National Radio Astronomy Observatory

Electronics Division Technical Note No. 219

Measurements of Automotive Radar Emissions received by a Radio Astronomy Observatory

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Abstract

The radio astronomy community within the United States and elsewhere around the world enjoys a high degree of radio spectrum protection in the 77 to 81 GHz region. The global automotive industry, motivated by recent European Commission mandates, is developing short range radar systems to operate in this band to address issues of safety; the spectrum 76-77 GHz has already been in use since 1999 for Long Range Radars (Adaptive Cruise Control). In an attempt to understand the impact upon radio astronomy observations, measurements sponsored by the National Science Foundation were performed on 2 different short range vehicular radar systems. The radar systems were provided by Robert Bosch GmbH and by Continental Corporation and were operated at separation distances of 1.7 km and 26.9 km from the University of Arizona's 12 Meter millimeter wave telescope[1]. Measurements results are reported, and compared with the recommendations in ITU-R RA.769-2.

1 Introduction

Portions of the 76-81 GHz spectral region are allocated to the Radio Astronomy Service (RAS) in the United States and worldwide either on a primary or a secondary basis, and radio observatories that observe in this part of the spectrum currently enjoy interference-free operations. The worldwide automotive industry is developing various car radar systems for safety and operational purposes that would operate in this band on an unlicensed basis. In an effort to understand the impact that such systems may have on radio astronomy installations, measurements of the emissions of representative radar units were made at the University of Arizona's 12 Meter (12-M) Telescope[1] located at Kitt Peak, Arizona in October, 2011. Emissions of two different automotive radars, manufactured by Robert Bosch GmbH and by Continental Corporation were measured. These units were mounted temporarily on the vehicle; in production, they are expected to

[1] The 12-M Telescope at Kitt Peak is operated by the Arizona Radio Observatory (ARO) of Steward Observatory, at the University of Arizona.

be placed within a vehicle's bumper. The transmitters were first located at a nearby car park 1.7 km distant, and secondly at a site 26.9 km away at Sells, AZ. The 12-M telescope receiver was tuned to a center frequency of 79 GHz (Continental radar) or 77.8 GHz (Bosch radar). The car radars were used in an FMCW mode, in which the CW signal is swept at a constant rate from 77.03 to 78.58 GHz, a total bandwidth of 1550 MHz (Bosch radar) or from 78.93 to 79.1 GHz, a total bandwidth of 170 MHz (Continental radar).

The received signal was observed using the standard radio astronomical filter bank spectrometer covering a 500 MHz band centered at the radar's mid frequency, with 2 MHz resolution. In normal operation the 12-M Telescope uses a Cassegrain optics system. However, for this test we used the 12-M Telescope receiver and horn feed, but the beam of the feed was redirected from the subreflector by mounting a plane mirror in front of it . The main reflector of the 12-M Telescope thus did not play any part in these tests. With this arrangement the 12-M dish mount was used to point the beam of the telescope feed at the radar to achieve a "line of sight" path from the radar to the telescope receiver. Figure 1 shows the arrangement; a photograph of the plane reflecting mirror in front of the subreflector is shown in Figure 2. The redirected beam is offset by approximately 43.4 degrees in azimuth and 80 degrees in elevation away from the normal 12-M antenna pointing direction.

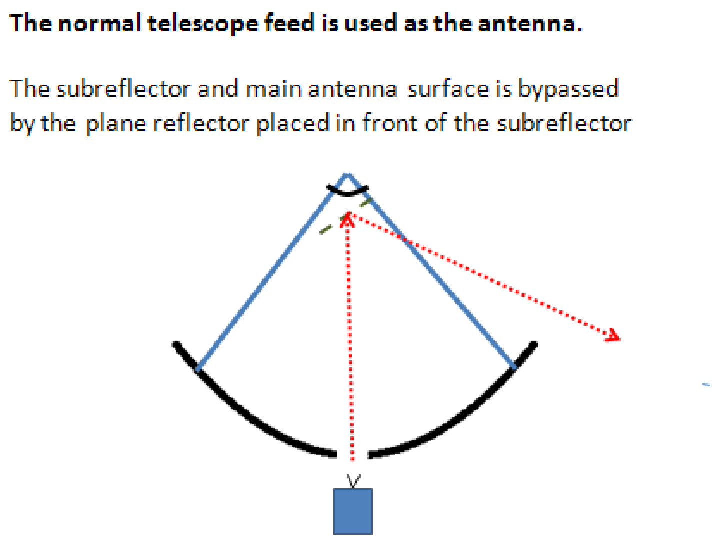

Figure 1 The normal secondary focus receiver and Cassegrain feed is used independently of the main 12-M reflector. An inclined plane reflector is placed in front of the subreflector, redirecting the beam from the receiver to the ground, rather than utilizing the main dish surface.

Figure 2 The inclined plane reflector in front of the subreflector redirects the signal received from the radar transmitter directly into the receiver, eliminating the use of the main antenna reflector. In the configuration shown, the signal is being received from the ground.

