Presentation to the AFCCE
March 16, 2005

DTV-DTV Interference Considerations

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Results of Recent Experimental Investigations.

Strongest DTV Signal Power

ERP = 30 dBK or	+ 90 dBm
Line-of-Sight Path Loss 5 miles, @ 615 MHz	106 dB
Power from a Resonant Dipole	- 16 dBm
Rooftop Antenna Gain (FCC)	10 dBd
Power from Directional Antenna	- 6 dBm
Downlead Loss @ 615 MHz (FCC)	4 dB
Average DTV Power to Receiver	**- 10 dBm**

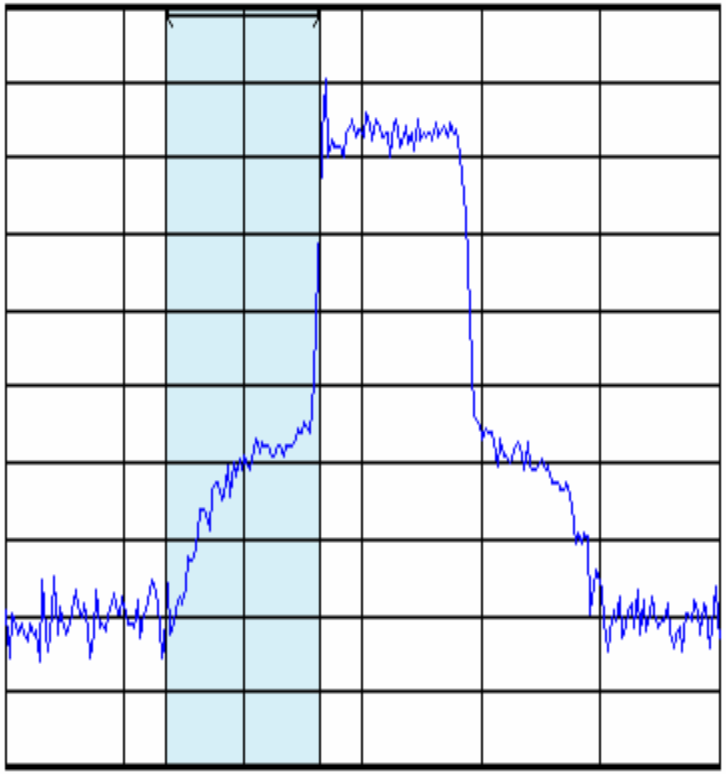
DTV Signal Power

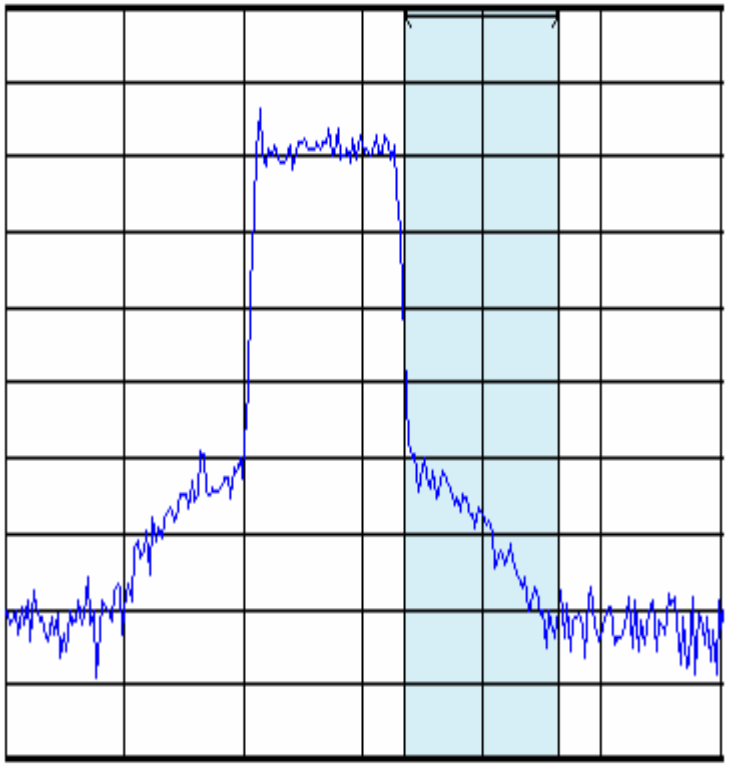
- Specified as Average Power
  - Directly relates to SNR.
- Max. Symbol Power of 8-VSB DTV = Average + 4.77 dB
- Max. Symbol ERP = 34.77 dBK
- Max. Symbol Power relates to Overload Level of DTV Signals
  - The cause of interference.

The Maximum Symbol Power of a Received Signal
- 5 dBm

3rd Order Non-Linear Distortion

DTV transmitters and receivers both generate 3rd order distortion products (IM3) which fall in the first adjacent channels, n-1 and n+1.

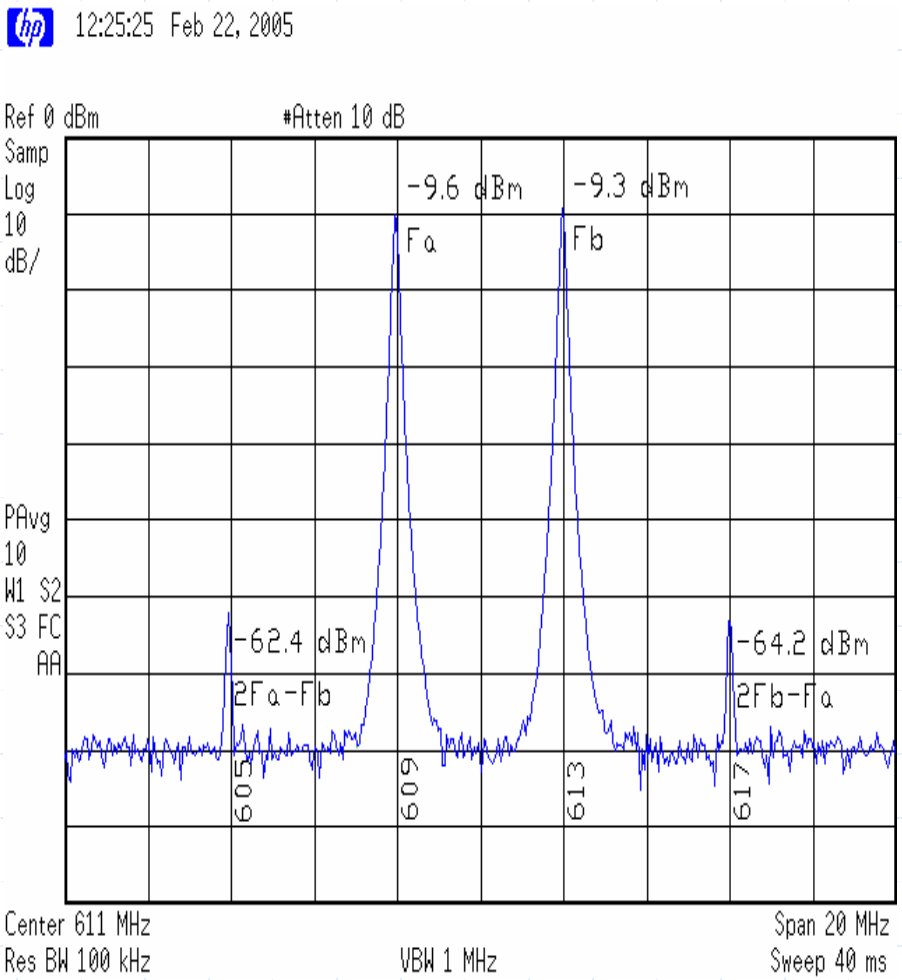




Classic Method of Measurement

Two-Tone Test Signal:

- Two unmodulated carriers Fa and Fb
- (Fb > Fa) and of equal power generate 3rd order Intermodulation Products (IM3) at 2* Fa – Fb and 2* Fb – Fa



