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3.4 Radio Telescope Interference from a Ground Transmitter

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ABSTRACT

We report measurements of RFI (Radio Frequency Interference) from a mobile ground transmitter to a radio telescope system. Radio telescopes are equipped with a very sensitive LNA (low noise amplifier) in their focus. Although they are designed to have maximum sensitivity to extra-terrestrial radio sources with large aperture toward a pointing direction, the gain in undesired directions are still so high that they are apt to receive nearby terrestrial-based emissions. In this experiment the Global Star System mobile terminal with a frequency 1612.8 MHz was used as a transmitter and the Kashima 34-m radio telescope received the signal from 172 remote points. The received strength are evaluated based on the definition of the ITU recommendation RA.769-1. The signals are very strong and often harmful to radio-astronomical observation. But the strength of the RFI is absorbed by the transmitting distance and its transmitted area.

Keywords: Radio telescope, Radio Frequency Interference (RFI), Low Earth Orbit Satellite (LEO)

1. Introduction

1.1 Increasing RFI and regulations

Radio astronomical telescope encountering RFI (Radio Frequency Interference) has become a serious problem (Thompson et al., 1991)[1].
Especially, as the the dense populated country, the RFI monitoring in Kashima 34m hasbeen reported by Kawaguchi 1998[2]. Although the RFI from the mobile service is expected to increase, active measurement of RFI emission using a transmitter around telescope have not reported. This is due to the diffidence to obtain a transmitter license within the radio protected bands by astronomer themselves. Last decade, most of the interference had been occurred between limited number of services, for example military facility, microwave satellite link station and radar system. To determine these interferences, a monitoring system in 408MHz is developed in Dominion Radio Astrophysical Observatory (Romalo et al. 1989)[3]. Now, there has been a large increase in the demand for communication frequencies made available these band to personal usage. Thus the huge number of transmitters will emerge around radio telescopes in near future. The LEO (Low Earth Orbit satellite) terminal is one of transmitter in the 1612MHz. Under the tightness of frequency resources, the frequency of the Global Star system's ground terminal overlaps into the radio astronomy band of 1613.8-1612MHz. The band between 1612-1613.8MHz is preserved for Hydro-oxyl line observation. The ITU (International Telecommunication Union) issued recommendation (ITU-R) RA.769-1[4], RA.1031-1[5] and M.1316[6] including maximum acceptable flux at the radio astronomy service and frequency-sharing methods for the coexistence of radio systems. The Ministry of Posts and Telecommunications, Global Star Japan K.K, and CRL (Communications Research Laboratory), carried out active RFI measurement using transmitter actively in the radio astronomy band.

1.2 Radio telescope and RFI

When a telescope receives RFI, its IF (converted Intermediate Frequency) spectrum or output power detector does not show actual sky emissions. Only in VLBI (Very Long Baseline Interferometry), there is a little possibility of recovering the data with weak RFI since it uses two separate telescopes and it can exclude localized RFI in data processing. But a connected radio-interferometer consist of closely located elements receive common RFI simultaneously. Furthermore a single-dish observation, there is no mechanism to deal with the incoming RFI. Even the VLBI telescopes will receive common interference if the RFI is due to a satellite.

Usually observer notice interference existence by a strong spectrum in the IF or irregular fluctuation in the detector output. It is less frequent to have couple narrow main-lobes toward ground RFI. Off beam direction RFI entry to a typical cassegrain radio telescope is assumed as three following reasons. The first is telescope minor-lobe coupling to RFI sources. From −60 to −80 dB minor lobes are periodically exist in any direction. These lobes are neglected during cerestrial observation. But these minor-lobes are capable of receiving ground RFI. The second is a direct coupling of the feed beam pattern to the RFI source. Feed horn beam pattern illuminates the sub-reflector has also has minor lobes λ/D separated direction of −60 to −80 dB level. The lobes are easy to couple ground object when they are in low elevation. The third reason is radio scattering and reflection happened with radio-telescope mechanical structure and nearby buildings. Telescope dish usually have a sub-reflector above the main-reflector, certain structures are required to support a sub-reflector. The magnitude of off-axis side-lobes are reported in Hunt et al. 1992[7]. To avoid step into detail of these incoming mechanism contributions, In our measurement we increased number of measurement. This enables the data to see them statistically.

