

**VIR JAMES P. C.**  
**TIMOTHY C. CUTFORTH P.E., DIRECTOR OF ENGINEERING**  
**BROADCAST ENGINEERING CONSULTANTS**  
965 S. IRVING ST. · DENVER, CO · 80219  
(303) 937-1900

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EMERGENCY REPAIR

## EXECUTIVE SUMMARY

In order to determine the suitability of the Squaw Mountain Communications Inc. site (Squaw Mountain) for Digital Television Broadcasting, a low power DTV transmitter was constructed on Channel 38 at Squaw Mountain under FCC Special Temporary Authority, and DTV reception from this site was measured over the Denver Metro Area and beyond.

Measurements were made over the whole market area from Parker to Greeley and in Jefferson County from Jeffco Airport to Roxborough Park and back into the mountain communities. The Squaw Mountain DTV signal was there even in most of the deep shadows. The data showed that even a low power DTV transmitter at Squaw Mountain (only 2.4% of the allowable DTV power) was amazingly adequate, providing a useable signal over virtually all of the Denver Metro Area and beyond, including shadowed areas of Jefferson County. Very few isolated locations were found where the shadow was not filled by the main DTV signal so as to even require an On-Channel Booster.

Based on the signal margins observed, a full power DTV facility operated from Squaw Mountain would provide indoor reception in most all Denver market locations with common indoor antennas. Indoor reception measurements generally found rather small differences in signal strength from outdoor measurements. Worst-case difference between indoor and outdoor measurement was 17 dB. The average attenuation for indoor versus outdoor was only 2 dB, and in some cases the indoor signal exceeded the outdoor signal. Overall, indoor reception did not seem at all difficult with a common inexpensive Radio Shack indoor antenna.

Reception in shadowed areas was found to be significantly better than previous computed coverage studies would lead one to expect. Only a few locations were found where no significant signal existed. A few locations were found where the signal was below the threshold of reception with our low power transmitter, but by an amount that would be expected to result in reception when a full power DTV facility is constructed. Receive locations with Line-of-Sight were universally found to have good DTV signal reception. Based on the many measurement locations in this study, most non Line-of-Sight locations will have useable DTV signals even where multiple obstructions exist.

## ON-CHANNEL BOOSTER TEST

In order to demonstrate the feasibility of filling in deeply shadowed areas such as Boulder, a second Special Temporary Authorization was obtained from the FCC and an On-Channel DTV Booster repeater was constructed and tested in Boulder. The Boulder Booster tests demonstrated the practicality of filling in significant shadows wherever they might occur.

## OTHER CONSIDERATIONS

Multipath was not found to be a problem from Squaw Mountain. Although multipath reflections are considered by broadcasters to be a serious problem in shadowed areas, the data gathered in these measurements found few locations where multipath reflections were significant at all. Practically all of the multipath observed was due to objects near the receive site and had no obvious relation to the transmitter site being observed. The highest multipath reflection at most measurement locations was more than 15 dB lower than the desired DTV signal.

The aiming of the antenna will not be critical for reception of DTV signals originating at Squaw Mountain. Observations were made at each measurement location as to the useable arc of reception for the antenna. Most were useable over a wide arc of 60 degrees or more.

This summary is the condensed version of the 1500+ pages of data and analysis from the Squaw Mountain DTV and Boulder On-Channel Booster tests.

## CONCLUSION

With the addition of an On-Channel DTV Booster to fill in Boulder, any full power DTV facility on Squaw Mountain would provide a useable DTV signal over more than 98% of all of the population in the market area.

Respectfully,

Timothy C. Cutforth P.E.  
30 October 2002

## MEASUREMENT PROCEDURES

Exhaustive data was gathered at 200+ locations in and around the Denver Metro Area, including received signal power, multipath characteristics and more. The reception results are shown on the map in the front pocket of this report, and the technical data can be found in the spreadsheets and the appendixes of the full report.

A measurement grid was selected that would provide a good sampling of the coverage over the Denver Metro area. Due to the expressed concern about shadowing on the west edge of the metro area, additional measurements were made along the west side of the grid to further define the extent and importance of shadowing in DTV reception. Exact measurement locations were dictated by space availability near a desired grid point where a measurement van and another vehicle could stop safely to accomplish the measurements. An assortment of outlying locations was also sampled.

Observations were made with typical home style outdoor antennas at 6ft height representative of set top receiving conditions and at 15 ft height representative of typical rooftop antenna mounting on a single story dwelling. Additional observations were also made using a simple dipole at 6 to 10 ft height and indoor observations were made using an industry standard double bowtie set top antenna. Based on the signal margins observed, a full power DTV facility operated from Squaw Mountain should provide useable signals in most Denver market locations and beyond with simple indoor antennas.

