Dealing with Radio Interference

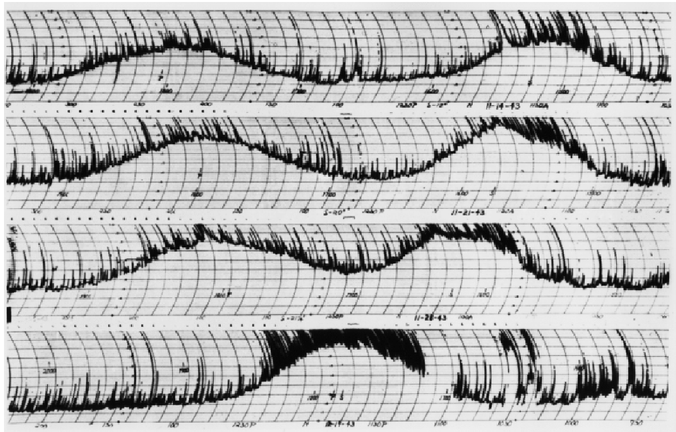
Axel Jessner, MPfR Effelsberg

jessner@mpifr-bonn.mpg.de

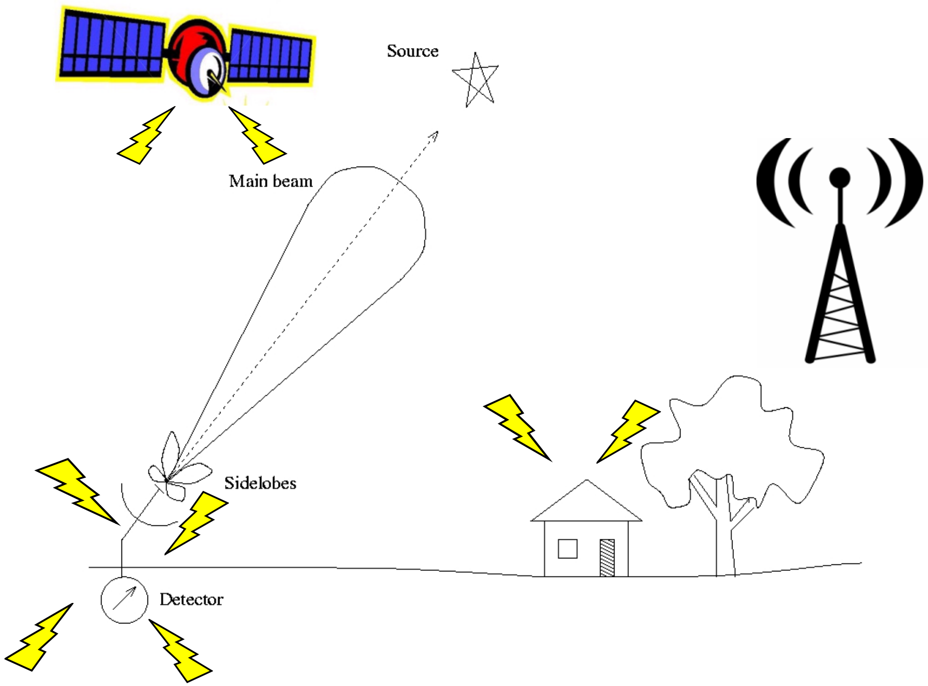
Links: www.craf.eu
www.astron.nl/rfi/

What is Radio Interference and What Causes it?

Radio interference is a signal of ***human origin*** which is detected in a radio astronomical observation



(Jim Cohen, 2005)



external:
TV, Radar, Satellites,
Data Processing, Electronics

internal:
oscillations, intermods,
harmonics, receiver noise

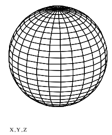
Antenna Gain is different for Astronomy and for RFI

Main beam

Effelsberg 21cm:

$$0.54\cdot\pi\cdot(50\cdot m)^2 = 4.241\cdot 10^3 \cdot m^2$$

$$G_{beam} = \frac{A_{eff}}{A_{iso}} = \frac{\eta\cdot A_{geo}}{\left(\frac{\lambda^2}{4\cdot\pi}\right)}$$



isotropic antenna:

$$\frac{(21\cdot cm)^2}{4\cdot\pi} = 3.509\cdot 10^{-3} \cdot m^2$$

$$G_{beam} = 1.209\cdot 10^6$$

$$10\cdot\log\left(G_{beam}\right) = 60.823 \text{ dBi}$$

Off-beam gain:
ITU-R S. 1428

$G = 32 - 25\log(\phi)$ dBi for $1^\circ < \phi < 47.8^\circ$

$G = -10$ dBi for $47.8^\circ < \phi < 180^\circ$

Average Antenna gain for RFI is $G_{rfi} \sim 1$ or 0 dBi (isotropic antenna)

…But not when the antenna points at the interferer!

Detrimental thresholds for total power observations

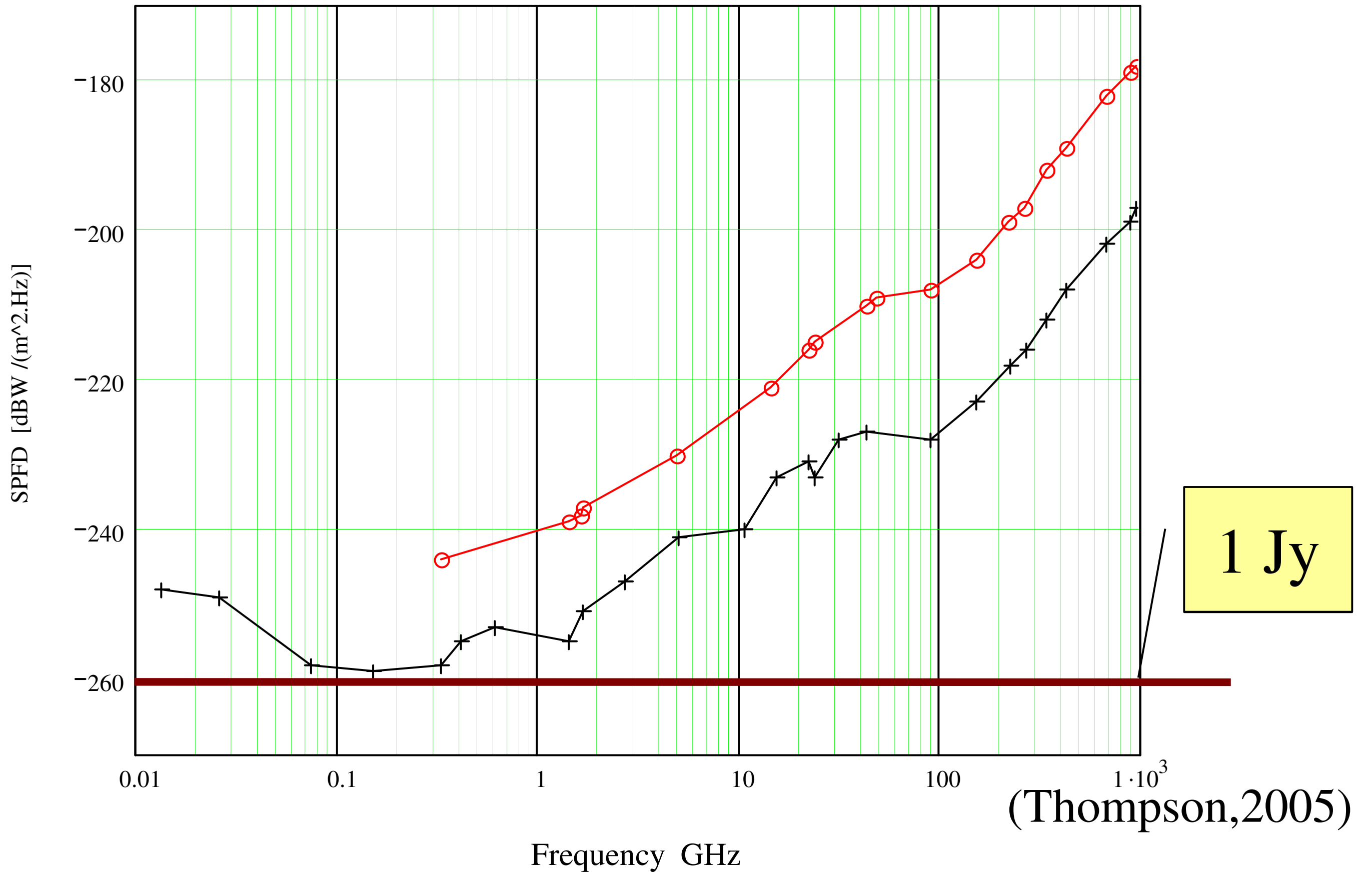
ITU-R RA 769

10% increase
in flux errors

I/N =0.1

$$S_H = \frac{0.4\pi k f^2 (T_A + T_R)}{c^2 \sqrt{\Delta f \tau}}$$

τ = 2000 s!



(Thompson,2005)

black, continuum; red, spectral line

RA Handbook Fig. 4.1 (p. 36)

The worst case: Destructive Interference

Cloudsat (since 2004):

5 satellites, downward pointing radar
94.05 GHz,
height 705 km,
peak power 1800 W,
antenna gain 63 dBi

→ peak E.I.R.P. > 10^9 W

50 mW into main Beam for ALMA

fortunately probability low ≈ 10^{-7} per site illumination

needs zenit pointing Antenna & Satellite passing directly overhead

(ALMA Memo 504)

EESS (new terrain radar sat):

9.6 ± 0.3 GHz
peak power 2500 W
pulse duration 70 µs
antenna gain 47 dBi

→ 0.275 W for Effelsberg RX lethal for 8.35 & 10.6 GHz

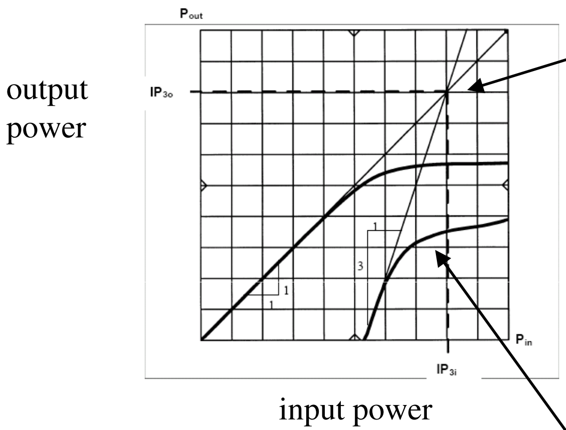
Probability: ≈ 10^{-3} per illumination !

