

Integrated Downconverter Modules for the GBT K-Band Focal Plane Array

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12/5/2008

I. INTRODUCTION

The Integrated Downconverter Modules (IDMs) comprise the warm-part of the GBT K-Band Focal-Plane Array (KFPA) front-end. They form the interface between the cooled electronics and the backend subsystems. As such, certain aspects of the design must be tailored to work with the existing IF Transmission System which will be used with the 7-pixel prototype array, however it was anticipated from the very beginning that the IDM design could be re-used for the fully-populated (~60-pixel) array with only minor modification, such as the substitution of one or two filters. Modularity, compactness, and rapid-development were top considerations for the design of these components.

II. IF FREQUENCY PLAN

The current IF Transmission System accepts eight input channels covering 1-8 GHz each. Within that band, 1.8 GHz chunks are selected for processing in the current GBT spectrometer. Had we decided to assign each polarization of each pixel to a separate channel, we would have been limited to only four dual-polarization pixels, or eight single-polarization pixels, which we determined would not be scientifically interesting. To get around this, we decided that half of the pixels would deliver IFs in the lower half of the 1-8 GHz band, while the other half would deliver IFs in the upper half of the band. One polarization of two separate pixels would then be multiplexed onto a common IF channel, giving us a maximum of eight dual-polarization pixels. For reasons of cost and geometric convenience, we reduced that to 7 pixels.

To implement this multiplexing scheme, we needed two different varieties of downconverter modules. The first, IDM1, selects any 1.8 GHz chunk within the 18-26.5 GHz RF band and downconverts it to an IF of 1.2-3.0 GHz. IDM2 selects the same 1.8 GHz chunk (from another pixel) and downconverts it to an IF of 5.9-7.7 GHz. The relatively wide-spacing between these IF bands simplifies the multiplexer design and improves pixel-to-pixel isolation.

III. DOWNCONVERTER OVERVIEW

Block diagrams of the two IDMs are shown in Figure 1 and Figure 2. These are both multi-chip modules utilizing almost exclusively off-the-shelf MMIC components. The only custom-designed components are the passive circuits, such as filters and microstrip transitions.

These modules are designed for dual-polarization. At the input of the signal path is a balanced low-noise amplifier, which eliminates the need for an isolator at this point in the system. Following this is the first stage of mixing using a high-side local oscillator with a desired IF output of 5.9-7.7 GHz. IDM1 goes through another round of mixing to develop outputs at 1.2-3.0 GHz, but IDM2 simply delivers this first IF after some additional gain and leveling. Making the first mixing stage in both modules identical simplifies the design and allows the first LO source to be shared.

Photographs of a completed IDM1 module are shown in Figure 3, Figure 4, and Figure 5. All high frequency components reside on the MMIC side of the block (Figure 4). The IF chain after downconversion to 1.2-3.0 GHz resides on the PCB on the other side of the block (Figure 5). The PCB for IDM2 does not have this low IF circuitry, so its PCB is about half as large. Otherwise the two blocks look the same.

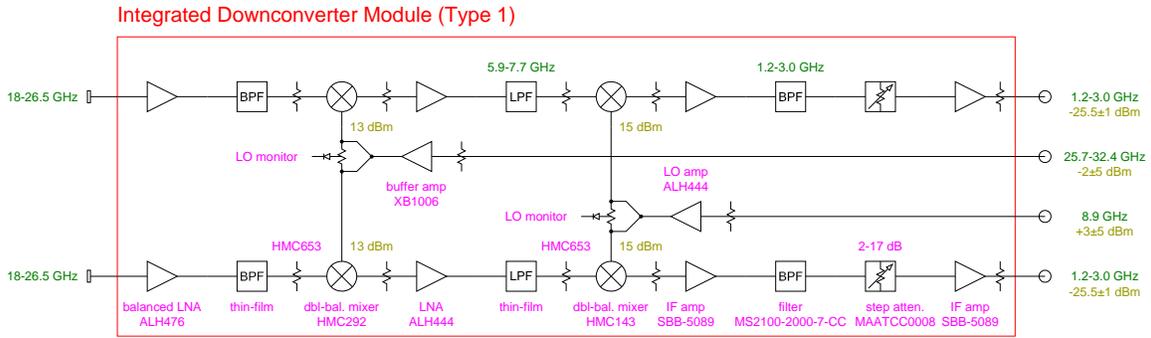


Figure 1. Block diagram of the Type 1 Integrated Downconverter Module (IDM1)

