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Interference on the Compact Array and Shielding Recommendations

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1. Introduction

A survey of interference by Mark Wieringa and Ravi Subrahmanyan[1] shows that there is considerable interference in the 20 and 13 cm bands (see Figs. 1 and 2). Figs. 3 and 4 [2] show less interference in the 6 and 3 cm bands.

To increase the sensitivity of the array to interference, the tests by Mark Wieringa and Ravi Subrahmanyan were made with *no* fringe rotation. During normal observations, the phases of the local oscillators in the antennas are rotated to stop fringes at the field centre. Phase rotation attenuates the effect of most interference. Interference at 8106 MHz and 8166 MHz for example, which appears as 40 Jy spikes in Fig. 4 with no phase rotation, is attenuated by a factor of 10 by the phase rotation when observations are made on a 337 m baseline.

George Graves has written a report[3] in which he outlines the radiation paths and suggests ways to reduce the interference in the compact array antennas.

Graham Nelson asked me to report on the sources of interference on the compact array and measures which could be taken to reduce that interference. The major sources of interference are summarized in Section 2, and measures which could be taken to shield the vertex room are listed in Section 3.

2. Sources of interference

The frequencies and sources of the interference in Figs. 1 to 4 are listed in Table 1. Although I have not yet identified all the sources of interference, it is clear that the worst interference in the 20 cm band is external to the AT antennas and comes from the GLONAS and GPS satellites and from terrestrial microwave links.

Internally generated interference is no less serious, but the frequencies affected are predictable. I have identified the 11th, 12th, 19th and 20th harmonics of the 128 MHz sampler clock frequency at 1408 MHz, 1536 MHz, 2432 MHz and 2256 MHz, respectively. Interference near 2240 MHz, may be the 7th harmonic of the 320 MHz local oscillator comb frequency, but is more likely to be a microwave link.

The amount of interference in the 20 cm band makes the choice of continuum band difficult. The 128 MHz continuum band centred on 1472 MHz, which is between the harmonics of the 128 MHz sampler clock at 1408 MHz and 1536 MHz, has interference at 1460 MHz and 1503 MHz. An alternative 128 MHz continuum band in the 20 cm band, centred on 1380 MHz (1316 MHz - 1444 MHz) has interference on some baselines at 1408 MHz.

Frequency (MHz)	Source of interference
1240	Source unknown
1250	Source unknown
1276	Source unknown
1343	Source unknown
1408	11th harmonic of 128 MHz sampler clock
1458	Source unknown
1477	Source unknown
1503	Transmitter on Mt Dowe
1530	Source unknown
1536	12th harmonic of 128 MHz sampler clock
1542	Source unknown
1545	Source unknown
1562	Source unknown
1576	GPS satellite coarse/acquisition code at 1575.42 MHz
1603-1615	GLONAS satellite
1680	Source unknown
1688	Source unknown
1691	Source unknown
1694	Source unknown
1720	Source unknown
2233	Receiver on Mt. Dowe
2242	Source unknown
2265	Receiver on Mt. Dowe
2280	Receiver on Mt. Dowe 1.5 Watt transmitter on Davies Hill, Tamworth.
2346	Source unknown
2432	19th harmonic of 128 MHz sampler clock
2489	Source unknown
2555	Source unknown
2560	20th harmonic of 128 MHz sampler clock, or 8th harmonic of 320MHz local oscillator comb frequency.
4294	Source unknown
4611	Source unknown
4621	Source unknown
4676	Source unknown
4889	Source unknown
5199	Source unknown
5641	Source unknown
6500	Source unknown
8106	Source unknown
8166	Source unknown
9106	Source unknown

Table 1.

Tests done by George Graves [4] indicate that interference must be picked up directly by the front ends rather than in the conversion system. I suspect that there is some interference from the electronics in the local oscillator, sampler or conversion racks in the vertex room (including harmonics of the 128 MHz sampler clock) which is radiated and is entering the receiver feeds in the cone room. (To be consistent with the terminology used in [3], I will refer to the room which contains the horns as the "cone" room and the room below, which contains the local oscillator, conversion and sampler racks, as the "vertex" room.)

2.1 Externally generated interference

GPS satellites transmit at two frequencies in the 20 cm band: at 1575.42 MHz they transmit the coarse/acquisition code and the precision code; at 1227.6 MHz they transmit only the precision code.

The Russian GLONAS satellites cause considerable interference. Each of the satellites transmits on one of 24 channels between 1602.56 MHz and 1615.50 MHz. In September, 1993, the frequencies of all satellites with carrier frequencies in the radioastronomy band, 1610.6 MHz – 1613.6 MHz, were changed to frequencies outside the band. There is still some interference in this band from sidebands of the other satellites. I understand that the Russians have agreed to remove all interference from the radioastronomy band by 1998[5].

Microwave ovens cause interference in the 13 cm band between 2400 MHz and 2500 MHz.