Use of DTV Signals to Measure IM3

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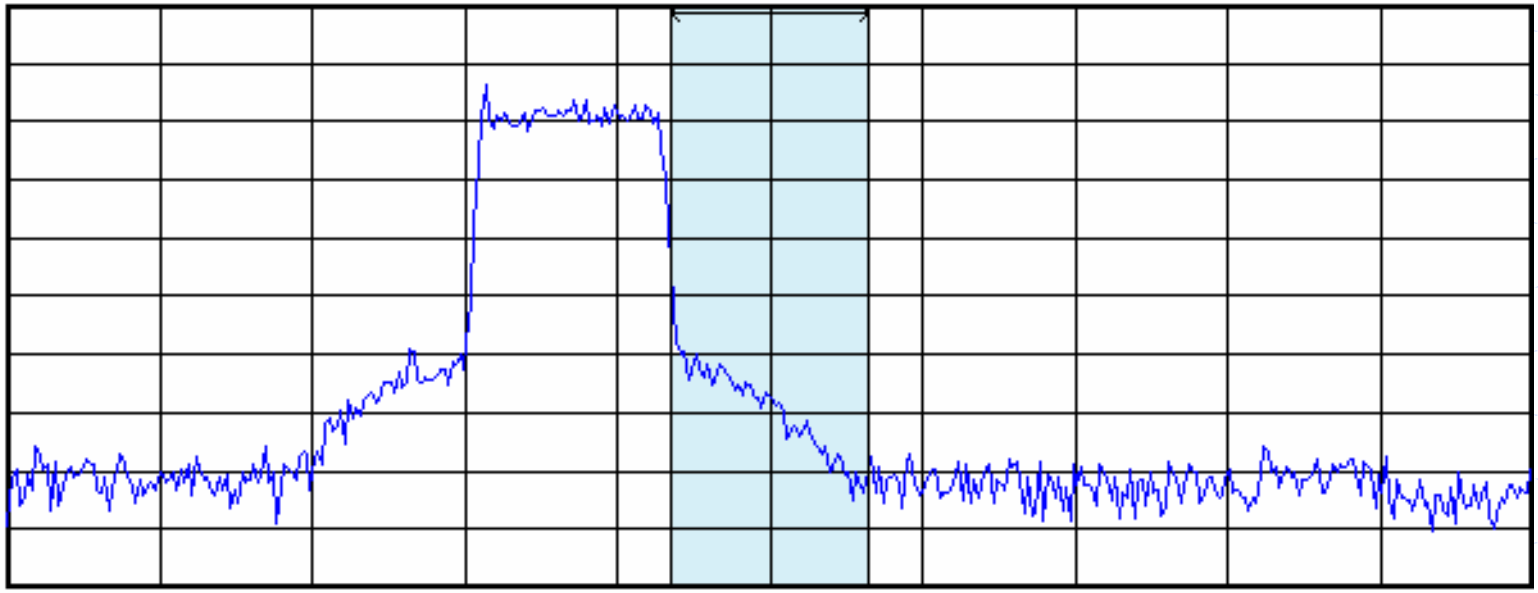
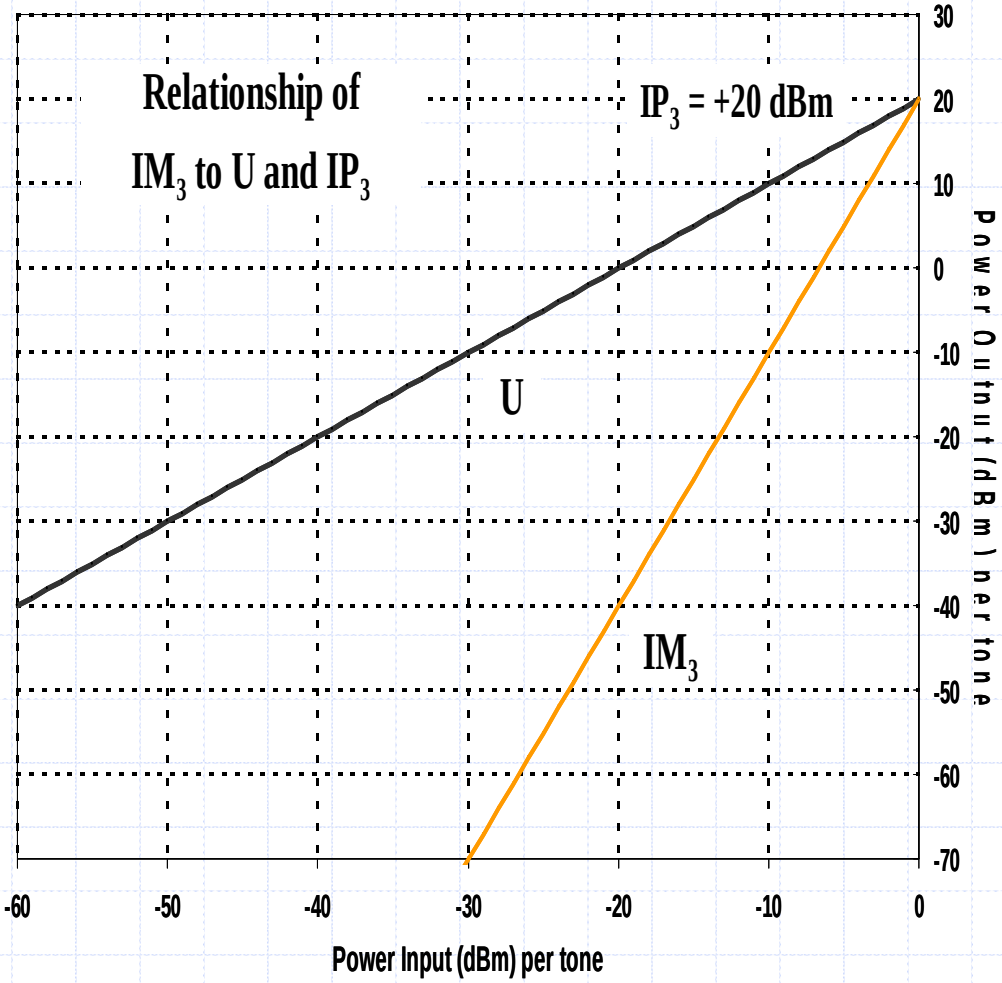
Figure 2 shows an 8-VSB Signal with 3rd order IM in the adjacent channels. It too could be used to measure IM3.



The Key Property of 3rd Order Intermodulation

- The distortion products change by 3 dB per dB change in the overloading signal power.
- Figure 3 shows this.



3rd Order Intercept Power (IP3)

- The power at which the signal power output and the IM3 power output are equal is called the Third Order Intercept Power (IP3) of the device measured.
  Figures 3 and 4 show IP3 = + 20 dBm.

