The Local Oscillator System for the Heterodyne Instrument for FIRST (HIFI)

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ABSTRACT

The Heterodyne Instrument for FIRST (HIFI) is comprised of five SIS receiver channels covering 480-1250 GHz and two HEB receiver channels covering parts of 1410-1910 GHz and 2400-2700 GHz. Two local oscillator sub-bands derived from a common synthesizer will pump each receiver band. The synthesizer, control electronics and frequency distribution will be performed in the spacecraft service module. The service module will be connected to the local oscillator unit on the outside of the cryostat with a WR-28 waveguide for each of the 14 local oscillator sub-bands. The local oscillator unit will be passively cooled and thermally isolated from the cryostat wall. The module is comprised of seven units, one for each receiver band, containing two multiplier chains consisting of a k- to w-band multiplier, a MMIC power amplifier operating in one of five bands between 71 and 113 GHz, the high frequency multipliers, launching optics and electrical distribution. The entire assembly will be cooled to 120K. The local oscillator system has the two fold technical challenge of providing broad band frequency coverage at very high frequencies. This will be achieved through the use of high power GaAs MMIC amplifiers and planar diode multiplier technology in a passively cooled 120 Kelvin environment. The design criteria and the resulting overall system design will be presented along with a programmatic view of the development program and development progress.

Keywords: Sub-millimeter, Heterodyne, Far-infrared, FIRST, Instruments

1. INTRODUCTION

The Far-Infrared and Submillimeter Telescope (FIRST) is the European Space Agency's fourth corner stone mission in the current Horizon 2000 science program. FIRST is designed to observe the cold universe of dust and molecules in the 670-80μm spectral region. The payload for FIRST will consist of three instruments designed for a mix of imaging, low-resolution spectroscopy ($\lambda/\Delta\lambda < 2000$) with limited spectroscopic imaging and high resolution ($\lambda/\Delta\lambda > 10^5$) spectroscopy through a 3.5 meter class telescope. The active sensors of all the instruments will be mounted in a cryostat filled with superfluid helium. Observations will be made from the L2 libration point of the sun-earth-moon system where passive cooling will facilitate operation of the telescope below 90 Kelvin. The cryogenic temperatures and space environment provide a nearly ideal environment for far-infrared observations by drastically reducing the stray light generated by the telescope itself and eliminating atmospheric opacity and noise contribution of ground based observations.

The HIFI instrument on FIRST will be a seven channel heterodyne receiver designed around a main band with five different superconductor-insulator-superconductor (SIS) tunnel junction receivers in a double sideband (DSB) configuration covering the frequencies between 480 and 1250 GHz. Two additional DSB receivers designed around transition edge diffusion cooled superconducting sub-micron hot electron bolometer (HEB) receivers will facilitate coverage of the spectral region between 1410 to 1910 GHz and 2400 to 2700 GHz. The instrument will use a 4-8 GHz intermediate frequency (IF) and will retrieve both polarizations of a single channel simultaneously generating 4 GHz of coverage with a one MHz maximum resolution

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acousto-optical spectrometer (AOS) and re-configurable high resolution autocorrelation spectrometer with a maximum resolution of 125 kHz. The instrument can be divided into several functional subsystems. The focal plane unit contains all the common optics and the seven receivers in the cryostat. The instrument control unit is the computer and software, which controls the instrument and collects the data from the spectrometers. The IF system contains two spectrometers of each type and the necessary 4-8 GHz signal processing components. The final subsystem is the local oscillator which provides the down conversion frequency for the mixers. The details of the local oscillator system are the subject of this paper.

2. SYSTEM REQUIREMENTS

The local oscillator subsystem of HIFI must provide a unique combination of frequency coverage at significant power levels and high frequencies. The primary scientific goal of the HIFI instrument is the complete coverage of the main band and an as complete as technically possible coverage of frequencies to 2.7 THz with more coverage than currently proposed being highly desirable by the radio astronomy community. The local oscillator system plays a key role in the observations by providing the absolute frequency reference and frequency switching for decomposition of the sidebands. A critical design requirement is to generate noise at low enough levels to remain insignificant in the overall system performance. Another major challenge for the local oscillator unit is the coupling of the local oscillator beams through the cryostat into the focal plane unit without significant losses. All these technical challenges must be achieved for a space environment in view of cost constraints at all the participating institutes.

