A Study of the Possibility of Radio Interference by the Raytheon Tucson Test Facility

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Purpose

Raytheon Missile Systems (RMS) is currently under contract with the Department of Defense (DoD) to design, test, manufacture, deliver and support, missiles and other Department of Defense weapon systems. Raytheon must make RF measurements to demonstrate that the systems comply with performance requirements. The purpose of this report is to assure that continued operation of the RF measurement test range known as the Tucson Test Facility (TTF), covered by FCC license KA2XAG, will not cause interference to other users of the RF spectrum.

Figure 1, Raytheon Missile Systems, USAF Plant 44

Background

RMS conducts RF measurement operations at USAF Plant 44 in Tucson, Arizona. The main entrance is shown in Figure 1. The Tucson Test Facility (TTF) is located in Building 827c on Plant 44.

The TTF operates on three fixed frequencies and five frequency bands. The fixed frequencies are 155 MHz, 815 MHz and 1330 MHz. The frequency bands are 2-4 GHz, 4-8 GHz, 8-12 GHz, 12-18 GHz and 32-38 GHz. When operating in the frequency bands, the frequencies are stepped (usually in 20 MHz increments) over the entire frequency band. Each transmission consists of multiple pulses within a 100-nanosecond time envelope.

Test facilities like the TTF are common at DoD prime contractors and Government installations. When Hughes Missile Systems Company purchased General Dynamics Convair Division in 1992, they moved the facility from Poway, California to Tucson, Arizona. The FCC license KA2XAG was also transferred during the move. Experienced RF test range engineers drew from years of experience to place and orient the radiating antennas at the TTF to minimize any potential interference to or from the range.

Another similar range is the Air Force's Radar Target Scattering Facility (RATSCAT), which uses 44 dBi gain antennas and 100 kW transmitters. It is located 8.7 nmi from flight facilities at Holloman AFB, New Mexico, and has operated for decades without interference problems. By comparison, the TTF radar range has 32 dBi gain antennas and 100 Watt transmitters. The TTF effective radiated power is 42 dB lower than that of RASCAT.

The TTF antennas are oriented such that the direction of propagation is in a southwestern direction, which is away from the Tucson International Airport and the main Tucson metropolitan area. RMS chose the TTF site primarily to mitigate the potential of electromagnetic interference (EMI) to Tucson. The TTF site relative to Tucson is shown in Figure 2.

