Multi-beam Correlator

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1 Introduction

The replacement of the current correlators with newer ones designed for 6 antennas on Plateau de Bure makes the previous correlator available for other uses. A proposal to send a pair of correlator units to Pico Veleta has been written by Marc Torres.

In the following a different scheme to reuse this hardware is presented. It requires more work to be implemented but gives more flexibility and allows to reuse a much larger proportion of the existing hardware. In both cases, the goal is to provide a high resolution spectrometer for the forthcoming multi-beam receiver (9 or 18 channels), but the extension proposed here also improves the capabilities for operation with single channel receivers (referred to as four-receiver operation in the following) and allows to use the correlators as polarimeters.

This is still a draft document and many points are still subject to revision, perhaps even radical ones.

2 Architecture

2.1 Overview

The proposed architecture is built around six identical machines, and is designed to provide three main modes of operation:

- the *four-receiver* mode, which provides a superset of the current capabilities,
- the *multi-beam* mode, designed to provide medium and high resolution spectrometry capability with 9 pixel multi-beam receivers,
- the *polarimetry* mode, a new capability, which takes advantage of the proposed architecture to transform the correlators into a full featured polarimetry analyser. This is achieved without any additional, special purpose, hardware.

From a logical point of view, the six machines, which replace the current pair of correlators, are in many cases better seen as three sets of two. The combination of a 200 % increase in the number of units with enhancements in the architecture raises the total number of channels by 350,%, up to 18432 in the highest resolution modes.

From a mechanical point of view, the proposed architecture preserves the current layout of one IF rack on top of a VME rack, keeping the same form factors. The layout of boards and modules inside the racks is however modified.

The installation of the complete system at the telescope would triple the footprint of the existing correlators if the current physical layout were simply extended. In order to avoid wasting the finite floor space of the backend and computer room, it may be necessary to arrange the machines in a more compact shape. While this issue is important, it will not be discussed further since it is completely independent from the main scope of this document, which concentrates on architecture and functionality.

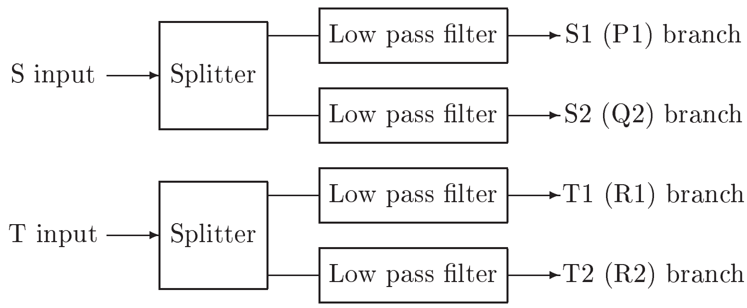

Figure 1: ST splitter module diagram.

2.2 IF processor rack

For mechanical reasons, the IF processor rack is an evolution of the 5 antenna interferometer version. The phase rotators, unnecessary for single dish operation, are removed in order to free enough slots to install in each rack six IF chains with two synthesisers.

2.2.1 Input selection

Six IF inputs are used for multi-beam operation while only two are used in the other modes. These 2 groups of inputs are separate, raising the number of IF cables connected to each machine to 8. In the following, the inputs of the first group are labelled P1, Q1, R1, P2, Q2, and R2 while the inputs of the second group are labelled S and T.

The first modules on the signal path in the IF rack, the up-converters, incorporate a switch whose original purpose was to select between the receiver inputs and an internal (one in each IF rack) noise source. The noise source was never connected in practice and was already removed in the 5 antenna interferometer configuration. This frees one module slot and allows to use the switches to select between the multi-beam and the other inputs.

The previous receiver inputs now become the multi-beam inputs, while a new module, called the ST splitter, has to be built to distribute the S and T inputs to the other inputs of the up-converters. As shown in figure 1, the ST splitter module is extremely simple. Additional details about the possible implementation of this new module are given in section 4.3.

2.2.2 Layout

Figures 2 and 3 present a possible layout of the modified IF processor. Each synthesiser provides frequency agility to a group of three up-converters, one to the left half and one to the right half.

The rear row of modules includes the up-converters, the new ST splitter module, power supplies, mains socket and power switch. On the front side, the modules are the 2 synthesisers, the image rejection mixers and the 820 MHz source which also include the reference clock distribution. This last module is the only one which moves from the back to the front side and may require some mechanical adapter since it is shorter than the other modules in the front row.

Figure 2: Rear view of IF processor.

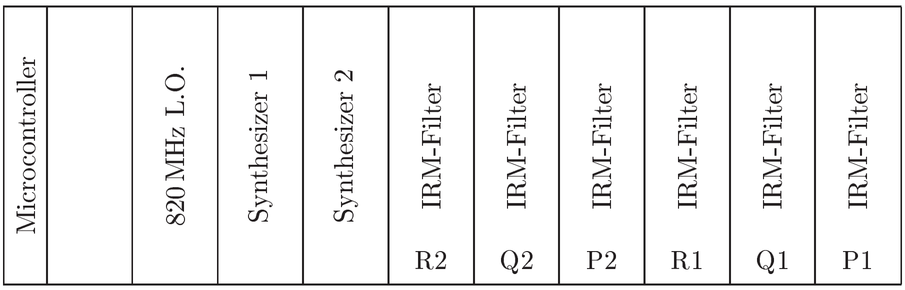

Figure 3: Front view of IF processor.

Note that one free slot remains in the front row and that the microcontroller occupies the remaining half-width slot on the left.

The IF rack layout is not definitive since it might actually turn out to be simpler from a mechanical point of view to leave the fixed LO source in the rear row while shrinking the space allocated to the power supplies and mains plug and switch. This last module is currently the widest one while it includes little more than a mains plug and power switch; this is revolting and makes it a primary target for space saving. The front row layout is also still subject to changes due to other considerations: it might for example be desirable to spread the IRM-filter modules more evenly across the whole width since they are the largest heat generators.

2.3 VME rack

The layout of the VME rack, as shown in figure 4, is essentially a straightforward extension of the current system to 6 samplers and 12 correlator boards. The distribution of sampled data through the backplane is however slightly more complex to provide some additional capabilities: polarimetry measurements need to perform cross-correlation which requires connections to the Y inputs of the boards and some high resolution modes make use of the additional X input of the correlator boards (labelled XFC in the documentation).

