Design, Construction and Characterization of an IF Processor for the FFT Spectrometer of the Yebes 40 Meter Radio Telescope

By José Antonio López-Pérez and David Cuadrado-Calle;
Centro Astronómico de Yebes (CAY)

Describes the design, construction and characterization of an IF processor for the adaptation of the IF signal frequency range of radio astronomy receivers.

Abstract

The radio astronomy receivers installed in the receiver room of the 40 meter radio telescope at the Spanish Centro Astronómico de Yebes (CAY) provide an intermediate frequency (IF) signal in the standard Very Long Base-Line Interferometry (VLBI) frequency range from 500 MHz to 1000 MHz. For single-dish observations, the IF signal must be sent to the Fast Fourier Transform spectrometer (FFTS) placed in the backend room of the radio telescope. This spectrometer is configurable in four different resolution modes that correspond to four different base band input frequency ranges. As the FFTS base band frequency input range doesn't match with the IF signal range from the receivers, a frequency down conversion is needed and it is provided by an analogue IF processor.

The present work shows the design, construction and characterization of an IF processor for the adaptation of the IF signal frequency range of the radio astronomy receivers to two of the Fast Fourier Transform spectrometer input frequency ranges. These frequency ranges are the one between DC and 100 MHz and the one between DC and 500 MHz.

The processor is made of commercial off-the-shelf (COST) components (amplifiers, filters, mixers, etc.) and it has been integrated inside a standard 19" 2U rack with 2 inputs for the receivers' IF signals (LHCP and RHCP channels), 2 outputs for the DC-100 MHz range and 2 outputs for the DC-500 MHz one. The resulting processor has been tested showing input and output return losses better than 13 dB and 15 dB, respectively, a mean power gain of 25 dB (± 1.5 dB) in its linear zone and an output power of +10 dBm at -1 dB gain compression point.

Introduction

The CAY 40 meter radio telescope is equipped with a Fast Fourier Transform spectrometer, so-called FFTS, from Radiometer Physics GmbH, for the detection and observation of molecular lines in *single-dish* mode.

The spectrometer has eight modules, each one configurable during booting in any of the operation modes described in Table 1.

Mode	Bandwidth (MHz)	Channels	Resolution (KHz)	ENBW* (KHz)
A	DC - 1500	8192	183,1	212
B	DC - 750	16384	45,8	53
C	DC - 500	16384	30,5	35
D	DC - 100	16384	6,1	7

Table 1 • Operation modes of the FTTS of the 40 m radio telescope. * ENBW = Equivalent Noise Band Width.

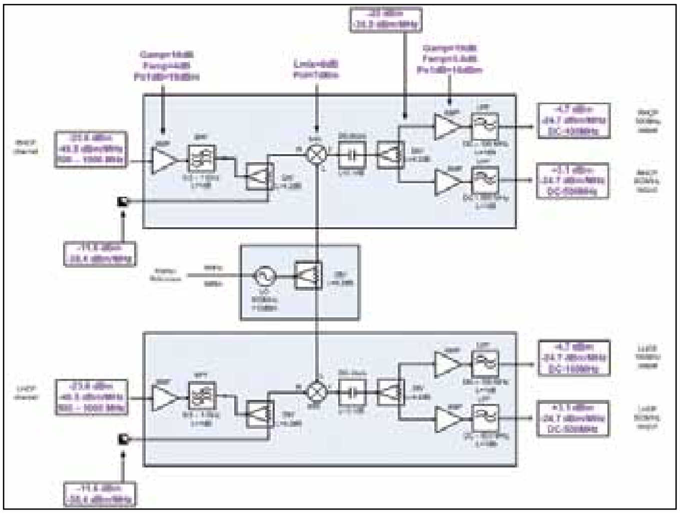


Figure 1 • Block diagram of the IF processor and power levels.

As the receivers installed in the radio telescope have their IF in the range between 500 and 1000 MHz, according to the specifications for standard VLBI receivers, a previous unit for down conversion to the FFTS input frequency range is needed, particularly for C and D modes, where the narrower resolutions can be achieved.

