

IF system upgrade for the SMT V.3

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Introduction

The IF system at the SMT needs work.

The current IF system is a result of 10 years of organic growth. The IF frequency changes several times from the receiver to the spectrometers, and the signal snakes across the building. It is optimized for the AOSes and the vintage 1-2 GHz wet-dewar receivers. The 4-6 GHz IF band is an afterthought.

This document discusses a proposal to improve the IF signal processing at the SMT. The need for this proposal is a result of the new sideband-separating receiver that produces four channels of IF signal at 4-8 GHz. The current IF system at the SMT is unable to handle such signals, and has been in need of improvement for some time.

This document is split into two parts: the IF infrastructure and the spectrometer interface.

The IF infrastructure is considered to be that equipment which takes signals from the receivers at both flanges and passes them to the spectrometer interface in the third floor computer room. The IF infrastructure is currently implemented as two channels at 3-4 GHz. It is proposed to instead use four channels at 4-8 GHz.

The spectrometer interface is considered to be that equipment which receives the IF signals in the computer room and processes them for use by the individual spectrometers. This processing is currently done by some equipment in the AOS controller rack and in the filterbank racks. It is proposed to add equipment to render the four 4-8 GHz IF signals usable by the existing spectrometers. Some modifications to the existing spectrometers may be necessary for optimal flexibility.

The current situation

There are currently two receivers on the left flange, both working at 1-2 GHz. One of these receivers, the 345 GHz receiver, is being converted to the 4-6 GHz IF band. We may add future receivers to this flange in the 4-8 GHz band.

The left Rx room equipment racks contain an IF/LO switch that is used to select the receiver. Also present is a box called the TP/attenuator/converter box that amplifies the IF signal, converts it to 3-4 GHz, and attenuates the signal according to commands received from the HOST1 computer. This box provides a pair of analog total-power measurement signals that are used for continuum observing and to calculate Y-factors for the receivers.

The telescope currently has two total power detector (TP)/attenuator boxes: one on the left Rx room and one in the JT receiver frame in the right Rx room. The one in the left Rx room is older yet is currently used for receiver calibration, as it has a usable software interface. The one in the JT rack has or had some TP data quality issues.

The left Rx room total-power display and IF converter box was made by MPI. It converts the receiver IF in either the 1-2 GHz or 4.5-5.5 GHz band to 3-4 GHz. This frequency band was proposed as a standard about 10 years ago, but was never implemented in a receiver. It is compatible with the AOS spectrometers. This box is still usable with the left flange legacy receivers. It would need reworking for use with any new 4-8 GHz receivers, however.

The dual-channel 4.5-5.5 GHz TP/attenuator box in the JT receiver frame was built a few years ago. Its total power display is sufficient for tuning but not for a facility continuum instrument, and it contains 1 GHz wide IF filters. Its lack of support for four channels is a major problem for use with the new four-channel receiver system.

The current JT-FFB IF path sends the 5 GHz signal from right Rx room to left Rx room, through the IF/LO switch, through the TP/attenuator/IF converter down to 3-4 GHz, from the left Rx room down to the AOS rack in the computer room, through the backend switch in AOS rack, through a converter to 5 GHz and through the ceiling to FFB rack.

When using the ALMA receivers, the 4-8 GHz receiver passband exceeds the range of the 4-6 GHz spectrometers. This problem has been solved temporarily with a cobbled-together IF frequency conversion system consisting of a pair of 12M MAC IF converters in line with the filterbanks, using a pair of HP synthesizers for setting the AOS center frequencies.

IF system upgrade

The proposed IF system

The upgrade plan for the IF infrastructure is to provide a facility total power monitor box in the right Rx room for use with all receivers. The reason to locate it there is to provide the shortest IF signal path possible for all receivers. This new box will provide for four IF channels at 4-8 GHz band. It will select the left or right flange receiver and pass the IF signals down to the spectrometer interface in the computer room on the third floor.

The description below is seen as providing the needed flexibility for handling a variety of receivers currently or soon to become available. The total bandwidth of the IF system is 16 GHz. The current array of spectrometers only covers 4 GHz of bandwidth, but it is possible to add spectrometers in the computer room to cover the wider bandwidth in front of the proposed spectrometer interface.

