Application Note
AN-7b

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TV Propagation & Multi-Path Effects

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Note: The original AN-7 was written in 2011 and the cable TV modulation method of 64-QAM was used for digital TV. Since then, the author has discovered the European Digital Video Broadcast - Terrestrial, DVB-T, modulation scheme. It has been found to be far superior for over-the-air transmissions than CATV 64-QAM, particularly in terms of receiver sensitivity and tolerance of multi-path. The reader of this app. note is also encouraged to read about DVB-T in application note, AN-17.

I am often asked the question by other hams. "How far can a ham TV signal go ?" My typical response is "Line-of-Sight". If you can see the other location, chances are you can get a TV signal to it. This has been borne out by many years of experience in ham TV. As opposed to very high power TV broadcast stations, hams are running low power (1 W to 100 W max) and our signals don't have the oomph to get much energy over and around path obstacles.

For line of sight propagation, there also becomes the question of "Where is the radio horizon ?" If we lived on a flat earth, the answer would be infinity. Because we live on a spherical earth (radius = 6370 km), the curvature of the earth limits our horizon. The line of sight horizon is set by pure geometry. Note this may not be your personal optical line of sight set by the resolution of your eyes.

distance (km) $\approx$ 3.57 * $\sqrt{\text{height (m)}}$ distance (miles) $\approx$ 1.23 * $\sqrt{\text{height (ft)}}$

The radio horizon is actually a bit further than the geometrical horizon. The refractive effects of the atmosphere cause a bit of bending in the radio waves and will push them typically about 15% further..

RF distance (km) $\approx$ 4.12 * $\sqrt{\text{height (m)}}$ RF distance (miles) $\approx$ 1.41 * $\sqrt{\text{height (ft)}}$

However, these atmospheric effects are totally dependent upon local weather conditions. In extreme cases, strong ducting might occur sending our RF waves far beyond the predicted RF horizon, while severe local storms might drop it back dramatically.

A few quick examples are: 6' => 3.5 miles, 30' => 7.7 miles, 100' => 14 miles, 1000 ft => 45 miles Adding antenna height at the receive site, we add the numbers for the two heights. For example transmitting from an automobile with an antenna height of 6ft.to a remote base station with the antenna on a 30 ft. tower, the radio horizon = 3.5 + 7.7 = 11.2 miles Obviously either putting up a higher tower or finding a high hill or mountain top works wonders. But of course, this is not news to us hams !

So after determining our radio horizon, the next issue to contend with is RF Path Loss. Path loss is the natural phenomena of radiating a certain amount of power but this power, again due to spherical geometry, gets spread equally over an ever expanding globe as it propagates away from the source. Thus the power density in watts / m^2 gets much smaller the further we get from the source. The formula for path loss is:

RF Path Loss(dB) = 20 * log10 (f in MHz) + 20 *log10(D in Miles) + 36.6dB

Note in this equation the frequency dependency, For example, going from 70cm to 23cm bands we suffer about a 10 dB hit in path loss. A few quick calculations will give you an appreciation of the importance of path loss. As an example, for the 70cm band (430 MHz) we get: 0.1 mile => 69dB, 1 mile => 89dB, 10 miles => 109dB, etc.

To determine the best case situation for a particular rf path we need to include all of the major rf components. Calculations are done easiest in dB with power levels expressed in dBm and antenna gains expressed in dBi. To determine the power input into the distant receiver, we need to know:

Rcvr Pwr(dBm) = Trans Pwr (dBm) - Trans Cable Loss (dB) + Tran Ant Gain (dBi)
-RF Path Loss (dB) + Rcv Ant Gain (dBi) - Rcv Cable Loss (dB)

An excellent, on-line, RF Link Budget Calculator is available to calculate your systems performance using the above equation. It also includes a look up table to determine your coax cable loss. It is found at: http://www.afar.net/rf-link-budget-calculator/

As an example using this calculator, let's enter the parameters of a typical 70cm ham TV station:

Transmitter Power = 5 watts (+37dBm) Cable Loss = 1.5dB each end
Yaggi Antenna Gain = 10dBi each end
Desired Receiver Power = -83dBm
(2 dB above threshold for P5, 64-QAM or 12 dB s/n, P2 for VUSB)