Much of the interference shown in Figs. 1 and 2 is probably due to microwave links. Col Easter, of the Department of Transport and Communications, District Radio Inspector's Office, Tamworth, provided lists of licensed transmitters and receivers within a 100 km radius of Narrabri and Coonabarabran. From these lists I have identified as probable sources of interference, the microwave links listed in Table 2. The moderately strong interference at 2280 MHz may be from a 1.5 Watt transmitter in Tamworth which is directed towards a receiver on Mt. Dowe, near Mt. Kaputar. Some of the unidentified interference in Figs. 1 and 2 may be due to microwave transmitters which transmit in the direction of the AT, but are more than 100 km from Narrabri.

Frequency (MHz)	Link
1503	Transmitter on Mt Dowe
2233.5	Receiver on Mt. Dowe
2265.5	Receiver on Mt. Dowe
2280	1.5 Watt transmitter on Davies Hill, Tamworth. Receiver on Mt. Dowe

Table 2.

2.2 Internally generated interference

Internally generated interference is most likely to be harmonics of signals already in the antenna. There are four potential sources of internally generated interference:

- the reference tones,
- the non phase-rotated 2 GHz and 7 GHz local oscillators,
- the phase-rotated UHF local oscillator and
- the 128 MHz sampler clock.

We rely on phase rotation in the antennas to attenuate the effects of internally generated interference. All interference entering the receiver system will be phase rotated in the conversion rack. Interference from harmonics of the reference tones, the non phase-rotated local oscillators and the phase-rotated UHF local oscillators from different antennas will not correlate because each antenna has a different fringe rate.

Most of the internally generated interference is from harmonics of the 128 MHz sampler clock. As shown in Appendix 1, the fringe rotation in the antenna exactly stops the fringe rate of all harmonics of the sampler clock which may enter the receiver system through the horn. Because the local oscillator system in each antenna is locked to the same reference frequency, harmonics of the sampler clock from different antennas will correlate.

Harmonics of the 128 MHz sampler clock may be radiated from the L1 Sampler Clock module or S1 Sampler module. In the sampler, a phase rotated 512 MHz clock is divided down to 128 MHz and used to clock the 4-bit samplers. The 128 MHz waveform, which is then returned to the sampler clock module, is a "square wave" with rise and fall times of about 2 nS.

The sampler module has two sets of ventillation holes in the 1.6 mm thick cover. Each group consists of 474, 3 mm diameter holes spaced 4.7 mm centre-to-centre. Using equations provided by George Graves[3], for a circular hole the attenuation *A*, in dB, is

$$A = 32 \cdot \frac{t}{d} \qquad (1)$$

where *t* is the pate thickness and *d* is the hole diameter. For *N* holes, the attenuation is reduced to

$$A = 32 \cdot \frac{t}{d} - 20\log_{10}(N) \qquad (2)$$

For one 3 mm hole in a 1.6 mm plate, eqn. (1) predicts an attenuation of 17 dB; for only seven holes eqn. (2) predicts ~0 dB attenuation. I don't think the present sampler module cover, which has 948 holes, can be providing any significant shielding. Increasing the thickness of the module cover will improve the shielding: eqn. (2) predicts an attenuation of 68 dB for a 12 mm thick cover plate.

As measurements[6] have shown that there is little difference between the signal radiated with a solid cover or with the perforated one currently in use, there may also be other mechanisms by which the sampler clock is being radiated from the sampler module. We might suspect the seal between the cover and the module, the OSP coaxial connectors or the backplane wiring.

Measurements[7] have also shown that the leakage from an OSP connector is about -90 dB, which is about 10 dB worse than that from an SMA connector. This agrees with the manufacturer's specification. As the power, control and monitoring wiring in the module has been shielded, it is difficult to see how the OSP coaxial connectors or the backplane wiring could be causing significant interference.

A solid cover, or a thicker cover with ventallation holes, would seem to be necessary, but it would be difficult to provide sufficient cooling for the module electronics. The measurements which show that there is little difference between the isolation of a solid cover and the perforated one indicate that even a solid cover plate may not, by itself, stop the interference from the 128 MHz sampler clock. Clearly more work is required to resolve this problem.

3. Shielding the vertex room

3.1. Apertures in the vertex room.

There are two paths by which interference from the vertex room may enter the cone room:

- the direct path, through the holes etc. in the cone room floor, and
- the indirect path, over the edge of the dish or through surface panels and then through the GORTEX window.

Interference which follows the indirect path will be attenuated more than that which follows the direct path as it must travel further. Interference can leave the vertex room of one antenna and may enter the cone room of another antenna through the GORTEX window.

The apertures in the vertex room are listed in Table 3. I have assigned a priority to the shielding of the apertures based on the size of the aperture and whether it is in a direct or indirect path. A description of each aperture and suggested shielding is given in Appendix 2.

At the highest priority are the open holes in the cone room floor:

- the trapdoor between the vertex room and the cone room,
- the gap around the turret itself and
- the small square hole in the floor, on the western side of the cone room.

Shielding the small square hole in the floor, and the trapdoor between the vertex room and the cone room is straight forward; I am concerned about the interference that may come through the area around the turret itself. Some options for sealing this gap are described in [3], but we may be able to attenuate this interference by no more than 10 or 20 dB. If this were the case, it would limit the shielding of the vertex room, and sealing the remaining, lower priority, apertures may not significantly improve the system performance.

