TOWER TALK ON TEN GIG
(10 GHz TV TOWER REFLECTIONS)

By: Ben Lowe
K4QF

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I. INTRODUCTION

Ten GHz is normally thought of as one of those “line-of-site” bands except when operating from an elevated location, bouncing off the moon, rain scatter, or during enhanced propagation (ducting) conditions. However, it is possible to have extended range contacts at any time under normal conditions by reflecting signals from what is normally the highest structure in most locations. In many medium to large cities, and numerous smaller cities, the highest structure is usually the television transmitting towers. The TV station operators learned long ago that they can propagate the longest distance by locating their transmitting antennas on tall towers, more often than not, on top of some of the tallest hills or mountains around. Fortunately for hams, the TV stations have provided 10 GHz operators a terrific source for making those longer range contacts using relatively small antennas and low power. Contacts in the 70 to 100 mile range, or even twice that range in some circumstances, are well within reason.

This paper provides a logical method for exploiting these towers our own use. It is only necessary to go outside, scan the horizon, and find one or more of these resources given to us by the TV stations: night scans work best! In most cases, these towers are the highest metallic structures in a particular location.

II. FINDING A SUITABLE TOWER

Fortunately for many operators, finding a tower is a simple matter of looking around. This is usually sufficient for finding towers at night within 20 to 30 miles, but after that point the curvature of the Earth begins to make the problem somewhat more difficult. In a usually case, one operator will often have visual contact with a tower, but the station on the other end is well beyond visual range. Additionally, it’s very useful to be able locate unknown towers before hand when a rover or portable operation is going to take place.

There is a good approximation to determine if a tower is within the radio horizon range. The following equation gives the range to the radio horizon, based on the 4/3 ^{rds} Earth radius:

$$R\text{, miles} = \text{range to the radio horizon} = \sqrt{2*h}$$

where: R = range in miles

h = height above ground in feet

For example, if a station were located on a hill that was 1,300 ft. above sea level (ASL) had the antenna on a 100 ft. tall tower, and the valley floor was 600 ft. ASL, then the antenna has an effective height of 1300 + 100 – 600 ft. In other words, this antenna is 800 ft. above the nominal Earth elevation. Using this height in the above equation results in a radio horizon range of 40 miles out to the horizon of the Earth. Many hams routinely experience communication ranges longer than this, but the antenna elevation on the other side of the QSO must be taken into account. A similarly equipped station along a 180 deg. line on the other side of the horizon, i.e. one with an 800 ft. tall antenna, could also see the Earth out to the 40 mile range, allowing these two stations separated by 80 miles with the horizon in between would have communications line of sight. Especially on VHF and UHF, often the ranges are greater due to troposcatter or some other mode propagation which extends beyond line of sight.

If you can't see a tower or don't know if one is out there, a great website for locating a tower or to determine the characteristics of a tower is:

http://wireless2.fcc.gov/UlsApp/AsrSearch/asrRegistrationSearch.jsp

At this site, a search executed for Huntsville, Alabama for towers between 800 ft. and 1,500 in height listed four towers that met the search criteria. Clicking on the registration number for the tallest, channel 54, yields the following information in Fig. 2 for this tower.

Antenna Structure

Structure Type	TOWER - Free standing or Guyed Structure used for Communications Purposes	
Location (in NAD83 Coordinates - Convert to NAD27)		
Lat/Long	34-38-00.0 N 086-30-47.0 W	11,001 NORTH SHAWDEE DRIVE
City, State	HUNTSVILLE , AL	
Center of AM Array		
Heights (meters)		
Elevation of Site Above Mean Sea Level 446.5		Overall Height Above Ground (AGL) 391.4
Overall Height Above Mean Sea Level 837.9		Overall Height Above Ground w/o Appurtenances 378.8

Figure 1 – TV Transmitting Tower Structural Information

The base height of the tower above sea level, given as the site "Above Mean Sea Level," shows the height as 446.5 meters. This dimension can easily be derived in feet by dividing the number by 0.3048 if this is more convenient yielding 1465 ft. The tower height "Above Ground level is 391.4 meters, with an overall height of 837.9 meters or 2749 ft., rounded up to 2750 ft. With the valley floor in this area at about 600 ft. above sea level, this places the tower top some 2150 ft. above the valley; quite a height rise. Using the equation on page 4 for this height results in a viewing range of 66 miles. Coupled with the 40 miles for the station mentioned on page 4 that is located on the 1,300 ft. hill with the 100 ft. tower gives a possible range between the two locations as 106 miles. Now, if the second station is located on the other side of the TV transmitting tower, this range can be extended even further. A station similarly equipped to the first station, another 106 miles directly on the other side of the TV tower now extends the communications range beyond 200 miles assuming no obstacles as shown in Fig. 2. Granted, this is somewhat akin to using a repeater to extend the communications range, but at 10 GHz, numerous reflectors, such as rain scatter, aircraft, etc., have been used to count as valid contacts.

