Repeaters and RF Safety: Return Visit 23 Years Later

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This is a brief review and update of the current FCC rules concerning RF exposure. In a newly strengthened regulatory environment, wherein we no longer have certain exemptions from station evaluation, we will update the recommendations made in an unpublished 2002 paper, Repeaters and RF Safety, (LH) attached herein.

Before May 2023, we were allowed to cite blanket exceptions to evaluation, based on effective radiated power (ERP) or via tables prepared for us and published in Supplement B of the 97-01 revisions of FCC Office of Engineering Technology (OET) Report 65. https://www.fcc.gov/general/oet-bulletins-line. This change was announced in a May, 2023 *QST* article by Greg Lapin, N9GL In the September, 2021 *QST*, Ed Hare, W1RFI, explained the new changes: The 2019 FCC Report & Order (R&O) can be found at https://docs.fcc.gov/public/attachments/FCC-19-126A1.pdf.

Review of the 2019 R&O (p. 94) shows that FCC has retained Supplement B of OET 65: *Additional Information for Amateur Radio Stations* for us to use.

Duty Cycle and the Other Duty Cycle

The 2002 paper picked up where the FCC left off concerning our frequent need to address multiple emitters, often the situation at any primo radio site. To our knowledge, all of the assertions in the paper are still correct. But the information supplied concerning duty cycle and transmit/receive time are lacking.

First, most repeaters use frequency modulation (FM). Unlike SSB, wherein we deal with inconstant RF, expressed as a per cent, the duty cycle for FM is just 100%, period. But we were initially confused by a second factor: key down per cent. We found that this factor serves to reduce the power the antenna terminal sees.

To calculate duty/time averaged power, we simply multiply:

Duty/time-averaged power = (P_o) (Duty Cycle) (Key time per cent)
wherein P_o = power delivered to antenna terminal
Duty Cycle in per cent expressed as a decimal (1.0 for FM)

(Equation 1)

The relevant example for average key-down time appears on pp 11-13 of *FCC OET-65 97-01, Supplement B,* available at the URL above. [FCC has done an admirable job in supporting the special operating needs of Ham Radio] In this example a 2 min transmit/2 min receive cycle is used. In a 6 minute interval, you are transmitting 4 minutes, for a ~ 66% cycle. This means we get to multiply the estimated power at the antenna terminal by 4/6, for a controlled environment. For the uncontrolled environment, a 30-minute segment is evaluated. (Please review discussion of P_o in our original paper, wherein the all-important subtraction of loss in excess of feed line loss is discussed)

To obtain Duty/time averaged EIRP: (This is the “EIRP” to be entered into E. 3, below).

Duty/time-averaged EIRP = (Duty/time-averaged power)(Isotropic Antenna gain)
Antenna gain must be expressed numerically (not in dB)

(Equation 2)

Numeric gain is acquired by converting published decibel gain over a dipole (dBd) via this equation:

$$G = 10^{dB/10}$$

This relation and a gain conversion table are found on page 18 of the FCC OET 65 cited above. Keys for this math can be found on a hand-held calculator. Antenna radiation efficiency is assumed to be 100%. To get isotropic gain, add 2.15 dB to the factory-specified dBd, before converting to numeric,

Do We Really Need to Do All This?

A table on page 79 of the R&O indicates the new threshold values for environmental evaluation. A sample calculation for one of our repeaters showed it to be liable for routine environmental evaluation. This finding showed us a need to perform an evaluation on each of our sites. Ed Hare’s article cited above explains this new exemption threshold. Please note this rule only applies to single on-site emitters.

Safe Separation Distance

You must first select/calculate the Maximum Permissible Exposure (MPE) from Appendix A (page 47) of the FCC paper. (also displayed in Hare’s article, cited above). This figure is given in mW/cm^{2}.. To calculate field intensity, the FCC specifies the following formula, as described in their original paper:

$$S = \frac{EIRP}{4 \pi R^2}$$

where S is field intensity in mW/cm^2
EIRP is Effective Isotropic Radiated Power in mW, corrected for Duty Cycle and Average Keying Cycle, per Eqns 1 and 2 above.
R is vantage point sight distance to antenna in cm

Equation (3)

This formula can be re-arranged to solve for the distance, R, at the maximum permissible exposure limit. It then looks like this:

$$R = \sqrt{\frac{EIRP}{4 \pi S}}$$

Equation (4)

MPE tables for occupational/controlled exposure and general population uncontrolled exposure are found on page 47 of FCC OET 65 and on page 98 of the 2019 R&O, and in Hare’s article.

