ATA Memo #18

The ATA RF-IF Converter

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Abstract

The ATA system will allow simultaneous access to the entire 0.5 – 11.2 GHz bandwidth to multiple users—each user will have the ability to steer an LO to view an approximately 500 MHz wide bandwidth anywhere within the entire range. To realize this, a wide bandwidth up/down converter scheme is necessary. This memo describes the properties of that system, the current state and an outline of one method of packaging and integration.

Introduction

The Allen Telescope Array (ATA) will display an unprecedented amount of observing flexibility, giving each tier of observing several levels of control. One possible definition of the various tiers of observers is listed below:

(N_P,M_P) Primary observer	Controls sub-array pointing Controls N_P tunings Controls M_P beams
(N_S,M_S) Secondary observer	Controls N_S tunings Controls M_S beams
(M_T) Tertiary observer	Controls M_T beams
(M_Q) Quadinary observer	Controls M_Q constrained beams

where

$$\sum_{i=1}^{P} N_{P,i} + \sum_{i=1}^{S} N_{S,i} \le N_T,$$

$$\sum_{i=1}^{P} M_{P,i} + \sum_{i=1}^{S} M_{S,i} + \sum_{i=1}^{T} M_{T,i} \le N_B,$$

$$\sum_{i=1}^{P} M_{P,i} + \sum_{i=1}^{S} M_{S,i} + \sum_{i=1}^{T} M_{T,i} + \sum_{i=1}^{Q} M_{Q,i} \le N_D,$$

N_T, total number of available dual polarization tunings,
N_B, total number of available simultaneous beams,
N_D, total number of available data paths,
P, number of sub-arrays,
S, number of secondary observers,
T, number of tertiary observers,
Q, number of quadinary observers.

Note that N_T is equal to half the number of up/downconverters per antenna (each of which are mixer pairs), since each local oscillator (LO) is split to convert dual polarization. There may be multiple secondary through quadinary observers – up to the total number of available data paths (N_D) for the different combinations. Each observer may also be one or more lower-tier observer[1]; and, by definition, there are P Primary Observers (one per sub-array, *i.e.* if you want two sub-arrays, you are two different Primary Observers). Each of the N_D data paths may be any linear or circular polarization.

There may be some internal inconsistencies and assumptions in the above scheme (*e.g.* the obvious ones, that there is at least one tuning/sub-array and one beam/tuning), but it begins to display the flexibility and complexity that we face. We do need to develop some consistent scheme for the software logic to be tractable.

The simultaneous bandwidth of the ATA will be approximately 600 MHz to 11.2 GHz, or a roughly 22:1 bandwidth and each tuning will select a roughly 500 MHz bandwidth within that range. This memo will describe the up/downconversion scheme, the current state of development and an outline of one method of packaging and integration.

Up/Down Converter

One way to convert an arbitrary frequency band in a single-sideband (SSB) fashion to a fixed band that is contained within the RF band, is to first transform the desired portion of the band to a higher frequency, filter, then down-convert. Other schemes would require a difficult and expensive tunable filter that would likely not have the desired passband properties, or use an image rejection filter, which would likely not have the desired isolation properties. A block diagram of the up/down conversion chain is shown in Figure 1 while Figure 2 illustrates the frequencies and bands involved.

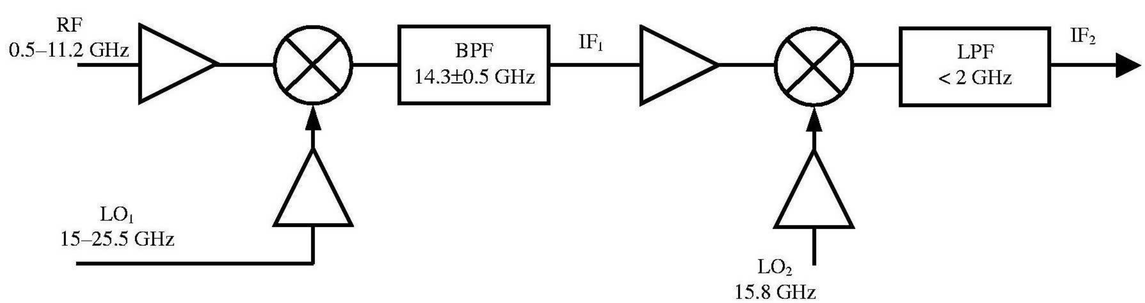

Figure 1: up/down mixer chain.