Apertures in the vertex room	Path	Priority	Comments
Trapdoor between the vertex room and the cone room	Direct	1	Trapdoor should be redesigned.
Area around turret	Direct	1	Difficult to shield
Small square hole in floor, on western side of the cone room	Direct	1	
Gap around cover over access hole under the C/X receiver	Direct	2	
Gap around receiver interface panel	Direct	2	
Air circulation fans	Direct	3	The existing vent panels approximate a waveguide beyond cutoff.
Vertex room doors	Indrect	3	
Air conditioner vents	Indrect	4	
Ungrounded outer conductors of coaxial cables and ungrounded shields on multicore cables passing through the hole in the vertex room floor	Indrect	4	These cables are difficult to shield.
UPS power on the turret and TURRET EMERGENCY STOP cabling	Direct	None	These cables are in unscreened Anaconda conduit but are unlikely to provide an interference path.
Mains cables passing through the floor of the cone room	Direct	None	These cables are in metal conduit and are unlikely to provide an interference path.
Turret drive motor access hole	Indrect	None	Welded or already shielded.

Table 3

3.2 Recommended action

1. The trapdoor between the vertex room and the cone room should be redesigned as described in Section A-2.1.
2. An attempt should be made to shield the gap around the turret as outlined in Section A-2.2.
3. The small square hole in the floor, on the western side of the cone room, can easily be shielded as described in Section A-2.3.

On one of the compact array antennas, the trapdoor, the gap around the turret and the small square hole in the floor should be shielded as described above and the interference compared with that measured when the trapdoor is open. For comparison, the interference should also be measured with the trapdoor and/or gap in the floor around the turret temporarily covered with sheets of aluminium which have had surface treated with chromate conversion (allodyned).

I also recommend the purchase of some RF absorber to line the cone room as suggested by George Graves [3].

5. References

[1] Wieringa, M. and Subrahmanyan, R., "A survey of interference in the 13cm and 20cm bands at the ATCA", May 18, 1992.

[2] Wieringa, M., private communication.

[3] Graves, G., "Radiated interference from the vertex room", AT 31.6.2/025.

[4] Graves, G., Gough, R., Amy, S. and Wieringa, M., "Interference within the antenna conversion system", AT 31.6.3/005.

[5] Chapman, J., private communication.

[6] Wilson, W., private communication.

[7] Graves, G., private communication.

A-1. Appendix 1: Internally generated interference

Interference from harmonics of the 128 MHz sampler clock are the dominant form of internally generated of interference. This is primarily because the phase rotation applied the incoming signal stops the fringe rotation of the harmonics of the sampler clock which enter the receiver system through the horn.

Consider the situation where we are observing a 128 MHz band at a centre frequency, f_0, (MHz), and are removing a fringe rate r at f_0. The phase rate of the UHF LO will be

$$\dot{p}_{L22} = r \cdot \frac{f_0 - 196}{f_0} \qquad (A1-1)$$

and the phase rate of the 128 MHz sampler clock will be

$$\dot{p}_{L21} = r \cdot \frac{128}{f_0} \qquad (A1-2)$$

so that the phase rate applied to the IF frequency, f_{IF}, (MHz), by the sampler will be

$$\dot{p}_{f_{IF}} = r \cdot \frac{f_{IF}}{f_0} \qquad (A1-3)$$

The phase rate applied to a frequency, f_{OBS}, (MHz), in the observing band will be

$$\dot{p}_{f_{OBS}} = \dot{p}_{L22} + \dot{p}_{f_{IF}} = r \cdot \frac{f_{OBS}}{f_0} \qquad (A1-4)$$

where

$$f_{OBS} = f_0 + (f_{IF} - 196) \qquad (A1-5)$$

The effect of the phase rotation in the antenna is to exactly stop the fringe rate on all the harmonics of the sampler clock which enter the receiver system through the horn. If f_{OBS}, is the n^{th} harmonic of the 128 MHz sampler clock,

$$f_{OBS} = n \cdot 128 \qquad (A1-6)$$

the interference will have a phase rate

$$\dot{p}_{n128} = n \cdot \dot{p}_{L21} = n \cdot r \cdot \frac{128}{f_0} \qquad (A1-7)$$

and, from eqn. (A1 – 4), the phase rate applied to the n^{th} harmonic of the 128 MHz sampler clock will be

$$\dot{p}_{f_{OBS}} = r \cdot \frac{f_{OBS}}{f_0} = r \cdot \frac{n \cdot 128}{f_0} \qquad (A1-8)$$

Because the local oscillator systems in all the antennas are locked to the same reference frequency, harmonics of the sampler clock from different antennas will correlate.

