Application Note
AN - 19

Analog & Digital TV Co-Channel & Adjacent Channel RFI Measurements

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In Boulder, Colorado, the local ARES group, BCARES, provides television support of emergency situations and large public events for the local law enforcement and fire authorities. This is usually done on the amateur 70cm (420-450 MHz) band, using four, 6 MHz TV channels simultaneously (Ch 57, 58, 59 & 60). In the past, BCARES has done this using the old USA broadcast standard, analog, NTSC, vestigial upper-sideband (VUSB), TV transmitters. BCARES is currently investigating transitioning to using new digital TV technology. Of particular interest is the European terrestrial digital TV broadcast standard, DVB-T. The question has been raised about what radio frequency interference (RFI) will result from operating so many analog and/or digital transmitters on immediately adjacent channels. A laboratory study was thus performed under controlled conditions to establish RFI baselines for future Analog TV (ATV) and/or Digital TV (DTV) BCARES operations.

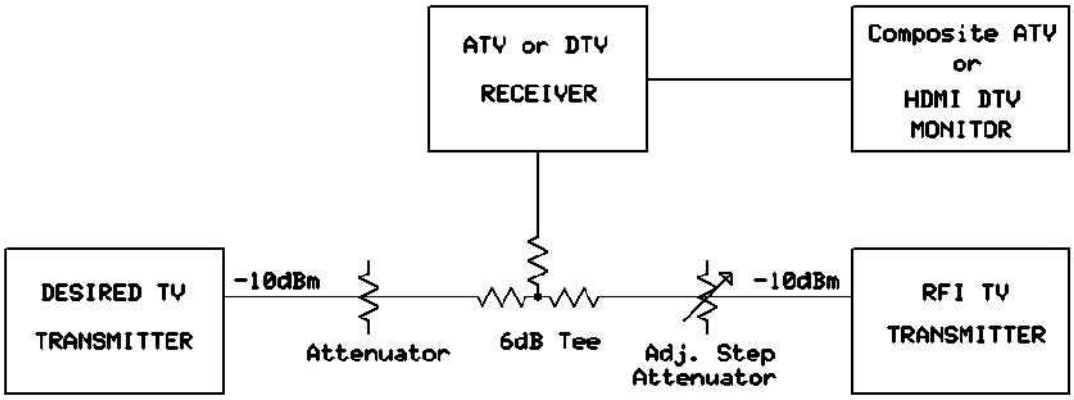

Fig. 1 RFI Test Set-Up

The RFI test set-up is shown in the Fig. 1 block diagram. The basic signals from either TV transmitter were initially set to approximately -10dBm. Note: For ATV, powers are measured in PEP, peak envelope power on the sync pulse tips. For DTV, average powers are measured. The desired TV signal input level to the TV receiver was set using fixed value SMA attenuators. The RFI input level to the TV receiver was adjustable using a combination of fixed and adjustable, 1dB & 10dB step, SMA attenuators. The desired

TV signal and the RFI signal were combined in an SMA resistive power divider/combiner tee which introduced an additional -6dB loss.

For ATV, a Pico-Macom model MPCD, CATV demodulator was used as the TV receiver. The video output from this demodulator was standard definition (480i), composite video. For DTV, a Hi-Des, model HV-110, DVB-T demodulator was used. The HV-110 provided both composite (std. def) or HDMI (high-def) video outputs. The video outputs were then observed visually for RFI effects on a high-definition (1080p), 32", flat screen video monitor.

For the ATV transmitter, two were used. The first provided an "Ideal" VUSB signal. It was a Pico-Macom model MPCMA, CATV, modulator. The second RFI source was a typical amateur quality VUSB-TV transmitter. It was a 10 Watt, KH6HTV VIDEO model 70-10AD. For the DTV transmitter, again two were used. The first provided an "Ideal" DVB-T signal. It was a Hi-Des model HV-100EH modulator. The second RFI source was a typical amateur quality DVB-T transmitter. This consisted of the Hi-Des modulator driving a 10W (ATV) / 3W (DTV) KH6HTV VIDEO model 70-7B Linear RF Amplifier. The outputs of the high power transmitters were attenuated using type N, high power attenuators to set the approximately -10dBm level to the test bench. The interfering, high power transmitters were also placed on the far side of the lab and connected to the test bench through a long length of lossy, RG-58 coax cable. This was done to minimize the radiated leakage from the transmitters from interfering with the extremely low signal levels (< -90dBm) sometimes used at the receiver input.