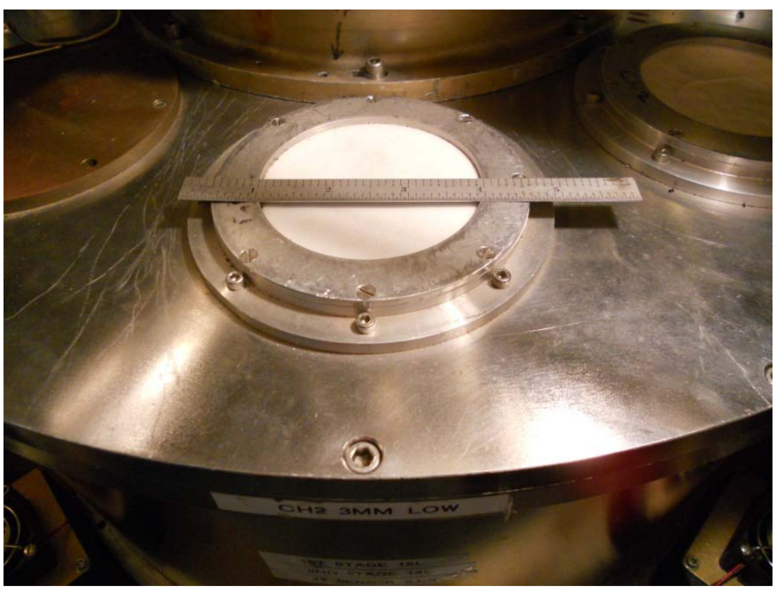

Figure 3 The 3-inch diameter window in the receiver Dewar is positioned immediately above the feed horn and SIS (superconductor-insulator-superconductor) mixer of the receiver used for these measurements. The signal is normally focused by the main 12-m diameter reflector onto the subreflector and then into the receiver. For these measurements, the signal from the radar is received directly, without utilizing the subreflector or the main 12-m antenna reflector at all.

The window above the SIS (superconductor-insulator-superconductor) mixer receiver in its Dewar is shown in Figure 3. The receiver itself is cooled to 4 K.
More details of the telescope's receiver optics can be found in the references below by Payne et al.

2 Beamwidth of the receiver feed

The beamwidth of the 12-M receiver feed was measured in a separate test in which the radar was located 1.7 km away in the parking lot of the 90" Steward Telescope (NB this is not a public parking area). With this line of sight path the radar signal was strong enough to easily determine the beamwidth in the vertical and horizontal directions by scanning the receiver beam across the radar source. The beamwidth was symmetrical in the vertical and horizontal directions with full-width half power of 3.1 +/- 0.1 degrees. Assuming a Gaussian beam this beamwidth corresponds to a gain of 35.8 +/- 0.2 dBi.

The main beam gain of a 12-M antenna, such as the mm-wave radio telescope at Kitt Peak, is about 78 dBi at 79 GHz, so the feed antenna used for these measurements is equivalent to a -42 dB sidelobe of such an antenna.

3 Receiver and system noise temperatures

The receiver noise temperature was calculated from the "Y factor" measurement using liquid nitrogen cooled absorber "cold" load (80K) and an absorber vane at ambient temperature (301K). The receiver noise temperatures were determined to be 75K and 108K respectively for the vertical (channel 1) and horizontal (channel 2) polarization channels of the receiver. For tests of the radar the system temperatures were assumed to be equal to the receiver noise plus the ambient temperature (301K) since the beam was always filled by the ground and atmospheric radiation when pointing at the radar; atmospheric attenuation over the 26.9 km path was some 4 dB, so atmosphere alone would have contributed some 180 K to the total receiver system noise over that path. We assume ground temperature and the atmospheric temperature over this near-horizontal path both equal to the ambient temperature.
A check of the receiving system was made by observing the Sun at an elevation of 10 degrees. This was the highest elevation at which the offset beam could be pointed and was reached with the 12-M dish mount pointed at the zenith. The "vane" calibrated temperatures measured on the sun were 167K and 170K respectively for the 2 channels. These values are close to the expected value of 168K above the atmosphere derived from the radio flux density of 10150.10^{-22} $W/m^2/Hz$ at 79 GHz (see Benz, reference below). To first order the vane calibration measurement corrects for the attenuation of the atmosphere, so this is excellent agreement. These solar observations are completely consistent with the measured receiver temperatures and the feed antenna gain.

4 Beam polarizations

The receiver consists of two independent channels, sensitive to orthogonal linear polarizations. The two polarizations are split via a grid of parallel fine wires, which transmits one polarization and reflects the other. Allowing for the orientation of the plane mirror in front of the subreflector, one of these channels is sensitive only to vertical linear polarization, the other to horizontal. Tests of the polarization were made with the radar at 1.7 km. With the radar transmitting its normal vertical polarization mode, the signal was very strong in channel 1 and at least 30 dB weaker in channel 2. When the radar was physically rotated by 90 degrees the signal appeared in channel 2 and was more than 30 dB down in channel 1.

5 Measurements of the radar at 1.7 km

Figure 4 and Figure 5 show the signals received from, respectively, the Continental radar with a nominal 200-MHz bandwidth, and the Bosch radar with a nominal 1550-MHz bandwidth.

In Figure 4, the emission shows two distinct features

(a) A plateau of emission approximately 170 MHz wide, and
(b) A spike of emission at the high frequency end of the overall emission.

In both figures, the vertical axis is in units of antenna temperature, ultimately calibrated against the hot (ambient) and cold (liquid nitrogen) loads that had previously been measured in front of the receiver. For reference, 1000 K of antenna temperature, with a receiver antenna of gain 35.8 dBi, corresponds to an spfd (spectral power flux density) at the receiver of -115.0 dBW/m^2/MHz.