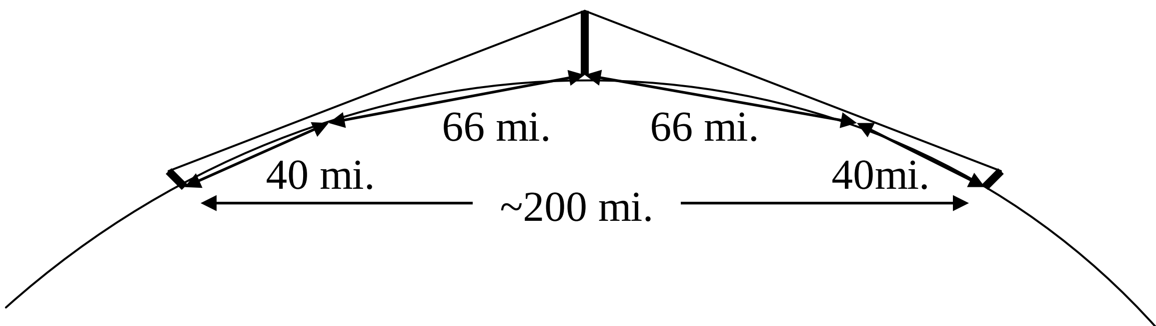

Figure 2 - TV Transmitting Tower Geometry For Typical Contacts

Another nice feature for locating TV transmitting towers is the use of the TV transmitter itself. While stations either have or are going to switch to digital transmissions, the old analog stations broadcast a very nice, stable, accurate TV picture carrier that can be used for antenna alignment. Many amateurs have long used these carriers as propagation indicators because the frequency is well know, the amplitude is constant, and the tower location is available producing a huge signal for monitoring. The picture carriers are 1.25 MHz above the lower frequency band edge for a particular channel. With digital transmission, this is going to change somewhat, but even the digital channels have a pilot tone that may serve the same purpose. This can be determined once the total switch is completed and more technical information for the digital transmissions becomes available to the public.

So, what makes a tower such a great reflector for 10 GHz? The legs of the transmitting tower are typically in the order of 4.5" to 6.0" (11.43 to 15.24 cm.) in diameter resulting in circumferences of 35.9 to 47.9 cm. With a 10 GHz wavelength of 3 cm., the circumferences, expressed in wavelengths, are 12 to 16 wavelengths. The vertical dimension of a tower leg for a 3 cm. wavelength is approaching infinity.

A round tower leg can be thought of as a spherical structure in the horizontal plane and a flat structure in the vertical plane. Since the cross member lengths are much greater than diameter of the legs, they can be considered as many, many wavelengths long for the 3 cm. wavelength signal, resulting in many reflection opportunities. The tower legs for an E-plane wave can be thought of the same as viewing a sphere. While the vertical dimension of the tower leg extends many, many wavelengths, the horizontally polarized wave probably sees only the round portion of the tower leg. For the round legs which are similar to the sphere, Fig. 3 taken from "Introduction To Radar Systems" by M.L. Skolnick shows the three reflecting regions for a sphere; the Rayleigh region, the Mie or resonance region, and the optical region. In the Mie region, resonances cause rather drastic reflection variations in the order of +/- 6 dB, but with dimensions greater than 10 wavelengths in circumference, the Optical region, the reflectivity is relatively constant determined only by the size of the sphere. In other words, above 10 wavelengths the reflectivity depends only on the apparent area of the sphere, not the wavelength! The Rayleigh region reflectivity is a different matter but not of concern here.