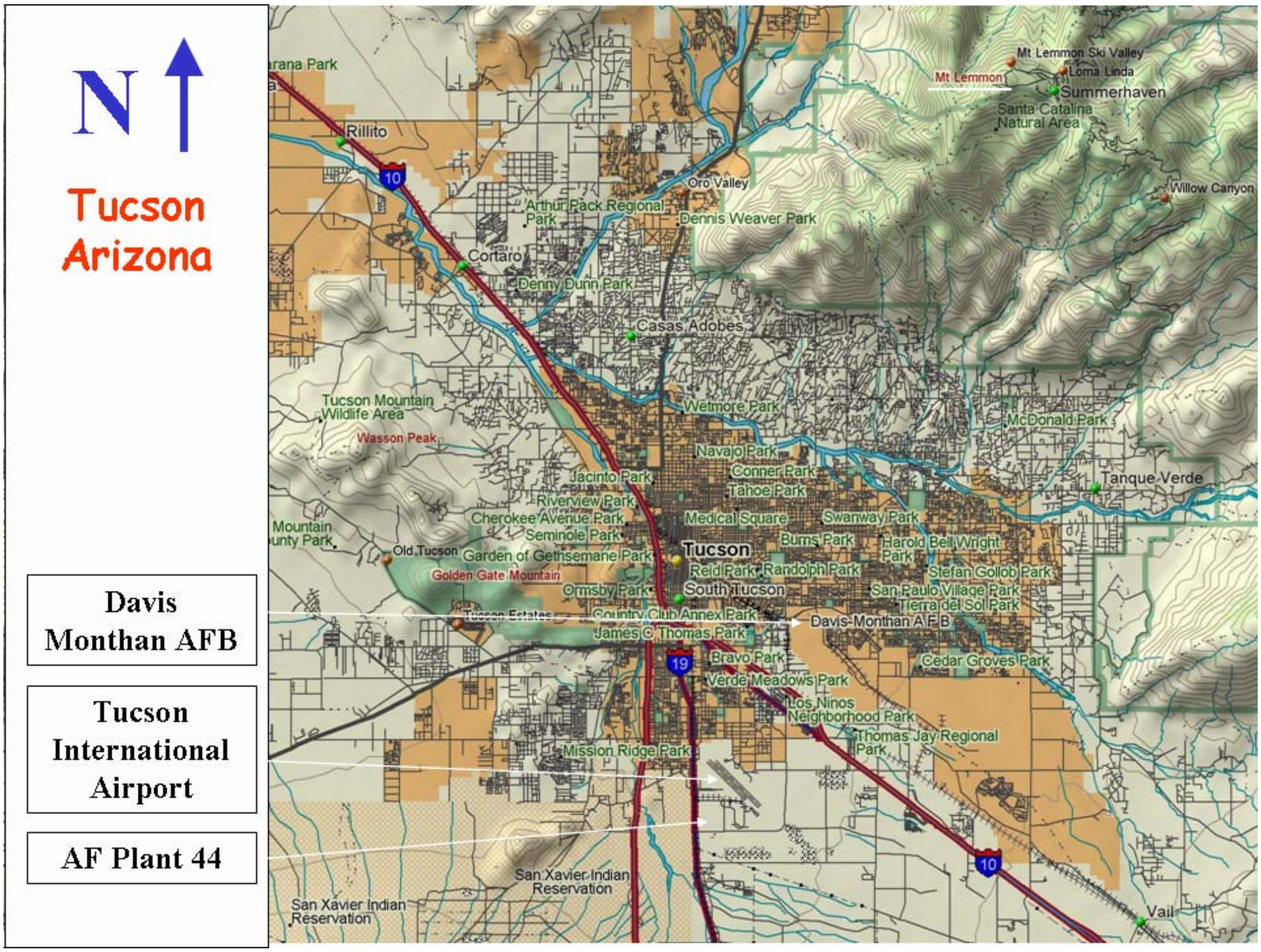

Figure 2, Tucson Map

The TTF antennas are at nearly ground level and are aimed down in elevation at -0.2 degrees as shown in Figure 3 and Figure 4. The metal buildings behind the antennas reduce the amount of radiation toward Tucson.

Figure 3, TTF Antennas

Figure 4, TTF Antennas side view

Figure 5 shows the view from the antennas shown in Figure 3 looking downrange to the southwest. The range itself is 520 feet long. The item under test would sit on the circular pad. The TTF antennas point toward the desert to minimize the interference to Tucson and to provide a quiet background noise level.

A few industrial businesses have been built along the road adjacent to USAF Plant 44. Operation of welders and other machinery has increased the noise level at TTF, which required the test engineers to increase transmitter power levels to make the required measurements.

Figure 5, Looking southwest downrange at target platform

Figure 6 is an aerial photograph above USAF Plant 44 that shows where the TTF radiates into the desert. The TTF antennas are pointed in the same direction as the photograph.

Figure 6, Aerial Map of TTF

Figure 7 is an aerial view that shows how the TTF is oriented.

