INTERNAL REPORT

Analog filters for the Digital Filter Bank of the SRT: scientific motivation, technical requirements, and proposed solutions

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Abstract

With the present report, we describe the main scientific drivers that led to the purchase of analog filters to be used in conjunction with the Digital Filter Bank of the SRT. The main details of the filters available and different options for their implementation are also described. In addition, the design and manufacturing requirement for a filters' switch aimed at a remote controlling of the filters interchange are outlined.

1. Scientific Rationale

So far, there is evidence for a total of three distinct classes of luminous **extragalactic H_2O masers** (the so-called 'megamasers'; for recent reviews on this topics, see, e.g., Lo 2005; Tarchi 2012):

(1) those tracing accretion disks in active galaxies ('disk-masers'); (2) those in which at least part of the H_2O emission is believed to be the result of an interaction between the nuclear radio jet and an intervening molecular cloud ('jet-masers'); (3) those associated with nuclear outflows ('outflow-masers').

In the following we concentrate on the first of the three classes of water masers described above. Indeed, disk-masers, through a combination of VLBI observations (to map the angular distribution of maser features) and single-dish monitoring measurements (to derive the possible velocity drift of the individual maser features) allow us to map nuclear accretion disks, to determine nuclear masses, and accurate distances to their parent galaxies, thus having an impact on the cosmic distance scale. NGC 4258 is the best studied target of this class (e. g. Greenhill et al. 1995; Miyoshi et al. 1995; Herrnstein et al. 1999; Bragg et al. 2000) but more targets are now under investigation (e.g., UGC 3789; Braatz et al. 2010), particularly thanks to the Megamaser Cosmology Project (Henkel et al 2012).

However, although much effort has been devoted to search for H_2O extragalactic masers, detection rates in large surveys have been disappointingly low: in the most successful surveys, detection rates are a few percent (e.g. Braatz et al. 1996; Tarchi 2012). Only recently, larger detection rates have been obtained by observing *ad hoc* samples: i. e. galaxies with particularly high 100μ FIR flux density or peculiar types of Seyfert galaxies (Henkel et al. 2005; Tarchi et al. 2011).

A contribution to the search for 22-GHz H_2O masers within the nuclei of galaxies could be definitely provided by the SRT taking profit of its high sensitivity and the capabilities of its K-band receiver.

In addition, the SRT is going to be a particularly suitable instrument to perform Galactic and Extragalactic molecular line mapping surveys, provided that relatively broad bands and sufficiently high spectral resolution are made available.

2. Technical Justification

In the framework of the aforementioned scientific goals, the SRT 22-GHz 7-feed receiver can be exploited by performing internal beam switching observations, in order to avoid loosing time on the off position.

A spectrometer that supports simultaneously bands with widths greater than 200 MHz is indeed advisable.

Such wide bandwidth capabilities are necessary because known H_2O masers in AGN display typically sub-Jy spectral lines distributed over a frequency interval of about 500 to 2600 km s^{-1}, where the interval is dictated by the rotation speed of the disk at radii where the maser action is excited (Fig 1). Being impossible to predict such interval, the widest possible instantaneous bandwidth is critical for efficient surveys of large numbers of galaxies.

The bands should be sampled with a high enough number of spectral channels. Indeed, typical linewidths of individual features can be as narrow as ~ 0.4 km/s (and, in some cases, even narrower). Hence, in order to be able to perform the aforementioned monitoring programs and have the chance to distinguish between different drifting features, a spectral resolution of ≤ 30 kHz is required. For bands of 128, 256, 512, and 1024 MHz, this implies a minimum number of spectral channels of 4096, 8192, 16384, and 32768, respectively.

In the following, the main characteristics in terms of instantaneous bandwidth and spectral resolution of the backends suitable for spectroscopic measurements presently available at the SRT are outlined.

