

The Two Towers



Testing “Improved IM radios” at a real world worst case location

Background

There is an ever-increasing awareness that some critical public safety communications are being interfered with by “cellular phones”. In fact some media reports (America’s Most Wanted, <http://www.amw.com/amw.html>) have declared an “interference emergency”. The 800MHz public safety band is adjacent to the cellular bands, and interleaved with the 800MHz SMR band, which is predominantly occupied by Nextel. There are cases where Nextel operates on channels adjacent to public safety systems. There are two radically different plans for solving the problem, the “consensus plan” (www.projectconsensus.org) that advocates re-banding to achieve better frequency separation between public safety and cellular operators, and the “balanced plan” (www.fix800mhznow.com) that favors solving interference cases on an individual basis.

Both sides agree that the majority of the interference is via two mechanisms. Out of band energy (OOBE) emitted by a cellular transmitter in the public safety band, and intermodulation (IM) products created when two or more signals combine to produce unwanted energy in the public safety band.

From my limited testing I believe that there are four mechanisms for interference to occur. Severe cases may involve combinations of these mechanisms.

- 1) True out of band energy (noise) from a cellular A or B band transmitter should be at a relatively low level in the public safety band compared to other forms of interference. There is always the chance that a discrete spur from a cellular transmitter could fall within the receive passband of the public safety radio. The sideband noise contribution from multiple Nextel transmitters operating in the same band as the public safety radio is likely to be a greater contributor. These types of interference are generated external to the public safety radio and cannot be influenced by improving the radio’s performance.
- 2) The total power impinging on the receiver’s front end in some locations can be great enough to cause blocking or totally swamp the receiver causing the radio to completely squelch. Narrowing the receivers RF bandwidth can mitigate interference of this nature. The varactor diode tuned filters present in most of our current receiver designs can generate IM or noise in the presence of 30 or more high level signals. Removing the usual Schottky diode across the receiver input also helps.
- 3) Intermodulation products can be generated internal to the radio. This is the usual case, and improving the radio’s IM performance will help resolve the interference issue.
- 4) Intermodulation products can be generated external to the radio. Typical sources include other transmitters at the site, in building amplifiers (BDA’s), and any non-linear element that is subjected to multiple high level signals. Since the unwanted signals are generated external to the public safety radio, improving the radio’s performance cannot influence them.

The Test Site

During the development of the improved IM radios I had been looking for a suitable test site where verifiable interference to public safety radios could be demonstrated. The search involved questioning police officers, CGISS and iDEN employees (involved in field testing), and visiting Nextel sites with radios in hand. None of these resulted in a reliable test site. Terry Mansfield in Schaumburg informed me of a site near my house where serious interference had been observed. I have driven past this site many times but failed to notice just what was there. This location was not mentioned by the Sunrise police officer that I talked to. I later realized that their public safety transmitter site is less than one mile from this location so their signals do not suffer interference here.

This site consists of two towers about 50 feet tall and about 500 feet apart. The south tower (the one on the right in the picture) was originally put up by Bellsouth (now Cingular) and AT&T installed the north tower. There are now six sets of cellular antennas (3 on each tower), several omni directional antennas, and several microwave dishes. This represents the six of the seven cellular carriers in this market. Nextel has their antennas on the south tower. The area, which used to be empty field, has become populated with warehouses making access to the areas adjacent to the towers difficult.

The Nextel site has a three-sector antenna system. The sectors face 30, 150 and 270 degrees. The sector facing 150 degrees is not accessible due to warehouses and private property. The signal strength at the closest accessible point is -40dbm, measured with a Nextel phone in trace mode. This signal strength is not deemed strong enough to warrant further observation.

The sector facing 30 degrees is aimed directly at a two-story warehouse complex that has the stairway and hallways on the exterior of the building. There are two points on this exterior that are accessible. I have been to both of these locations multiple times (with the same Nextel phone) and have measured signal strength between -29 and -36dbm. It is not known if the Nextel system, the phone, multipath, or a combination of the three causes the variation in readings. Radio testing was performed at both of these locations. The rear location (back stairs) is directly in front of the Nextel antenna system, but obstructed from all other directions. This means that all of the desired public safety signals are subject to multipath, and repeatability is not good. The front location (front stairs) is further from the Nextel antenna and slightly off axis. A clear path exists to the east that does not obstruct the desired public safety signals. It is also possible to use the building to block the towers if desired.