From Figure 4, the plateau of emission is 968 K, corresponding to an spfd at the receiver of -115.1 dBW/m^2/MHz. Integrating over the 170 MHz of emission, this becomes a power flux density (pfd) of -92.8 dBW/m^2 at the receiver. Allowing for a free space path and an atmospheric attenuation of 0.3 dB, this corresponds to a total emitted power (EIRP) at the transmitter, just within the plateau of emission, of +13.0 dBm. Expressing this as a spectral EIRP at the sensor, this is -9.3 dBm/MHz. This is in excellent agreement with the -9 dBm/MHz measured by the sensor manufacturer, and which represents the maximum power allowed by the European Norm EN 302 264.

The spike of emission in Figure 4 has a peak brightness temperature of 5982 K, as measured in a 2-MHz filter channel. Excluding the plateau of emission, that corresponds to a received spfd of -107.2 dBW/m^2/MHz. This spike of emission is only visible in this pre-series sensor and would be removed for the production version of the sensor. It is not considered further here.

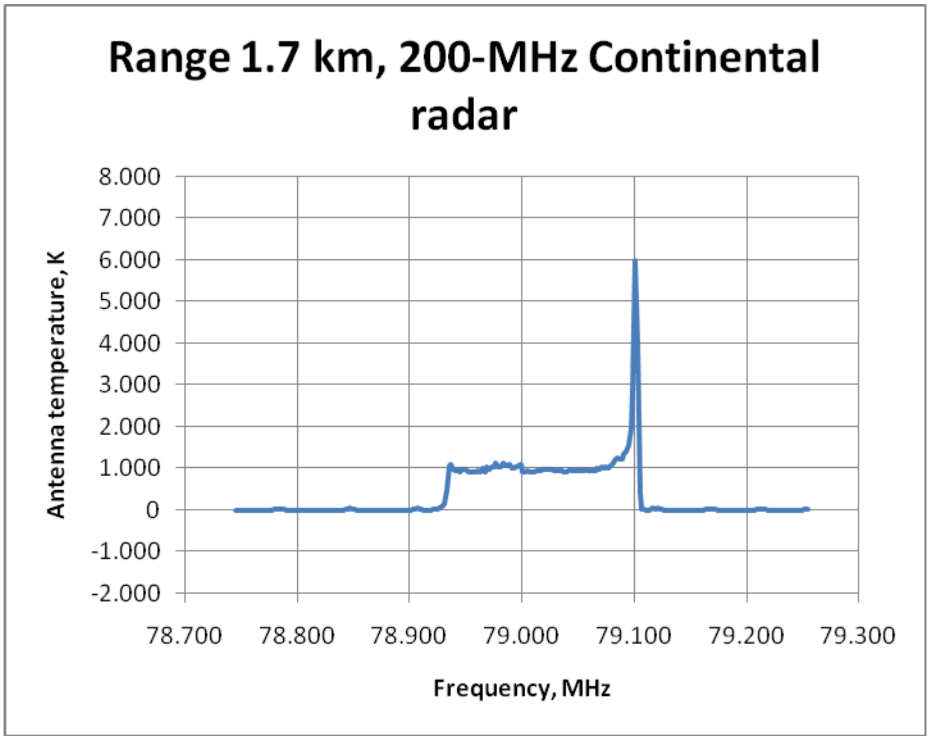

Figure 4 The received signal from the Continental radar, with a nominal 200-MHz bandwidth, at a distance of 1.7 km. See text for comments.

Away from the main emission of the transmitter, say +/-150 MHz in Figure 4, there is some residual response, but at a much lower amplitude of about 11 K. This is some 27 dB down on the peak emission of 5892 K. The theoretical rms receiver noise fluctuations for this observation are only ~0.084 K.

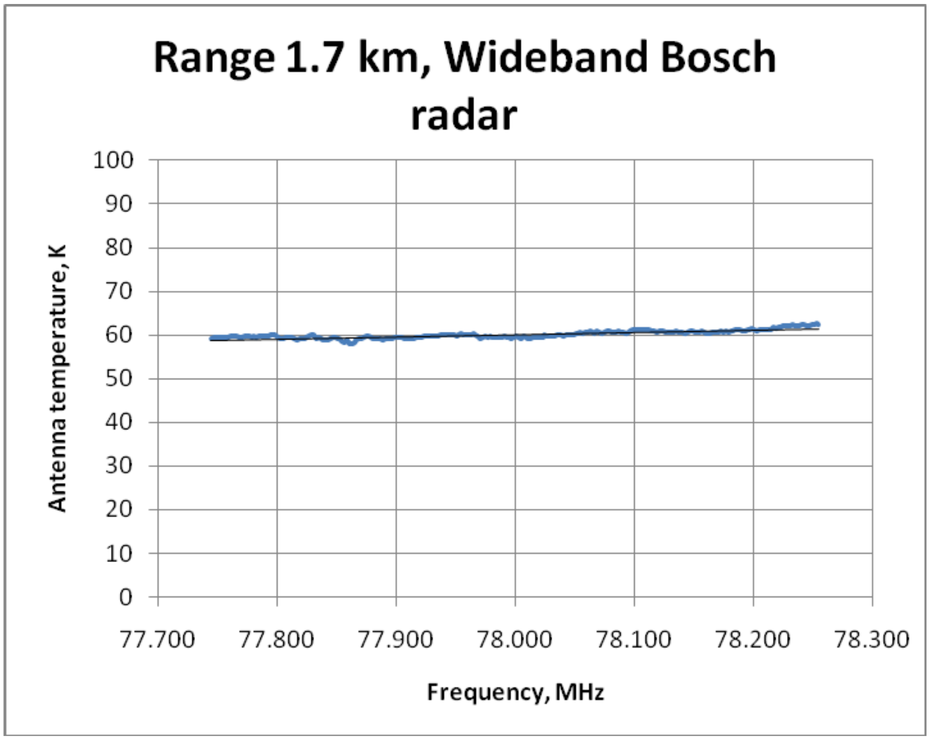

Figure 5 The signal received from the 1.7 km distant Bosch wideband radar, centered o n 77.8 GHz. Although the transmitted signal is nominally 1550 MHz wide, the receiver only sees the central 512 MHz of that band.