Harmonics of the UHF local oscillators in different antannas will not correlate as they have different phase rates and these phase rates are not stopped by the phase rotation in the antenna. If f_{OBS}, is the n[th] harmonic of the UHF local oscillator,

$$f_{OBS} = n \cdot f_{UHF} \tag{A1 – 9}$$

the interference will have a phase rate

$$\dot{p}_{nf_{UHF}} = n \cdot \dot{p}_{L22} = n \cdot r \cdot \frac{f_0 - 196}{f_0} \tag{A1 – 10}$$

and, from eqn. (A1 – 4), the phase rate applied to the n[th] harmonic of the UHF local oscillator will be

$$\dot{p}_{f_{OBS}} = r \cdot \frac{f_{OBS}}{f_0} = r \cdot \frac{n \cdot f_{UHF}}{f_0} \tag{A1 – 11}$$

The phase rotation in the antenna would exactly stop the fringe rate of the n[th] harmonic of the UHF local oscillator if

$$f_{UHF} = f_0 - 196 \tag{A1 – 12}$$

that is, if there were only one mixer before the sampler. As the AT has at least two down conversions before the sampler, the phase rotation on harmonics of the UHF local oscillator is not stopped by the phase rotation in the antenna.

A-2. Appendix 2

A-2.1 Trapdoor

At present the trapdoor attenuates interference only a little. The trapdoor should be redesign so that it is a solid metal door with a honeycomb ventilation panel. A range of ventilation panels is described in [3]. The hinges on the trapdoor should be offset so that a conductive gasket can be used to seal around the trapdoor. The trapdoor design should also make changing the C/X receiver easier.

CA02 note : Paint on the metal spray around the trapdoor door will need to be removed mechanically (or with a suitable solvent).

A-2.2 The gap in the cone room floor around the turret

A cross-section of the is gap in the cone room floor around the turret is shown in Fig. 5. The gap between the cone room floor and the turret floor (gap A) varies between 5 and 10 mm, and the gap between the turret floor and the guide ring (gap B) varies between 0 and 10 mm. A range of options is described in [3]. It would be best if we could find a "non-contacting" means of shielding the gap around the turret.

CA02 note : Paint on the metal spray on the cone room floor around the turret will need to be removed mechanically (or with a suitable solvent).

A-2.3 Small square hole

There is a rectangular hole 50 mm by 70 mm in the floor on the western side of the cone room. No one knows why it is there. It should be covered and sealed with a conductive RFI gasket.

A-2.4 The gap around the cover over the access hole under the C/X receiver

The floor of the turret around the cover over the access hole under the C/X receiver has been metal sprayed. The access hole cover is presently installed from the underside, rather than from the top where it could make contact with the metal sprayed area. A conductive RFI gasket is not used.

The metal on the underside of the vertex floor and around the edge of the access hole cover should be ground back to bare metal and coated with Electrodag conductive paint. A conductive RFI gasket should be used to seal the gap.

A-2.5 Receiver interface panels

The aluminium receiver interface panels in the vertex room have had a chromate conversion treatment and the flanges on the turret to which they are attached have been metal sprayed. A conductive RFI gasket is needed to seal the gap.

A-2.6 Air circulation fans

There are two air circulation fans. The air inlet vent frame is 217 mm square and is screwed to a 265 mm square flange. The vent itself is 173 mm square has 15 mm square holes which are 12 mm deep. Note that access to the bottom of the northern air circulation fan is impeded by the cable tray.

Interference from the air circulation fans may not be a great problem because the interference must pass through the existing vent panels which approximate a waveguide beyond cutoff.

Honeycomb ventilation panels could be installed. A range of ventilation panels is described in [3]. The flange should be ground back to bare metal and coated with Electrodag conductive paint. A conductive RFI gasket is needed to seal the gap.

A-2.7 Vertex room doors

There is a 0 to 10 mm gap 15 mm wide between the doors and the door jam. At present there is only a rubber weather seal on some antennas; other antennas have no weather seal. A range of materials is described in [3].

Glue and paint on the metal sprayed area around door will need to be removed mechanically (or with a suitable solvent).

A-2.8 Air conditioning vents

Interference from air conditioning vents may not be a great problem because the interference must pass through the existing vent panels, which approximate a waveguide beyond cutoff, and then find its way out of the air conditioning duct. The path then is over the edge of the dish or through surface panels.

The air conditioner outlet is 480 mm by 580 mm; the flange is 600 mm by 700 mm. Two sets of adjustable louvers to direct air flow are screwed to the flange.

The air conditioning return air vent is 480 mm by 580 mm with holes 10 mm square, by 10 mm deep. The return air flange is 600 mm by 700 mm.

Honeycomb ventilating panels, as described in [3], could be installed. The flanges would need to be ground back to bare metal and coated with Electrodag conductive paint. A conductive RFI gasket is needed to seal the gap.

A-2.9 Cables going through the vertex room floor

Ungrounded outer conductors of coaxial cables and ungrounded shields on multicore cables passing through the hole in the vertex room floor may provide a TEM mode interference path. The only way to shield these cables would be to run them all through grounded bulkhead connectors.

A-2.10 UPS power on the turret and the TURRET EMERGENCY STOP cabling

The UPS power on the turret and the TURRET EMERGENCY STOP cabling come through the floor of the cone room in unscreened Anaconda conduit.