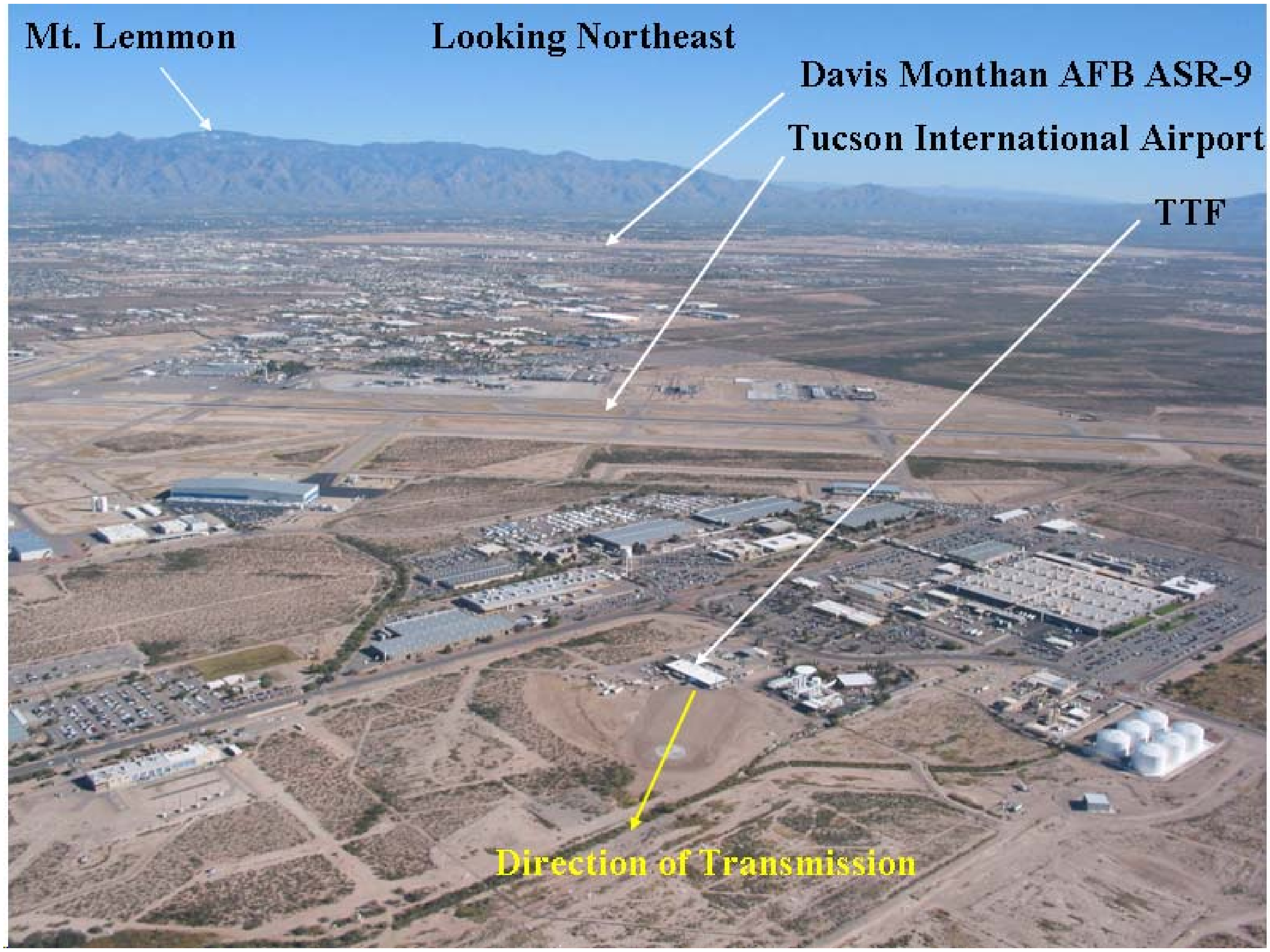

Figure 7, Aerial View of TTF and Tucson

Interference Analysis

On October 2, 2007 The FCC OET office asked for an interference analysis for the following frequencies.

- 155 MHz
- 2000-2290 MHz
- 2900-3700 MHz
- 5650-5925 MHz
- 32-39 GHz

The analysis is supporting evidence that increased TTF peak power levels of 50kW, 250kW, 350kW and 1MW do not cause harmful interferences to the existing "fixed microwave" incumbents in the area.

As part of the analysis effort, Raytheon researched the FCC records for licensees in the area and found many licenses holders in these frequency bands. There are no FCC licenses on 155 MHz. However there are several near 155 MHz that are listed below.

1. KJP434 TUCSON, CITY OF 154.98 is in the backlobe of TTF.
2. KJS766 ARIZONA, STATE OF 154.935, 155.475 located in Ajo AZ which would be sidelobe of TTF.
3. KNAW586 PASCUA YAQUI TRIBE 154.965 MHz located in the backlobe.
4. KNET724 ARIZONA, STATE OF 154.795, 154.8, 154.92, 156.2875 and 158.88 MHz located statewide fixed base and mobile.
5. KOA255 TUCSON, CITY OF 154.725, 155.01, 155.73, 155.75 all located in the backlobe.
6. KOF346 ARIZONA, STATE OF 154.86, 154.935, 155.475 MHz located on Mt. Lemmon also in the backlobe of the antenna.
7. WPKF921 CHUKUT KUT DISTRICT OF TOHONO O ODHAM NATION Terminated.
8. WPRS335 ARIZONA, STATE OF Terminated.
9. WPYP272 ARIZONA, STATE OF 154.905 MHz Lukeville AZ is in a sidelobe.
10. WPZZ841 INDIAN OASIS- BABOQUIVARI USD#40 155.0475, 155.6175, 155.7225 also in is a sidelobe.
11. WQBK278 COCHISE, COUNTY 154.98, 155.04, 155.925 Patagonia In a sidelobe.
12. WQF388 ARIZONA, STATE OF 154.785, 154.8 154.905, 154.92 MHz.
13. WXM682 ARIZONA, STATE OF 154.795, 154.935, 156.09 MHz backlobe.
14. WYZ441 PIMA, COUNTY OF, WIRELESS SVCS DIV 155.085 MHz Tucson is in the backlobe, Ajo is in the sidelobe.

All of the listed licenses are for voice communications systems. Raytheon RF engineers analyzed several RF interference analysis programs to select one that is suitable for predicting potential RF interference from the TTF. All programs only consider worst case continuous wave (CW) transmissions and do not take the 100-nanosecond pulsed transmitted waveform into account. Other programs were useful in showing the signal levels around the Tucson area. Figure 8 and Figure 9 show the predicted signal levels in the Tucson area that are based on analysis software.