Airborne mil. Radar on 3.3 GHz:
Thermal effects seen in Effelsberg at 2.7 GHz!

Intermodulation Products - 1

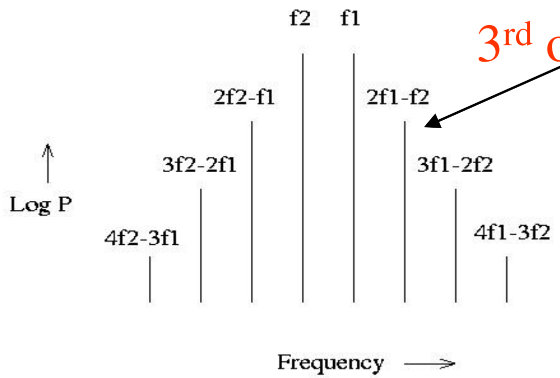
(Jim Cohen, 2005)

1. No real amplifier is linear
2. two sinewaves generate many IM products in a non-linear amplifier

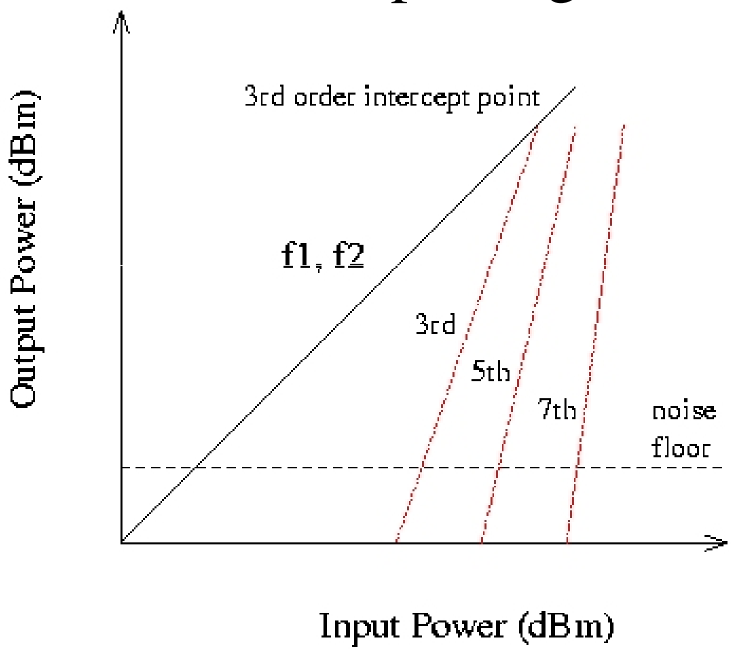


IIP_3

3rd order



Intercept Diagram



$$S_3 = 3 \cdot S_1 - 2 \cdot IIP3$$

Higher order intermods grow even faster

Intermodulation Products - 2

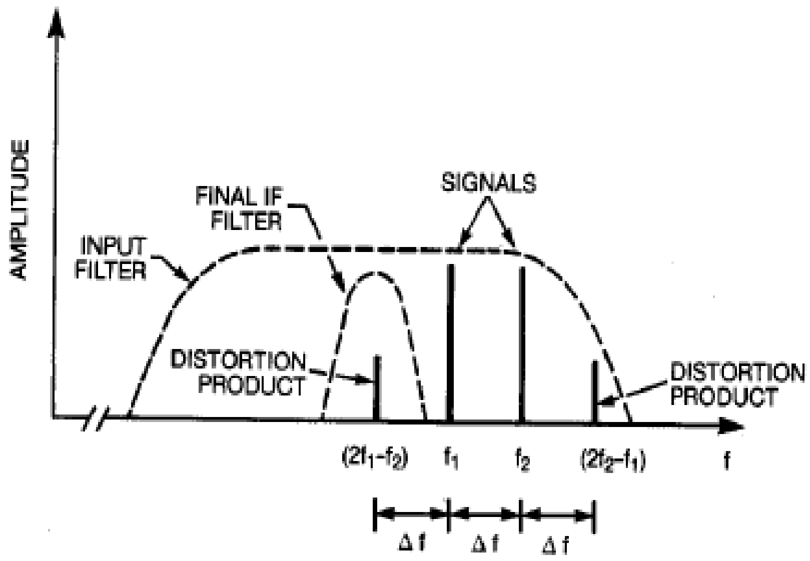


Figure 2. Third-order distortion products from two signals inside the receiver input filter.

(E.N. Watson, 1987)

Expected at

f_2 - 2 δf

Limit:

$$S_1 < \frac{S_{769}(f) + 2 \cdot IIP3}{3}$$

Example: 1.612 GHz

Spectroscopy: S_{769} =-190 dBm with a typical -25 dBm IIP3 .

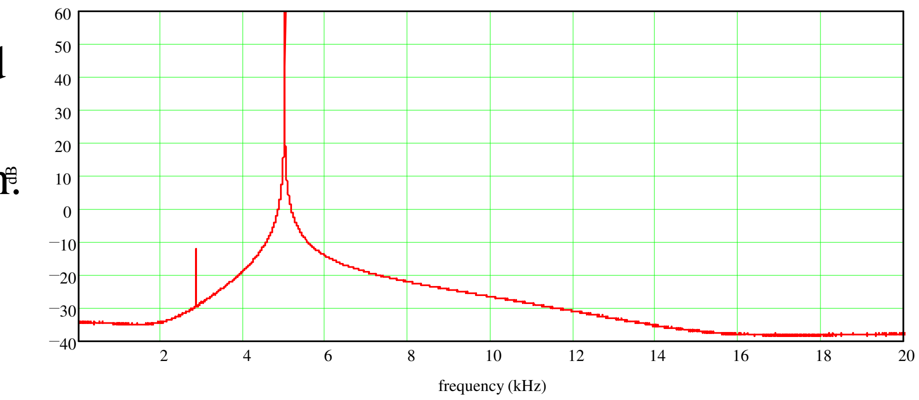
=> **-80dBm**

a 100 W GSM station 10 km away will provide -67 dBm !

Intermodulation Products - 3

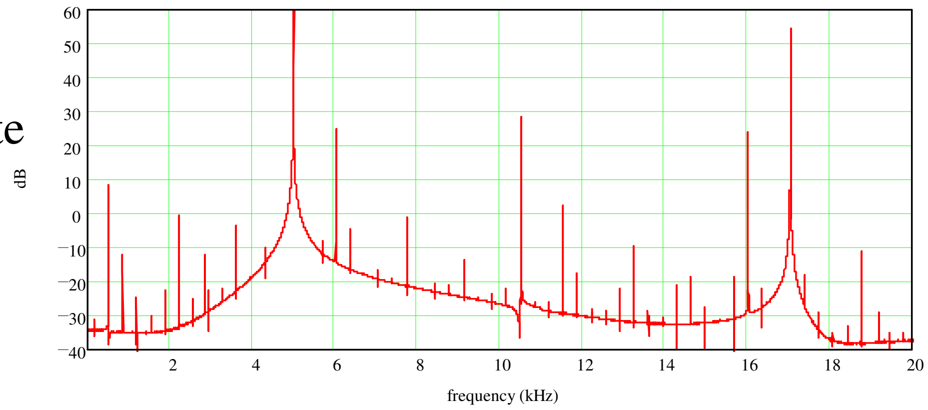
Intermodulation may also occur in numerical processing!

FFT Spectrum of a pure 5 kHz sinusoid plus a weak 2.5 kHz signal sampled with 44ksamples/s and 16 bit resolution.