Design

Figure 1 shows the block diagram of the IF processor. The processor is composed of two equal conversion chains (one for each circular polarization sense, LHCP and RHCP, according to VLBI standards) and one common local oscillator (LO) at 500 MHz that enables the necessary frequency down-conversion.

The IF input signals are amplified and filtered in the 500 MHz to 1000 MHz range, before reaching the mixer, to filter out unwanted signals and noise. One sample of the input signal is sent to an auxiliary output by means of a power splitter. This is to allow the connection of other devices for analysis (backends, Mk-4 terminal...) or diagnosis (spectrum analyzer). After the mixer, the signal, which is now in base band, is divided into two ways and amplified again. Then one way is low-pass filtered to DC - 100 MHz and the other to DC - 500 MHz.

Integration

All the components shown in the block diagram of Figure 1 have been integrated in a standard 19” 2U rack. Figure 2 shows the final look of the processor.

Laboratory Measurements of the IF Processor

Return losses of the input ports

Figure 3 shows the result of the S11 parameter measurement in the input ports of both LHCP and RHCP channels of the IF processor.

It can be seen that both channels have a good input matching in the frequency range between 500 and 1000 MHz with return losses better than 13 dB.

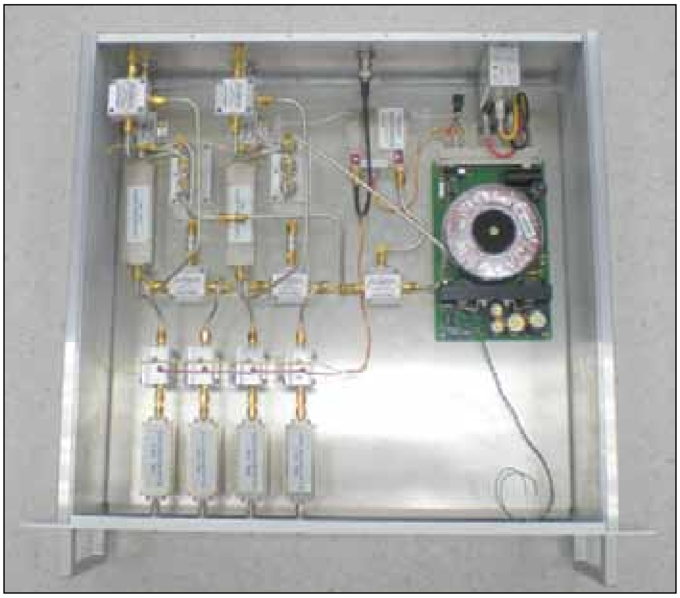
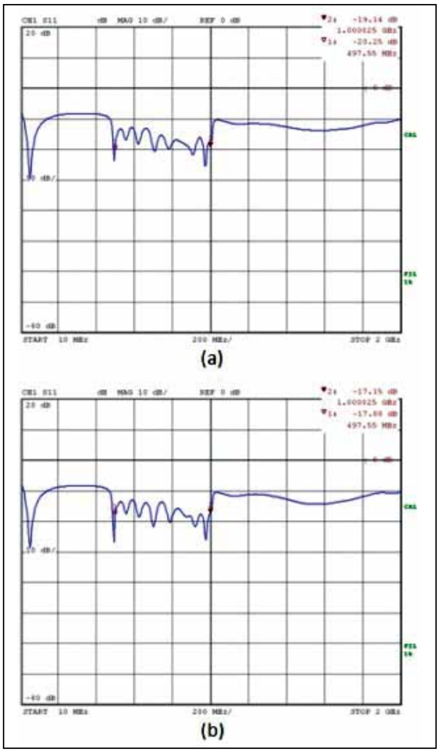
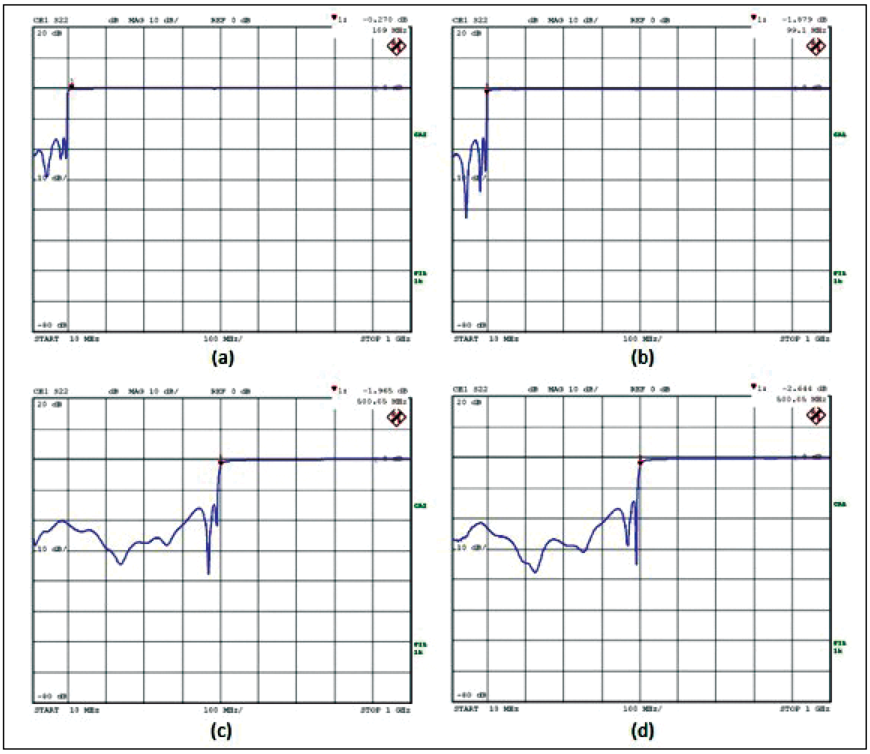


