Spectrum slicers for FFT spectrometers

Gilles BUTIN

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1 introduction

The new receivers (EMIR...), now in use at Pico Veleta, deliver, in the backend room, their outputs under the form of intermediate frequencies covering the 4–8 GHz band. However, the new Fast Fourier Transform spectrometers are only able to process signals in baseband, from DC to 1.6 GHz at the most: some intermediate machinery is needed to interconnect them.

2 Presentation

The spectrum slicers are analog processors designed to prepare the I.F. signals delivered by the receivers, so that they can be sent to FFT spectrometers. Each spectrum slicer is housed in a 4U height, 19" rackable case, and can deliver signals to twelve FFT units. Two such machines share a common powering rack (fig. 1 below).



fig. 1: two spectrum slicers (left) which their common power rack (right).

3 Inputs and outputs

3.1 Main inputs

The essential function of the spectrum slicers is to split the 4 GHz-wide bandwidths (4–8 GHz), delivered on the I.F. cables by modern receivers (EMIR), into three smaller downshifted parts, suited to the narrower bands that can be processed by the FFT spectrometers: on the back side of each machine, four such inputs are available, on "N" connectors (fig. 2), onto which four I.F. cables can be plugged. The maximum bandwidth that each spectrum slicer can simultaneously process in this mode is 4×4 GHz = 16 GHz.

3.2 Auxiliary inputs

Alternatively, twelve auxiliary inputs are available, to process the I.F. frequencies directly in baseband, as offered by more ancient receivers (HERA...). In this mode, no frequency shift is carried out by the machine, and there is a one-by-one correspondance between the twelve inputs and the twelve outputs, which process the same 0.1-1.45 GHz. In this mode, the operation is restricted to filtering out the unwanted signals (anti-aliasing), and amplifying the useful ones to the power level needed by the FFT units.



Fig. 2: two spectrum slicers and their common power unit, seen from back; the four N connectors of the bottom row are the main inputs, the twelve of the top row are the auxiliary ones; the four connectors of the middle row are the auxiliary outputs, presently terminated by 50 Ω loads.

3.3 Control connector

The configuration of the machine, made by internal switches, is controlled by a remote computer, via a 37-pins sub-D connector located at the extreme left side of the back panel (see fig. 2). For maximum flexibility, what is obtained at each output (which input—main or auxiliary—is selected, which tradeoff is chosen between resolution and bandwidth) is configurable independently.

3.4 Front panel outputs

On front panel are available, on SMA female connectors, the twelve outputs to be connected to the FFT units (see fig. 1).

3.5 Back panel auxiliary outputs

On the back panel are available, on four N connectors, attenuated copies of the four 4–8 GHz I.F. inputs (see fig. 2). They can be used for monitoring purposes, or, eventually, to connect any sort of future backend. When unused, they must be terminated by 50 Ω loads.

3.6 Reference input

The internal hardware uses local oscillators, which must be locked on the station clock: a 100 MHz reference must be delivered on a SMA female connector present on the right part of the back panel (see fig. 2).

3.7 Powering

On the left side of the back panel, a round SOCAPEX connector permits to power the unit (see fig. 2).

3.8 Alarms

On the extreme right of the back panel, a 15-pins sub-D connector (see fig. 2) sends to the computer twelve alarms which reflect the status of twelve internal local oscillators. Above the connector, twelve individual red leds lit if their related oscillator goes out of lock; at the same time, at the extreme left of the front panel, a pair of leds inform the operator of the status of the machine: under normal circumstances, all red leds must be off, and a green led must be lit on front panel.

4 Menu of resolutions and bandwidths

Two tradeoffs between bandwidth and resolution are offered by the FFT backends. The spectrum slicers must be configured accordingly:

4.1 Wideband mode (and low resolution)

When an FFT machine is configured in its coarse resolution ($\approx 200 \text{ KHz}$)¹, it offers its maximum bandwidth of 1.6 GHz. Nevertheless, to avoid aliasing, a lowpass filter must be switched on in the allocated spectrum slicer output, and, due to its non-rectangular frequency response, frequencies up to only 1.45 GHz are actually available. In main mode, concatenating by software three such subspectra permits to synthesize, without gaps, the full 4 GHzwide spectrum (4–8 GHz) delivered on each I.F. input cable. In auxiliary mode, this resolution and bandwidth tradeoff is offered independantly for each of the twelve auxiliary inputs.