Despite the lack of on channel and adjacent channel facilities listed in the FCC database it was found that several translators authorized to move to new channels in this area were still operating on Channel 38. Because of this it was necessary to coordinate with the operators to shut off their Channel 38 translator operation for a short time so that measurements of the Channel 38 DTV signal could be accomplished in each affected area. Practically, no measurements were possible in the affected areas when the translators were on air. For instance, the translator operating on Channel 38 in Boulder was shut off only on one day for testing the main DTV signal and for two days to test the DTV on-channel Booster for the Boulder area.

Without the excellent test equipment we might have assumed that no DTV reception was possible in each area having an unexpected translator when in fact the limit was interference from that unexpected source.

Because of this unforeseen interference, reception tests made by others of the Squaw Mountain DTV demonstration signal may have been unsuccessful when the signal was in fact quite adequate for normal reception.

At each measurement location the antenna was raised and aimed for maximum signal. There were only two or three locations where the greatest signal was from a reflection rather than from the direction of Squaw Mountain. The antenna was then rotated until the Samsung set lost lock to determine the antenna arc of reception and this arc was recorded. Then the antenna was reset to the peak signal and the signal data printouts were printed from the Rohde & Schwarz analyzer along with the graphs of the reflection data and the spectrum analyzer response. The attenuator was set to provide the preferred  $-50$  dBm signal to the Zenith PRO-DEMODO receiver and the tap energy file was downloaded for printout. All data was referenced by measurement location number. The threshold of viewing (TOV) was determined by attenuating the signal until each receiver lost lock, and then recording the attenuator setting. The Hewlett Packard precision attenuators facilitated accurate attenuation calibrated to one dB.

At each measurement location the RCA receiver was connected to a consumer Yagi antenna which was handheld at about the 6 to 8 ft level above ground. The RCA receiver computes a convenient quality number for the signal which is related to signal strength and other factors not revealed in the owners manual. This number was recorded in our data also. A perfect picture accompanied any quality number of 34 or higher and the highest number ever observed was 94.

When all data had been recorded, all of the measurement data sheets for that location were clipped together and placed in an individual folder for later analysis and the measurement van and the Suburban were driven to the next site.

At each site the DTV picture was viewed on the Samsung and RCA receivers and the audio listened to. Overall the picture was perfect as was the audio whenever the receivers were locked and even 1 dB above threshold.

Indoor measurements were made at some locations where convenient access to the house was available. The measurement van was parked adjacent to the house and a cable was run into the house. An industry standard double bowtie style antenna was taken into a room where an existing analog TV receiver was and the antenna moved around near the TV to pick the best orientation near the TV set. Then a full set of measurements were made on the signal strength and quality of the signal as was done for a normal outdoor van test. The measurement locations where indoor measurements were made are circled with a black outline on the on the location map.

Normally the indoor measurement was given the next location number in sequence from the outdoor measurement at the same location.

## **EQUIPMENT**

The test transmitter facility was assembled from the latest broadcast equipment supplied by equipment manufacturers. Likewise much of the sophisticated cutting edge test equipment installed in the test van was graciously supplied by manufacturers. See the full list of acknowledgements in the appendix. Without this excellent equipment these measurements could not have been accomplished in a timely fashion or in this level of detail. See the attached block diagrams of the DTV test transmitter, reception test instrumentation, and the On-Channel Booster.

The MCI transmit antenna was installed on an existing tower at Squaw Mountain. The Zenith exciter provided a digitally recorded demonstration program. The LARCAN MX1000 amplifier increased the power to 500 Watts. The transmitting equipment was installed in a building at the base of the tower. The digital transmission equipment operated flawlessly throughout the measurements and the on air digital signal quality was excellent.

## **RECEIVE TEST INSTRUMENTATION**

Four receivers were used in the test instrumentation. A Samsung SIR-T150 set top converter in the test van as well as an RCA F38310 DTV traveling in a separate vehicle allowed testing with typical consumer receivers. A Zenith PRO DEMOD and a Rohde & Schwarz EFA Television Test Receiver allowed collection and display of the technical parameters of the received signal. An Agilent 4407B spectrum analyzer allowed easy orientation of the test van receive antenna for maximum signal. The Zenith PRO DEMOD allowed the collection of S/N ratios both before and after processing, as well as capture of the equalizer tap energies. This data was logged using a laptop computer connected to the Zenith PRO DEMOD output. The Rohde & Schwarz EFA 53 allowed the display and printing of modulation error ratio, bit error ratio and segment error ratio as well as total signal power within the 6 MHz transmission bandwidth. During the On-Channel Booster tests, the precision frequency readout of the EFA 53 allowed us to determine whether the signal we were receiving was coming directly from the main transmitter on Squaw Mountain or from the booster, as the pilot offset frequencies for the two signals were slightly different. We observed no areas where the main signal and booster signals interfered with each other to cause loss of reception.