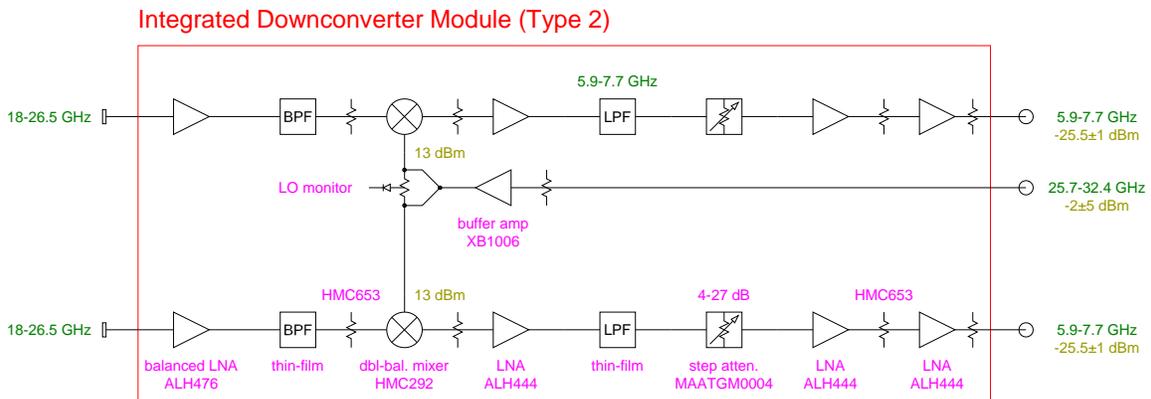


Figure 2. Block diagram of the Type 2 Integrated Downconverter Module (IDM2)



Figure 3. Photograph of a fully assembled IDM1 module.

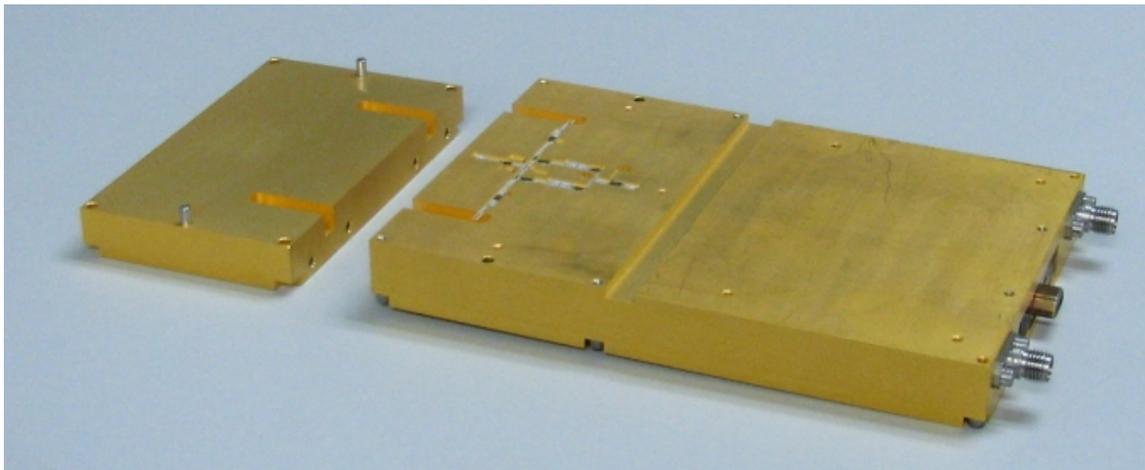


Figure 4. Photograph of the IDM1 module with MMIC cover removed.