This result (minimum safe distance or MSD) tells how close you can safely approach a radiator. The FCC table of MPE is subdivided into controlled and uncontrolled exposure You must consider ground reflection effects, if your antenna is low to the ground (< 10m or so), or if your antenna is on a roof top. In this case, you must multiply *S*, your expected field intensity by **2.56**. This is important: the effect may be great enough to push your station into non-compliance with its corresponding 5% MPE.

For a single-occupancy site, the licensee need only confirm that persons remain outside the circle of radius *R*, around the antenna. If this is the case, licensee makes an appropriate log entry and his task is completed.

If there are multiple radio site occupants, proceed as follows: (FCC OET 65: p 33). Calculate the power density at the vantage point. This requires a site visit with tape measure to obtain the distance 2 m (~6 ft) above ground to the antenna mast base. With the height of the antenna, you solve a right triangle to get the sight distance. This is *R* in Equation 4. From your site survey, the formula is solved for each visible emitter's MPE at its operating frequency.

If all visible emitters exhibit field intensities < 5% of their assigned MPE all are in compliance. and your work is finished! If for any visible emitter, calculated field intensity, *S*, at the chosen vantage point is > 5% of its MPE, you've got more work to do.

Using Eqn (3), calculate *S* for each antenna visible from the vantage point. Arrange these numbers in a column alongside the appropriate MPE for each. Calculate the per cent of each emitter's MPE. and list them.

Sum these per cents. They must not exceed 100. If they do, you may need to adjust a transmitter/feed line/antenna system to achieve <= 100%. If the neighbors are the RF elephant in the room, this may be impossible, in which case, fencing and signs will be needed. But see the possible exception above.

What to Do if Your Station Is Non-Compliant?

The FCC and Hare offer a number of steps you can take, if you find your station is non-compliant. Prominent among these are education (for us, license exam questions), FCC-approved signage, (at nearly all of our shared sites), adjustment of beam heading to avoid the neighbors – not feasible with radio links, and RF power reduction. But before tailspin, have a look at your calculations: did you slip a decimal point – a devilishly easy to make error, forget that your RF power must be in expressed in milliwatts, distances in centimeters ? Did you actually measure vantage point ground distance, enter the tower height in the correct units when solving your viewpoint triangle? Our red face will tell you that we have made all of these errors.

The required calculations are not difficult, but they are tricky due to incompatible units of measure and calculations to several places to the right of the decimal point. We experienced much frustration and fatigue from the numerous key entries required. We then sought help from the Internet.

Available On-Line Calculators

In 1967, Wayne Overbeck, N6NB, (SK this month) published a brief computer program, “RF Safety BAS” written in Basic, which closely followed the prescription found in FCC OET 65. This software outputs the very-important safe separation distance. Later, the Dr. Robert F. Cleveland at the FCC revised Wayne’s contribution and published a similar public domain on-line calculator in 2021.

Our Evaluation of Intertie Radio Relay Repeater Sites

To begin a system-wide evaluation of Intertie’s stations, we collected currently available programs for comparison and review. All of them calculate the correct MPE for controlled and uncontrolled environments, using the cited FCC table. All allow selection of ground effect.[1] Most report safe separation radii for the 2 environments, But not all agree. Only Overbeck & Cleveland (2021) and *Hintlink* yield the site-specific power density at a given observation point. You must have this information to evaluate a multi-user radio site.

