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Mixer-Preamp to Receiver Interface Considerations for ALMA Band 6

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The NRAO CDL is preparing to construct test receivers for use in production of the Band-6 mixer-preamps for ALMA. The discussion below applies primarily to the mixer-preamp to test receiver interface, but should also be useful as a guide to the mixer-preamp interface with the cartridges — all the listed connections will be available on the mixer-preamp and can be used as desired by the cartridge designer (NRAO/Tucson for Band 6). For example, in the cartridges it might be decided to use two-wire bias to the SIS mixers at the cost of much of the diagnostic capability of the six-wire scheme.

Mixer-Preamp Configurations for ALMA Receivers

The preferred configuration for ALMA mixer receivers uses sideband-separating mixers with either 8 GHz IF bandwidth from one sideband or 4 GHz each from upper and lower sidebands. The fall-back configuration, in case sideband-separating mixers are not ready in time, uses double-sideband mixers, in which case 8 GHz IF bandwidth must be used to meet the ALMA bandwidth requirement of a total of 8 GHz IF bandwidth per polarization channel. The relative merits of sideband-separating and double-sideband mixers for ALMA are discussed in [1, 2].

Sideband-separating and double-sideband mixers can be balanced or single-ended. A balanced mixer has two main advantages compared with a single-ended mixer: the balanced mixer requires substantially less LO power than a comparable single-ended mixer with a ~20 dB LO coupler, and the balanced mixer does not require a separate LO coupler. (Note that interferometric (*e.g.*, Martin-Puplett) and resonant LO diplexers are not considered for ALMA because of their bandwidth limitations, need for mechanical tuning, and large physical size.)

Mixer-Preamp to Receiver Interface

Appendix I describes the interface between the mixer-preamp and the test receiver when balanced sideband-separating mixers are used. These details are easily modified for other mixer-preamp configurations (*e.g.*, single-ended mixers and/or double-sideband mixers). Table I summarizes the major interface requirements for the possible front-end configurations. Column 5 gives the required LO power relative to that required at the input of a single unit mixer. (In the case of single-ended mixers, it is assumed that the LO is introduced through a 20 dB coupler ahead of the mixer.) Column 6 gives the number of wires to each mixer-preamp, based on the information in Appendix I. The number of IF coaxial cables, given in column 7, depends on the IF bandwidth of the individual mixer-preamps. Note that, in the case of a sideband-separating mixer with 8 GHz IF bandwidth, only a single IF cable is required per channel because the received sideband (upper or lower) can be selected by switching the polarity of the bias on one half of the mixer. The last column gives the mixer-preamp power dissipation, based on the information in Appendix 1, but does not include heat loading from wires, cables, infrared, or the mixer magnet which is assumed to be superconducting.

Reduction of Number of Conductors

It has been pointed out [8] that the wiring list in Appendix I contains a number of wires which may be redundant or non-essential in the production receivers (cartridges). These are listed in Appendix II, with comments on the pros and cons of eliminating them. In light of the discussion of reliability in the next section, a natural tendency to syrmatophobia[1] is probably unjustified — wires should not be eliminated if doing so would significantly reduce diagnostic capability at the cartridge level and, hence, the serviceability of the cartridge; the additional wires are not likely to degrade reliability significantly. For example, using two-wire bias to the mixers (as opposed to the six-wire scheme) would make it difficult to determine whether a short circuit was in the wiring harness, in the bias-T, or at the SIS junction, without disassembling the cartridge.

Considerations of Complexity and Reliability

The additional complexity of a receiver with a balanced sideband-separating mixer-preamp, compared with a simpler single-ended mixer-preamp, will obviously not *improve* the reliability of the receiver. But is the increase in failure rate due to the more complex receiver of significance in the ALMA context? *Is it likely that a failure mode will occur with an MTBF which is acceptable for the simpler configuration but not acceptable with the more complex receiver?* Without hard data on the failure rates of the mixers, IF amplifiers, connectors, wiring harnesses, and other components in the receiver, it is not possible to put a number on the MTBF, but some general observations may be useful: (i) The SIS mixers and HFET IF amplifiers used for many years at NRAO have been extremely reliable once installed in a receiver dewar. The few failures have almost all been associated with mechanical tuners (not to be used for ALMA) and misaligned Microtech connectors (see below). (ii) Spacecraft typically have many more interconnections than an ALMA receiver, but are highly reliable. (iii) The connectors proposed for the mixer-preamp (Nanonics Dualobe) are qualified by NASA and the U.S. military for space and airborne applications [3]. The SIRTF spacecraft has over 350 cryogenically cooled Dualobe connectors with a total of 1,600 conductors. (iv) To my knowledge, receivers on the 12-m telescope suffered only two wiring-related failure modes — one was quickly corrected, and the other is avoidable by choice of connector: (a) Enameled wires epoxied to a 4 K copper heatsink were found, after a few thermal cycles, to develop a short-circuit to the (grounded) heatsink — this was corrected by using an anodized aluminum heatsink. (b) Pins in Microtech connectors were damaged due to misalignment during mating — Dualobe connectors cannot be engaged if they are not well aligned.

