Interference at a VLBI Station: Analysis and Mitigation

Gino Tuccari
Istituto di Radioastronomia - INAF

Items

- RFI: What is and Where come from?
- How RFI affect observations single-dish and VLBI
- Example at a correlator
- Analysis at a station
- Front-end mitigation
- Back-end mitigation
- Conclusions

RFI

- For a radiotelescope is:

  - any unwanted signal
  - often with level > > cosmic sources
  - produced by ground communications
  - produced by the radiotelescope equipment
  - produced by space communications

RFI (cont.)

- Allocated bands are very often too narrow for the wide band required to achieve high sensitivity
- Spectral line sometimes not in the protected band
- Radio astronomy and geodesy then must observe bands allocated for other services
- Radiotelescopes need to find strategies and methods to minimize error effects on useful data

How RFI affect observations (cont.)

- Sensitivity of a radiotelescope + receiver is set by the system noise temperature => tolerance to RFI needs to be compared to this
- Probability to have RFI in the main beam is low, but still possible
- In normal condition RFI enter the system trough the side lobes
- An easy approximation for most of the cases is that we dispose of an additional 0 dBi antenna with collecting area $\lambda^2 / 4\pi$

How RFI affect observations (cont.)

RFI to noise power ratio is then

$$RFI/Sys = \frac{Frfi \frac{\lambda^2}{4\pi}}{K\ Tsys\ B}$$

In single-dish observations with integration time *t* such value is multiplied by $\sqrt{B\,t}$ and represents the most sensitive observing mode to RFI.

Harmful thresholds in the RFI flux density can be defined for typical observing conditions. For instance tolerating a 10% RFI level with respect to the system noise produces thresholds of

-170 dBm/m^2 @ 100MHz, -160 dBm/m^2 @ 1GHz,
-130 dBm/m^2 @ 10GHz, -100 dBm/m^2 @ 100GHz

How RFI affect observations (cont.)

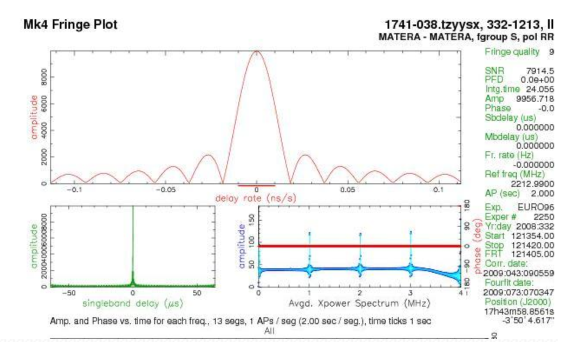
In VLBI RFI introduce additional uncorrelated noise so the correlation coefficient is modified like

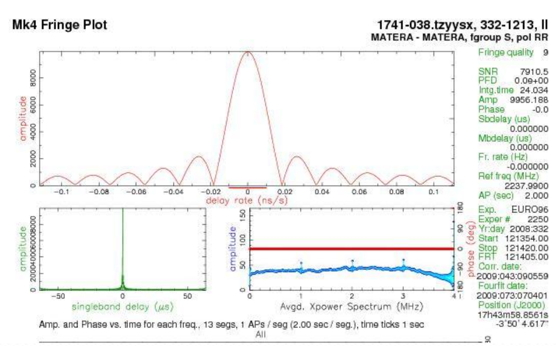
$$\rho_{rfi} = \rho \left[1 - \frac{1}{2}\left(\frac{\sigma rfi}{\sigma}\right)\right]$$

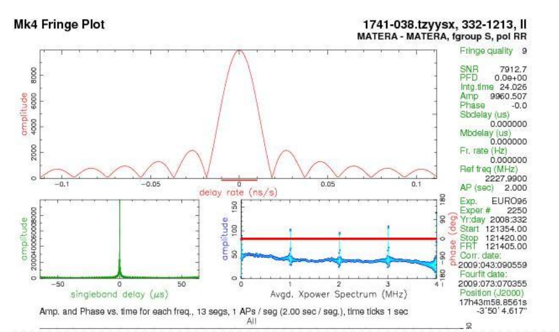
RFI in practice increase the system temperature in one or both stations reducing the sensitivity

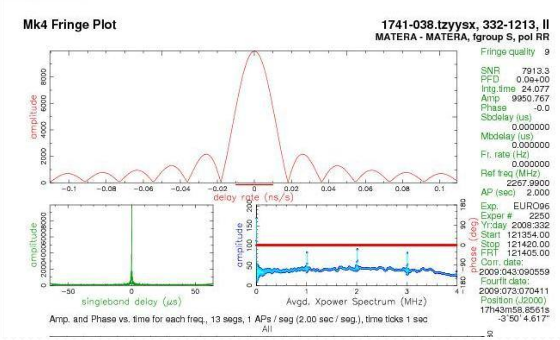
Typically the harmful level in VLBI is about 40 dB greater than the single-dish case tolerating a 1 % interference to system noise ratio