Voice communication equipment will not respond to 100-nanosecond signals because the signal duration is too short to pass through their narrowband IF filters, which are typically 10 kHz wide. One pulse train from the TTF has less effect on a voice communication radio than a lightning strike. All of the licensed systems use frequency modulation (FM). FM receivers are designed to reject amplitude variations in the received signals, which further reduces the likelihood of interference. Motorola makes a variety of handheld and fixed-location voice communication products. Their engineers stated that voice communication equipment will not respond to 100-nanosecond RF bursts.

To verify that TTF does not interfere with voice communication equipment, RMS engineers conducted a test using a Motorola handheld radio on the TTF range. Raytheon engineers tuned the radio to 155 MHz and placed it in the TTF main beam on the range with the TTF transmitter also set to 155 MHz. As expected, the radio did not respond to the maximum-power emissions from TTF. Raytheon engineers repeated the tests on 815 and 1300 MHz. In all cases, the radios had absolutely no response to the transmitted signals.

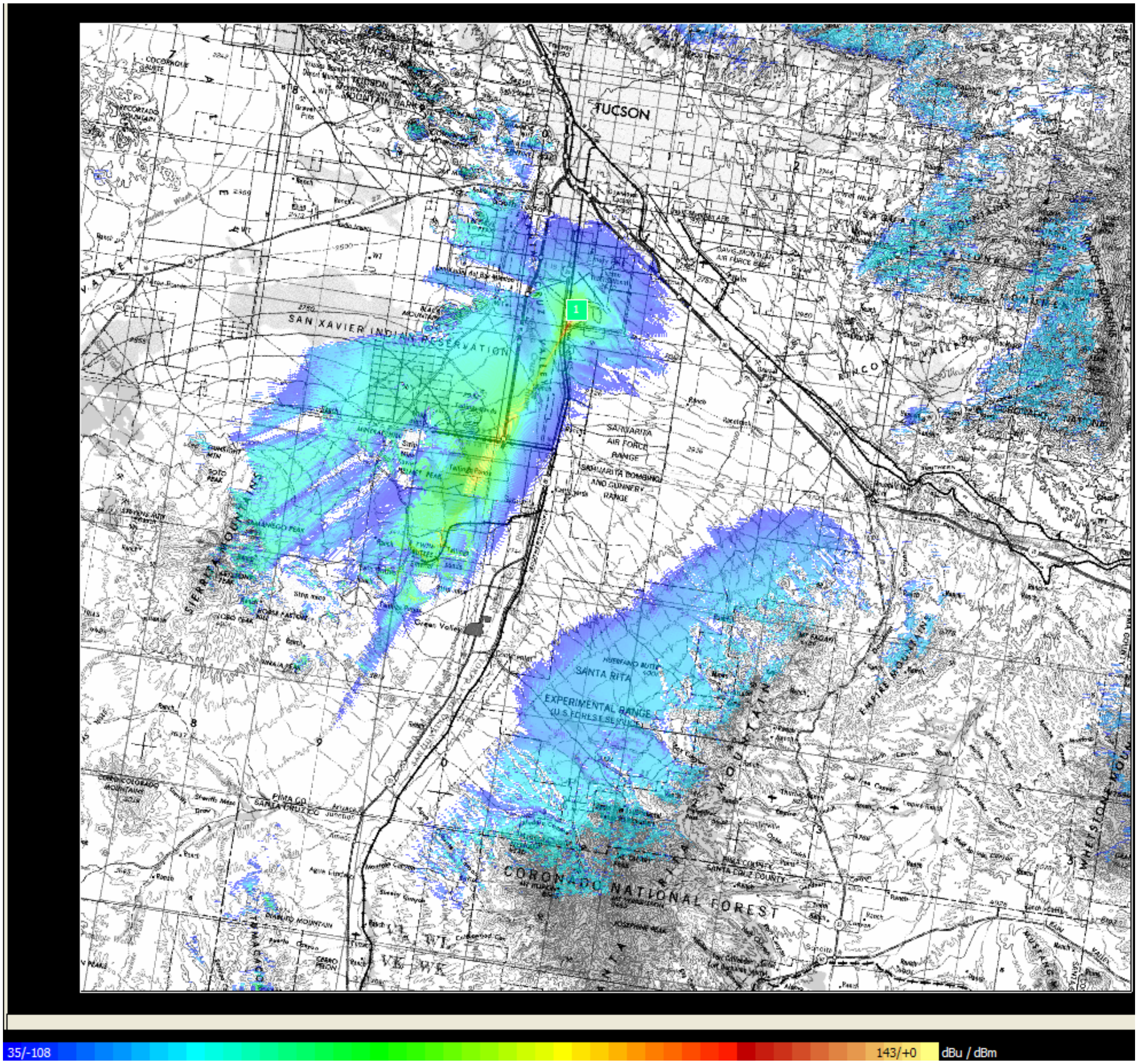

Figure 8, HTZ Warfare Analysis 2 GHz