- IP3 cannot be measured, it is computed

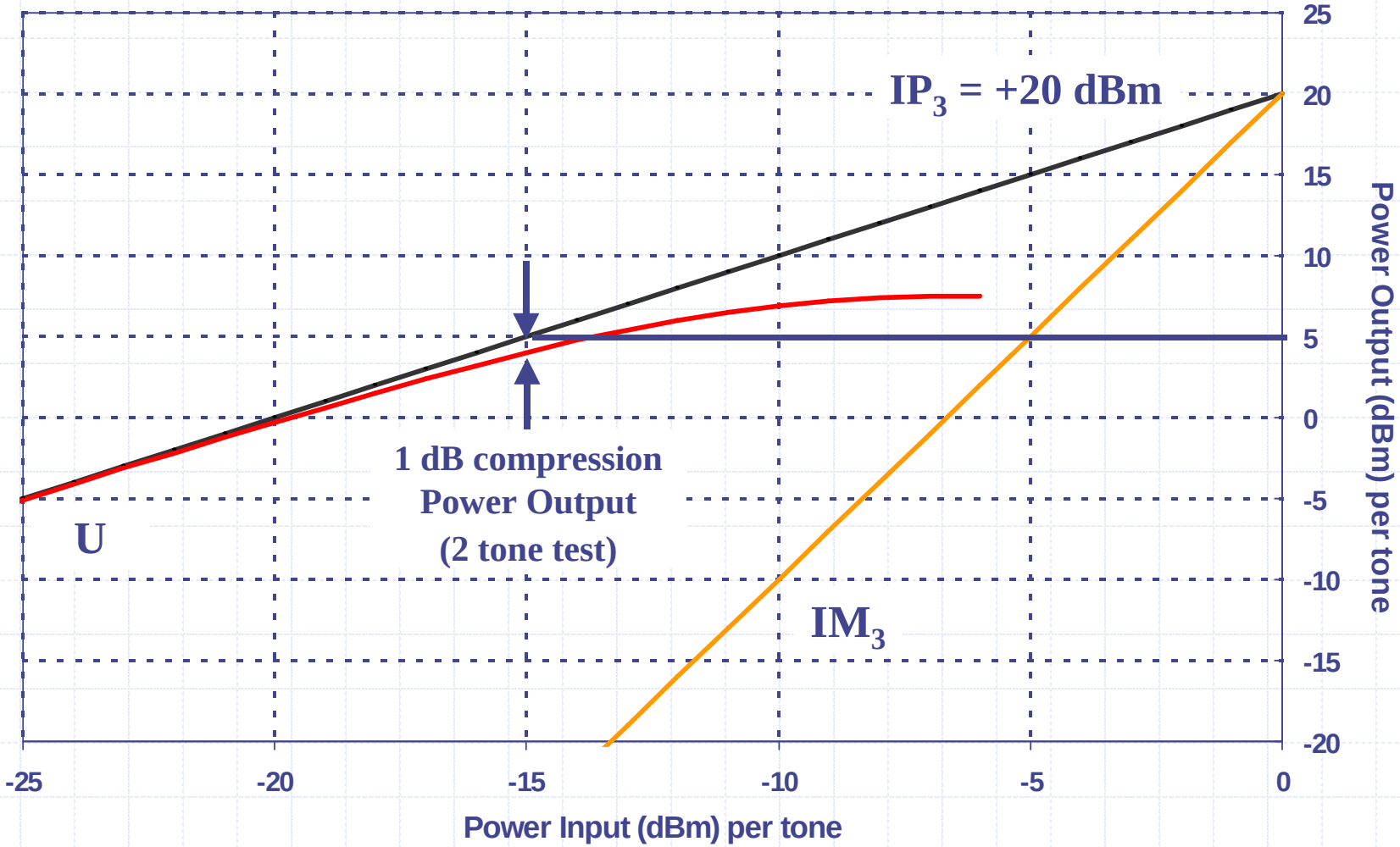
$$\mathbf{IP3 = U + (U - IM3) / 2}$$

- (U – IM3) is often called the Adjacent Channel Protection Ratio **(ACPR).**

3rd Order Distortion also Causes Signal Compression

- As signal power output increases, non-linearity causes gain reduction.
- The power output at which gain reduction equals 1 dB is a critical device parameter.
- 1 dB compression is 10 dB below IP3 for a single-tone test signal.
- 1 dB compression is 15 dB below IP3 for a two-tone test signal.

Relationship of 1dB Signal Compression Power to IP3

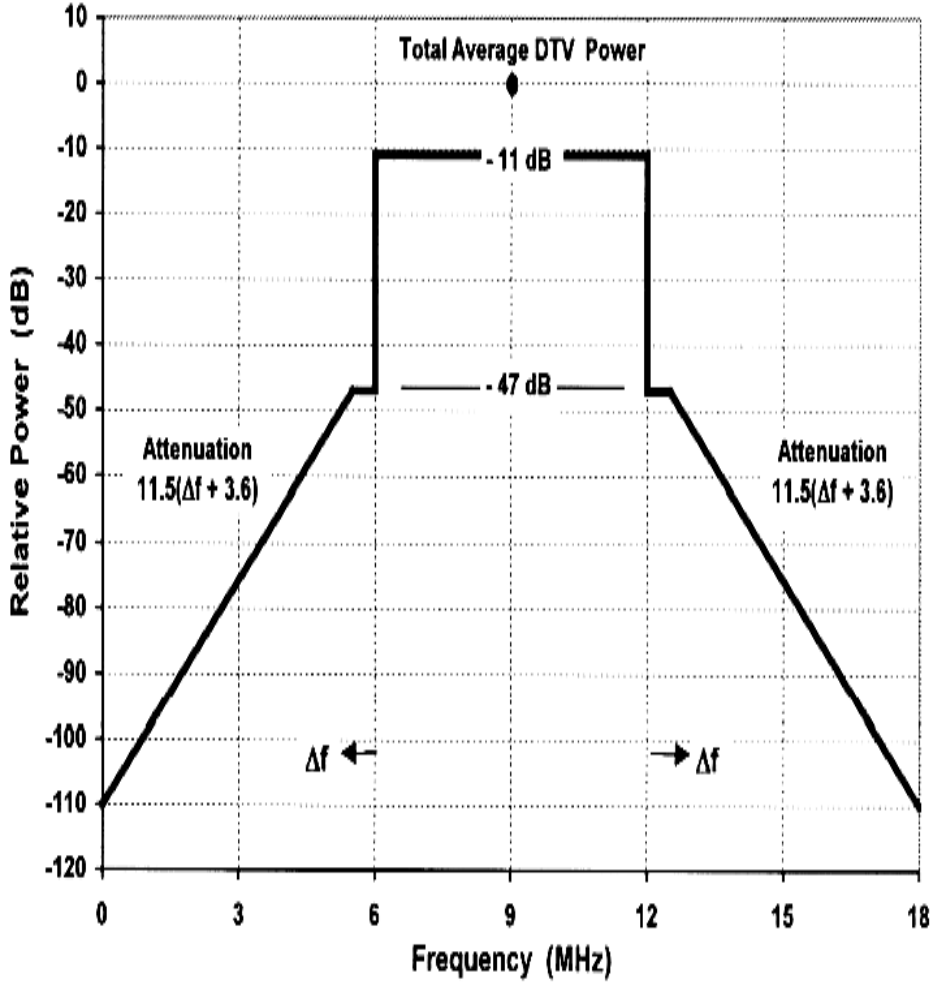


1 dB Compression Power for DTV

- The max. power symbols of 8-VSB modulated DTV signals should be below the 1 dB compression power rating of the receiver.
- This matter deserves further research.
- Cross-modulation from a strong Undesired DTV signal onto a weaker Desired DTV signal is a third artifact of 3rd order non-linearity.

FCC RF Mask for DTV Transmitters

- The FCC RF Mask shown in Figure 5 specifies IM3 is 36.7 dB below the signal power.
- The area under the Mask in each Adjacent Channel is 44.5 dB below the in-channel DTV power.



Relationships of IP3, IM3 and U

$$IP3 = U - (ACPR) / 2$$

$$IP3 = U - (U - IM3) / 2$$

$$IM3 = 3 * U - 2 * IP3$$

Note:
ACPR is a parameter called Adjacent Channel Protection Ratio.

FCC Mask Implications

- Area under the Mask in-channel = U.
- Maximum permitted sideband splatter

  = U – 44.5 dB.
- Receiver IF selectivity attenuates sideband splatter by about 2 dB.
- Sideband splatter appears as noise within the Desired channel U – 46.5 dB.
- D min > 15.2 dB + (U – 46.5 dBm).

Mask Implications (continued)

- FCC D/U limit on ACI: - 42 /- 43 dB (1997).
- FCC D/U limit on ACI: - 26 / - 28 dB (1998).
- FCC Mask permits D/U = - 31.3 dB.
  - OK for lower or upper ACI only.
  - No margin for lower and upper ACI.
- This assumes negligible IM3 is generated by receivers.

Example of 3rd Order Intermodulation Calculations

- Undesired signal on either Adjacent Channel
  U = - 10 dBm power.

- Sideband splatter into Desired Channel
  I = - 56.5 dBm power.

- Minimum D signal power = U – 27 dB
  D/U = - 27 dB (average n+1, n-1).

- D min (FCC) = - 37 dBm.

Example of 3rd Order Intermodulation Calculations (continued)

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- This assumes no IM3 is generated in the receiver with – 5 dBm max. symbol power to receiver.
- Minimum receiver IP3 calculation
  - Max. value for I + IM3:

	- 37 dBm - 15.2 dBm	= 0.000 006 026 mW
Received I =	- 56.5 dBm	= 0.000 002 239 mW
	Max. IM3 (Rx)	= 0.000 003 787 mW
	Max. IM3 (Rx)	= - 54.2 dBm

IP3 = - 10 – (54.2 – 10) / 2 = + 12.2 dBm.

Range of ERP for DTV Signals in the UHF Band

- 479 Stations
  - 50 kw (17 dBk)
- 707 Stations
  - 200 – 1000 kW (23 – 30 dBk)

- Transmitted ERP Range = 13 dB

Reducing IM3 with Signal Attenuation

By attenuating RF signal before the Mixer, IM3 generated within the receiver can be mitigated.

Example:

IP3 (Rx) = 0 dBm

No attenuation

U	=	- 10 dBm
IM3	=	- 30 dBm
+ SNR	=	15.2 dB

With 15 dB attenuation

U	=	- 25 dBm
IM3	=	- 75 dBm
+ SNR	=	15.2 dB
D min	=	- 59.8 dBm
Attn	=	15 dB

D min = - 14.8 dBm

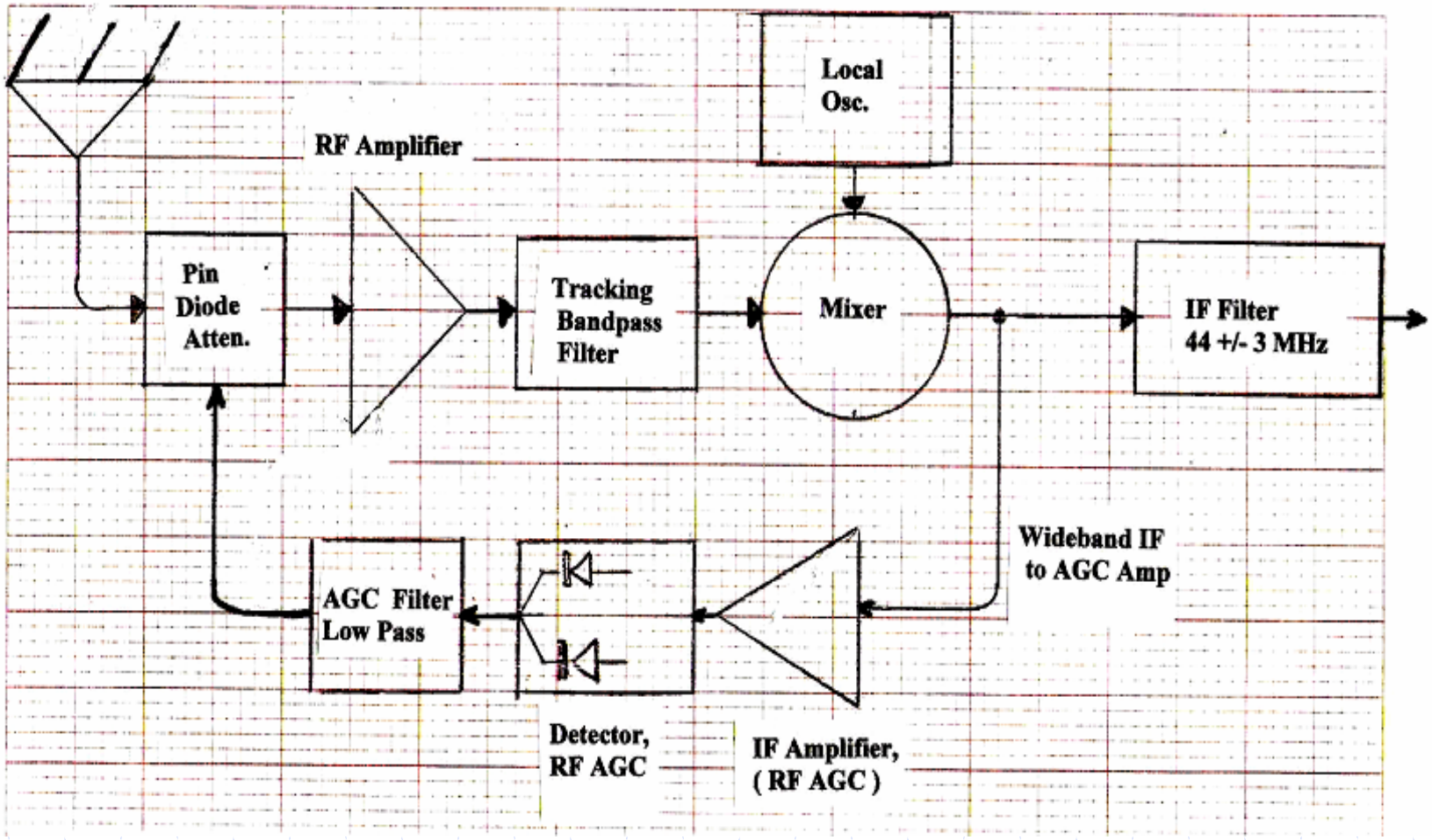
D min = - 44.8 dBm

Reducing IM3 with Signal Attenuation (continued)

- IM3 generated in the receiver can be mitigated by signal attenuation before the Mixer.
- Sideband splatter received cannot be mitigated.
- Attenuation should be automatically optimized to maximize viewer satisfaction.

- Best way to implement smart attenuation is:
  - ***Wideband RF Automatic Gain Control***

Wideband RF Automatic Gain Control for Receivers



Will Wideband RF AGC be Implemented in Receivers?

- Technique dates from 1936
- Used in “top-of-the-line” all-wave receivers before WWII
- Probably NOT used in TV receivers
  - The interference problem it solves does not exist in CATV systems or for DBS subscribers
    - These are the major markets

Potential Interferers (Miami, Florida) into UHF DTV Channels

No. of Interferors	Desired Channel(s)
1	52
4	46, 47
7	30, 32
8	20, 26
9	18, 19
10	22, 24

DTV – DTV Interference

Interference	Signal-to-Noise Ratio	Tuner (RF) Selectivity	Tuner Overload
Co-Channel (CCI)	Yes	No	No
Adjacent Ch (ACI)	Yes	No	Yes
UHF Taboo (TCI)	Yes	Yes	Yes

Note: SNR > 15.2 dB for Standard ATSC Signal

SNR > 9 dB for the Rugged Data via E-ATSC
15.2 dB for the Higher Data Rate Data

UHF Taboo Channel Interference (TCI)

- Most Taboos are non-linear
- Result from mixer overloading by strong signals on Taboo channels
- If D = Channel (n), Taboos are:

  n +/- 2, +/- 3, +/- 4 and +/- 5
- RF Selectivity cannot;
  - mitigate interference from n+/-2,
  - slightly mitigate interference from n+/- 3
  - mitigate interference from n+/- 4, 5

TCI Continued...

- However, will receivers provide RF selectivity?
- RF Selectivity requires tracking RF Filters which cannot be integrated onto an IC
  - take space in tuners.
- Tracking Filters were not required in analog receivers because of the UHF Taboos.
  - (20 to 75 mile spacings between Tx on Taboo channels)

TCI Continued...

- As TCI is due to a non-linear process, (Mixer overloading) it can be controlled by;
  - RF Signal attenuation or...
  - Automatically reducing RF Amplifier Gain when strong signals near the desired signal are detected.
    - “WIDEBAND RF AGC” known since 1936 in all-wave high end radios.

TCI Continued...

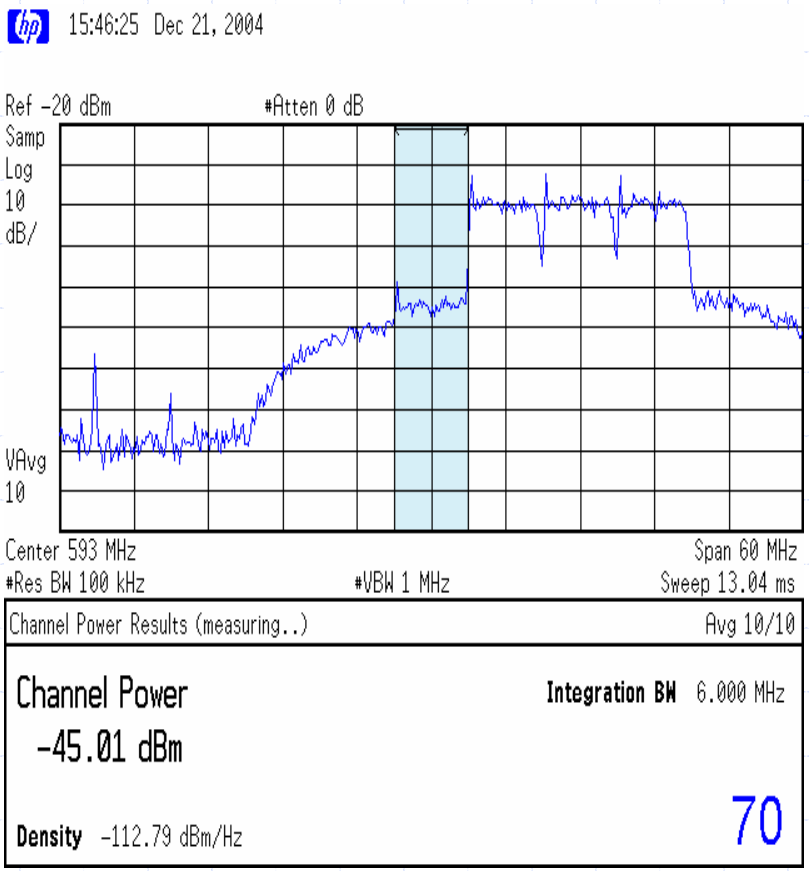
- Pairs of channels which can cause IM3 in a locally used Third Channel

$$2(n-4) - (n-8) = n = 2(n+4) - (n+8)$$
$$2(n-3) - (n-6) = n = 2(n+3) - (n+6)$$

$$2(n-1) - (n-2) = n = 2(n+1) - (n+2)$$
$$2(n-2) - (n-4) = n = 2(n+2) - (n+4)$$

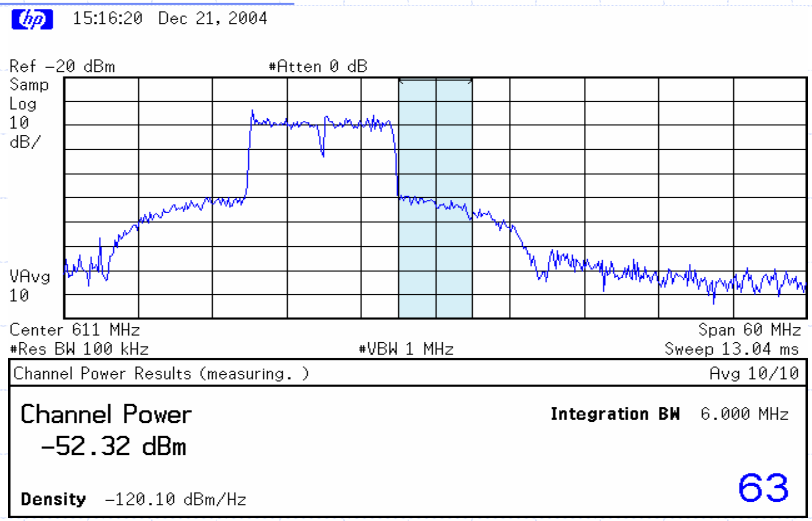
NOTE: No tests involving multiple undesired signals were specified for testing of DTV systems. With a single undesired signal what is found is the threshold at which cross-modulation (X-M) blocks reception. IM3 is generally significant at lower U levels than for X-M

