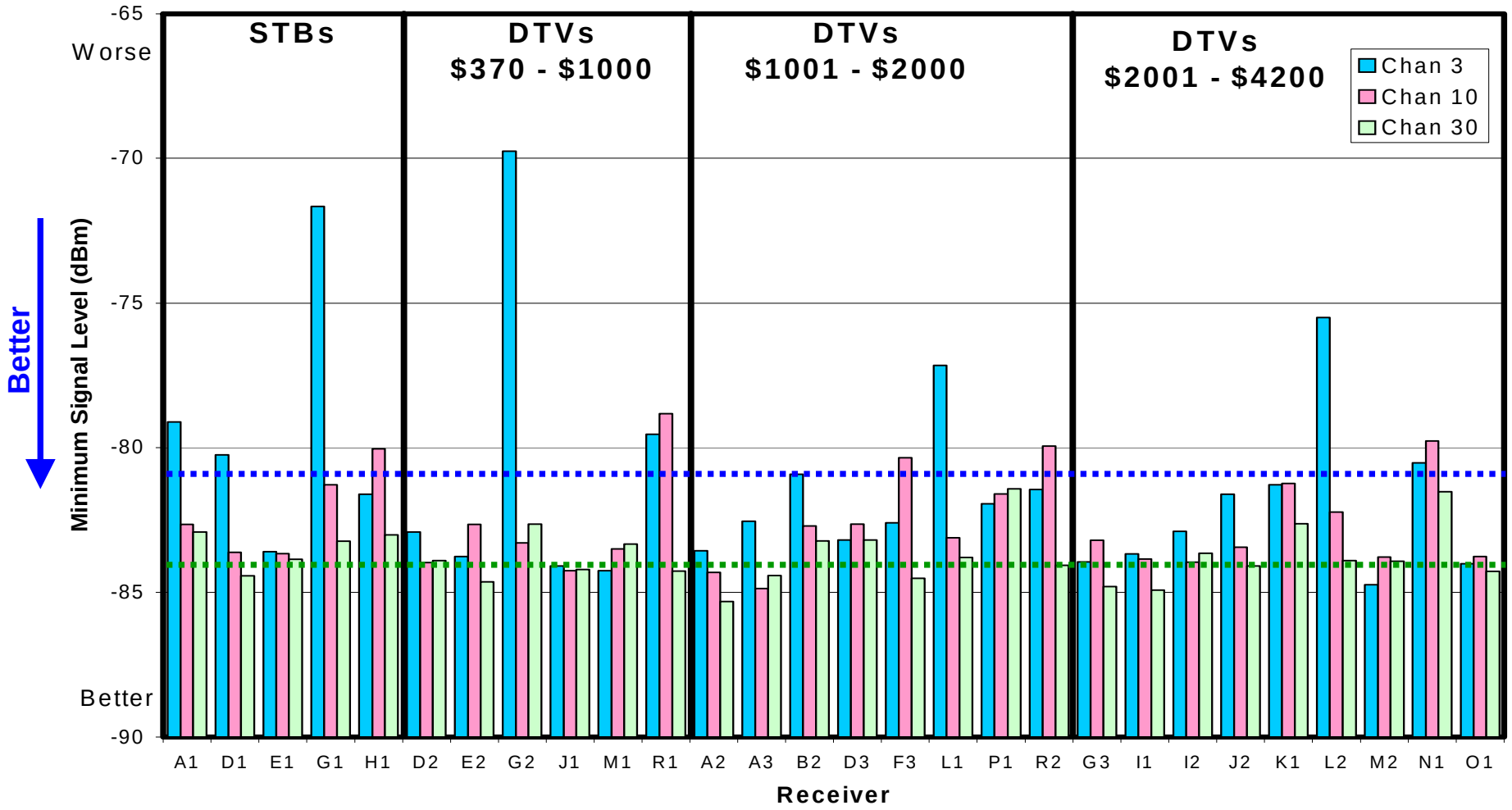
- 28 receivers … 16 brands
- TVs total 2200 pounds and 82 linear feet of width

Benign Signal Measurements

(Measure Minimum Signal & Required CNR; Infer Noise Figure)

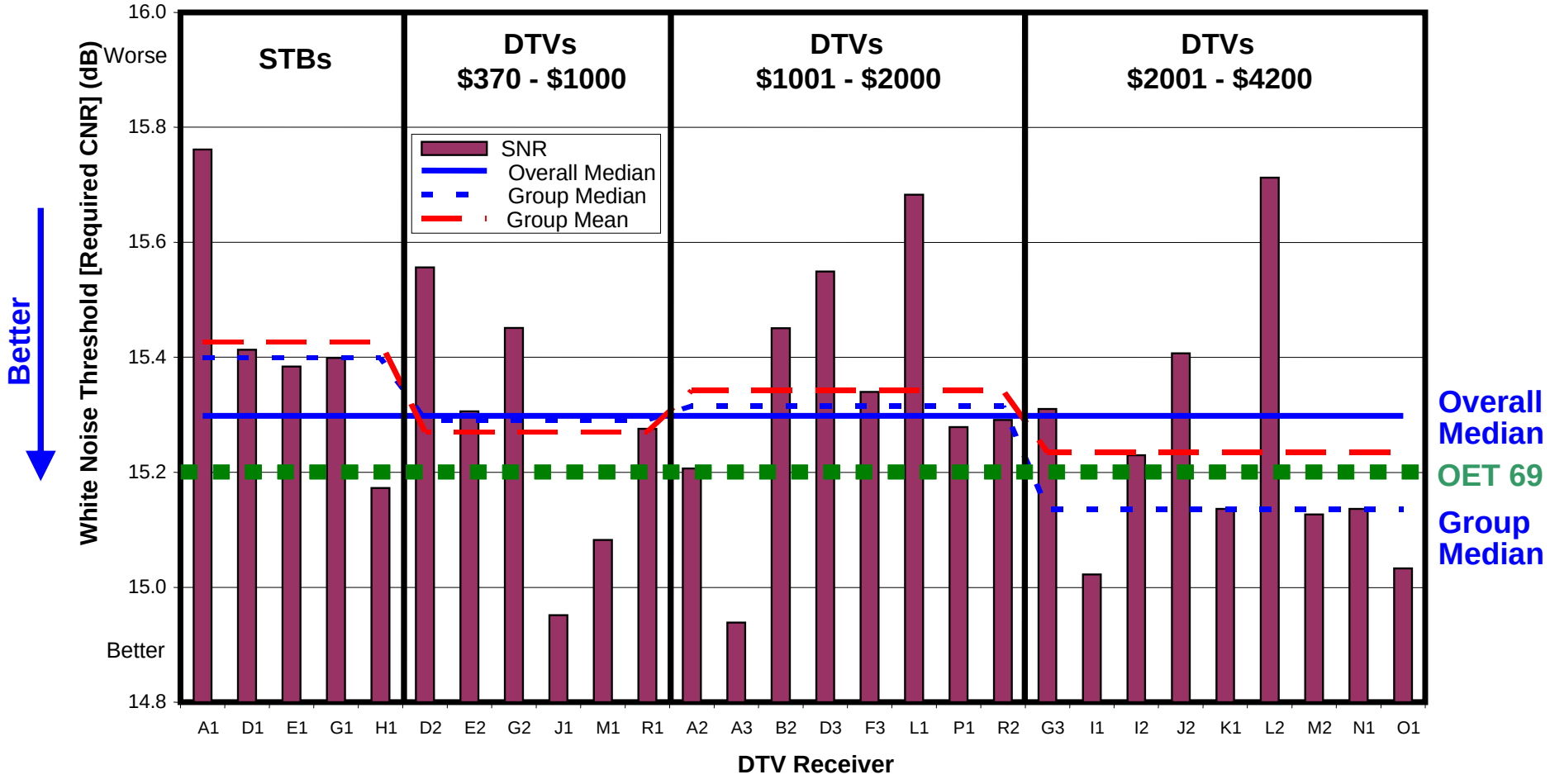


Minimum Signal at Threshold
on Channels 3, 10, & 30



- OET69 predicts -81 dBm for Chan 3 & 10 and -84 dBm for Chan 30
- ATSC recommends receiver sensitivity of at least -83 dBm
- Note outliers on Chan 3 exceed expectation by up to 11 dB

Required CNR (White Noise Threshold)

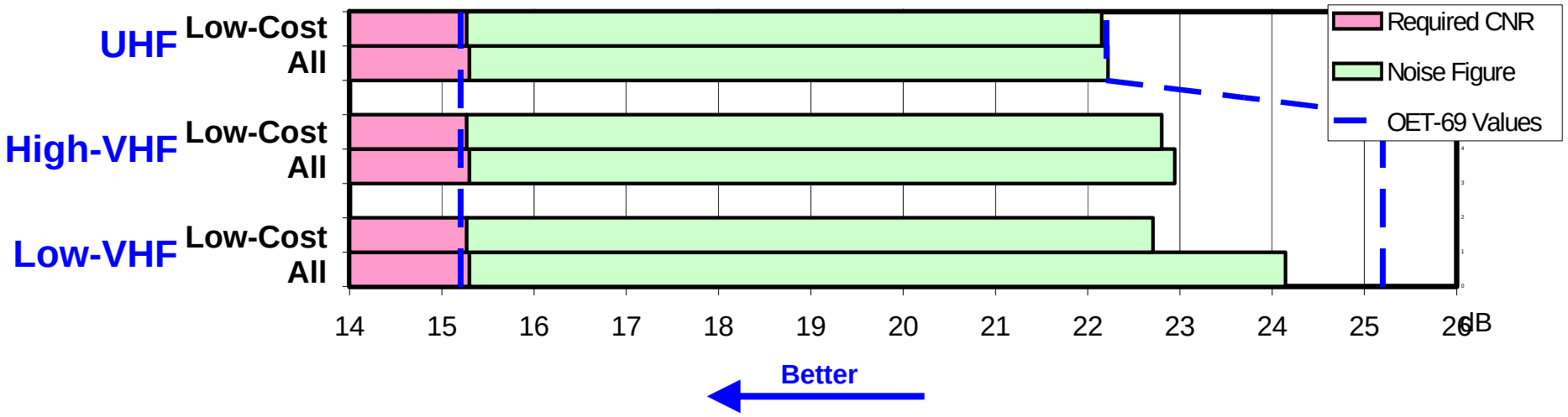


- **Within each group, samples are listed in a randomized brand order rather than price order**
- **Standard deviation is only 0.2 dB. Best receiver differs from worst by 0.8 dB.**
- **Correlation w/price is *not* statistically significant (-9% for all, +7% for TVs only)***

* 10% probability that sample from uncorrelated population will show correlation > +32% with 28 samples or >+35% with 23 samples (TVs only)

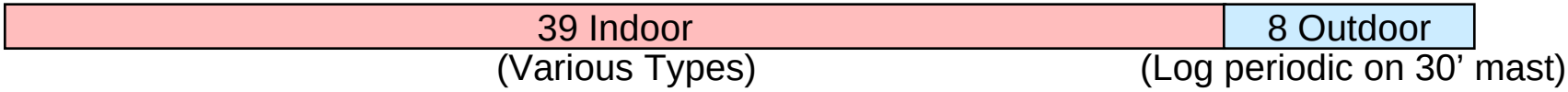
Conclusions:
Reception Performance Re OET 69 Model