2.4 Distribution box connection

A simplified diagram of the current distribution of telescope IF to the correlators is shown in figure 5. While the correlators have eight inputs in total, full

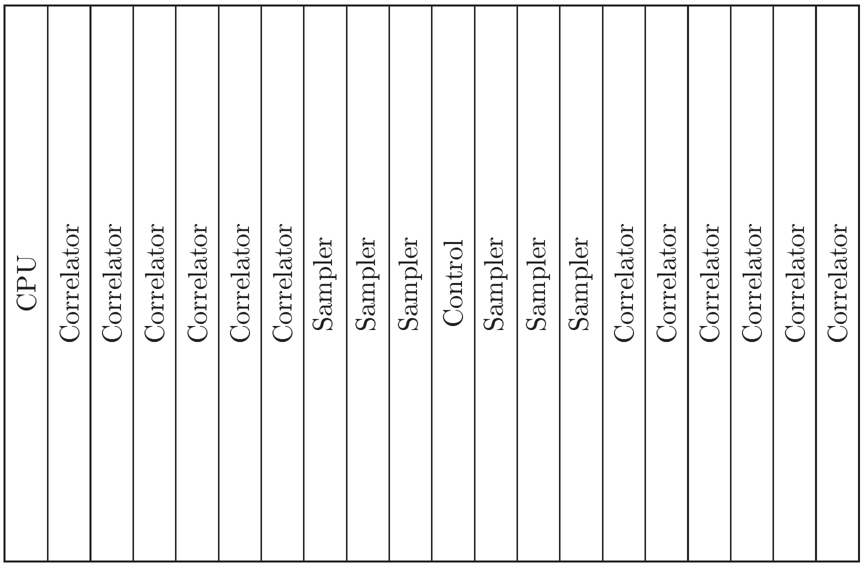

Figure 4: VME rack layout.

flexibility for four receivers is achieved by using only six selector modules of the distribution box thanks to the fact that they provide two identical outputs (indicated on the diagram by two signals coming from the same point).

The proposed architecture having a total of twelve synthesisers, up to twelve independent bands, two per correlator, are provided in four-receiver mode. Although it is not immediately obvious, the connection scheme shown in figure 6 provides complete flexibility without increasing the number of selector modules of the distribution box dedicated to the correlators. The additional degree of freedom is provided, somewhat indirectly, by the ST splitter modules: in each chassis the S2(Q2) and either the S1(P1) or the T1(R1) branches are used.

In summary, the connection to the distribution box for four-receiver and polarimetry modes only requires four additional cables.

2.5 Multi-beam receiver connection

This section only states the IF distribution needs of the correlator spectrometers as envisioned in this proposal, a complete discussion of the IF distribution scheme which will be adopted for multi-beam receivers being clearly out of the scope of this document.

The fundamental characteristic of this proposal is that, in multi-beam mode, each pair of correlators processes three pixels, providing up to four independent bands per pixel.

Only the cases of one or two multi-beam receivers have been considered in the following, since the simultaneous use of a larger number of multi-beam receivers does not seem to be practical. In practice, any distribution scheme which works for two receivers will obviously work for one; time constraints might force to provide a provisional system usable with a single receiver, despite the fact that building temporary systems is highly undesirable.

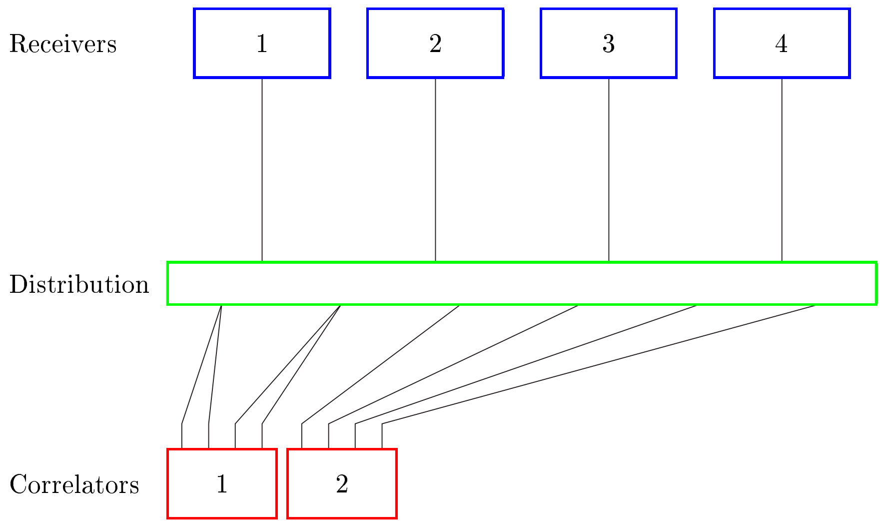

Figure 5: Current correlator distribution diagram (simplified).

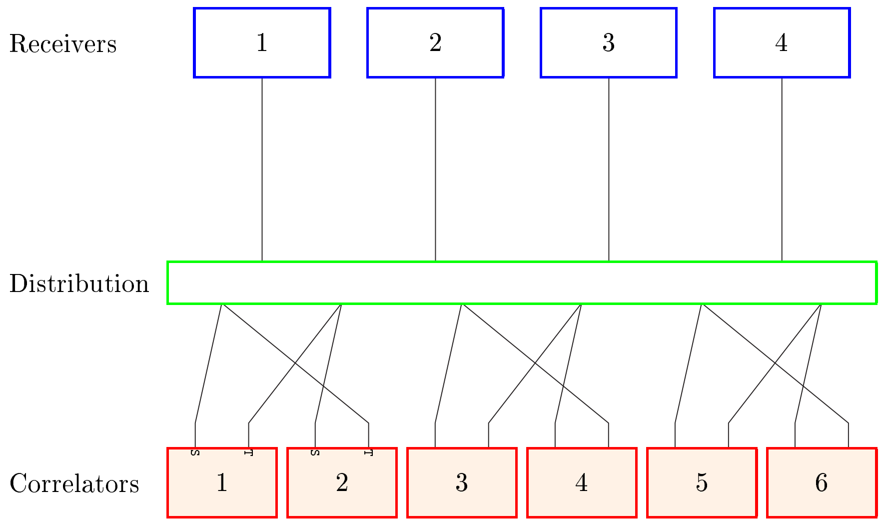

Figure 6: Proposed correlator distribution diagram for four-receiver and polarimetry modes (simplified).

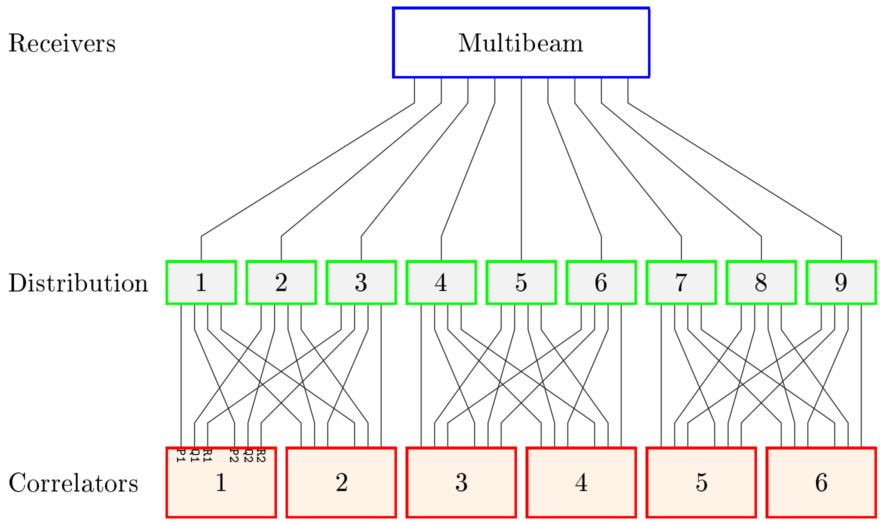

Figure 7: Proposed single multi-beam distribution diagram (simplified).