The proposed hardware additions may be implemented in stages to ease the financial and engineering time burden. For example, channel steering may be implemented by swapping cables rather than building a switch box. The order of implementation if staged would be:

1. Frequency steering lashup with two MAC converters & two HP synthesizers
2. Four channel 4-8 GHz TP/attenuator box
3. Frequency steering box with four MAC converters
4. Channel steering box
5. More filterbank channel steering hardware as needed

The legacy receiver switch and converter are minimal effort, since we have the needed equipment on hand; it just needs to be rearranged in the boxes.

IF signal specification

A standard IF power level will be defined as part of the facility upgrade, with the purpose of allowing PI instruments to be easily specified and to make testing easier. The proposed power level is -20dBm total power over the receiver bandwidth. The receiver is expected to contain a bandpass filter to limit its IF signal to the 4-8 GHz band. Receivers with narrower bandwidth are expected to filter their output so that no out-of-band power is emitted. The signal slope shall be no more than +/-3dB over the receiver's IF band.

Left Rx room

The left Rx room will have two switches and one IF converter. The legacy 1-2 GHz receivers on the left flange will be selected with a 1-2 GHz switch, then converted with an IF converter to 5 GHz. There is a 3-4 GHz to 4.5-5.5 GHz converter box in the AOS rack for which a schematic has been found. It can be easily modified to serve as the legacy receiver IF converter.

A new 5 GHz switch will select one receiver from the left flange to feed the new TP/attenuator box in the right Rx room. The 5 GHz switch will be designed to have four channels for greatest flexibility, but may be initially equipped with only two channels.

The right receiver is assumed to put out a signal of one to four channels at 4-8 GHz. There will be no facility receiver selection switch for this side - if a receiver frame has several receivers, it will be expected to contain the switch. There will, however, be a left/right Rx IF switch in the TP/attenuator box to select which flange is currently being used.

The left Rx room has a computer, HOST1, is due to be replaced with a computer similar to the JT receiver tuning computer.

Right Rx room

The right Rx room is characterized by using receivers each of which is a self-contained unit that gets bolted to the flange for use. As such, each receiver tends to be self-contained with regard to tuning and control equipment. Therefore, it makes sense to continue this tradition by incorporating all necessary tuning and power monitoring equipment into the receiver frame.

The right Rx is expected to have its own power monitor usable for tuning the receiver. A display, easily visible to the operator during the tuning procedure, is expected to exist on or near the receiver frame. The tuning computer display is the prime candidate for this display. To this end, it would be sensible to equip the tuning computer with a portable LCD display that can be easily moved around and clamped to any convenient support arm as needed.

The 1.3mm ALMA receiver will need its total power/attenuator box upgraded to cover the 4-8 GHz band and to contain four channels rather than two. It is likely that a new box will be built to provide enhanced stability and ease of access to all parts.

IF selection and Total power

A new four-channel total power/switch box will be built to select between left flange and right flange receiver IF signals. A set of total power detectors will provide continuum power signals to the DBE computer for observations, pointing and Y-factor measurement. Total power monitor displays will be provided, as well as BNC outputs for connecting oscilloscopes or meters.

A remote total power display box will be provided at each flange for operator tuning use. This box will have attenuator up/down step pushbuttons and 3.5 digit LED total power display for each channel. It will be portable so that the operator may place it in the best viewing position while fiddling with the receiver tuning controls.

New IF cable routing

The proposed IF path sends the four 4-8 GHz signals from the receiver selection switch in the left Rx room and from the right flange to the new 4-channel TP box in the right Rx room to the new spectrometer interface to be placed in the AOS rack in computer room. Four IF cables are needed to send the signal from the new TP/attenuator box in the right Rx room to the AOS rack on the third floor.

Spectrometer interface

We now have in hand one broadband receiver developed for ALMA, and another is on the way. The output band of these receivers is two channels each of 4-8 GHz. Since our current spectrometers do not support this band, we are limited to using such receivers at 4-6 GHz using the current spectrometers.