Figure 2 • Integrated IF processor.


(a)

(b)

Figure 3 • LHCP (a) and RHCP (b) input ports return losses.


(a)

(b)

(c)

(d)

Figure 4 • Return losses of the output ports LHCP DC-100 MHz (a), RHCP DC-100 MHz (b), LHCP DC-500 MHz (c), RHCP DC-500 MHz (d).

Return loss of the output ports

Figure 4 shows the return losses of the output ports of the processor.

According to these measurements, the return losses at the output ports are better than 15 dB through all the output frequency range.

Gain curves and 1 dB compression point

In order to determine the processor's gain, a power sweep has been carried out at several frequencies of the input signal. The resulting gain curves are represented in Figure 5.

According to these graphs, both channels have a gain of 25 dB (± 1.5 dB) on their linear zone.

The output power at -1 dB gain compression of the processor has been calculated for the wideband output of both LHCP and RHCP channels. The computations have been carried out at 950 MHz, and the results are shown in Figure 6.

Hence, it can be considered that *the output power at -1 dB compression is +11 dBm for the LHCP channel and +10 dBm for the RHCP channel.* As the processor has a mean gain of 25 dB and it is highly recommended to leave a security margin of 5 dB at least, the *maximum recommended input power to the processor is -20 dBm.*

Installation in the Radio Telescope

Once the processor has been completely characterized in terms of matching, power levels and gain, it has been