2.5.1 One multi-beam receiver

In the case of a single multi-beam receiver, the distribution is obviously extremely simple and can be based on amplifiers and power splitters as illustrated in figure 7. This figure does not take into account the needs of other spectrometers, therefore splitters with a larger number of outputs might be required.

2.5.2 Two multi-beam receivers

In the case of two multi-beam receivers, the only practical solution is to design and build small distribution boxes. The final distribution scheme, for the correlators at least, would probably look like figure 8.

Incidentally, this diagram shows that cable clutter may be reduced if the distribution boxes are located close to the correlators since they have less inputs than outputs. In other words, the suggested scheme favours physically grouping together spectrometers by pixels rather than by function or nature (filter banks, correlators, etc. . .).

3 Operation and configuration details

3.1 Four-receiver mode

The four-receiver mode offers a superset of the existing capabilities.

The readers which are fortunate to see this report in color will notice that one half of the bands is drawn in red or orange while the other half is drawn in blue or green. This is a visual hint of the connections to the distribution box since the S input of one correlator is connected to the same receiver as the T input of the other in the same pair.

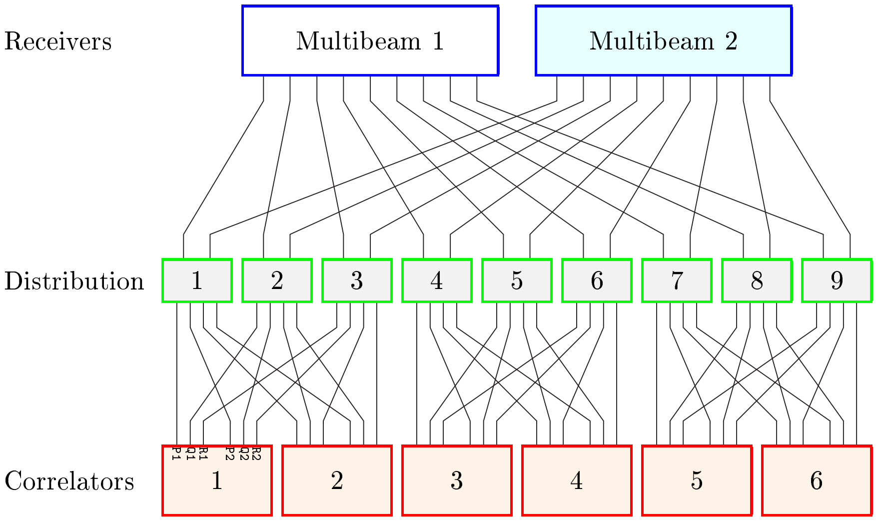

Figure 8: Proposed dual multi-beam distribution diagram (simplified)

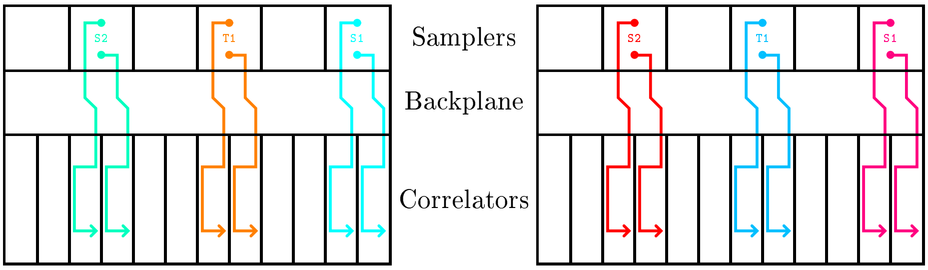

Figure 9: Low resolution four-receiver configuration (Only either the S1 or the T1 branch in each machine is actually used).

3.1.1 Low resolution configurations

The low resolution modes, in which a pair of correlator boards is used to analyse the L and U outputs of a sampler, are identical to the existing ones. This is illustrated by figure 9.

3.1.2 40 kHz resolution configuration

In this mode, illustrated by figure 10, the difference with the current correlator is that it uses two pairs of correlator boards in pass-along mode, instead of one, and performs the autocorrelation of both the U and L bands. This doubles the bandwidth, which is especially interesting for spectral surveys of dark clouds and comets.

The consequences of the bandwidth increase are even more dramatic when using frequency-switch since the folding operation reduces the bandwidth of the final spectrum by the frequency throw, which has to be chosen as a multiple of about 7.5 MHz in order to minimise the most troublesome ripple component and produce usable spectra. The 20 MHz elementary bandwidth of the current system, in practice limited to 17.5 MHz by the cut-off of the anti-aliasing filters,

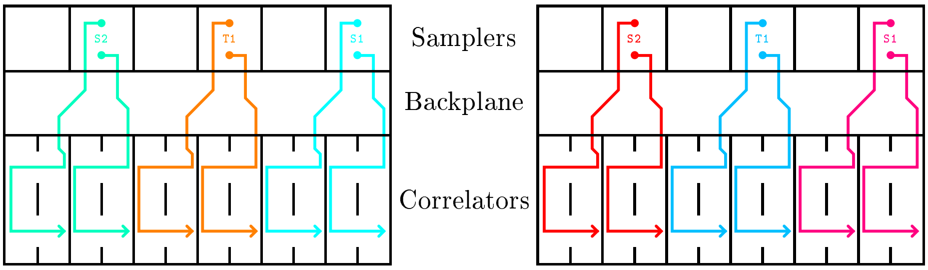

Figure 10: 40 kHZ resolution four-receiver configuration (Only either the S1 or the T1 branch in each machine is actually used).