The requirements for the HIFI local oscillator are derived from the needs of the mixers the instrument is designed around. The fundamental requirement is that the local oscillator will provide enough power to pump the mixers regardless of their performance. A worst case calculation assumed that the SIS mixers used would be the standard proven Nb/Al_2O_3/Nb devices with normal metal wires and ground planes and Nb HEB mixers for the upper two bands. This calculation gives an upper limit on the local oscillator power needed, since mixers that meet the SIS performance baseline will by necessity have less loss than those assumed in the power calculation. In the case of the Nb HEB mixers, a worst case value of 100nW absorbed in the device was assumed for the calculation. Table 1 is the frequency coverage and power required of each of the receivers bands including a 50% margin for lifetime de-rating. The local oscillator must provide coverage for each of these bands with a minimum of a two GHz of overlap in the IF coverage (upper and lower sideband overlap) when there is a change in the local oscillator or receiver band.

Table 1 receiver bands, coupling schemes and local oscillator power required.

	RX Frequency Band	Coupling Scheme	Power μW
Band 1	480-642 GHz	10% Beam splitter	38
Band 2	640-802 GHz	10% Beam splitter	135
Band 3	800-962 GHz	Diplexer	15
Band 4	960-1120 GHz	Diplexer	20
Band 5	1118-1250 GHz	Diplexer	36
Band 6	1410-1910 GHz	Diplexer	1.2
Band 7	2400-2700 GHz	Diplexer	1.2

The next major functional requirement is that the local oscillator does not add significant extra noise to the receivers. In this case, both the amplitude modulated (AM) or power fluctuations and frequency modulated (FM) or phase fluctuations noise at the IF offset from the carrier are a concern. Even though DSB receivers reject FM noise to the ratio that the upper and lower sidebands are matched, both AM and FM noise need to be considered because frequency multipliers convert AM to FM and FM to AM as a function of how they are biased and operated [1]. The system design goal is to have the noise in the IF from the local oscillator at three-tenths the quantum noise limit. Additionally to avoid electromagnetic interference with the IF system the avoidance of any fundamental oscillator generated signals in the 4 to 8 GHz IF band is required. Table 2 is a calculation of noise power allowed in the IF band compared to the power absorbed in the SIS or HEB device. The critical specification for the local oscillator is the carrier to noise ratio at the output, since all the losses affect the noise as well as the carrier. In this case the absorbed pump power is representative of a mixer, which would meet the sensitivity requirement and would be most affected by excess LO noise. A single junction is assumed for all bands except 5 where a twin junction mixer is the baseline.

Table 2 Noise, absorbed pump power and carrier to noise ratio (C to N)

		0.3*Quantum Limit		Absorbed Pump Power		C to N
	Receiver Frequency	Kelvin	dBm	nW	dBm	dBc
Band 1	480-642 GHz	9	-189	256	-36	153
Band 2	640-802 GHz	11	-188	320	-35	153
Band 3	800-962 GHz	14	-187	384	-34	153
Band 4	960-1120 GHz	16	-187	448	-33	154
Band 5	1118-1250 GHz	18	-186	1000	-30	156
Band 6	1410-1910 GHz	28	-184	30	-45	139
Band 7	2400-2700 GHz	39	-183	30	-45	138