Here is what we found:

Overbeck, W. Complying With the FCC’s New RF Safety Rules. *CQ VHF* Jan., 1967. pg 30-31:
Overbeck, W, and Cleveland, R.F http://n6nb.com/rfsafety.htm. (Open page, scroll to last item in menu list on the left – an. *.exe* file – and download it.)
Lake Washington Ham Radio Club (Overbeck, updated): KL7WH
https://lakewashingtonhamclub.org_static_rfcalculator_files
ARRL (used Lake Washington): https:www.arrl.org/rf-exposure-calculator
RF Exposure; https://www.rf-exposure.io
Hintlink: VP9KF https://hintlink.com/power_density.php
Packet Warriors; McCormick, J.D.: https://github.com/jxmx/rf-exposure-calculator
Ham Radio School: https://hamradioschool.com/rf-exposure-calculator
(University of Texas Radio Club calculator circa 1992, has been taken down)
In 2010, FCC published a brief summary paper for the cell phone industry. It contains the relevant math and a cogent discussion: https://fcc.report/FCC-ID/XYD-TCNM-V/1284714

We started with *Packet-Warriors*, because at that point, they were the only ones to report duty/time averaged EIRP. From the beginning, we were suspicious of their “theoretical ERP”, which seemed inordinately high. One of us (TB) managed to locate the error and corrected it. These programs are often written in JavaScript, wherein the writer has the option to hide the source code on the server.. At that point, we were stopped in our tracks.

We contacted John McAuliffe, W1DRF at ARRL, who candidly explained that their Calculator was “borrowed” from the Lake Washington Radio Club. We contacted Don Sayler, W7CXR at the club, who indicated that their source code was available and showed us how to obtain it. He stated that others park their code on the server side of JavaScript, making it invisible. He suggested hovering a cursor over the page and right-clicking. From the menu, select *View Frame Source. T*heir group deliberately used client-side JavaScript, “so that the code could be viewed by anyone.” Don’s guidance provided an excellent window on the algebra involved and made it possible to confidently run each required calculation by hand and compare our results with those from each on-line calculator.

1 Caution! Not all algorithms tolerate toggling between ground effect and no ground effect in an otherwise completed data entry, They will require you to start an evaluation from scratch.

We needed to obtain vantage point specific field intensities. Until we discovered the *Ham Radio School* calculator, it appeared that no one was doing this. One of us (TB) made a few mods to this program, also. Because this is copyrighted material, we are not at liberty to publish these. But the 2021 FCC Overbeck-Cleveland revision is pretty darned good.

In the mean time, we found Wayne Overbeck's original "RF Safety BAS" and the late updates thereunto. At this point, we saw that *Packet Warriors* was misreporting the critical duty/time averaged figure as EIRP. No, their figures are duty/time-averaged power at the *antenna terminal*. To get EIRP, the numerical antenna gain over an isotropic reference must be multiplied in. Only then, can the number used in the numerator of Equation3 1 and 2 above. (Calculation of the correct P_o power at an antenna terminal, EIRP and ERP, definitions and conversion are discussed in our original paper).

The spread sheet compares the input/output of each calculator. We entered data from our theoretic "Intertie standard station" to compare each evaluation. Briefly, this "station" outputs 100 watts to 100 ft of LDF4-50, with 1.5 dB/100ft loss, 100% duty cycle. 3 min transmit, 3 min receive, ground effect not included.

You will see that most of the programs yield consistent minimum safe distance (MSD) estimates. Most require you to self-compute power at the antenna terminal – an invitation to an early data-entry disaster (been there!). Since *Packet Warrior's* "theoretic ERP" estimate seems to be dead wrong, we've computed ERP and EIRP and inserted the figures in the table. *Hintlink's* calculator's power density at a vantage point does not coincide with FCC. All FM repeaters have a 100% duty cycle, so this entry is not shown, Some ask for minutes transmit and minutes receive; others, just the decimal per cent transmit. As usual, consistent units are an absolute must to avoid disastrous arithmetic errors.

On the spread sheet, we have added figures obtained from the FCC R&O Table 1 threshold for max allowed power at the calculated separation distances. In the typical repeater scenario shown, the threshold at the minimum distance is a nominal 10 watts: way below our duty/time average ERP example of 216 watts. Hence, evaluation must proceed for nearly all of us!