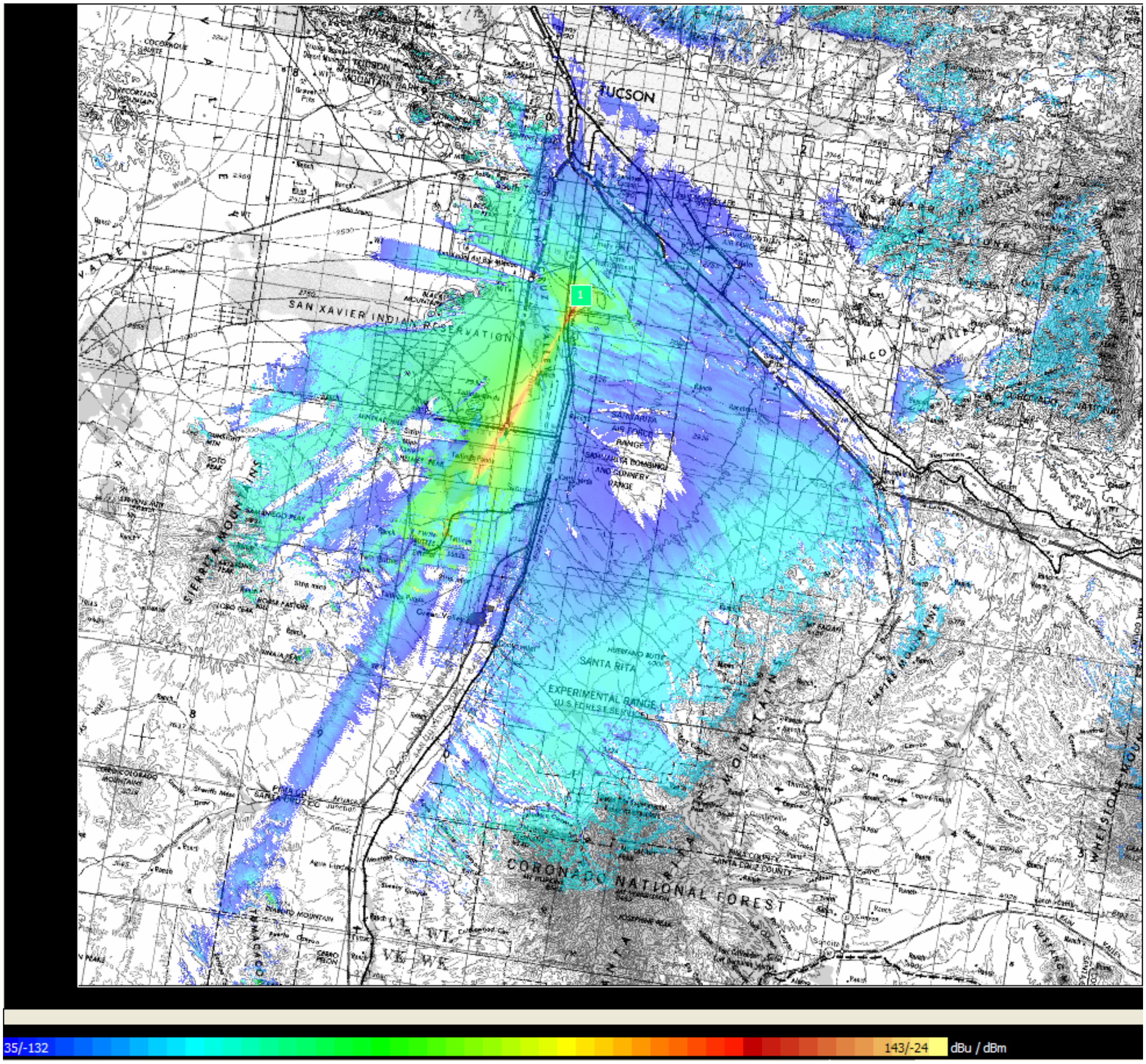

Figure 9, HTZ Warfare Analysis 32 GHz

Air Traffic Control Considerations

The geometrical relationship between the TTF to Tucson area Air Traffic Control (ATC) systems is shown in Figure 10. All ground-based ATC systems are in the back or far side lobe radiation pattern of the TTF and are shielded by the adjacent building and the plant complex in general. The ATC systems use 11 frequencies. The ASR-9 radar uses three frequencies; 2.725 GHz, 2.73 GHz and 2.865 GHz. The ASR-9 radar is located 4.7 nmi from the TTF at an azimuth of 41 degrees from True North. The Television Microwave Link (TML) uses 14.815 GHz at 4.7 nmi and 5.5 nmi from the TTF, and a future planned TML frequency is 15.15625 GHz, which will be located at 4.7 nmi from the TTF. These are all at an azimuth of 41 degrees from true north. The Low Density Radio Communication Links (LD-RCL) uses four frequencies. Transmitters at 7.225 GHz and 8.133 GHz are located on Mount Lemmon at 21 nmi northeast of the TTF at an azimuth of 30 degrees. Two more transmitters are 8.30 GHz and 8.365 GHz and are located at 5.3 nmi at an azimuth of 83 degrees from true north, and 6.0 nmi at an azimuth of 60 degrees from true north respectively.