Another noise requirement is that the local oscillator does not limit the dynamic range of the observation. The local oscillator should only contribute a small amount (10%) to the overall instrument line shape. The local oscillator noise should be low enough to facilitate the observation of a weak line on the wing of a strong one. A 20dB adjacent channel dynamic range and 40dB dynamic range for channels ten or more apart has been assumed as the 10% level for the 100kHz nominal channel bandwidth of the autocorrelation spectrometer and the 1 MHz nominal channel bandwidth of the AOS spectrometer. Once again the noise is injected at the mixer where the strong and the weak line are mixed with the carrier and the noise. The 20dB adjacent channel dynamic range in the autocorrelation spectometer's 100kHz channel bandwidth results in a phase noise at the mixer of –70dBc/Hz at 100kHz offset from the carrier. The 40dB of dynamic range requirement for ten channels between signals translates to a –90dBc/Hz at 1 MHz offsets. The wide band spectrometer has a 1 MHz channel bandwidth, which results in a –80dBc/Hz phase noise requirement for 1 MHz offsets but once ten channels are between signals this is increases to –100dBc/Hz for all offsets between 10MHz and 4 GHz. Table 3 is a list of what these specifications translate to in the 71 to 112.5 GHz power generation band for a variety multiplication options. In this calculation it is assumed that noise grows at 20log(N) +1dB per stage of multiplication, where N is the harmonic number. The extra dB is added for intrinsic multiplier noise such as the shot noise, hot electron noise, trapping and scattering noise in the diode devices employed [1].

Table 3 Phase Noise Referred to 71-112.5 GHz

Phase Noise at Mixers			Local Oscillator		Phase Noise at 71-112.5		
100 kHz	1 MHz	10 MHz	N	Stages	100 kHz	1 MHz	10 MHz
-70	-90	-100	6	2	-88	-108	-118
-70	-90	-100	8	3	-91	-111	-121
-70	-90	-100	12	3	-95	-115	-125
-70	-90	-100	16	4	-98	-118	-128
-70	-90	-100	24	4	-102	-122	-132

The other system requirements are for absolute frequency accuracy to be better than the system accuracy of 1 part in 10^7, which translates directly into a requirement that the master oscillator be accurate over the five year lifetime. For frequency switching to take place with no more than 10% dead time the frequency synthesizer below 20 GHz should be able to step 0.1 to 2 MHz in 50ms or less. The spectrometers will be blanked during the synthesizer settling time. Since FIRST will not be used as an interferometer, phase coherence is not needed during frequency switching.

Functionally the local oscillator system needs to launch the signal into the focal plane unit with less than a few percent of power loss. This needs to be achieved with a polarization 45 degrees from either mixer into the FPU in a way that minimizes standing waves. The entire local oscillator should be implemented with less than 50 Watts DC and as low a mass as possible. For reliability anything common to more than one multiplier chain will be redundant. In order to maximize the limited lifetime of the FIRST mission, heat delivered to the cryostat shell or interior should be minimized.

3. SYSTEM CONFIGURATION

The local oscillator subsystem of HIFI on FIRST will consist of a source unit and a control unit in the service module at near ambient temperature and the local oscillator unit on the out side of the cryostat exposed to cold space. The engineering task was to optimize the overall performance of the system with a minimum of cost. The initial payload study for FIRST [2] had assumed varactor tuned Gunn sources and multiplier chains including for receiver bands covering 480-1200 GHz. Further analysis of real constraints such as the available of space qualified sources suggested that the proposed 10% bandwidth high power Gunn sources were not going to be available. The design implication was a much more complicated local oscillator system with four multiplier chains per receiver band. It was also clear that the multitude of Gunns would require a complex synthesizer for phase locking and there would be little or no commonality in multiplier designs. At this point the design effort was infused with three new technologies GaAs power amplifiers [3] and balanced planar diode multipliers [4,5], which had recently demonstrated broad band tuner-free operation [6,7] and planar membrane diodes optimized for THz operation [8,9]. The overall system was redesigned to take advantage of these technologies using a modular approach.