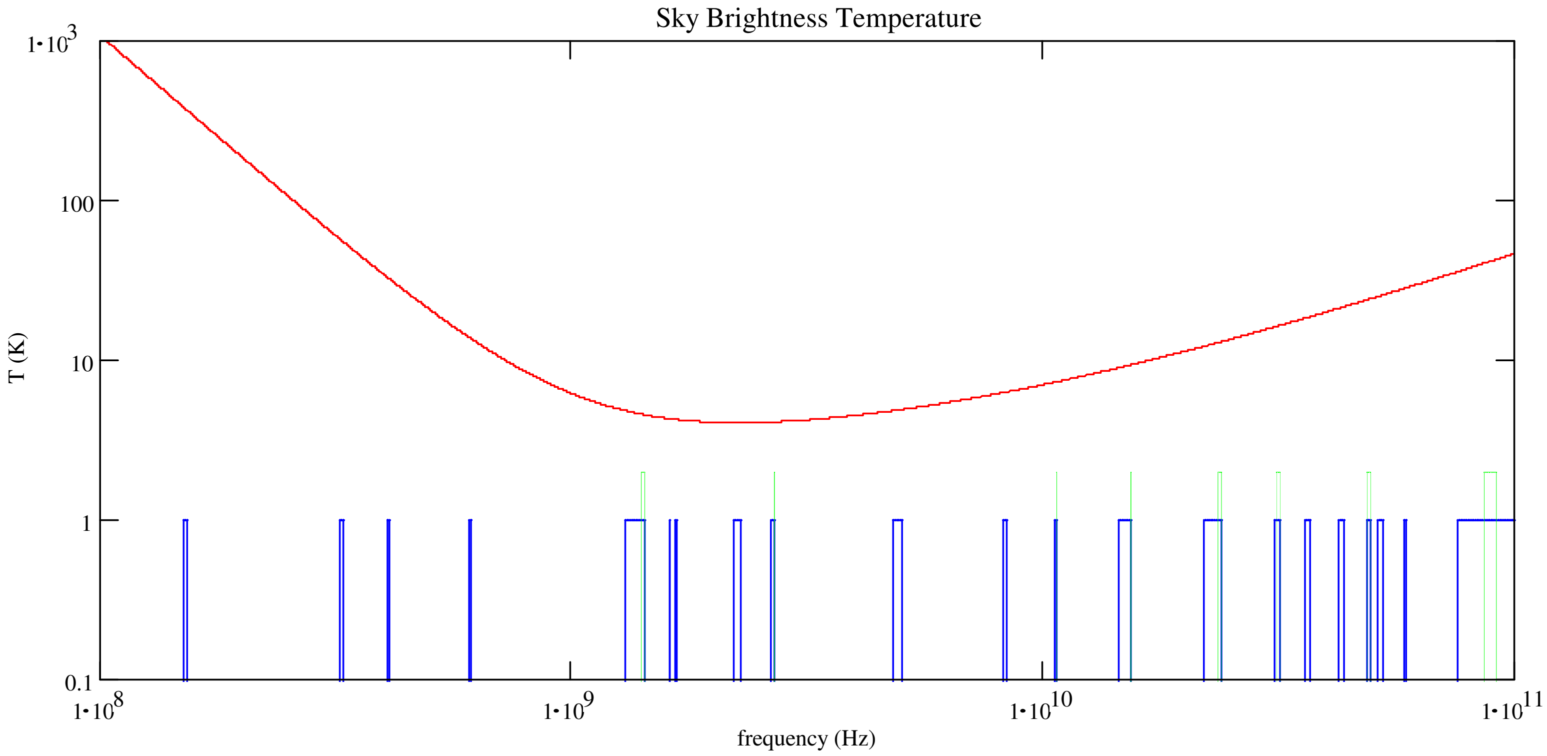
An 8 byte real fft was used for the computation.

The same signal sampled at the same rate but processed with a four byte real fft.



Digital systems are inherently non-linear:
take care to operate them with sufficient margins!

All RFI is undesirable, but some is legitimate!



Radio astronomy has exclusive use of only 0.7% of the spectrum below 30 GHz (green).

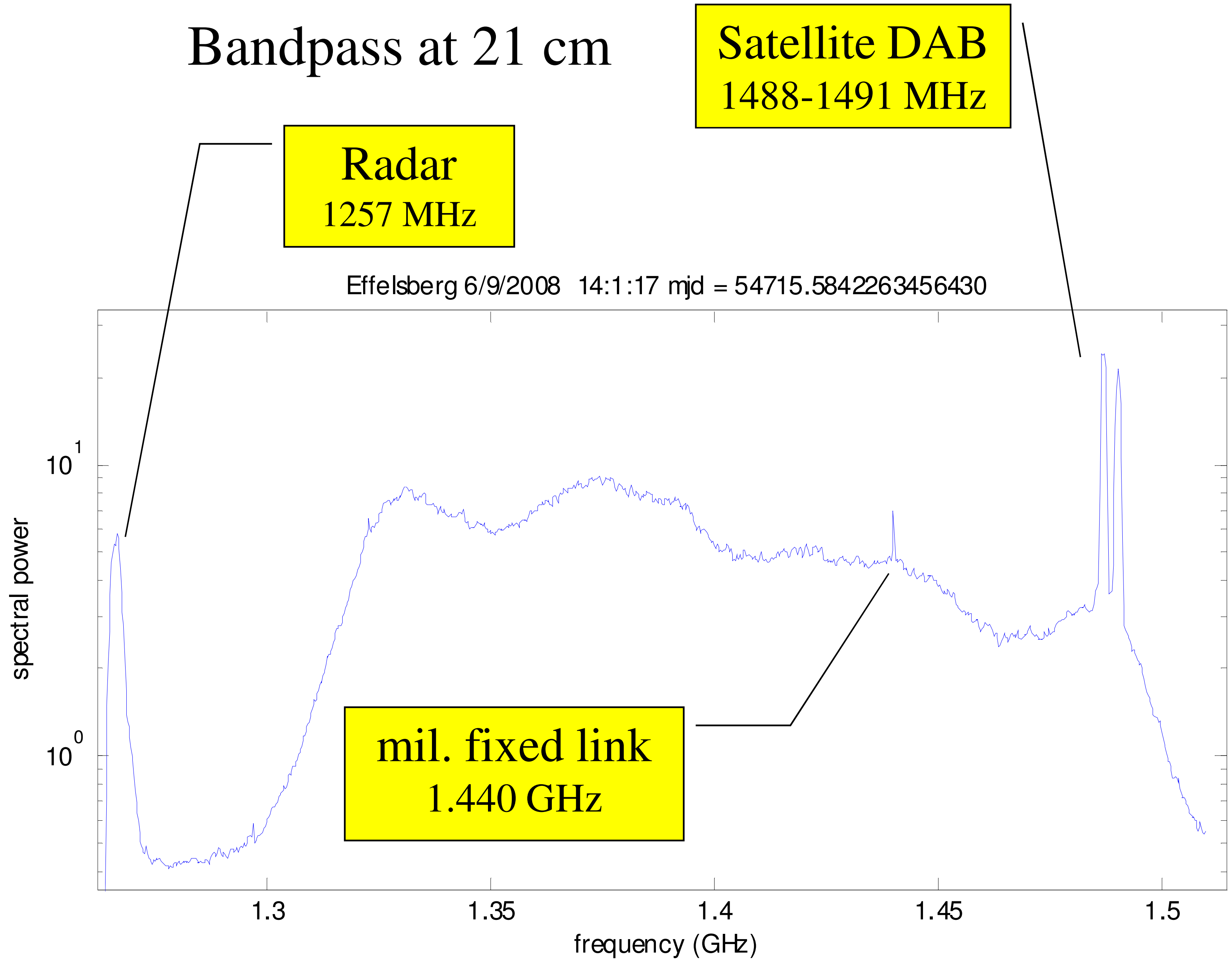
Radio astronomy shares most of the other bands (blue) with other services.

2% Data loss caused by another service is considered tolerable by the authorities

Many observations have to be outside allocated bands

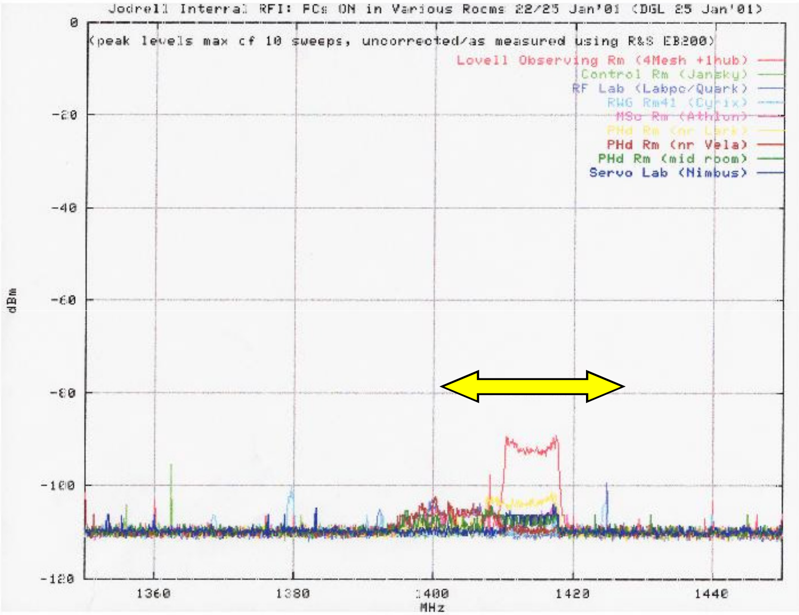
ITU-R RA 314: '...that administrations be asked to provide assistance for spectral line observations outside allocated bands...'

Bandpass at 21 cm



The enemy within

Computers, networks, correlators, modern electronics, …



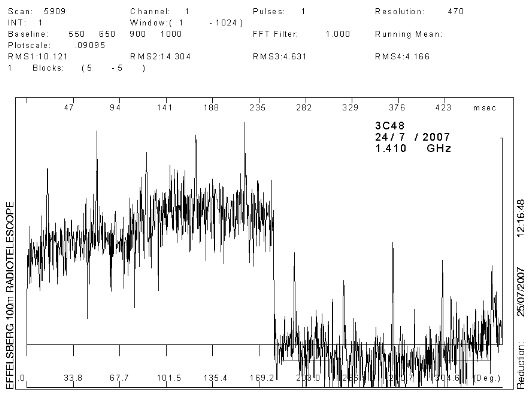
PCs at 1420 MHz

Shielded box 40dB

No operation of any ***unshielded*** high performance electronics on the Telescope site!