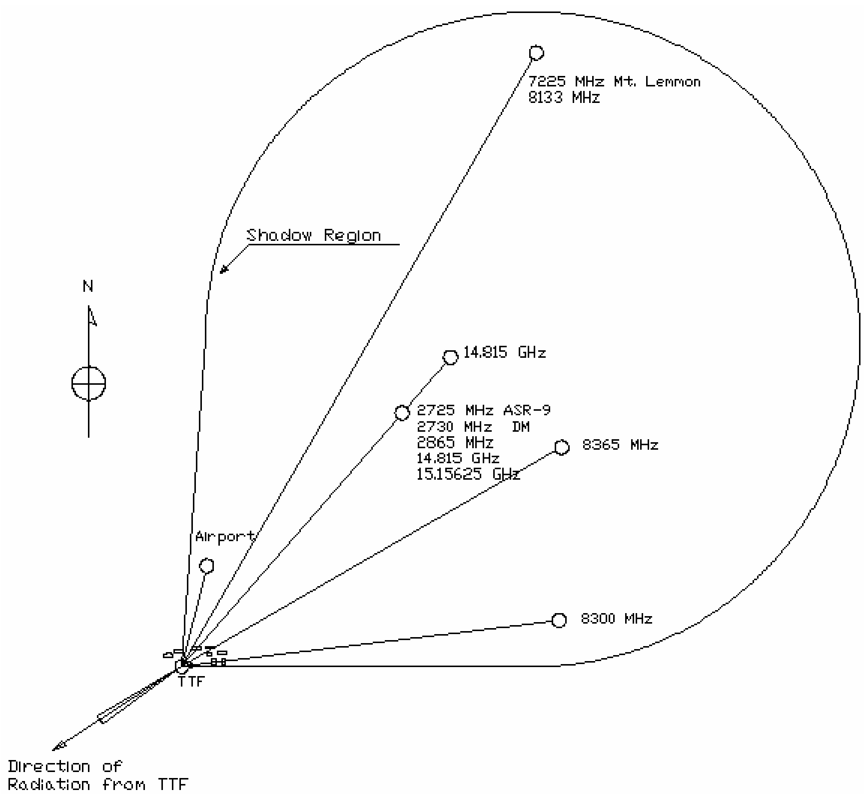

Figure 10

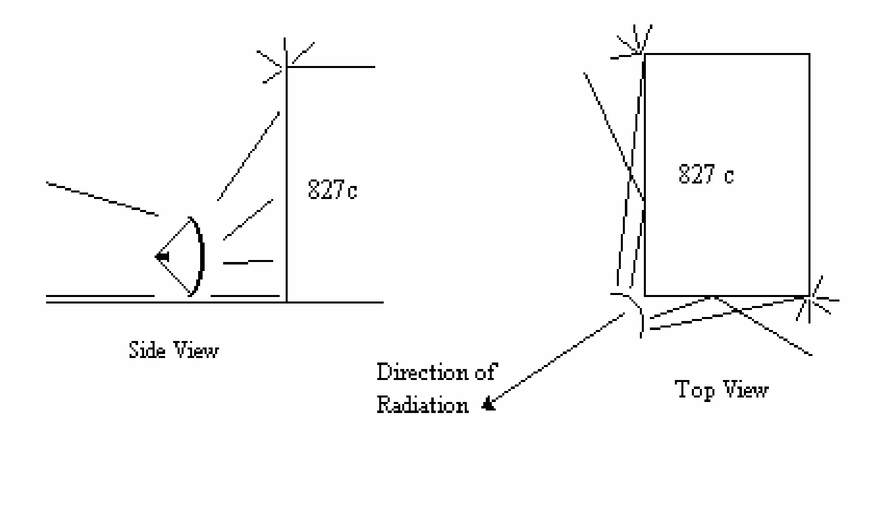

Figure 11, TTF Building attenuation

The TTF is a ground plane measurements range utilizing the effects of ground bounce where the ground reflected wave forms an interference pattern modulating the radiation pattern of the source to produce a lobe structure where the peaks of the lobes occur at odd multiples of the angle $\theta_n = \lambda/4H_a$ and nulls at even multiples of the angle. The lowest lobe is used to illuminate the test item. This lobe structure forms the vertical field. The horizontal field pattern is that of the parabolic reflector used for that frequency. In order to effectively use the first and primary lobe the antenna heights are set by the relationship $H_a = \lambda R/4H_t$ where R is the range to the test target, H_t is the test target height and λ is the wavelength.[1] The Range of the test target is fixed at 520 ft to the Southwest of the antennas, which are located 8 ft from the Southwest corner of Building 827c as shown in Figure 12. The target height is nominally set between 8 to 12 ft from ground level. With the target height and range fixed the antennas will be nearly at or slightly below ground level and radiating in the direction of the target at an azimuth of 237 degrees from true north. The TTF antennas are parabolic reflectors with rolled edges that are greater than $\lambda/4$, reducing the edge diffraction of the reflector and thereby minimizing the side and back lobe radiation[2]

The TTF uses Traveling Wave Tube Amplifier (TWTA) transmitters with a nominal output power from 10 to 100 Watts, pulse modulated at a duty cycle around 0.005%. Using the antenna gain and transmitter power at 2.725 GHz the effective radiated power (ERP), ERP = $P_i + G_a$, is 7906 Watts or 38.9 dBW.

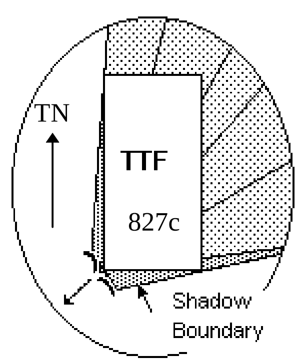

Figure 12, TTF Antenna Shadow Boundary

As shown in Figure 11 the back and far sidelobe radiation of the antennas are shielded by building 827c. Well established theories on reflection and diffraction[3, 4] show that most of the RF energy radiated to the north and east is reflected from the building walls forming a shadow boundary which encompasses all ATC facilities. Figure 11 shows the reflection effects. Edge diffraction losses are added to the propagation loss equation for the TTF radiated power. Propagation losses to ATC facilities from the TTF are increased by shadowing of buildings in the proximity of the TTF. The