When a strong RFI is received, two problems besides reception of undesired spectrum will arise in the receiver system. One is the saturation of LNA (Low Noise Amplifier. The design of astronomical receiver system placed importance on low NF (noise figure) performance, but does not have dynamic-range. LNA in front-end and successive post amplifiers are optimized for NF. As the LNA saturation occurs, the output becomes RFI monotonic signal. Post amplifiers may over loaded too. The other problem is IM (inter-modulation) in frequency conversion. IM occur in the non-linear part of the receiver with strong signals more than two. It will happen between two strong RFIs or between a local-oscillator and RFI. When there are two component f_1 and f_2, IM produces another frequency spectrum of mf_1-nf_2, where the m and n are natural numbers. This means regardless of radio astronomy band protection, neighboring strong communication can produce radio astronomy in-band spectrum in the receiver system.

2. Measurement of RFI Strength

In order to measure RFI levels, Global Star Japan K.K and our group performed an experimental transmission on June 10th 1998, during mid-night. It have been monitored that the other ground based cellular base stations are relatively quiet between 12PM and 6AM, transmitter of 0.7 W CW output with a vehicle to whip. The mobile transmitter moves around the telescope. As in Figure 1, we measured 240 RFI points of distance between 0 to 20 km. Each point are located along road. The mobile vehicle stopped during each measurement. Due to traffic conditions, 173 point measurement data were obtained. The Kashima 34-m radio telescope received the signal stowed in zenith and measured the strength of transmitter with the spectrum analyzer. Thus the all signals are entered from off-beam direction. The Kashima 34m telescope is located between northern hilly area and southern developed plain area. The data points are differently marked by three transmit region : hilly area, plain area and nearby town area within 2-km circle. Figure 2. shows all the measurement against to its distance. Power flux density of the RFI is plotted from receiver noise floor in spectrum analyzer. Using the Appendix, monitored signal strength relative to receiver noise floor is converted to flux. Since the converted strength of the off-beam entry does not provide exact flux density happened at telescope location, It should be expressed as the 'apparent' flux density. Usually, this is the data observatories can show the existence of RFI to the other services. Since the 'apparent' flux density from off-beam coupling is lower than the real flux. Usually they are strong RFIs above the ITU-R regulation.

The measurement show the following results.