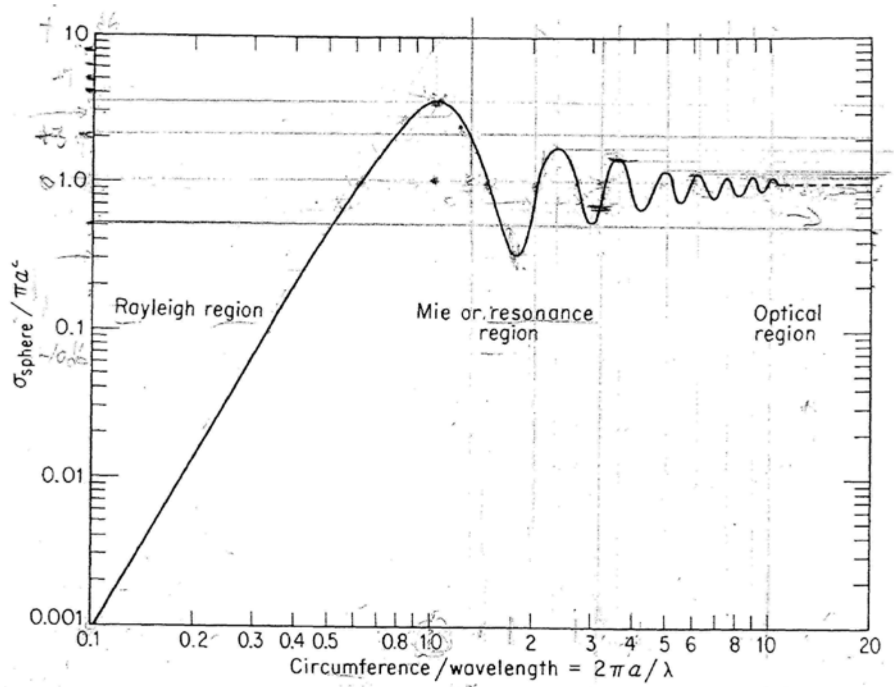

FIG. 2.10. Radar cross section of the sphere. a = radius; λ = wavelength.

Figure 3 – Radar Cross Section For a Sphere For Different Regions

The point is this. Whether the tower reflection is from the vertical members or the cross members, there are plenty of opportunities for good reflections.

Another issue is the bi-static angle between stations on each end of the link with the path to the tower; i.e. the angle between the path from station A to the tower and the tower to station B. Fig. 4, taken from “The Scattering and Diffraction of Waves” by King and Wu, gives the reflection variation from spheres, analogous here to the round tower member, for bi-station angles.

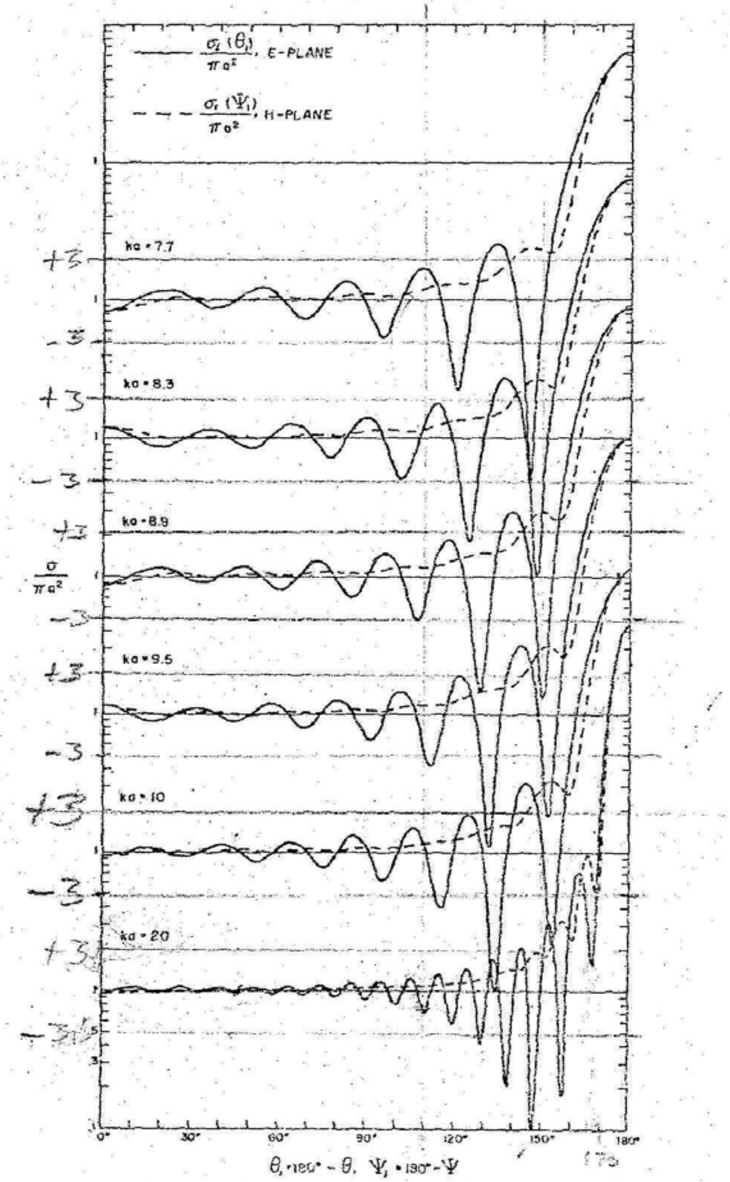

Fig. 68c. Same as Fig. 68a, for different values of ka.