- **Median receiver performance closely matches OET 69 model**
  - Required CNR:
    - Actual receivers match OET 69 model
      (Study also suggests that required CNR may degrade to 16 dB in median multipath conditions)
  - Noise Figure:
    - Actual receivers perform better than model at VHF & match model at UHF



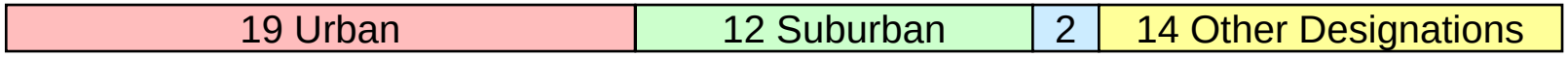
Measurements with Multipath

- **50 ATSC-Recommended RF-Captures of DTV Signals**
  - RF recordings from TV antennas in NYC + Washington DC area
  - 23 or 25 seconds duration
  - Represent ***difficult multipath conditions***
- **Selected 47 captures for testing** (Omit 3 of 50 due to lack of video content)
  - Antennas



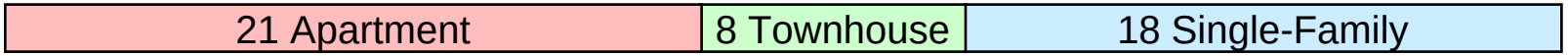
(Various Types) (Log periodic on 30' mast)

  - Site description



Rural

  - Housing type

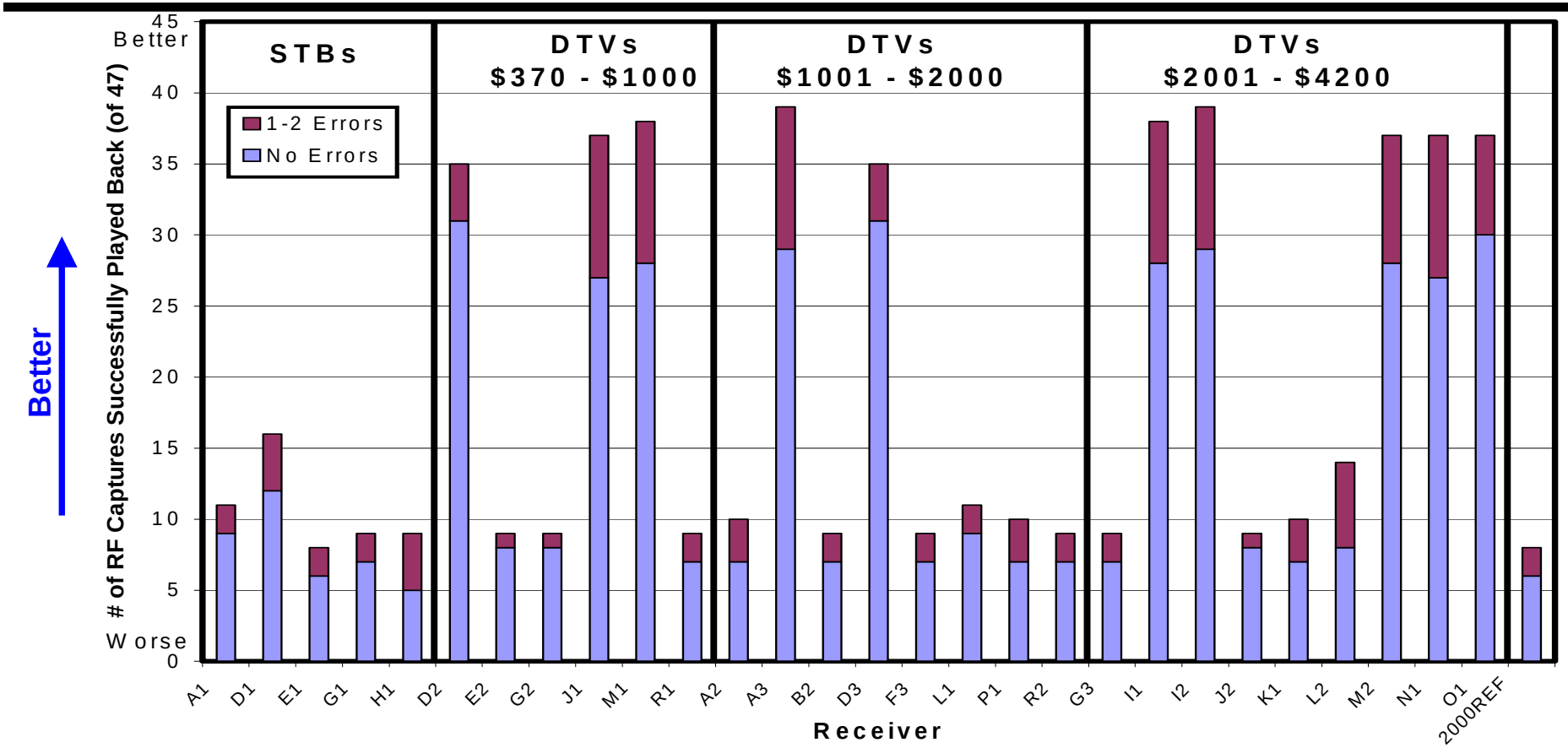


- **Test**
  - Count # of captures successfully played on each TV [tabulated 2 success criteria]
  - Channel 30 only

# of Tests = 29* receivers x 47 captures = 1363

* Includes instrumented receiver

Multipath Performance Using Field Captures



- **Two tiers of performance. Upper tier includes latest chipsets from two manufacturers**
- **Reference receiver from year-2000 field tests fell in lower-tier**
  - With mast-mounted antenna, handled in 99% of test-site/broadcast-station combos having sufficient field strength*
- **Upper-tier performance may be of significant value when indoor antennas are used**

* Inglis, William H & Means, David L, "A Study of ATSC (8-VSB) DTV Coverage in Washington, DC, And Generation Changes in DTV Receiver Performance", OET Report FCC/OET TRB-00-2, Technical Research Branch, Laboratory Division, Office of Engineering & Technology, FCC

Conclusions:

Multipath Effects on Reception Performance

- **Benign signal conditions** (*i.e.*, no multipath)
  - Little variability *except* in low VHF (primarily due to 2 same-brand "outliers")
    - Noise figure accounts for most of the variation
  - No statistically significant correlation with price
- **Difficult multipath conditions**
  - Two performance tiers
    - ***Lower tier*** (12 TVs & 4 STBs)
    - ***Upper tier*** (10 TVs) handled ~4 times as many RF captures as lower tier
    - An in-between tier (1 TV & 1 STB) was slightly above lower tier in performance
  - Performance was ***not*** dependent on price
  - Performance was dependent on introduction date; upper-tier performance achieved by
    - ½ of receivers introduced March 2005 or later
    - None of the receivers introduced earlier

Interference Rejection Capabilities Study

- **Measurements of the ability of DTV receivers to reject interference from signals on TV channels other than the one to which the TV is tuned**

- **The test results are intended to support assessments of interference to DTV reception from:**
  - Non-TV use of vacant TV channels (use of TV “white-space”)
  - Non-TV use of spectrum adjacent to spectrum reclaimed for new uses (*e.g.*, TV channels 52 to 67)), and,
  - Other DTV stations

- **Results also show degree to which consumer DTV receivers comply with the voluntary standards in the ATSC Receiver Performance Guidelines**

Interference Rejection Study
Two Types of Tests

- **Tuner type**
  - Single conversion vs. double conversion
  - Knowledge of tuner type aids in identifying channel offsets at which receivers are likely to be susceptible to interference

- **Interference Rejection**
  - Unlike co-channel interference rejection, out-of-channel interference rejection of DTV receivers depends on receiver characteristics such as tuner selectivity, tuner image performance, automatic gain control (AGC) implementation, and tuner overload characteristics.
  - Measurements intended to reveal 1) whether the out-of-band rejection capabilities of today's consumer DTV receivers differ from the Grand Alliance receiver and 2) to characterize performance in the presence of pairs of interferers

- **Total of 2055 measurements performed**

Tuner Type Tests

- **Tuner Type Considerations**
  - Single conversion vs. double conversion
    - Double conversion takes IF out of TV bands, less likelihood of IX from signals on IF related channels
    - Traditional single conversion TV tuner uses 44 MHz IF; greater likelihood of IX from signals on IF related channels, *i.e.*, +/- 7 and +/- 14 and 15
  - DTV interference criteria based on Grand Alliance double conversion tuner
  - Indications that current sets use single conversion tuners

- **Tuner Type Test Results**
  - Tuner type tests were performed on a sample of 30 DTV receivers
  - Same 28 examined in reception performance study + 2 more
  - Local oscillator sensing was sufficient to ID the tuners in 28 sets; the remaining 2 were subjected to limited IX performance tests
  - All 30 were found to have single conversion tuners

Interference Tests – Scope and Design

- **Approach**
  - Measured the maximum level at which an undesired signal can be injected into the TV receiver's antenna input without adversely affecting TV reception of the desired signal (D/U ratios)
  - Examined effect of undesired signals on adjacent channels to reception at different levels of the desired signal
  - Measured signals on all channels +/- 15 channels adjacent to the desired channel and multiple interferers
  - All tests on desired signals in the UHF band (most channel 30; some channel 51)
  - Splatter (co-channel IX) vs. receiver vulnerabilities
    - Test set-up suppressed leakage of undesired emissions into the desired channel (mainly affects first adjacent channel tests)

Interference Tests – Scope and Design

- **Interfering Signal Sources**
  - ATSC 8-VSB DTV signal used for desired signal and first adjacent channel undesired signal
  - Pseudo-random Gaussian noise signal bandlimited to the same spectral width as a DTV signal (5.38 MHz, 3-dB width) used for undesired signals in most tests at other spacings
  - Except for the small pilot tone of the DTV signal, both types of signals exhibit noise-like signal characteristics and relatively flat spectra similar to those of most modern digital communication systems
  - A few tests were performed using an OFDM signal (5 MHz, 3 dB width)

- **Interfering Signal Bandwidth**
  - Most tests used signals nearly filling a 6 MHz channel
  - A few tests were performed using a 1-MHz wide Gaussian noise signal for comparison.

Interference Tests – Scope and Design

- **DTV Signal Levels**
  - If D/U ratios were constant with changes in desired signal level, measurements at a single desired signal level would be sufficient to characterize the interference susceptibility of a TV receiver at a given channel offset
  - However, the tests showed that threshold D/U ratios vary with signal level, and do so in ways that vary among the different channel offsets on different TVs. The nature of the variation also changes with signal level.
  - To address these factors, tests were performed at three desired signal levels specified by the ATSC: -28 dBm, -53 dBm, and -68 dBm as well as one additional signal level, D_{MIN} + 3 dB, where D_{MIN} refers to the minimum signal level at which a given DTV receiver can operate.
  - In addition, modeling was performed to extend the results down to D_{MIN} + 1 dB.