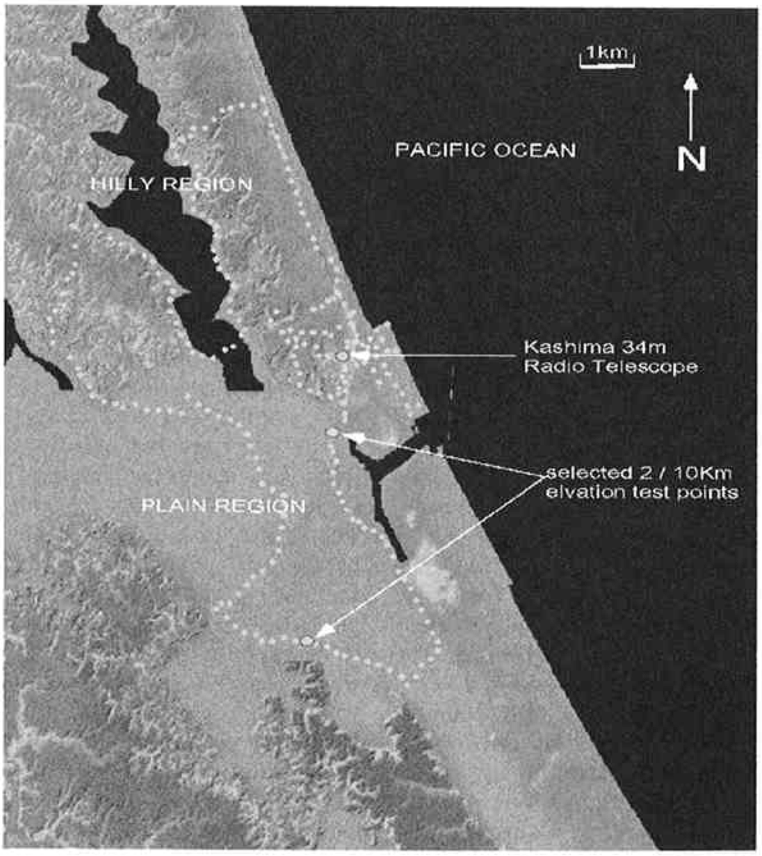

Fig. 1 240 RFI measurement position around Kashima 34m telescope. Route centered the radio telescope and the round trip distance about 240km. The map gray scale indicate the altitude. Kashima is east Kanto-plane face to the Pacific. The maximum altitude of this area is less then 70m from the sea level.

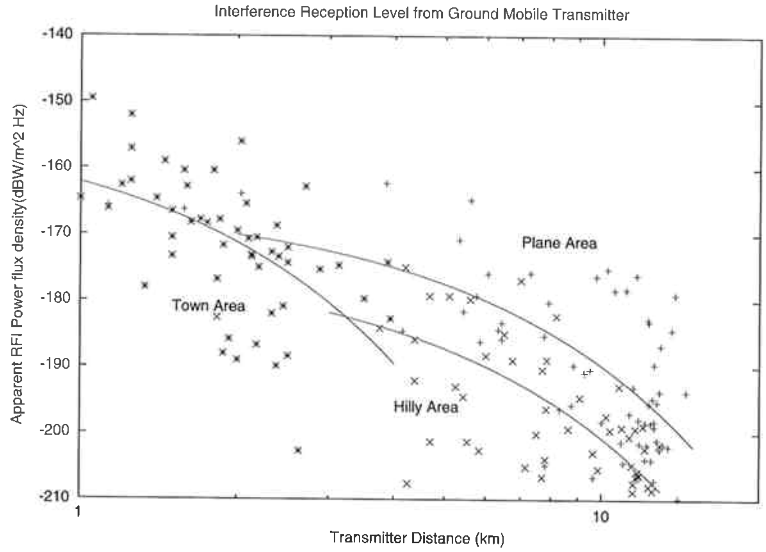

Fig. 2 Measured RFI power flux density against the distance from radio telescope. Data from hilly northern direction, plain factory region, localized city area plotted in different mark.

(1) The LNA (Low Noise Amplifier) system including down converter of the telescope is often saturated, when the transmitter is located within 2-km radius from the telescope.
(2) When the transmitter is separated more than 2-km from the telescope, the interference is too strong to carry out any observation.
(3) When the transmitter is being separated from the telescope, gradually the interference decreases. The strength of the signal is depend on its area. As described in Section 2.1, the amplitude varies 20 dB to 40 dB due to the off-beam coupling. Although, the statical distribution shows general tendency of RFI reduction from the transmitting area. In a hilly area with thick vegetation the RFI level is absorbed and 10 dB lower than in the developed plain area without screen. This is confirmed regression analysis shown with solid lines.
(4) The signal is still detectable from transmitter in the 15km point. In some data, the strength of terminal become comparable to injected calibration-tone for VLBI. The tone is usually used as 1-percent power of the band spectrum. Thus it is possible to carry out VLBI continuum observations when transmitters are separated. But they are still harmful to other observations.