We can expect some initial failure modes to be found in any newly designed receiver package, and thorough testing of prototypes should reveal most of these and allow them to be cured.

Table I. Mixer-Preamp to Receiver Interface for a Single Polarization Channel

Type of mixer-preamp	IF bandwidth GHz	No of unit mixers	No of unit IF preamps	Relative LO power dB	No of wires to ea. mixer-preamp	No of coax cables	Mixer-preamp power mW
Balanced, sideband-separating	8	4	2	6	48	1	19
Balanced, double-sideband	8	2	1	3	27	1	10
Single-ended, sideband-separating	8	2	2	23	36	1	19
Single-ended, double-sideband	8	1	1	20	21	1	9
Balanced, sideband-separating	4	4	2	6	48	2	19
Single-ended, sideband-separating	4	2	2	23	36	2	19

References

[1] http://www.mma.nrao.edu/memos/html-memos/alma168/memo168.pdf
[2] http://www.mma.nrao.edu/memos/html-memos/alma304/memo304.pdf
[3] J. Effland, NRAO CDL internal memo, Jan. 2001.
[4] http://www.nanonics.com/dualobe.html.
[5] http://www.mma.nrao.edu/memos/html-memos/alma278/memo278.pdf
[6] ftp://ftp.cv.nrao.edu/NRAO-staff/akerr/EDTN163.pdf
[7] ftp://ftp.cv.nrao.edu/NRAO-staff/akerr/EDTN163addendum.pdf.
[8] L. R. D'Addario, private communication, 4 Dec. 2000.
[9] G. Lauria, "Cartridge to mixer-premplifier gain and power dissipation," internal memo to JRDG, Jan. 2001.

[1] συρματοφόβία = aversion to wires; σύρματα = wires, φόβος = fear.

Appendix 1: Band-6 Mixer-Preamp to Test Receiver Interface Details When Balanced Sideband-Separating Mixers Are Used

Each polarization channel of the Band-6 receivers will consist of a balanced sideband-separating mixer (BSSM) with integral IF preamps. Each BSSM contains four elemental SIS mixers and is attached to two IF preamps whose outputs are combined in an IF quadrature hybrid to separate the downconverted USB and LSB signals.

Connections to the 4-K stage:

Mixer bias -- 6 wires per mixer x 4 unit mixers = 24 wires per channel.
Magnetic bias -- 2 wires per channel.
Mixer temperature monitor -- 2 wires per channel.
Mixer heater (for degaussing) -- 2 wires per channel.
Preamp bias -- (7 wires + 2 wires for LED's) x 2 preamps = 18 wires per channel.
LO connection to multiplier -- 1 waveguide (overmoded) per channel.
Coaxial output connection -- 1 cable per channel if IF bandwidth is 8 GHz, 2 cables per channel if IF bandwidth is 4 GHz (USB and LSB).

TOTAL mixer-preamp connections at 4 K: 48 wires + 1 w/g + 1 or 2 coaxial cables per channel

Thermal loading: (Note, in the following, the importance of ~15 K heatsinks on conductors terminated at 4 K.)

IR loading -- depends on IR filtering and optics configuration.
Each mixer bias-T will dissipate 0.25 mW max. (assuming 1k series protection resistors). There are 4 bias-T's per BSSM —> 1 mW max. per BSSM.
Each IF preamp will dissipate ~9 mW —> ~18 mW per BSSM.
LED's will require only an occasional pulse, so will not contribute significantly to the thermal load.
Temperature sensor, 1.6 V at 10 μA —> 16 μW per BSSM.
Bias wiring -- 48 wires, 36 AWG phosphor bronze, 6" long:
15 K to 4 K —> 0.2 mW per channel.
(*cf.*: 80 K to 4 K —> 5 mW per channel).
LO waveguide -- WR-10 (overmoded) 304 SS, 0.010" wall, 2" long, plated inside 50 μ-in Cu:
15 K - 4 K —> ~ 0.7 mW per waveguide —> ~ 0.7 mW per channel.
(*cf.*: 80 K- 4 K —> ~ 28 mW per waveguide —> ~ 28 mW per channel.)
IF coaxial cable -- 0.085" coax with SS outer/SS inner/PTFE, 3" long:
15 K - 4 K —> 0.23 mW per cable —> 0.23 or 0.46 mW per channel.
(*cf.*: 80 K - 4 K —> 9 mW per cable —> 9 or 18 mW per channel.)