In Figure 5, showing the Bosch radar, the central 512 MHz of emission centered at 77.8 GHz, has a mean brightness temperature of 60.1 K. The corresponding spfd of this at the receiver is -127.2 dBW/m^2/MHz, with a received pfd (assuming 1550 MHz emission bandwidth) of -95.3 dBW/m^2. Again, allowing for the inverse square path loss and 0.3 dB of atmospheric attenuation, that corresponds to an effective isotropic radiated power (EIRP) of 13.7 dBm at the transmitter.

6 Measurement of the radar EIRP at 27 km.

The primary tests of the radar were made by driving to the seldom used airport at Sells, AZ. which is 26.9 km away and is in clear view of the 12-M telescope. The receiver beam was pointed at this location using angles computed from the GPS-determined locations of the radar at Sells and the 12-M telescope. After clearly detecting the radar in the spectrum of channel 1 the beam position was checked and found to be very close to the peak which was reached with a very small adjustment in elevation. The observed spectra are plotted in Figure 6 and Figure 7 in units of degrees Kelvin of antenna temperature. Each spectrum is the difference of the spectra taken for 30 seconds with the radar turned on followed by 30 seconds with the radar emission suppressed by covering its antenna with layers of absorber. This sequence may be repeated and the results averaged, in order to improve signal-to-noise ratio. The peak in the spectrum at 79.1 GHz, as already seen with the measurements at 1.7 km, is due to an initial low scan rate of the FMCW and is not expected in normal automobile radar operation. As before, the EIRP can be estimated from the integrated power over the 170 MHz width of the FMCW after correcting for the free space and atmospheric path loss and receiver antenna gain.

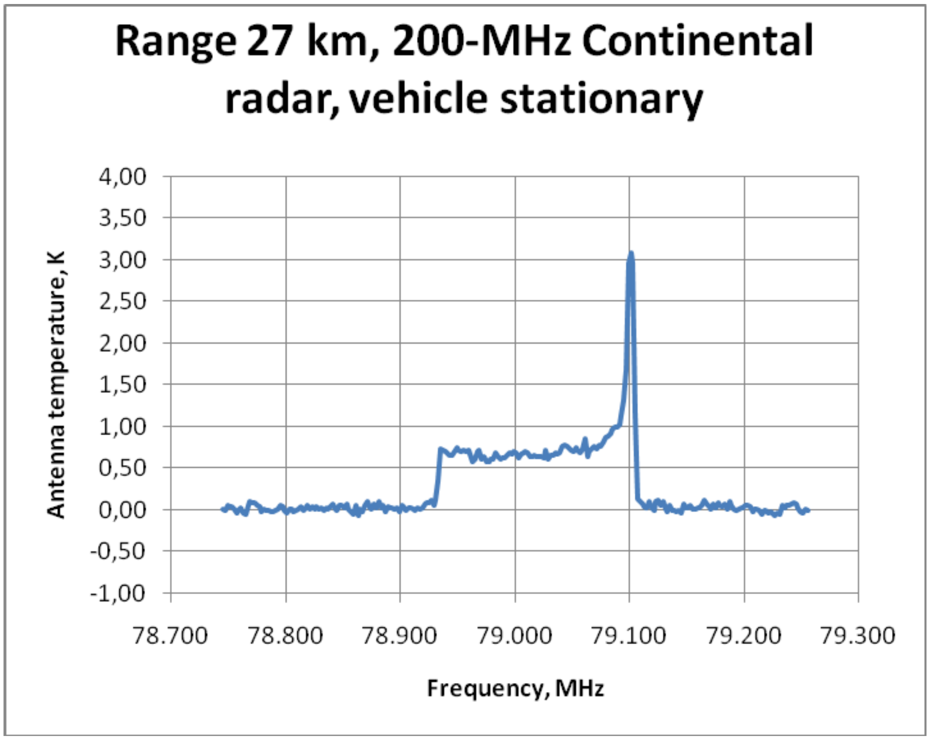

Figure 6 At a range of 26.9 km, this is the emission seen from the Continental 200-MHz radar, with the vehicle stationary. The average plateau of emission has a brightness of 0.68 K, while the high frequency spike is 3.08 K. The noise in the spectrum on either side of the emission is 0.038 K, close to the theoretical receiver noise of 0.036 K.

Figure 6, with the vehicle at 26.9 km and stationary, the received spfd of the plateau of emission is -146.7 dBW/m^2/Hz; the spike of emission is some 6.6 dB stronger. The received pfd of the plateau is -124.4 dBW/m^2. Allowing 99.6 dB for the free space path loss and 4 dB for atmospheric attenuation, the estimated EIRP of the plateau of emission is 9.2 dBm.

From Figure 7, with the vehicle in motion, the observed spfd of the plateau is -144.7 dBW/m^2/Hz, with the spike stronger by a similar factor. The received pfd of the plateau is -122.4 dBW/m^2, with an estimated EIRP for the plateau component of 11.2 dBm. While in motion, the antenna remained in an orientation facing the distant receiver. The received signal was averaged over 30 seconds.