– **XARCOS:** it has an output of 8x2 'segments', suitable to be used with the 7-feed (14 IF) K-band receiver. The instantaneous bandwidth ranges from 0.488 MHz (tunable in the range 135-240MHz) to 62.5 MHz (tunable in the range 135-240MHz), with a maximum number of spectral channels of 2x2048 per polarization, per output 'segment'. Thus, for each beam the actual maximum instantaneous bandwidth is 62.5

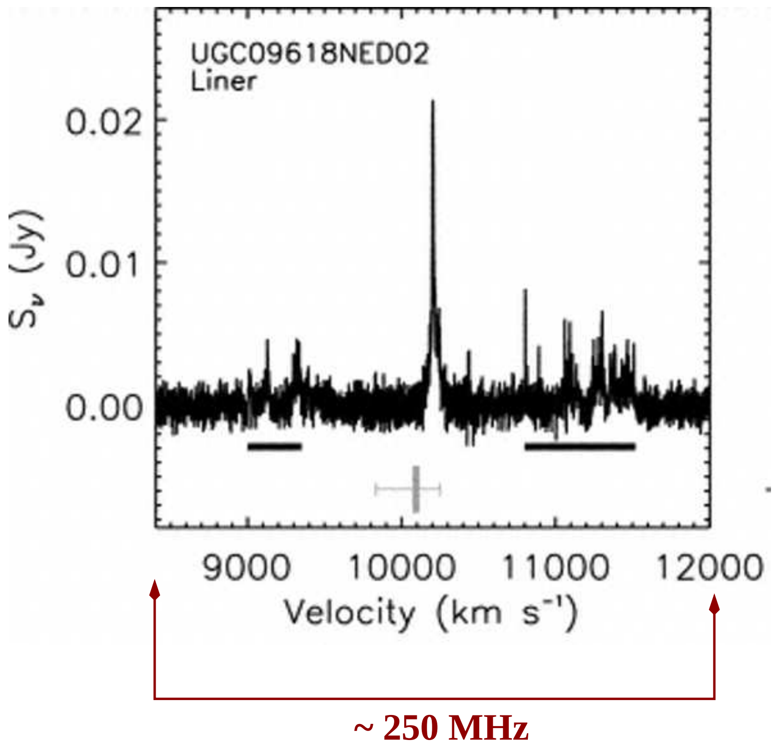

Figure 1: Spectrum of the water maser emission found in UGC 9618 showing the systemic and high-velocity satellite maser features. The SRT bandwidths ≥ 200 MHz are necessary at 22 GHz to detect them simultaneously. The spectrum is taken from Kondratko et al. (2006).

MHz that, with 2048 spectral channels, yields a spectral resolution of 30 kHz.

– **DFB:** this Digital Filter Bank presently offers a bandwidth of 1024 MHz with a maximum number of channels of 8192 and 16384 for a single beam (2 IF), when full or no polarization is requested, respectively, and of 4096 and 8192 for a dual beam (4 IF), when full or no polarization is requested, respectively. Thus, assuming a dual beam observation with no polarization information, the bandwidth is of 1024 MHz with 8192 channels, yielding a spectral resolution of 0.125 MHz, corresponding to ∼ 2 km/s at 22 GHz.

– **DBBC:** it is designed for VLBI experiments (spectro-polarimeter) and has 4 IF with a maximum bandwidth of 1 GHz usable for two beams. It is a very flexible instrument that can, in principle, provide, when suitably programmed, a variety of combinations of bands and spectral channel numbers.

It is quite straightforward to notice that, in order to pursue the scientific programs described earlier in this report (requiring instantaneous bands larger than 150 MHz in combination with spectral resolution of, at least, 30 kHz) only the last two backends may be suitable, the DFB and the DBBC. Since, however, the use of the latter is currently oriented only toward VLBI and RFI-monitoring measurements with the SRT, the DBBC option will not be considered in this report.

In the particular case of the DFB where the maximum number of channels (=8192 for a dual beam and no-pol mode) cannot be increased, smaller bands than the 'standard' 1024-MHz one need to be made available to the backend in order to increase the final spectral resolution. This can be achieved by a number (depending on the number of subbands requested) of 'ad hoc' analog filters installed just before the backend.

Possible sub-bands are summarized in the attached Table. A selection of preferred suitable bandwidths and the corresponding spectral resolution (for 8192 channels) are reported in columns 1 to 3. The minimum and maximum IF frequencies of the (sub)bands allowed by the DFB firmware filters (cols. 4–5), and those provided by the aforementioned frontend circuit are also shown.