TCI -Mitigation

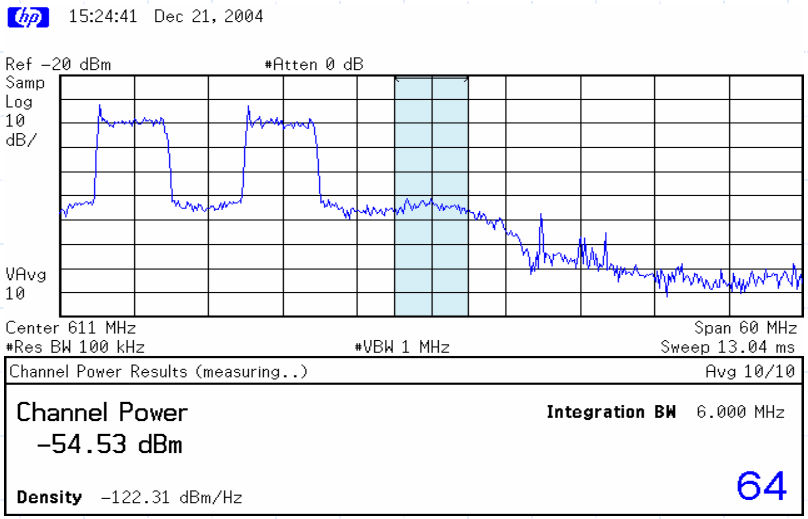


- U in Channels 35, 36 and 37 = -20.5 dBm
- IM3 in Channel 34 = -45 dBm

TCI -Mitigation



- U in Channel 35 and 36 = -19.6 dBm (ea.)
- IM3 in Channel 37 = -52.3 dBm



- U in Channel 33 and 35 = -19.6 dBm (ea.)
- IM3 in Channel 37 = -54.5 dBm

Multiple U vs. Single U

- One U @ -19.6 dBm

  IM3 = -58.7 dBm

- Two U @ -20.0 dBm (ea.):

  IM3 = -52.3 dBm

  IM3 Increases by = 6 dB

- Three U @ -20.5 dBm (ea.):

  IM3 = - 43.9 dBm

  IM3 Increases by = 15 dB

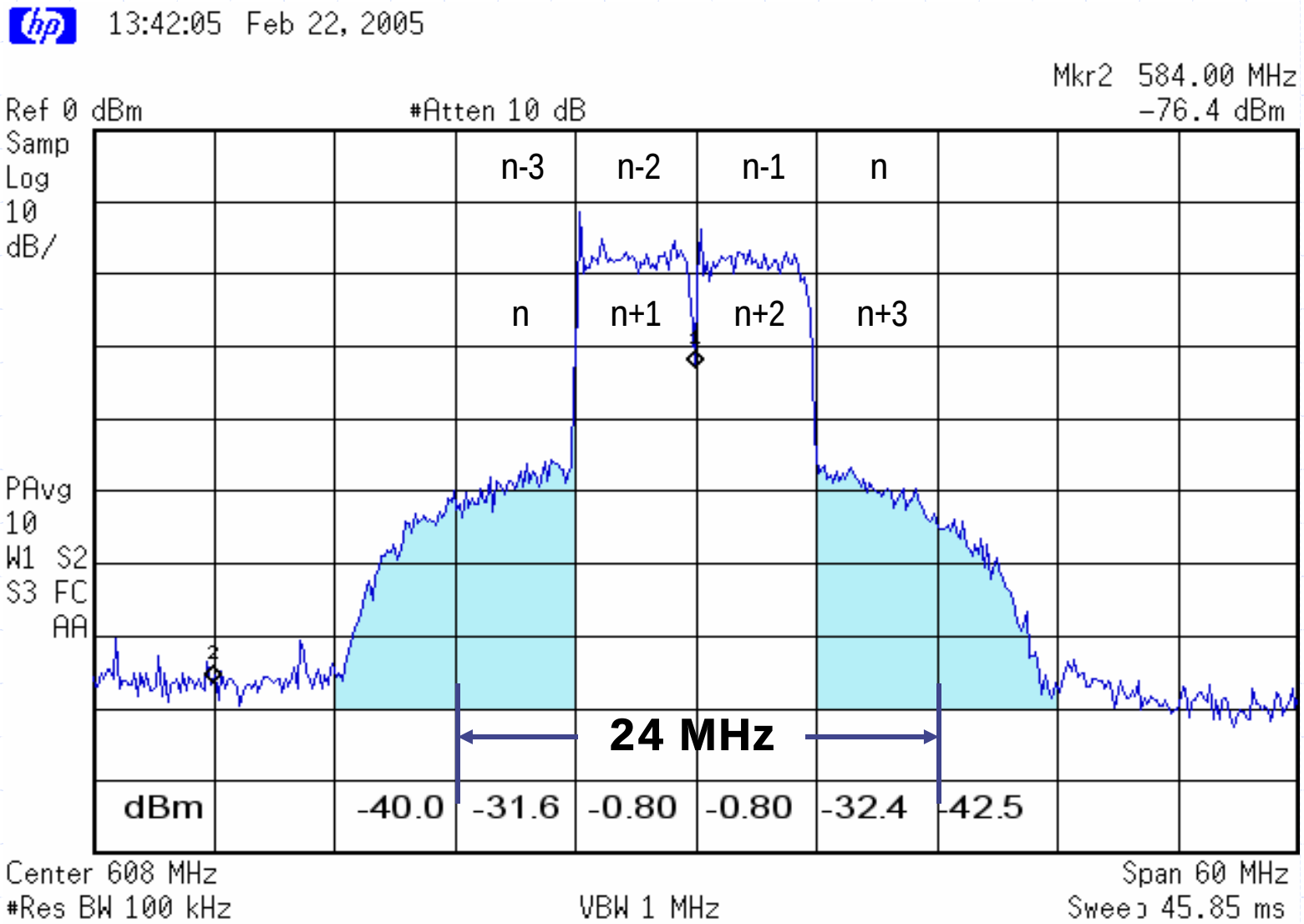
Scenario U (n-1) and U (n+1)