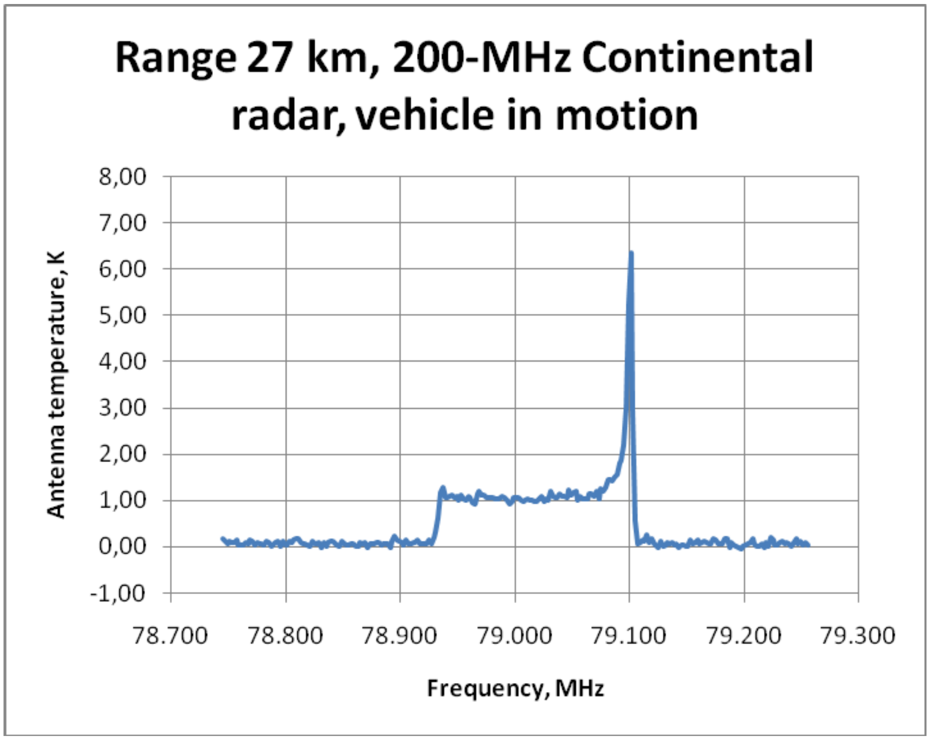

Figure 7 At a range of 26.9 km, the emission from the Continental 200-MHz radar, with the vehicle in motion. The plateau of emission has a brightness of 1.07 K, and the high frequency spike 6.4 K. The receiver noise on either side of the emission is 0.053 K, very close to the theoretical receiver noise of 0.049 K.

Figure 8 shows the observed emission from the 800-MHz Continental radar, with the vehicle in motion. The mean brightness of the observed emission at the range of 26.9 km is 0.41 K, although only the central 500 MHz of the 800-MHz spectrum are seen in the receiver. This corresponds to an observed spfd at the receiver of -148.8 dBW/m^2/MHz, with a pfd of -119.8 dBW/m^2. With the free space loss and 4 dB of atmospheric attenuation, this corresponds to an EIRP of 9.2 dBm.

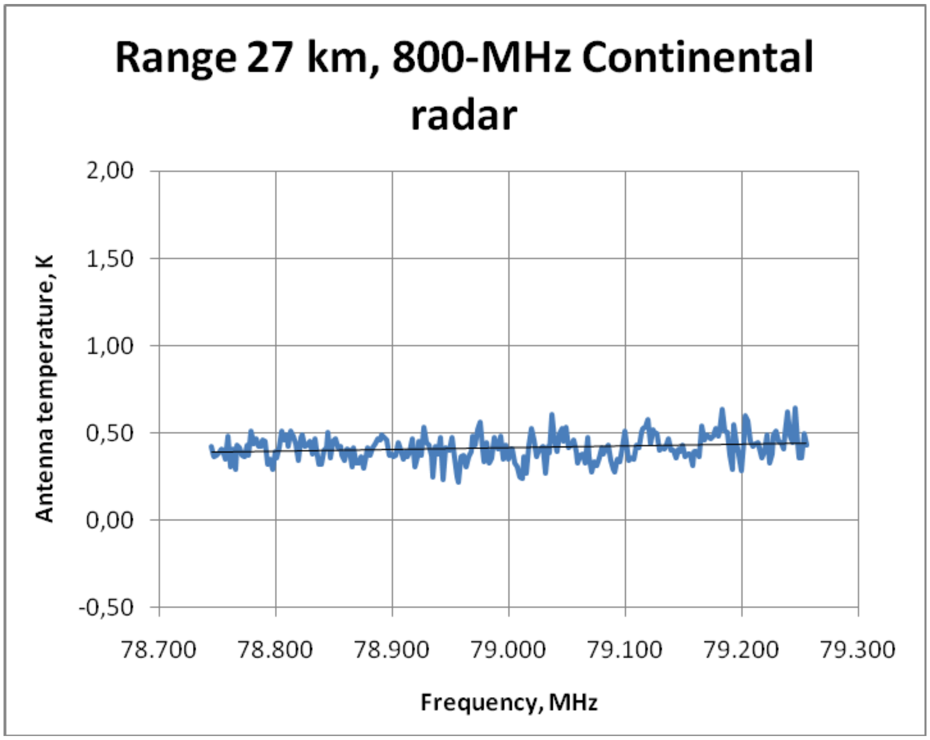

Figure 8 Range 26.9 km, observed emission from the Continental 800-MHz radar, with the vehicle in motion. The plateau of emission has a brightness of 0.41 K, although only the central 500 MHz of the 800 MHz emission spectrum are observed.