Figure 4 – Scattering Variation For Bi-static Angles

With the tower leg circumferences of 12 to 16 wavelengths, shown as “ka” in the plots, only the bottom two plots are significant where ka = 10 and ka = 20. For these plots, the reflectivity null is within 3 dB except for relatively sharp angles around 130 deg. 150 deg. where the reflectivity can be degraded about 10 dB. Of course, as might be expected, at 180 degrees, the reflectivity can be enhanced by 20 dB to almost 30 dB indicating that both stations should have the best signal when they are both on the same angular heading from the TV tower. However, even when one station is at those least favorable angles, 130 and 150 degrees, there are plenty of opportunities for reflections from the horizontal members of the tower.

$$\cos \alpha = (b^2 + c^2 - a^2)/(2*b*c)$$

$$\cos \alpha_1 = (b^2 + c^2 - a^2)/(2*b*c)$$
$$\cos \alpha_1 = (57.1^2 + 25.5^2 - 75^2)/(2*57.1*25.5)$$
$$\alpha_1 = 129.5\,°$$

$$\cos \alpha_2 = (b^2 + c^2 - a^2)/(2*b*c)$$
$$\cos \alpha_2 = (57.1^2 + 24^2 - 54^2)/(2*24*57.1)$$
$$\alpha_2 = 70.3\,°$$

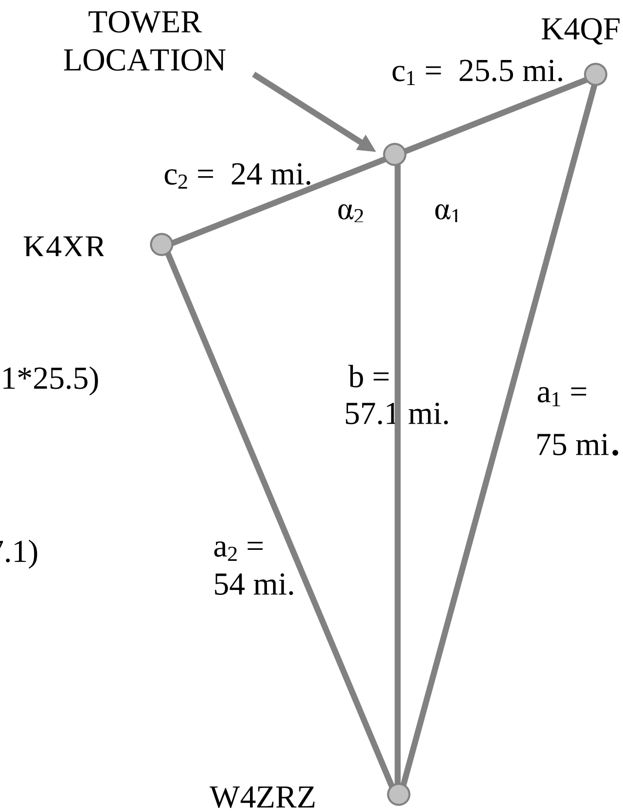

Figure 5 - Geometry For Tower Contacts

The point is this. It is critical to have both horizontal and vertical control of the antenna angular position in order to find the "hot spot" on a TV tower as the signals reflecting from the tower can come from many scattering surfaces on the tower. With 10 GHz antenna beamwidths on the order of 1 to 3 degrees, it's easily possible that not the entire TV tower that is nearby is illuminated by the beamwidth of an antenna.

TOWER SCATTERING CHARACTERISTICS

Tower scattering characteristics from typical TV transmitting towers are listed on the following below and on the following page.

- Typical tower leg diameters are 4.5 to 6 in., resulting in circumferences of 12 λ to 16 λ. Tower cross members are many, many wavelengths.

- Tower legs can scatter at any angle. Cross members are probably more directive.
- No known data is available for TV tower modeling.
- For ka (circumference in wavelengths) = 10 λ, scattering curves show sharp, but deep, nulls at 135° and 155°. Nulls appear to be about 5° wide and are ~10 and 6 dB.
- Angle from W4ZRZ to tower to K4XR is 70.3 ° with very little effect on reflectivity of tower.
- Angle from W4ZRZ to tower to K4QF is 129.5 °; could have significant effect.

Using the Bistatic Radar Range Equation, Equa. 1, where the radar transmitter and radar receiver are not co-located, gives an idea of what signal levels to expect.