(Jim Cohen, Jodrell Bank, 2005)

The Effelsberg Active Subreflector

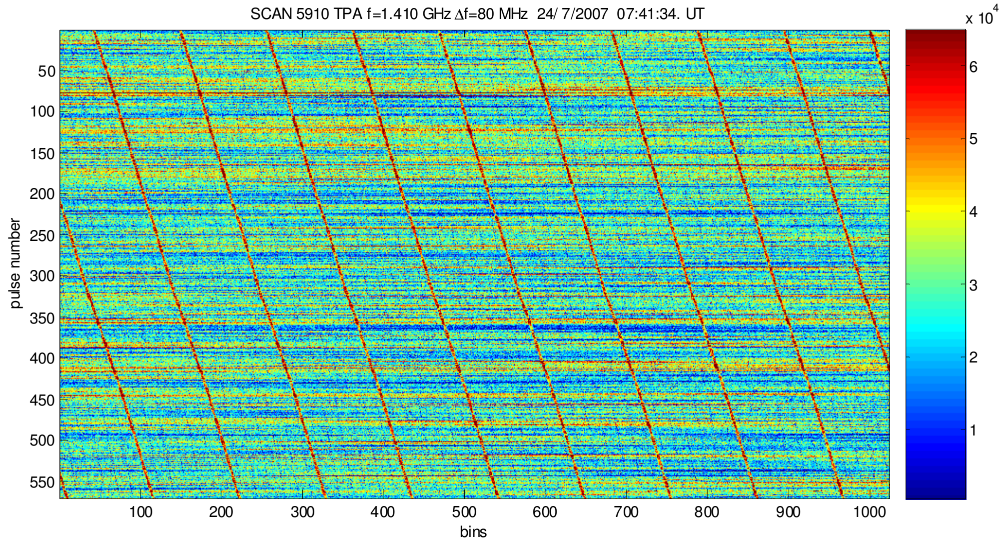


p=24 ms,
w= 320 µs

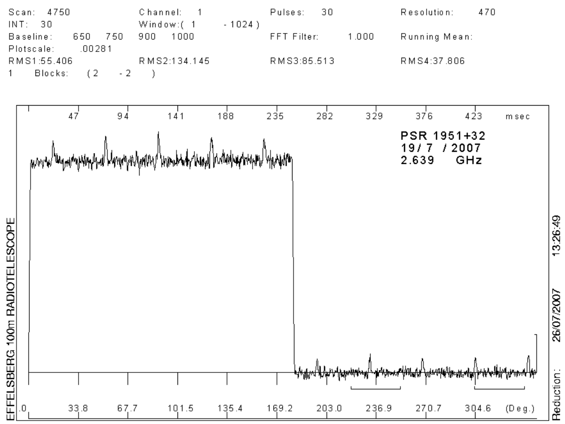
ca. -95dBm
emitted

0.4 Jy @ 1.41 GHz

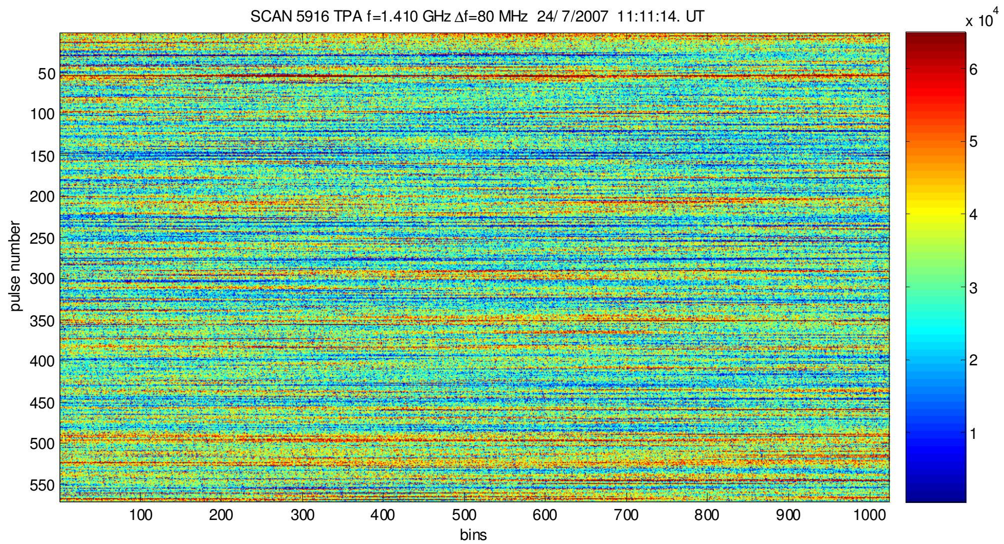
on



500 ms



off



0.1 Jy @ 2.7 GHz

ΔT_{sys}< 10% but PSR Timing Precision was degraded!

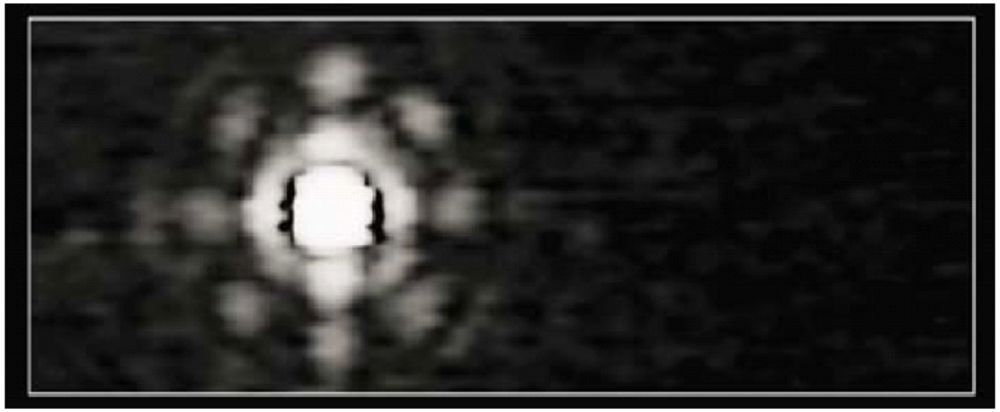
ASTRA-1D (10.6-10.7 GHz)

International primary allocation 10.6-10.7 GHz , 10.68-10.7 GHz ‚no emissions permitted'!

ASTRA 1D Satellite lauched 1995, operates on 10.714 GHz with bandwidth 26 MHz.
➔ exceeds ITU-R RA 769 limit by a factor of 10000!

FIGURE 6.3

Map of the extragalactic source 3C84 in the 10.6-10.7 GHz band with the Effelsberg 100 m radio telescope



Radio_063

3C84 with 20.5 Jy at 10 GHz
field 30'x12'
before launch of ASTRA-1D

(ITU Handbook for Radioastronomy, 2003)

FIGURE 6.4

Map of the same sky field as in Fig. 6.3, but with interference received at Effelsberg radio telescope

Radio_064

Same source, 10° offset from ASTRA-1D undetectable!

Sky blockage!

Unsucessful against Luxembourg operator!

End of life in 2007 => 31° E over Turkey

18 cm Band: GLONASS und IRIDIUM (Strong government interests involved here!)

OH-Line at **1610.6-1613.8 MHz**, protected radioastronomy band for spectroscopy

==> planetary nebulae,
stellar winds,
final stages of stellar evolution.

GLONASS Satellites (Russian navigation system)

with bad suppression of spurious emissions

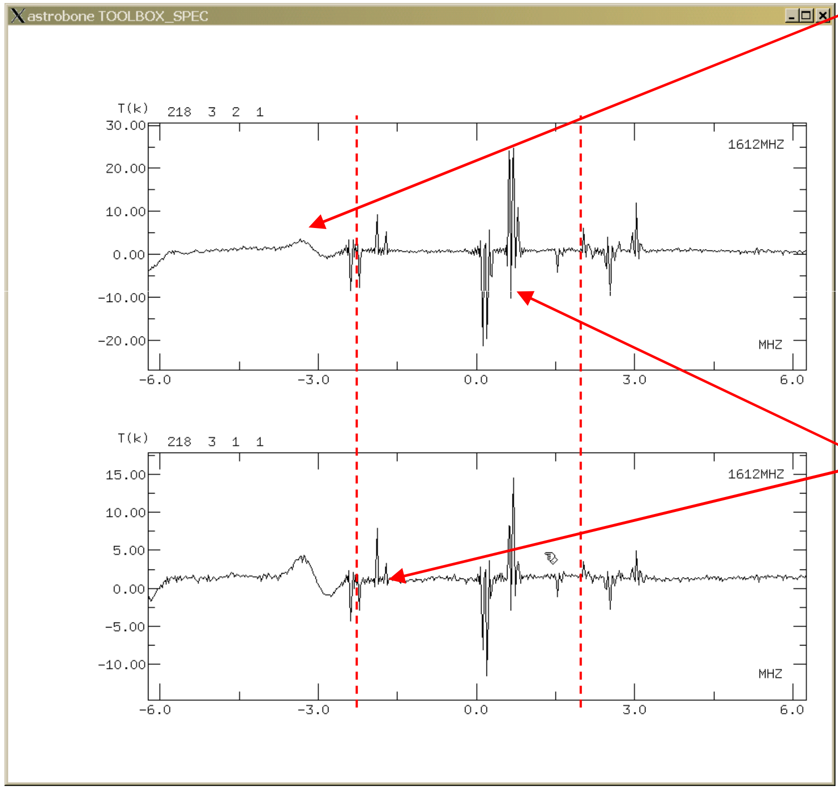
Agreement after protracted negociations by CRAF:

Lowering of operational frequency for GLONASS

to <1605.4 MHz,

Better filters on future satellites.

The situation has improved!



06.03.2006 20:15 UT Effelsberg Centre frequency 1612 MHz.
GLONASS at –3 MHz (1609) and massive narrow line RFI.