- U = -19.6 dBm (ea.) TOTAL U = -16.6 dBm

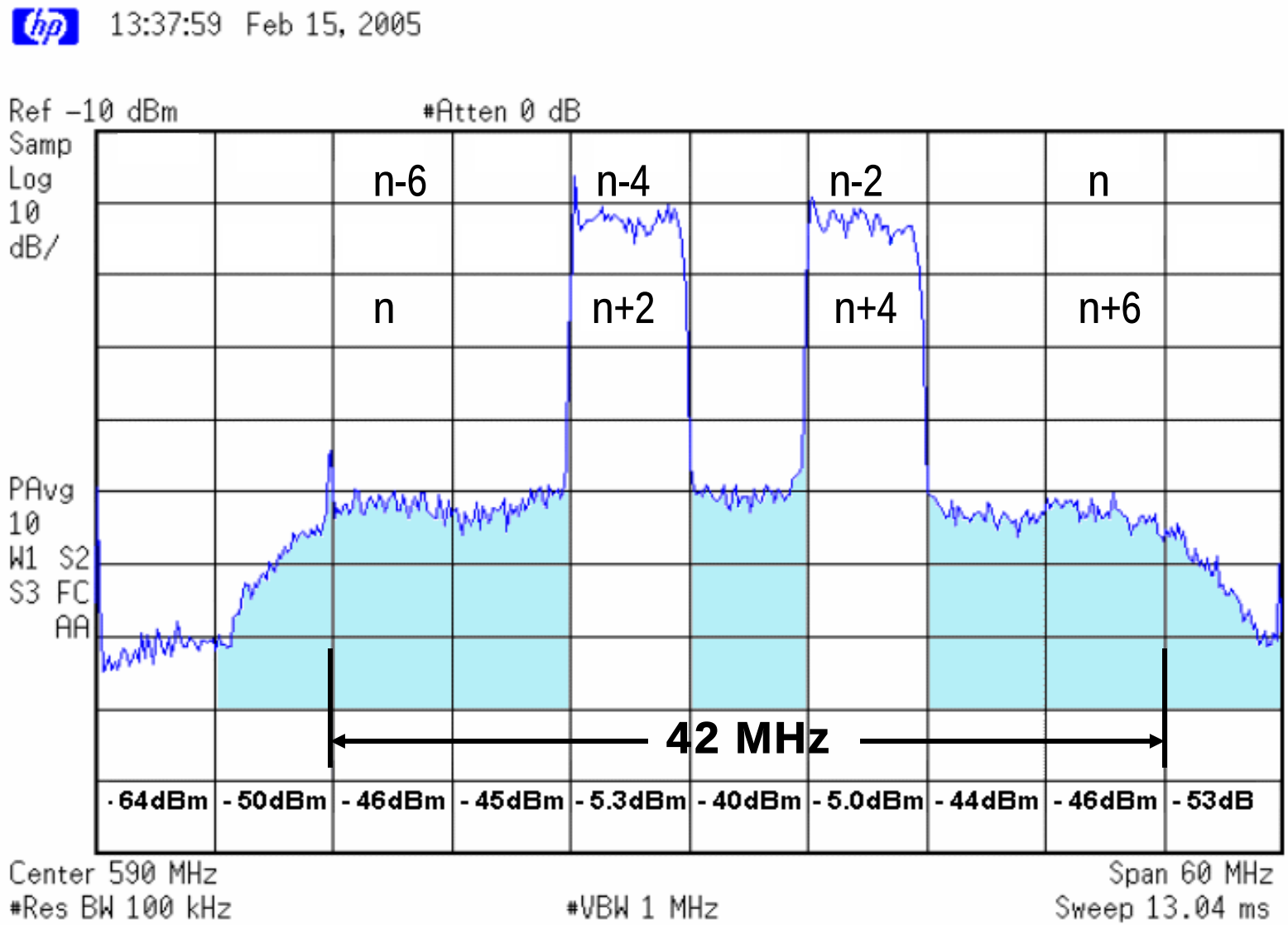
Sideband Splatter	=	-46.5 dB
Noise in D Channel from U	=	-63.1 dBm
IM3 (Rx)	=	-52.3 dBm
TOTAL Noise	=	-52.0 dBm
+SNR	>	15.2 dB
Usable D Signal Power	>	-36.8 dBm

6 dB HIGHER than for a Single U on n+/-1

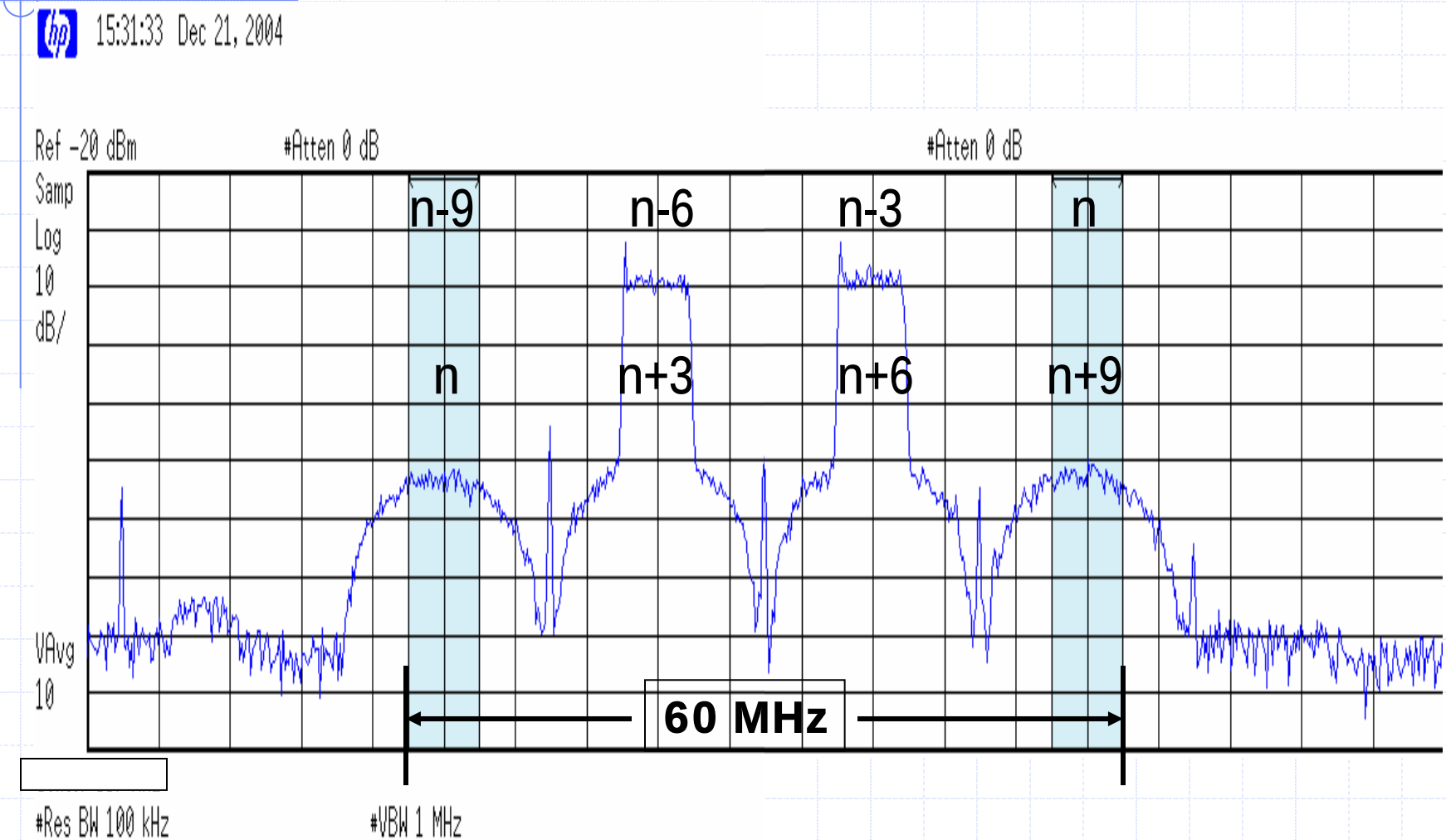
Interference into (n) from the [n-2, n-1] and [n+1, n+2] Channel Pairs



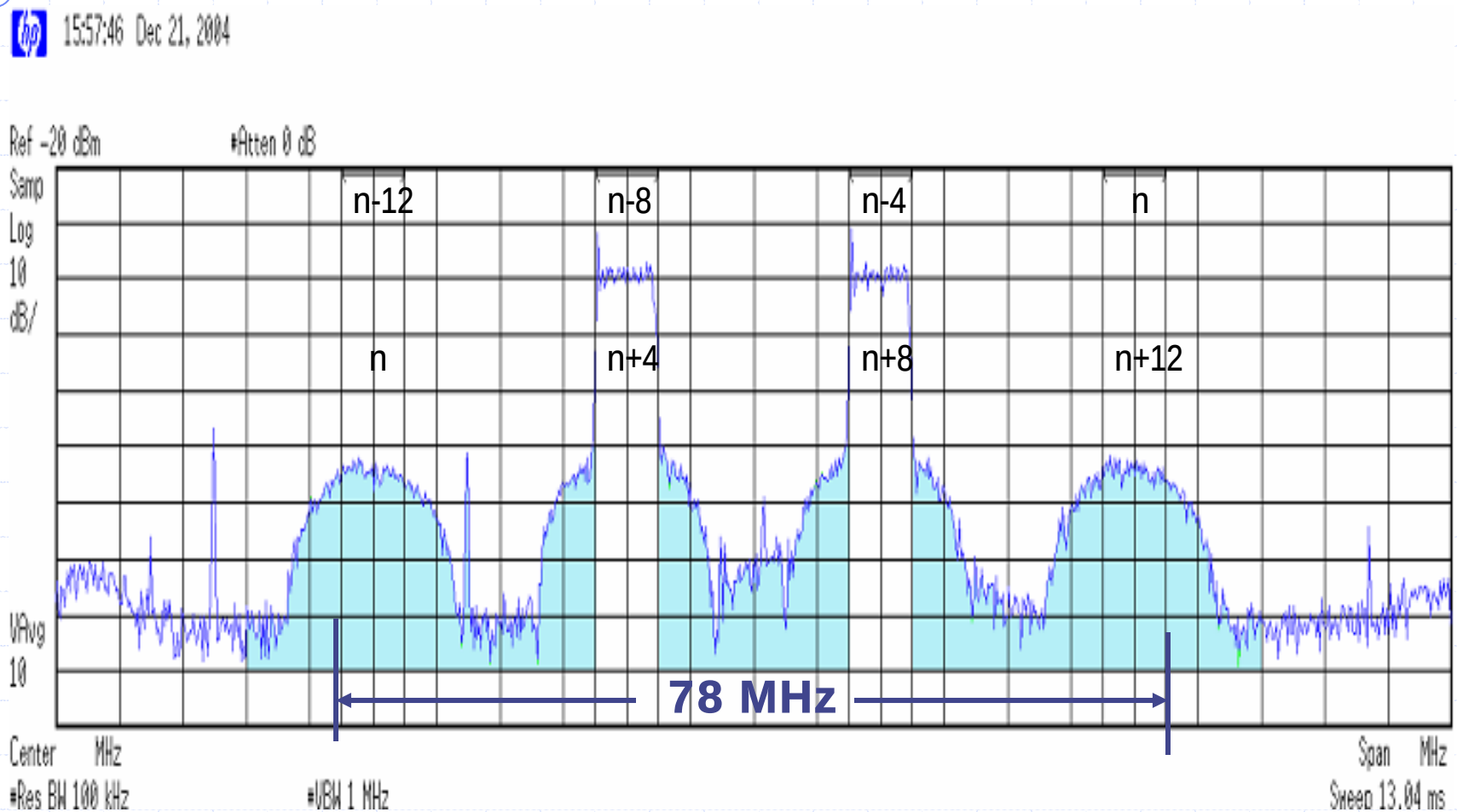
Interference into (n) from the [n-4, n-2] and [n+2, n+4] Channel Pairs