"Live" video was transmitted by both transmitters. For standard definition, an ordinary DVD player was used. For high-definition (1080p), a Blu-Ray DVD player was used. For DTV, it is very important to use "live" video with motion for these tests. This is because when a DTV receiver loses a signal, it displays on the monitor a freeze frame of the last image decoded. Without motion, it is thus difficult to immediately know when one has lost a DTV signal. Different movie discs were played on each player. This made it easier to distinguish on the monitor which transmitter was dominating and capturing the receiver.

To establish absolute ATV pep power levels and ATV & DTV spectrums, a Rigol model DSA815 spectrum analyzer was used. For DTV average power levels, an HP-432A power meter was used. A Fluke 6060B signal generator was used for calibrated CW RFI. Calibrated, SMA, attenuators were then used to set the lower power levels.

ATV RFI measurements were all performed with the desired transmitter's signal strength set to -65dBm at the receiver input. At this level, the monitor displayed an almost perfect, P4.5, picture, with just a very minor amount of video noise in the picture. The rf s/n was about 35dB. >40dB s/n is required for a perfect P5 picture. For ATV, the first and lowest level of RFI observed was labeled *Minor*, was when a very slight change was made in the picture's background "noise". This level was barely perceptible and would be deemed by a typical user as unnoticeable and totally acceptable. The second RFI level, labeled *Moderate*, was when a visible sync pulse and perhaps a "ghost" image from

the RFI transmitter would crawl across the screen. A typical user would consider this objectionable, but he could still watch the desired picture. The third, worst RFI level, labeled *Bad*, was complete destruction of the desired picture. The conclusions presented on the next page are for *Moderate* RFI. Tests were also performed for RFI from a CW or narrow-band FM voice signal. For ATV, the RFI appears as a high frequency beat note everywhere in the displayed picture.

For DTV, RFI behaves differently than for ATV. A digital signal is either perfect or non-existent. The threshold between DTV on and off is very sharp, typically a change of only 1 or 2dB at most. Right at the digital "cliff" threshold, sometimes "Pixelating" occurs with intermittent break-up of portions of the displayed picture. Many DTV receivers will freeze the last decoded image on the monitor screen when they cease to decode the signal. For the Hi-Des HV-110 DVB-T receiver, the digital threshold was measured to be -97dBm. Initially measurements were made with the desired DTV signal set to the same strong level as for ATV, namely -65dBm. They were then repeated for a weak signal level of -90dBm. It was found that the RFI results measured were identical for either DTV receiver inputs of either -65dBm or -90dBm. Thus, all of the succeeding DTV, adjacent channel RFI measurements were performed with a weak desired signal of -90dBm. For co-channel RFI measurements, they were performed with a strong signal of -65dBm.

The full details and all measurement results are presented in Appendix 1 & 2 at the end of this paper.

CONCLUSIONS for an analog, NTSC, VUSB-TV operation on all 70cm, 6MHz channels using typical amateur TV transmitters with LSB/USB ratios of -20 to -30dB

1. Moderate RFI is considered to be the presence of a crawling sync pulse through the desired picture.
2. The worst case is with an interfering transmitter on the immediate, adjacent upper channel. When this transmitter's signal strength is >+12dB higher than the desired signal, moderate RFI will occur. For the adjacent lower channel, the interfering signal must be >+25dB higher than the desired signal.
3. For operation with at least one empty 6 MHz guard channel, the interfering signal must be >45dB stronger than the desired signal for moderate RFI to occur.
4. Co-Channel RFI - An interfering signal at -21dB below the desired signal will cause moderate RFI.
5. CW RFI - Moderate RFI occurred at -25dBc for signals inside the 6 MHz channel. Outside the channel bandwidth the receiver rejected well interfering CW signals. An interfering signal ± 6MHz from the video carrier needed to be greater than + 45dBc.

CONCLUSIONS for a DVB-T operation on all 70cm, 6MHz channels using typical amateur TV transmitters with spectrum regrowth breakpoints of -30dB.