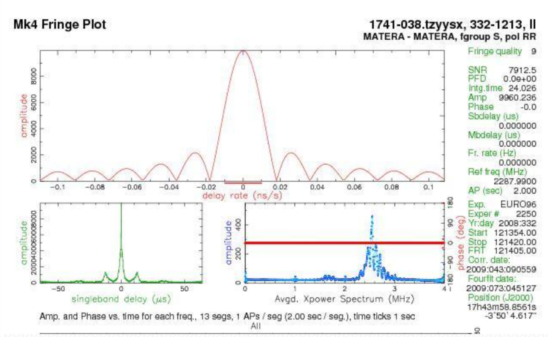
Example at the correlator

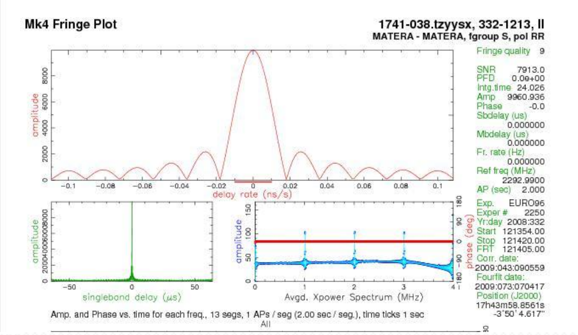




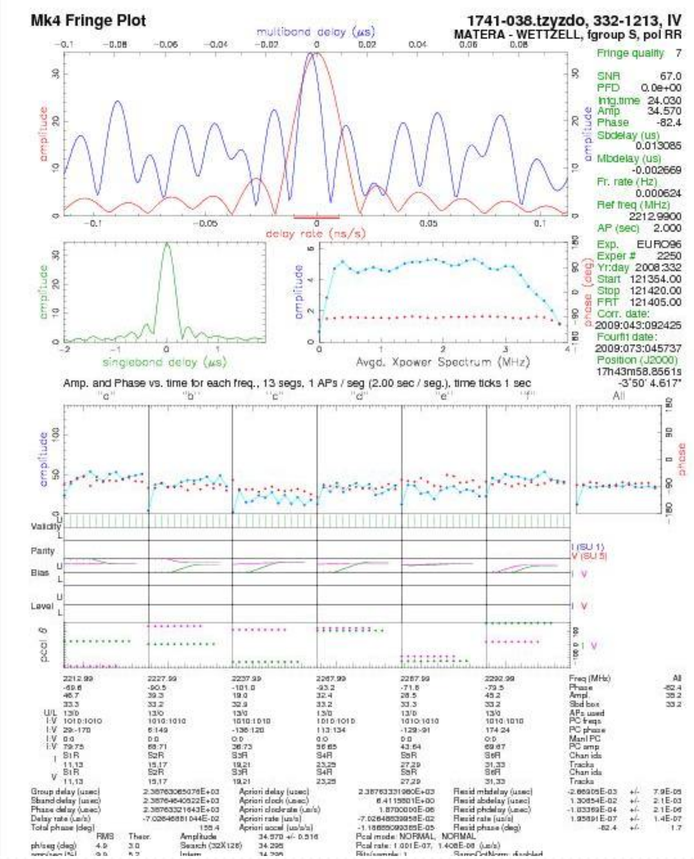


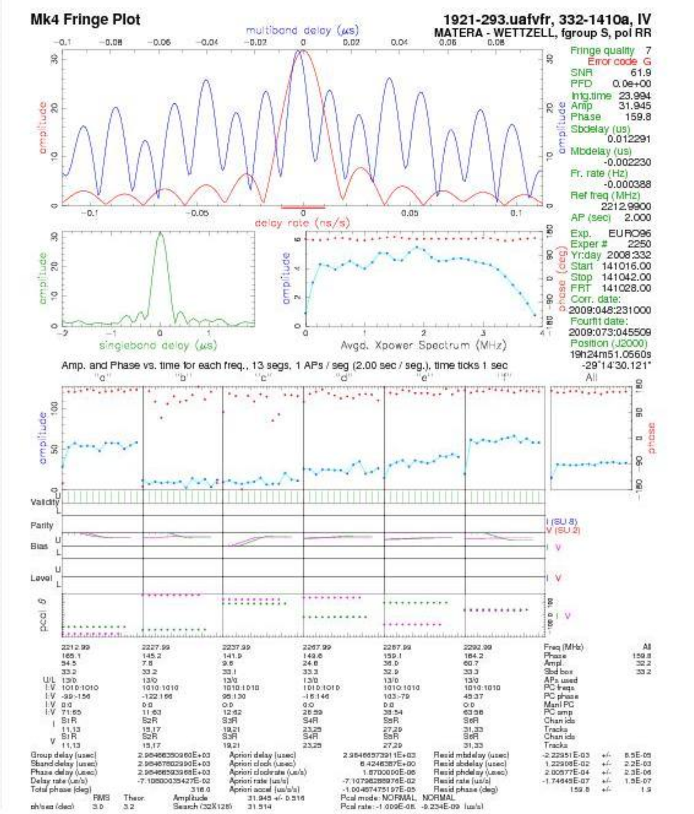


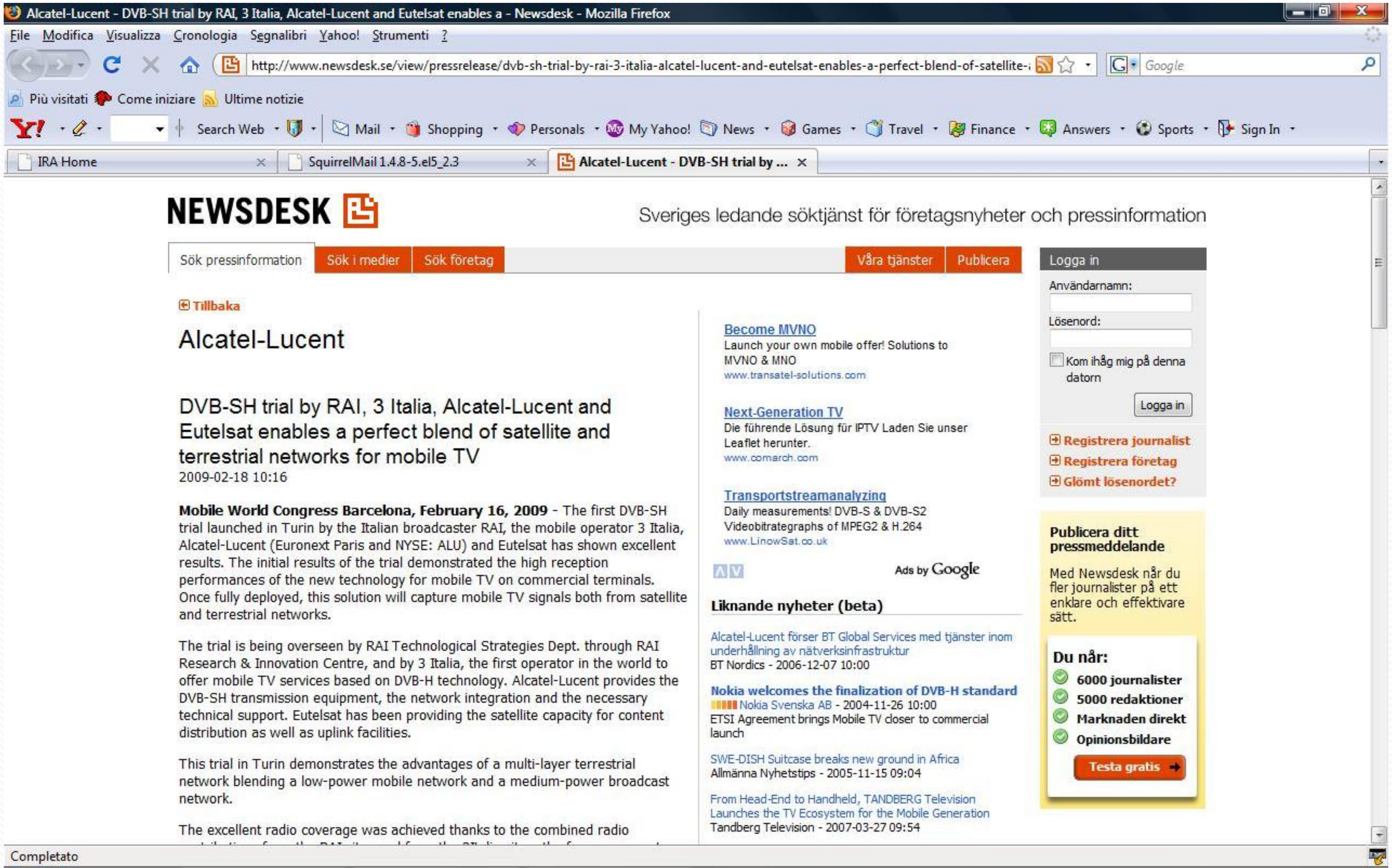




Example at the correlator







Alcatel-Lucent - DVB-SH trial by RAI, 3 Italia, Alcatel-Lucent and Eutelsat enables a - Newsdesk - Mozilla Firefox

http://www.newsdesk.se/view/pressrelease/dvb-sh-trial-by-rai-3-italia-alcatel-lucent-and-eutelsat-enables-a-perfect-blend-of-satellite-

NEWSDESK

Sveriges ledande söktjänst för företagsnyheter och pressinformation

Sök pressinformation | Sök i medier | Sök företag | Våra tjänster | Publicera

Tillbaka

Alcatel-Lucent

DVB-SH trial by RAI, 3 Italia, Alcatel-Lucent and Eutelsat enables a perfect blend of satellite and terrestrial networks for mobile TV

2009-02-18 10:16

Mobile World Congress Barcelona, February 16, 2009 - The first DVB-SH trial launched in Turin by the Italian broadcaster RAI, the mobile operator 3 Italia, Alcatel-Lucent (Euronext Paris and NYSE: ALU) and Eutelsat has shown excellent results. The initial results of the trial demonstrated the high reception performances of the new technology for mobile TV on commercial terminals. Once fully deployed, this solution will capture mobile TV signals both from satellite and terrestrial networks.