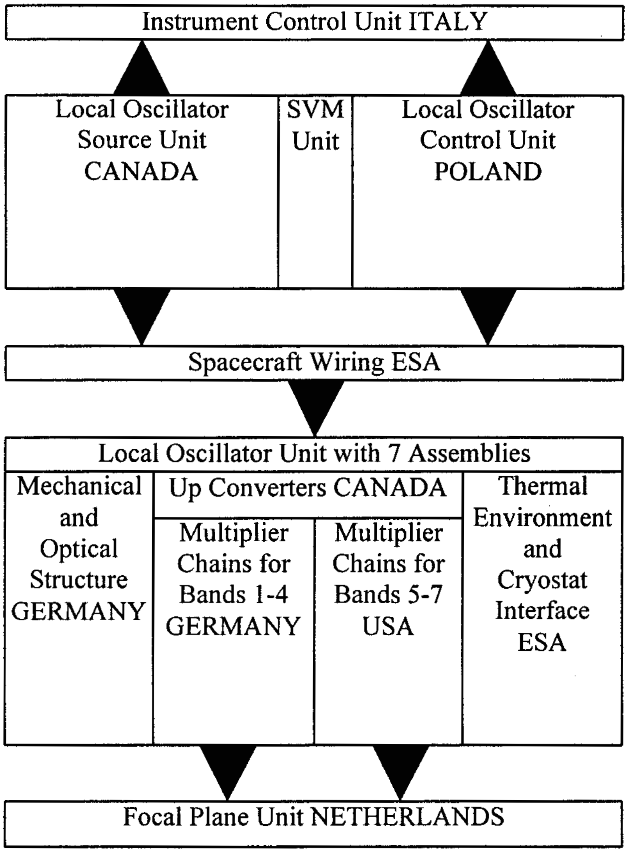

Figure 1. The basic local oscillator configuration with national responsibility is shown schematically. A line within a larger box or an arrow between boxes represents an interface between the components and or the spacecraft. Managing and optimizing these interfaces is a major political task for the subsystem.

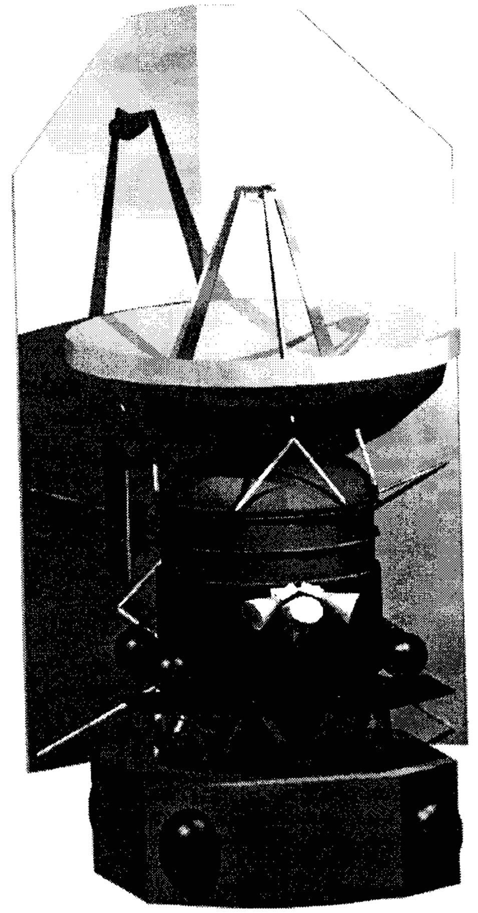

Figure 2. The configuration of the FIRST spacecraft showing the local oscillator unit (the box on the upper left side of the cryostat.) The radiator shown is for an earlier configuration of the local oscillator unit. The service module is the unit under the cryostat. The final thermal configuration of FIRST and the local oscillator radiators remains to be determined by ESA, but thermal models with a further optimized sun shield predict a cryostat shell below 45 Kelvin even with a two square meter local oscillator radiator dissipating 12 watts.

The basic system configuration is shown in Figure 1. The three major parts of the HIFI local oscillator system are the source unit, the control unit and the local oscillator unit. The first two reside in the service module and will be made by in Canada and Poland, respectively. The local oscillator unit is to be assembled in Germany with components from the United States, Canada and Germany. The wire harness (including waveguide) and the mechanical and thermal interfaces are part of the European Space Agencies FIRST spacecraft. Figure 2 is a rendering of the local oscillator unit on the FIRST spacecraft.

Figure 3 is the microwave configuration for the source unit. Figure 4 is a schematic configuration for multiplier and amplifier chains.