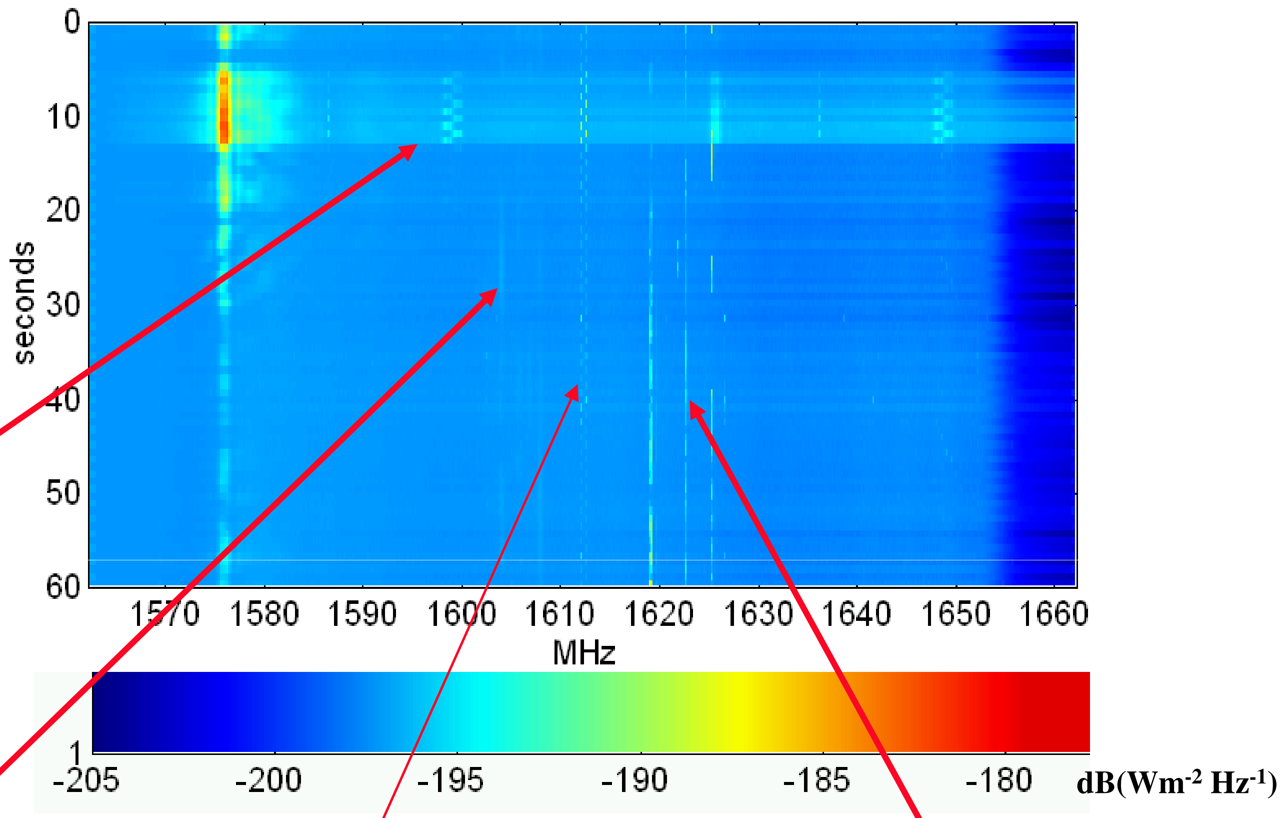
Iridium: 66 Satellites, US-Satphone for remote operations.
Strong and time-variable spurious emissions in RA band, seen by every one.

Iridium denied this
*‚**no reports of interference**‘*
and used legal tricks to procrastinate!

IRIDIUM Interference in Effelsberg - 1

FFTS Observation 2991 on 13.03.2007.

normal fswitch mode,
time resolution 0.5 s
(single phases plotted)



FFTS input level too high (10dB) creating local IM artefacts that move in sky-frequency

weak GLONASS at 1608, outside the alloc. Band.

FFTS centre channel artefact

Time variable primary Iridium signal

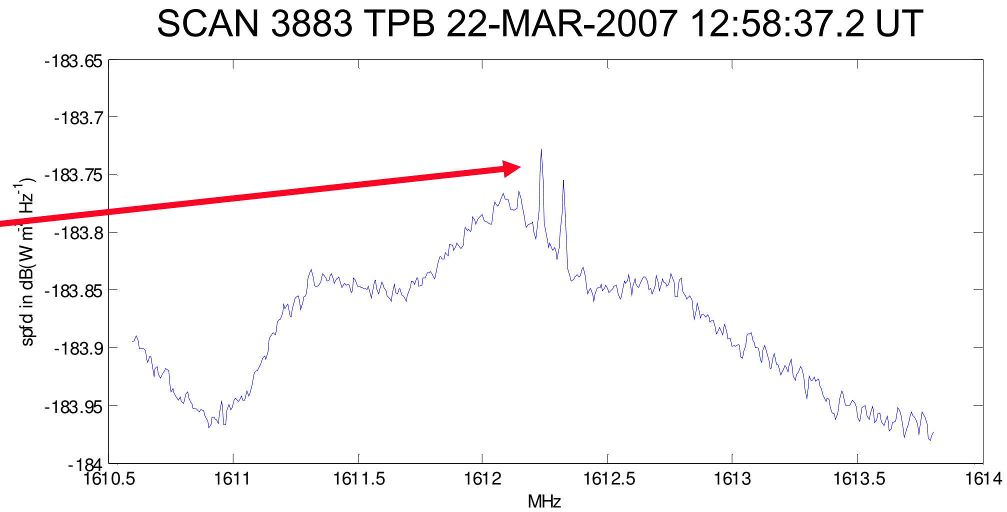
A spectrogram can help to identify RFI and its sources.

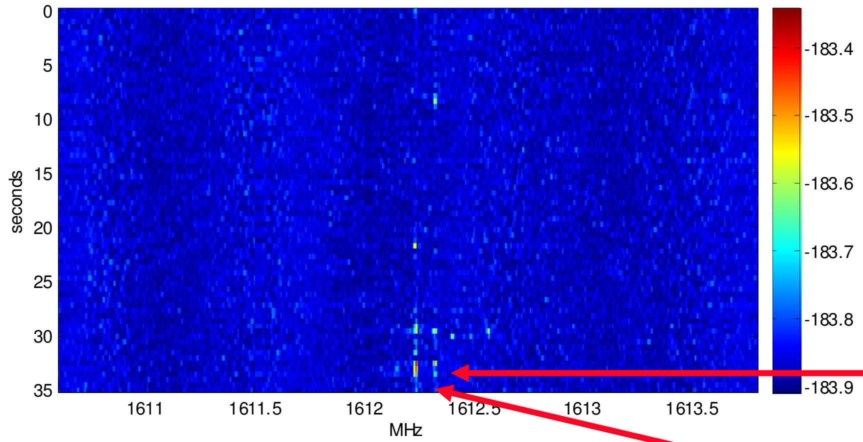
IRIDIUM Interference in Effelsberg - 2

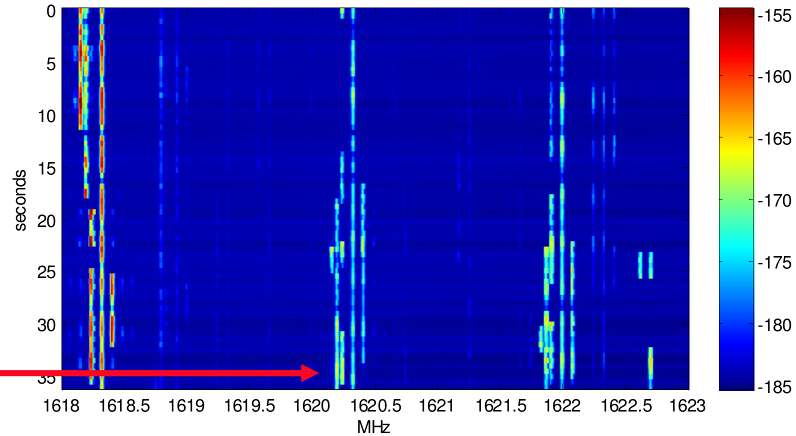
30 second FFTS fswitch Observation
$\Delta f = 0.5$ MHz

$$10\cdot\log\left(10^{\frac{-183.7}{10}} - 10^{\frac{-183.8}{10}}\right) = -200.128 \quad \mathrm{dBWm^{-2}Hz^{-1}}$$

too strong by a factor of 1000!





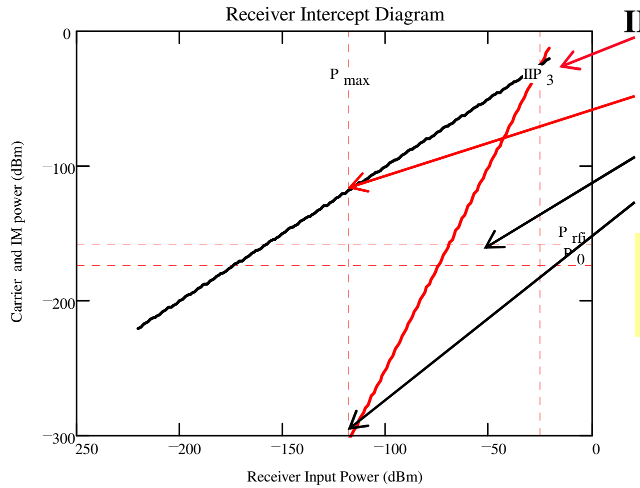


observed main frequencies:
1.61825 & 1.62025 GHz, IM seen at $f_1 - 3\cdot\delta f = 1.61225 \cdot \mathrm{GHz}$

f_1-3df $=4f_1-3f_2$ is a 4+3=**7-th order IM product !**

IRIDIUM conjectured that these are receiver intermods!