calculated incident field at the receiver in the shadow region includes the additional diffraction attenuation in addition to the free space attenuation. The diffraction parameter is a function of the ratio of transmitter to receiver distance multiplied by the height of the obstruction, and is expressed as $v=H_{bldg}[2(D_{tx}+D_{rx}/\lambda(D_{tx}D_{rx})]^{1/2}$. The computed edge diffraction losses are approximately 40 dB. The direct path to the avionics systems is therefore attenuated by the calculated diffraction loss of 40 dB reducing the output power PERP = $P_{ERP} + L_{diff}$. of the TTF to -1.1 dBW or 28.9 dBm

The TTF antennas are near or at ground level and fixed in azimuth, pointing in a Southwest direction of 237 degrees from true north. Calculating the antenna patterns as a function of angle, shows that the sidelobes and backlobes are more than 40 dB down from the main beam. The direction of ATC facilities in relation to the TTF's antenna radiation pattern shows that all ATC systems fall in the backlobes or far side lobes of the TTF antennas. Since the avionics systems are in the back and sidelobes the radiated peak output power must be adjusted by the sidelobe attenuation factor addition to the diffraction loss. Using a nominal sidelobe loss factor of 41 dB makes the radiated power Padj = $P_{ERP} + L_{diff\,+}\,SL_{attn}$, in the direction of ATC facilities, -42.1 dBW or -12.1 dBm.

Radiating over a distance of 4.7 nmi to the most sensitive of the systems, the ASR-9 with a minimum discernible signal (MDS) of -110 dBm and an antenna gain of 33 dB, the radiated power from the TTF will be attenuated by an additional 119 dB of free space loss making the power density at the antenna of the ASR-9 at -141 dBm /cm^2.

The IF receiver bandwidth of the ASR-9 is approximately 1.3 MHz. and is nearly at the matched filter condition for its 1 μs pulse. The matched filter condition BW=1/τ needs to be preserved to maximize the signal to noise ratio (snr) of the received energy to noise spectral density.[5] $(S/N)_{mf} = E/N_o$ for a CW system. For a single pulse matched filter condition this is expressed as $S\tau/N_o=P_r\tau G_r\lambda^2/4\pi^3R^4kT_s$. The energy processed by the receiver is the peak power over the time duration of the pulse (τ) which in the case of the received TTF pulse is 50 ns. This is far from a matched filter condition and using well described data on matched filter loss[6] we calculated the filter matching loss to be greater than 10 dB.