Interference Tests - Scope and Design

- **Receiver Sample**
  - Because of the large number of variables in interference rejection testing, measurements were performed on only ten receivers
  - Seven of these included one of each brand selected from among receivers exhibiting “fifth-generation” (“Upper Tier”) DTV demodulator performance in the SHVERA Study
  - An eighth TV was procured in 2006
  - The remaining two receivers, on which only limited interference rejection testing was performed, were the those for which the LO tests were inconclusive

Single Channel Results

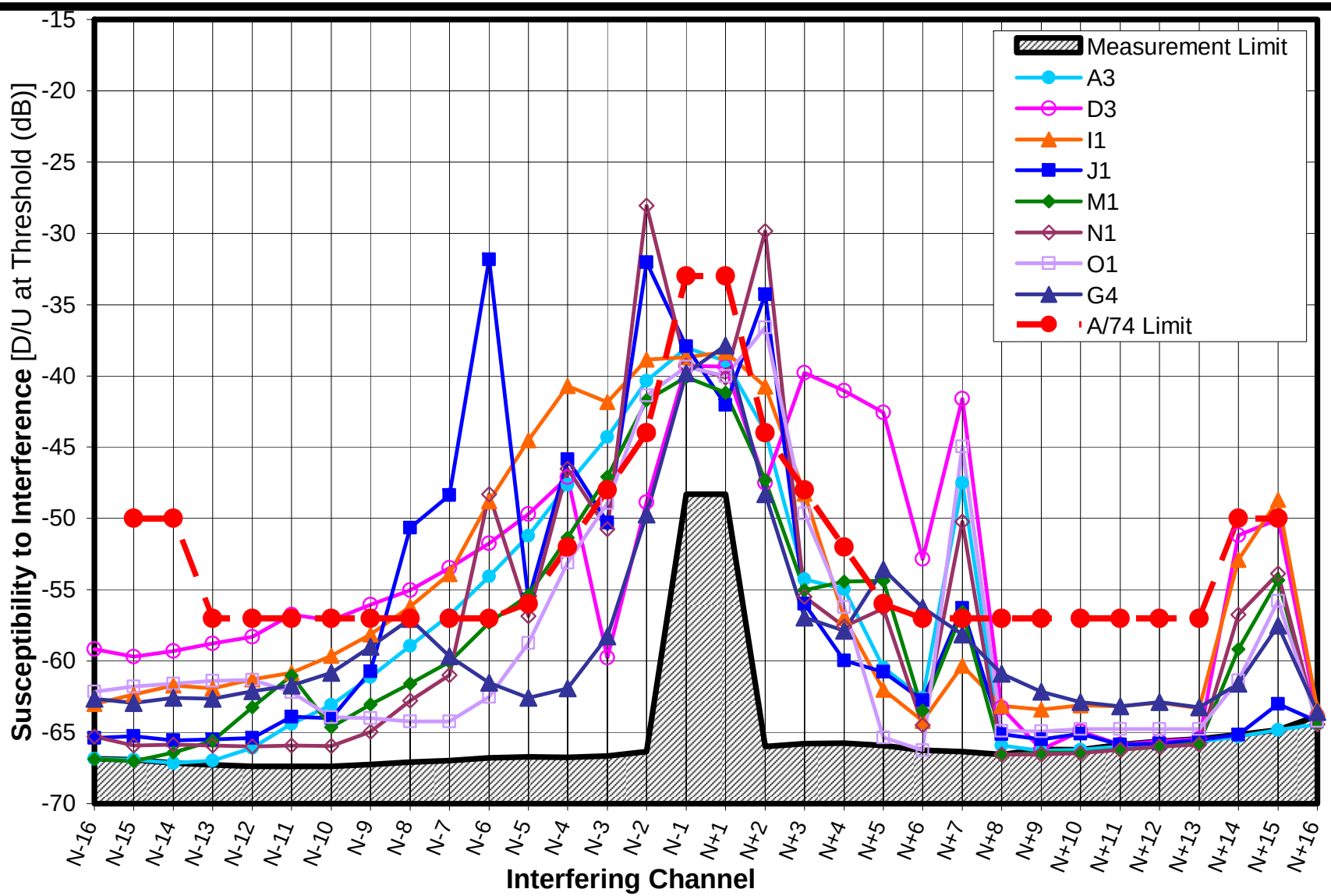


Figure 5-1. D/U of 8 Receivers at D = -68 dBm on Channel 30

Single Channel Results

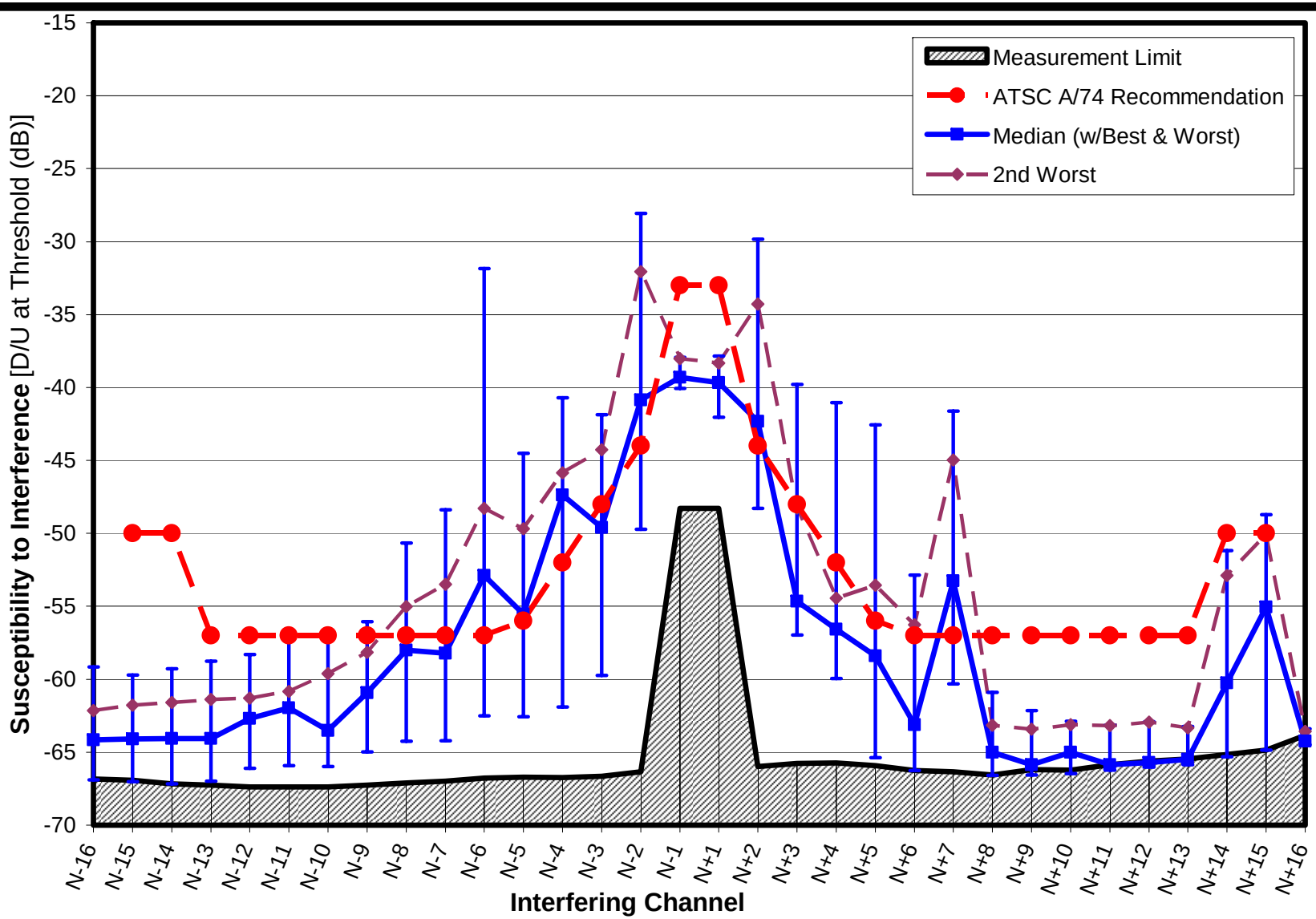


Figure 5-2. D/U Statistics at D = -68 dBm on Channel 30