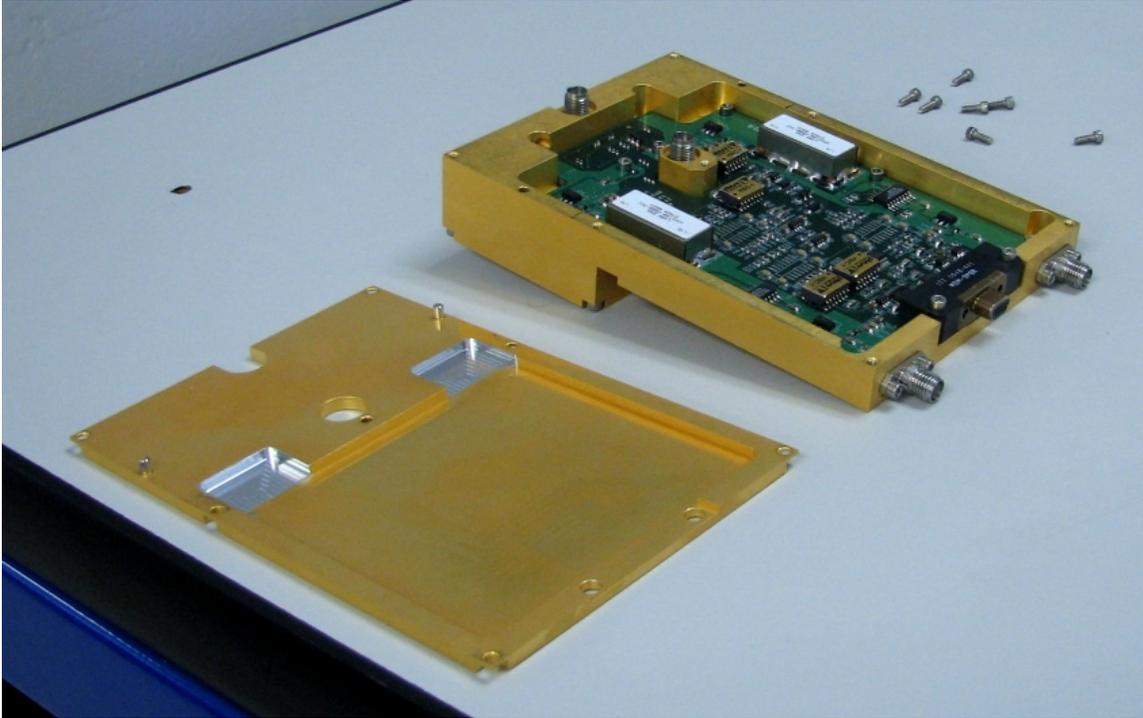


Figure 5. Photograph of the IDM1 with PCB cover removed.

IV. TEST RESULTS

Both IDMs were thoroughly tested in the lab before integration with the single-pixel prototype. The results are summarized in Table I.

parameter	specified or predicted	IDM1 meas.	IDM2 meas.	comments
noise temperature	600 – 800 K	not measured	not measured	
gain	30 dB	30 dB	30 dB	IDM1: attenuators at maximum IDM2: attenuators mid-range
RF bandwidth	18 – 26.5 GHz	18 – 26.0 GHz	18 – 26.5 GHz	test equipment limited to <26.5 GHz
IF bandwidth	1.8 GHz	1.8 GHz	1.8 GHz	
IF slope/ripple	3 dB	8 dB	2 – 3 dB	
output power	-25 ± 0.5 dBm	-25 ± 0.5 dBm	-25 ± 0.5 dBm	assuming predicted front-end gain
headroom	>30 dB	+33 dB	+35 dBm	
LO1 power required	-8 dBm	-5 dBm	-4 dBm	
LO2 power required	-2 dBm	-2 dBm	n/a	
image rejection	25 dB	32 dB	32 dB	
channel isolation	30 dB	20 dB	35 dB	
return loss	RF input: -17 dB IF output: -19 dB LO1 input: -12 dB LO2 input: -10 dB	-11 dB -11 dB -6 dB -12 dB	not measured	