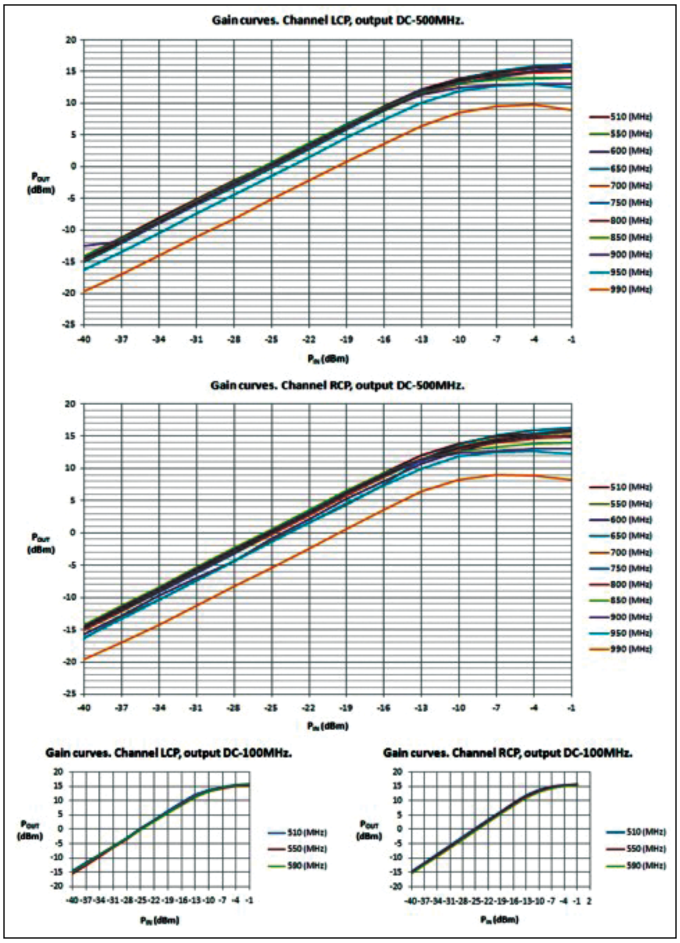


Figure 5 • Gain curves.

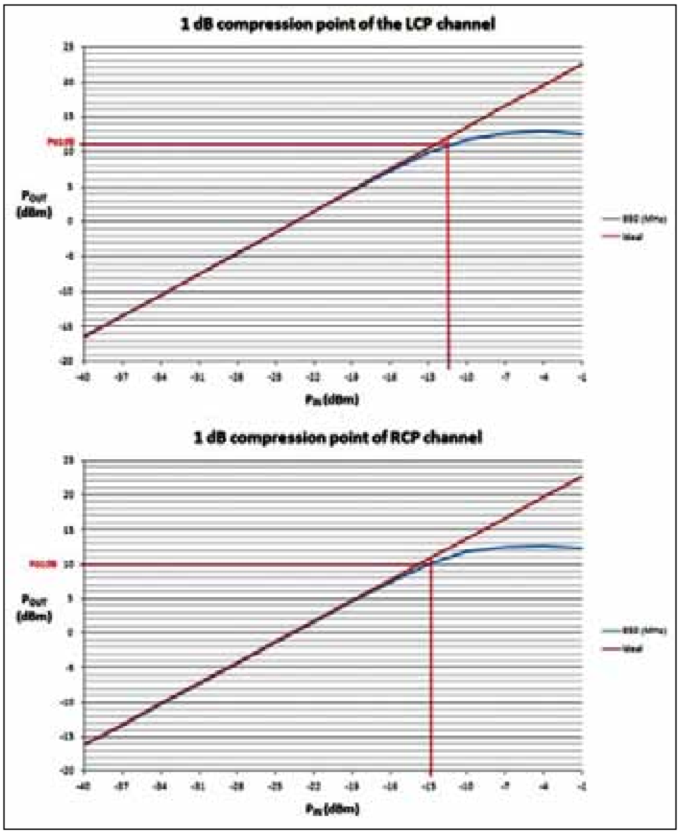


Figure 6. Linearity of the IF processor.

installed in the backend room of the Yebes 40 meter radio telescope.

As it is shown in Figure 7, the IF processor has been installed in the same rack as the FFT spectrometer, just below it.

Measurements in the Backend Room

In order to measure the behaviour of the IF processor in the backend room, an additive white gaussian noise (AWGN) generator has been used together with a band pass filter between 500 MHz and 1000 MHz. This system provides a signal with similar characteristics than the astronomical one. The set AWGN generator plus filter has been characterized according to the set-up shown in Figure 8.