Single Channel Results

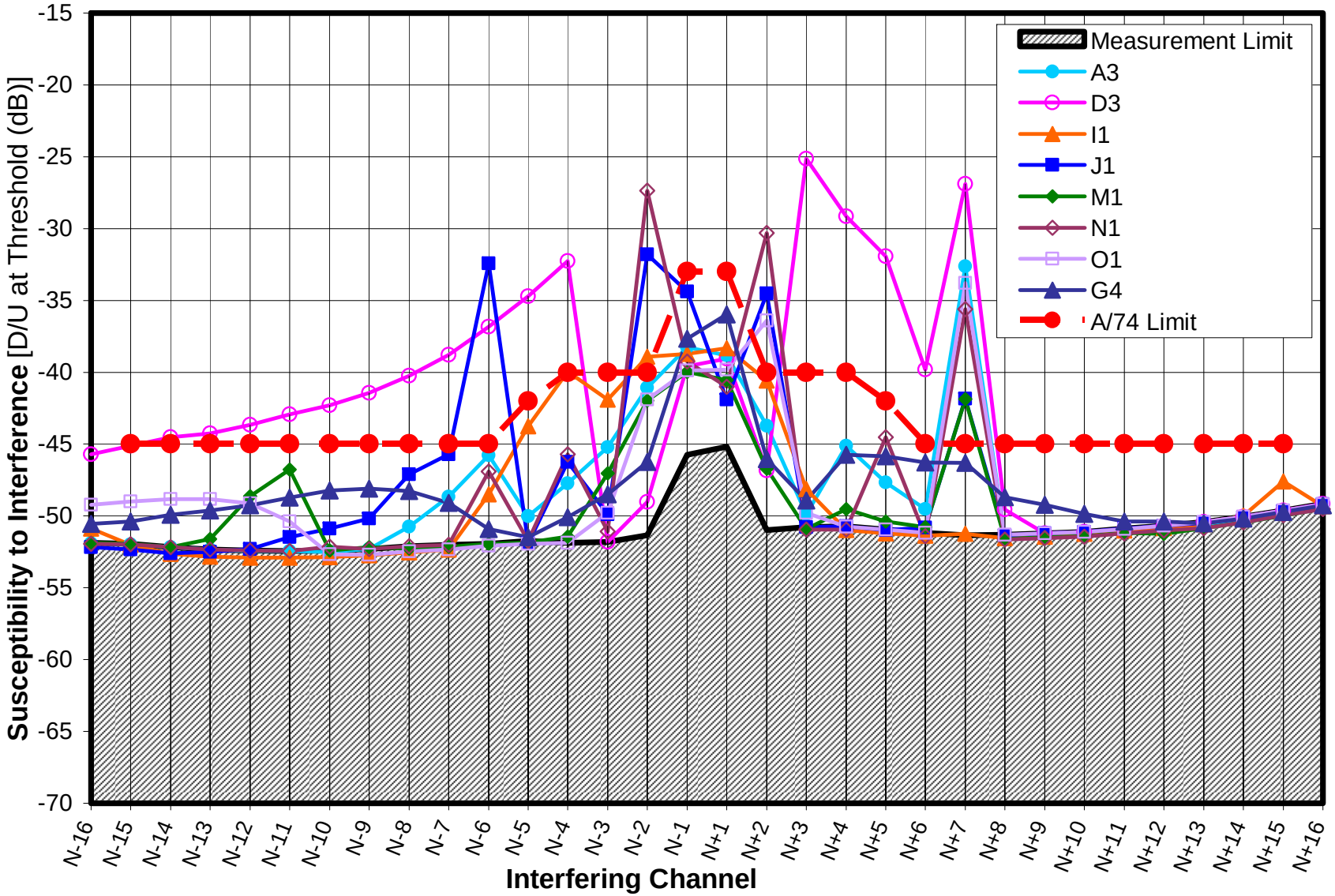


Figure 5-3. D/U of 8 receivers at D = -53 dBm on Channel 30

Single Channel Results

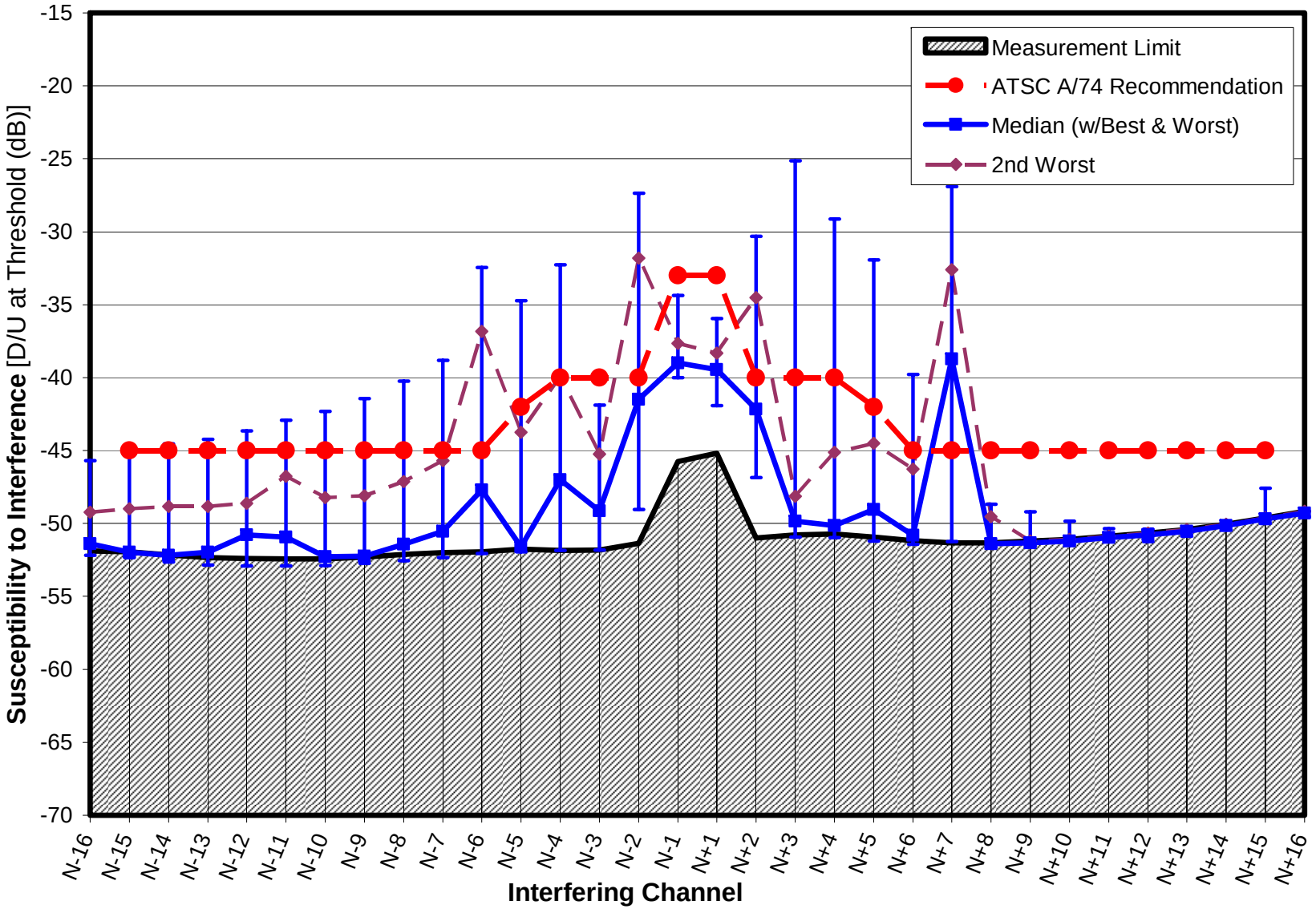


Figure 5-4. D/U Statistics at D = -53 dBm on Channel 30

Single Channel Results

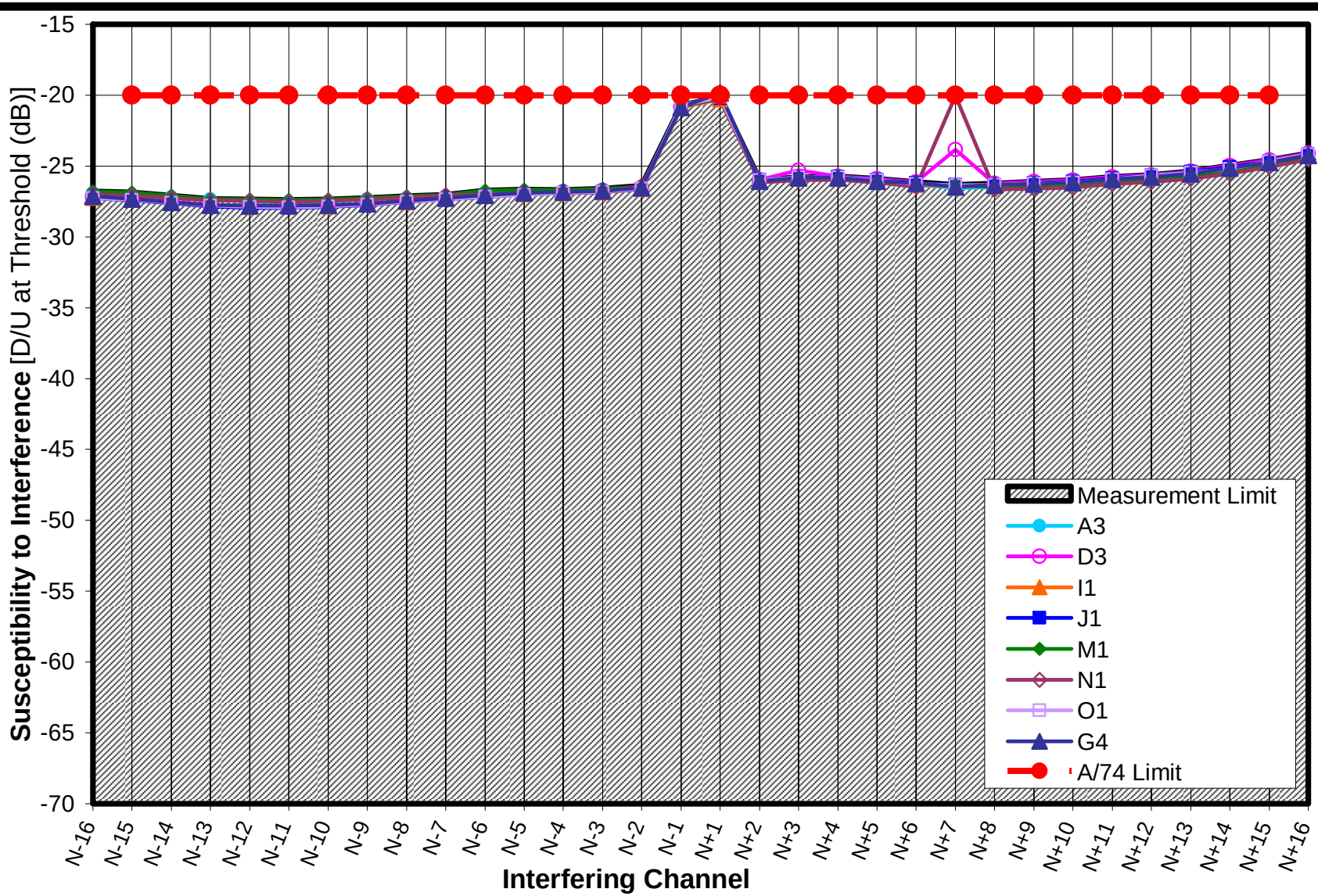


Figure 5-5. D/U of 8 receivers at D = -28 dBm on Channel 30

Single Channel Results

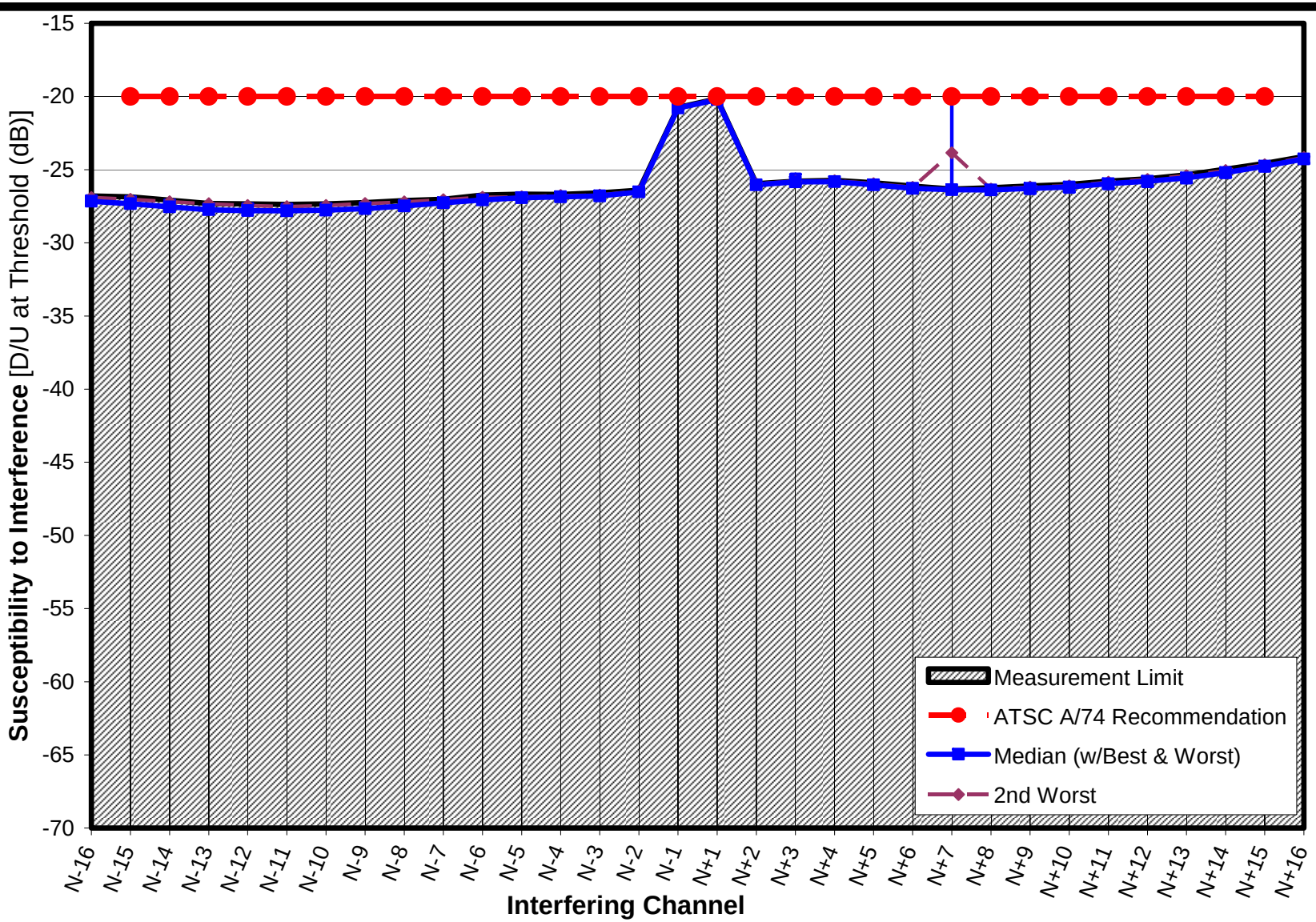


Figure 5-6. D/U Statistics at D = -28 dBm on Channel 30

Single Channel Results

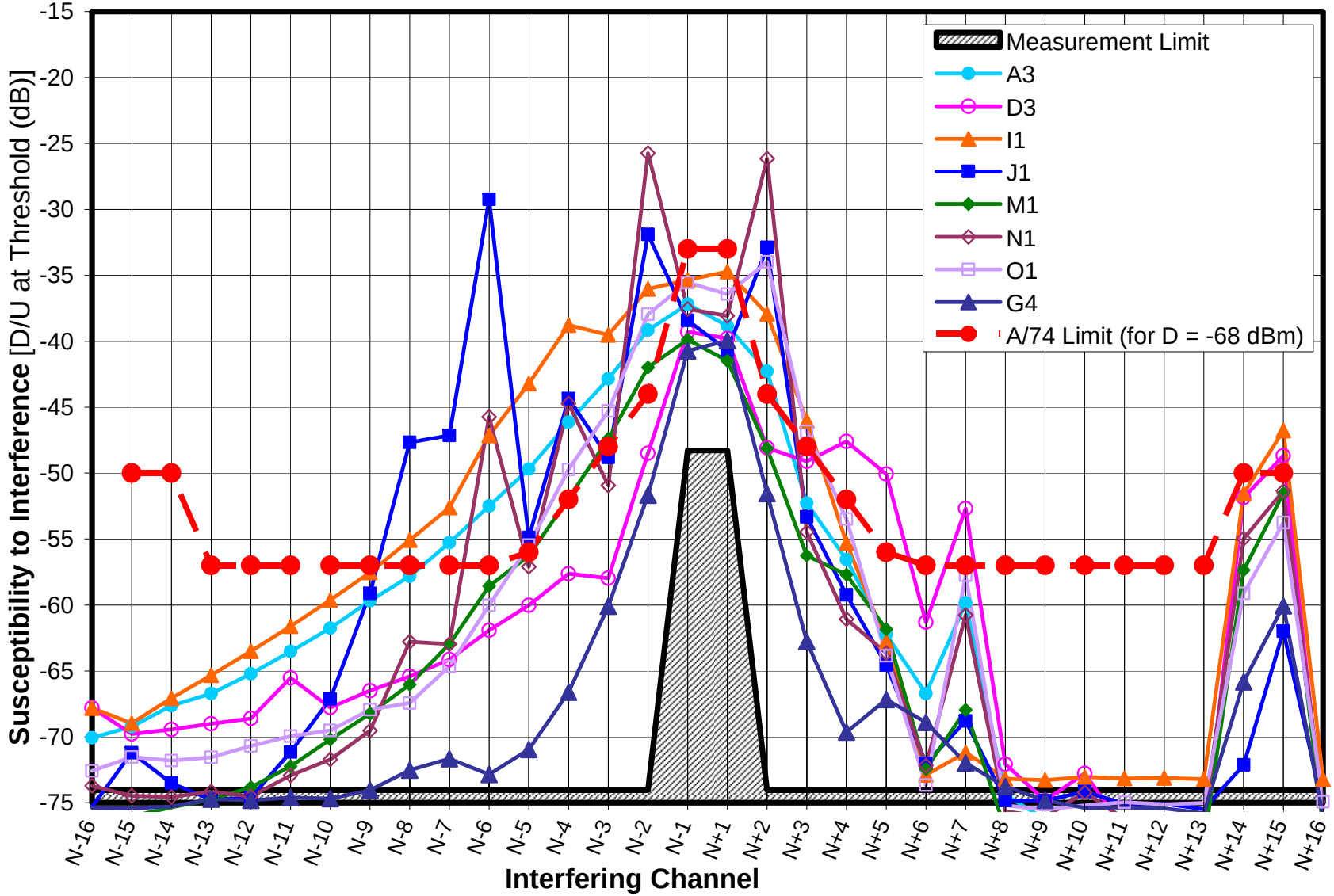


Figure 5-9. D/U of 8 receivers at D = D_{MIN} + 3 dB on Channel 30

Single Channel Results

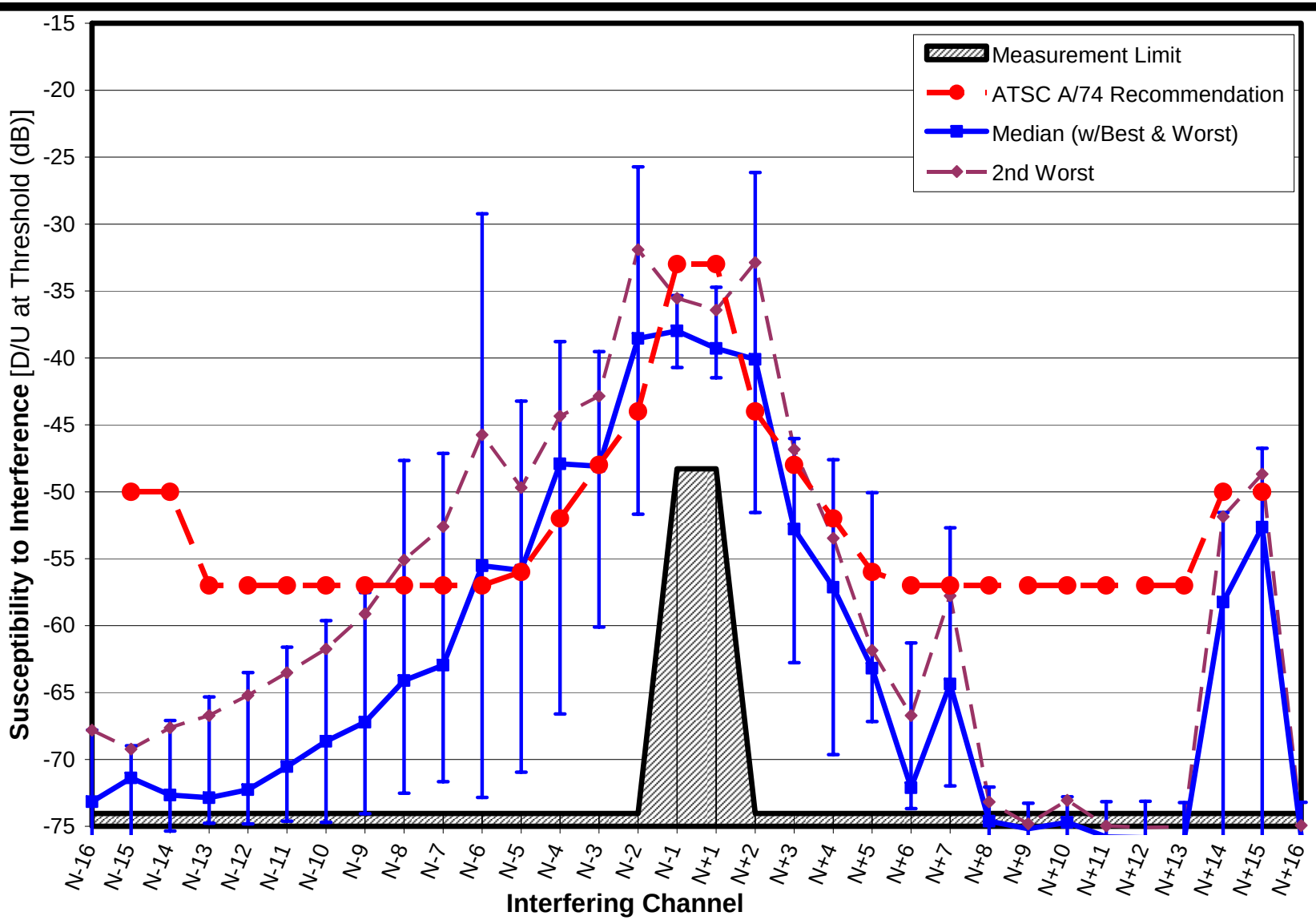


Figure 5-10. D/U Statistics at D = D_{MIN} + 3 dB on Channel 30

Single Channel Results