We'd say that nearly all the calculators are adequate in predicting MSD's. Repeater licensees have more work to do. One of the more comprehensive programs can help a lot. Multi-user sites demand a full evaluation!

Field Measurements

We used our Site Inventory with photographs and site visits to construct an evaluation of each of our active radio station sites. Of the 22, we found 5 roof top antenna systems, and 3 uncontrolled environments. The remainder were located on towers protected by fenced/locked corrals. Because of the **2.56** times increment in field intensity due to roof top (ground) reflections, we paid particular attention to co-located radios there. Fences too close to a tower, or no fence provoked selection of "uncontrolled" parameters here.

Wherever we shared a site, we calculated field intensities at selected vantage point (s). We compared these values with 5% of frequency-specific maximum permissible exposures, to see if each of our values fell below this threshold. If all emitters fell below 5% of their specific MPE, our task ended, and we reported full compliance. If not, we proceeded to the next step:

In this case, we computed per cents of each frequency-specific MPE (ours and our neighbors on-site) and summed these, to be certain that that sum was equal to, or less than 100%. This step was necessary at San Antonio West and Kerrville, whereat we found at least one emitter exceeding 5% of its allotted MPE. (FCC OET 65: p 35-39)

Results

We modified the *Ham Radio School* calculator to function above 300 MHz and to include reporting of minimum safe distances, ERP and EIRP, duty/time averaged power at antenna terminal, and the EIRP resulting when isotropic antenna gain is multiplied in. The program computes the 5% MPE values to compare with a selected vantage point eyeball distance specified power density.

We found all twenty-two of our sites met FCC-specified safety standards. We are inserting evaluation spread sheets in each station log and recording. along with a signed log entry indicating compliance.

Conclusion

We have successfully evaluated each of our radio-relay repeater sites for compliance with the FCC current RF radiation standards. To make the math easily repeatable, we located the best available on-line calculator and modified it such that it accurately supports most of the required calculations. Licensee must only solve a right triangle to obtain eyeball to emitter distance. With these tools, evaluation of sites with multiple transmitters is now possible.

April 24, 2025
Attached:
Table 1: Calculator Comparison
Figures 1-3 Photos to illustrate multi-user sites, controlled and uncontrolled environments

Table 1: RF Caluculator Comparison

RF Exposure Calculators | Intretie, Incorporated | Comparison | 07/25/2025

Algorithm trials					
Inputs (Calculators vary in expected inputs)	Overbeck and	Lake Wash	ARRL	Packetwarriors	RF Exposure
Calculator inputs	Cleveland 2021	Ham Radio			
Radio	I2	I2	I2	I2	I2
Frequency (MHz)	444	444	444	444	444
Feedline Length				100	
Feedline loss dB/100ft				1.5	
Antenna gain (dBi)	10	10	10	10	10
TX Time (min)		3	3	3	3
Rx Time		3	3	3	3
Tx Time %	50				
Gnd effect ? Y/N	N	N	N	N	N
Power at antenna (W) Tx pwr minus cable losses	70.8	70.8	70.8	Not displayed	70.8
Outputs					
ERP Tx Pwr x Ant non-isotropic gain minus losses				431.51	
ERP Time/Duty Averaged					
EIRP, not tme/duty averaged is 1.64 x ERP				707.95	
Time/duty avg power (W) Pwr @ antenna x key down %	35.39729			35.4 W	
Time/duty avp EIRP Time/duty avg pwr x antenna gain	353. 9729			(incorrect:see	
Uncontrolled exposure				text	
Maximum Permissible Exposure: MPE (mw/cm^2)	0.3	0.296	0.296	0.3	0.296
Minimum Safe Distance MSD (m)			3.0849	3.08	3.085
Minimum Safe Distance MSD (ft)	10.1	10.1209	10.1211	10.12	10.1213
Field Intensity S mw/cm^2					
Vantage point dist (ft)	20				
S for this dist mw/cm^2	0.0758				
S as % this MPE					
Controlled exposure					
MPE (mw/cm^2)	1.48	1.48	1.48	1.48	1.48
MSD (m)			1.3796	1.38	
MSD (ft)	4.5	4.5262	4.5263	4.53	4.5262
Evaluation threshold per FCC 2019 R&O Max ERP watts					