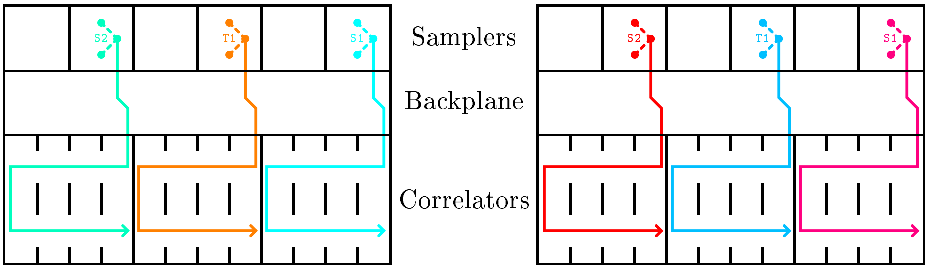

Figure 11: 20 kHZ resolution four-receiver configuration (Only either the S1 or the T1 branch in each machine is actually used).

often forces observers to use several bands for a single spectrum; this is frequent when using the minimal frequency throw, in which case the bandwidth after folding becomes about 10 MHz, and systematic when a larger throw has to be selected for any reason: overlap caused by hyperfine structure, spectrum polluted by a mesospheric line , etc... In contrast, using both sidebands of the IF processor provides sufficient bandwidth for the overwhelming majority of observations performed in frequency-switch mode. *Put a table ?*

In practice the resolution setting of 80 kHz becomes only useful to reduce the amount of data produced, which can still be beneficial for on-the-fly mapping for example, but the same bandwidth can always be analysed with a resolution of 40 kHz, automatically solving the dilemma between bandwidth and resolution in this important case.

3.1.3 20 kHz resolution configuration

This resolution is obtained by setting a block of four boards in pass-along, as illustrated by figure 11. This means that the elementary bandwidth is 20 MHz since only sideband of the IF processor is analysed. As already implemented in the current system, setup software programs the UU mode bits of the samplers to select between the L and U band as a function of the frequency range to analyse in the incoming IF band.

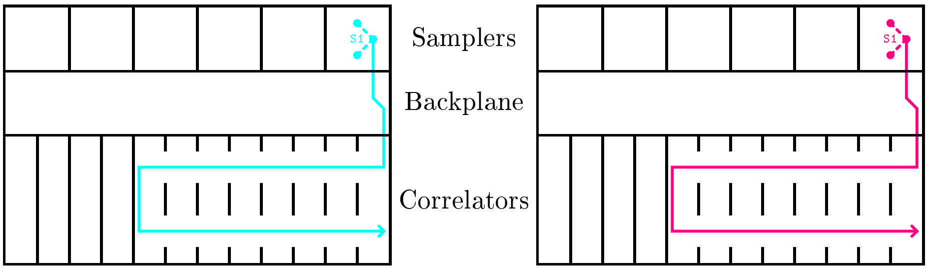

Figure 12: 10 kHZ resolution four-receiver configuration.

3.1.4 10 kHz resolution configuration

At this resolution, each machine can only provide one band since it requires eight boards in pass-along mode as illustrated in figure 12. Since the S2 band, used in lower resolution configurations, cannot feed eight boards in pass-along mode, it is replaced by the S1 band which is connected to the same receiver; this is an internal implementation detail which does not affect in any way the configuration flexibility seen by the observers.

Although it seems to be a waste, all attempts to provide the possibility to use another band in parallel with the 10 kHz band resulted in very complex configuration rules. Furthermore all lower resolution configurations in four-receiver mode actually use only eight correlator boards or less, selecting which ones to achieve flexibility. It seems natural to avoid breaking the straightforward configuration rules based on resource usage since few observers really need this resolution and the relative cost of this resolution is much lower than with the current system: four 10 kHz resolution bands use two thirds of the resources, leaving the possibility of adding for example one medium resolution band, like 80 MHz bandwidth with 320 kHz resolution, in parallel with each high resolution band. Section 3.4.1 presents another way of using the hardware, probably better suited to the needs of the observers who ask for the highest possible resolution.

3.1.5 Summary

The previous diagrams show a pair of correlators with in most cases two usable bands per correlator. The bands are actually completely independent and can be mixed freely with up to 4 bands per pair of correlators; there is only one exception to this rule: a 10 kHz resolution band requires one full correlator as shown in the diagrams.

For readers familiar with the current observation control software, table 1 show the percentage or resource usage of the correlator for the current and proposed system. In many cases, especially for the 20 kHz and 40 kHz resolution modes, the capabilities of the current system are tripled.

3.2 Multi-beam mode

As already stated, in multi-beam mode each pair of correlators processes three pixels. The configuration of the of the three sets of IF processor and the correlator have to be identical, but the system is still very flexible.

		Current system		Proposed system	
Channel Spacing (kHz)	Elementary Bandwidth (MHz)	Resource Usage (%)	Maximal Bandwidth (MHz)	Resource Usage (%)	Maximal Bandwidth (MHz)
10	20	50.00	40	16.67	120
20	20	25.00	80	8.33	240
40	20	12.50	160	—	—
40	40	—	—	8.33	480
80	40	12.50	320	8.33	480
320	80	12.50	640	8.33	960
1250	160	12.50	1280	8.33	1920

Table 1: Summary of four-receiver mode capabilities. The channel spacing figures are rounded to the commonly used values and the usable bandwidths are actually slightly smaller because of the cut-off of the anti-aliasing filters.

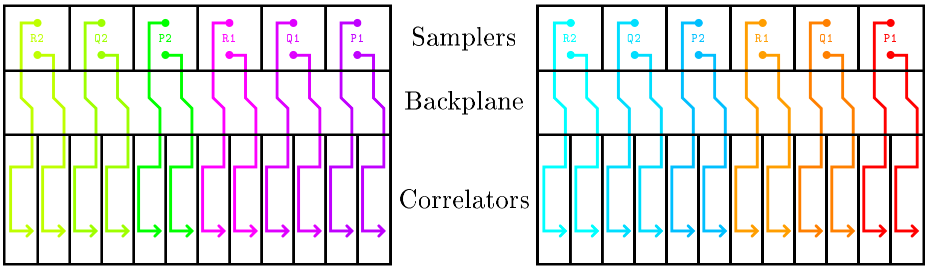

Figure 13: Low resolution multi-beam configuration (3 pixels shown).

3.2.1 Low resolution configurations

The low resolution modes, illustrated by figure 13, provide up to 640 Mhz bandwidth per pixel at 1.25 MHz resolution for nine pixels.

3.2.2 40 kHz resolution configuration

At this resolution setting, the elementary bandwidth is 20 MHz, half of what is provided in the four-receiver mode, since only one band can be analysed by two correlator boards in pass-along, as illustrated by figure 14.

3.2.3 20 kHz resolution configuration

This resolution, illustrated by figure 15 is obtained by setting both synthesizers of a chassis to the same frequency and configuring the machine as three sets of four boards in pass-along mode.

3.2.4 Summary

Table 2 summarizes the multi-beam capabilities in terms of resource usage as displayed by the observing software.