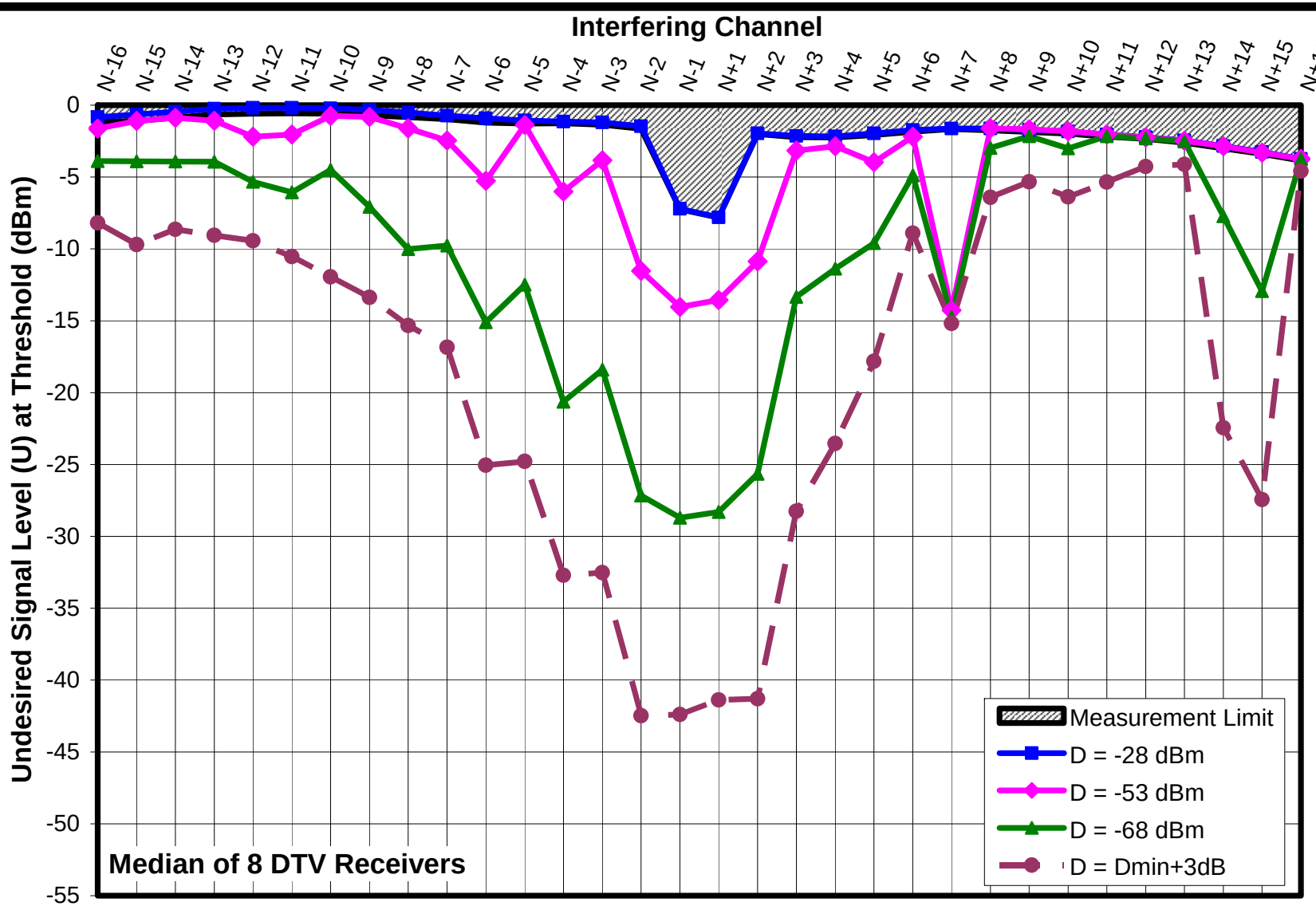


Figure 5-12. Median Threshold U of 8 receivers at Four Signal Levels on Channel 30

Single Channel Results

- **Evaluation**
  - No receiver appeared to fully achieve the ATSC recommended guidelines for interference rejection performance
  - After taking into account differences between the Gaussian-noise interferer used for most of the tests and the 8-VSB interferer specified by the ATSC, the best-performing receiver appears to fail the guidelines at only one channel offset, and there by only 1 dB.
  - A second receiver failed to meet the voluntary guidelines by 1 to 2 dB at two channel offsets.
  - The remaining five receivers failed to meet the guidelines at two to 16 channel offsets; the worst failure for each of those receivers ranged from about 8 to 24 dB.