3. New Hardware Requirements for the DFB

In order to achieve the DFB (sub)bands of 512, 256, and 128 MHz (split into 8192 channels), **three analog filters are necessary**. The IF frequency ranges (minimum and maximum IF frequency vales) of these filters should match one of the ranges imposed by the DFB firmware for the corresponding bandwidth. The choice of the filters' IF frequency ranges should take into consideration, in particular, the necessity to avoid radio frequency interferences (RFIs) in such IF ranges. *It is strongly advisable that the possibility exists for the observer to switch between the different filters in an automatic and remote way.*

4. Proposed solutions for the DFB filters and main technical characteristics

Three main solutions were proposed to accomplish the aforementioned requirements:

- **LFCN225 PCB FSTP Filter:** Presently, it is possible to use for broadband receivers (with bandwidth of 2 GHz, e.g., the MFK and 7-GHz receiver) only the smallest PFB tunable on the printed board circuit (PCB) of the focus selector of the total power backend (FSTP, Maccaferri et al. 2011) situated in EER of the SRT.

  The operator will have to select the smallest filter and set the DFB simulating the "0-512 MHz band" option. It is clear that the band is limited, since it ranges from 100 to 300 MHz. This solution is temporary since it limits the BE DFB capabilities. This option is already available for the SRT. The other receivers with a narrower bandwidth (i.e., the L and P band receivers) do not need the aforementioned filter since their band is already fixed.

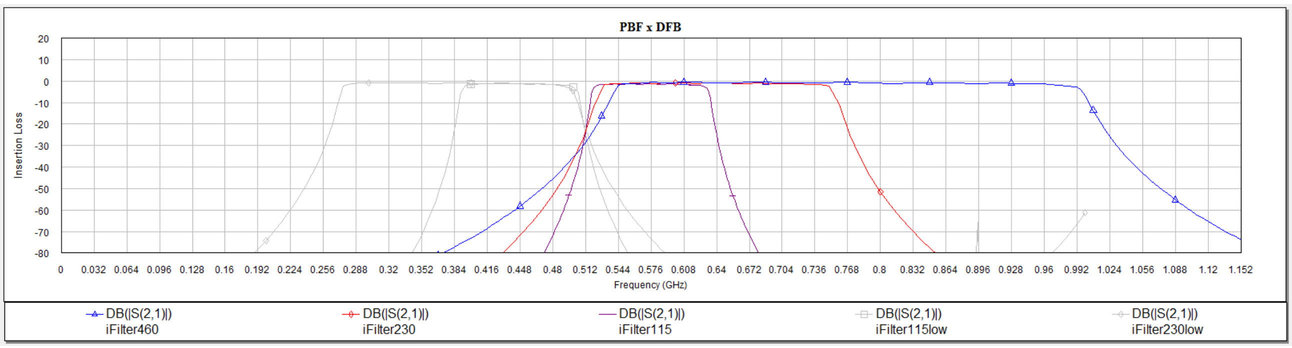

Figure 2: Transmittance plot of RLC series BPF-250 tubular filters BPF-250-**768-460**-9-F-M; BPF-250-**640-230**-9-F-M; BPF-250-**576-115**-9-F-M. The first number in bold-face format is the central frequency followed by the bandwidth.

- **RLC series BPF-250 tubular filters with no remote interchange capability:** It is possible to obtain BPF tubular filters, that can be inserted each time on the DFB. This solution is quite straightforward for a quick application, however, it may, on a long term, not be the optimal one for the users being the interchange between filters not possible from remote. In addition, for some antenna places where the DFB may be mounted this option may be not favourable. The costs for 3 filters for 4 channels (12 filters in total) may be of 5000-6000 euros. In the case of frequent filter changes, mechanical breaks may be possible.

  Due to construction constraints the large filter (theoretically the 512 MHz) cannot cover more than 60-70% of the band. This fact forces the central frequency to a value of 768 MHz and a bandwidth of 460 MHz (with a 3 db cut). In order to have filters of limited size it is recommendable to build also the other two filters in the upper side of the bandwidth (i.e., 512-1024 MHz). It is, however, not forbidden to build them in the 0-512 MHz part of the band (see light grey lines). As shown in Fig.2, it is also desirable to have at least a 20-25dB rejection level in the band.

Selected filters: BPF-250-**768-460**-9-F-M; BPF-250-**640-230**-9-F-M; BPF-250-**576-115**-9-F-M.

The first number in bold-face format is the central frequency followed by the bandwidth.