[1] Some of those combinations may be redundant. For instance, a (2,2) Primary+(1,2) Secondary observer, is really a (3,4) Primary.observer.

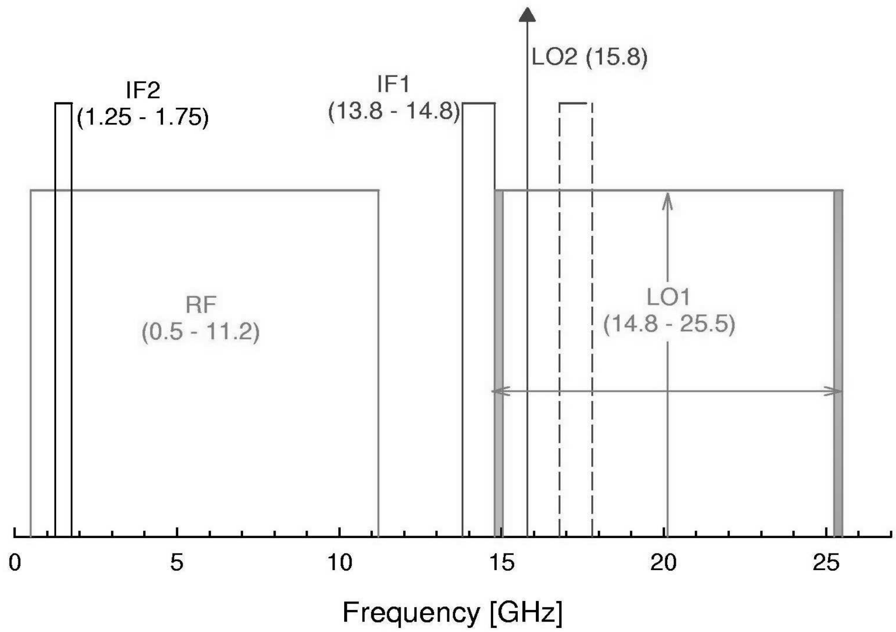

Figure 2: Frequency bands for up/down-converter.

As can be seen, the RF band extends up to 11.2 GHz and the first LO is steerable from about 14.8 GHz to 25.5 GHz. This will place any point within the RF band in the first IF band, which here extends from 13.8 – 14.8 GHz. This separation between RF and IF_1 then makes feasible an IF_1 bandpass filter (BPF) with sufficient attenuation at the top of the RF band and the bottom of the image (which starts at 16.8 GHz and is the dashed, blue line) for the second down-conversion stage. The second LO is fixed at 15.8 GHz, so IF_2 then spans 1 – 2 GHz and is ready to either be down-converted to baseband for sampling, or downsampled directly, and converted to a digital bit stream. Note that the LPF is not the final anti-aliasing filter – a more stringent filter will also be included on the A/D board after the LPF for that purpose. The mixers and filters should meet the nominal specifications of Tables I and II, respectively

Table I: Mixer specifications

	Mixer 1	**Mixer 2**
RF range:	0.5 – 11.2 GHz	13.8 – 14.8 GHz
IF range:	13.8 – 14.8 GHz	1 – 2 GHz
Conversion loss:	5	5
Noise figure:	8	8
Flatness over 500 MHz	1 dB	--
Flatness over entire band	3 dB	1 dB
RF VSWR:	2:1	2:1
LO VSWR:	2:1	2:1
IF VSWR:	2:1	1.5:1
IP2:	+20 dBm	+ 20dBm
IP3:	+10 dBm	+10 dBm

LO at RF port:	-30 dBm	-30 dBm
RF-IF isolation:	20 dB	20 dBm
LO at IF port:	-20 dBm	-20 dBm
LO power:	-10 dBm	-10 dBm

Table II: Filter specifications.