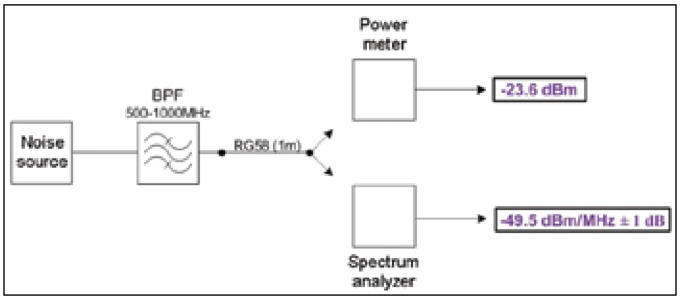


Figure 8 • Test signal characterization.

Figure 7. Front view of the IF processor (bottom rack) installed in the backend room below the FFTS.

Once the level of the test signal has been measured, it has been injected in the IF processor where the power levels and the spectrum of each output port have been measured. The test bench used for carrying out these measurements is shown in Figure 9.

The power level values obtained at each output port are shown in Table 2.

Figure 10 shows the spectrum of the input signal and the ones obtained at the monitoring ports, the DC-100 MHz outputs and the DC-500 MHz outputs. These spectra have been obtained with the spectrum analyzer configured with 10 dB/div and a resolution bandwidth of 1 MHz.

Dynamic Power Range

The FFTS has a power detector and a LED diode indicator on each module that allows one to know whether the power at the input of the analogue-to-digital converter (ADC) is optimum or not. This detection system, together with the AWGN generator, have enabled several tests to find out the optimum power range at the input of the IF processor for the suitable operation of the set IF processor plus FFTS. Table 3 shows the results.

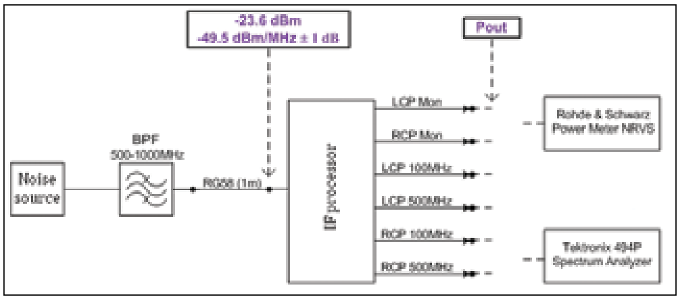


Figure 9 • Test bench for the IF processor measurements in the backend room.

	Absolute power (dBm)	Power density (dBm/MHz)
LCP Mon	-13.3	-39.7
RCP Mon	-13.3	-40.1
LCP DC-100MHz	-5.3	-25.1
LCP DC-500MHz	2.5	-26.1
RCP DC-100MHz	-5.2	-25.1
RCP DC-500MHz	2.6	-25.1

Table 2 • Power level values at the output ports.

Conclusions

An analogue IF processor has been designed, built and characterized in Yebes laboratories to adapt the output signal of the 40 meter radio telescope VLBI receivers to the input frequency range of the FFT spectrometer (modes C and D).

The final performance of the IF processor is summarized as follows:

- The input and output return losses are always better than 13 dB and 15 dB, respectively.
- The processor has a mean power gain of approximately 25 dB (± 1.5 dB) on its linear zone.
- The output power at -1 dB compression point is +11 dBm for the LHCP channel and +10 dBm for the RHCP channel.

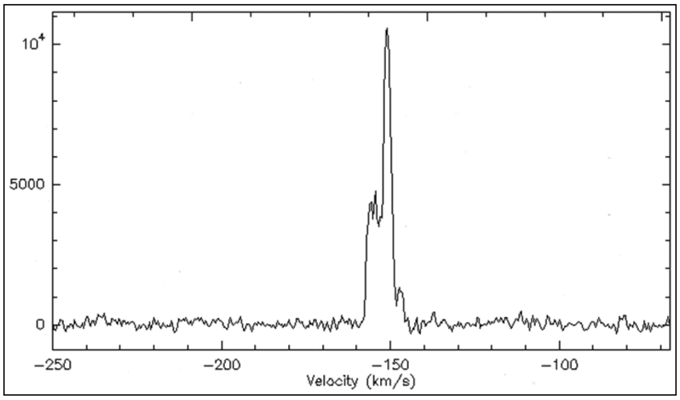


Figure 11 • Uncalibrated spectrum of SiO maser emission at 86 GHz from IK-Tau star.