The sector facing 270 degrees (west) is free from obstruction for over ½ mile in front of the sector. Hiatus road is due west of the antenna. On the west side of the road is a field where cattle graze that is not accessible. Signal strength measurements were made along the edge of the road between the pavement and the field. A point was chosen where the Nextel signal measured -24dbm. This is where testing was performed. The picture at the beginning of the report was taken at the testing site. This was by far the strongest Nextel signal that I had encountered, so I asked one of our engineers who works with Nextel if this was normal. It turns out that this site covers a large conservation area where there are no towers so it is quite strong. It is believed that the other cellular carriers might adopt the same strategy, since there are no towers to the west of this site for several miles (not many people either).

The Radios

There were a total of five radios used for the tests. They are explained below:

- 1) Radio #1 is a standard unmodified XTS5000. It is used as the control unit that the other radios are compared against.
- 2) Radio #2 is an XTS500 in which the varactor tuned filters in the receiver front end have been replaced with Saw filters. No other changes were made to this radio. This radio was an experiment to see if improved filtering would help eliminate interference. This change also improved the receive sensitivity and the IM.
- 3) Radio #3 is modified to operate with 80db receiver specs. It contains a unique transceiver board. The transceiver board incorporates the dual LNA design using a passive Mini-Circuits mixer. The front end selectivity is obtained using Saw filters. A discrete LO buffer generates the required LO power. An IF amplifier is incorporated which is also a discrete design. This design is known as the Cirrus receiver architecture. The match between the LO buffer and the mixer is critical and was optimized for good performance across both the 700MHz and 800MHz bands. This radio was the second of the three original "80db radios".
- 4) Radio #4 is modified to operate with 80db receiver specs. It contains a unique transceiver board. The transceiver board incorporates the same dual LNA design as radio #3 with a WJ passive mixer. The front end selectivity is obtained using Saw filters. The IF amplifier is the same discrete design used in radio #3. The LO buffer is an RFMD integrated circuit (RF2361). The match between the LO buffer and the mixer is critical and was optimized for best performance at 867MHz, the frequency used by many public safety agencies. There is no 700MHz band in this radio (SAW filters are in short supply). This radio was an experiment to see if 85+db IM over the 866 to 869MHz range could be achieved and if it would be advantageous in a real world situation.
- 5) Radio #5 is modified to operate with 80db receiver specs. It contains a unique transceiver board. The transceiver board incorporates two RFMD RF2361 IC's. The LNA is an RF2361 IC operated on 3.8 volts biased at 10 mA. At this operating point the IP3 should be about +8dbm. The front end selectivity is obtained using Saw filters with a WJ passive mixer. The IF amplifier is the same discrete design used in radio #3. The LO buffer is also an RF2361 IC. The match between the LO buffer and the mixer is not critical and the data sheet values were used. I made this radio to satisfy my curiosity about the RF2361 chip and its application in a wideband receiver. It wasn't intended to be an 80db radio until I raised the operating current in the LNA and discovered that it worked quite well. There is no 700MHz band in this radio (SAW filters are in short supply).

All radios have the switchable RF attenuator in the front end, which can be disabled using the CPS software. It was enabled for all field testing on all radios.

The Bench Test Data

The radios were tested for receiver parameters on the bench prior to field testing. Receiver sensitivity, third, and fifth order intermodulation were measured across the 800MHz band at two MHz intervals. No data was taken at 862MHz or 700MHz because these frequencies were not available in all radios. The frequencies used were the same as the field test frequencies whenever possible. The data follows.

Frequency	851.0625	853.6375	855.0875	857.2375	859.3625	860.8625	864.0625	866.6375	867.6625	868.3125
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RADIO #1 Unmodified

Standby current = 77mA

12 db sinad	-121	-121	-121	-121	-120.8	-120.8	-120.7	-120.7	-120.8	-121
IM3 +1,+2MHz	-77.5	-78	-77.5	-77.5	-77.5	-77.5	-77	-77	-77	-77
IM3 -1,-2MHz	-78	-78	-77.5	-77.5	-77.5	-77.5	-77.5	-77.5	-77.5	-77.5
IM5 +2,+3MHz	-93	-93	-92.5	-92.5	-93	-93	-93	-93	-93	-93
IM5 -2,-3MHz	-93	-93.5	-93	-93	-93	-93	-93	-93.5	-93.5	-93.5

RADIO #2 SAW filters

Standby current = 77mA

12 db sinad	-121.5	-121.8	-122	-121.9	-121.6	-121.7	-122	-121.9	-121.8	-121.8
IM3 +1,+2MHz	-79	-78.5	-78.5	-78.5	-78.5	-79	-80	-79.5	-79.5	-79.5
IM3 -1,-2MHz	-79.5	-79	-78.5	-78.5	-79	-79	-79	-78.5	-78	-78
IM5 +2,+3MHz	-93	-93	-93	-93	-93	-93	-93	-93	-93	-93
IM5 -2,-3MHz	-93	-93	-93	-93	-93	-93	-93	-93	-93	-93