	BPF	**LPF**
Insertion loss:	6 dB	3 dB
Pass band:	13.8 – 14.8 GHz	< 2 GHz
3dB bandwidth:	1.25 GHz	
Rejection:	40 dB at RF_{high} and $Image_{low}$	
Ripple over passband:	1 dB	
Flatness over passband:	1 dB	

Note that an apparent discrepancy exists in the width of IF_2, which has been quoted as both 500 MHz and 1 GHz, and is indeed specified here as a <2 GHz LPF. This reflects the desire to preserve flexibility in the eventual processing bandwidth. Although current plans call for 500 MHz or less, the wider bandwidth is specified here in the analog side in the eventuality that wider bandwidths will be used in future incarnations of the backend processor. In that case, the A/D units (which contain the anti-aliasing filters) can simply be replaced, with no need to replace the analog RF-IF units (at least until the desired bandwidths exceed 1 GHz).

This extra bandwidth does make the realization of the BPF more difficult, however. The desired RF and image rejection is 60 dB, however these are not symmetric around the center of the pass band ($14.3^{+2.5}_{-3.1}$ GHz). For a symmetric filter, the 60 dB BW is then only 5 GHz, with a 1 GHz 3dB BW. One could increase LO_2 by 300 MHz to make it symmetric at ±3.1 GHz, however the top of IF_2 then increases to 2.3 GHz, which is greater than current A/D boards can handle for direct downsampling. Clearly some trade-offs in filter realization and future flexibility need to be addressed.

Since there are 350×2×4×2 = 5,600 different conversions (350 antennas with dual polarizations, with 4 dual-pol channels and two conversions per channel[2]) and hence that many mixers; the use of MMIC's was felt to be warranted and therefore the Netherlands Foundation for Research in Astronomy (ASTRON) was contracted to begin the design of this mixer. In order to minimize complexity and cost, a single-balanced mixer was designed and tested. However, both the conditioning buffers and the single-balanced implementation appear to not be sufficient, so an improved buffer has been designed, as well as a double-balanced mixer. The new design is currently being sent to the foundry for iteration number 2. The new design appears much superior, but a single-balanced version with the new input buffers is also being manufactured as a back-up.

Since each mixer is a double-balanced mixer, the conditioning buffers (shown as the amplifiers before each mixer input) act as baluns. Not shown after the mixers are IF baluns to get back to an unbalanced line. These are required since the filters will be off-

[2] The actual number is still open to debate. Three dual-pol channels may instead be implemented, or 4,200 separate mixers. The rest of the document will assume that $N_T = 4$.

chip and relatively large, so it is better to have just one of each filter. The mixer chain then consists of two MMIC mixers (although the second mixer could be a different packaged mixer), an off-chip edge-coupled BPF on ceramic, an off-chip LPF and possibly two off-chip baluns on the two IF stages. Unfortunately this is not the desired degree of integration that was hoped for; however, each MMIC still does consist of two (or three) active baluns and a double-balanced mixer.

RF-IF Unit

The up/down chain will be integrated into a minimum field-replaceable unit, which takes dual analog fiber, N_T tunable LO's and one fixed LO to produce N_T dual-polarization L-band channels. In addition to the elements mentioned above, the RF-IF unit will likely contain the following:

- Mounting for the fiber-optic-to-microstrip (F/O-μ) converter
- Amplifiers spanning 500 MHz to 25.5 GHz
- 2 N_T-way RF splitters to parse the two RF input signals (dual linear polarization) and condition the signals for Mixer 1
- N_T 2-way LO_1 splitters to parse the N_T independent K-band LO signals for Mixer 1
- 1 ($2\times N_T$)-way splitter to parse the fixed K_u LO for Mixer 2.

Figure 3 shows one possible implementation of a slide-in box that would plug into a 19" rack backplane. Each fiber pair (corresponding to one antenna) gets one box for a total of 350 such units. Presumably, increasing the number of independent tunings would require a fiber splitter and another full set of RF-IF units.