4.2 High resolution mode (and narrow band)

If the fine resolution ($\approx 50 \text{ KHz}$)² of an FFT machines is chosen, a reduced bandwidth of only 800 MHz is available, and a different anti-aliasing filter must be switched on inside the spectrum slicer, limiting the usable maximum frequency to 710 MHz. In main mode, concatenating by software three such subspectra permits to synthesize a reduced 1.82 GHz-wide continuous spectrum (5.29–7.11 GHz), centered at 6.2 GHz, close to the exact center (6 GHz) of the 4–8 GHz I.F. bandwidth. In auxiliary mode, each of the twelve auxiliary inputs can be independently configured to process the incoming signal with this resolution and bandwidth.

5 Architecture

5.1 Overview

The block-diagram of a spectrum slicer is depicted on fig. 3. Each of its four main inputs is sent to a 4-ways power splitter:

• one copy of each input is sent directly to an auxiliary output connector, for monitoring purposes, or later connection of more spectrometers.

¹there are 2^{13} channels: the exact channel spacing is 1600 MHz/ 2^{13} = 195.3125 KHz ²there are 2^{14} channels: the exact channel spacing is 800 MHz/ 2^{14} = 48.828125 KHz

• each of the three other ones undergoes a downshift into baseband (by a local oscillator and a mixer), before being sent to a switch, whose task is to select either this downshifted signal or the one coming from an auxiliary input. Then, an anti-alias circuit, made of a pair of switchable lowpass filters of 710 and 1450 MHz cut-off frequencies, prepares the signal for the sampling operation carried out in the FFT backends, by removing the spectral components located above the Nyquist frequency.



fig. 3: block-diagram of one frequency slicer

5.2 Subspectra extraction ("spectrum slicing")

In fig. 4 is depicted in more details the first part of the treatment undergone by the 4–8 GHz I.F. spectrum entering the main input: on each of the three used branches, a bandpass filter (BPF) selects only part of the incoming band, which is then downshifted to baseband by a mixer, pumped by a local oscillator. Finally, a coarse lowpass filter (LPF) eliminates the unavoidable leaks of the local oscillators, which could saturate the subsequent stages.



fig. 4: splitting the main input in three smaller subbands; the frequencies in bold figures are for the wideband mode.

According to the chosen resolution, the frequency of each of the three local oscillators is set either below, or above the cut-off of the related bandpass filter: this permits to downshift to baseband either the bottom or the top part of the band of the bandpass filter (see fig. 5 and 6, and the table p. 8).



5.3 Coordination with the local oscillators

In main mode, the anti-alias filters, which limit, in baseband, the maximum usable frequency to either 710 MHz or 1.45 GHz (see fig. 7), must be set in accordance with the setting of the local oscillators, so that the extracted bands are the ones described in the frequency plans of fig. 5 and 6:

bandpass	oscillator	extracted	antialias	obtained
filter	set at	subband	set at	downshifted band
	3.85 GHz	3.95 - 5.30 GHz	1.45 GHz	100 MHz - 1.45 GHz
low				
	$6.00 \mathrm{~GHz}$	5.29 - 5.90 GHz	$710 \mathrm{~MHz}$	100 MHz - 710 MHz
	5.20 GHz	5.30 - 6.65 GHz	1.45 GHz	100 MHz - 1.45 GHz
center				
	$7.20~\mathrm{GHz}$	6.50 - 7.11 GHz	$710 \mathrm{~MHz}$	$90~\mathrm{MHz}$ - $700~\mathrm{MHz}$
	8.10 GHz	6.65 - 8.00 GHz	1.45 GHz	100 MHz - 1.45 GHz
high				
	$5.80 \mathrm{~GHz}$	5.90 - 6.50 GHz	$710 \mathrm{~MHz}$	100 MHz - 700 MHz

Note: since all the high resolution anti-alias filters have an identical 710 MHz cut-off frequency, the bands actually obtained from the "center" and "high" plates extend up to 710 MHz, but only the part limited to 700 MHz is really needed to obtain a continuous spectrum by concatenation.

5.4 Input selection and anti-aliasing

In both modes, one of the baseband signals is selected by a switch, which chooses either the auxiliary input or the signal delivered by one of the mixers. Then, a pair of other switches sends it through one of two anti-alias low pass filters (see fig. 7). On the branch of the 1.45 GHz lowpass filter, a 3.5 dB attenuator balances the total power, which, otherwise, would be higher, due to the wider bandwidth.



fig. 7: selection of intput and anti-aliasing filter.

In baseband, the obtained shapes of the edges are, on the high side, the one of the anti-aliasing filter, and on the low side one or the other of the bandpass filter, according to the setting of the corresponding local oscillator.