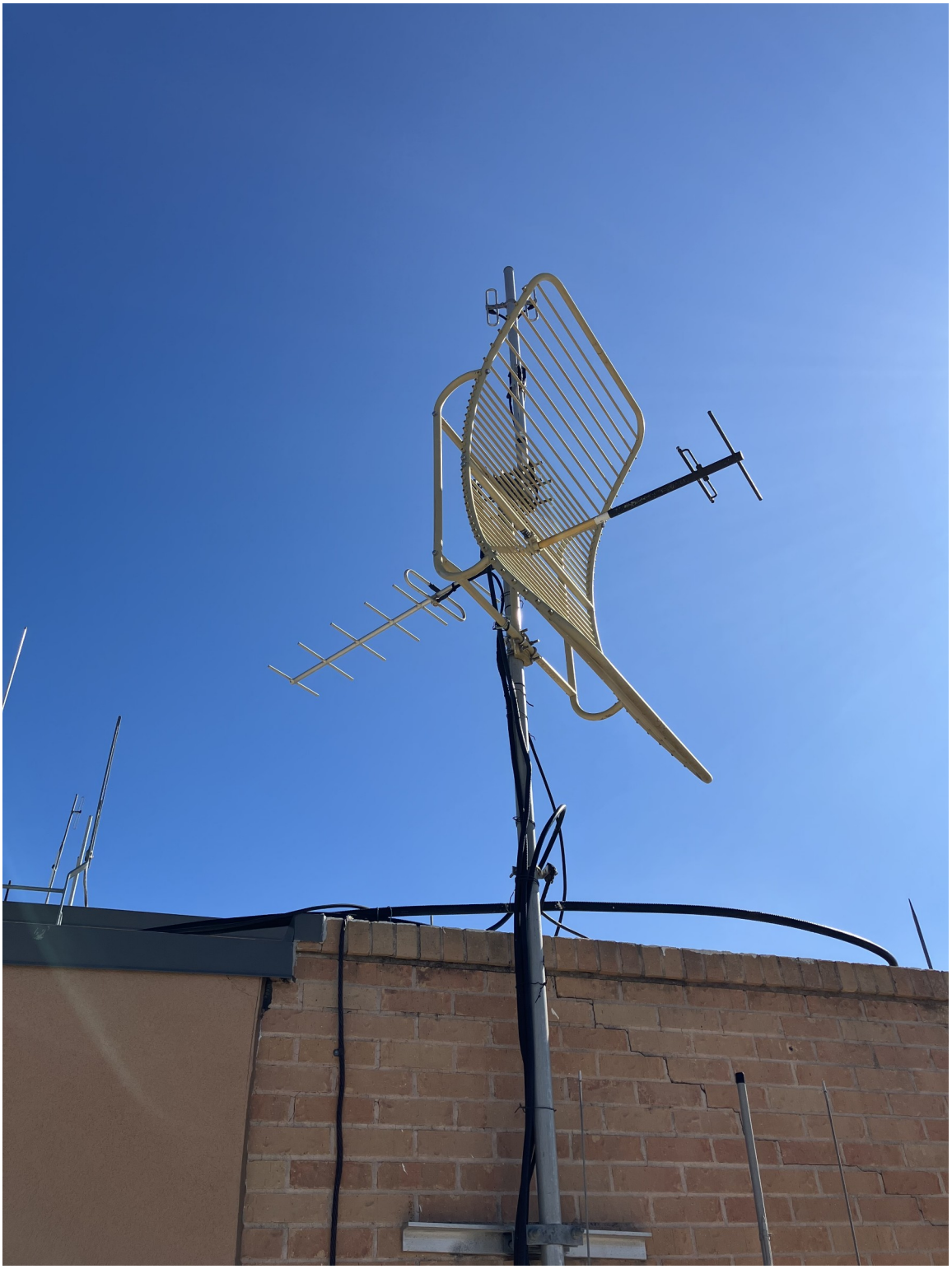

Figure 1: Multi-user antenna farm: DB-408 at top Commercial repeater; SRL 307 Yagi and Scala PR-410 Paraflector Ham Radio Links. Site is on a locked roof top: Controlled Access.