The proposed spectrometer interface has the task of converting the four 4-8 GHz IF channels to frequencies usable by the existing AOS and FFB spectrometers. Since there are only four GHz of spectrometer available to observe the 16 GHz of available receiver IF bandwidth, some hardware has to be built to steer the four IF channels to the various spectrometers at the frequencies that they will accept. Since astronomers may desire either dual or single sideband spectra from one or both channels in varying bandwidths, the spectrometer steering equipment must be agile in both channel selection and frequency.

The spectrometers

The FFB filterbank spectrometer system input consists of two IF channels over a 4-6 GHz band. These two inputs are further split up and subdivided in the filterbank racks to feed eight 1-MHz resolution filterbank sections of 256 MHz each, two 250-KHz resolution filterbank sections of 64 MHz each and two 40 KHz resolution, 200-MHz wide chirp spectrometers.

The AOS input is three channels over a 3-4 GHz band. There are two 1 GHz wide AOS units called A and B, and a 250 MHz wide unit called AOS C. AOS C currently has an input centered at 3.5 GHz but it is potentially steerable over 3.0-4.0 GHz. Some work is needed to fully implement this steerability.

The proposal to connect the above spectrometers to the four 4-8 GHz IF channels involves building a channel steering box to select which IF signals are observed and a frequency steering box to convert 1 GHz wide portions of the selected IF channels to the frequency range expected by the spectrometers. These two items are described in detail below.

Channel steering box

The four IF channels must be routed to the four wideband spectrometer channels. This could be as simple as a USB/LSB selector switch, or it can be a switching matrix that allows any combination of IF channels to go to the spectrometers.

The proposed solution is to build a switch box that allows each spectrometer to observe any of the four IF channels from the receiver. This would be built from four four-way power dividers and four SP6T RF switches. It would be controlled by computer.

The following matrix shows several useful combinations of receiver to spectrometer switching...

USB dual polarization, 2 GHz bandwidth

	IF A USB	IF A LSB	IF B USB	IF B LSB
AOS A	5-6			
AOS B	6-7			
AOS C	6			
FFB A			5-6	
FFB B			6-7	
FFB25			6	

LSB dual polarization, 2 GHz bandwidth

	IF A USB	IF A LSB	IF B USB	IF B LSB
AOS A		5-6		
AOS B		6-7		
AOS C		6		
FFB A				5-6
FFB B				6-7
FFB25				6

dual SB dual polarization, 1 GHz bandwidth

	IF A USB	IF A LSB	IF B USB	IF B LSB
AOS A	5.5-6.5			
AOS B			5.5-6.5	
AOS C	6			
FFB A		5.5-6.5		
FFB B				5.5-6.5
FFB25A		6		
FFB25B				6

dual SB single polarization, 2 GHz bandwidth

	IF A USB	IF A LSB	IF B USB	IF B LSB
AOS A	5-6			
AOS B	6-7			
AOS C	6			
FFB A		5-6		
FFB B		6-7		
FFB25		6		

USB single polarization, 4 GHz bandwidth, two narrow lines

	IF A USB	IF A LSB	IF B USB	IF B LSB
AOS A	4-5			
AOS B	5-6			
AOS C	5.0-5.2			
FFB A	6-7			
FFB B	7-8			
FFB25	7.2-7.4			

Frequency steering box

Since the AOSes are stuck at 3-4 GHz and the filterbanks at 4-6 GHz, both will need some form of IF conversion to achieve steerability over the 4-8 GHz band. This requires dual-conversion IF processors to allow tuning over such a broad range without worrying about IF images.

Several methods have been contemplated:

- A. Use four MAC IF converters to produce 3 or 5 GHz outputs from some 1 GHz portion of the 4-8 GHz IF band
- B. Convert the LOs in the filterbanks to operate over a wider range, allowing 4-7 GHz input range
- C. Build four IF converters to produce 4-6 GHz outputs from the 6-8 GHz portion of the IF band for FFB
- D. Build four IF converters like A. to produce 3 or 5 GHz outputs from some 1 GHz portion of the 4-8 GHz IF band
- E. Build 15 IF converters to produce 2 GHz outputs from some 250MHz portion of 4-8 GHz

Option A (the current choice) uses four IF converters left over from the decommissioned 8-beam MAC IF processor to provide the frequency conversion of a 1.2 GHz segment in the 4-8 GHz IF band to either 5 GHz or 3.5 GHz center frequency. Option D is the same thing only using new hardware to free up the MAC IF converters for use at the 12M if needed.