BISTATIC RADAR RANGE EQUATION:

$Pr = (GrGtPt\sigma_b\lambda^2)/((4\pi 3)R_1*R_2)$ Equa. 1

Expressing all terms in meters and taking 10 log of each to get signals in dBm's yields:

$Pr = Gr + Gt + Pt + \sigma_b + \lambda^2 – 33\ dB - 20log(R_1) - 20Log(R_2)$

$Gr=Gt=37$ dB, $Pt=+39$ dBm, $\sigma_b=-36.1$ dBsm, $\lambda^2=-30.8$ dB, $R_1=57$ mi, $R_2=25$ mi.

Pr = 37dB + 37dB + 39dBm - 36.1dBsm - 30.8dB – 33 dB - 99.3dB - 92.3dB = -178.5 dBm + tower gain

Fig. 6 shows the E-plane and H-plane illumination of a sphere. Since the electrical field is horizontal, i.e. horizontal polarization, the sphere is illuminated as shown.

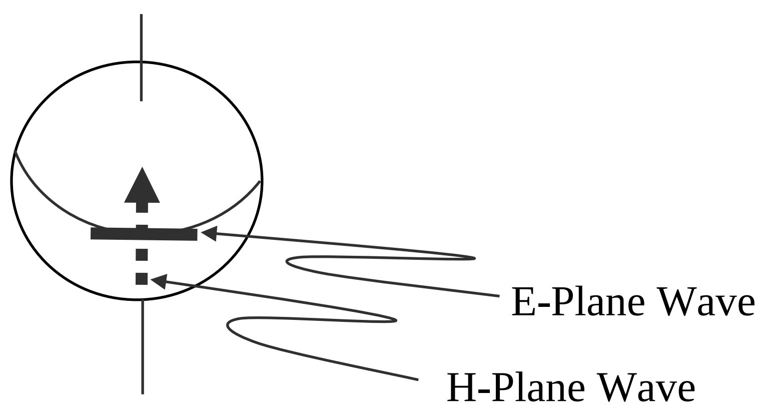

Figure 6 - Horizontal Illumination of Sphere

Viewing from the top of the sphere, the point exactly opposite from the point of illumination at 180 degrees around the sphere is the point where surface currents all add in phase and at the same amplitude as shown in Fig. 7 below.

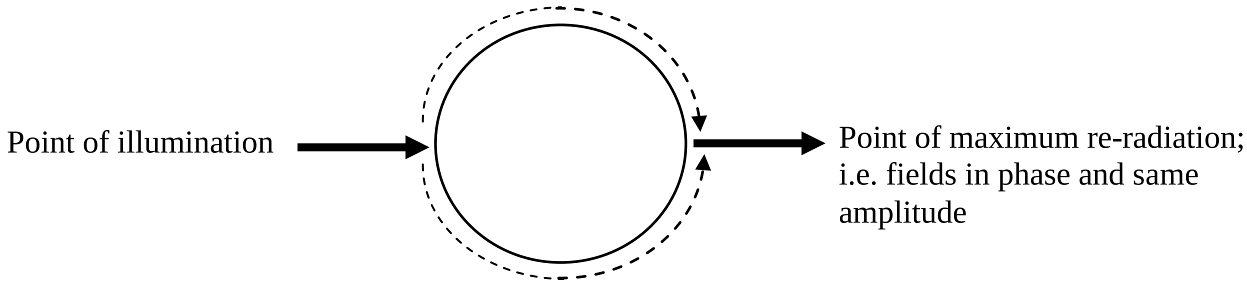

Figure 7 - Surface Current Distribution Around A Sphere

Moving the sphere vertically generates a cylinder, or, another way to view this is that a vertical cylinder such as a tower leg is essentially a stack of spheres. This concept is depicted below in Fig. 8 for typical TV transmitter tower leg dimensions with 50 % overlap of the spheres.