RADIO #3 original 80db

Standby current = 80mA

12 db sinad	-120.2	-120.2	-120.1	-120.1	-120.2	-120.3	-119	-119	-119.7	-120
IM3 +1,+2MHz	-82.5	-82	-82	-82.5	-83.5	-84	-85	-85	-85.5	-85.5
IM3 -1,-2MHz	-81.5	-82	-82.5	-83	-83	-82.5	-83.5	-84	-84	-84
IM5 +2,+3MHz	-93	-93	-92.5	-93	-93.5	-94	-93.5	-93.5	-93.5	-93.5
IM5 -2,-3MHz	-93	-93	-93	-93	-93	-93	-93	-93	-93.5	-93.5

RADIO #4 IM optimized @866

Standby current = 78mA

12 db sinad	-117.6	-117.4	-117.2	-117.3	-117.3	-117.4	-118.5	-118.8	-118.8	-118.7
IM3 +1,+2MHz	-83.5	-84	-84.5	-85.5	-86	-86	-87	-87	-87	-86.5
IM3 -1,-2MHz	-82.5	-83	-83	-84	-85	-85	-86	-88	-88	-88.5
IM5 +2,+3MHz	-93	-93	-93	-93	-93	-93	-93	-93.5	-93	-93
IM5 -2,-3MHz	-93	-93	-93	-93	-93	-93	-93	-93	-93.5	-93.5

RADIO #5 dual RFMD chips

Standby current = 81mA

12 db sinad	-122.4	-122.5	-122.6	-122.8	-122.5	-122.3	-122.3	-122.1	-122.2	-122
IM3 +1,+2MHz	-84.5	-84	-84.5	-84.5	-84.5	-84	-84	-84	-84.5	-84.5
IM3 -1,-2MHz	-87	-86.5	-85.5	-85	-85	-84.5	-85	-85	-85	-85
IM5 +2,+3MHz	-94.5	-94.5	-95	-95.5	-95.5	-96	-95.5	-95	-96	-96
IM5 -2,-3MHz	-95	-95	-95	-94.5	-95	-95	-95	-95	-95	-95

The First Field Test

The first field test was conducted on Dec. 20, 2003. This was the Saturday before Christmas. It turned out to be the busiest shopping day of the 2003 Christmas season. The cell site used for these tests covers the area on the North side of the Sawgrass Mills mall (the largest mall in Florida), and the Sawgrass Expressway. During the time that this test was underway multiple attempts to use my Nextel phone were met with constant "System Busy Try Later" responses. It would be safe to say that cellular traffic on this site was heavy. Radios 1 and 3 (2, 4 and 5 did not exist yet) were tested at the three test locations outlined above. The radios were all programmed for receive only operation on all major public safety systems within 50 miles of the location. The front end attenuator was enabled for all tests on both radios.

The radios were first taken to the "front stairs" location. Here comparisons were made to see if there were distant public safety systems that were receivable on the modified radios that were not receivable on the unmodified radio. The local police system was not a problem on any radio, their transmitter is less than one mile away. All public safety systems that operate in Broward county were receivable on both radios, although there were some cases where the modified radio worked better, there were no local public safety systems that were unusable due to interference. The RSSI readings on my Nextel phone were -30dbm. There is unobstructed view to the north and to the east (Boca, Palm Beach) from this location.

The Boca Raton police department (20 miles away) was the most obvious case where there were differences between the radios. Their systems operate at 852 to 854 MHz and their signals are weak. The unmodified radio would not unsquelch on any of their transmissions, no signals could be heard when the monitor button was pressed. The modified radio could receive all of their transmissions although some were barely readable. The Palm Beach County Sheriff system (25 miles) also exhibited similar characteristics although they could sometimes be received on the unmodified radio. They operate at 861 to 865MHz.

The radios were then taken to the "back stairs" location. It was impossible to conduct a repeatable test at this location. The modified radio seemed to operate better but different results were obtained each time the same test was performed. It should be noted that this location is surrounded by concrete and steel buildings on all sides (severe multipath) and directly adjacent to the north tower. The Boca Raton police system was not receivable on any radio at this location. The Palm Beach county system was hit or miss on both radios, and movement as small as one inch made a clearly readable signal disappear. The RSSI readings on my Nextel phone were again -30dbm.