1. DVB-T operation is either a perfect P5 picture - or with RFI no picture at all.

2. Signal strengths exceeding 30dB difference on adjacent channels will block reception on the weaker signal.
3. Signal strengths exceeding 50dB difference on channels separated by at least one empty, guard channel will block reception on the weaker signal.
4. Co-Channel RFI - No picture was received whenever the signal strengths from both transmitters were within ± 6dB of each other. Which ever transmitter's signal strength was +8dB stronger than the other one would capture the DVB-T receiver and give a perfect P5 picture.
5. CW RFI - For interfering CW signals within the DVB-T pass-band that are >20dB stronger than the desired signal, the receiver will stop decoding the picture. For interfering CW signals that are at least 4 MHz away from the DVB-T center frequency, they must be >45dB stronger than the desired signal to cause the receiver to stop decoding.

CONCLUSIONS for a mixed operation on all 70cm, 6 MHz channels with both analog, NTSC, VUSB-TV and digital, DVB-T, typical amateur TV transmitters.
1. When the desired signal is an NTSC, VUSB-TV and the interfering signal is from a DVB-T transmitter on an adjacent channel, the DVB-T signal must be >20dB stronger than the NTSC signal to cause moderate RFI. This RFI appears as an increase in the video noise on the picture. This is essentially the same level as adjacent channel RFI between two NTSC, VUSB-TV transmitters.
2. When the desired signal is a DVB-T and the interfering signal is from an analog, NTSC, VUSB-TV transmitter on an adjacent channel, the NTSC signal must be >40dB to block the DVB-T reception. This is 15 to 25dB better than with an all NTSC, VUSB-TV operation.

Appendix 1: RFI to NTSC, Analog, VUSB-TV

Analog TV Test Set-Up: The desired NTSC, VUSB-TV signal was generated by a Macom MPCMA, CATV modulator running "live" video from a DVD player. It was operated on Ch 59 (433.25MHz) with RF output set to -10dBm (pep). A second TV transmitter was the interfering RFI source. It was also running "live" video from a second DVD player with different program material. It was operated on both co-channel (59) and lower and upper adjacent channels (57, 58, 60 & 61).

NTSC Test 1: RFI from an Ideal, Pure VUSB-TV Source
Macom MPCMA, CATV modulator used as the RFI source.

RFI	Minor	Moderate	Bad	Notes
Ch 57	+40dB	can't meas	can't meas	
Ch 58	+28dB	+41dB	can't meas	Adjacent lower channel
Ch 60	+26dB	+31dB	+39dB	Adjacent upper channel
Ch 61	+37dB	can't meas	can't meas	
Ch 59	-34dB	-18dB	-5dB	Co-Channel RFI

Conclusion: The worst case for RFI is from the adjacent upper channel. Moderate RFI occurs when it is about +30dB stronger than the desired channel. It must be about +40dB stronger for the adjacent lower channel.

NTSC Test 2: RFI from a typical Amateur VUSB-TV Transmitter

Second test was with a "typical" amateur quality, NTSC, VUSB-TV transmitter which does not have perfect suppression of the lower sideband. Typical LSB/USB ratios ranged from -18dB to -27dB. KH6HTV VIDEO model 70-10AD used as the RFI test source.

RFI	Minor	Moderate	Bad	LSB/USB	Notes
Ch 57	+36dB	+51dB	can't meas	-18dB	
Ch 58	+17dB	+25dB	+43dB	-22dB	Adjacent lower chan.
Ch 60	+1dB	+12dB	+38dB	-27dB	Adjacent upper chan.
Ch 61	+30dB	+43dB	can't meas	-27dB	
Ch 59	-35dB	-21dB	-5dB	-25dB	Co-Channel RFI

Conclusion: The imperfect lower sideband rejection does degrade the RFI performance approximately in the same amount as the dB ratio of the LSB/USB. As before the worst case was RFI from the adjacent upper channel. In this case for moderate RFI the interfering signal was only +12dB stronger than the desired channel, compared to about +30dB for the ideal, case, Test #1. For the lower, adjacent channel, the interfering signal needed to be about 25dB stronger than the desired channel for moderate RFI.