The three receivers and the spectrum analyzer in the test van were fed from the same antenna (Radio Shack 15-2160 Yagi) mounted 15 feet above the ground. The input signal passed through an input attenuator and bandpass filter before being amplified and split to the individual receivers. The input attenuator was used to obtain the receive margin. The bandpass filter (TOKO TK3308 tuned to 614-620 MHz) was necessary to avoid intermodulation distortion in the following broadband amplifiers due to high signal levels from high power broadcast transmitters. While the filter added 2.2 db to the noise figure of our test system, it made possible measurements that otherwise could not have been made in the presence of interfering signals that sometimes were more than 50 dB higher than the desired signal.

The complete list of equipment used in the project is attached. The performance of each piece of equipment and/or cable was individually measured and/or verified.

## ANALYSIS AND FINDINGS

A terrain profile was drawn for each receive location to determine whether there was Line-of-Sight to each location. A large number of locations measured were obstructed paths. Even so a majority of the obstructed locations had a good receive margin even at the low power of our test transmitter facility. Only locations very close behind a steep escarpment were found to have no measurable signal. With 16 dB of additional signal available to a full power DTV facility it is very likely that most of the measurement locations with a measurable signal will be able to receive a useable DTV signal from Squaw Mountain.

Multipath due to moving vehicles was only significant in a couple of isolated locations. It is unlikely that any DTV viewer will locate his receive antenna on the right of way for a heavily traveled street as was sometimes necessary for parking the measurement van.

Although it was not an official measurement location, DTV reception was found to be possible on the street in front of the Channel 50 studios with two very large multi-story buildings blocking the path. Official measurement locations were generally selected to be near residences where possible since most TV viewing takes place in the home.

Some concern has been expressed over the possibility that DTV transmitters might end up spread between several different sites, causing viewer inconvenience when “channel surfing” by requiring constant antenna reorientation. Observations were made at each measurement location as to the useable arc of reception for the antenna. Most were useable over a wide arc of 60 degrees or more, indicating that in actual usage the aiming

of the antenna will not be critical for reception of DTV signals originating at Squaw Mountain. At most locations it should be practical to watch DTV signals from multiple mountain sites without rotating the antenna. There is also the possibility that the majority of DTV facilities (or perhaps all of them) may chose to locate at Squaw Mountain, which would eliminate this as a concern.

## ON-CHANNEL DTV BOOSTER TEST

Because of the mountainous terrain bordering the West side of the populated section of the Denver area, there are some areas that are deeply shadowed from any given transmitter site. The City of Boulder is one of those areas with deep shadows from nearly all existing TV full power transmitter sites. Therefore it was determined that a demonstration of the technology to fill in deep shadows with an On-Channel DTV Booster would be valuable. A second Special Temporary Authority was obtained from the FCC to allow retransmission of the low power DTV Channel 38 test signal from Squaw Mountain into Boulder from a conveniently available location on Davidson Mesa adjacent to Highway 36 overlooking the Boulder valley.

While making preliminary measurements of the reception characteristics at the Boulder booster site, reception of the DTV signal from Squaw Mountain was found to be impossible due to a large interfering signal from an NTSC (Analog) translator operating on our channel. This station (a Boulder translator for a station on Mount Morrison) had been authorized to move to another channel, but had not yet done so. Arrangements were made with the operators of this translator to turn off their signal during the times we were testing.

Equipment was obtained that could receive the Channel 38 over the air DTV signal, regenerate the data, and retransmit it on Channel 38 at a low power level (8 watts transmitter power, 50 watts ERP). Direct over the air receive of the main DTV signal was chosen due to the availability of equipment and because of the short time available for testing. With the assistance of Kent Parsons, a TV Booster expert from the University of Utah, the On-Channel Booster was assembled and functional in one half day.