A-2.11 Mains cables passing through the floor of the cone room

There are seven mains cables passing through the floor of the cone room. These are all in metal conduit and should not be a problem.

A-2.12 The turret drive motor access hole

The turret drive motor access hole has been sealed and should be RF tight. The cover on the access hole was originally bolted and welded. In 1993, the access holes on some of the antennas were opened and the covers bolted in place. Ron Beresford and John Grenenger recognized the need to prevent RFI leaking out this aperture. I understand that when the covers were replaced, the metal surfaces were coated with Electrodag conductive paint and a conductive gasket was used.

Figure 6

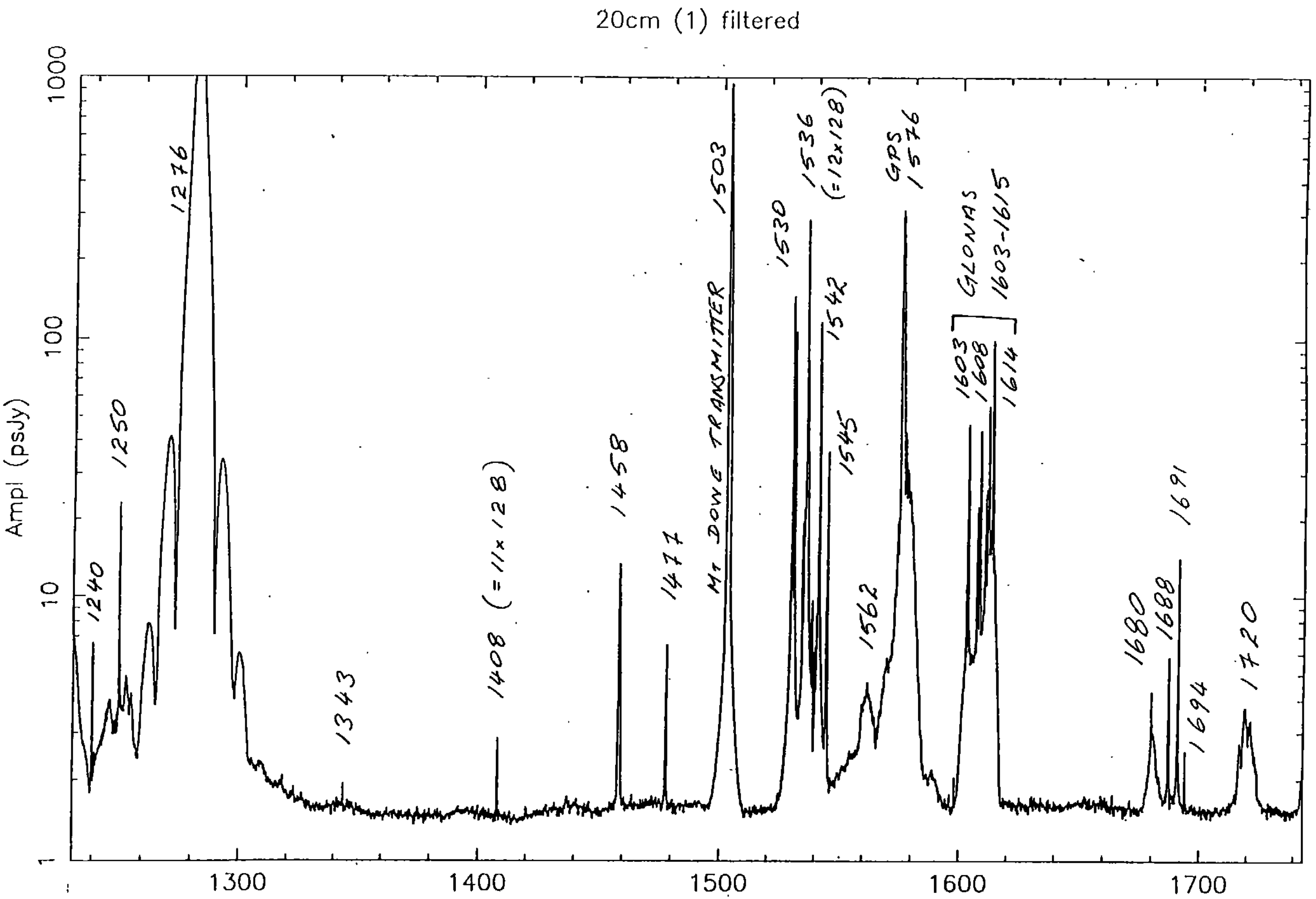

Fig. 1. Interference in the 20 cm band, taken from [1].