Single Channel Results

- **Evaluation (cont'd)**
  - In terms of absolute signal levels that can cause interference, the DTV receivers are at their most vulnerable when operating at low desired signal levels
  - At low desired signal levels, the DTV receivers are as susceptible to interference from the second-adjacent channels (N-2 and N+2) as from first-adjacent channels (N-1 and N+1)
  - The receivers tend to be more susceptible to interference from N+2, N+1, N-1, N-2, N-3, N-4, and sometimes N-6 than from the mixer image channel offsets of N+14 and N+15
  - At moderate desired signal levels, the receivers exhibit relatively high susceptibility to interference from channel N+7. This interference threshold is nearly constant in terms of absolute power of the undesired signal necessary to cause interference at different levels of desired signals

Multiple Interferers

- **Purpose**
  - To Determine Extent to which Pairs of Undesired Signals Creates an IX Effect that Exceed the Effects of Individual Signals through 3rd Order Intermodulation (IM3)

- **Approach**
  - Limited study to two interferers and IM3 effects
    - Undesired signals on N+K and N+2K place IM3 products on N
  - Measured paired-signal interference thresholds with equal power and unequal power interferers
  - For N = channel 30, interferers on N+K and N+2K were white Gaussian noise signals, except that N+/-1 was an 8-VSB signal
  - Examined IX susceptibility at desired signal levels of -53 dBm, -68 dBm, and in some cases D_{MIN}+3 dB
  - Tests were performed for K=+/-1 to K=+/-5

Undesired Signals at Equal Power

Undesired Channel Pair	Excess of Paired-Signal D/U Above Summed D/U's (dB)							
	D = -68 dBm				D = -53 dBm			
	Min	Mean	Median	Max	Min	*Lower Bound on* Mean	*Lower Bound on* Median	*Lower Bound on* Max
N-5/N-10	1.8	9.8	9.8	15.7	3.4	*11.7*	*11.7*	*0*
N-4/N-8	0.4	5.7	5.1	12.2	3.4	*9.5*	*9.8*	*16.3*
N-3/N-6	-1.2	5.2	3.1	15.1	-0.2	5.9	6.4	11.3
N-2/N-4	-1.9	-0.2	-0.6	3.0	-6.6	0.5	0.2	5.6
N-1/N-2	-0.3	0.7	0.2	4.0	-0.3	0.7	0.1	3.6
N+1/N+2	-1.5	0.0	0.3	0.6	-1.3	0.6	0.5	2.3
N+2/N+4	-1.5	2.7	0.1	11.3	-1.2	4.0	3.9	11.4
N+3/N+6	-0.2	7.2	6.8	14.1	2.1	*9.8*	*9.9*	*14.7*
N+4/N+8	1.5	8.2	7.0	16.4	0.7	*8.7*	*8.9*	*13.8*
N+5/N+10	0.0	7.9	9.1	12.8	-0.3	*7.1*	*7.3*	*13.7*
	-1.9	**4.7**	**4.1**	**16.4**	**-6.6**	***5.9***	***6.8***	***16.9***

Figure 9-2. Statistics of Paired-Signal D/Us Relative to Summed D/Us on 30

Undesired Signals at Unequal Values

- **Limited Tests**
  - Only two receivers tested:
    - Receiver G4 with an undesired pair on N+2/N+4
    - Receiver M1 with an undesired pair on N+3/N+6
  - These receivers selected based on their relatively high differences between paired-signal D/U and summed D/U measurements
  - Signal levels tested: -53 dBm, -68 dBm, and D_{MIN}+3 dB
  - Measurements taken by attenuating one undesired signal with respect to the other and then adjusting both until TOV was found