IRIDIUM Interference in Effelsberg - 3



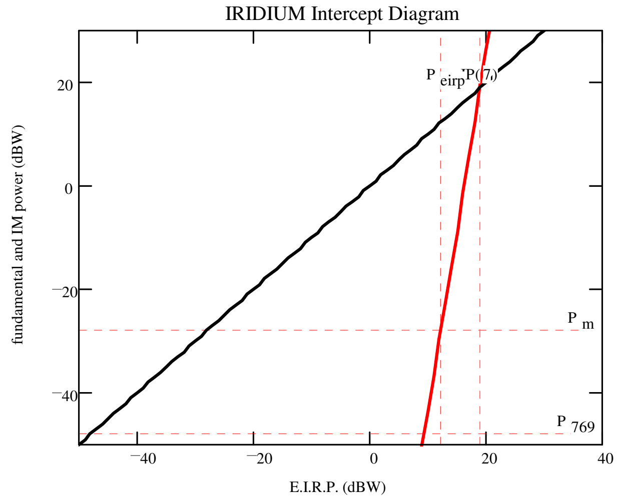
IIP(3)=-25dBm,- typical value

-118 dBm primary carriers (P_{max})

-158 dBm interference line at 1.6225 GHz (P_{rfi})

-304 dBm = 3· P_{max} - 2·IIP(3) expected from receiver

primary signal was too weak (by >120 dB!) to cause local IM effects
=> IM from TX!



Estimate of 'Secret' Transmitter IM Characteristics:

Free space path loss for d=1500 km distance of satellite to Effelsberg given by

92.5+20log(f/GHz)+20log(d/km) = 160 => -118+160-30 = 12 dB(W)
public IRIDIUM specs: 11 dB(W)

Interfering power in band -158+160 = -27 dB(W)

With $IP(m) := \frac{m \cdot P_{eirp} - P_m}{m - 1}$ we get IP(7)= **19dB(W)**

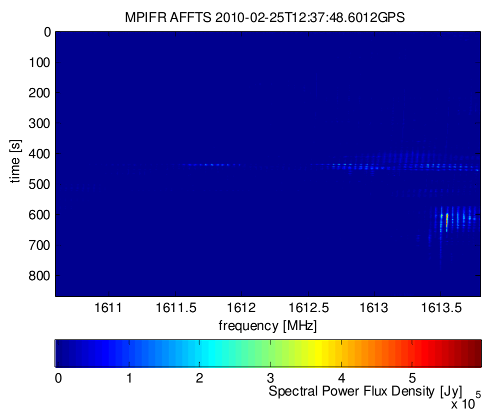
Proof of interference by 7th order IM from the IRIDIUM satellites!
Not disputed by IRIDIUM!

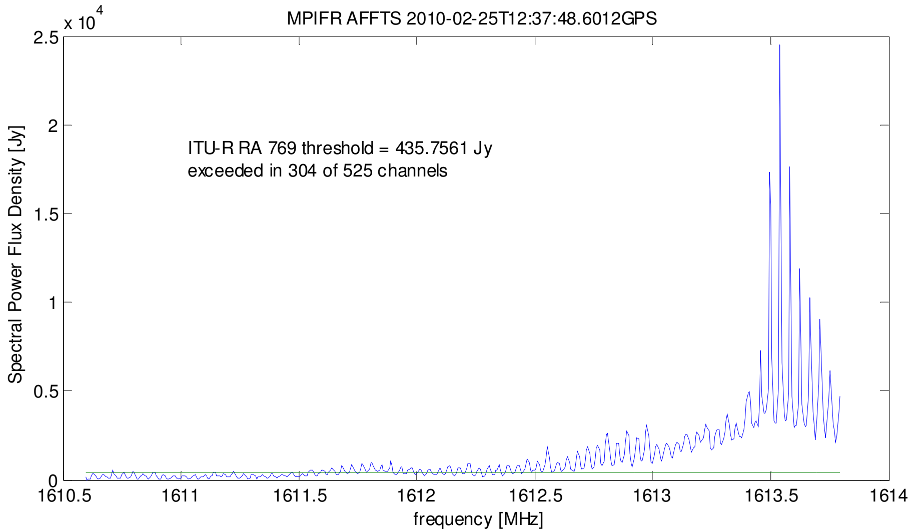
IRIDIUM Interference in Effelsberg - 4

Iridium now admits causing RFI,- but insignificant (<2% in any particular channel),

Astronomers see > 18% of all spectra contaminated with lines of varying frequencies, but sensitivity is low (20-30 dB above protection limit), because telescope cannot track LEO satellites.

Astronomers were invited by ECC committee to measure emissions using the Leeheim satellite station which can track IRIDIUM satellites:





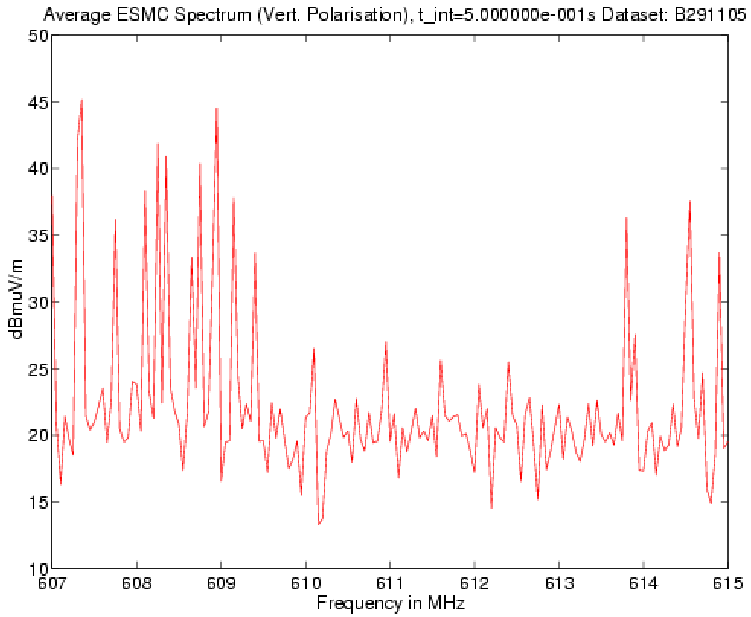
> 60% of the band is contaminated by rfi from IRIDIUM during each satellite transit.

2010: ECC Report & Order for new satellites placed by IRIDIUM

UHF Channel 38 (608-614 MHz)

Allocated frequency shared by radio astronomy with TV-broadcasting.

5.149: Administrations are requested ‚to take all practicable steps‘ to protect radio astronomy from interference.



Spectrum 607-615 MHz, from 29/11/2006 with ESMC surveillance receiver in Effelsberg.

Peak fluxes 10^{13} Jy

Escape to 830 & 860 MHz

(unused channels reserved for military comm.)

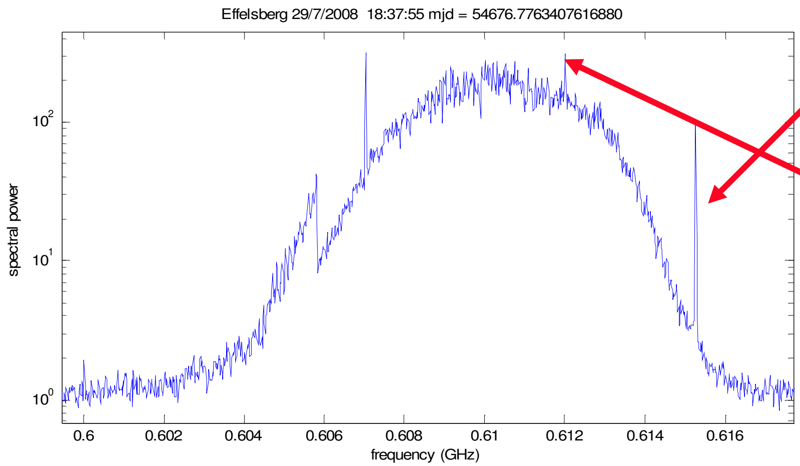
This observations on 800 - 900 MHz have become impossible because of strong RFI!

TV channels have been reallocated for DVB-T,
very good co-operation with BNetzA on channel 38

UHF Channel 38 today

f_c=608 MHz
BW = 8 MHz

T_{sys}= 230 K

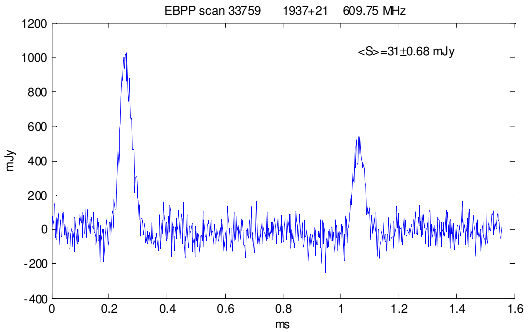


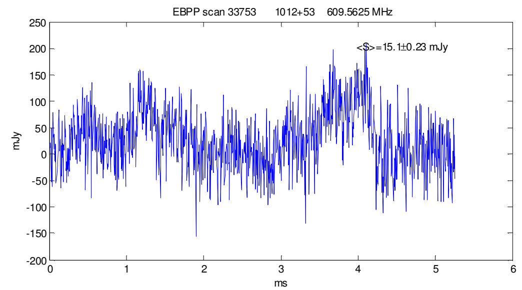
rfi from TV present, but mainly on adjacent bands
=> needs better IF filters

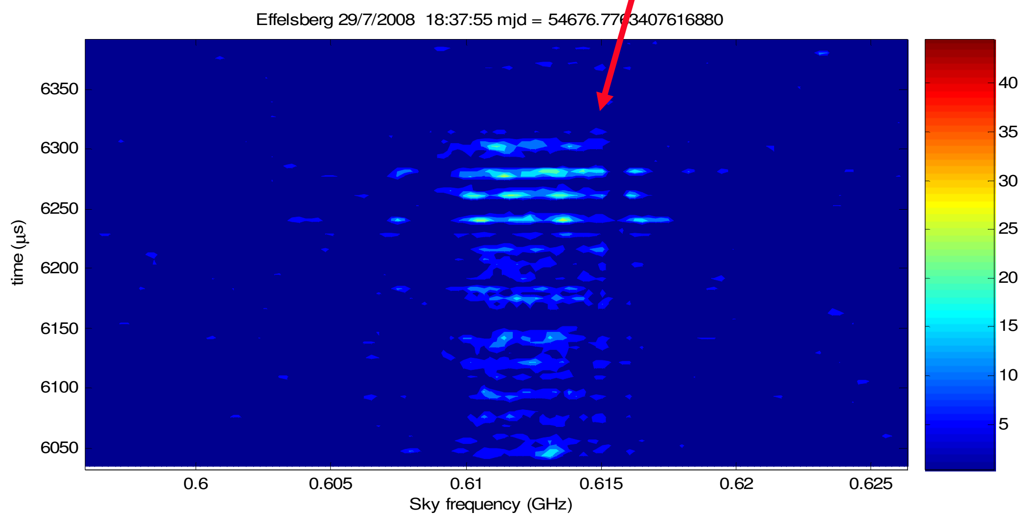
4th- harmonic from H-Maser dissociator
=> better shielding needed

some **illegal pulsed** rfi
=> identify & eliminate

t_{int} = 600 s







p=1.212 s,
0.475 s,
0.732 s

A useful band for PSR timing, but small BW requires longer t_{int}.