The mixers would require a mounting package (likely ceramic) and would then be mounted on a, say Duroid, multilayer board. The BPF would also likely be implemented on ceramic and inserted on the board. To improve EMC, the BPF will likely need to be enclosed in a metal box which could be soldered in place over it. The LO distribution would be in stripline on the lower layers. SMA connectors on the front would import the LO's and a Dsub connector (with coax and pins) on the back would export the L-band output to the A/D units via the backplane, as well as bring in DC power and provide any (limited) control lines. The fiber input would either be connectors or piggy-tails, which would be spliced to. If leakage from the optical fiber inputs is a problem, a metallic sleeve (aluminum foil?, metalized mylar?) and ring could be installed over the fiber.

There are many issues here due to the wide bandwidths. For instance, the 4-way RF splitters have the 22:1 bandwidth, and the 2-way LO_1 splitters require an octave. Since resistive splitters will likely be required, there will be more loss than just the 6 dB and 3 dB loss due to the splitters, so gain will be required over those large bandwidths as well. Gain flatness is then an issue. LO gain may possibly be accommodated by varying the synthesizer output power, depending on the gain flatness of the LO input buffers. For best performance, the LO power should be sufficient over the entire band to operate in an LO-saturated rather than LO-starved mode.

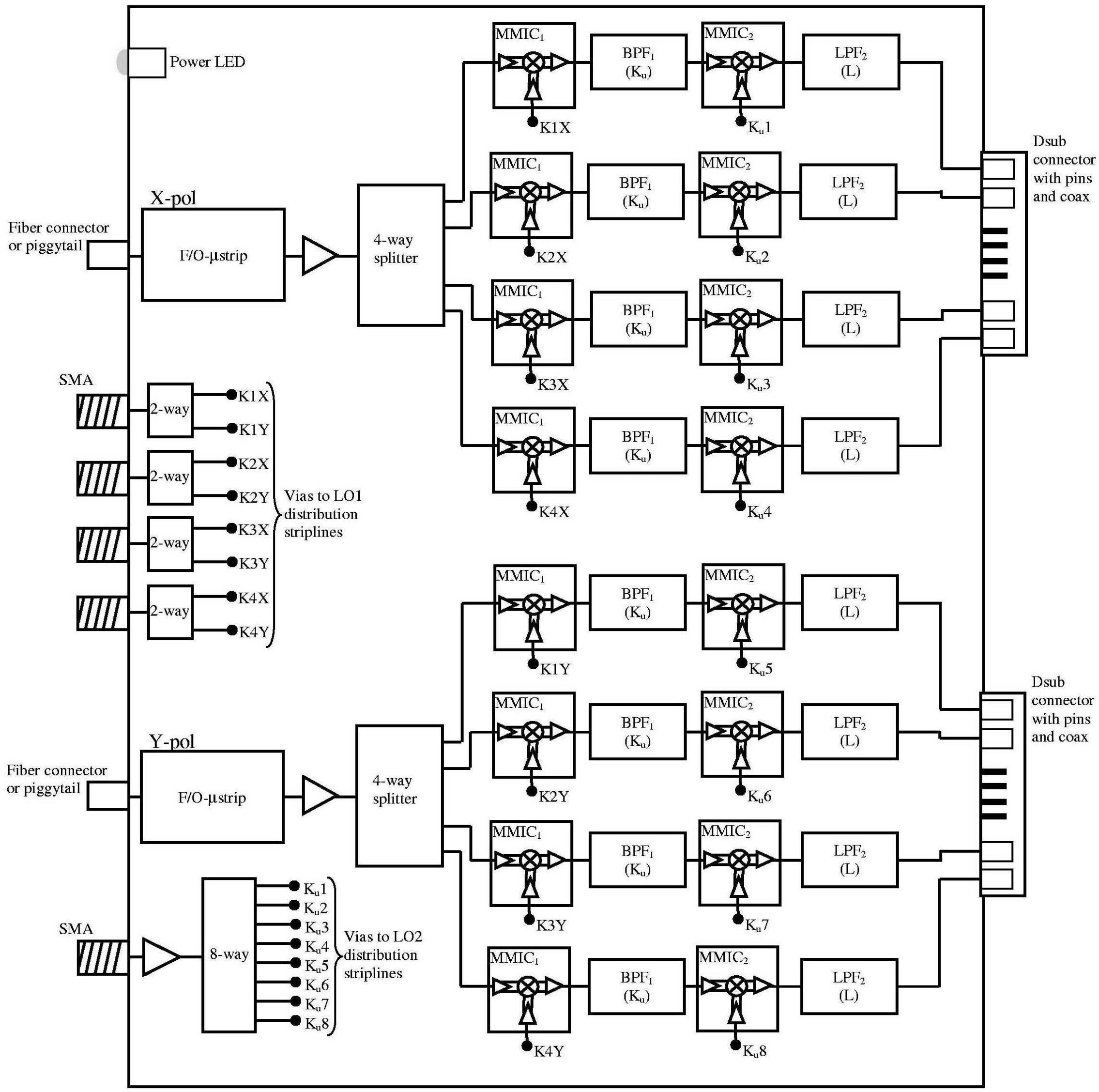

Figure 3: One proposed RF-IF unit.

The fiber-to-microstrip transition is being developed independently, but it obviously plays a pivotal role in the performance of this unit so its properties must be determined before any detailed discussion of RF levels into the mixer chain. Specifically its output level and flatness must be known to specify the proceeding amplifier (which should have a very flat response), as well as the RF input buffer. It is hoped to have no variable gain at this point to reduce complexity – any variable gain will hopefully be achieved at the front-end where it is needed anyway to handle the limited dynamic range of the optical fiber driver. There will likely be an equalizer in the front-end. In addition, the footprint and power consumption of the fiber transition must also be known.

Power consumption and dissipation is also critical in the design of this unit, since it is envisioned that it be a completely closed RF-tight module that is stacked alongside many other such units. The inclusion of fans make it a much more difficult unit to make and maintain. Hopefully sufficient grounding (*i.e.* thermal) connections with adequate rack and room temperature control will be adequate, but this is definitely not assured.

Other specifications include the LO input levels to the unit as well as the output L-band level to the A/D boards.