NTSC Test 3: RFI from a CW transmitter

A CW signal generator simulating an FM voice transmitter (1kHz tone, 5kHz dev.) was injected along with the desired -65dBm (pep) NTSC, VUSB-TV signal. Tests were performed at various frequencies, both within and outside the channel bandwidth.

Conclusion**:** CW signals within the channel bandwidth, i.e. +4 MHz & - 1/2 MHz of the video carrier, were most likely to cause RFI. Minor RFI occurred at -30dBc, moderate at -25dBc and bad at -20dBc. Outside the channel bandwidth the receiver rejected well interfering CW signals. An interfering signal ± 6MHz from the video carrier needed to be greater than + 45dBc.

NTSC Test 4: RFI from an ideal DVB-T, Digital TV Transmitter

Hi-Des model HV-100EH modulator was used as the RFI source.

RFI	Minor	Moderate	Bad	Notes
Ch 57	+29dB	+43dB	+48dB	
Ch 58	+19dB	+27dB	+35dB	Adjacent lower channel
Ch 60	+14dB	+19dB	+23dB	Adjacent upper channel
Ch 61	+29dB	+41dB	+48dB	
Ch 59	-33dB	-18dB	-11dB	Co-Channel RFI

Conclusion: RFI from a DTV signal appears simply as additional white noise, thus lowering the video s/n. A DTV signal on the same channel can be tolerated as long as it is about -20dB weaker than the desired analog channel. The worst case for adjacent channel RFI was again on the upper channel with a DTV signal needing to be about +20dB stronger to cause moderate RFI. This was mid-way between the analog results in tests 1 & 2.

NTSC Test 5: RFI from a typical amateur DVB-T, Digital TV Transmitter
Hi-Des model HV-100EH modulator driving a KH6HTV VIDEO model 70-7B Linear Amplifier was the RFI source. Output power = +35dBm with spectrum regrowth shoulder breakpoint at -30dB.

RFI	Minor	Moderate	Bad	Notes
Ch 57	+24dB	+32dB	+44dB	
Ch 58	+5dB	+18dB	+31dB	Adjacent lower channel
Ch 60	+15dB	+21dB	+25dB	Adjacent upper channel
Ch 61	+25dB	+38dB	+46dB	
Ch 59	-34dB	-21dB	-6dB	Co-Channel RFI

Conclusions: Similar results as previous test #4. As expected, some additional RFI resulting from the broader out-of-band spectrum skirts on the amateur DTV signal. A DTV signal on either the lower or upper adjacent channel, 20dB stronger than the desired signal, will cause moderate RFI. This was about 8dB better than the results obtained with a comparable analog, amateur TV transmitter.

Appendix 2: RFI to DVB-T Digital TV

Digital TV Test Set-Up: The desired DVB-T signal was generated by a Hi-Des model HV-100EH modulator running "live" 1080p video from a hi-def, Blu-Ray DVD player. It was operated on Ch 60 (441MHz) with RF output set to -10dBm (avg). The digital parameters for the DVB-T modulator were set as follows: H.264 encoding, 6Mbps max. bit rate, 6 MHz bandwidth, QPSK modulation, 8K FFT, 5/6 code rate (FEC), and 1/16 guard interval. A second, DVB-T TV transmitter, using the same coding parameters, was the interfering RFI source. It was also running "live" video from a second DVD player with different program material. It was operated on both co-channel (60) and lower and upper adjacent channels (57, 58, 59 & 61).

DVB-T Test #1 RFI from a Perfect DVB-T Transmitter
For the first test, the transmitters were both the Hi-Des HV-100EH modulators. Thus, this is to be considered the "Perfect DVB-T" situation with very clean DVB-T spectrums.

Conclusions:
1. There was no difference noted in the RFI thresholds for either -65dBm (strong signal) or -90dBm (weak signal), thus all of the remaining adjacent channel

measurements were performed with the desired signal strength set at -90dBm (weak). For co-channel measurements, the desired signal strength was set to -65dBm.

2. For either the upper or lower adjacent channel, the RFI threshold was when the interfering signal was approximately +40dB stronger than the desired channel.

3. For channels spaced at two channels or more away from the desired channel, the RFI threshold was when the interfering signal was approximately +57dB stronger than the desired channel.