Counter Strategies - Protection

WRC 1959 Allocations of exclusive bands to radio astronomy and protection criteria (RR 5.340, 5.149, ITU-R 769) secured by international law, executed by national administrations.

ITU – RR 5.340: ‚**No emissions are permitted** on the following Bands:
1.4, 2.7, 10.7, 15.4, 23.6, 31.3 … GHz'

Continuous process at ITU/WRC/ECC by IUCAF, CRAF/CORF/RAFCAP to secure clean frequency bands for RA.

But:

too few and too narrow bands for modern radio astronomy

too many committees and technical studies, difficult and slow progress to counter pressure from industry and some governments to 'release' protected bands.

+ current fashion of spectrum liberalization and frequency auctions

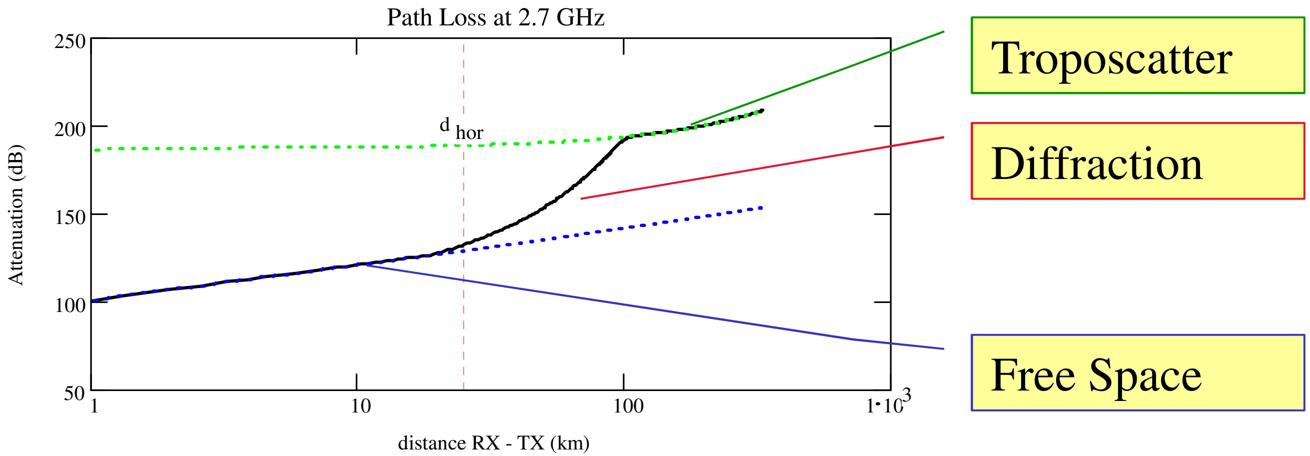
=> RA is under constant scrutiny: **Frequency resources are valuable,-**

How more valuable (than entertainment) is radio astronomy for society?

EC Spectrum Policy Group Report #6 on scientific use of Spectrum (2006)
ITU Report ‚Essential role of Observations' (2010)

Counter Strategies - Avoidance

Separation and Topography can provide good shielding



\+ Improves with frequency !

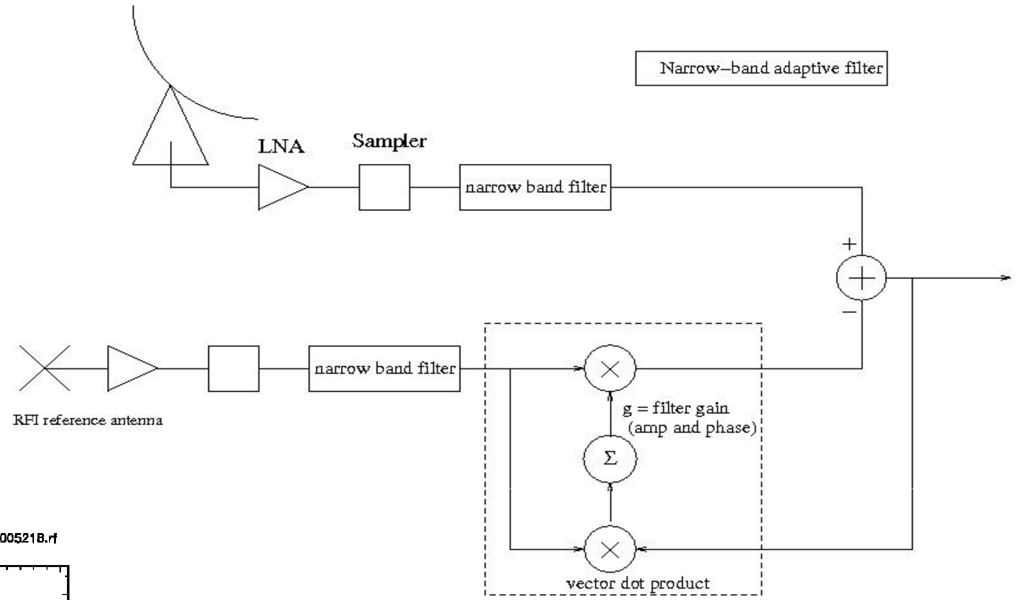
-Not so effective against air- and space-borne rfi

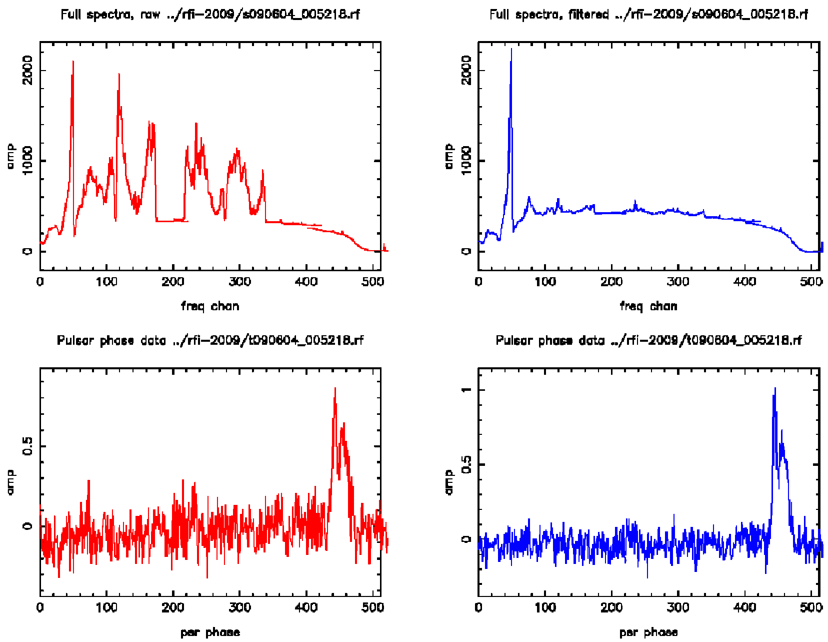
- needs admin. Recognition and protection

In force for Greenbank, SKA (AUS, South Africa), ALMA,
But impossible in EU

Counter Strategies - Cancellation

1. Characterize RFI
2. Subtract it from the signal





+ Works well for modest I/N
+ adapts to changes in refence signal
- < 10-20 dB improvement
-No multiple interferers per band
- increases noise temperature when rfi is present,- signal degradation

(Kesteven, RFI2010 Groningen)

Counter Strategies - SDR

SDR = Software Defined Radio (adaptive receivers)

1. Detect and mark (**flag**) rfi in time and frequency domains
2. Remove (**excise**) rfi from data. on-line & off-line

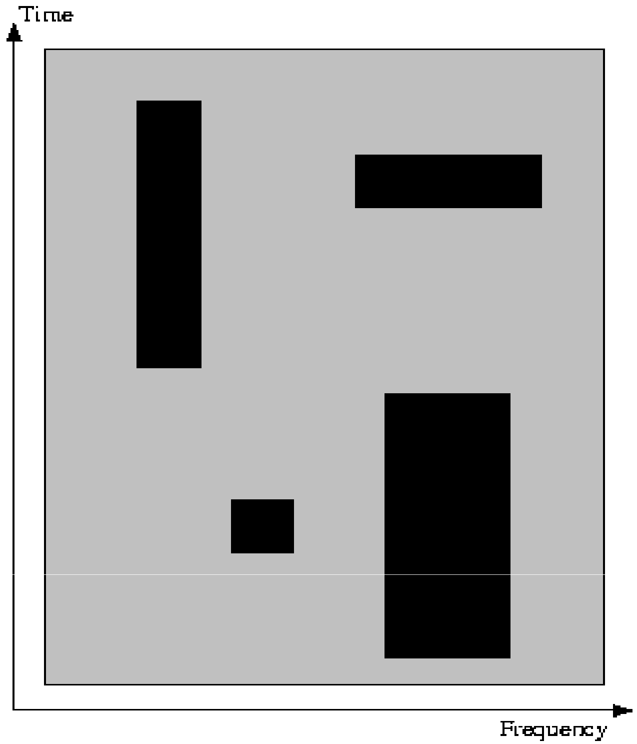
Successful: **LOFAR, Bonn HI survey**

Basis of observer‘s off-line rfi removal, can be automated.