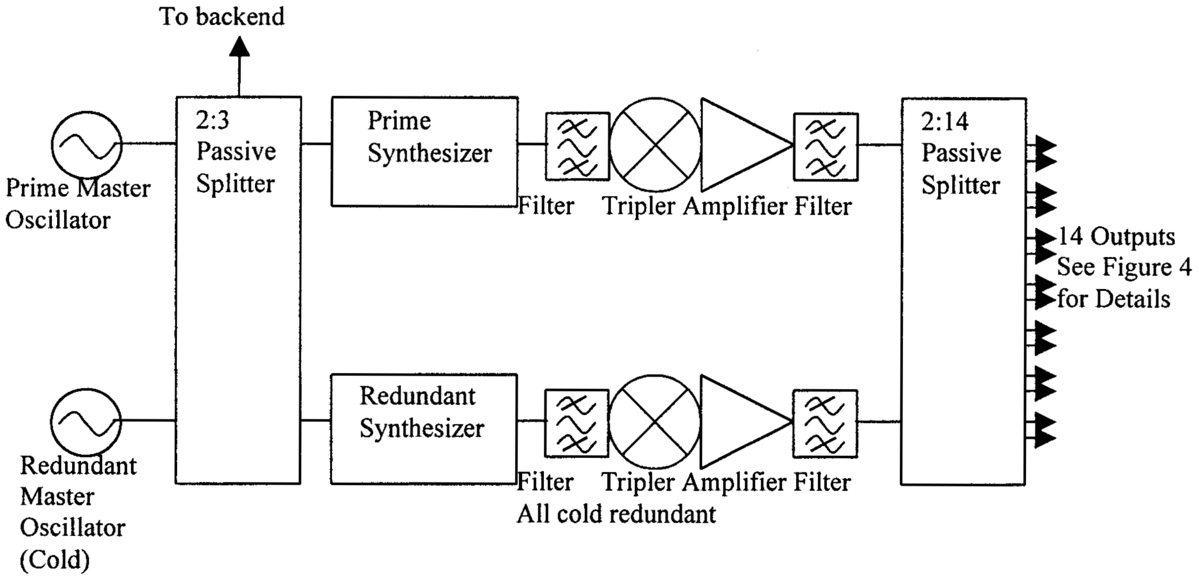

Figure 3. The source unit configuration is schematically shown. The schematic is limited to functional components and more filters and amplifiers will be required to achieve the proper signal levels and noise requirements. The detailed design of this unit is taking place at MPB in Canada. Complete redundancy of all active components is required since all local oscillator bands are affected.

The local oscillator system is designed around making the high frequency multipliers and amplifiers work as well as possible and still meeting the requirements of space operation, mass, power and noise. The remainder of this section goes through the rationale for the current design in level of difficulty starting with achieving the high frequencies, bandwidths and power levels required. The noise minimization, optics and mechanical construction are addressed in subsequent sections as is the modularity of the system.

3.1 High Frequency Amplifier and Multiplier Bands

The HIFI local oscillator system is designed to directly use a common synthesizer to drive power amplifiers in five different bands covering 71-112.5 GHz. The scheme for the local oscillator using only doublers and triplers with no more than one tripler in any multiplier chain was proposed by Erickson [10] and adapted to fit the receiver bands being developed for HIFI. The baseline configuration uses balanced doublers wherever possible, for the simple reason that the balanced configuration eliminates the need for a third harmonic idler circuit through a very simple symmetry and can achieve this in a relatively low Q circuit. Planar triplers can now be made broad banded and fixed tuned [11], however the bandwidth is roughly half what can be achieved with a balanced doubler. The principle of the frequency plan is that the first stage multiplier bandwidth be sufficient to drive all successive stages and so on for the second stages and third stages. The overall system design assumed 15% bandwidth was possible for the source and any multiplier with an isolator at the input, while ~10% was possible for stages without the benefit of isolation. Initial experiments have shown feasibility, but the details of matching the input and output impedance of successive stages will be the major challenge for the final implementation. Table 4 is a listing of the input bands and the specific multipliers under development for HIFI. The output bands are shown in bold and the two stages, which slightly violate the design principle by requiring more or different bandwidth than the output band at the same stage of multiplication are denoted by parenthesis.