Figure 1

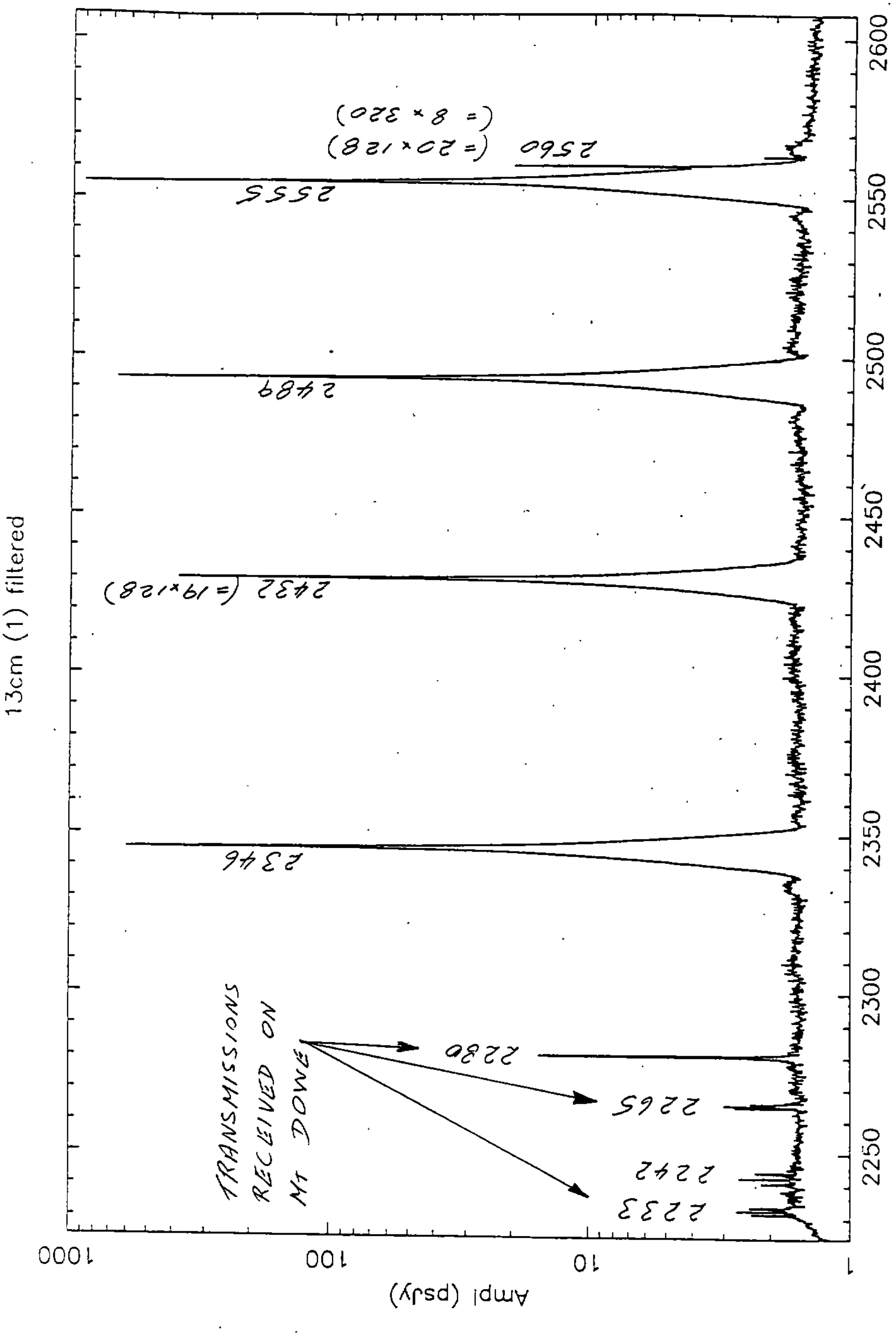

Fig. 2. Interference in the 13 cm band, taken from [1].