The trial is being overseen by RAI Technological Strategies Dept. through RAI Research & Innovation Centre, and by 3 Italia, the first operator in the world to offer mobile TV services based on DVB-H technology. Alcatel-Lucent provides the DVB-SH transmission equipment, the network integration and the necessary technical support. Eutelsat has been providing the satellite capacity for content distribution as well as uplink facilities.

This trial in Turin demonstrates the advantages of a multi-layer terrestrial network blending a low-power mobile network and a medium-power broadcast network.

The excellent radio coverage was achieved thanks to the combined radio

Liknande nyheter (beta)

Alcatel-Lucent förser BT Global Services med tjänster inom underhållning av nätverksinfrastruktur
BT Nordics - 2006-12-07 10:00

Nokia welcomes the finalization of DVB-H standard
Nokia Svenska AB - 2004-11-26 10:00
ETSI Agreement brings Mobile TV closer to commercial launch

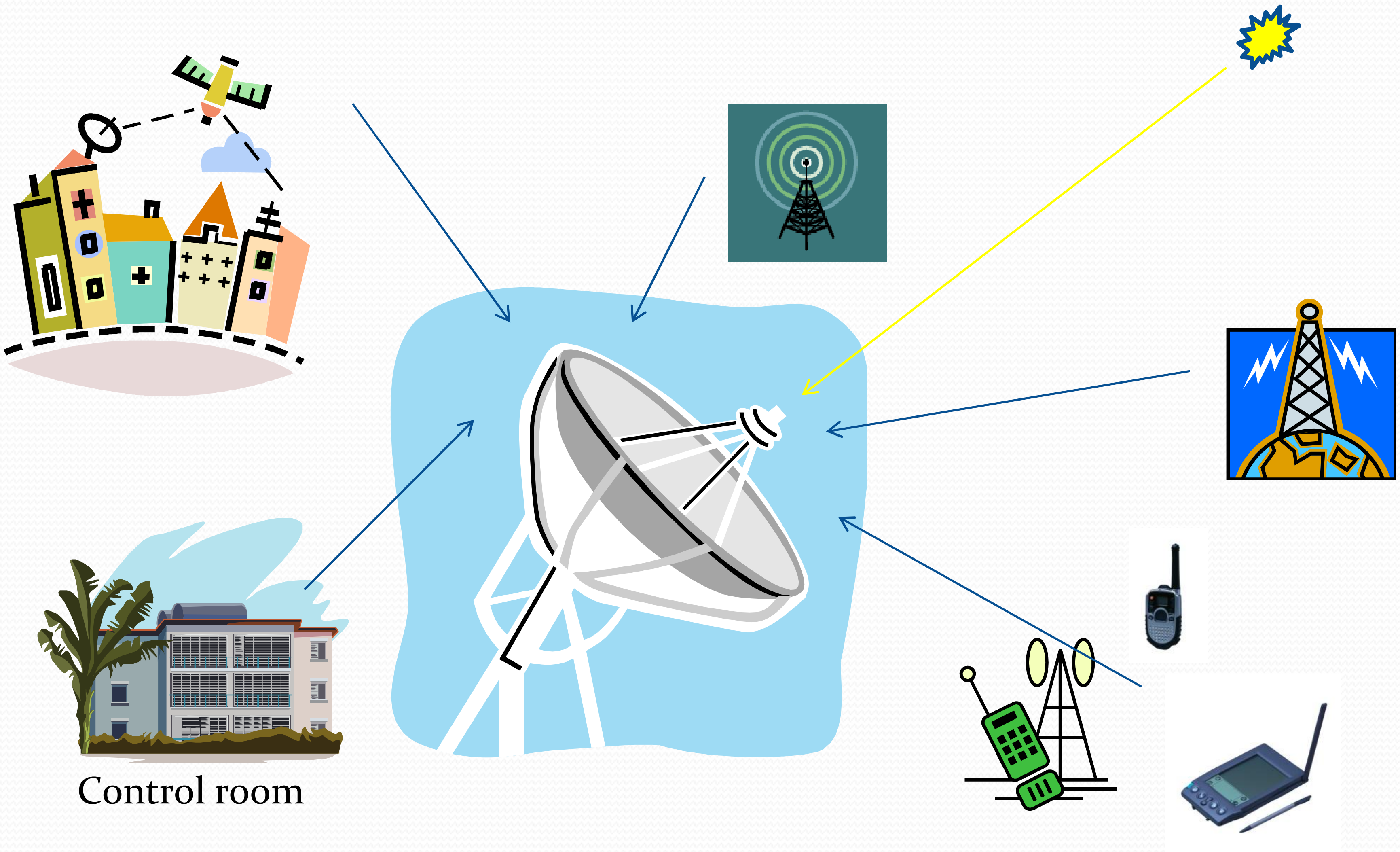
SWE-DISH Suitcase breaks new ground in Africa
Allmänna Nyhetstips - 2005-11-15 09:04