Undesired Signals at Unequal Values

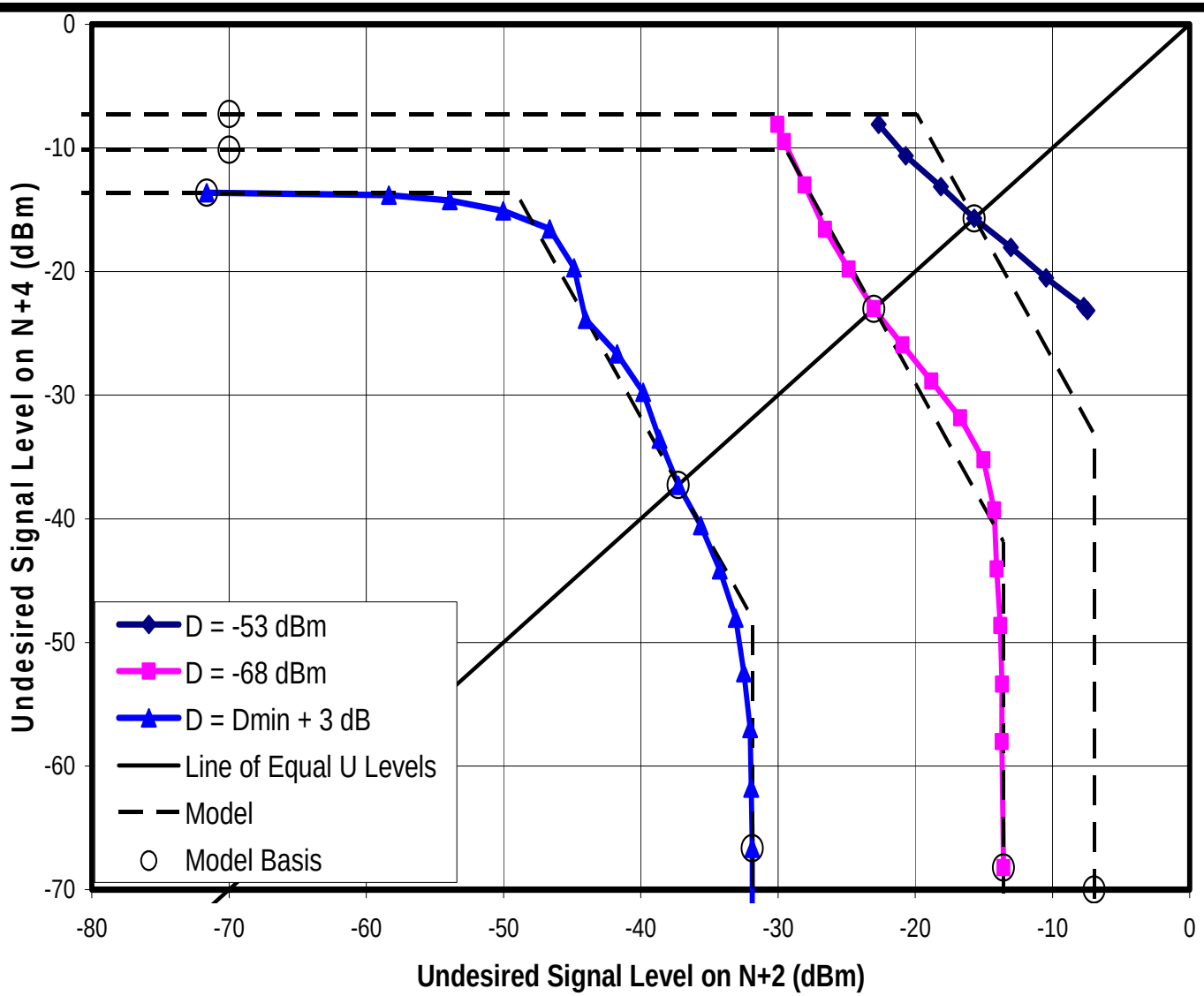


Figure 10-1. Threshold U for Paired, Unequal Undesired Signals on Receiver G4

Undesired Signals at Unequal Values

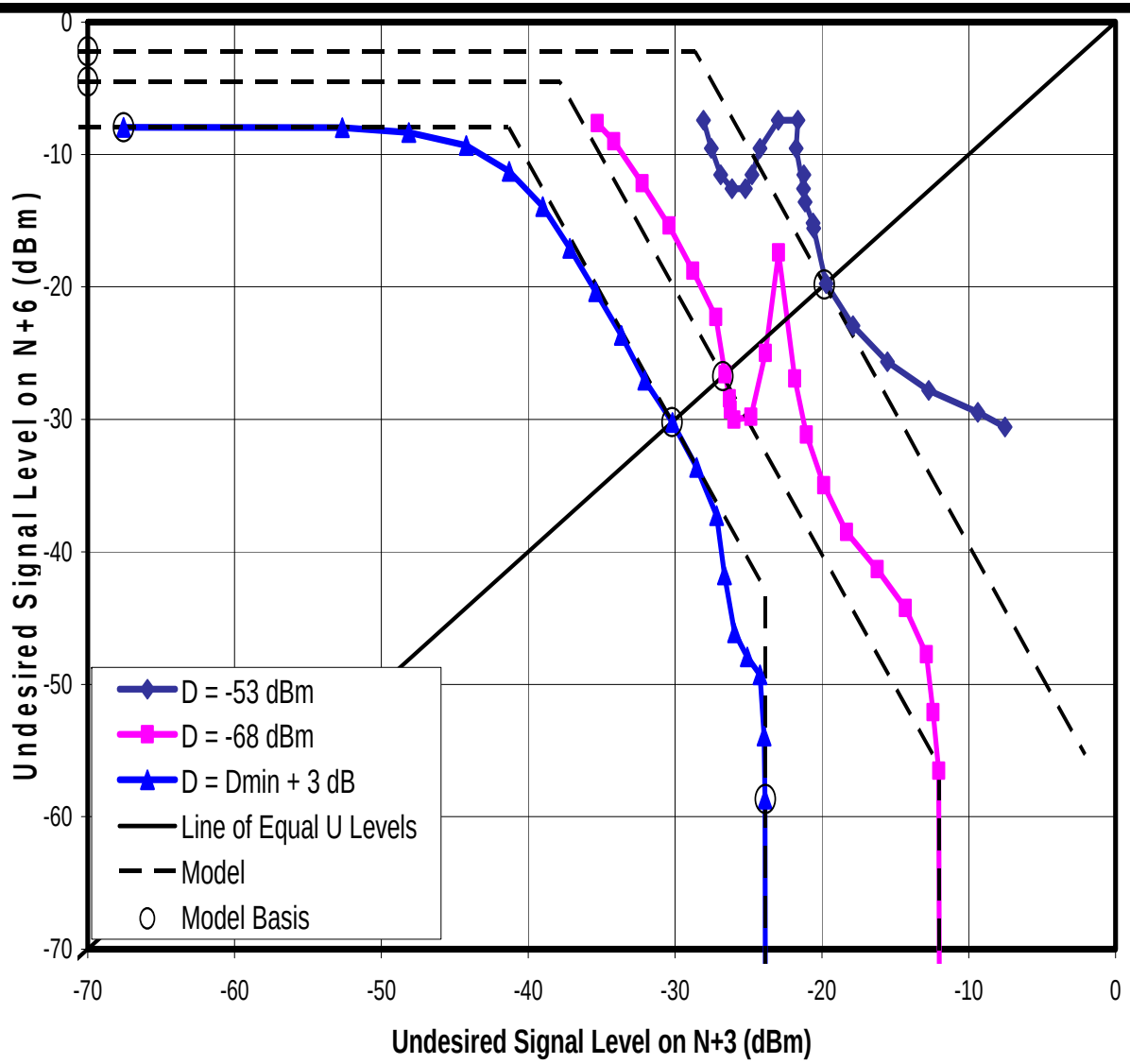


Figure 10-2. Threshold U for Paired, Unequal Undesired Signals on Receiver M1

Multiple Undesired Signals

- **Evaluation**
  - Most of the sample shows very little IM3 interaction from the N-1/N-2 and N+1/N+1 pairs
  - Even at N-1/N-2 and N+1/N+2 about half the receivers show little evidence of IM3; however the others show IX effects up to 11 dB above the effects of the individual interferers
  - At larger channel spacings there is evidence of IM3 from signal pairs significantly exceeding the effects of the individual interferers
  - When IM3 pairs occur, they are the dominant interference mechanism for channel offsets from about N+4 to N+10 and from N-5 to N-10. (Measurements were not performed beyond N+10 and N-10.)
  - For spacings closer to N, the paired-signal effects are less likely to dominate

Multiple Undesired Signals

- **Evaluation (cont'd)**
  - No paired-signal measurements were performed beyond N+10 and N-10, so it is not known how far out the effect continues; the effect was seen to diminish with increasing distance from N
  - Paired-signals have the potential to create even greater IX susceptibilities if an existing exceeds the measured equal-power-level threshold for paired signals
  - Greatest vulnerabilities occur when the stronger undesired signal is on N+K and it exceeds the equal power paired-signal threshold; receiver susceptibility increases to IX on the N+2K channel increases by twice the N+K excess above the threshold

Interference Rejection Thresholds of DTV Receivers

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(Research Study by Steve Martin)
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Undesired Signals at Equal Power

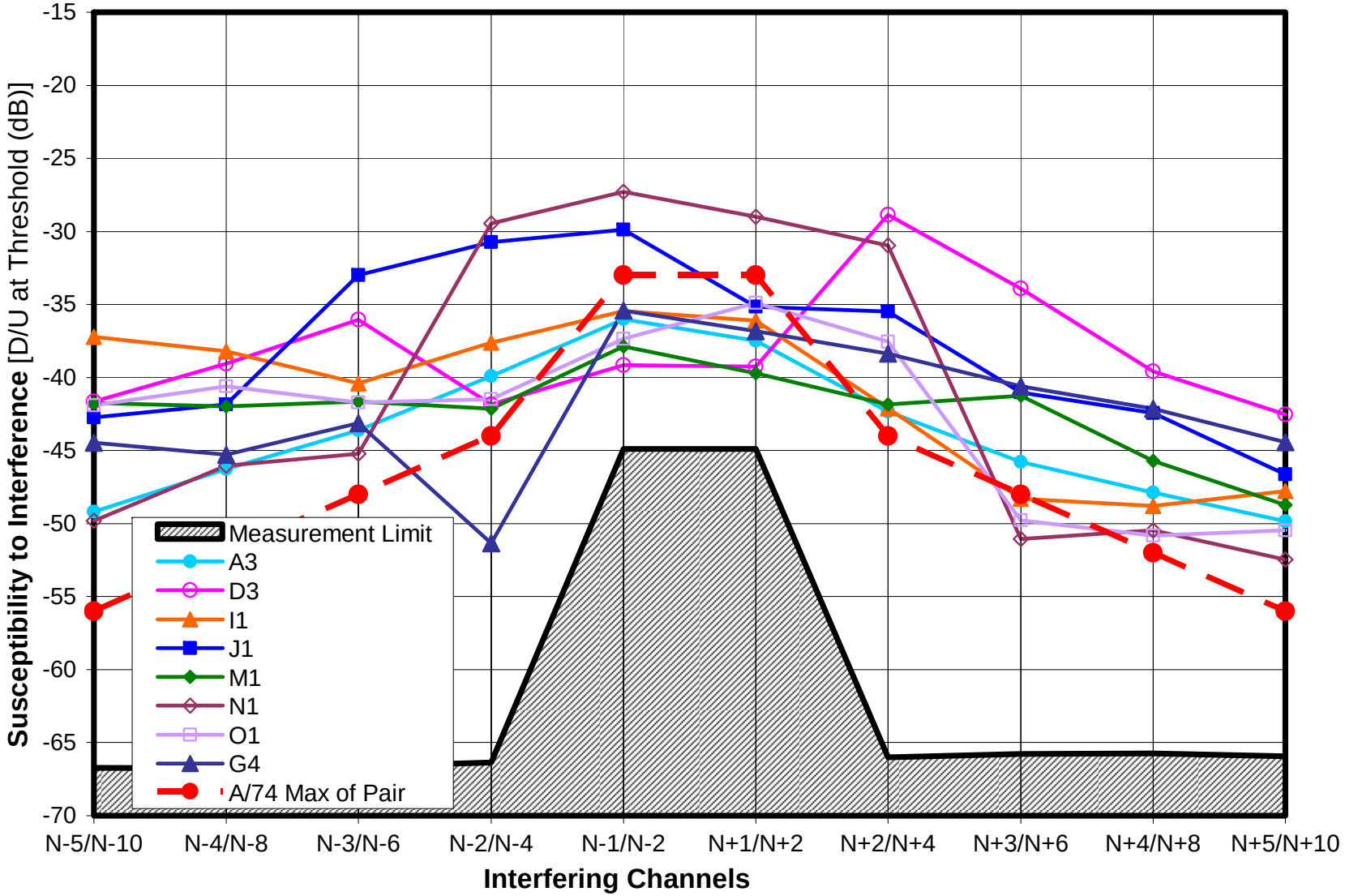

Figure 9-3. Paired-Signal D/U of 8 receivers at D = -68 dBm on Channel 30

Undesired Signals at Equal Power

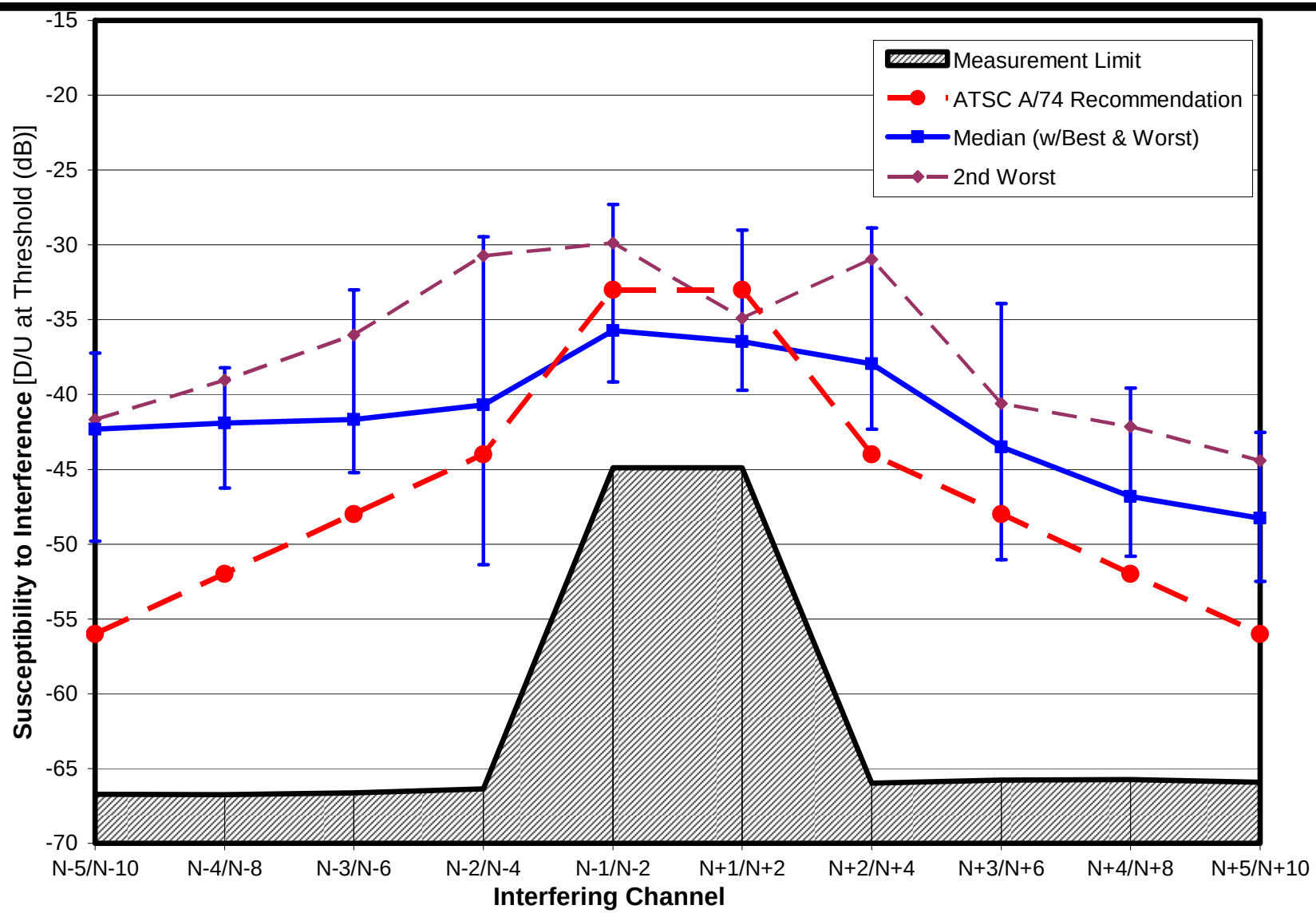

Figure 9-4. Paired-Signal D/U Statistics of 8 receivers at D = -68 dBm on Channel 30