Conversion Gain vs. RF

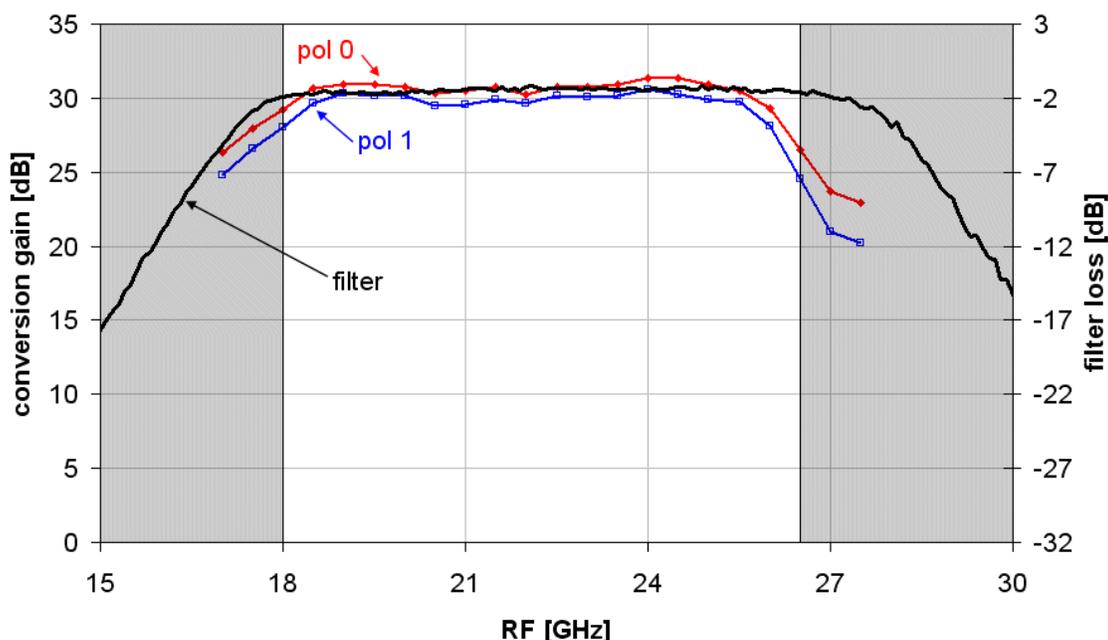


Figure 6. Plot of the IDM1 frequency response along with the measured passband of the RF filters. The early roll off in the gain at the high end is due to LO power starving. This was corrected in IDM2.

Although IDM1 fails to meet requirements in several areas, we believe the causes of these problems are well understood, and their solutions have already been determined. This is borne out by the fact that IDM2 has far fewer problems, which admittedly is simpler but which we also had more time to troubleshoot.

The first issue is that IDM1 is somewhat limited in gain, requiring the internal step attenuators be set to maximum in order to achieve the required power level. This is due to a misinterpretation of the datasheet for one MMIC amplifier with regard to its bias conditions.

Another related issue is the early gain roll off at the upper end of the RF band (see Figure 6). This is clearly not due to mistuning of the filter, because wafer probe measurements show its response to be exactly as predicted. Instead, we determined it was caused by LO power starving. The mixer is most sensitive to LO power at the band edges. The same amplifier used in the RF signal path is used in the LO1 path, and it suffered from the same biasing error.

The biasing error was corrected in time for IDM2, which uses the same amplifier in an identical RF and LO1 path, and shows neither the low gain nor the early roll off. Future versions of IDM1 will also carry this correction.

The next problem with IDM1 is crosstalk between the two channels. This crosstalk has a strong dependence on IF frequency, but not on RF frequency, suggesting the problem lies in PCB cavity where the IF circuitry resides. Both IF chains are mounted on the same PCB in the same cavity. It was believed that generous placement of substrate vias would be sufficient to isolate them, but apparently this was not the case. In the revised version of this module, the housing will be channelized to keep these two circuit paths in separate cavities. This issue is believed to be the root cause of the excessive IF ripple, the channel isolation, and the poor IF return loss. IDM2, which does not have this circuitry on the PCB, does not show any of these problems.