Channel	Input power range of the IF processor
Channel RCP 100MHz (Board 1 of the FTTS)	-30.6 dBm (-56.5 dBm/MHz) < $P_{\text{IN PROCESSOR}}$ < -20.6 dBm (-46.5 dBm/MHz)
Channel LCP 100MHz (Board 2 of the FTTS)	-30.6 dBm (-56.5 dBm/MHz) < $P_{\text{IN PROCESSOR}}$ < -20.6 dBm (-46.5 dBm/MHz)
Channel RCP 500MHz (Board 3 of the FTTS)	-36.6 dBm (-62.5 dBm/MHz) < $P_{\text{IN PROCESSOR}}$ < -27.6 dBm (-53.5 dBm/MHz)
Channel LCP 500MHz (Board 4 of the FTTS)	-37.6 dBm (-63.5 dBm/MHz) < $P_{\text{IN PROCESSOR}}$ < -27.6 dBm (-53.5 dBm/MHz)

Table 3 • Power levels study for the proper operation of the FFTS.

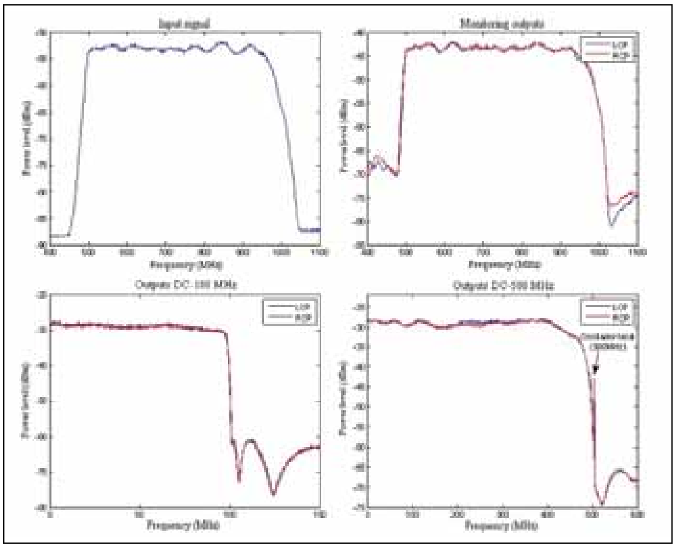


Figure 10 • Spectrum on each port of the IF processor in the backend room.

Currently, the processor is installed in the backend room of the radio telescope. It is in operation and has an excellent performance. It is being used for the detection of molecular lines in different frequency bands. For instance, Figure 11 shows a 7 KHz resolution spectrum of the silicon monoxide (SiO) maser at 86 GHz from IK-Tau star.

About the Authors:

José A. López-Pérez received his Degree in Telecommunication Engineering in 1996 and his Doctorate in 2012, both from the Polytechnic University of Madrid. After finishing his degree, he joined the Institut de Radio Astronomie Millimétrique (IRAM) in Grenoble (France) for two years. After this, he became part of the staff of the Yebes Astronomy Center (CAY) in Spain, where he currently works. He is responsible for the design and construction of the radio astronomy receivers, for the holography measurements of the 40 meter radio telescope surface and the monitoring of the RFI environment. Contact information: +34 949290311 (Ext. 205); ja.lopezperez@oan.es.

David Cuadrado-Calle received his Bachelor's Degree in Telecommunication Systems Engineering in 2010 and his Master's Degree in Information and Communication Technologies in 2012, both from the University of Alcalá (Spain). He has worked at the receivers division of the Yebes Astronomy Center (CAY) for more than one year and his areas of interest are related to RF and microwave circuits and systems. Contact information: +34 626967299; d.cuadrado@oan.es.