As outlined here, this unit has absolutely no control or monitor points (except one LED to indicate the box has power), which is desirable but risky. Some variable gain element on the RF input to mixer 1 would be nice since *e.g.* K1 could be tuned to 11 GHz while K2 is tuned to 600 MHz and it is hard to imagine sufficient RF gain flatness to accommodate this. That would require, however, eight variable gain elements per box and attempts will be made to equalize the signal over the bandwidth.

A diode detector at some point in the box to indicate RF power would also be handy, possibly right after the first RF amplifier and/or between the two mixers (if you are going to have two monitor points, you might as well have a dozen). However, this could also be done essentially in software. *I.e.*, if a digital channel indicates no RF power from an antenna (or from any combination of tunings from an antenna), someone could unplug the RF-IF unit from the rack, plug it into a test fixture which would have a detector at each L-band output to determine whether the fault was in the RF-IF unit or the digital units following it. Similarly, a test fixture could be made to determine whether a fiber has RF power on it or not to determine whether a problem was in the RF-IF unit or the preceding front-end components. One could then imagine a portable test fixture that would be brought to the offending antenna to further determine the source of the problem.

RF-IF Racks

As stated above, this is one of 350 (or so) units to be integrated into racks, with I/O, LO and power distribution. Given the number of signals and LOs, there are obviously many routings of cable to account for. To reduce the number, one possible rack arrangement is outlined below and shown in Figure 4. Analog fiber comes in from each antenna (along with the LOs) and digital ribbon fiber goes out for processing. The analog RF-IF units plug into a backplane (which is soldered completely around in the inside to be RF tight) from the front and the A/D boards plug in from the back. The back has an RF tight door, likely with RF absorber on it.

The 5 LO's per antenna get routed to one distribution box in each rack (middle unit in Figure 4); get split out four ways to each row; then finally get split out sixteen ways to each RF-IF unit. One additional rack houses the five synthesizers and splitter to route the LOs to each rack. Another rack would house any test fixtures desired. Given the 16 units per row and 4 rows per rack, this yields 6 racks for 350 antennas, plus the additional rack for the local oscillators and the additional rack for testing. This yields a total of 8 racks. These racks would likely be housed in a "bunker" paneled with anechoic absorber. The digital fiber ribbon (or copper?) would be routed to another room for processing.