There comes the question of what to do with the 250KHz filterbanks and the chirp units and AOS C. The scientists agree (per 5/31/06 ARO staff meeting) that the narrow spectrometers' tuning may be fixed at the center of the wideband spectrometers.

The approach considered here is to piggyback the narrow spectrometers on the wide spectrometers' IF converters. We just need to make sure that the frequency band selected for the wide spectrometer will overlap completely with the narrow spectrometer. The way to do this is to make the filters in the IF converters be more than 1 GHz wide, perhaps 1.2 GHz. Each narrow spectrometer then has a switch to select which of two wideband signals to be piggybacked onto.

AOS C will require its steering to work if it is to be used at the crossover point between AOS A and AOS B when stacking them for 2 GHz bandwidth. There is some steering capability for AOS C in its IF processor box, but the computer control has not been connected. A serial port and some software is needed. There are two filters in that IF processor box, one of which is useful at the center of the 3-4 GHz band but the other may need to be replaced with a filter in perhaps the 3.8-4.2 GHz band.

An alternative is to reconfigure AOS C to accept a 2.1 GHz input frequency, and use the same type of IF processing as in the filterbanks for frequency steering within the 4-6 GHz band. In this mode, AOS C would resemble a CTS unit.

AOS BE switch box

This IF switching box was designed for the AOS spectrometers only, and it operates at 3-4 GHz. It currently swaps IF A vs IF B. We would do well to add an AOS C source switch to select the better of IF A or B.

Computer control is recommended if we add an AOS C switch to this box. This box currently has a serial control port that isn't connected to a computer. We could use the AOS computer for this since it has a spare serial port.

Work To Do

The following lists of things to purchase and assemble are rough estimates and subject to change.

New left Rx selection switch

The left Rx room will need a switch to select either a legacy 1-2 GHz Rx signal or a modern 4-8 GHz signal. This switch will be designed to handle four IF channels, although there is currently only a requirement for two channels to be populated with switch hardware. It requires computer control. This box will probably not have IF amplifiers in it.

New ALMA rack four-channel TP/attenuator box

The JT total power box will be replaced with a four-channel 4-8 GHz unit located in the flange rack with the receiver. This box will contain at least:

- Four isolators on input and output signals
- Four 0-12 GHz RF switches for Rx insert (band) selection
- Four 4-8 GHz bandpass filters for the IF channels
- Four 4-8 GHz amplifiers with gain to go from ~-60dBm Rx output to ~-20dBm Rx rack output
- Four HP mechanical 0-11dB attenuators
- Four power splitters or 3dB couplers to pick off total power
- Four total power detector assemblies with four analog outputs each
- Connectors for one remote total power display box and BNC monitor outputs
- Control circuitry to operate attenuators and input switches via computer/front panel
- Linear power supplies to power all the above items (15V, 28V)

The box itself is a problem in the present design - there is very little isolation of RF and analog vs. control and power wiring. A Bud 4U rackmount box with a baseplate separating the RF and power/control halves (as in the FFB IF processors) would be a better way to go. I can easily convert the FFB drawings to the current needs.

The attenuators are currently available as unused surplus from Max Gain in Ga. for \$130 each - HP 33320H opt H09
<http://www.mgs4u.com/RF-Microwave/RF-attenuators.htm>

Four total power detectors need to be built. I am proposing a simple Schottky diode detector, operational amplifier and low pass filter, sending the total power signals out as analog voltages. These will have a decently long thermal time constant.

The IF amplifiers need to be stable with respect to temperature changes over a 10 minute period. They will definitely be attached to a thermally isolated mass, which may or may not have a controlled heater. We already have thermal control systems worked out from the FFB project.