The calculator gives the answer of 250 miles for pure, unobstructed line of sight path for a 0 dB fade margin. For a 15 dB fade margin, this is cut back to 44 miles. The theoretical results really only apply for outer space applications. In the real, terrestrial world, we encounter a lot of other obstacles. In the fall of 2011, I and several other Boulder area TV hams ran a set of TV propagation field trials. See Application Note, AN-3 for details. We made measurements of the actual received signal strength in dBm. One observation that stood out was "Over very clear, line-of-sight paths, with directional antennas, where multi-path was not a major issue, the actual path loss was typically 5 to 15 dB worse than the calculated, theoretical path loss."

OBSTACLES to RF PROPAGATION The above equations were for ideal, unobstructed, line of sight situations. What can limit us in the real world ? Lots of things including: ground reflections, vegetation, tall buildings, urban building clutter, hills, ridge lines, mountains, etc. The absorption by vegetation, due to water content, goes up with increasing frequency. I have noticed a significant difference in the signal loss hitting our local TV repeater between summer and winter. When the leaves are gone from the trees between my qth and the repeater, my signal strength at the repeater, especially on 23cm significantly improves. Getting over obstructions to our line of sight path involves diffraction which can introduce considerable extra dB loss. Most of the rest of the losses result from Multi-Path. This is reflected waves from other objects which arrive at the receive site later in time and can cause standing wave patterns in the receive signal which at certain frequencies might totally null out the desired direct path signal.

RF PATH PROFILING As I said earlier, for ham TV we really need a true line-of-sight path. How can I determine if I have an unobstructed RF path ? With ***Google Earth***, http://www.google.com/earth/index.html it is extremely easy to determine your path profile. However, the resultant path profile shows you the earth's elevation along your desired path, but it does NOT tell you the elevation of any above earth obstacles, such as buildings, etc. Close, visual examination of Google Earth's aerial views along the path may disclose these obstructions.

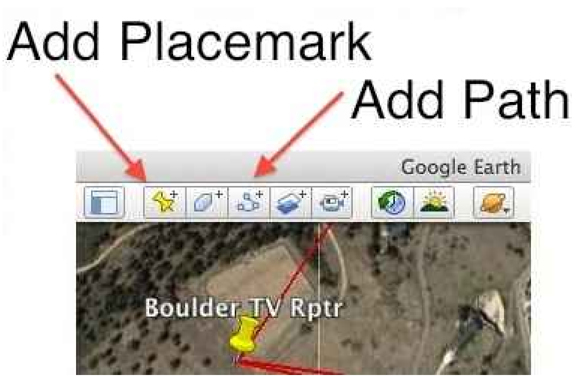


Fig. 1 Google Earth Task Bar

After you launch Google Earth, then zoom in to find your transmitter site. On the "Task Bar", Fig. 1, select "Add Placemark". With your mouse cursor, position the cross-hairs for the yellow thumbtack at your transmitter site and then give it a title. Repeat the process for your intended receiver site.