TOTAL 4 K heat loading = (IR loading + 20 mW per channel) assuming conductor dimensions and material as above, two coaxial cables, and heatsinking of all conductors at 15 K.

4-K Hardware:

IF quadrature hybrid (one for each BSSM): The CDL is evaluating a commercial 4-12 GHz quadrature hybrid for 4 K operation.

Connectors:

Multi-pin: The CDL is using Nanonics Dualobe connectors [4] for mixer-preamp development. These have 25-mil pin spacing and are available in a variety of styles, *e.g.*, surface mount, through-hole mount, and pre-wired with any desired type of wire. The construction prevents pin damage due to misalignment during mating. Dualobe connectors are approved by NASA for space applications and by the U.S. military for airborne use. They are used in space on HST, SIRTF, Muses-CN, and GLAST, and on the F-22 and F-18 aircraft.

Coaxial: Wiltron type-K female connectors will be used at the output of the IF preamplifiers. (K–connectors are compatible with SMA connectors.)

Waveguide flanges: Waveguide flanges should be of the flat or anti-cocking type, compatible with the MIL spec UG-387 type of flange but with improved dimensional precision, as recommended in ALMA Memo 278 [5]. It is not clear yet whether the feed horn for Band 6 will be fabricated as an integral part of the mixer block or as a separate unit with a waveguide flange. The LO input to the mixer block will be by waveguide, probably overmoded waveguide to reduce the loss between the final LO multiplier and the mixer.

4-K RFI filters: See section on RFI filters. Probably not required for the Band-6 ALMA receivers.

Heat strap connections: According to Rose-Innes: "...heat transfer between gold surfaces is about 20 times better than between copper surfaces...," which is in approximate agreement with our measurements of the thermal resistance of various bolted joints at 4 K (EDTN 163 [6] and addendum [7]). Gold-plated copper should therefore be used for thermal connections. Indium gaskets are not necessary.

Rose-Innes also states that the thermal conductance of a bolted joint in a vacuum is proportional to the contact force but independent of the area. The current developmental design for the BSSM/preamp has provision for attachment of two 4-K heat straps, one to each preamplifier body, each with up to ten #2-56 screws in an area approximately 0.4" x 0.6".

Heatsinks -- All conductors need to be well heatsunk to ~15 K before connection to the 4-K stage.

Multi-wire cables: The CDL is evaluating two types of heatsink for multiconductor cables: one uses a PC board mounted on an anodized aluminum plate with thermally conductive epoxy, and the other uses a thin kapton PC board with its copper groundplane soldered to the heatsink.

Coaxial cables: Current NRAO practice is to use cables with SS or beryllium copper outer conductors, solid PTFE dielectric, and a center conductor of SS, beryllium copper, or SPCW (silver-plated copperweld). From a thermal point of view, a small-diameter all-SS cable is best. Heatsinks are attached only to the outer conductor -- it is assumed (perhaps erroneously [8]) that radial thermal conduction through the PTFE dielectric is sufficient to cool the center conductor. It is possible that the IF hybrids will provide an effective 4-K heatsink for the coaxial cables from the 15-K stage.

Waveguide: The LO waveguide from 15 K should not require heatsinking to 4 K before the mixer. (LO waveguides directly to 4 K from 80 K may require 4-K heatsinks.)

RFI filters: Most NRAO SIS receivers have low-pass RFI filters on all wires entering the dewar. The CDL test receivers also have a low-pass filter at 4 K in the mixer bias leads.

Room-temperature RFI filters: Electrical interference coupled into the bias circuits of SIS receivers is often troublesome, and it has been found that interference levels in telescope receiver cabins can be worse than in the laboratory. To ensure that RFI is not coupled into the mixer or IF amplifier bias wiring inside the dewar, the ALMA test receiver dewars should be well shielded against electrical interference, and *all* connections entering the dewar should do so through low-pass RFI filters, even leads to temperature sensors, heaters, solenoids, *etc*. The RFI filters should be mounted in a metal wall which completely separates the electrically quiet and noisy regions, as, *e.g.*, in the RFI filter pods used on the 12-m telescope receivers. The filters used in the present CDL test receivers are:

SIS bias: Spectrum Control 9001-100-1010 (0.375" dia., pi-circuit, nominally -39 dB at 150 kHz).
All other conductors: Spectrum Control 51-729-304 (0.140" dia. LC circuit, nominally -17 dB at 3 MHz).