From Head-End to Handheld, TANDBERG Television Launches the TV Ecosystem for the Mobile Generation
Tandberg Television - 2007-03-27 09:54

Logga in
Användarnamn:
Lösenord:
Kom ihåg mig på denna datorn
Logga in
Registrera journalist
Registrera företag
Glömt lösenordet?

Completato

At a VLBI station



At a VLBI station

- If we need to fight against an enemy it's better we know who is and where is coming from
- Any station should have personnel dedicated part of the time to have knowledge of RFI
- A systematic and automatic monitoring could be worth to be set
- A list with the RFI information of frequency, polarization, direction, bwd, time presence, etc. represents a sort of RFI_ID_card
- Standardization could be worth

Example of equipment to monitor RFI

INTERFERENCES RECEIVER SYSTEM

Antennas

- 2 X log periodic antenna SAMA TELECOMUNICAZIONI mod. LPD-M3
- 2 X log periodic antenna CREATE
- 1 X 2 mt. prime focus parabolic reflector

Spectrum analyezer HP 8569B

Communication receiver ICOM IC-R9000

PAL monitor and video recorder

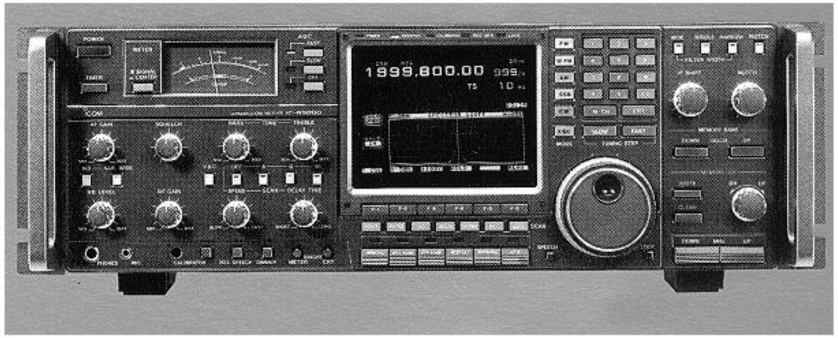
Antennas position controllers

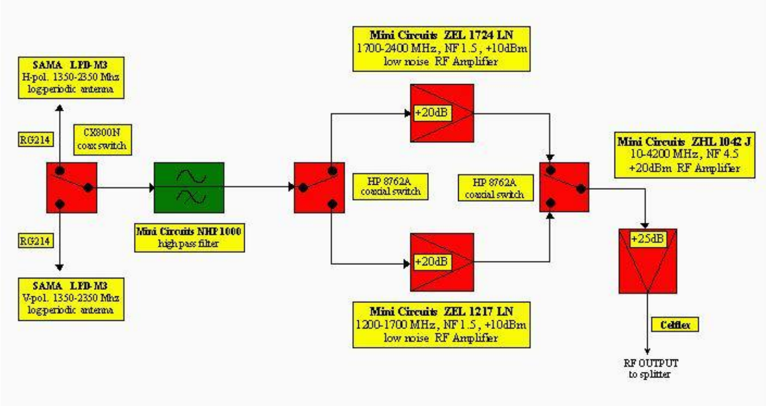
- 1 X model YEASU G-2700SDX
- 1 X model YEASU G-2800SDX