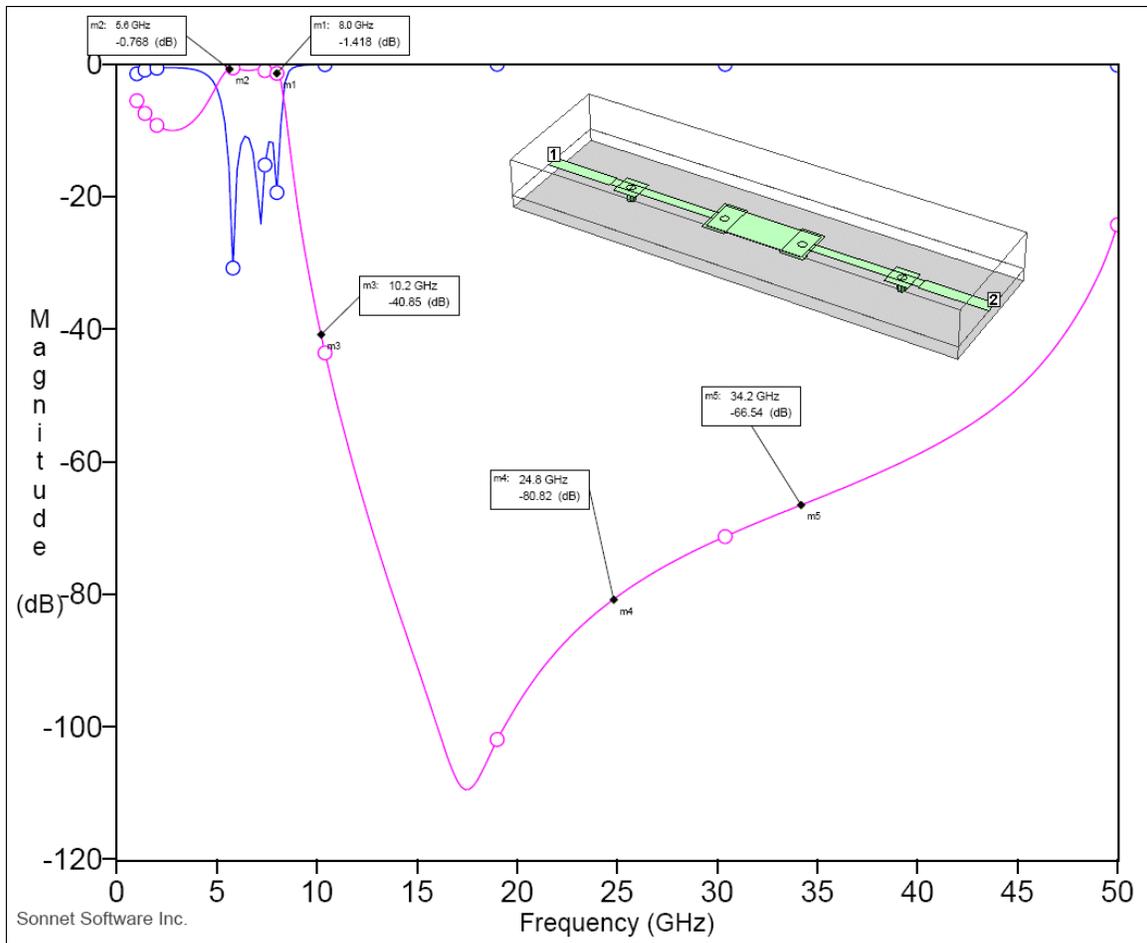


Figure 7. Simulated response of improved IF filter designed to alleviate the IDM1 spur problem.