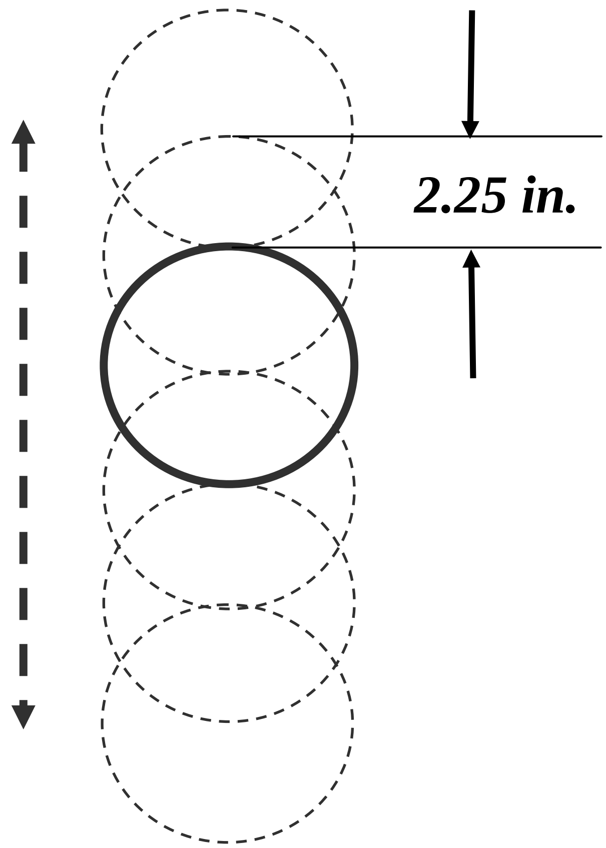

Figure 8 - Tower Leg Generation From Sphere Stacking

For a typical tower leg diameter of 4.5 in., the radar cross section of one sphere is – 36 dBsm, or 36 dB below 1 square meter, and the tower leg for 10 GHz is then 12λ.

TOWER LEG DIAMETER = 4.5 in. = 11.4 cm.

TOWER LEG CIRCUMFERENCE = 35.9 cm. = 12λ

σ_b= - 36.1 dBsm

W4ZRZ's effective height of 600 ft. places his signal at ground level at 40 mi., leaving only 17 mi. (57 – 40 mi.) to tower. Therefore, his antenna can illuminate essentially the entire 1285 ft. tower = 15420 in. as shown in Fig. 9 below.

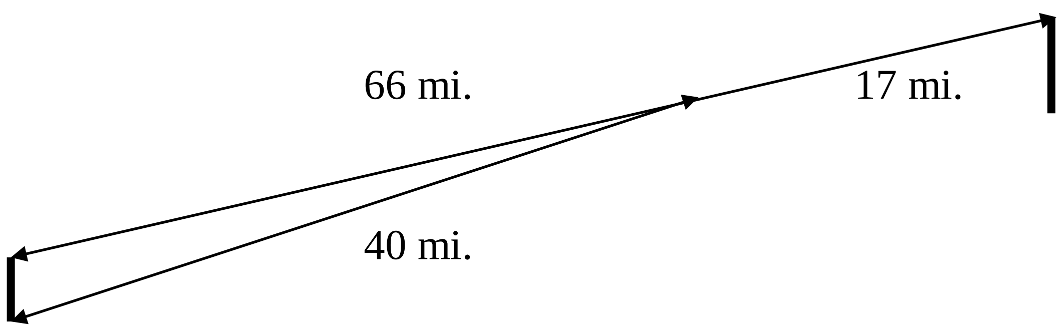

Figure 9 - Tower Illumination by W4ZRZ

From these parameters, the tower gain is approximated as follows. For 4.5 in spheres stacked in half sphere increments, 2.25 in., this equates to 6853 spheres or ~ 38.4 dB gain. For tower with 3 legs, add 5 dB for 2 additional legs for a total tower gain of 43.4 dB. From this the estimated signal to noise ratio is determined for the W4ZRZ signal at the K4QF location. With tower illumination signal of -178.5 dBm and tower reflection gain of 43.4 dB, available signal level is -135.1 dBm. For a receiver sensitivity = kTBF, or for 2 KHz BW and 2.5 NF and 1 dB cable loss in dB = -174 dBm/Hz + 33 dB + 2.5 dB + 1 dB = -137.5 dBm. Therefore, excess signal is ~ 2.4 dB; sufficient for CW and but not for SSB. Moving the K4QF station 2.5 mi. from tower increases S/N by 20 dB to 22.4 dB which is sufficient for SSB.

The results of testing various geometries are listed as follows.

RESULTS OF TOWER TESTS W/ K4XR & W4ZRZ

- First test with K4XR and K4QF portable ~ 2 mi. from tower and W4ZRZ 57 mi. south of the tower produced SSB QSO's for all.
- For the 2nd test, K4QF worked K4XR (50 mi.) with S8 signals, easy SSB contact, possibly direct path or off of tower almost directly in the path. K4XR is 2,000 ft. below line of sight of direct path.
- After frequency coordination and tower alignment with K4XR as reference source, K4QF heard W4ZRZ with sufficient CW signal for QSO.
- W4ZRZ heard K4QF signal but not sufficient for QSO.
- Changing K4QF dish from1 ft. to 3 ft. dish should increase signal about 8 dB if aiming issues can be resolved.
- Stabilizing frequency will help a lot!
- It's important to illuminate a substantial portion of the tower length to achieve tower gain.