Interference into (n) from the [n-6, n-3] and [n+3, n+6] Channel Pairs



Interference into (n) from the [n-8, n-4] and [n+4, n+8] Channel Pairs

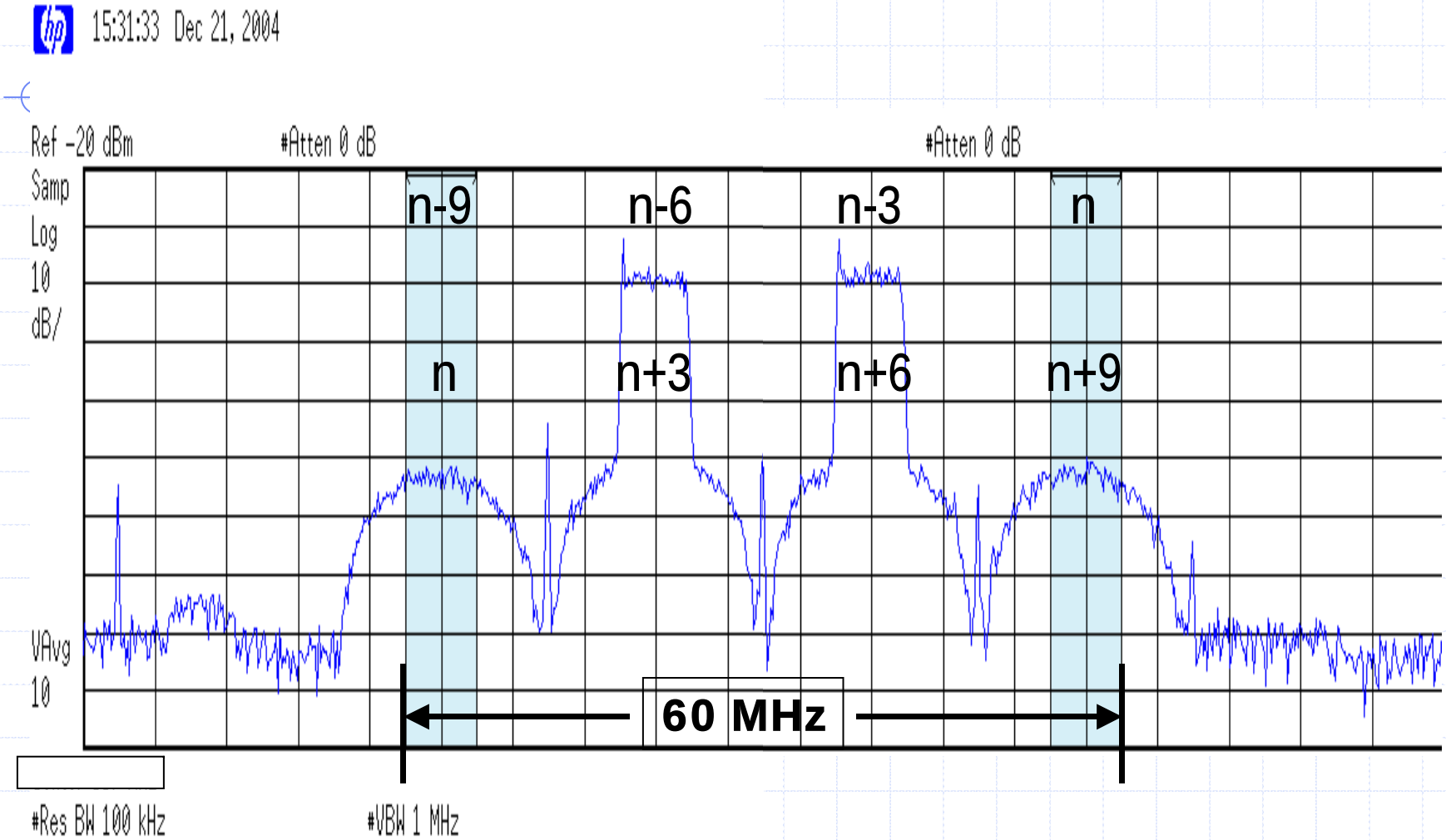


IM3 vs. Cross-Modulation (X-M)

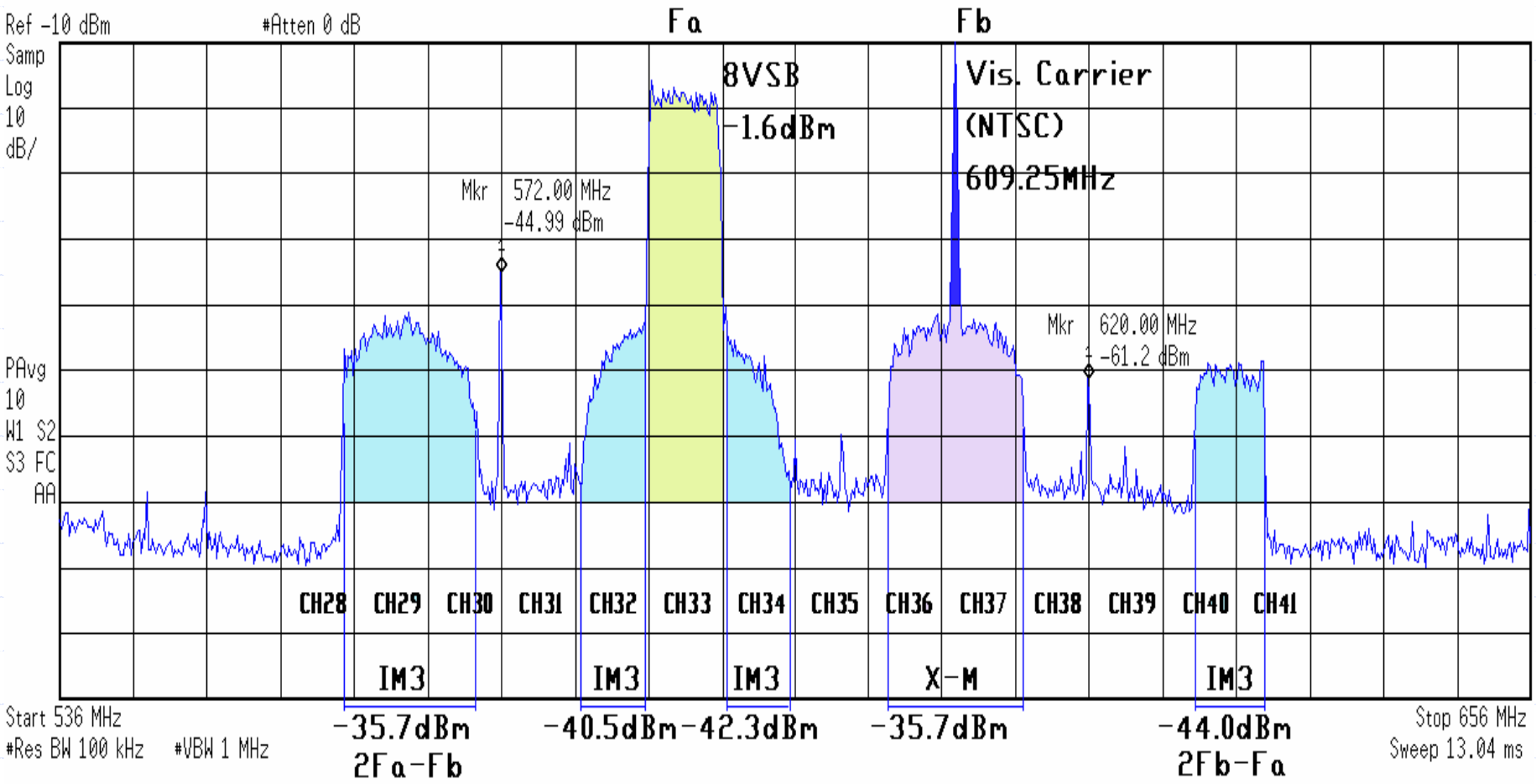
- IM3 can contribute noise into the Desired channel from either or both Adjacent Channel(s) and/or the identified channel pairs.