5.5 Power levels

On the way, the level of the signal is increased by three amplifiers (see fig. 8):

- in the first switch case, to compensate for the losses of the mixing operation (only the input coming from the mixer is amplified).
- in the last switch case, the output is pre-amplified to increase the general level before the final stage.
- finally, a driver with a high compression point (19 dBm at -1dB compression) rises the total power to the milliwatt requested by the FFT spectrometers.

6 Hardware description

A complete spectrum slicer (see fig. 9), is made of twelve vertically mounted steel plates ("slicer" plates, see fig. 10) upon which coaxial hardware is fixed, plus somme auxiliary devices (distribution of I.F. and reference) and control electronics (input and output interfaces to computer).

Three families of plates are needed, according to the part of the incoming 4–8 GHz I.F. band it can extract; a color label indicates to which family a plate belongs:

- the plates with a red label process the "low" frequencies: it extracts signals from the subband 3.95 to 5.90 GHz
- the plates with a yellow label process the "center" frequencies: it extracts signals from the subband 5.30 to 7.11 GHz
- the plates with a blue label process the "high" frequencies: it extracts signals from the subband 5.90 to 8.00 GHz



fig. 8: three "slicer" plates and a 4-ways power splitter are needed to process one I.F. cable.



Fig. 9: an open spectrum slicer, seen from top, showing the twelve steel plates, mounted vertically; their color labels indicate to which family each plate belongs. On top, the five silvery rectangular cases distribute the 100 MHz reference to the local oscillators.

Slicer plates: processing each I.F. cable needs three "slicer" plates, one of each family, as the one shown in fig. 10 below, and a 4-ways front power plitter (see fig. 8, in which the 100 MHz reference, needed to lock the local oscillators on the station clock, is not shown).



Fig. 10: a slicer plate of the "center" frequencies family.

7 Detailed technical specifications

7.1 Main inputs processing (4–8 GHz cables inputs)

WIDEBAND MODE						
input: -47 dBm/MHz power density on 50 Ω "N" connector						
0	utput: 0	dBm total power on 50	Ω SMA connected	or		
input	input	put extracted output		output		
bandwidth	cable	bandwidth	cable	bandwidth		
(GHz)	label	(GHz)	label	(GHz)		
		3.95 - 5.30	cable 1 lower			
	cable 1	5.30 - 6.65	cable 1 center			
		6.65 - 8.00 (inverted)	cable 1 upper			
		3.95 - 5.30	cable 2 lower			
	cable 2	5.30 - 6.65	cable 2 center			
3.95 - 8.00		6.65 - 8.00 (inverted)	cable 2 upper	0.1 - 1.45		
		3.95 - 5.30	cable 3 lower			
	cable 3	5.30 - 6.65	cable 3 center			
		6.65 - 8.00 (inverted)	cable 3 upper			
		3.95 - 5.30	cable 4 lower			
	cable 4	5.30 - 6.65	cable 4 center			
		6.65 - 8.00 (inverted)	cable 4 upper			

HIGH RESOLUTION MODE								
input: -47 dBm/MHz power density on 50 Ω "N" connector								
0	output: 0 dBm total power on 50 Ω SMA connector							
input	input	extracted	output	output				
bandwidth	cable	bandwidth	cable	bandwidth				
(GHz)	label	(GHz)	label	(MHz)				
		5.29 - 5.90 (inverted)	cable 1 lower	100 - 700				
	cable 1	6.50 - 7.11 (inverted)	cable 1 center	90 - 700				
		5.90 - 6.50	cable 1 upper	100 - 710				
		5.29 - 5.90 (inverted)	cable 2 lower	100 - 700				
	cable 2	6.50 - 7.11 (inverted)	cable 2 center	90 - 700				
5.29 - 7.11		5.90 - 6.50	cable 2 upper	100 - 710				
		5.29 - 5.90 (inverted)	cable 3 lower	100 - 700				
	cable 3	6.50 - 7.11 (inverted)	cable 3 center	90 - 700				
		5.90 - 6.50	cable 3 upper	100 - 710				
		5.29 - 5.90 (inverted)	cable 4 lower	100 - 700				
	cable 4	6.50 - 7.11 (inverted)	cable 4 center	90 - 700				
		5.90 - 6.50	cable 4 upper	100 - 710				

7.2 Auxiliary inputs processing

Bandwidth:	90 MHz - 1.45 GHz in wideband mode
	90 MHz - 710 MHz in high resolution mode
Input levels:	-47 dBm/MHz (power spectral density)
Output levels:	0 dBm total power on 50 Ω "N" connector

7.3 Unwanted signals rejection

Three types of unwanted signals can contaminate the output spectrum:

- discrete spurious leaking from the local oscillators (or their harmonics or subharmonics): they are kept at least 10 dB below the total power present in the narrowest channels (50 KHz-wide), and are further attenuated by the on-off calibration procedure.
- image frequencies, due to the finite attenuation of the bandpass antiimage filters: they are kept at least 40 dB below the normal sky signals.
- signals beyond the Nyquist frequency, due to the finite attenuation of the lowpass anti-alias filters: as above (40 dB).