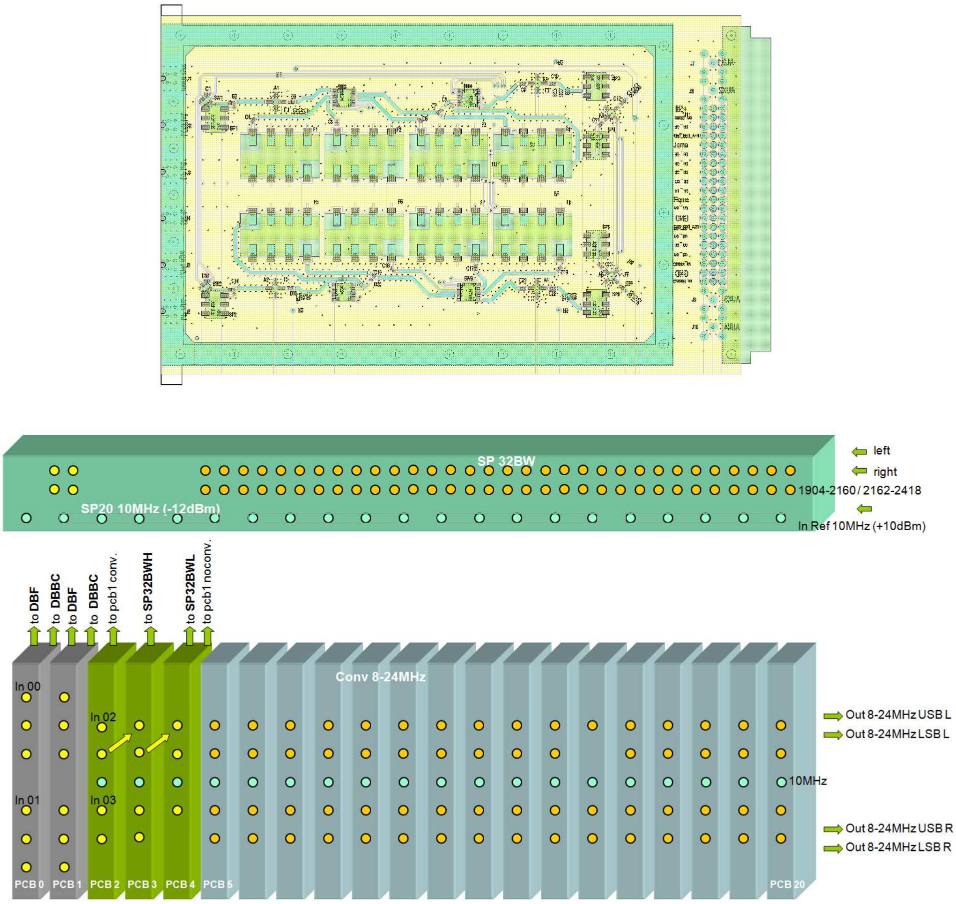

Figure 3: Top: a PCB Eurocard; Bottom: the analog BE Pulsar basket.

- **Commutable filter bank inserted in the analog BE Pulsar basket:** Taking profit of the expected availability of the "BE Pulsar", it is possible to develop and insert the PCB Eurocard (Fig. 3). These device are properly designed to host already a filter commutator for BPF A-INFO filters (with a surface mount) suitably constructed. Expected performances will be identical to those of item 1 with the relevant advantage of the possibility to remotely switch between filters. Also the cost is expected to be either equal or even less than that of option 2.

  Taking profit of the analog BE Pulsar basket it is possible to develop a fully remotely-controlled filter bank on a chip (Fig. 3). This relatively-simple chip is expected to host surface mount filters produced by the A-INFO Company. The filters curve are similar to those shown in Fig.2. The PCB should theoretically be designed in one or two weeks and can be developed also by involving staff members of the Cagliari Observatory.