4. For co-channel interference, i.e. when the interfering transmitter is on the same channel, no picture was received whenever the signal strengths from both transmitters were within ± 7dB of each other. Which ever transmitter's signal strength was +8dB stronger than the other one would capture the DVB-T receiver and give a perfect P5 picture.

5. When the Hi-Des HV-110 receiver displays a signal to noise ratio of 6 to 8dB, the receiver will no longer decode a picture.

DVB-T Test 2: RFI from a typical amateur DVB-T, Digital TV Transmitter

Hi-Des model HV-100EH modulator driving a KH6HTV VIDEO model 70-7B Linear Amplifier. Output power = +35dBm with spectrum regrowth shoulder breakpoint at -30dB.

Conclusions:

1. For either the upper or lower adjacent channel, the RFI threshold was when the interfering signal was approximately +30dB stronger than the desired channel. This was 10dB worse than the ideal, perfectly clean spectrum case.

2. For channels spaced at two and three channels away from the desired channel, the RFI threshold was when the interfering signal was approximately, +49dB and +51dB respectively, stronger than the desired channel. This was about 7dB worse than the ideal case.

3. For co-channel interference, i.e. when the interfering transmitter is on the same channel, no picture was received whenever the signal strengths from both transmitters were within ± 6dB of each other. Which ever transmitter's signal strength was +8dB stronger than the other one would capture the DVB-T receiver and give a perfect P5 picture.

4. When the Hi-Des HV-110 receiver displays a signal to noise ratio of 7 to 9dB, the receiver will no longer decode a picture.

DVB-T Test 3: RFI from a CW transmitter

A CW signal generator simulating an FM voice transmitter (1kHz tone, 5kHz dev.) was injected along with the desired -65dBm DVB-T signal. Tests were performed at various frequencies, both within and outside the channel bandwidth.

Conclusions:

1. Worst case is for an interfering CW signal on the center frequency pilot carrier. If this CW signal is >17dB stronger than the desired signal, the receiver will stop decoding the picture.

2. For interfering CW signals within the DVB-T pass-band that are >20dB stronger than the desired signal, the receiver will stop decoding the picture.
3. For interfering CW signals that are at least 4 MHz away from the DVB-T center frequency, they must be >45dB stronger than the desired signal to cause the receiver to stop decoding.

DVB-T Test 4: RFI from an Ideal, Pure NTSC VUSB-TV
Macom MPCMA, CATV modulator used as the RFI source.

Conclusions:
1. Worst case is co-channel interference on the same channel. When the interfering NTSC signal is >+12dB stronger than the desired signal, the DVB-T receiver will stop decoding.
2. The Hi-Des HV-110 receiver does an excellent job of rejecting RFI from NTSC, VUSB-TV signals on adjacent channels.
3. There is a difference between the RFI threshold on the immediate adjacent channels. This is due to the asymmetry of the NTSC, VUSB-TV spectrum. The threshold is +45dB for the lower channel and +52dB for the upper channel.
4. For all the other channels further away from the desired channel, the RFI threshold is 60dB.

DVB-T Test 5: RFI from a typical amateur analog, NTSC VUSB-TV Transmitter
Second test was with a "typical" amateur quality, NTSC, VUSB-TV transmitter which does not have perfect suppression of the lower sideband. Typical LSB/USB ratios ranged from -18dB to -27dB. KH6HTV VIDEO model 70-10AD used as the test source.

Conclusions:
1. Worst case is co-channel interference on the same channel. When the interfering NTSC signal is >+6dB stronger than the desired signal, the DVB-T receiver will stop decoding.
2. The Hi-Des HV-110 receiver does an excellent job of rejecting RFI from NTSC, VUSB-TV signals on adjacent channels.
3. There is a difference between the RFI threshold on the immediate adjacent channels. This is due to the asymmetry of the NTSC, VUSB-TV spectrum. The threshold is +40dB for the lower channel and +41dB for the upper channel. The upper channel is about 10dB worse for the typical amateur transmitter compared to the ideal transmitter due to the imperfect suppression of the VUSB's lower sideband which lands directly into the passband of the desired DVB-T signal.
4. For all the other channels further away from the desired channel, the RFI threshold is better than +55dB. This is about 5dB worse than the ideal case.