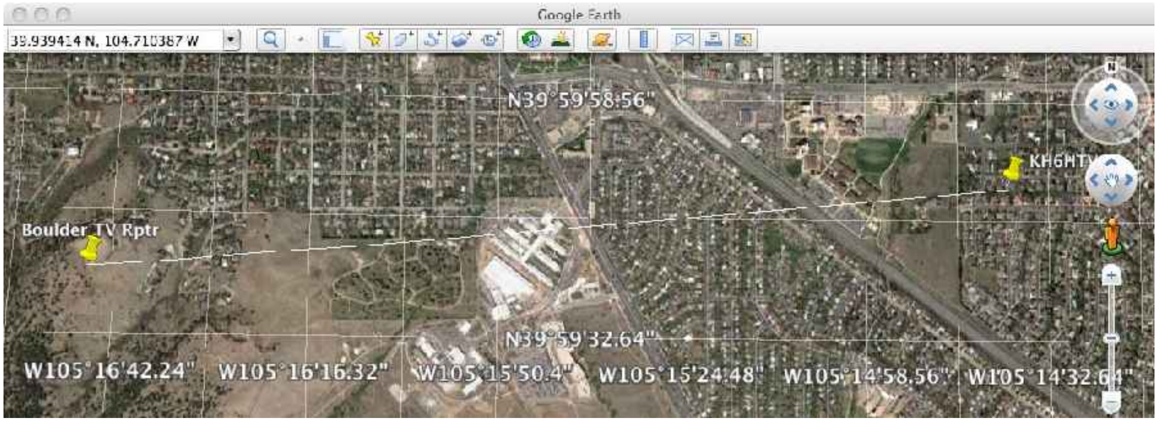
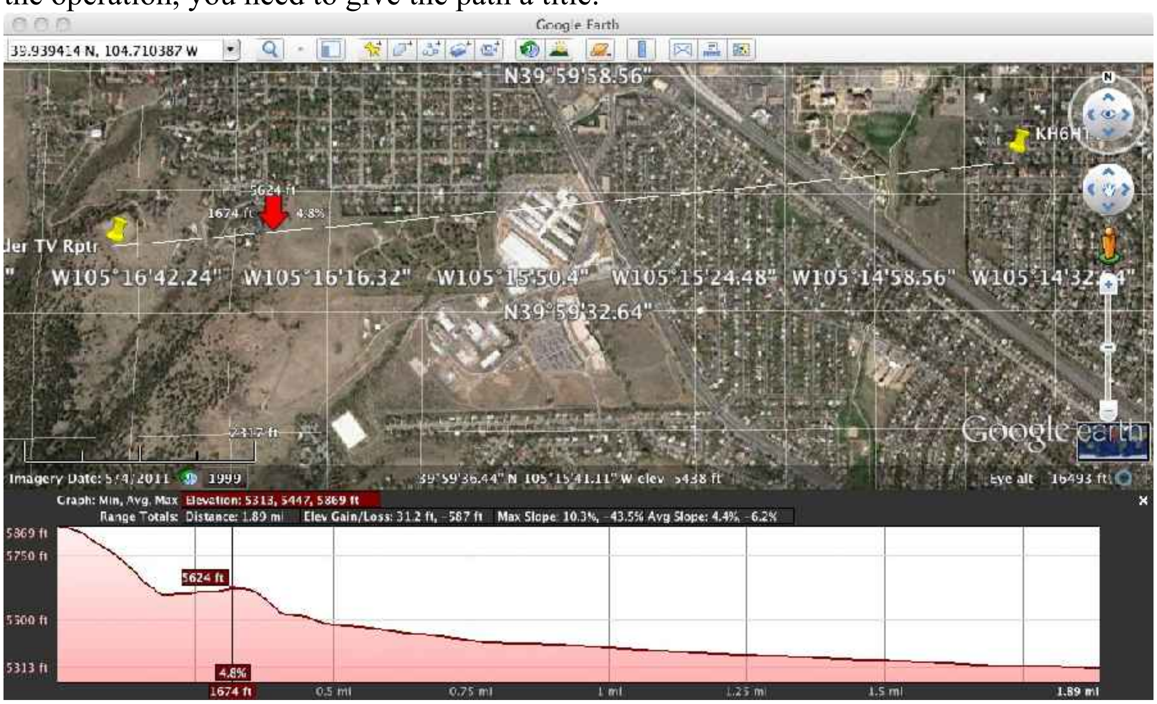


Fig. 2 Example of placing a "Path" (white line) between two placemarks.

Next on the "Task Bar", select "Add Path". Position the cursor over the transmitter site and left 'click'. Now move the second cursor to the receive site and again left 'click'. A white line will appear connecting the two points. If the receive site is a long distance away, you can unzoom the image and use the 'move' button to go in the direction of the receiver site and then again zoom into it before placing the second cursor. To complete the operation, you need to give the path a title.



.Fig. 3 Example of Google Earth Path Profiling

The next and final step is to position the 'hand' cursor over the path line and right 'click' your mouse. This brings up a new menu of choices. Select "Show Elevation Profile". Google Earth will then compute the complete elevation profile for the path from your transmitter to your receiver and display it at the bottom of the screen, Fig. 3. With your mouse you can now move the Red Arrow cursor along the path and see where the various elevations are located in the aerial view.