- Step 1. needs knowledge about possible rfi:
  => statistical description for automation
- difficult for i.e. TDMA signals and
- for the separation of low level rfi from weak sources

- Step 2. can become tedious, or involve high processing loads and dedicated hardware.

- Unavoidable loss of $\Delta f \cdot \Delta t$ => increase of observation time, loss of transient features



(Fridman, RFI2010 Groningen)

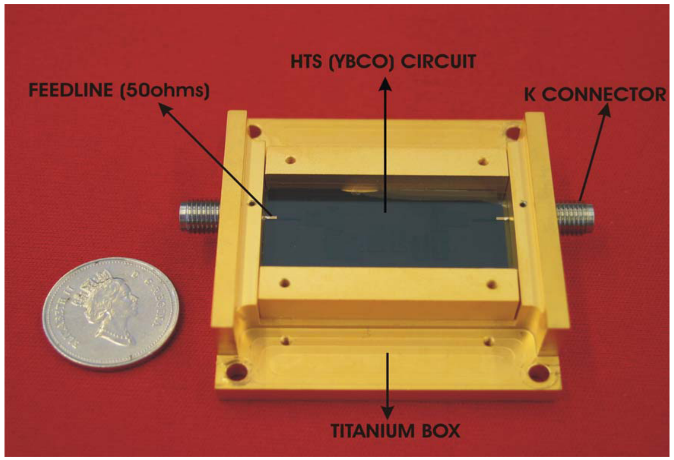
1. Protect
2. Avoid
3. Adapt

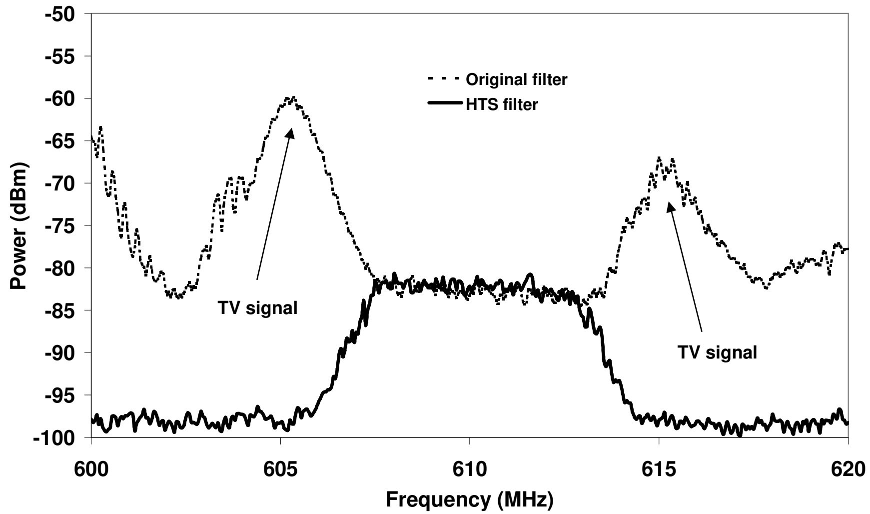
UHF Chan. 38, the technical solution

High T superconducting filters

- High Q: low loss, so can go in front of low noise amplifier
- Compact: high ε_r (23.6 for $LaAlO_3$), novel resonator designs
- T_{crit} ~ 70K, can fit in a normal dewar

University of Birmingham and
Jodrell Bank Observatory





Zhou J., Lancaster M.J., Huang F.,
Roddis N., Glynn D., 2005

June 20, 2008: Ofcom
OFFICE OF COMMUNICATIONS

Recognised Spectrum Access
as applied to Radio Astronomy
A report on introduction of RSA for Radio Astronomy and released spectrum

How Effective are Technical Solutions ?

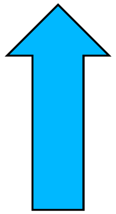
3.2 Currently RSA bands are non-tradable;
however **it is Ofcom's intention to extend the *market mechanism* to radio astronomy by making selected RSA bands tradable**. We are currently consulting on proposals to allow it to be traded.

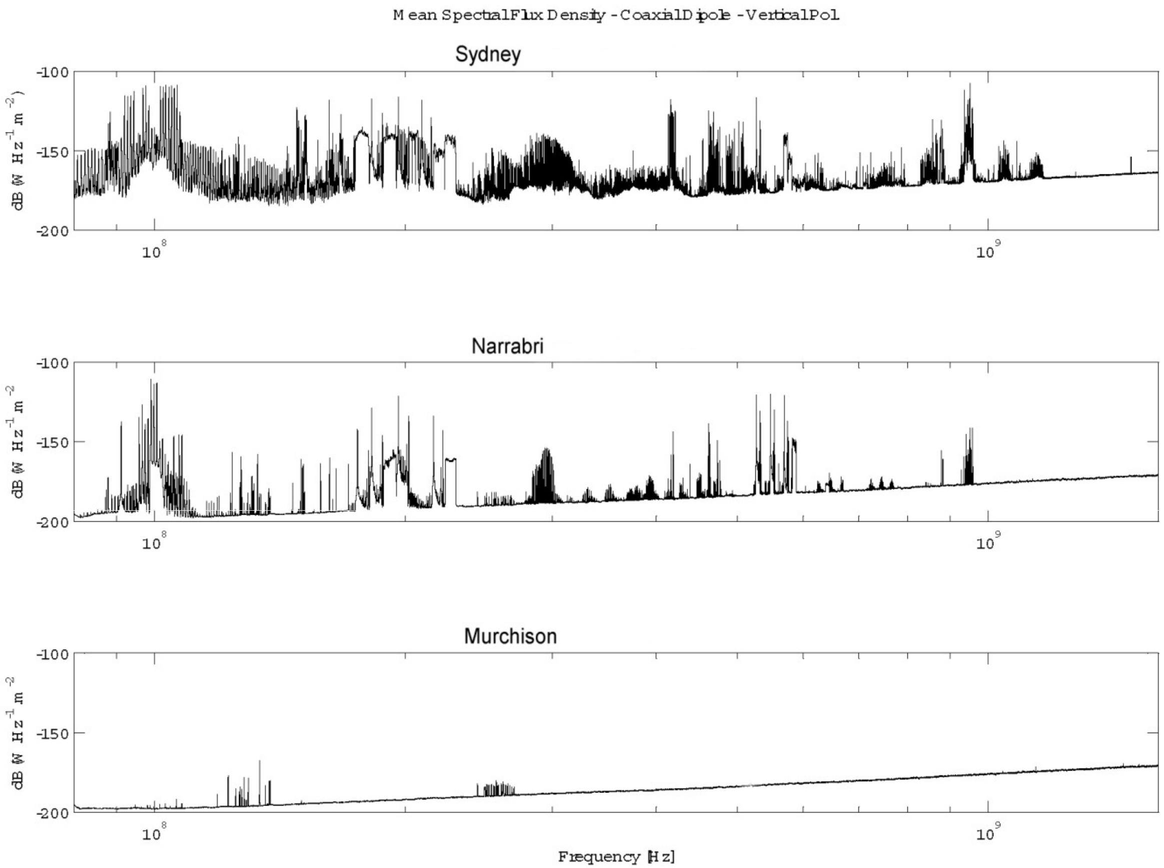
RA bands taken away („released spectrum") **in UK**:
38 MHz, 80 MHz, 150 MHz, 1.664 GHz, 10.7 GHz, 31.5 GHz

Protection of radio astronomy (**in UK to 2012**; internationally before and after 2012)
To prevent interference to UK radio astronomy in channel 38, the winner(s) of spectrum in channels 37, 38 and 39 will be subject to TLCs which will prevent transmissions within defined geographical areas **up to 2012.**
To prevent interference to international radio astronomy, the winner of spectrum in channel 38 will be subject to emission limits such that the spectrum will mainly be suitable for low power services (although potentially for high power services in the future if international restrictions on emissions were eased).
Standard TLCs will be awarded to the winners of spectrum in channels 37 and 39 but network deployments in these channels is likely to be constrained in order to limit the emissions made outside UK borders. (http://www.ofcom.org.uk/consult/condocs/clearedaward/clearedaward/)

The World Wide Trend

Effective spectrum use in urban areas as desired by industry and governments





Low **active** spectrum use as needed by radio astronomy

(Kesteven, RFI2010 Groningen)

Concluding Remarks

Observers:

1. Expect to encounter RFI (visible and invisible)
2. recognize and understand it
3. document it: *Time, Frequency, Jy* (**calibrated values!**)
4. don't despair, but notify and seek advice!

Engineers:

1. Receivers need low T_{sys} and high $\mathbf{IIP_3}$ at the same time!
2. ensure a RFI clean telescope site,
   do not operate unshielded high performance electronics there.
3. any emission you can detect in the lab is lethal for observations.
4. Employ mitigation techniques to clean up what cannot be avoided

Everyone:

1. Cooperate with colleagues and **obtain support from regulators!**
2. Don't rely on technical fixes and don't boast about them.
   => Demands for weaker protection will be the consequence.
3. Be alert, ideological fashions and trends can be destructive.