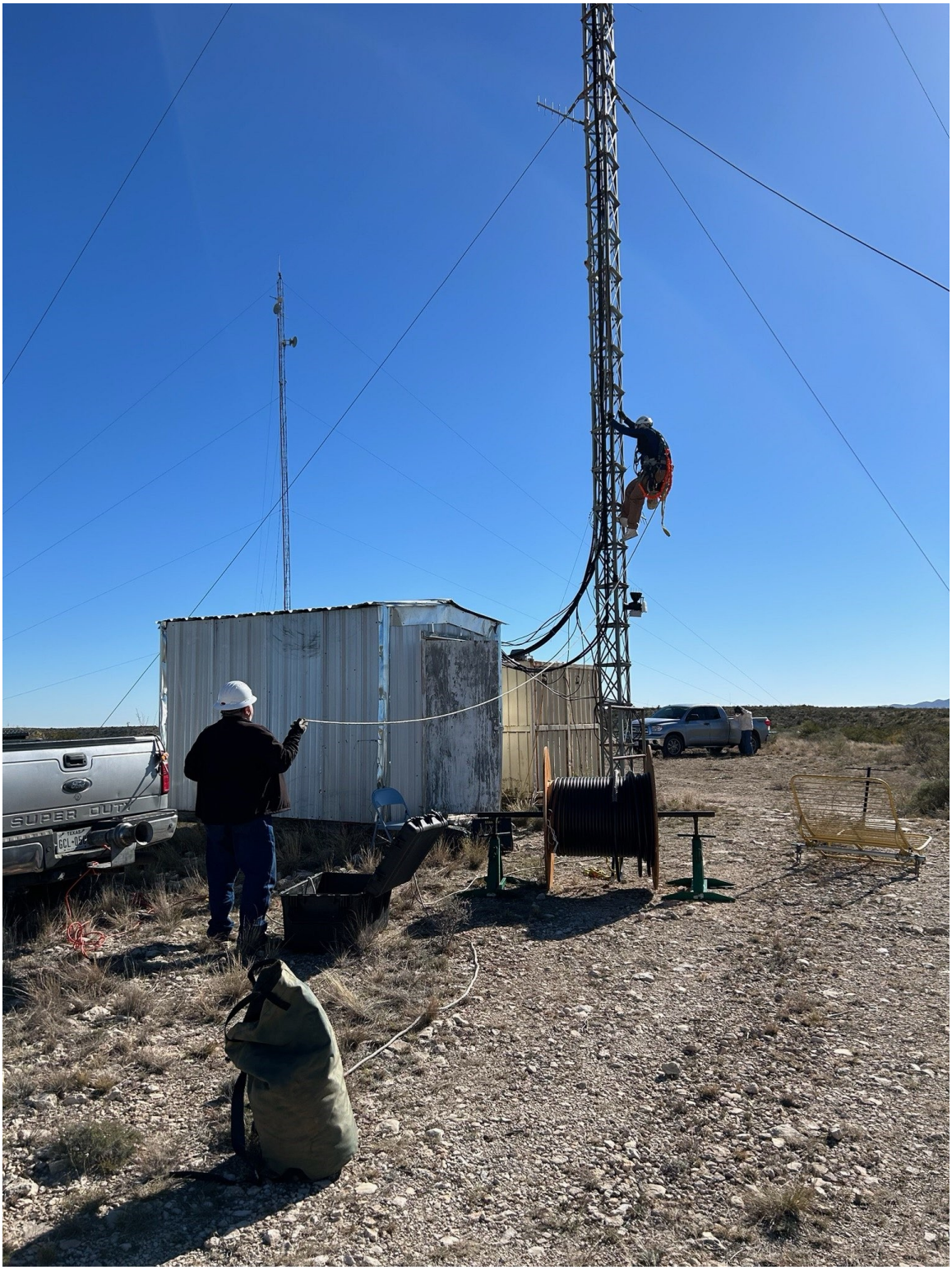

Figure 2: Very remote <u>uncontrolled</u> site: Has locked gate ½ mile away, but land is leased to hunters in-season. Emitters include State of Texas, Ham Radio and a separate commercial microwave system.