Fig. 10 below shows a night time exposure of the 950 ft. tall towers visible from the K4QF location at a range of 25 miles. With 5 of 7 lights visible, ~ 500 ft. of 950 ft. tower is within view. The horizon, along with a few tree limbs, is also visible.

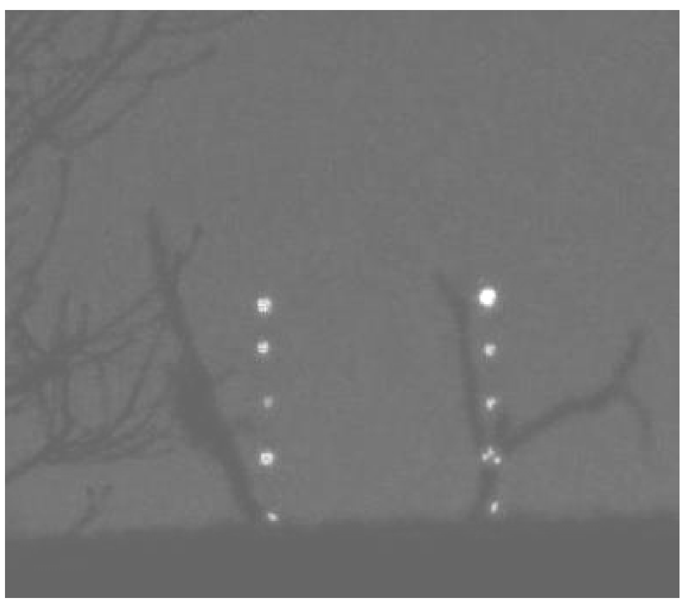

Figure 10 - Night Time Exposure of TV Towers

III. FIELD RESULTS

As is the case for many "discoveries," this mode of propagation was not the results of in depth, scientific research but was more the results of blind luck. K4XR and myself went "roving" one afternoon during the summer with the intent to determine how well signals reflected from water tower on a local mountain. A trip to the mountain did not produce a suitable location for viewing the tower without looking through significant foliage. Taking a road down the back side of the mountain placed us in a valley, and K4XR wanted to at least try to receive some signal from W4ZRZ some 60 miles to the south before darkness arrived. Setting up in the valley and pointing the 2 ft. dish in the direction of W4ZRZ did result in a weak signal on CW. However, peaking the antenna for maximum signal was not in the direction to W4ZRZ but toward the TV transmitting tower back up on the same mountain that was easily viewable from the valley. Signals were peaked permitting an SSB contact, and a decision was made to return at a later date to check out this mode for contacts. Several quick checks were made toward other towers on the mountain, a cross country power line transmission tower and a 500 ft. tall communications tower, and these did produce useable signal levels but nothing produced the strength of signal as did the TV tower.

A second trip to the valley, this time to the other side of the mountain but with an excellent view on the TV tower, was taken to set up the 10 GHz stations in a church parking lot. Two portable stations were set up, both the station for K4XR and for myself, K4QF. K4XR's station has some 3 watts output and uses a 2 ft. diameter dish. My station has 2 watts out with a 1 ft. diameter dish. W4ZRZ, on the other end on the link, has 8 watts to a 3 ft. diameter dish. The boresight angle from W4ZRZ to the TV tower is 178.8 deg., and the angle from the TV tower to our portable location was 283.0 degrees, resulting in a bi-static angle of 104.2 degrees. Contact between K4XR and W4ZRZ was easily established, and then a contact between K4QF using the lower power and smaller dish and W4ZRZ quickly followed even on SSB. The range from W4ZRZ to the TV tower was 57 miles, and the range from K4XR/K4QF to the tower was 1.7 miles. Figure 3 on page 6 hints that perhaps a 20 dB increase could have been gained if K4XR and K4QF had set up on the same bearing from the TV tower to W4ZRZ.

IV. CONCLUSION

This method of communications for the 10 GHz band provides another method in which the line-of-sight range can routinely be extended. For stations located in metropolitan areas with possibly more than one TV transmitting tower available, it opens the possibility for backyard communications out to a considerable range. Additionally, using the popular “Rain Scatter” software by K0SM and a flight tracking website such as “Flightaware.com” to locate large, commercial aircraft with radar cross section signatures around + 20 dBsm, either mono-static or bi-static contacts should be possible if the tracking issue with narrow beamwidths can be resolved. By combining several technical routines, aircraft reflected contacts become more feasible all the time.