7 Summary of results

Table 1 Summary of Measurements

Fig	**Radar**	**Tb peak** K	**Tb plateau** K	**Prx** dBm	**Meas. Range** km	**Free space loss** dB	**Atm. Atten** dB	**Pfd** dBW/ m^2	**Spfd** dBW/ m^2/ MHz	**EIRP** dBm	**Avoid. Zone radius** km
4	Cont.200 Stationary	5982	968	-86.4	1.7	135.0	0.3	-92.8	-115.1	13.0	39
5	Bosch.WB Stationary	-----	60.1	-88.9	1.7	135.0	0.3	-95.3	-127.2	10.5	15
6	Cont.200 Stationary	3.08	0.68	-118.0	26.9	159.0	4.0	-124.4	-146.7	9.2	30
7	Cont.200 In motion	6.36	1.07	-116.0	26.9	159.0	4.0	-122.4	-144.7	11.2	34
8	Cont.WB In motion	-----	0.41	-113.4	26.9	159.0	4.0	-119.8	-148.9	13.7	25
-	**RA.769 1 MHz bw spectral line threshold**	-	-		-	-	-	-	**-148**	-	-

Notes on columns in above table:

Fig: The figure number in this document, from which the data in each row of the table were derived.

Radar: A description of the specific automotive radar. “Cont.” means the radar provided by the Continental Corporation, and “Bosch” by Robert Bosch GmbH. “200” means a nominal bandwidth of 200 MHz (in fact 170 MHz) and “WB” means the wideband radar with a nominal bandwidth of 800 MHz (Continental) or 1550 MHz (Bosch).

Tb(peak) K: The antenna temperature in degrees K measured for the peak of emission found at 79.1 GHZ, as seen within a 2-MHz filter channel. This is for reference, but is not used in the subsequent calculations.

Tb(plateau) K: The antenna temperature in degrees K measured for the plateau of emission, excluding any isolated peaks, as seen within 2-MHz filter channels. The remaining columns in this table are based on this plateau of emission, not on the stronger peak at 79.1 GHz.

Prx: The power received, dBm. Calculated from Tb plateau .k. B, with k Boltzman’s constant = $1.38.10^{-23}$, and B the bandwidth in Hz. For “Cont 200” the bandwidth is 170 MHz, for Bosch WB 1550 MHz, and for Cont.WB 800 MHz.

Meas. Range km: The line-of-sight distance, in km, between the automotive radar and the receiver used for these measurements.

Free space loss dB: This is the attenuation introduced by the free-space Range (km) given in the adjacent column, for isotropic transmit and receive antennas. This is calculated from $20.\log(4.\pi.d/\lambda)$, with d the distance in meters and λ the wavelength in meters, and does not include atmospheric attenuation.

Atm. Atten dB: This is the computed additional attenuation introduced by the atmosphere at this frequency, for the corresponding line-of-sight distance given in the “Range” column. A value of 0.15 dB/km is taken.

Pfd dBW/m^2 : This is the power flux density, integrated over the assumed transmitter bandwidth, of the total emission from the respective radar, at the receiver. Units dBW/m^2. This includes *only the plateau of emission*, not any isolated spikes within the spectrum. The receiver antenna gain of 35.8 dBi is taken into account in this calculation.

Spfd dBW/m^2/MHz: The spectral power flux density at the receiver, in units of dBW/m^2/MHz. This is derived from the previous column using (where possible) the measured bandwidth of emission, or by an assumed transmitter bandwidth.

The last line of the table gives the threshold spfd for interference taken from Table 2 in ITU-R RA.769-2, converting from “per Hz” into “per MHz” units.

EIRP: The derived effective isotropic radiated power (EIRP) at the transmitter, based on the received pfd shown in a previous column. Units of dBm. This is calculated from
EIRP = power_received + path loss + atmos.loss – recv_ant_gain, with
power_received from column 5 of this table,
path_loss from column 7,
atmos.loss from column 8,
and with *recv_ant_gain* = 35.8 dBi.

Avoidance Zone radius: Obtained by scaling the 1.7-km or the 26.9-km measurements to give the minimum distance from the radio telescope that would be necessary for a single transmitter, mounted on a single vehicle, to give a level of interference at or below the threshold specified in ITU-R RA.769, which is defined for a 0 dBi receiving antenna gain. In calculating the avoidance zone radius, an atmospheric attenuation of 0.15dB/km has been added to the normal free space inverse square distance path loss. This distance is then calculated from the difference between the observed spfd (column 10, Table 1) and the RA.769 value for spfd (last row, column 10), with the corresponding distance corresponding to this differential loss taken from Figure 9.
This is included purely for illustrative purposes. For multiple transmitters on a given vehicle, and for more than one vehicle in view of the telescope, the avoidance zone radius would be correspondingly increased. Mitigation factors such as any terrain shielding, orientation of the transmitter antenna with respect to the observatory, or attenuation of the transmitter if mounted behind the vehicle bumper have not been taken into account, and would tend to reduce the avoidance radius.