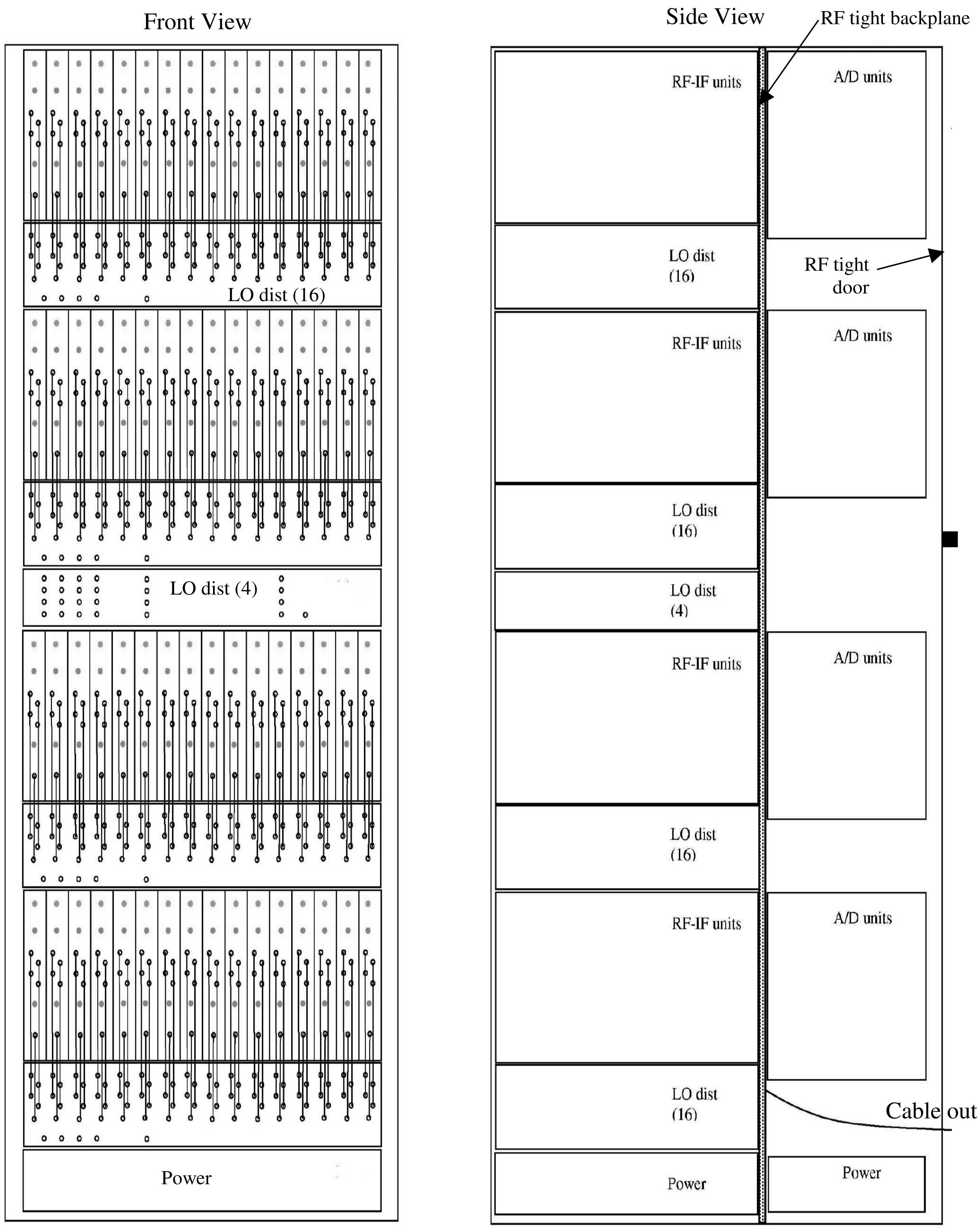

Figure 4: Schematic layout of one RFIF/AD rack Each row consists of 16 RF-IF units with a 16-way splitter in the front, and 16 A/D units in the rear. In addition, a 4-way LO splitter is included (middle unit) and power (bottom unit).