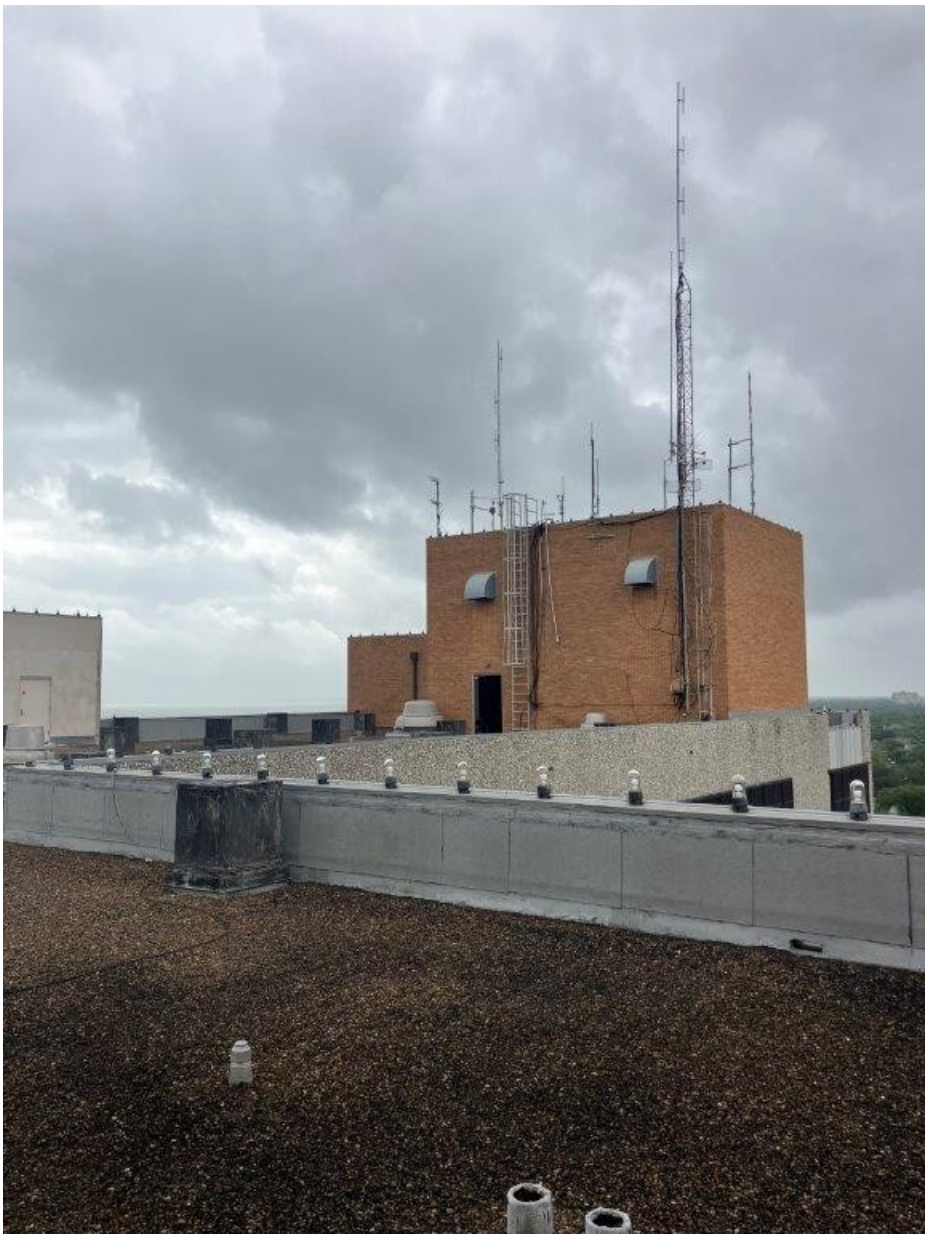

Figure 3. Rooftop Controlled Access