Finally, the most serious issue with IDM1 which is not reflected in the table is the presence of LO spurs. A great deal of design effort was expended to anticipate the most likely low-order spurs and develop a frequency plan that avoids them, but the spurs we have seen are of a much larger order (10+). Spurs of that order are dense in the LO1 x LO2 frequency plane, making them impossible to "tune out" in a wideband system. Instead, greater filtering is our only recourse. Fortunately, the known large spurs all depend on a low-order harmonic of the LO1 frequency, and careful calculations have shown that the levels are consistent with the anticipated leakage of LO1 through the first mixer. The solution, then is to provide the best possible low-pass filtering after the first mixing stage, to prevent the two LO signals from interacting. A filter has been designed with this in mind and is currently in fabrication. Its layout and simulated performance are shown in Figure 7. Once again, IDM2 shows no sign of this problem (due to having only one LO), but this filter will most likely be included in the revision anyway for consistency.

In order to get very wide, very deep stop-band, the filter design shown in Figure 7 requires lumped element shunt capacitors with vias directly beneath them. This is an unusual requirement for thin-film technology, and while the vendor has claimed that they can fabricate the filter as designed, the spur issue is of such importance that a more conventional backup solution has been developed. This utilizes two low-pass filters with different cutoff frequencies in cascade. The simulated result of these cascaded low-pass filters is shown in Figure 8. Clearly the stop-band performance is not quite as good, but the manufacturability of this solution is well known.

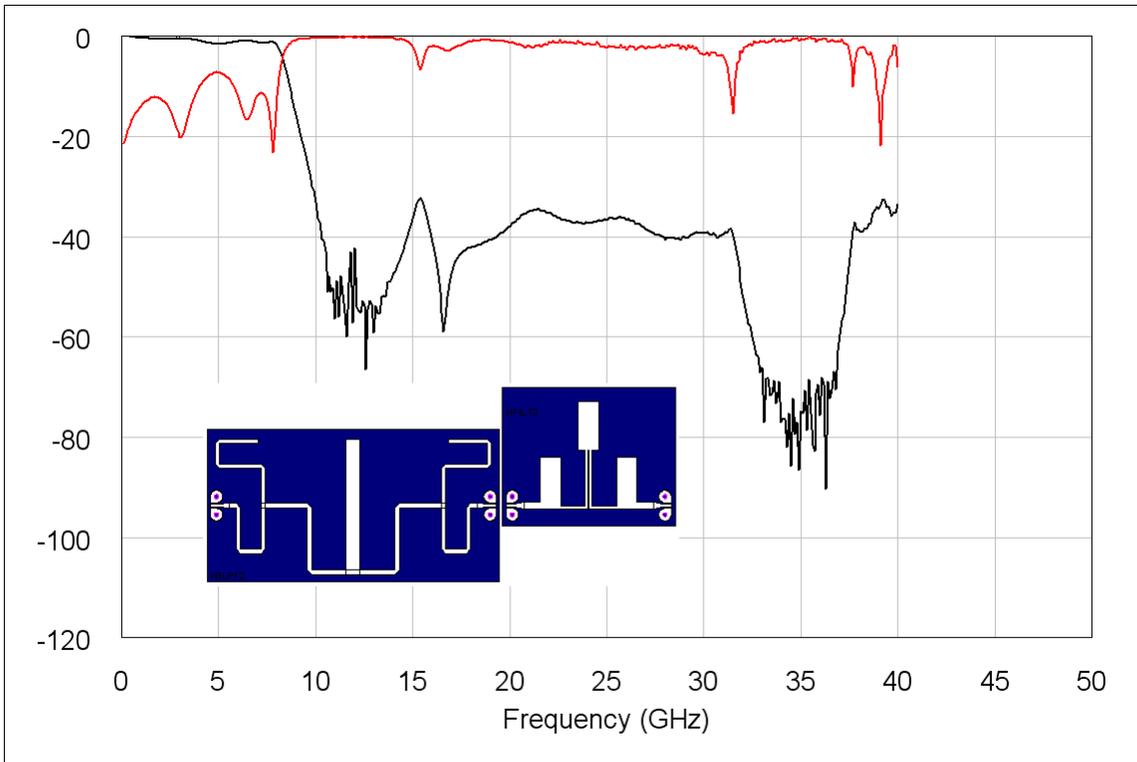


Figure 8. Simulated response of cascaded low-pass filters.