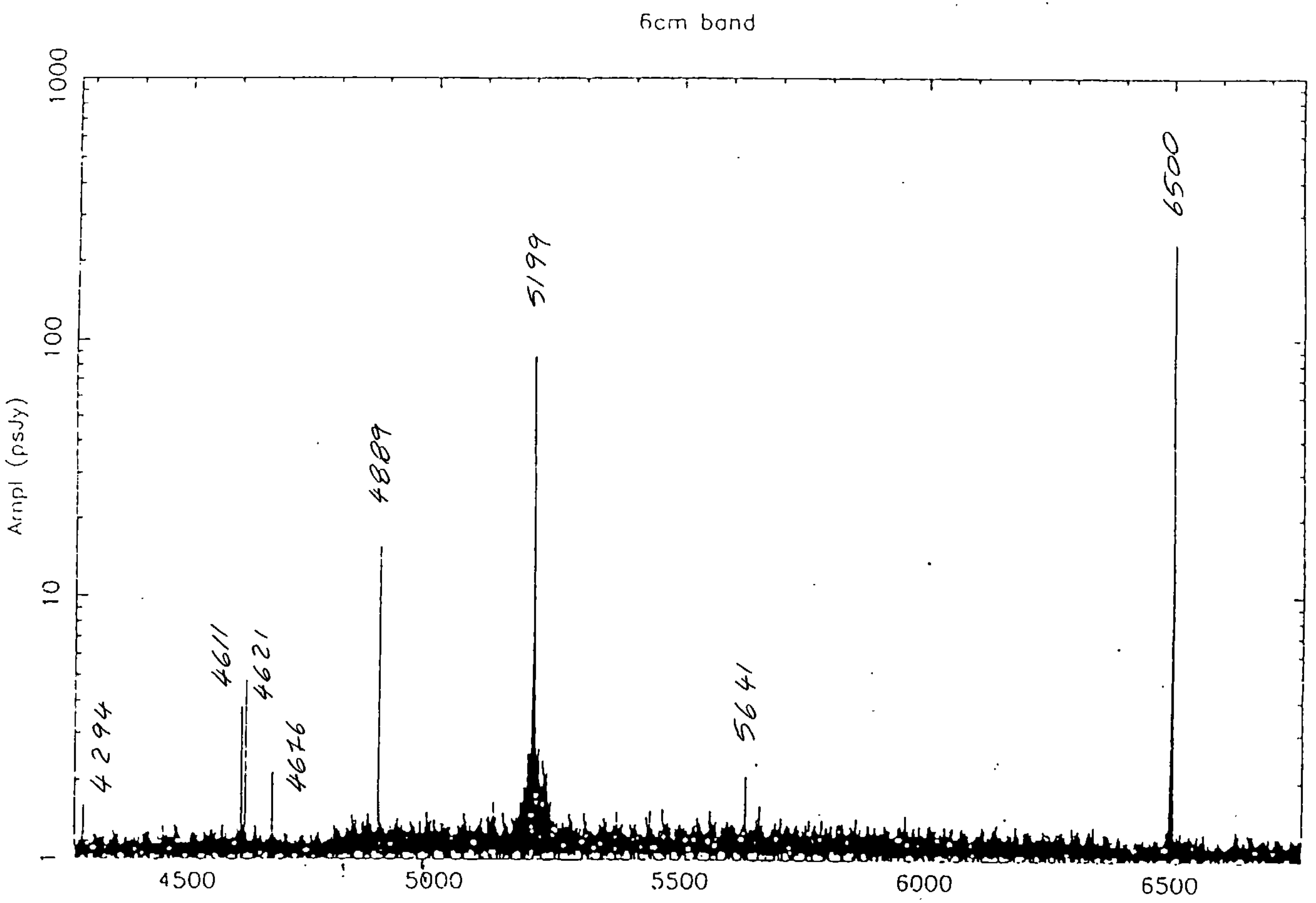

Fig. 3. Interference in the 6 cm band[2].