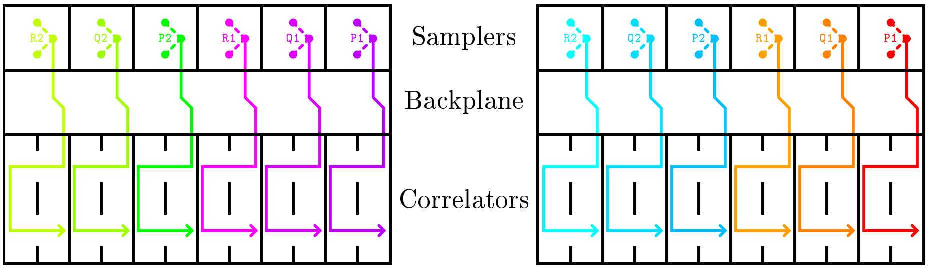

Figure 14: 40 kHz resolution multi-beam configuration (3 pixels shown).

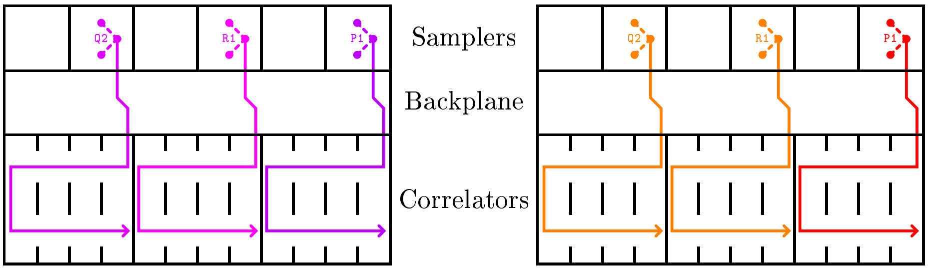

Figure 15: 20 kHz resolution multi-beam configuration (3 pixels shown). Both synthesisers of a given IF processor have to be set at the same frequency.

Channel Spacing (kHz)	Elementary Bandwidth (MHz)	Resource Usage (%)	Maximal Bandwidth (MHz)
20	20	50.00	40
40	20	25.00	80
80	40	25.00	160
320	80	25.00	320
1250	160	25.00	640

Table 2: Summary of multi-beam mode capabilities.

3.3 Polarimetry mode

When polarisation is taken into account, the electromagnetic field received from a source can no more be described by a scalar value; a set of four real quantities is instead required to fully characterize the radiation. The commonly used Stokes parameters, noted I, Q, U, and V, are such a set although other choices are possible.

The telescope is equipped with pairs of orthogonally polarised heterodyne receivers for each frequency band. By tuning two receivers at the same frequency, it is possible to build four spectra defined by:

- H_R the power spectrum of the horizontally polarised receiver,
- V_R the power spectrum of the vertically polarised receiver,
- R_R the real part of the cross-correlation spectrum,
- I_R the imaginary part of the cross-correlation spectrum.

The Stokes parameters spectra, from now on denoted with an S subscript to avoid confusion, are related to the preceding spectra by the following simple relationships:

$$I_S = H_R + V_R, \quad Q_S = H_R - V_R, \quad U_S = R_R, \quad V_S = I_R$$

Therefore, from a configuration point of view, the problem reduces to finding a way to simultaneously perform the autocorrelations of both receivers and their cross-correlation.

Before describing the possible correlator configurations which can be achieved with a minimal increase in complexity, some considerations on the methods used to carry out the observations and calibrate them are warranted.

3.3.1 Observing procedures and calibration

move to a later part As a side note, performing the cross correlation of two receivers requires phase coherence from the local oscillators, which in the current state of the telescope means that the same references have to be used for both receivers.

3.3.2 Low resolution configurations

They are illustrated by figure 16. For the autocorrlation functions, only one half of the channels are used to match the resolution provided by the board performing the cross-correlation. This means that the possible resolutions are 2.5 MHz, 625 kHz and 156.25 kHz depending on the time multiplex factor.

Note that some samplers have to be set in UU mode and that only U bands can be processed, which prevents exploring the incoming signal below about 105 MHz, approximately 20 MHz above the lower limit of the IF band. This restriction would not have existed if the samplers had provided an LL mode instead of the UU mode since synthesizers have enough safety margin to explore the upper end of the IF band as a lower sideband, while the lower limit is due to the synthesizer coming too close to the bandpass filter edge at the output of the up-converter.

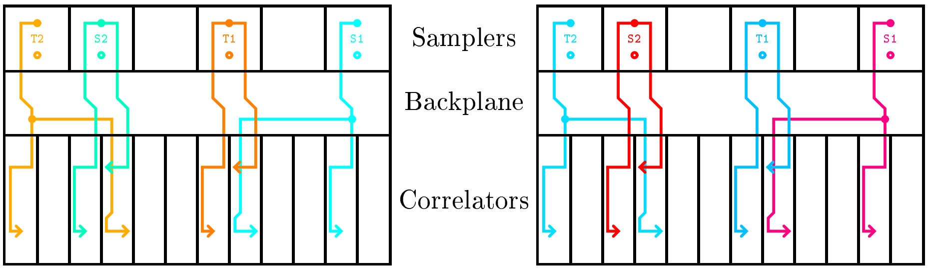

Figure 16: Low resolution polarimetry configuration.

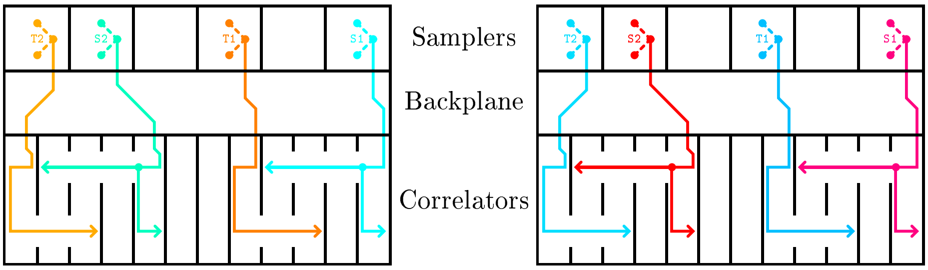

Figure 17: 80 kHz resolution polarimetry configuration.

3.3.3 80 kHz resolution configuration

This mode, illustrated by figure17, requires five correlator boards in a configuration which is a hybrid of pass-along and autocorrelation configurations. The leftmost and rightmost boards provide the autocorrelations and the three intermediate boards are set in pass-along mode although only the two leftmost of these boards provide the cross-correlation. The fourth board, in left to right direction, is only here to provide an additional delay to the samples coming from the fifth board since the first board feeds the second one after two internal propagation delays through its shift registers.

There is no restriction on the part of the IF band which may be explored, since the L output of the samplers is used, which corresponds to either sideband of the IF processor depending on the UU mode bit setting.

Note that the right half band does not require any dedicated backplane connections.

3.3.4 40 kHz resolution configuration

This configuration, illustrated by figure 18, provides only one band per correlator since it requires ten correlator board using the same techniques as the 80 kHz resolution configuration.