The operator often needs to see the total power indicators while tuning the receivers. Thus, it has been proposed to build a analog total power display box to be fed from twisted-pair DC signals out of the total power box. This would be placed conveniently in the operator's field of view. Each display box will contain four LED panel meters and a DC power supply for the meters. A set of attenuation up/down control pushbuttons would be a handy addition. We should plan it to have a little computer to handle the pushbutton encoding so that it can be changed around easily if needed. Perhaps it will use SPI for communication - nothing that takes a lot of engineering time, but is fairly flexible and easy to use.

New facility TP/switch box

The facility continuum power function of the left Rx room total power box will be replaced with a four-channel 4-8 GHz unit located in a rack in the right Rx room. This box will contain at least:

- Four isolators on input and output signals
- Four 0-12 GHz RF transfer switches for left/right Rx selection
- Four 4-8 GHz amplifiers with enough gain to overcome cable losses and internal losses
- Four power splitters or 3dB couplers to pick off total power

Four total power detector assemblies with four analog outputs each
Connectors for analog total power outputs to BNC monitor and DBE computer
Control circuitry to operate input switches via computer/front panel
Linear power supplies to power all the above items (15V, 28V)

The total power detectors will be high class. This basically means low noise, slow drift via box-in-a-box packaging. Thermal control of the power detectors may be used but is probably not necessary.

Frequency steering box

This is a new box that steers each of four 4-8 GHz IF sections to one 1 GHz wide spectrometer.
There are two approaches to this problem under consideration:

Option A. Full 4-8 GHz steering of AOS and FFBs using four or more MAC IF processors

This option provides greater frequency latitude than Option B. It also requires more work, since several IF converters have to be assembled and tested, housed and controlled.

Option B. Limited 4-7 GHz steering of AOS and FFBs by upgrading YIGs

This option requires little work, since it basically uses the IF processors in the FFB to do the work. It is limited to 7 GHz rather than 8 GHz at the high end, which may be a showstopper for the astronomers.

Analysis of work required for each of the above options

Option A. Full 4-8 GHz steering of AOS and FFBs using four or more MAC IF processors

We have available six IF processors from the 12M MAC system. This IF processor, once modified for this application, accepts an input in the 4-8 GHz band and converts it up to 10 GHz, then down to some lower frequency determined by the second LO frequency and by the output amplifiers installed.

Converting the AOSes and the filterbanks to be steerable over the 4-8 GHz band requires at least four converters. Each wide AOS needs one, and each wide filterbank rack needs one. The narrow spectrometers will borrow spectrum from the wide spectrometers' converters - see below. The output frequencies are:

FFB A,B 4.3-5.6 GHz
AOS A,B,C 2.9-4.2 GHz

We would need to supply two copies each of two different second LO frequencies. These could be generated with DROs driving amplifiers and splitters. The approximate frequencies are:

FFB 15 GHz
AOS 13.5 GHz

Amplifier to make +17dBm from 12-18 GHz: Cio CA1218-303
Splitter 3 way 12-18 GHz: Pulsar PS3-19-451/9S

Convert the spare 12 meter MAC IF processors for use at 4-8 GHz input band and either 3-4 GHz or 4-5 GHz output band. Bandwidth is 1.3 GHz. We have already converted two of these processors for the ALMA test (minus filters).

We have eleven units, two of which are in use at the 12M. The others are at:

	12M	SMT	Tucson
complete	1	2	1
incomplete	2	1	3

One problem is that we don't have enough PLL PC boards for these boxes, since several of them had been built as fixed-frequency converters. We will need to buy some blank PC boards and obsolete parts, and/or redesign boards for modern

parts. A big expense is that the RF amplifiers and some mixers need to be replaced for the higher frequencies we're using. Another problem is that the RF sampler device from the HP 5350B counter is no longer available, and we don't seem to have any spare units on hand beyond the six required pieces. HP 5350B counters sell for \$300 on ebay.

There are three known problems with the IF processors.

1. The YIG oscillator overheats due to insufficient heatsinking.
2. The YIG oscillator drifts with temp, causing the fine loop to go out of range.
3. There is a good bit of close-in spurs and noise in the YIG tone.

The above items can be corrected.

#1 requires metalwork.

#2 requires a thermistor and a correction amplifier to correct the coarse tune coil voltage, or it be fixed in the 8751 microcontroller code.