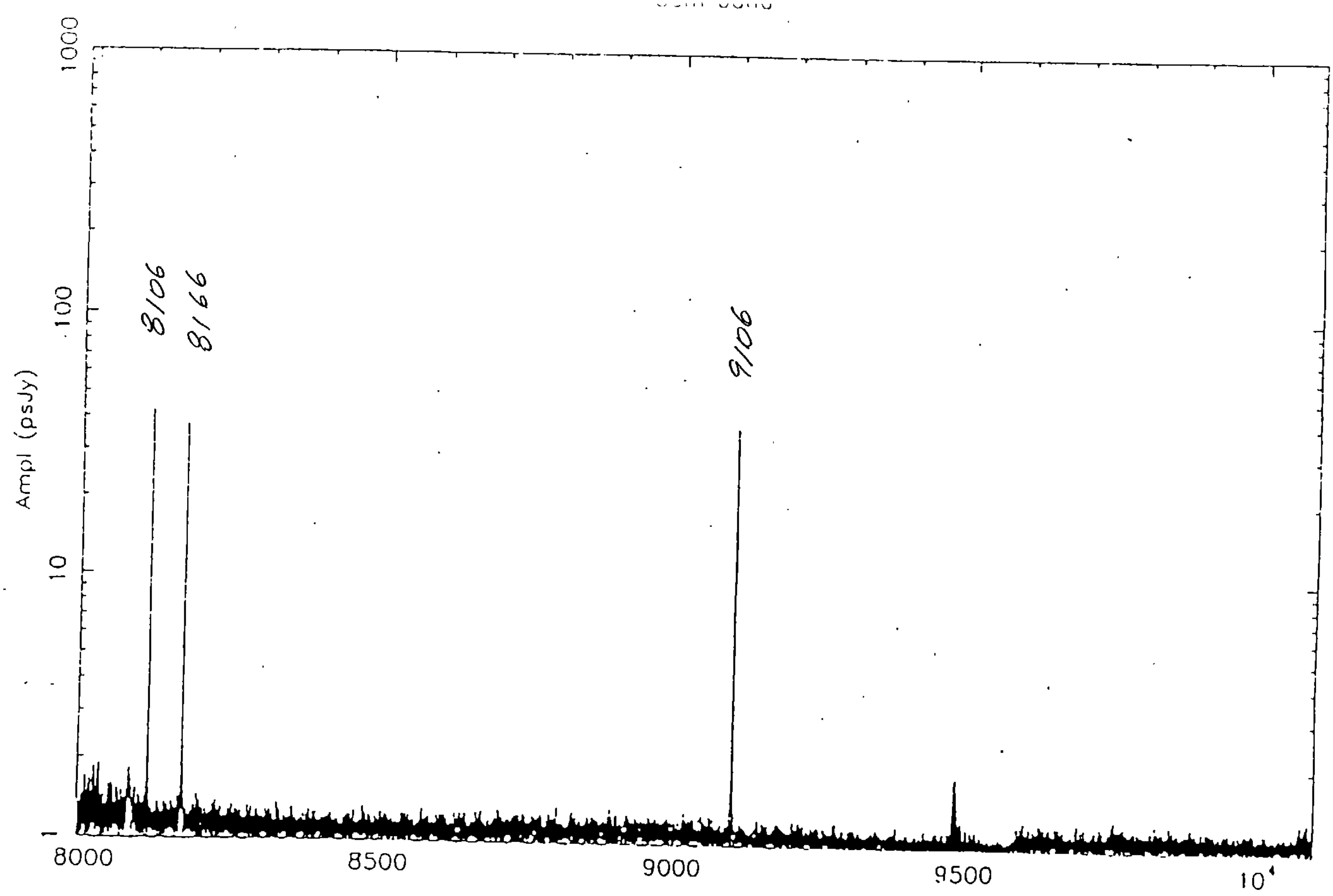

Fig. 4. Interference in the 3 cm band[2].

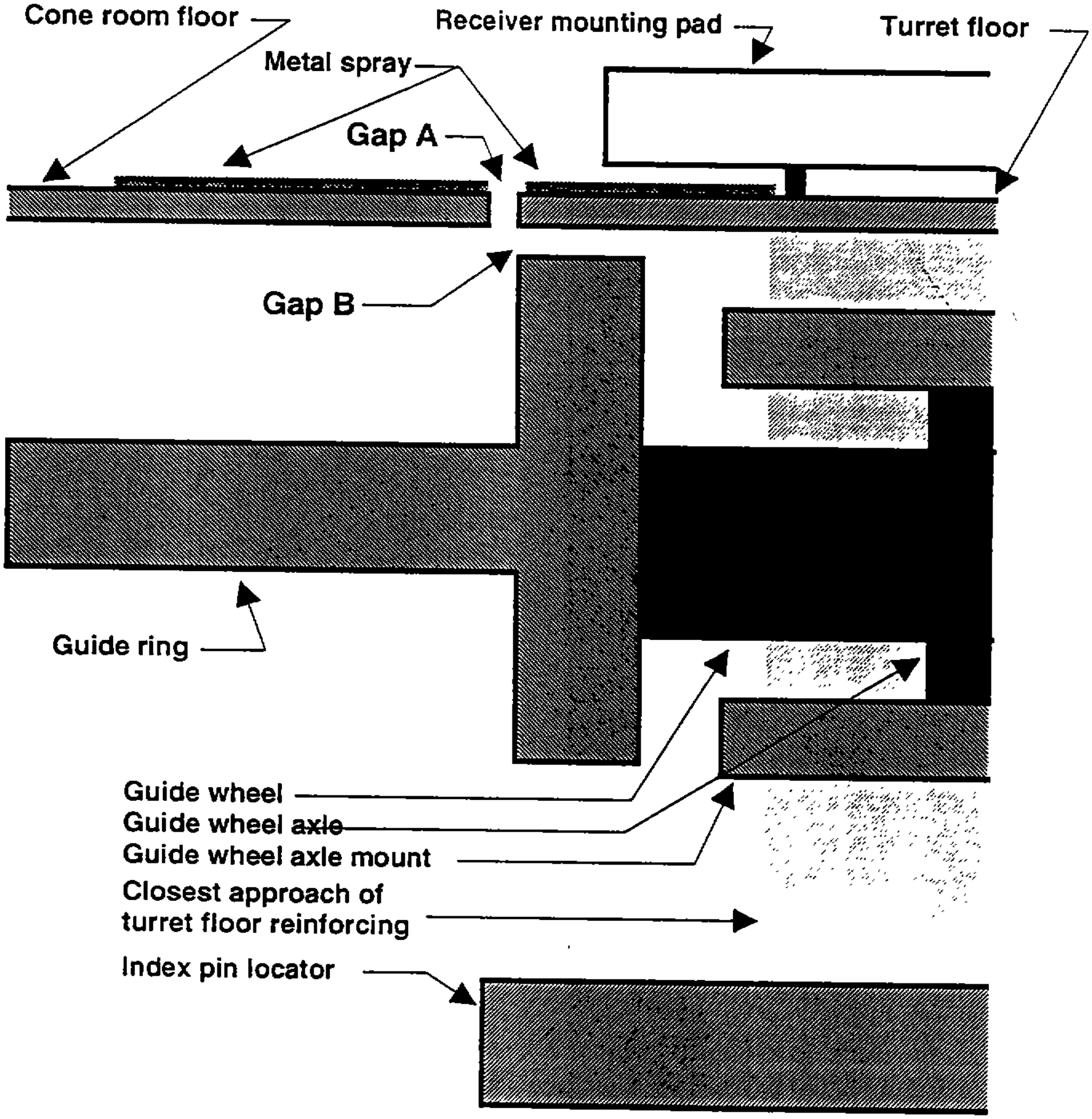

Fig. 5. Cross-section of the gap in the cone room floor around the turret.