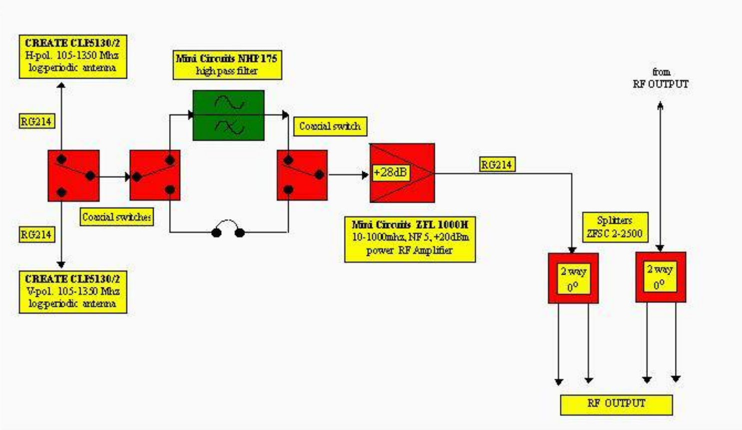
Antennas systems block diagram

Plotter HP 7470A

How to monitor





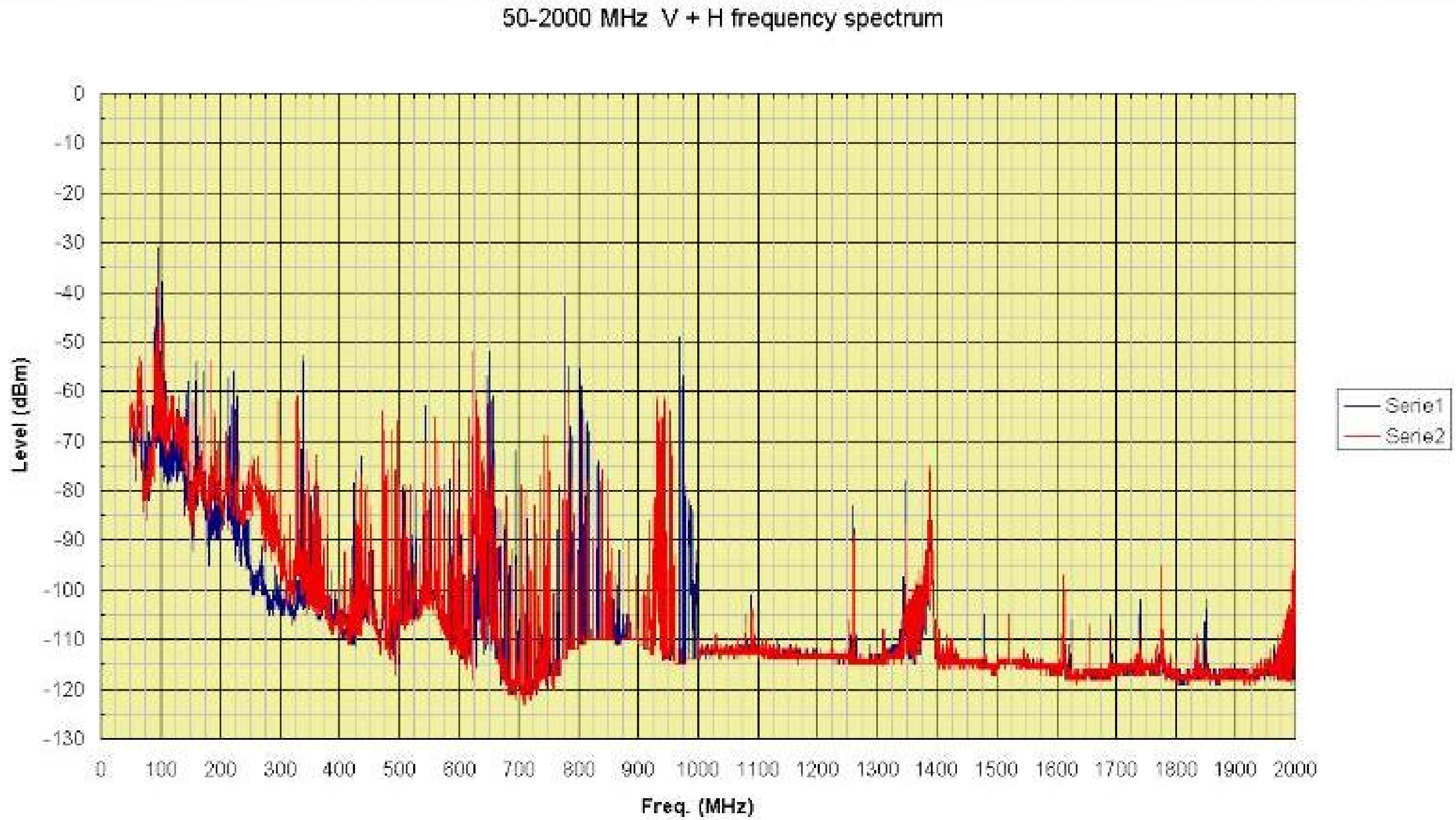


When to monitor

50-2000 MHz RFI Monitoring data archive

Month / Year	2005	2006	2007	2008
January	Data Spectrum	Data Spectrum	Data Spectrum	Data Spectrum
February	Data Spectrum	Data Spectrum	Data Spectrum	Data Spectrum
March	Data Spectrum	Data Spectrum	Data Spectrum	Data Spectrum
April	Data Spectrum	Data Spectrum	Data Spectrum	Data Spectrum
May	Data Spectrum	Data Spectrum	Data Spectrum	Data Spectrum
June	Data Spectrum	Data Spectrum	Data Spectrum	Data Spectrum
July	Data Spectrum	Data Spectrum	Data Spectrum	Data Spectrum
August	Data Spectrum	Data Spectrum	Data Spectrum	Data Spectrum
September	Data Spectrum	Data Spectrum	Data Spectrum	Data Spectrum
October	Data Spectrum	Data Spectrum	Data Spectrum	Data Spectrum
November	Data Spectrum	Data Spectrum	Data Spectrum	Data Spectrum
December	Data Spectrum	Data Spectrum	Data Spectrum	Data Spectrum