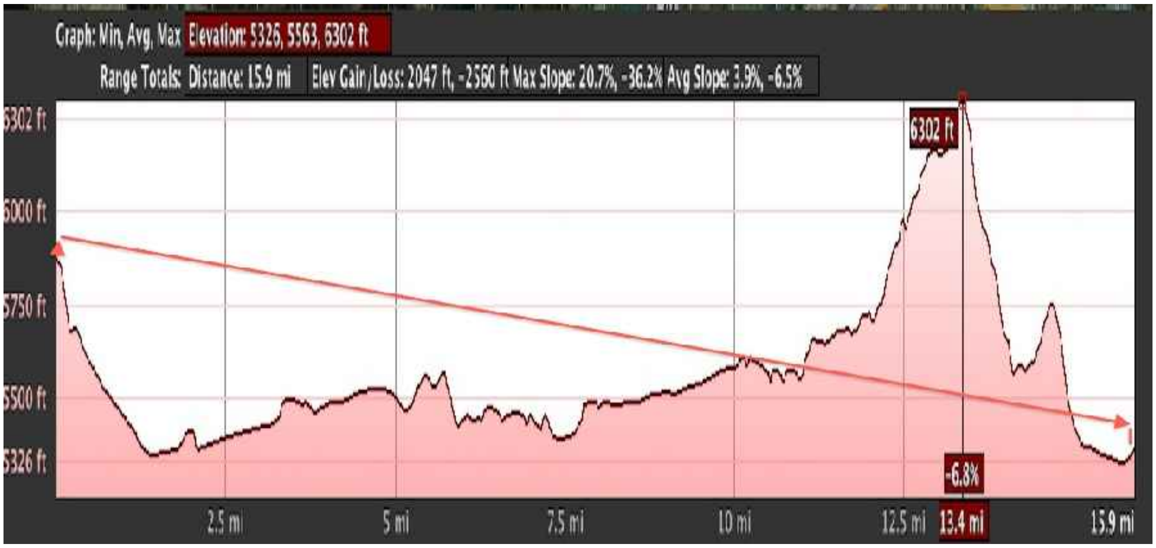


Fig. 4 Example of an impossible BAD RF path.

Fig. 5 Example of a bad path that can be corrected with tall antennas.

The example shown in Fig. 3 was for a very good, line-of-sight RF path. Ham TV works well over this path with P5 pictures. Fig. 4 shows an example of a really bad RF path over which I guarantee that you will never get a ham TV signal over. Fig. 5 however is a bad RF path that can be solved with the addition of 50 ft. antenna towers at both ends.

ANALOG TV MULTI-PATH For conventional, analog TV, either VUSB or FM we all are familiar with the visual effects of multi-path. We call it "Ghosting" when we see one or more fainter replications of the picture displayed to the right of the main image. They are displaced to the right because the image is written on the TV screen in a left to right scan and the "ghosts" are multi-path signals that have arrived at the receiver later in time. If the ghost appears to the left of the main image, then the strongest signal into the receiver is not the direct path but some alternate reflected path, while the left displaced ghost is the direct path signal It has been my experience with FM TV, that multi-path sometimes does not display itself as ghosting. Instead it seems to make the pictures fuzzier and less crisp. In severe cases, it seems to cause pixilation.

QAM - DTV PROPAGATION & MULTI-PATH A series of field tests have been run to determine how well a QAM-64 DTV signal will propagate as an over-the-air broadcast in multi-path conditions. I have been assisted in these tests by Bill McCaa, K0RZ. The best results to date have been over a 75 mile path from Cheyenne, Wyoming to Bill's qth on Davidson Mesa in Boulder, Colorado. [See Application. Note, AN-11]. For many of these tests, I was operating mobile with the 70cm, DTV transmitter in my car and using a Larsen 5/8 wave, mag mount antenna. For the tests with Bill, he observed the received signal on a commercial DTV receiver and on his HP spectrum analyzer. Bill made several interesting observations regarding what he observed on the spectrum analyzer relative to multi-path interference to the DTV signal. See Fig 6. These were all with very strong signals, of at least 20dB above the DTV receiver's threshold.