An attempt was made to test the radios on Hiatus Road. I was here for only a short time due to impending darkness and very heavy traffic. During this time three things became obvious. The interference at this location is very strong, the modified radio is clearly an improvement, and some systems that were receivable at the other locations were not receivable on either radio here. Standing between the Nextel tower and the radio greatly improved reception.

This was a very non – scientific test, conducted during Christmas vacation. The purpose was to determine if the 80db radio architecture was useful. This casual field test taught us that the 80db radio was worthy of a better-controlled experiment.

The Second Field Test

The list of Nextel frequencies for the test site was obtained and a spreadsheet was created that details the third order IM products from those frequencies. All IM products that were outside the 851 to 870MHz band were removed from the list. All frequencies that were used by Nextel anywhere in South Florida were also dropped from the list, since they were not likely to be used by public safety. The resulting list of frequencies was programmed into the five radios outlined above. The previous public safety systems were also programmed into the radios.

Since the quality of a received signal is a subjective measurement a rating scale was devised to assign a number to a signal based on certain criteria. All measurements taken were based on the agreement of two people in assigning the number.

0 – No reception when monitor button is pressed and the radio is moved and tilted.

1 – Intermittent locking of the abacus chip (noise changes pitch)

2 – Abacus lock is usually continuous but signal not intelligible

3 – Continuous lock signal is sometimes intelligible if radio is held just right

4 – Mostly intelligible signal, breaks squelch

5 – Always intelligible signal but quite noisy requires effort to understand

6 – Clear easy to understand signal, has obvious noise

7 – Good signal not fully quieted, obvious noise when radio is moved or tilted

8 – Fully quieted signal, noise detected only when radio is moved or tilted

9 – No noise detected when tilted or moved, only when antenna is covered with hand

10 – No noise detected when antenna is covered with hand.

The radios were then tested in my backyard (ground level) on each of the frequencies on the intermod list to determine which of these frequencies had usable public safety signals on them. This location was chosen due to the absence of strong interfering signals. The strongest Nextel signal was -77dbm (measured with my Nextel phone in trace mode). There are no nearby cellular towers. Thirty-six frequencies had usable public safety signals. Thirteen signals were chosen from those frequencies based on the fact that they were used frequently, which were characterized by signal quality using the above scale. As expected there were no discernable differences in the five radios at this location.

FREQUENCY	USER	USAGE	SIGNAL QUALITY	REMARKS	LOCATION
853.6375	Boca PD	voice	4	weak voice signal infrequent use	20 miles north east
855.0875	pvt system	trunk cntl ch	7	strong data signal	unknown
859.3625	Broward county	voice	8	fully quieted voice channel	local simulcast countywide
859.7125	Miami PD	voice	7	strong voice channel	20 miles south east
860.8625	?	trunk cntl ch	7	strong data - trunking control	unknown
866.3625	Dade county	voice	4	weak voice channel	15 miles south east
866.6375	Ft lauderdale	voice	5	relatively weak voice channel	8 miles east
867.6625	Dade county	voice	4	weak voice channel	15 miles south east
867.7625	Palm Beach county	trunk cntl ch	5	weak trunking control channel	25 miles north
867.7875	Dade county	voice	4	weak voice channel	15 miles south east
867.9125	Dade county	trunk cntl ch	6	trunking control not full quieting	15 miles south east
868.2875	Ft lauderdale	voice	7	voice ch almost full quieting	8 miles east
868.3125	Ft lauderdale	voice	5	relatively weak voice channel	8 miles east

Nextel signal level = -77dbm

The radios were then tested at the three locations previously visited. The front end attenuator was enabled for all tests on all radios. Not every frequency was tested at each location because some channels were infrequently used. Each radio was rated by the same two people at each location and assigned a signal quality number using the same criteria as before. Some frequencies were tested more than once in some locations by using the buildings (tests 1 – 3) or myself (tests 12,13 and 15 – 18) to block the line of sight to one or both towers. Where two radios scored similarly side-by-side comparisons were made to determine the best radio. When the two people could not agree on a clear winner the radios were scored the same. The test results are below:

FRONT STAIRS TEST:

Height = 15 feet above ground

Test #	FREQUENCY	Radio #1	Radio #2	Radio #3	Radio #4	Radio #5	
1	853.6375	0	0	1	1	2	both towers visible
2	853.6375	2	2	4	3	4	south tower visible, north tower behind building
3	853.6375	6	6	7	7	7	both towers behind building
4	866.3625	3	3	4	4	4	
5	867.7875	1	2	3	4	4	
6	867.9125	1	3	4	5	5	
7	868.3125	6	7	8	8	8	