4-K RFI filters: The simple L-band bias-T's used in most NRAO SIS receivers do not have very high IF isolation between the DC bias connector and the IF amplifier port. It has been found that thermal noise on the bias wires between room temperature and 4 K can couple enough noise into the IF to add a few degrees to the receiver noise temperature. For this reason, the CDL test receivers have a simple 4-K low-pass filter (a capacitor to ground) at the 4-K heatsink in each mixer bias lead. (For some reason, this 4-K low-pass filter appears never to have been incorporated in the "rocket" receivers on the 12-m telescope.) In the new 4-12 GHz bias-T's being used in the CDL, the bias-port isolation is greater and there should be no need for additional 4-K RFI filters.

Appendix 2: Redundant and Non-Essential Conductors

It has been suggested [8] that some of the wires listed in Appendix I may be redundant or unnecessary. In considering wiring to the mixer-preamps in a test receiver or cartridge, it is important to understand the mixer-preamp configuration. The balanced sideband-separating mixer preamp currently being developed for Band 6 in the CDL consists of four modules: the mixer block, two identical IF preamps, and an IF quadrature hybrid. Mixer bias is provided through the preamp modules; each preamp contains a pair of bias-T's which are connected through a split microstrip line at the input of the amplifier to the unit mixers of the balanced sideband-separating mixer. Each preamp has a single 37-pin Dualobe connector for mixer and amplifier bias — *i.e.*, there are two 37-pin Dualobe connectors for the complete mixer-preamp assembly. Each Dualobe connector has the following connections: mixer bias (12 wires), amplifier bias (7 wires), and LED bias (2 wires). In the ALMA production mixers, there will also be a connector on the mixer block for the magnet supply (2 wires), temperature sensor (2 wires), and heater (2 wires).

Possible wire reductions suggested in [8] are listed in the left column below, and comments on the effects of such a reduction in the right column.

1. Mixers: (6 wires per unit mixer) x (4 mixers per channel) = 24 wires per channel	
a. The ground source and ground sense are common to all mixers of a block (they connect to the block). Could eliminate 6 wires per channel.	*It may be possible to combine 2 source grounds and 2 sense grounds in each preamp, saving 4 wires per channel.*
b. There is no point in running separate sense wires for I and V from the same point in each elementary mixer. This could eliminate 4 wires per channel.	*Should be OK, although we ran into a problem when we did this in a prototype preamp — the response to bias changes became very slow — don't yet know why.*
c. The separate ground sense wire is probably unnecessary. Saves an additional 1 wire per channel.	*Not good to combine source and sense grounds.*
2. Magnets. Each channel has a separate mixer block and, hence, a separate magnet, but do they have to be separately adjustable? Could eliminate 2 wires per channel.	*We are not sure how critical the magnetic field is.*
Does the field have to be adjustable at all if it is sufficiently large? If not, then permanent magnets can be used and the number of wires is zero.	*The present Band-6 mixers require 50-100 gauss at the first minimum of $J_C(B)$). Much higher fields would require more amp-turns, larger magnetic circuits (iron), and/or smaller gaps between the pole pieces; these are difficult to achieve with the present mixer-preamp configuration.* *Experience with permanent magnets (neodymium) in receivers on the 12-m telescope was unsatisfactory because they appeared to lose magnetization with repeated thermal cycling.*
With perhaps (4 junctions) x (4 unit mixers) = 16 junctions per channel, does a small field allow adequate suppression of Josephson noise in all junctions, even if it is adjustable?	*Has been OK for the balanced and sideband-separating mixers we have tested.*

3. Heaters. Is there a need for a heater on each mixer block? Could have a single heater for the whole 4-K stage.

A local heater on each mixer will allow more rapid heating and re-cooling to eliminate trapped flux.

4. Preamps. (7 wires per preamp) x (2 preamps per channel) = 14 wires per channel.

Do we really need three stages of preamp, or would two (maybe even one) be sufficient?

It is expected that three stages will provide all the gain needed inside the dewar [9]. Fewer stages could be used in the preamp with an additional amplifier at 15 K or 80 K — this would require at least two stages at 4 K and 2 stages at 15 K or 80 K [9].

Servo control of the bias (constant-current bias) should be necessary only for the first stage. The other stages (if any) should operate from a fixed voltage supply.

Not sure if that will work with future designs.

LEDs: 2 wires per preamp = 4 wires per channel when balanced sideband-separating mixers are used. Could supply all LED's in the receiver from a single pair of wires.

Each preamp has a multi-pin connector which can include the LED connections. The LED's could be daisy-chained, but that would make a more complicated and vulnerable wiring harness.