The presentation of table 4 over simplifies the problem of actually achieving the necessary bandwidth because it neglects the very important aspect of impedance matching between the different stages of multiplication. It also simply ignores the problem of conversion efficiency. It should be noted that the state-of-the-art conversion efficiency at 1 THz is less than 1% [12]. The impedance can usually be matched rather well [13] especially if compromises in the conversion efficiency are made. The result is that the bandwidth can be achieved, but only at the expense of output power. The system task is to provide an environment where the overall performance is optimized. Four things can be done to achieve the bandwidth need 1) high power broad band sources, 2) broad band multiplier circuits, 3) implementation of the chain to minimize matching problems 4) cold operation to improve early stage efficiency and output power. The first two have been largely achieved and the fourth is implicit in the passively cooled 120 Kelvin configuration presented here.

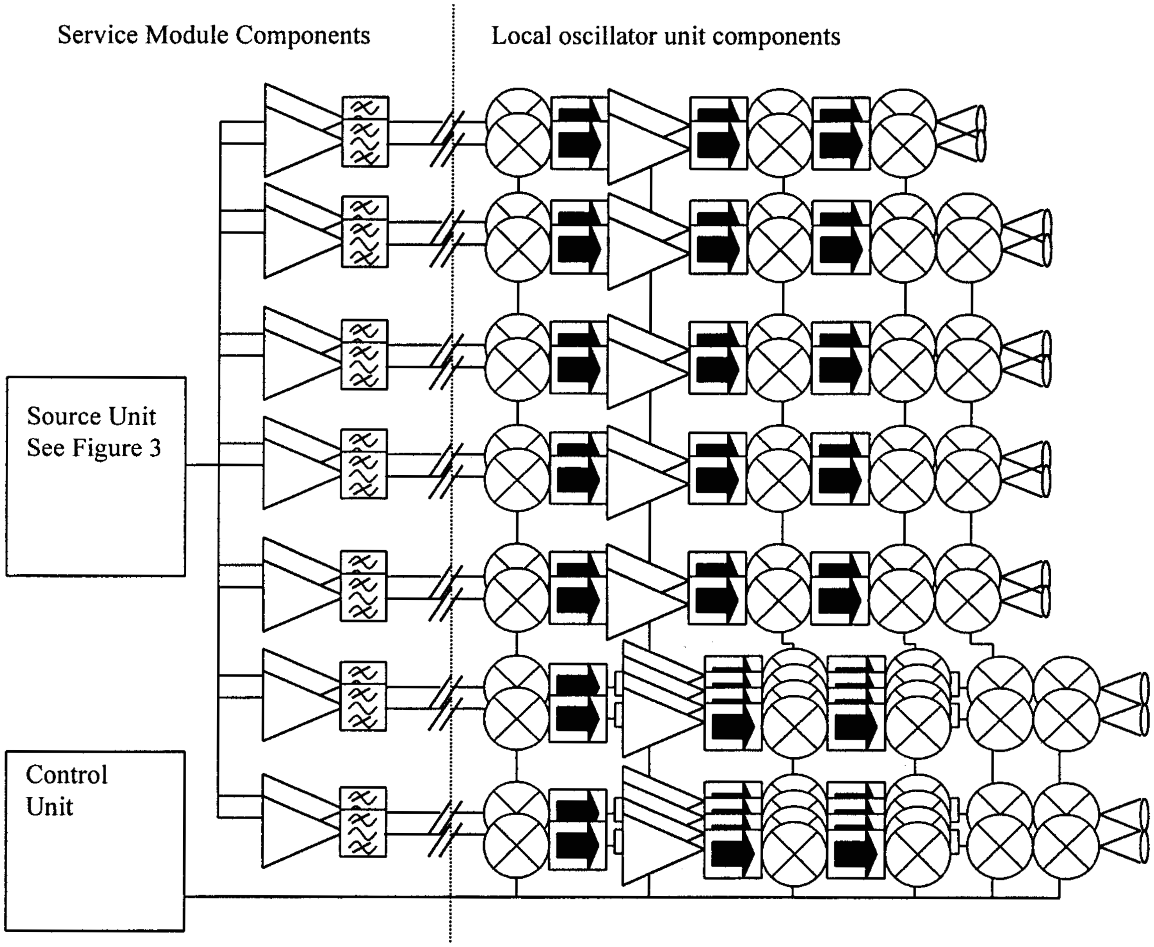

Figure 4. Schematic configuration of the multipliers, isolators, amplifiers, power combining and feedhorns in the HIFI local after the signal is split into the 14 sub-bands. The RF input to each of these units is in the 26-40 GHz frequency range. The feedhorns are dual mode horns and each amplifier in the local oscillator unit is a module containing three or more MMIC amplifiers. The left side of the schematic (before dotted line) resides in the service module while the remainder is in the local oscillator unit. The multiplier chains are ordered from top to bottom starting with band 1 at the top. The frequencies for the amplifiers and multipliers and type of each multiplier are given on Table 4. The top four bands multipliers (for receiver bands 1-4) are being designed and built by Radiometer Physics GmbH while the lower three band multipliers, are being built by the Jet Propulsion Laboratory. The control unit is being designed and built by Space Research Center in Poland. System integration is under the direction of Max-Planck-Institute for Radioastronomy-Bonn.