What to monitor



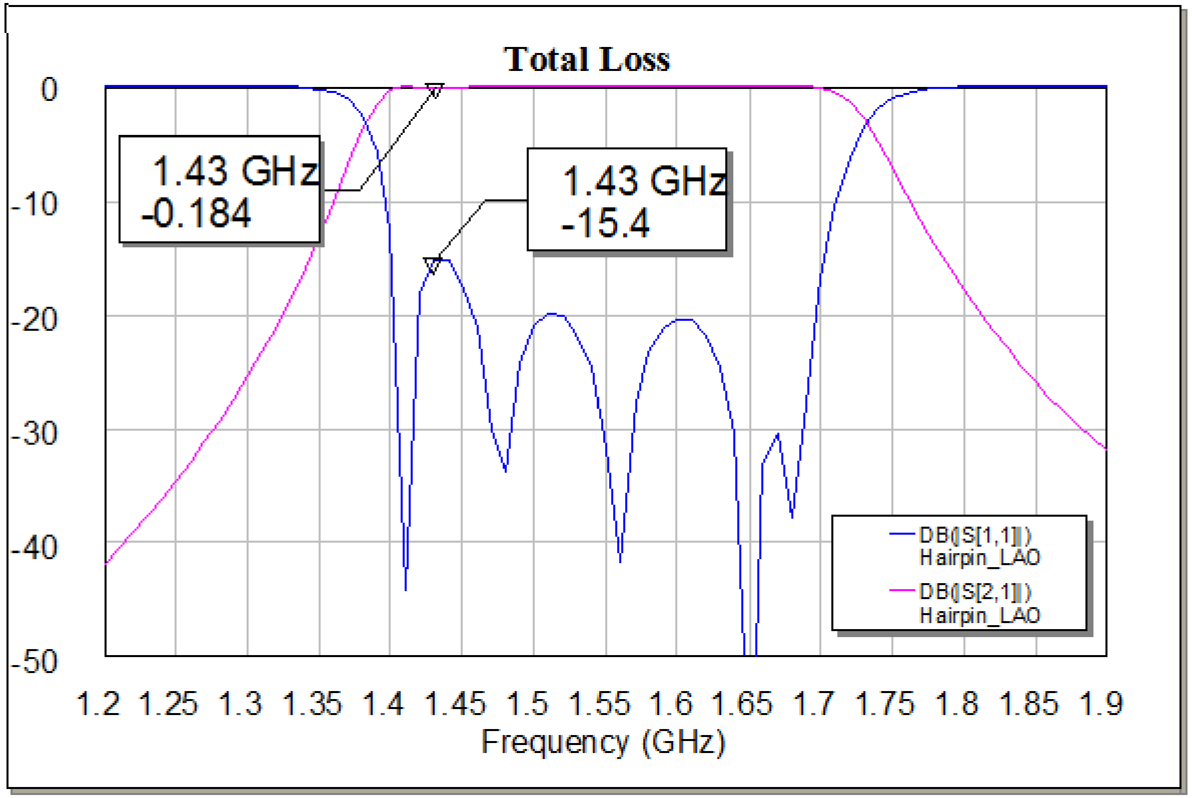
Example of log file

```
file: may99nt.txt
data format:
station:                                Noto VLBI Radiotelescope
scanning (y or n):              y
receiver:                               ICOM R-9000
antenna type:                   Local calibrated RFI system
antenna height (m):             12
antenna location:
antenna polarisation:           Horizontal / Vertical  worst case   N direction
number of frequency bins:       19500
lowest frequency (Hz):          50e6
highest frequency (Hz):         20e8
number of spectra:              48
start date (UT dd mm yyyy)):    15 05 1999
start time (UT ss mm hh)):      09 30 00
duration of one scan (s):       4800
channel integration time (s):   8
channel bandwidth (Hz):         1e5
signal unit:                    dBm
power flux density unit:        dBW/m^2
rfi id:
rem:

Freq.   Ampl.
MHz   dBm

50      -67
50,1    -65
50,2    -64
50,3    -64
50,4    -63
```

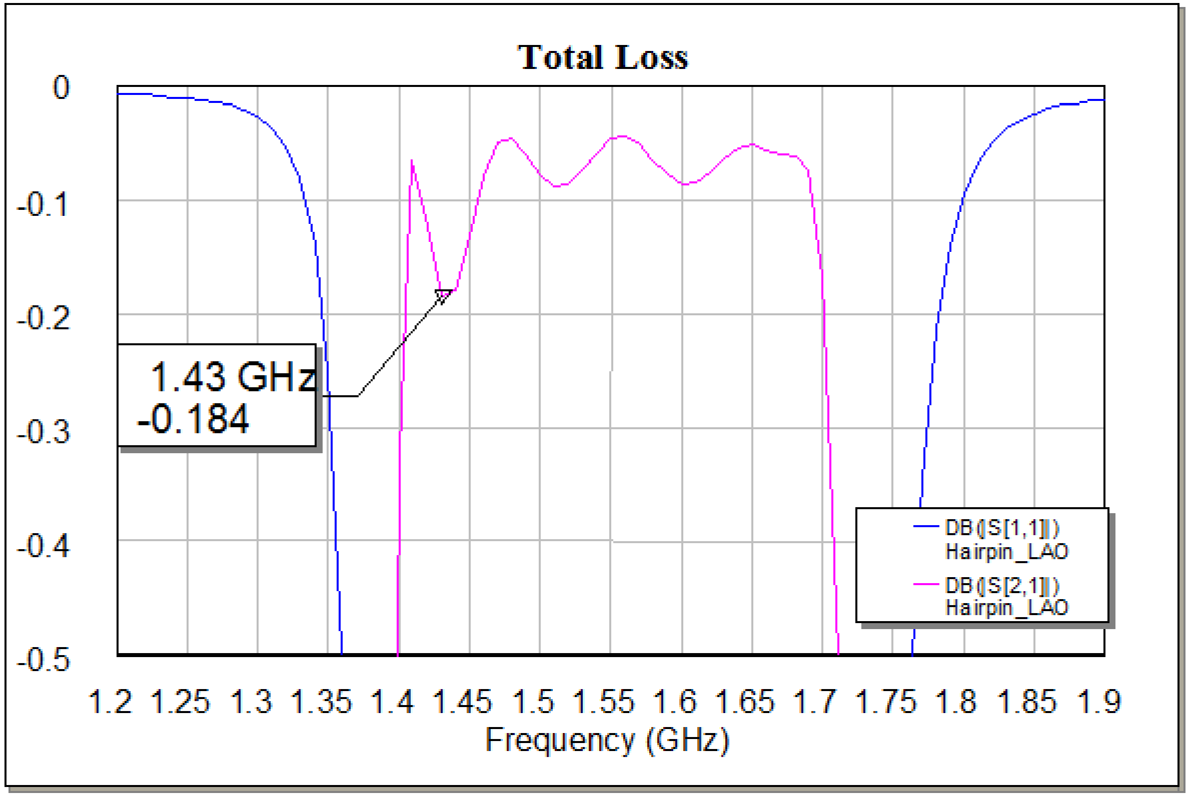
Very strong interference

- For worst case RFI able to saturate (or distroy) the front-end LNA some pre-filtering would be required
- Hight Temperature Superconducting (HTS) materials could offer a solution
- Different possibilities, one explored: YBCO on $LaAlO_3$ substrate
- In Noto extensively studied and simulated X, C and L
- L band filter realised in Noto to reduce a strong radar emission
- Other examples (few) are in literature

Noto L band HST Filter



Noto L band HST Filter



Other examples

IFTU-29

Superconducting Microstrip Wide Band Filter for Radio Astronomy

Yuanzhi Li, Michael J. Lancaster, Frederick Huang, and Neil Roddis

School of Electronic, Electrical and Computer Engineering, The University of Birmingham, Edgbaston, Birmingham, B15 2TT, United Kingdom

Jodrell Bank Observatory, University of Manchester, Macclesfield, SK11 9DL, United Kingdom

Abstract — **A ninth order wide-band bandpass filter is presented for radio astronomy applications. The filter, for Jodrell Bank Radio Observatory, is designed to have a fractional bandwidth of 26.14% and a center frequency of 1.53 GHz. It uses both straight and hairpin resonators in order to achieve the wide bandwidth. In addition, the filter is integrated with two spur-line notch filters for second harmonic suppression. Good agreement between simulated and experimental results is obtained.**

I. Introduction

Since the discovery of high temperature superconductor (HTS) [1] in 1986, there has been increasing use of HTS materials in microwave components. HTS microwave filters started to emerge during the early 1990s, and much effort has been put into filter designs for narrow band applications [2]-[3]. However, there are still not many wide band HTS filters reported. Here we are interested in a wide band filter for radio astronomy application.