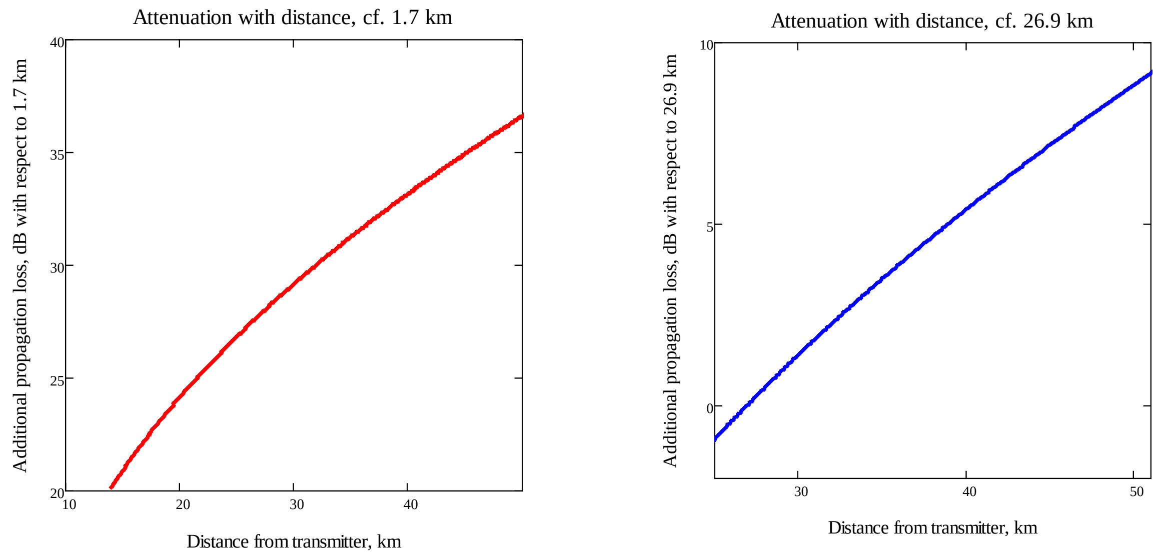

Figure 9 The extra propagation loss vs. distance, compared to a distance of 1.7 km (left) or 26.9 km (right), including both inverse square of distance free space loss and 0.15 dB/km of atmospheric attenuation.

8 Comparison with ITU-R RA.769.

The measured values of Table 1 above can be compared to the threshold interference levels defined in ITU-R RA.769. That recommendation contains separate recommendations for the case of broadband interference (Table 1 of RA.769, "continuum"), or for narrow-band (Table 2 of RA.769,"spectral line") interference. In the current context, allowing for the dilution of the 170-MHz or 1550-MHz bandwidth of the interfering transmitter signal over the 8 GHz receiver bandwidth as defined in RA.769, the different interference thresholds are within a few dB of each other.

8.1 Spectral Line Threshold

First we consider the spectral line case. Table 2 of ITU-R RA.769-2 gives a threshold level of interference detrimental to radio astronomy spectral-line observations in this frequency band of -208 dBW/m^2/Hz, equivalent to -148 dBW/m^2/MHz. As seen in Table 1 above, by chance most of the measurements described here give an spfd at a distance of 26.9 km within a few dB of this limit. The rightmost column of Table 1 above gives the necessary avoidance zone radius in order that the corresponding transmitter measured here does not produce an interference level at the radio telescope in excess of the spectral line threshold defined in RA.769. Note this is purely for illustrative purposes, and applies to a single transmitter on a single vehicle.

8.2 Continuum Threshold

The corresponding continuum spfd threshold interference level, taken from ITU-R RA.769-2 Table 1, is -228 dBW/m^2/Hz, equivalent to -168 dBW/m^2/MHz. This is 20 dB more stringent than the spectral line case discussed above. However, the interfering emission in this case must be averaged over 8 GHz. For example, if emission from a single Continental 170-MHz bandwidth radar were diluted over 8 GHz, the average spfd per MHz would be reduced by 8000/170 = 16.7 dB, which by chance is close to the 20 dB greater stringency of continuum interference threshold.

Note that, if there are several transmitters on a given vehicle *on different frequencies*, then although the spectral line threshold spfd (in any 1 MHz band) may remain unchanged, nevertheless the average spfd within an 8-GHz band, as defined by the RA.769 continuum threshold, would increase correspondingly. Table 2 below summarizes the comparison between our measurements and the threshold for interference to continuum observations defined in RA.769-2.

Table 2 Comparison of Measurements with RA.769 Continuum Threshold

Fig	**Radar**	**Tb plateau** K	**Meas. Range** km	**Atm. Atten** dB	**Transmitted bandwidth** MHz	**Spfd, diluted over 8 GHz band** dBW/m^2/MHz	**Avoidance Zone radius** km
4	Cont.200 Stationary	968	1.7	0.3	170	-131.8	48
5	Bosch.WB Stationary	60.1	1.7	0.3	1550	-134.3	41
6	Cont.200 Stationary	0.68	26.9	4.0	170	-163.4	38
7	Cont.200 In motion	1.07	26.9	4.0	170	-161.4	43
8	Cont.WB In motion	0.41	26.9	4.0	800	-158.9	51
-	**RA.769 8 GHz bw continuum threshold**	-	-	-		**-168**	-

Table 2 Comparison of the measurements with the spfd threshold of interference for continuum observations, as defined in Table 1 of RA.769-2

Notes on columns in above table:

Fig: The figure number in this document, from which the data in each row of the table were derived. Same as Table 1.

Radar: A description of the specific automotive radar. “Cont.” means the radar provided by the Continental Corporation, and “Bosch” by Robert Bosch GmbH. “200” means a nominal bandwidth of 200 MHz (in fact 170 MHz) and “WB” means the wideband radar with a nominal bandwidth of 800 MHz (Continental) or 1550 MHz (Bosch). Same as Table 1.

Tb(plateau) K: The antenna temperature in degrees K measured for the plateau of emission, excluding any isolated peaks, as seen within 2-MHz filter channels. The remaining columns in this table are based on this plateau of emission, not on the stronger peak at 79.1 GHz. Same as Table 1.