3.3.5 Summary

Table 3 summarizes the polarimetry capabilities in terms of resource usage as displayed by the observing software. Two possibilities have been considered when building this table:

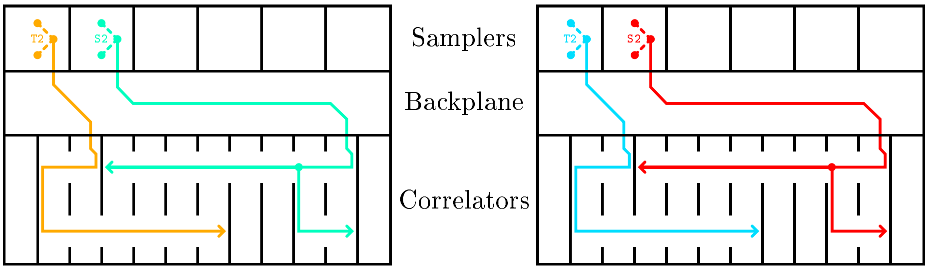

Figure 18: 40 kHz resolution polarimetry configuration.

- a flexible interface, which allows to specify several individual bands, possibly of different resolutions, at arbitrary positions in the passband.

- a simplified interface, in which all bands of a given pair of correlators are set at the same resolution and concatenated to build a single spectrum

While the first solution is more similar to what is available in four receiver mode, the utility of such a complex setup for polarimetry observations is questionable. It also forces an additional restriction when two pairs of receivers are used in polarimetry mode: due to the limitation of the connections to the distribution box, one pair of receivers could use up to two thirds of the resources while the other one would be limited to one third, which is inconsistent with the full flexibility provided by the four-receiver mode and potentially confusing.

The simplified interface eliminates these problems by providing only configurations which correspond to full utilization of a pair of correlators; it should be sufficient for most polarimetry observations and represents in any case a huge improvement over the currently available polarimeter systems.

Using eight distribution box selectors as shown in figure 24 would allow even splits between two pairs of receivers; this is however a decision which cannot be taken lightly since distribution box selectors are a very scarce and valuable resource.

Full flexibility would require to expose the four switchable branches of the correlator as four external inputs; at this point the only practical implementation seems to be to build the distribution matrix right into the correlators, bypassing the distribution box and connecting instead the four inputs to the four receivers from the outputs of the cable processor through power splitters. This is a significant additional design effort and the benefits seem low in comparison to the cost.

It is not clear whether any of these enhancements would have any useful applications in polarimetry mode: when using one pair of receivers, the flexibility provided by three independent bands of the simplified interface looks more than sufficient. The impossibility of splitting evenly between two pairs of receivers appears to be a limitation. It should be remembered, however, that both pairs of receivers will be used at very different frequencies, like 113 and 226 GHz for **CN** observations, *continue*

	Flexible interface		Simplified interface		
Channel Spacing (kHz)	Elementary Bandwidth (MHz)	Resource Usage (%)	Elementary Bandwidth (MHz)	Resource Usage (%)	Maximal Bandwidth (MHz)
40	20	16.67	40	33.33	120
80	20	8.33	80	33.33	240
160	20	8.33	80	33.33	240
625	40	8.33	160	33.33	480
2500	80	8.33	320	33.33	960

Table 3: Summary of polarimetry mode capabilities. When two pairs of receivers are used in this mode, one pair cannot use more than two thirds of the resources and the other more than one third.

3.4 Additional possibilities

A warning about the following: don't take it too seriously. Capabilities which may easily be added.

3.4.1 6.5 kHz resolution

Software only. While few observations require 10 kHz resolution, the ones that actually need it often scream for the highest possible resolution. In this case, put all twelve boards in pass-along to build a correlator with 3072 delays, this gives a channel spacing of 6.5 kHz (exactly 5000/768). The only requirement is an FFT program which can accept non powers of two. Since it is only a factor 3, efficient algorithms exist, the fact that they require an additional temporary array is irrelevant.

3.4.2 Coupled receiver operation

Software only. It has become fairly common to observe in parallel with two receivers tuned at the same frequency. This in theory improves the signal to noise ratio by $\sqrt{2}$. It seems natural to offer configuration possibilities that help this will be called coupled mode in the following. In coupled mode, S1 and T1 bands are used simultaneously. S2 and T2 too except for 20 and 40 kHz resolutions.

Syntax might be simple at the beginning to avoid confusing the observer and adding needless complexity to the software: only modes which fully utilize a given pair of correlators make sense. 20kHz/60MHz, 40kHz/

AUTOCORR 20 (60—120—180) offset /COUPLED receiver_1 receiver_2

AUTOCORR 40 (120—240—360) offset /COUPLED receiver_1 receiver_2

AUTOCORR 80 (160—320—480) offset /COUPLED receiver_1 receiver_2

AUTOCORR 320 (320—640) offset /COUPLED receiver_1 receiver_2

AUTOCORR 1250 640 0 /COUPLED receiver_1 receiver_2

While it does not allow to describe the full flexibility the system could offer, it covers the important case of line surveys (up to two times 360 MHz at 40kHz resolution and two times 480 MHz at 80 kHz resolution), and halves the cost

	Flexible interface		Simplified interface		
Channel Spacing (kHz)	Elementary Bandwidth (MHz)	Resource Usage (%)	Elementary Bandwidth (MHz)	Resource Usage (%)	Maximal Bandwidth (MHz)
20	2×20	≈ 11.11	2×60	33.33	2×180
40	2×40	≈ 11.11	2×120	33.33	2×360
80	2×40	8.33	2×160	33.33	2×480
320	2×80	8.33	2×320	33.33	2×960
1250	2×160	8.33	2×640	33.33	2×1920

Table 4: Summary of coupled mode capabilities.

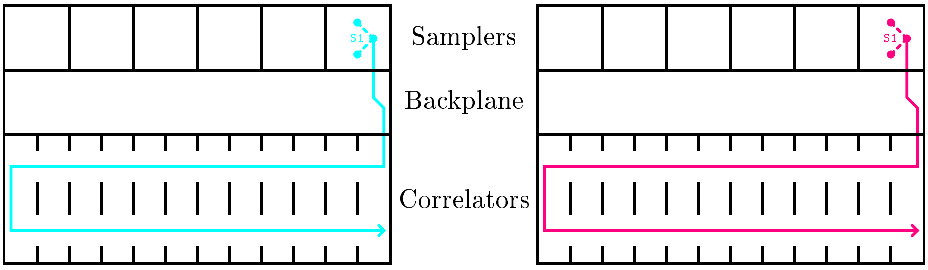

Figure 19: 6.5 kHZ resolution four-receiver configuration.

of 500 MHz frequency coverage at 1.25 MHz resolution. However on the eight remaining bands complete flexibility is lost...

Not completely free, since it actually interferes with four-receiver mode operation but potentially useful. It might be provided as a set of prefedefined configurations to limit complexity.

No problem if only coupled mode is used...

Flexibility can be enhanced but not all restrictions can be lifted if 8 distribution box selectors can be used, with all four inputs of one correlator pair individually programmable.