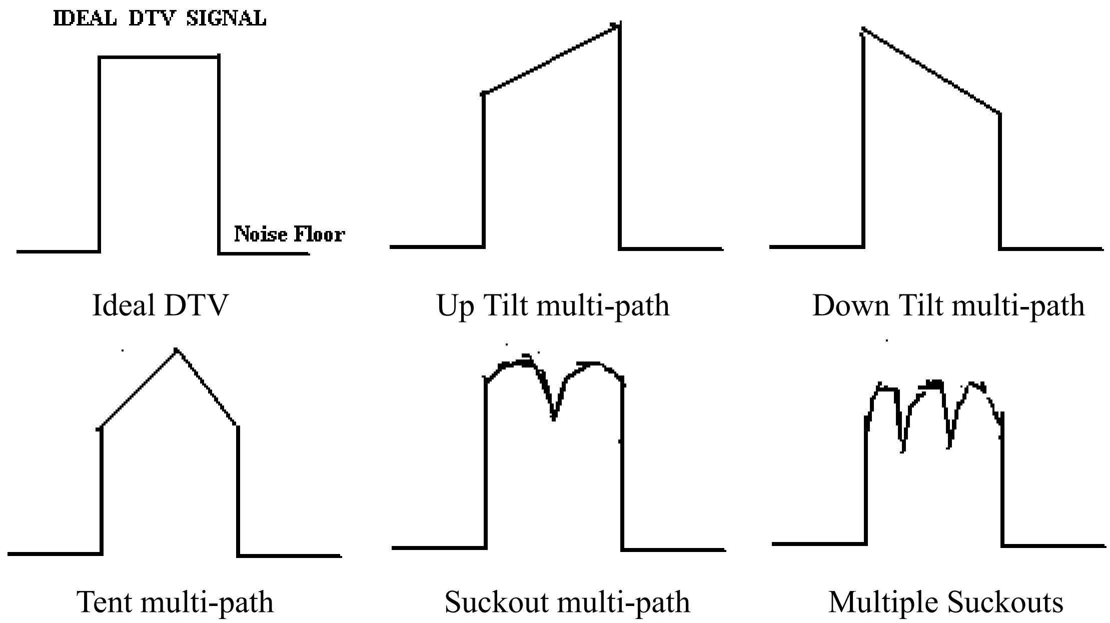


Fig. 6 Examples of various types of multi-path effects on a DTV signal spectrum.

1. With an up tilt or down tilt or tent like structure to the spectrum with tilts of up to 10 dB, the DTV receiver would still decode OK and give a P5 picture.

2. With one or more, sharp, deep, suck-out nulls in the spectrum, the DTV receiver would lock up

I also made other field tests solo, while driving around Boulder and up onto the surrounding mesas and mountain. For these I transmitted the 70cm, QAM-64 DTV signal from my home qth using an omni directional collinear antenna at 30 ft. In general, except for my immediate neighborhood, I was unable to receive the DTV signal while my car was in motion. If I stopped at stop lights, etc. I would often get a picture. at further distances. At key, good, visual line of sight locations, I would also stop and set up a yaggi antenna. The rf path distances for these sites ranged from 1.9 to 4.1 miles. At some locations, I would get a P5 picture. At other locations that also seemed to be ideal, I got nothing. It should be noted that Boulder has some very large mountains immediately to the west of the city which shoot up a couple of thousand feet above the city and act as major reflectors for multi-path. They are about 2 miles due west from my qth in the Boulder valley. From these various tests I have reached the following conclusions regarding multi-path and it's effect on receiving successfully QAM-64 DTV.

1. QAM-DTV signals are susceptible to blocking by multi-path.

2. In general, in-motion, mobile, QAM-DTV does not work. The DTV receiver takes one to two seconds typically to acquire a signal. With rapidly fluctuating signal levels and also various multi-paths, the DTV receiver has insufficient time to acquire lock. Similar effects were also noted when attempting to receive mobile ATSC-8VSB signals from the commercial Denver DTV stations on Lookout mountain. They didn't work well in a mobile environment either.

3. A true, "line-of-sight" RF path is required. Mountains, hill tops, ridge lines, large buildings, vegetation, etc. block QAM-DTV.

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4. Usually a directional, Yaggi antenna is required to minimize the multi-path interference. Sometimes, the best antenna orientation is not on 'bore-sight', but in some other direction to put the multi-path signal in a null of the antenna pattern.