The ASR-9 also has a cosecant^2 antenna with a 2.2 degree beam elevation. The intercept of the TTF pattern and the main beam of the ASR-9 show the TTF beam to intercept the ASR-9 beam at approximately 0.02 degrees in elevation. Calculating the off axis beam loss by $40\log(R_m/R_i)$ shows an approximate loss of 15 dB. This loss reduces the ASR-9 antenna gain making the effective intercept gain of the ASR-9 as 18 dBi.

Using the intercept antenna gain the matched filter loss and the power density at the antenna the power at the receiver of the ASR-9, is -123 dBm. With a minimum discernible signal (MDS) of -110 dBm the calculated peak power received from the TTF is 13 dB below the ASR-9 MDS.

The ASR-9 is also a moving target detection (MTD) radar and as such employs target detection and signal processing not for single pulse detection but with multiple pulses per scan. The ASR-9 requires 20 pulses per scan to successfully implement MTD. The first 10 pulses are at one PRF and the 2nd 10 pulses are at a slightly different PRF. This is used to minimize range ambiguity. The received TTF signal is not synchronous with the ASR-9 receive timing. As the ASR-9 integrates the 20 pulses for target detection and processing, the TTF pulses received by the ASR-9 would be integrated out and suffer an additional 13 dB of integration loss (10 log (20)). This clearly shows that the TTF will not interfere with the ASR-9.

The Television Microwave links (TML) and low density radio communications links (LD-RCL) are in the shadow region of the TTF. These systems have very directional antennas as indicated with the antenna gains (Table 1 Appendix A). These systems have a nominal MDS of -78 dBm. Calculating the path losses for the links, not including any sidelobe losses or processing losses at the microwave links antennas and receivers, shows that the TTF radiated energy at the communication link receivers falls at more than 30 dB below their MDS. The following Table 1 shows the power received at the microwave link receiver.

Table 1, Power Received at Microwave Link Receivers

Frequency (GHz)	P_{pk} (dBm)	P_{avg} (dBm)	Range (ft)	$P_{density}$ (dBm/cm^2)	$G_{receive}$ (dB)	Power @ Rcvr (dBm)
7.225	45.4	21.5	129504	-170	41	-119.1
8.133	44.7	20.8	129504	-169	41	-124.6
8.3	44.7	20.8	32224	-157	41	-112.6
8.365	44.7	20.8	36480	-157	41	-113.7
14.815	44.7	20.8	28576	-151	36	-121.6
14.815	44.7	20.8	33440	-151	42	-116.9
15.15625	44.7	20.8	28576	-151	36	-121.7

Occasionally an aircraft will approach Tucson International Airport from the south. This approach pattern would intersect the upper lobes of the ground bounce energy. The airborne system in question is the aircraft radar altimeter operating at 4.3 GHz. Radar altimeter antennas are normally horns or microstrip antennas. With an approach altitude of about 1000 ft AGL and a range from the TTF of 7000 ft the TTF beam would be in the far side lobe (81 degrees) of the aircraft horn antenna[7] reducing the receive gain by at least 40 dB. The TTF antenna beamwidth at 4.3 GHz is 6.9 degrees. This generates a fly-through zone of 844 ft at 7000 ft in range. With an aircraft approach speed of 180 knots, or 304 feet per second, the aircraft will be in the fly-through zone for 2.8 seconds. This is the period of maximum possible RF interception. Assuming a signal processing loss of 20 dB due to non coherence of the TTF with the altimeter radar, the radiated power of the TTF would be at the MDS of the altimeter radar. Radiating at the altimeter frequency would not be an interference problem.

The spot frequencies of 155 MHz, 815 MHz are not within the frequency bands any ATC facilities and therefore do not pose an interference threat. The spot frequency of 1.3 GHz is used by the FAA. The distance of the nearest long range search radar to the TTF is more than 120 miles. Propagation losses for that frequency are on the order of 140 dB reducing the power at the search radar receiver below its MDS of -114 dBm.

FCC frequencies for the cellular phone service ~ 900 MHz are out of band and as such the TTF will not interfere with these systems. In general the signal processing of communications equipment is based on error correcting schemes which would by default process out any narrow non-coherent/ random pulse signal.

Conclusion

The Tucson Test Facility has not caused any interference since it began operation over 10 years ago. Other systems operated by the government and other contractors, using almost the same exact equipment have not caused any interference problems when operating with much higher power levels. The lack of interference issues is due to the extremely low duty cycle and the small amount of time on each frequency.

Raytheon Missile Systems is confident that there is no cause for concern in the operations of the TTF.

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