3.4.3 High resolution polarimetry

Software only

3.4.4 Multi-beam polarimetry

Possible only if the relative phase of the synthesisers is controlled.

3.4.5 Extended 20 kHz bandwidth

Not worth since coupled mode provide essentially the same with more flexibility.

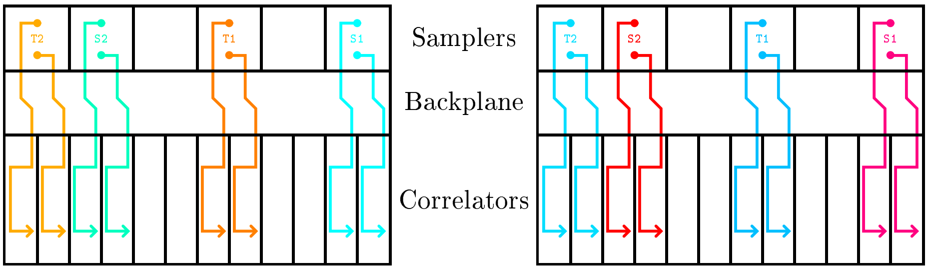

Figure 20: Low resolution coupled mode four-receiver configuration.

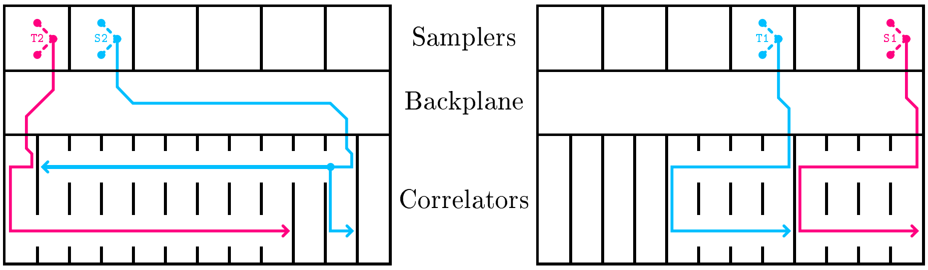

Figure 21: 20 kHz resolution polarimetry configuration. Synthesiser 1 of the right machine and synthesiser 2 of the left machine are set at the same frequency. Left machine provides Stokes parameter I and Q from autocorrelations, right machine provides U and V from cross-correlation (the autocorrelation channels allow to adjust the sampler levels without changing the configuration and to permanently monitor power levels)

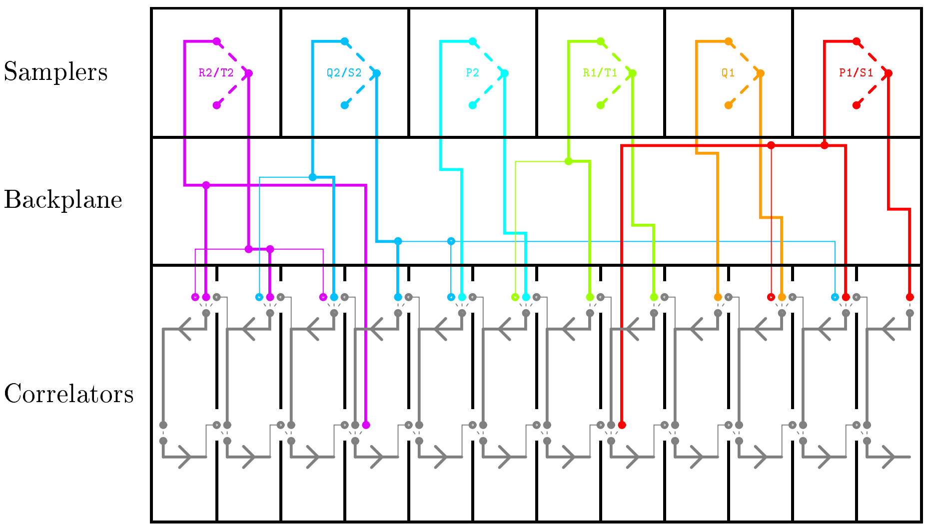

Figure 22: Data distribution diagram.

3.5 Summary

4 What has to be designed and built ?

4.1 Backplane

The current lower backplanes used at Pico Veleta are designed for 4 sampler boards and up to 12 correlator boards. The interferometer version accepts 5 sampler boards and 10 correlator boards. Therefore they have to be redone to accept 6 sampler boards and 12 correlator boards as proposed in this design. This board has to be redesigned in any case, it is larger than the 5 antenna interferometer version but with a simpler and less crowded layout since the left and right halves are largely independent.

Figures

4.2 Control Board

A new central control board has to be designed in order to provide the necessary signals for the samplers (six 160 MHz clocks), and the control signals and clocks for the whole chassis. The current 160 MHz phase lock oscillator can be reused.

More details on this board will be given later in an addendum to this document.

4.3 ST splitter

It is a simple module consisting of 2 RF splitters and 4 low-pass filters. To match the other input path, this module has to attenuate the input signal by 6 dB. This is exactly what a resistive power splitter would provide, so the module might be completely passive as shown in figure 1. The output of this modules are connected through semirigid cables to the former noise source inputs of the up-converters. Although it does not seem to be required, is is cleaner from a design standpoint to buffer the outputs of the splitters with low power monolithic amplifiers, preferably running off the +5 V supply.

5 What has to be modified or upgraded ?

5.1 Image rejection mixers

Apply to all the models the modifications which have been implemented in Granada:

- Improve stability by changing the input bias circuitry of the video amplifier and replace the field-effect transistor by a bipolar transistor.
- Improve the reliability by reducing the bias of the MSA0504 amplifier (this modification has already been applied to some units of the interferometer)

Removal of the 10MHz anti-aliasing filter on the few units from the interferometer which implement this capability does not seem necessary.

5.2 Samplers

Improve stability by replacing the voltage reference with a better one and replace a few resistors with 1% tolerance models.

Remove the delay lines.

5.3 Fixed oscillator (820 MHz source)

Modify to produce 6 820 MHz and 2 5 MHz reference outputs for the synthesisers. Currently the Pico Veleta models provide 4 820 MHz and 4 5MHz outputs while the interferometer ones provide 5 820 MHz and 1 5MHz outputs.

This is the module with the biggest surgery, if it can't be done cleanly, it might be better to rebuild the modules from scratch, keeping the same enclosures which already provide 8 outputs.

5.4 Synthesisers

Modify all synthesisers to provide 3 outputs: the interferometer ones already provide 5, removing the unnecessary components will reduce power dissipation. The Pico Veleta models only provide 1 output, the modification is however simple since the circuit was originally designed to provide up to 4 outputs.

5.5 IF rack backplane

All the control input and outputs (or most of them) have to be rewired to provide the necessary connections. Note that the number of control bits actually decreases since there are only 2 synthesisers instead of 4 and the 2 sets of 3 anti-aliasing filters instead of 4 independent ones. This reduces the number of outputs by 6 (4 for the filters and 2 for serial data to the synthesisers) and of inputs by 2 (synthesiser lock alarms).