Table 4 Amplifier and Multiplier Bands for the HIFI Local oscillator

Source Frequency	35.5-39.8	26.6-30.7	29.3-33.2	30.7-35.4	35.3-37.4
x2	71-79.5	N/A	N/A	N/A	N/A
x3	N/A	80-92	88-99.5	92-106	106-112.5
Power Amp	71-79.5	80-92	88-99.5	92-106	106-112.5
x2	142-159	160-184	176-199	184-212	212-225
x2x2	284-318	323-355	352-398	378-424	424-450
x2x3	N/A	**488-546(1a)**	N/A	**560-633(1b)**	N/A
x2x2x2	N/A	**647-710(2a)**	(709-796) **724-793(2b)**	**807-848(3a)**	N/A
x2x2x3	**852-953(3b)**	**967-1042(4a)**	**1056-1113(4b)**	(1127-1265) **1127-1242(5a)**	1272-1350
x2x2x2x2	N/A	N/A	**1418-1592(6b)**	N/A	N/A
x2x2x3x2	**1704-1906(6a)**	N/A	N/A	**2400-2530(7a)**	**2544-2700(7b)**

The power amplifier modules designed for HIFI will have greater than +23dBm output after an isolator. This has been demonstrated at room temperature over an 89-105 GHz bandwidth. Operation of this amplifier at 120 Kelvin results in additional power margin for de-rating of performance. The details of these amplifiers are presented in a paper by Samoska *et al.* [14]. Cold operation of planar multipliers results in a 15-50% increase in output power depending on the input power level and diode doping with the lower doped higher input power multipliers improving the most [11]. Additional information on cooling of varactor multipliers is given by N. Erickson [10] and Louhi et al. [15]. The use of isolators between the first and second stages of multiplication at 140-225 GHz is planned. The isolators effectively make the source of the system in the 142-225 GHz range and result in no more than two stages of multipliers to be cascaded without isolation in the main HIFI band. Cryogenic isolators for 140-170 GHz with 0.8dB insertion loss have been demonstrated [11]. Above 1 THz the multiplication is largely resistive and the reactive mismatch between stages should cause less of a bandwidth problem. The problem is purely one of conversion efficiency and sufficient pump power. As a result the multipliers for bands 6 and 7 will have parallel input stages and will be power combined after the second doubler. Details of the multiplier circuit development and diode device technology is presented in a paper by Bruston *et al.* [16].