With the increasing radio communications activities of recent years, the radio spectrum is becoming intensely crowded and this trend is set to increase at an extraordinary rate. Radio astronomy is particularly sensitive to interference of this type. A high temperature-superconducting (HTS) filter, at the front-end of the receiver, has the potential to effectively eliminate the interference from adjacent bands. Such a filter will have negligible loss, have extremely sharp filter skirts and be small enough to fit into the current low temperature systems.

This work reports a nine pole Chebyshev HTS bandpass filter design and its fabrication according to the specification from Jodrell Bank Radio Observatory (Table I). The nine-pole filter structure (Fig. 1) consists of two types of half wavelength resonators, simple straight resonators and folded hairpin resonators. The coupling structure achieves strong coupling and gives the filter the required fractional bandwidth of 26.14%. In order to suppress the second harmonic, each feed line of the two ports, is integrated with one spur-line filter.

TABLE I
FILTER DESIGN SPECIFICATION FROM JODRELL BANK

Pass Band	1330 - 1730 MHz
Stop Bands	900 - 1310 MHz 1750 – 3000 MHz
Pass Band Insertion Loss	0.1 dB max
Stop Band Rejection	20 dB min
Connectors	K102 F
Maximum Dimensions (inc connectors)	100 × 50 × 15 mm³
Operating Temp	20K

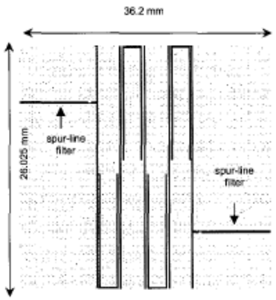


Fig. 1. Layout of the nine-pole filter for 0.5-mm-thick lanthanum aluminate substrate.

0-7803-7695-1/03/$17.00 © 2003 IEEE

II. Filter design

The nine-pole Chebyshev filter is designed to meet the Jodrell Bank specifications (Table I), which requires a bandwidth of 400 MHz and 20 dB second harmonic suppression. The synthesis of Chebyshev filters is well known, and the design procedure used here can be found in [4]. However, to achieve such a wide band response, strong coupling between adjacent resonators is needed. There are a few microstrip filters with fractional bandwidth above 25% reported [5,6,7], but some of them [5,6] are not likely to be suitable for higher order filter design. For example, the stub-line filter [7] will introduce extra low frequency spurious responses. Hence, a new filter structure is introduced here, which consists of half wavelength and hairpin resonators. The positions of the hairpins (Fig. 1) give the highest coupling, as the gap between two resonators remains the same. Resonators with 0.2 mm line width are used in this filter. By adjusting the gap between resonators, the required coupling values can be obtained to realize the filter bandwidth of 400 MHz.

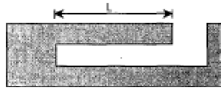


Fig. 2 Microwave spur-line filter

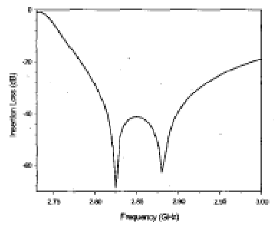


Fig. 3 Simulated responses of two integrated spur-line filter

Fig. 2 shows a layout of a spur-line filter. It is essentially a simple bandstop filter suitable for moderate bandwidths (around 10%) [8]. The filter is embedded in the 50Ω microstrip feed. The spur-line filter consists of a pair of coupled lines a quarter wavelength long, one line is open ended; both lines are connected together at the other end. The length of the spur line L (Fig. 2), is determined from the center frequency of the stop band. The filter can be designed by the procedure described by Bates [8]. To increase the rejection, two spur-line filters are applied here, to produce notches at the band pass filter second harmonics. The two spur-line filters were simulated using the Sonnet EM simulator [9]. Fig. 3 shows that the two spur-line filters can achieve 20 dB rejection across bandwidth of at least 250 MHz when not connected to the main filter.

The complete filter topology depicted in Fig. 1 provides low cross coupling between non-adjacent resonators. However, such unwanted cross couplings cannot be completely avoided in a filter with such strong couplings. Hence, a circuit model has been completed in Microwave Office [10] in order to optimize the whole filter in terms of flat bandpass, low insertion loss and high harmonic suppression ratio. Sonnet EM simulator was used to provide final accurate responses.

III. Experimental Results

The filter was fabricated on a 0.5 mm thick $LaAlO_3$ substrate with YBCO thin film deposited on both sides. The superconducitng ground plane of the filter was evaporated with gold to make good electrical contact to the packaging. To avoid thermal stress, the filter was bonded onto a gold-plated titanium carrier and packaged inside a titanium housing. Metallic screws are used for tuning the filter. The filter was cooled in a cryogenic cooler and was measured using an HP8722E vector network analyzer.

Fig. 4 shows the measured results at 20K of the nine-pole filter before tuning, compared with Sonnet EM [9] simulated results. They show excellent agreement. This filter is also tuned at 20K. Fig 4 gives the measured results after tuning. The maximum passband S_{11} observed is less than -15 dB. Most of the second harmonic has been suppressed to -20 dB. It can be seen from Fig 5, that the filter response has been considerably improved by the tuning process to a level better than the simulated results. The passband ripple (Fig. 6) has been reduced to 0.2 dB. Passband S_{21} is better than -0.3 dB, somewhat short of the original specification, and its bandwidth is from 1330 to 1730 MHz, which meets the specification in Table I. The minimum passband insertion loss of 0.1 dB has a

Other examples (cont.)