A few simple input/output ports on the new control board could be used to perform the functions on the microcontroller:

- lock alarms (2 synthesiser and 1 820 MHz): 3 bits
- filter bandwidth control: 4 bits
- synthesiser serial data: 2 bits
- synthesiser serial clock: 1 bit
- multi-beam or four-receiver operation switch: 1 bit (2?)

or in total 8 output and 3 input bits. Since the addressing of all the correlator is based on 16 bit words, it might be wise to implement this as a pair (one input, one output) of 16 bit ports connected to 34, 37 or 40 pin connector. This would provide additional bits for as yet unforeseen future needs. Some care in the choice of components is required to ensure that powering only either the IF rack or the VME chassis does not result in latch-up or other nasty behaviour.

The following is *wrong*, but removing the microcontroller is a good thing. Removing the microcontroller would also free a slot in the IF rack which might be put to better use (for example if an additional module is required to expand the bandwidth to 1 GHz).

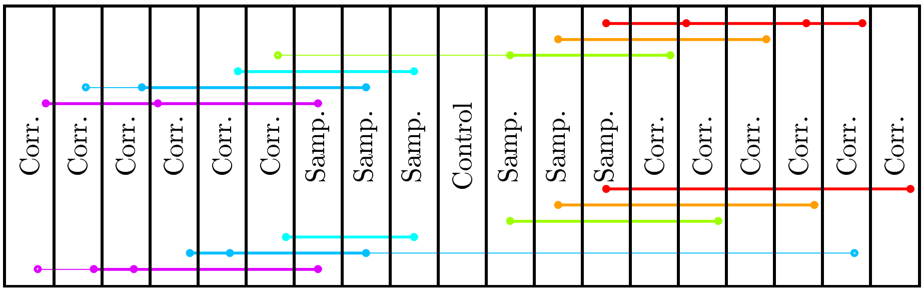

Figure 23: Backplane distribution layout (seen from front of VME chassis).

6 Extension to 1 GHz bandwidth

While extending the bandwidth of the IF processor to 1 GHz seems feasible, it looks like a major investment, probably more important than the one proposed here, since it requires rebuilding a large number of IF processor modules.

Of course, since this proposal reuses a larger proportion of the existing IF processors than the previous one, extending the bandwidth will require a larger investment. The design effort should be similar though, but is impossible to assess precisely without knowing the details of the implementation. The following points should be taken into account to ensure that the bandwidth extension is compatible with the proposed architecture:

- in the ST splitter modules:
  - the power splitters should be specified to work over the full 1 GHz bandwidth,
  - the cut-off frequency of the low-pass filters is different,
- the up-converters, if modified or redesigned (which appears to be unavoidable), should not drop the input switch feature, fundamental in this proposal. If the input low-pass filter is moved after the switch, then no such filter is necessary in the ST splitter module, saving 24 filters,
- if additional oscillators or synthesizers are needed, they should be designed to provide a sufficient number of outputs,
- the distribution scheme of the reference clock will have to be extended or revised if additional phase-locked sources are needed,

These are not fundamental design considerations, showing that bandwidth extension is largely independent from the correlator architecture proposed in this report.

7 Order of operations

One half of the new system can be built out of the components coming from Bure and replace one of the current correlators. The second half can only be finalized with components from the second correlator, however this is only a matter of taking modules out of the previous correlator and installing them in the new chassis.

Item	Pico Veleta	Plateau de Bure	New system	Left
L.O. 820[1]	2+1	6+1	6+2	2
Synthesizers[1]	8+1	6+1	12+2	2
Correlator	16+2	120+12	72+8	70
Samplers[2]	8+1	30+3	36+4	2
IRM[2]	8+1	30+3	36+4	2
Upconverters	8+1	30+3	36+4	2

Table 5: Summary of hardware reuse.

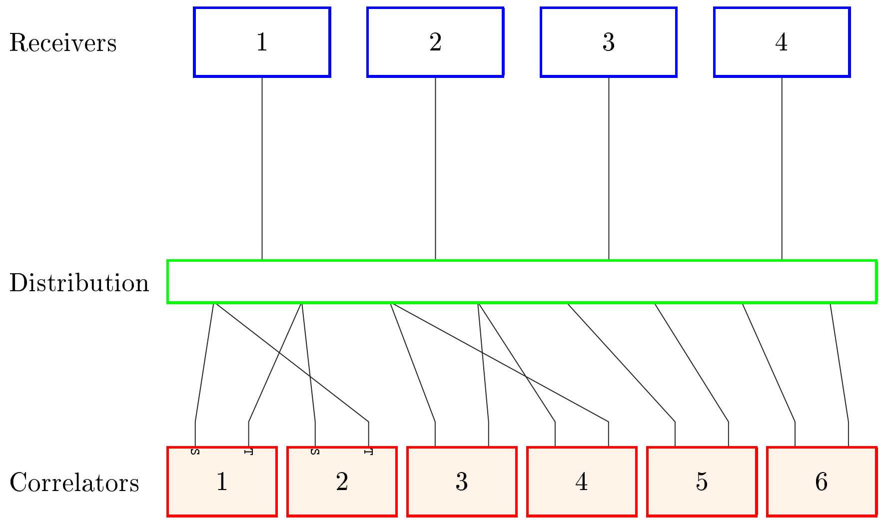

Figure 24: Possible correlator distribution diagram for enhanced flexibility in polarimetry and coupled modes (simplified).

8 Summary of HW reuse

Table 5 shows how much of the current hardware is actually reused. The number of spares available on the Plateau de Bure has been estimated by the 10 % rule. The same rule has also been applied for the rebuilt Pico Veleta system, with the additional requirement of a minimum of two spares (to be able to bring one down to Granada for repair in the lab).

The table clearly shows that a very large percentage (95 %) of the most valuable part of the correlator (IF chains and samplers) is put to new use. Only slightly more than half of the correlators boards are reused, trying to reuse a larger proportion would make the system significantly larger (more VME crates) with apparently very little practical advantages.

9 Conclusion

This is only one of many possible schemes. It is an attempt at a system which is useful both for multi-beam and four-receiver operation, significantly expanding the capabilities of the telescope for high resolution spectral line surveys.

Polarimetry capability is added at a truly minimal cost: it requires only a few additional backplane connections and appropriate software but does not need any dedicated hardware.

The configuration rules are simple, analog to the current ones which have shown to work well in practice, and provide a superset of the current capabilities for four-receiver operation. For multi-beam operation, the capabilities per pixel represent about one half of what the current system provides for single channel receivers (but which has to be shared between four receivers instead of two multi-beam receivers).

Finally the required investment in time and money appears very low in comparison with the provided capabilities.