  Selected filters: WBLB-S-BP-**576-115**; WBLB-S-BP-**640-230**; WBLB-S-BP-**768-460**

  For the "broad filter" option the bandwidth can be slightly broaden up to 480 MHz (presently, filters allow for a 70% bandwidth). In Fig. 4, the markers highlight the minimal rejection of the image band

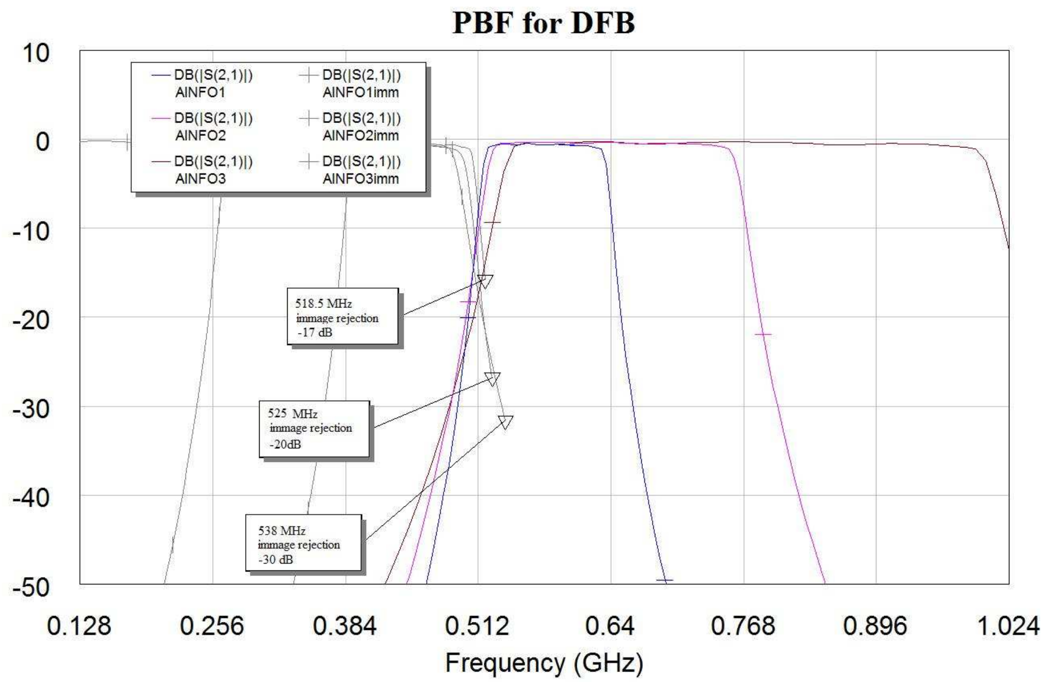

Figure 4: Transmittance plot of PCB Filters: WBLB-S-BP-**576-115**; WBLB-S-BP-**640-230**; WBLB-S-BP-**768-460**. The first number in bold-face format is the central frequency followed by the bandwidth.

of the corresponding filters.

5. State-of-the-Art and Final remarks

The purpose of this report was to illustrate the main scientific motivation and the available technical possibilities/devices to provide the DFB with analog filters aimed at offering the possibility to obtain bandwidths with widths different than the one presently provided by the backend. The choice among the three options illustrated in the previous section has now been done. The filters and strategy to implement a 'Commutable filter bank' (option 3 in Sect. 4) has been selected due to its versatility and lower manufacturing costs. In addition, the work to assembly the filterbank is at an advanced stage. A thorough description of the single components of the device and of the manufacturing steps are, however, outside the scope of the present work and will be the subject of a more exhaustive future publication.

Acronyms

BE	Backend
BPF	Band Pass Filters
DBBC	Digital Base Band Converter
DFB	Digital Filter Bank
EER	Elevation Equipment Room
FSTP	Total Power Focus Selector
MFK	Multi feed K-band receiver
IF	Intermediate Frequency
PCB	Printed Circuit Board
RFI	Radio Frequency Interference
SMBP	Surface mounted band pass

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Table 1: Suitable bandwidths, corresponding frequency and velocity spectral resolution (for 8192 channels), minimum and maximum IF frequencies of the (sub)bands allowed by the DFB firmware filters, and subbands provided by the frontend filters.

Bandwidth MHz	Max resolution MHz	Δv (@22 GHz) km/s	DFB-IF(low) MHz	DFB-IF(high) MHz	Frontend Filters
1024	0.125	1.659	0	1024	100-1300MHz 100-800 MHz
512	0.0625	0.830	0 512	512 1024	100-330 MHz
256	0.03125	0.415	0 256 512 768	256 512 768 1024	
128	0.015625	0.207	0 128 256 384 512 640 768 896	128 256 384 512 640 768 896 1024	
64	0.0078125	0.104	0 64 128 192 256 320 384 448 512 576 640 704 768 832 896 960	64 128 192 256 320 384 448 512 576 640 704 768 832 896 960 1024	