3. Discussion and Conclusion

The telescope receiver system is saturated by the transmitter in local town area. The IF output is dominated by the strong interference. Under this condition, the noise band-pass characteristics of the receiver system is disappeared. To avoid to have such conditions, Global Star Cooperation and CRL agreed to prohibit terminal operation within the local area based on telescope observation schedule. Technically, one other method to cure the LNA from saturation is a band selected sensitivity LNA system. Although a slight insertion loss increases system noise temperature, NRAO (National Radio Astronomical Observatory) employed a cooled bandpass filter in front of LNA. In addition, new LNAs should be choose by a RFI bearing parameter. The parameter of amplifier 1dB gain compression power (P1dB GCP) represents its dynamic range performance before saturation. When the strong RFI enter the system, We confirmed IM in the IF. All measured data converted to flux using RA 769-1 shown in Figure 2, did not satisfy the radio astronomy acceptable level of RFI from coexistent service.

When the terminal separated outside the saturation area, the level of RFI is being decreased. The strength of the RFI is not exceed more than free space loss $P_r/P_t = (\lambda/4\pi D^2)$. Where the P_r is received power, P_t is transmitted power, λ is wavelength and D is the distance between the transmitter and the telescope. We found that there is -10dB RFI signal absorption from transmission from the hilly area. This shows the telescopes surrounded by complex geological environment has advantage of less RFI. As for the weak RFIs, A new method to reduce the RFI using adaptive cancellation system has developed by Burnbaum et al. 1998[8]. Although the digital system is in development stages before practical usage, they substantially reduced RFIs.

We conclude the RFI measurement result as the typical case of Kashima 34m and an example for other telescopes RFI evaluation. RFI around radio telescopes are increasing. All observatory should carefully check newly introduced radio service and they should monitor radio astronomy in-band out-band environment with the receiver.

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Appendix

For the radio astronomy observations, ITU-R 769-1 takes important role to define harmful interference level of radio telescopes from other radio services. Followings are summarized it's practical calculations from ANNEX1 and TABLE1.

In ITU-R 769, radio-telescope is defined as a radiometer measuring received power. At the beginning it is the same as the sensitivity treatment in famous textbook written by Kraus. Minimum detectable power in radio-meter is

$$\frac{\Delta P}{P}=\frac{1}{\sqrt{2}}\cdot\frac{1}{\sqrt{\Delta f_0\cdot t}} \quad \cdots\cdots (1)$$

where the Δf_0 is receiver bandwidth, t is integration period. ΔP is r.m.s. in 1σ to 3σ. In a radio telescope the power is often measured with noise equivalent temperature T. It's conversion relation is

$$\Delta P = k\Delta T, \quad P = kT \quad \cdots\cdots (2)$$

where the $k=1.38\times10^{-23}$ $(\mathrm{J\cdot K^{-1}})$ is the Boltzmann constant. Thus

$$\Delta T=\frac{T}{\sqrt{2\cdot\Delta f_0\cdot t}} \quad \cdots\cdots (3)$$

ΔT is minimum measurable noise temperature. Usually system temperature T includes T_a, the antenna temperature and T_r, the receiver noise temperature. The variation of the T_a depends on antenna configurations and operation conditions. T_r is also varied by LNA performance. Theses values are prepared in TABLE-1 of the ITU-R RA.769-1. In observation the telescope observed an object for certain integration time. In ANNEX-1, typical integration of $t=2000$ sec is employed for typical integration case. Using T_a, T_r, t, ΔT is derived for a typical telescope and this is a basis of RFI evaluation.