- X-M can noise-modulate the Desired signal from any or all Undesired signals at the mixer input.

- Relative importance IM3 vs. X-M unknown.
  1 dB compression of DTTB signals is probably too much.

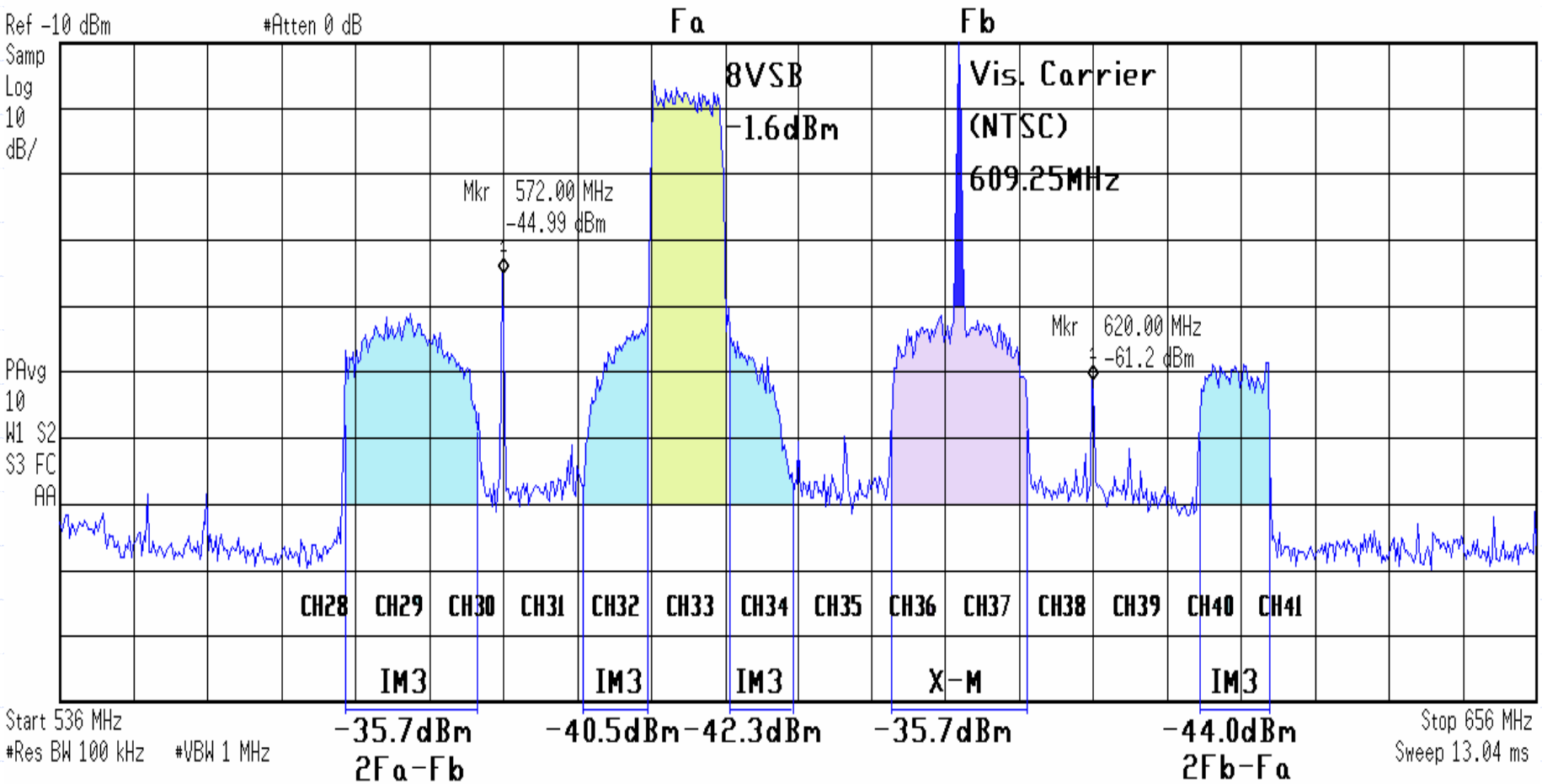

15:31:33 Dec 21, 2004
Ref -20 dBm
#Atten 0 dB
#Atten 0 dB
Samp
Log
10
dB/
n-9
n-6
n-3
n
n
n+3
n+6
n+9
VAvg
10
60 MHz
#Res BW 100 kHz
#VBW 1 MHz

Cross Modulation (X-M) vs. Intermodulation (IM3)



Cross Modulation (X-M) from a DTV signal into an NTSC Channel appears as noise surrounding the Visual Carrier of CH37 @ 609.25MHz

Cross Modulation (X-M) vs. Intermodulation (IM3)



Intermodulation between an unmodulated carrier @ 609.25MHz and a DTV signal results in Third Order Intermodulation products (IM3)

2Fa-Fb below the DTV spectrum 10.76 MHz wide and

2Fb-Fa above the CH37 carrier 5.38 MHz wide

Signal Blocking - De-Sensitization

- Blocking occurs at a Desired Signal power which is a function of IP3.
- For example, Dr. Oded Bendov has calculated that for – 10 dBm output from a Mixer whose IP3 = + 4 dBm blocking would occur.
  - The S / (X-M + in-channel IM3) would be 15 dB.
- Receiver IP3 should be significantly higher;
  - + 15 dBm to avoid blocking and interference.

Conclusions

1. CCI:
   Receiver design cannot improve CCI. Only directional rooftop antennas can mitigate CCI.

2. ACI:
   Is due to sideband splatter radiated by all DTV transmitters and appears as noise in the Desired Channel (I).

3. Additional IM3 may be generated in tuners by Undesired Signals on nearby channels.

Conclusions (continued)

4. The total of N + I + IM3 determines the minimum usable Desired signal power.

$$D > 15.2 + N + I + IM3$$

5. IM3 generated in receivers depends on the total U power at the Mixer input and the Input 3rd Order Intercept Power of the Mixer.

6. $IM3 = 3 * U - (U - IP3) / 2.$

Conclusions (continued)

7. IP3 should be > + 15 dBm to avoid interference within the protected area of stations.

8. This level of IP3 may not be available.

9. Attenuating the antenna signal by 15 dB will reduce Rx IM3 generated by 45 dBm.

10. Reducing RF amplifier gain by 15 dB will accomplish this goal.

Wideband RF Automatic Gain Control (Conclusions, Continued)

11. Technique known since 1936 for radios.

12. Control signal is derived from Mixer IF output (before IF filter).

13. Provides automatic attenuation of strong Undesired signals near the Desired channel.

14. This protects Mixer and RF amplifier against overloading.

UHF Taboos (Conclusions, continued)

15. Most UHF Taboos are due to 3rd order non-linearity in the tuner (Mixer).

16. Adequate attenuation of Undesired signals on UHF Taboo channels is extremely difficult to realize in consumer electronic products.

17. Tuned circuits do not lend themselves to VLSIC fabrication (Tuner on a chip).

RF Selectivity of Consumer Receivers (Conclusions, Continued)

18. Many compact TV receivers have been built without tracking filters which are not needed for the NTSC marketplace dominated by CATV and DBS media.
19. It is not known whether tuner designers in the Orient understand the need for tracking filters in receivers.
20. Consumer receivers do not employ double conversion tuners such as was used by Zenith in the tested prototype DTV receiver whose performance is the basis of DTV allocations.

Broadcast Spectrum Congestion

(Conclusions, continued)

21. Allotment of Adjacent Channels in a community for TV has never been done.

22. RF selectivity at UHF cannot be effective against ACI, and marginal for n +/- 2 UHF Taboo.

23. Avoid allotment of n – 2 with n – 1 and n. Avoid allotment of n + 2 with n + 1 and n.

24. RF selectivity could be effective against other UHF Taboos.

Thank You and Acknowledgements

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- The spectrum analyzer used was provided by the courtesy of Mr. Harvey Arnold of SBG.

- Dr. Oded Bendov's help is also gratefully acknowledged.

- The content and its Conclusions are strictly those of the author.