Meas. Range km: The line-of-sight distance, in km, between the automotive radar and the receiver used for these measurements. Same as Table 1.

Atm. Atten dB: This is the computed additional attenuation introduced by the atmosphere at this frequency, for the corresponding line-of-sight distance given in the "Range" column. A value of 0.15 dB/km is taken. Same as Table 1.

Transmitted bandwidth: This is the actual bandwidth occupied by the emissions from each transmitter. For multiple transmitters on different frequencies, this figure would have to be correspondingly increased.

Spfd, diluted over 8 GHz band: This is derived from the column **Spfd** in Table 1, but allowing for the dilution of the transmitted signal over the 8 GHz receiving band defined by RA.769. An amount *10.log(B/8000)* is added to the values tabulated under **Spfd** in Table 1, with B corresponding to the bandwidth of the radar emission in MHz, given in column 6. The last row in this table contains the spfd threshold of -228 dBW/m^2/Hz taken from Table 1 of RA.769-2, equivalent to 168 dBW/m^2/MHz.

Avoidance Zone radius: Exactly as in Table 1, but for the RA.769 continuum threshold. This distance is calculated from the difference between the observed spfd given in column 7, **Spfd diluted over 8 GHz**, and the RA.769 value for continuum spfd threshold (last row, column 7), with the distances corresponding to this differential loss derived as before from Figure 9.
As with Table 1, this is included purely for illustrative purposes. For multiple transmitters on a given vehicle, and for more than one vehicle in view of the telescope, the avoidance zone radius would be correspondingly increased. Mitigation factors such as any terrain shielding, orientation of the transmitter antenna with respect to the observatory, or attenuation of the transmitter if mounted behind the vehicle bumper have not been taken into account, and would tend to reduce the avoidance radius.

9 Estimated errors

Most of the received spectra were taken with the radar at a height of 1.6m at a fixed location. Tests made with the vehicle moving over a paved surface in Sells resulted in an increase in signal strength of about 2 dB. This change was most likely the result of a change in the ground reflection which interferes with the signal via the direct path. For example, a ground reflection coefficient magnitude of 0.3 (-10 dB) results in a variation of about +/- 2 dB depending on the reflection phase, which depends on the height of the radar and the elevation angle of the line of sight to the receiver. Uncertainty in the atmospheric attenuation is another source of error. The 225 GHz “tipper” radiometer at the 12-M telescope was used to derive a zenith precipitable water vapor content of 4.3mm, which corresponds to 11% relative humidity at 300K. Using the curves of Shambayati the attenuation at 79 GHz is estimated to be 0.1 dB/km for the water vapor and 0.04 dB/km for the dry atmosphere for a total of 4 dB for the 26.9 km path. The uncertainty in this estimate is about +/- 1 dB. Using the ITU-R P.620 recommendation, for a high dry site the total atmospheric attenuation would be about 0.135 dB/km, in good agreement with Shambavati. Another estimate was obtained by measuring the contribution of the atmosphere to the receiver noise. At an elevation of 3 degrees the atmosphere contributed 100K which corresponds to 4.8 dB of attenuation. If we assume a scale height for the water of 2 km then the path length at 3 degrees is 38 km, so that the loss for a horizontal path of 26.9 km is estimated by this alternate method to be 3.5 dB.

The estimates of EIRP made at different distances are in quite good agreement. With the vehicle stationary, the estimated EIRP from 26.9 km of the plateau of emission from the Continental, 200-MHz radar is 9.2 dBm; however, the comparison with results when the vehicle were in motion suggest that this value may be artificially low, presumably because of ground reflections. With the vehicle in motion at 27 km, 11.2 dBm was derived. See Figure 6 and Figure 7. At 1.7 km, the corresponding estimate (Figure 4) is 13.0 dBm, some 1.8 dB greater. This difference of 1.8 dB might be attributable to an underestimate of atmospheric attenuation over the 27 km path, to different reflections from the road and nearby terrain, or to differences in orientation of the transmitter antenna with respect to the receiver at Kitt Peak. The elevation angle towards the Kitt Peak receiver from the 1.7 km distant site was approximately -6 degrees, while from the Sells airport was approximately +10 degrees. The spfd derived here from the measurements at a distance of 1.7 km of the Continental (170 MHz) radar was -9.3 dBm/MHz, while the manufacturer measured -9.0 dBm/MHz. Considering the possible sources of error, the agreement with the manufacturer’s data, and between the different measurements at different distances reported here, is considered to be very good.

10 Conclusions

Tests performed with short range vehicular radar systems, operated at distances of 1.7km and 26.9 km from the University of Arizona’s 12 Meter millimeter wave telescope, demonstrated that these radars could have a significant impact upon radio astronomy observations in the 77 to 81 GHz region. A zone of avoidance of about 30 to 40 km around a mm-wave observatory would be needed, in order to keep interference from a single vehicle below the threshold defined in RA.769-2. Smaller zones of avoidance might suffice in areas without direct line of sight to the radio telescope and/or by taking some of the above mentioned mitigation factors into account. ITU-R RA.1272-1 specifically recommends that such zones be established around mm-wave astronomical observatories, following the procedure outlined in Recommendation ITU-R RA.1031-2.

References:

"Millimeter and Submillimeter Wavelength Radio Astronomy", John M. Payne, Proceedings of the IEEE, Vol 77, No. 7, July 1989, pp 993 - 1017.

See Fig 2 in:
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