Undesired Signals at Equal Power

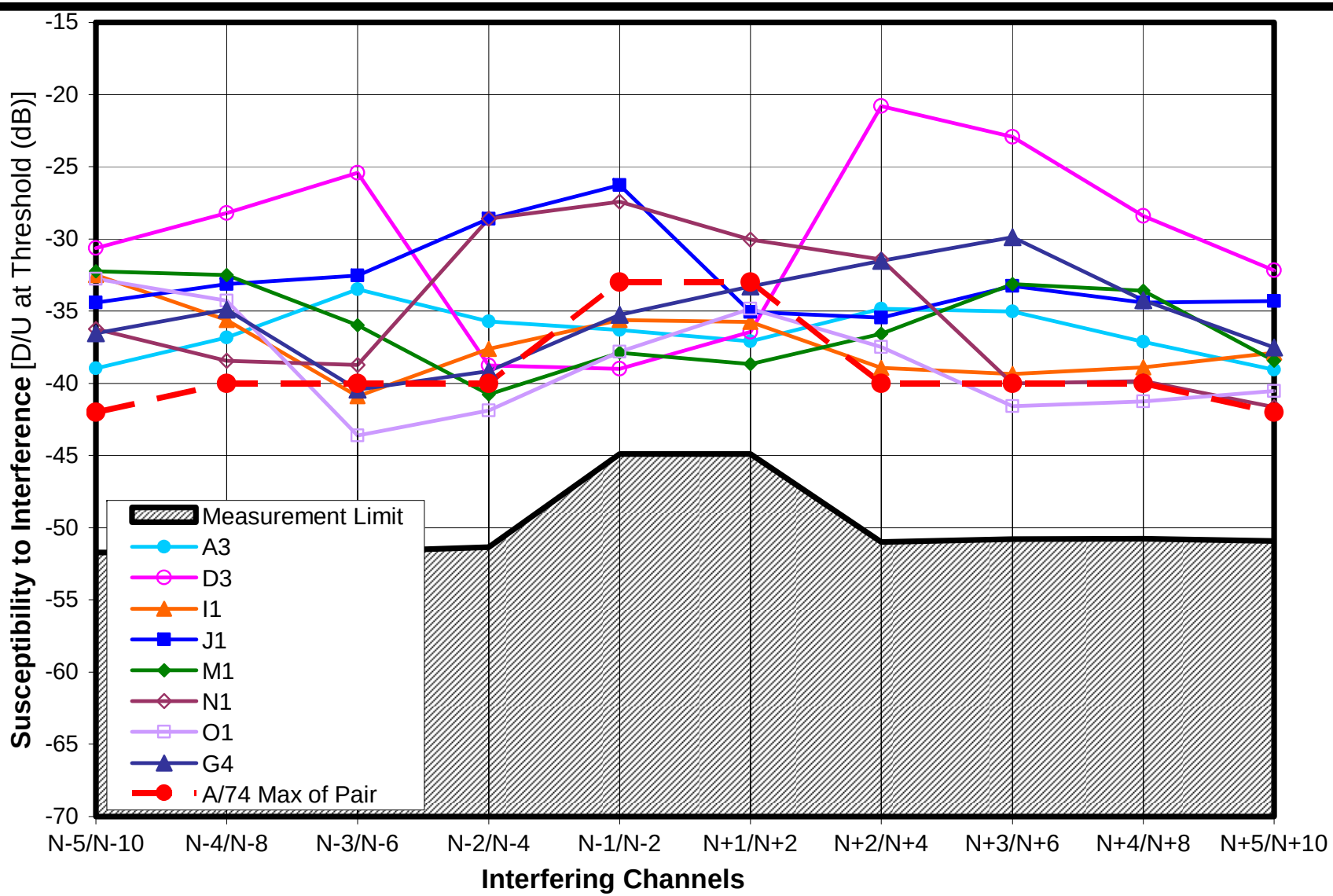

Figure 9-5. Paired-Signal D/U of 8 receivers at D = -53 dBm on Channel 30

Undesired Signals at Equal Power

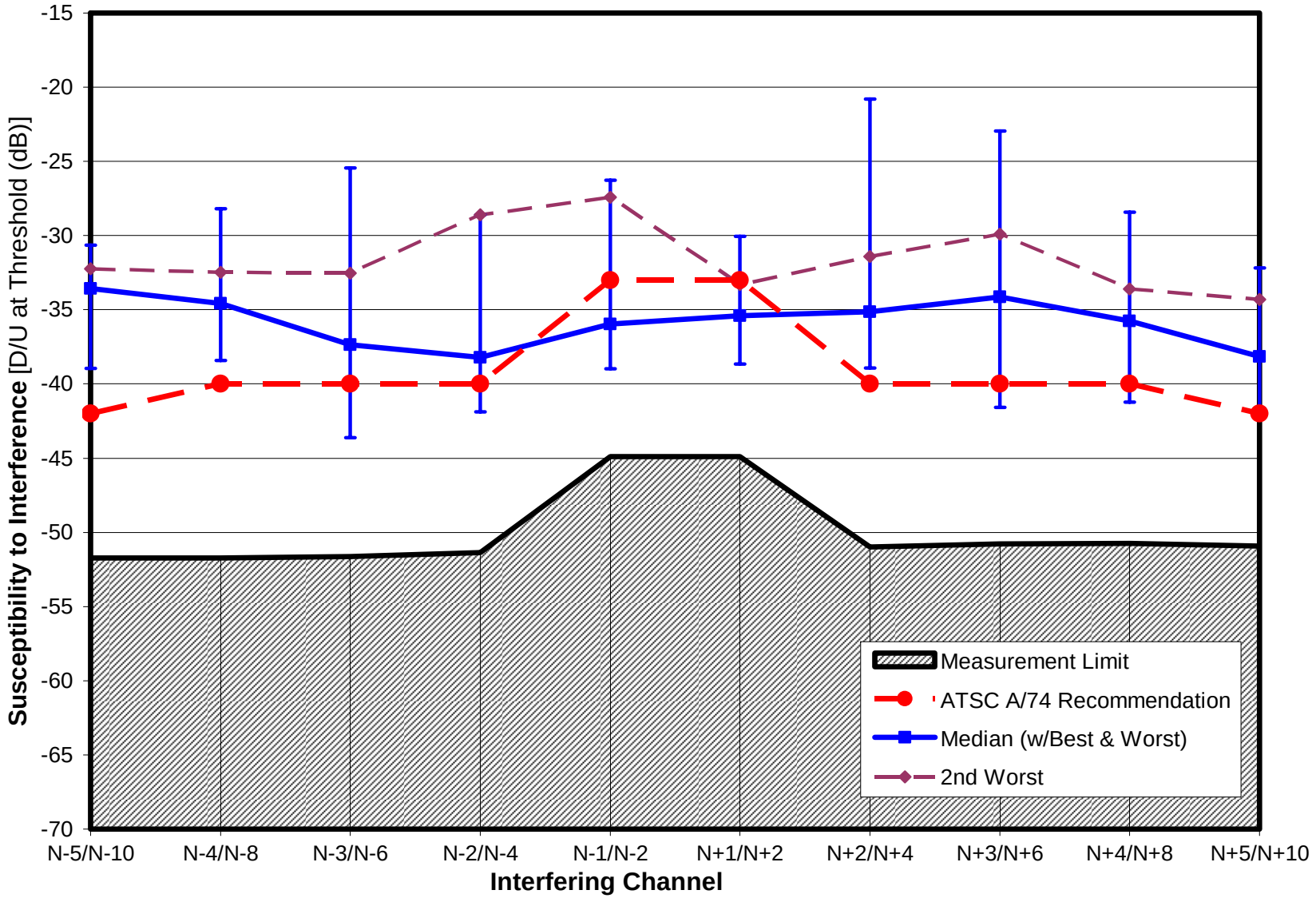

Figure 9-6. Paired-Signal D/U Statistics of 8 receivers at D = -53 dBm on Channel 30

Undesired Signals at Equal Power

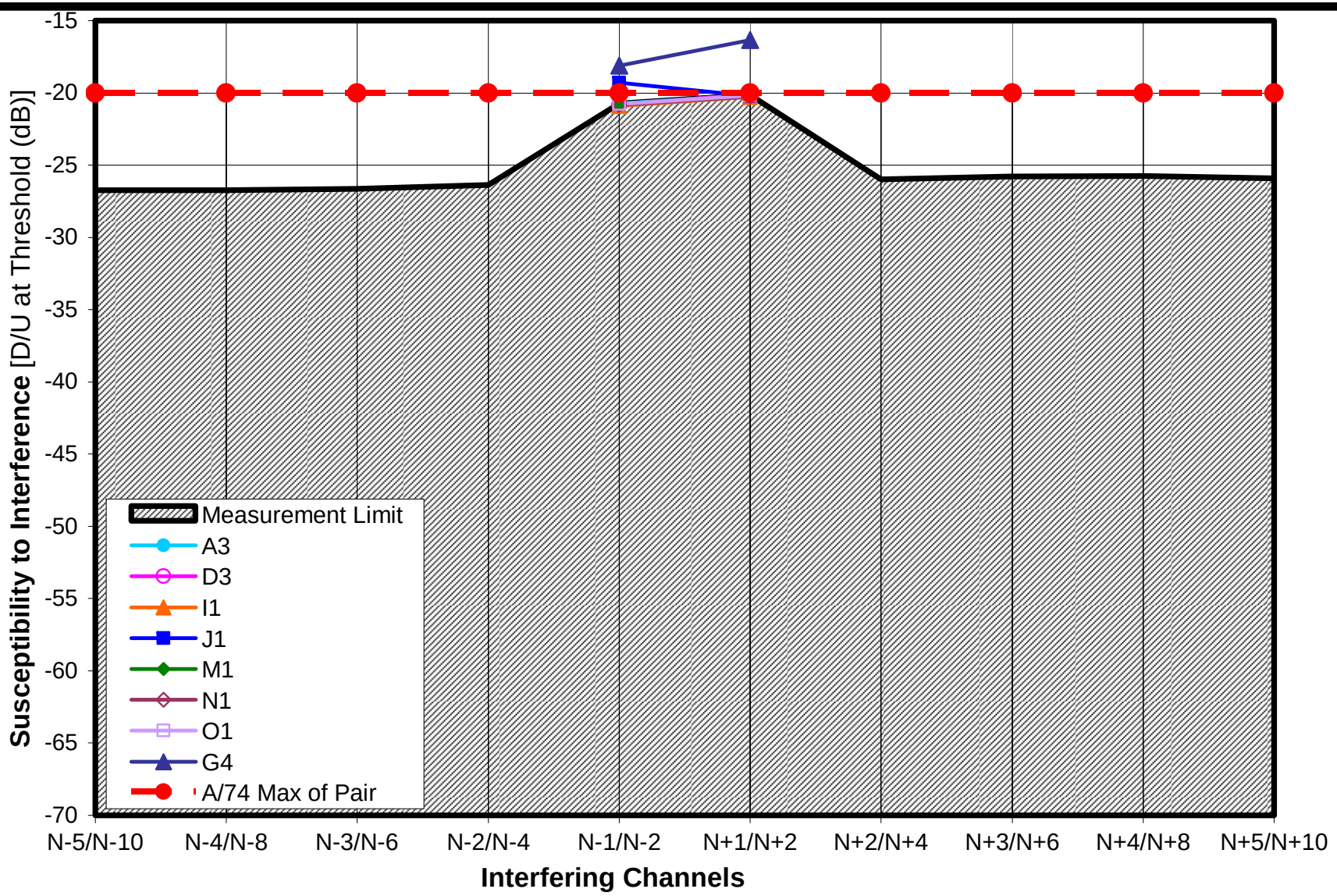

Figure 9-7. Paired-Signal D/U of 8 receivers at D = -28 dBm on Channel 30