ITU-R, RA.769-1 suggests the telescope will allow 10% harmful RFI power. The harmful power ΔP_h is

$$\Delta P_h = 0.1\cdot\Delta P\cdot\Delta f_0 \quad \cdots\cdots (4)$$

On the other hand, power flux density is useful for expressing the RFI level. There is an assumption that the harmful power Ph is received at an isotropic antenna as a measurable quantity. An effective aperture area for the isotropic antenna is $A=c^2/4\pi f^2$ then, the power flux density $S_h\Delta f_a$ is obtained by correcting ΔP_h,

$$10\log\left[\frac{f^2\cdot 4\pi}{c^2}\right]=20\log f-38.6\mathrm{dB} \quad \cdots\cdots (5)$$

In this equation f is given by MHz. S_h (spectral power flux density) is obtained using assumed bandwidth also defined as a typical value in TABLE-1.

RFI evaluation at 1665 MHz is shown an an example. The following parameters are found in ITU-R, RA.769-1, TABLE-1

(1) Radio astronomical observation center frequency: fc 1665MHz.
(2) Assumed Bandwidth: $\Delta f_a=10$ MHz (scientifically needed at the frequency)
(3) Minimum antenna temperature: $T_a=10$ K (typical antenna noise temperature)
(4) Receiver noise temperature: $T_r=20$ K (typical receiver noise temperature)

Using the equation (1) to (5), RFI strength is obtained as follows,

(5) Minimum detectable ΔT (mK)

$$\begin{aligned}\Delta T &= T/\sqrt{2\cdot\Delta f}\\ &=(T_a+T_r)/\sqrt{2\cdot\Delta f_0\cdot t}\\ &=(10+20)/\sqrt{2\cdot10^7\cdot2000}\\ &=0.15\mathrm{mK}\end{aligned}$$

(6) Power Flux Density ΔP (dB(W/Hz))

$$\begin{aligned}\Delta P &= 10\log[k\Delta T]\\ &=10\log[1.38\times10^{-23}\cdot0.15\times10^{-3}]\\ &=-267\mathrm{dB(W/Hz)}\end{aligned}$$

(7) Harmful Input Power allowable is ΔP_h (dBW)

$$\begin{aligned}\Delta P_h &= 10\log[0.1\cdot\Delta P\cdot\Delta f]\\ &=-10-267+70\\ &=-207\mathrm{dB(W/m^2)}\end{aligned}$$

(8) Harmful Power Flux density $S_h\Delta f_a$

$$S_h \Delta f_a = \Delta P_h + 20 \log f - 38.6$$
$$= -207 + 20 \log(1665) - 38.6$$
$$= -181.2 \text{dB}(\text{W/m}^2)$$

(9) Harmful Spectral Power Flux Density S_h

$$S_h = 10 \log[(S_h \Delta f_a)/\Delta f_a]$$
$$= -181 - 70$$
$$= -251 \text{dB}(\text{W/m}^2 \cdot \text{Hz})$$

Example of RFI measurement

In order to evaluate certain RFI levels that appeared in telescope IF, measuring its equivalent noise temperature first. A comparison with hot load, cold load, injected noise diode, or known strong radio sources, equivalent noise temperature of the RFI is obtained. Equation (6) could be used to convert the RFI to the power flux density. When there is 3dB interference is monitored from noise floor (sky level) at Kashima 34m radio telescope ($T_a = 28$ K, $T_r = 10$ K in 1610 MHz), Using physical temperature of hot load (294 K) and cold load (53 K) in front of the receiver and output difference of 6.0dB, $G/T = 8.5/(294-53)$. Then the

$$P_h' = 10^{0.3} \times (241/8.5)$$
$$= 56.9\text{K}$$

this measurement can be converted into Spectral flux density with the ITU-R, RA.769-1 (ANNEX 1-2) in order to compare it to the other service.

$$S_h' = 10 \log(56.9 * 1.38 * 10E-23)$$
$$= -211 \text{dB}(\text{W/Hz})$$

The calculated RFI flux is stronger than ITU-R RA.769-1 defined -267(dBm/Hz) in the band. Strict understanding of the definition without main-lobe coupling, a telescope is not measuring accurate flux. But this calculation never over estimate RFI strength. Using this apparent flux received, it is important to explain situation compared ITU-R, RA.769-1 to the other services.