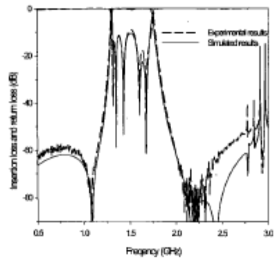


Fig. 4 Experimental and simulated filter responses before tuning

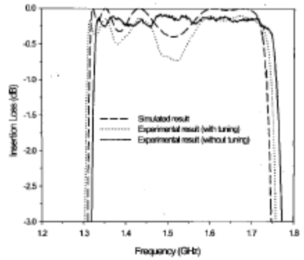


Fig. 6 Experimental and simulated passband responses

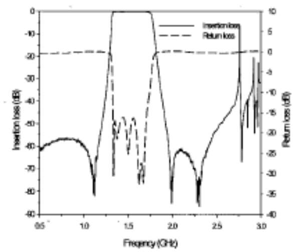


Fig. 5 Experimental filter responses after tuning

contribution from the connections at the input and output ports.

IV. CONCLUSION

A design of a nine-pole filter for radio astronomy has been discussed. The HTS filter was fabricated on a $LaAlO_3$ substrate with dielectric constant of 23.6. After tuning, the filter response has an insertion loss of less than 0.3 dB and maximum S_{11} of –15 dB. The -0.3 dB level of the filter passband has been tuned in the required frequency band of the specification. The good performance of the HTS filter demonstrates that wideband performance can be achieved with harmonic suppression in a filter suitable for radio astronomy applications.

The filter is currently being tested in Jodrell Bank Observatory.

ACKNOWLEDGEMENT

The authors would like to thank the Jodrell Bank Radio Astronomy Observatory for providing opportunity and support for the filter testing. The authors would also like to thank Dr. H. T. Su for his help in measurement, Dr. X. Xiong and D. Holdom for fabricating the HTS circuit, and Mr. C. Ansell for his technical support. The work was supported by the UK Engineering and Physical Sciences Research Council.

REFERENCES

[1] J. G. Bednorz, and K. A., Muller, "Possible high Tc Superconductivity in the Ba-La-Cu-O System", *Z. für Phys.*, vol. 64, pp. 189, 1986.

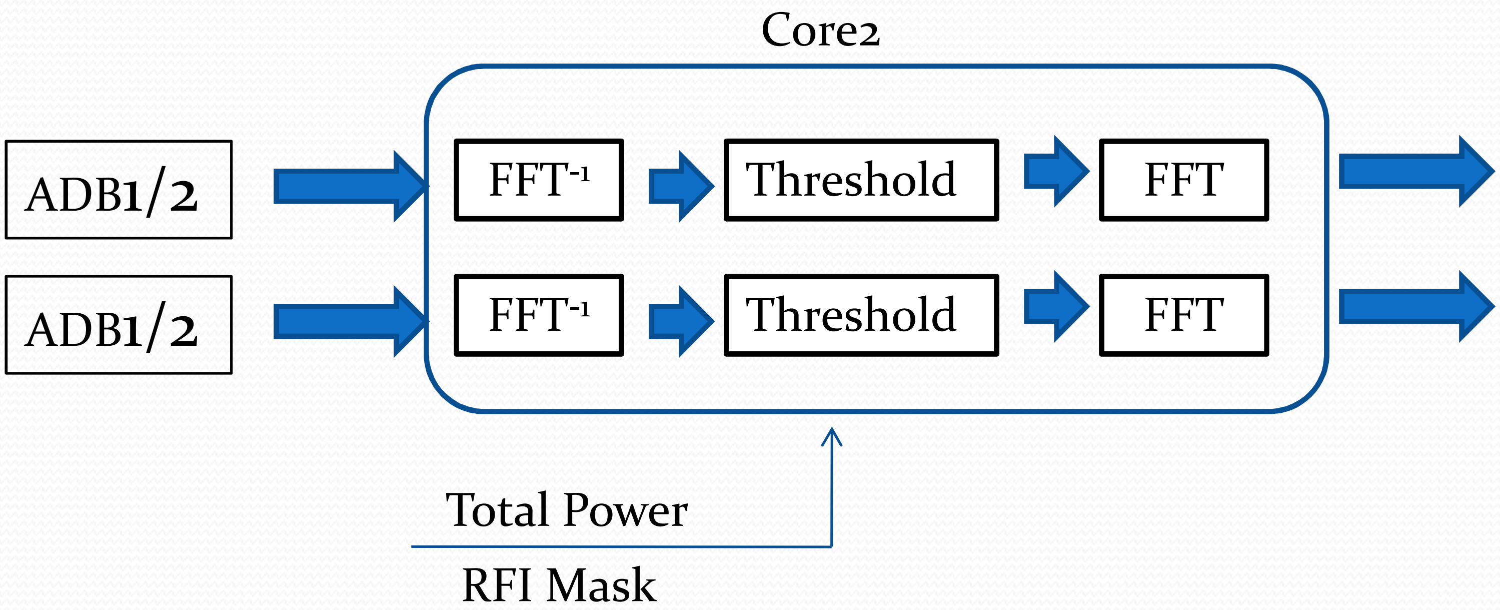
[2] J. S. Hong, M. J. Lancaster, J. C. Mage, "Cross-coupled HTS microstrip open-Loop resonator filter on LAO substrate", *IEEE MTT-S*, vol. 4, pp. 1559-1562, 1999.

Relevant RFI: mitigation in digital domain

- Can be removed at different stages in the digital process
- Time – Frequency – Time domain conversion and clipping have been extensively simulated and tested at pre-conversion stages in the DBBC (simple)
- More complex operations can be realized based on real-time cancelling (complex but possible, see several examples in literature, eg. Westerbork)

Method adopted in the DBBC

- An additional Core2 is required as front-end element for 2 polarizations



Conclusions for VLBI2010

- It looks reasonable to evaluate whether a station should dispose of RFI monitor equipment
- It could be worth to evaluate if a standardized method is useful
- A real-time RFI log file to be added to other observation logs?
- With a continuous receiving band a tuning strategy to avoid RFI is possible
- Worst case signals (saturation) needs to be treated case by case
- Mitigation to reduce large peaks in the band is possible with digital methods before band conversion