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(Editor's note: The info below is from a recent email from Ben to M.D. WA4DXP about how this propagation works best using a TV tower as a re-radiator.)

Hi M.D.,

You are correct in that Fig. 4 in my paper shows that when you line up exactly 180 degrees on the opposite side of the tower from the station you are working, the tower leg reradiates on the back side of the tower with a nominal 20 dB enhancement of the signal. Keep in mind that this is based on my tower simulation which is a large number of spheres stacked on top of each other. I “simulated” the tower in this manner because I didn’t have access to one of the sophisticated radar cross section simulations such as “X-patch” that is used by the radar signature analysis folks. What I did have is the characteristics of spheres (”The Scattering and Diffraction of Waves”) from a study I did about 30 years ago for one of the intelligence agencies. At first, this didn’t seem logical to me, but then when I thought about the spheres reradiating the signal instead of reflecting the signal, it did make more sense as I showed in Fig. 7 with the surface skin currents around the sphere all adding in phase and with the same amplitude exactly half way around the sphere. So, I “modeled” the TV tower leg as a stack of spheres.

When I presented this paper at the Microwave Update Conference in 2009, several people had some comments as you might imagine. One person said that the reflections probably came from the horizontal member of the tower instead of the vertical members.

However, another ham who was from Florida said that was definitely not the case. He said he was back away from a TV tower pointing at the tower and working stations behind him, so he decided that the best way to enhance the signal was to move right up next the tower and beam his signal up the tower illuminating the horizontal members. When he did that, he almost lost the station he was working. I ran my own tests to see if I could verify the “180 degree around the tower” theory. Fig. 4 in my paper shows that between 0 and ~110 degrees, you have a nominal re-radiation level. It also shows that between 110 degrees and 170 degrees you have a lot of lobing, and between 170 degrees and 180 degrees you have a big peak with the maximum at 180 degrees. I first checked the signals from the Presbyterian Church parking lot down on Bailey Cove Rd. This gave me about a 90 degree angle from my station on the other end, W4ZRZ, in Springville which is on I-59 about 30 miles north of Birmingham. I could work him o.k. from that location by point at the tower. I then tried the same thing from my house at Skyline where I have a clear shot at the towers on Monte Sano. Looking at Fig. 5 in the paper, you can see that the included angle from W4ZRZ and myself is about 130 degrees. I finally heard him very weakly, but he couldn’t hear me at all. I was running 2 watts, and Jimmy was running 8 watts. K4XR in Hartselle could work W4ZRZ just fine, and his included angle was about 70 degrees. So I then decided to put the “180 degree” concept to test. I went to the lot in front of PPG just at the intersection of Hwy. 72 and Shields Rd. at set up. >From that location at ~600 ft. ASL and looking at the Chan. 19 and Chan. 31 towers on Monte Sano, I was looking into the north end of Monte Sano, a couple of miles away, which is at about 1600 ft. ASL, a 1000 ft. rise. To say the least, it is hard to fathom that I would get any direct propagation from W4ZRZ who is directly south of the towers with the 1000 ft. high terrain blockage between us. Since Monte Sano is a long ridge, I also do not believe I could get any Knife Edge Radiation over the ridge. From that location with the two stations at 180 degrees from each other, W4ZRZ had by far the strongest signal I have heard from him by using the tower re-radiation. He was driving my S meter to S-8 on SSB, a very easy station to copy and well above the noise. Since then I have worked him several times from that same location with the same results, so I don’t believe it was any kind of propagation anomaly.

As for the disappearance of the TV picture carriers from the analog transmissions, the digital stations do have a pilot tone for their transmissions. I decided to go to the "source," Cactus, to find out the logic in TV station assignments and frequencies versus channel numbers, but he said it was convoluted at the least. The increasing channel numbers don't necessarily mean increasing frequencies for the pilot tones. I suppose you'd have to get a listing of what station were on which frequencies. Since this paper has been published and is in the public domain, feel free to post it anywhere you like including the HARC website. I would love to get up a 10 GHz beacon up on Monte Sano to use for receiver sensitivity checks, frequency alignment, and antenna aiming alignment. A good location would be the old fire tower that is east of the TV stations, but I don't have access to. It's already covered with antennas, so one more small one would not make any difference.

So far, my best DX on 10 GHz is K4TO who is about 60 miles east of Lexington, KY. I worked Dave on a duct, both on CW and SSB, last November for a range of 244 miles. I was set up on the deck at my house.

73's….Ben