A block diagram of the On-Channel Booster is provided at the back of this report. A special antenna mount was fashioned to stack four Radio Shack Yagi type receive antennas into a gain array with good rejection in the direction of the Booster transmit antenna. The receive antenna was aimed for the maximum received DTV signal from the Squaw Mountain site. The signal was sent to a Zenith Trans-coder, a PSIP enhanced VSB translator which received and decoded the DTV signal and remodulated it at an IF frequency. The IF output from the Zenith Transcoder was fed into 1100 ft of RG6 cable

that carried the DTV signal down to the transmitter which was located adjacent to the transmit antenna. The IF signal was upconverted to Channel 38 and amplified to 8 Watts by the Larcant-TTC MX20 amplifier. The Channel 38 signal was fed to a Scala Log Periodic antenna model 1469. The resulting 50 Watts ERP aimed just North of the center of Boulder was received over a wide area. The transmit power was essentially limited by regeneration effects. The interference potential and the "RF HAZARD" potential are both insignificant for facilities at this level.

In order to properly decode the received signal, the booster receiver requires at least 15 dB more received power from the main transmitter than it receives as feedback from the Booster transmitter. Due to the low power transmitted from the main transmitter on Squaw Mountain, high isolation was required at the Booster. This isolation was achieved by designing the receive antenna array to have a null in the direction of the booster transmit antenna and by moving the booster transmit antenna away and down from the receive antenna and by limiting the transmitted power.

Terrain shielding between the receive antenna and the transmit antenna set the absolute limits for an over the air On-Channel Booster repeater. A higher DTV transmit power at the main site would allow a higher transmit power at the Booster site. A power increase to normal full power at the Squaw Mountain site would allow about 16 dB of power increase at the Booster even with a simple installation like this. While this test configuration still resulted in adequate coverage of the Boulder area, Kent Parsons has noted that the isolation problem can be completely eliminated by delivering the signal to the booster site via a microwave link or with fiber optics. This would allow optimal placement of the transmitting antenna, and also would not limit the ERP of the booster transmitter. Using this configuration, a booster can inexpensively be made to provide superb coverage of extensive shadowed areas. The On-Channel Booster test locations start with number 200 and higher.

The low 50 Watt power level achieved for this test provided service to about 90 percent of Boulder. Because of the directionality of the transmit antenna and the relatively low power, no interference zone between the main and the Booster signal was observable. Clearly a broader antenna pattern and a higher ERP would be useable for any permanent On-Channel Booster at Boulder and such a Booster should reach 98% or more of Boulder as well as areas to the north of Boulder.

Signal measurements at multiple locations found that the signals from full power DTV Channel 32 on Lookout Mountain and the UHF full power analog stations on Lookout Mountain and Mount Morrison are rather low in level and reception is spotty in Boulder.

The FCC has currently authorized several On-Channel Boosters to fill in DTV coverage in different parts of the country as either experimental or STA operations. The FCC rules will be catching up with the technology soon, and demonstrations such as this one will help drive the FCC process.

It is likely that the shadow over Boulder is the only gap in coverage large enough to justify a Booster in the Denver Market. Although there are other small shadowed areas the total population in any one shadow area is quite small and will probably not justify construction of a Booster system.

## CONCLUSIONS

- ❑ A low power DTV test transmitter on Squaw Mountain covered a very high percentage of the Denver Metro Area and beyond, including the shadowed areas of Jefferson County.
- ❑ DTV reception in areas with non-Line-of-Sight paths from Squaw Mountain is very likely except in the most extreme locations.
- ❑ A full power DTV facility on Squaw will cover virtually all of the Denver Metro Area and beyond except for Boulder.
- ❑ Multipath is not a significant problem for DTV reception from Squaw Mountain.
- ❑ Shadowed areas that were found to have little or no signal (other than Boulder) contain very little population.
- ❑ Indoor reception of DTV signals from Squaw Mountain will be achievable with commonly available inexpensive indoor antennas at most locations.
- ❑ Antenna aiming will not be critical in most locations for DTV reception from Squaw Mountain.
- ❑ The maximum successful reception distance was not determined since driving to the edge of useable coverage required excessive travel time otherwise needed to document the close in shadow areas. Even the low power DTV test signal from Squaw Mountain went well beyond the populated market area. Signal strengths were well above margin at our farthest measurement location at 74 miles.
- ❑ A successful DTV facility can be rapidly deployed on Squaw Mountain with limited expenditure.
- ❑ The Boulder DTV On-Channel Booster demonstration showed that pockets of deep shadowing can be filled as desired.
- ❑ A DTV On-Channel Booster can be constructed rapidly and successfully to fill in important shadow areas such as Boulder.

## CONCLUSIONS

Continued

- The FCC is open to authorize On-Channel Boosters as either Special Temporary Authority or as Experimental Authorizations to further the technology of Digital Broadcasting and to provide enhanced DTV service to the public.
- A low power DTV On-Channel Booster was shown to cover most of Boulder.
- Squaw Mountain is in fact a suitable site for Broadcast DTV service for the Denver Metro Area and beyond.