#3 may require a new ref PLL board, or we may be able to tweak PLL parameters.

Parts needed to finish four IF processors:

- * Input amps, 4-8 GHz, qty 2
- * Output amps, 3-4 GHz, qty 2
- * Mixers, 18 GHz RF to 6 GHz IF, qty >1
- * BP Filters, 9.9 GHz Fc, 1.0 GHz BW, qty 2
- * Main loop PC boards, qty 2
- * Ref loop PC boards, qty 2
- * YIG temp correction boards, qty 8

IF processor box:

- * machine a bunch of Al plate as needed.

Second LO box:

- * Second LO bricks, ~13.5 & 15 GHz, qty 2
- * Second LO splitters, 12-18 GHz, qty 2
- * Second LO amps, 12-18 GHz, 17dBm, qty 2
- * machine a bunch of Al plate as needed, mount DROs etc.

Power supply box:

- * Several linear power supplies
- * Bud box, rackmount
- * baseplate, machined from Al plate stock

Controller:

- * Computer parallel port (free?)

Option B. Limited 4-7 GHz steering of AOS and FFBs by upgrading YIGs

We can extend the frequency range of the filterbanks with not too much trouble, just a bunch of money. Micro Lambda, who made the YIG synthesizers for the FFB, now makes the same device but with 3 GHz wide tuning instead of 2 GHz wide. It would cost \$700 each for retrofitting our 13 synthesizers with the wider tuning range, a total of \$10K. We would also need to change out the LO lowpass filters and possibly the mixers, as these items are also limited to 6 GHz IF (8 GHz LO) frequency.

We would also need to install similar YIG synthesizers to make the AOSes agile over the 4-7 GHz range. They are \$2500 each in that quantity.

Total cost - \$25K in parts and 2-3 man-weeks of engineering time.

Channel steering box

We need to build a new channel steering box to allow allocation of the different spectrometers to the four IF channels. This is a straightforward switching matrix with four inputs and four or five outputs, depending on what we do with AOS C.

Specs:

Inputs: Four 4-8 GHz IF channels

Outputs: Four 4-8 GHz IF channels

Switches: Each output may be driven by any one of four inputs

Parts required:

Four 4-output power dividers, 4-8 GHz

Four SP6T terminated RF switches, 12 GHz

Control board with Ethernet or serial I/O

Power supplies, box, etc.

345 Legacy TP/Atten upconverter box replacement

This box will be replaced with the 3-4 to 4-6 GHz upconverter box that currently feeds the FFB. Its input needs to be reworked to 1-2 GHz from 3-4 GHz.

We have a leftover Miteq 6.5 GHz oscillator from the Texas Filterbank. This replaces the 8.5 GHz synth.

Change the 10 MHz ref input on rear panel to 100 MHz.

Replace the input isolators with 1-2 GHz units.

Check that the mixers have the right input freq. range; if not, use the mixers from the 345 TP/attenuator box.

AOS C converter

The AOS C converter will need to be frequency agile - it may be sufficient to give it a wider filter or it may need another converter added at about 2 GHz in addition to the wider filter.

It also needs its RS-232 frequency programming interface to work. It may be functional but we haven't yet found any documentation that describes its interface protocol.

Computer interfaces

To control all these IF processors we plan to make, we need a PC board that will connect to the network and to a bunch of RF parts such as synthesizers, relays, DC signals, etc. It would be nice to make a single board design that can be used in every box we build for the foreseeable future.

RS-232 serial I/O is an obvious choice, as it has lower complexity and RF emissions than Ethernet etc. However, there are now Ethernet to serial port adapters such as the Lantronix XPort for \$50 which provide a complete TCP/IP stack in an Ethernet connector shell.

The CPU could be a simple PIC or other such microcontroller. It has to interface to many parallel I/O bits and perhaps an ADC or two. It needs a serial I/O port for communication with the XPort device. The code could be assembly language or microcontroller C. There may well be different code for each controller board, since it may have to talk to several types of synthesizers etc.

The relay control may be as simple as several SN75468 Darlington driver chips driven from 8-bit 74HCT273 registers. The synthesizer control would typically be an SPI or similar serial bus.