Nextel signal level = -37dbm

BACK STAIRS TEST:

Height = 15 feet above ground

8	853.6375	0	0	1	1	1	Boca Raton (source) is behind concrete building
9	867.7875	0	1	2	2	2	Unobstructed path to source
10	867.9125	0	2	3	3	3	Unobstructed path to source
11	868.3125	6	6	8	8	8	Unobstructed path to source

Nextel signal level = -36dbm

HIATUS ROAD TEST:

Height = ground level

12	853.6375	0	0	1	1	1	facing the towers, source to left (not blocked)
13	853.6375	3	4	6	6	6	facing west, towers behind me, source to right (not blocked)
14	855.0875	1	5	6	6	6	
15	866.6375	0	1	1	2	2	facing the towers and source
16	866.6375	5	5	6	7	7	facing west, towers and source behind me
17	867.6625	0	1	2	2	3	facing the towers, source to right (not blocked)
18	867.6625	7	7	8	8	8	facing west, towers behind me, source to left(not blocked)
19	867.7625	0	2	2	2	3	
20	868.2875	0	4	7	7	8	worst interference, Ftl. PD only 8 miles away

Nextel signal level = -25dbm

Conclusions

Several conclusions can be drawn from these tests, some of which are not obvious by looking at the data:

- 1) The 80db receiver architecture is a large improvement over the unmodified radios.

- 2) The difference between the three different 80db designs is small.
- 3) The radio with the SAW filters is an improvement in some cases, but offers no improvement in others. This radio also exhibits better IM and receive sensitivity than the unmodified radio. These two factors alone could explain the improved operation.
- 4) The interference on the higher frequencies (tests 15 - 20) at the Hiatus Road site is of a repetitive nature with about a 1.5 Hz rate. It sounds like some sort of a beat note. This can be heard as a variation in quieting (mild interference) or a buzzing sound that comes and goes at a 1.5 Hz rate (severe interference). The buzzing sound was less objectionable on Radio #5.
- 5) In the extreme case (test 20) the Fort Lauderdale police system, which is only 8 miles away, could not be detected on the unmodified radio in any position. It could sometimes be heard when standing with the towers behind me. The signal was understandable most of the time on radio #2, but could not be relied on. This system was full quieting on radio #5 when facing the tower and noise was only heard on #3 and #4 at the interference peaks. The interference to this channel must be generated inside the radio. Here an 80db radio is necessary for reliable reception. It does not matter which one.
- 6) There are cases (tests 12, 15 and 17) where the 80db radios offer some improvement but the signals were still not usable. In these cases turning around and facing away from the towers (tests 13, 16 and 18) while holding the radios at chest level made the signals readable. The interference to these channels must be primarily generated external to the radio and cannot be cured with a 100db radio. It should be noted that these channels are the closest ones to the majority of Nextel's frequencies (862 to 864MHz).
- 7) Results are NOT always repeatable. The interference generated from this site must vary depending upon cell phone usage and system loading. I have been back to the Hiatus Road location with radios (#1 and #5) in hand twice since this testing was done and there is always some interference present but the frequencies that get blasted change every time. Radio #5 has always been clearly superior to radio #1. The Nextel signal level has always been between -24 and -27dbm.
- 8) It has been suggested that Nextel alone is not responsible for the interference, that the interference is worse when other cellular operators are present. This is shown to be true in test #2. When the tower occupied by AT&T (and 2 others) is blocked by the building (Nextel still visible) the interference is reduced.

Further Testing

At this time activities on the 80db receiver have concluded. There are many other projects that take priority. If time permits, or if other personnel become involved, I would like to suggest the following experiments:

- 1) A portable spectrum analyzer and a directional antenna be brought to the site. This is a challenge at the Hiatus Road location, since no electricity is available and all equipment must be carried across a busy four-lane road. Power is available at the other locations.
- 2) If the logistics can be overcome a VSA (89441 or 89600) would be invaluable in determining if the external interference was due to sideband noise from Nextel.
- 3) If an 89600 (or possibly an 89441) can be brought to the site a sample of the entire 800MHz band and the cellular A and B bands can be acquired and later used in the lab (in an ESG) to recreate the test conditions.
- 4) The schottky diode in the front end be removed in an otherwise unmodified XTS5000. The radio should then be compared to an XTS5000 at the site. There is so much RF energy present at the Hiatus Road location that the diode may become a mixer.

If further testing takes place the results will be added to this report.