7.4 Auxiliary outputs

Bandwidth:	3.95 - 8.00 GHz
Output levels:	-54 dBm/MHz (power spectral density)
Impedance:	50 Ω (N female connector)

7.5 Station clock (reference) input

Frequency:100 MHzWaveshape:sinewaveImpedance:50 Ω (SMA female connector)

8 Appendix

8.1 Power rack

The power unit (fig. 1 and 2), made of plug-in modules for easier maintenance, delivers, to each of two spectrum slicers, the necessary DC power, via a 12-pins round SOCAPEX connector:

power supply for one spectrum slicer				
	needed	available		
voltage	current	current	use	comments
+5 Volts	1.5 A	2 A	logic & driver amp	adjust at $5.1V$
+8 Volts	5.3 A	$2 \times 3 \text{ A}$	analog electronics	2 plug-in modules
12 Volts	1.7 A	3 A	fans	floating
+18 Volts	0.1 A	1 A	local oscillators	

For each spectrum slicer, the +8 volts is split in two plug-in modules: one powers the right half of the spectrum slicer, the other the left one. On each spectrum slicer, and in the power unit, three fans help keeping low the temperature. In the power unit, an additional +12V 3 Amperes unit is needed to power its own fans.

SOC	SOCAPEX CONNECTOR PINOUT			
Pin	Function			
1	Sense $+8V$ (first half of rack)			
2	Power $+8V$ (first half of rack)			
3	Sense common return $(0V)$			
4	Power common return $(0V)$			
5	Sense $+8V$ (second half of rack)			
6	Power $+8V$ (second half of rack)			
7	Sense $+18V$			
8	Power $+18V$			
9	Sense $+5V$			
10	Power $+5V$			
11	Floating $+12V$ for fans			
12	Return of floating 12V for fans			

8.2 Alarms connector

Connector: sub-D 15 points, female Logical levels: 0V and +5V

Pin	Control line	Pin	Control line	Pin	Control line
1	Lock Alarm-1	6	Lock Alarm-6	11	Lock Alarm-11
2	Lock Alarm-2	7	Lock Alarm-7	12	Lock Alarm-12
3	Lock Alarm-3	8	Lock Alarm-8	13	GROUND
4	Lock Alarm-4	9	Lock Alarm-9	14	GROUND
5	Lock Alarm-5	10	Lock Alarm-10	15	GROUND

8.3 Control connector

Computer control: the machine is computer-controlled, via an electronic interface board (fig. 2, on the left of the back panel). A total of thirty-six static bits has to be sent from the remote computer, on a 37-pins sub-D male connector, organized in twelve groups of three (one per plate):

name	function	effect with $+5V$	effect with 0 V
		(or left open)	
AUXIN	auxiliary input	selects	selects
		auxiliary input	main input
OSCHF	oscillator at	sets oscillator at	sets oscillator at
	high frequency	higher frequency	lower frequency
AA710	anti-alias	selects 710 MHz	selects 1.45 GHz
	$710 \mathrm{~MHz}$	anti-alias filter	anti-alias filter

PINOUT						
(inpu	it impedance:	100 K	Ω to +5 Volts)			
Pin	Control line	Pin	Control line			
1	AUXIN-1	19	AUXIN-7			
2	OSCHF-1	20	OSCHF-7			
3	AA710-1	21	AA710-7			
4	AUXIN-2	22	AUXIN-8			
5	OSCHF-2	23	OSCHF-8			
6	AA710-2	24	AA710-8			
7	AUXIN-3	25	AUXIN-9			
8	OSCHF-3	26	OSCHF-9			
9	AA710-3	27	AA710-9			
10	AUXIN-4	28	AUXIN-10			
11	OSCHF-4	29	OSCHF-10			
12	AA710-4	30	AA710-10			
13	AUXIN-5	31	AUXIN-11			
14	OSCHF-5	32	OSCHF-11			
15	AA710-5	33	AA710-11			
16	AUXIN-6	34	AUXIN-12			
17	OSCHF-6	35	OSCHF-12			
18	AA710-6	36	AA710-12			
		37	Ground			

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