3.2 Noise Control

A major consideration in the system design is how to meet the required noise levels. The most important part of the noise spectrum to control is the noise at the IF offset from the local oscillator pump frequency. The technical problem with measuring this noise at any step in the local oscillator is that the SIS mixers on HIFI will be the best AM noise detectors in existence and the generated noise grows as 20Log(N) after being multiplied N times. As a result, noise control is required in all parts of the local oscillator. Clearly the control of noise must start in the source unit with the minimization of spurs. Since all synthesizers require some sort of down conversion and locking of the fundamental output, the design challenge is to avoid generation of signals in the 4-8 GHz offset band. Since multipliers will be used in the rest of the local oscillator system, it is essential that the fundamental oscillators be at a frequency above the IF upper limit of 8 GHz. Additionally, down conversion and locking will be facilitated by mixing with fixed frequency oscillators also above 8 GHz care has been taken in selecting frequencies with no fundamental mixing products and a minimum number of low order mixing products in the 4-8 GHz offset. All mixers in the synthesizer will be carefully isolated from the output path and filters, fixed and or tracking will be used to further eliminate spurs from the synthesizer. The fundamental synthesizer units will be packaged hermetically and power supply lines will be filtered. An engineering version of the fundamental synthesizer is under construction at MPB in Canada under contract with the Canadian Space Agency. Additional filtering will be employed during the up-conversion process to 71-112.5 GHz. The filtering is necessary since the use of broad band synthesized source along with broad band amplifiers and fixed tuned multipliers ensures that spurious noise will not propagate and grow in the multiplication process.

The carrier to noise requirement given in Table 2 converted back to the w-band amplifier is –181dBc. The thermal noise at the 120 Kelvin amplifier is –178dBm/Hz and the input power is +3dBm. The maximum possible carrier to noise ratio is 181dBc, which means that the input noise to the power amplifier needs to be at or very close to the thermal limit. The carrier to noise ratio can be improved by increasing the signal level delivered to the power amplifiers. The system design allows 7dB of loss in the waveguide distribution and a 13dB conversion loss in the multiplication to 71-112.5 GHz. If these losses are reduced, the carrier to noise ratio can be improved. Additionally, the power amplifiers will be operated in a saturated mode, which will result is some suppression noise away from the carrier. Unfortunately a good SIS mixer is the best noise detector available, so the critical test of amplifier noise requires use with a receiver. A test using a 22 Kelvin receiver at the Caltech Submillimeter Observatory observed slightly better system temperatures with the power amplifiers and concluded that no detectable noise was added [17]. Any system level adjustments to power levels will be made after the development model is tested in 2001. It should be noted that some extra margin is built into the system due to the IF band offset rejection of the diplexer used for the local oscillator injection in the higher bands and the fact that the added noise specification is 0.3 times the quantum limit.

Noise can also find its way into the local oscillator through bias lines and ground loops in and between the local oscillator unit on the outside of the cryostat and the service module. There will be approximately two meters of distance between the service module and the local oscillator unit connected with waveguide. The concern is that microwave waveguide components such as amplifiers and multipliers are grounded to the waveguide case. In the case of HIFI these components are distributed in the service module and the local oscillator unit in two very different locations allowing for a multitude of ground loop problems. As a result the source unit and the control unit are separate units grounded at the microwave components they control in the service module and the local oscillator unit, respectively. Electrical isolation between the two units will be achieved by an electrical ground break in the waveguide between the two units. The bias lines will be subject to two stages of filtering, one for low frequencies and one for higher frequencies, at the output of the control unit and in the local oscillator unit. Should pickup of GHz signals prove to be a problem in the development model local oscillator unit, additional filters targeting GHz frequencies will be installed in the flight multiplier housings. The last consideration is that the bias lines for the multipliers and power amplifiers will each be kept in a separate shielded cable. Distribution of these signals in the local oscillator unit will be achieved in separate hermetic assemblies. The cables used will be 100 percent shielded whenever possible.

The last part of the noise problem and one that can be measured directly at low frequency is the phase noise close to the carrier. Since the noise outside a phase lock loop bandwidth is entirely due to the oscillator used, the synthesizer will rely on a YIG tuned oscillators with low noise varactor based circuits. These oscillators have a specified phase noise of –115 dBc/Hz at 100kHz offsets at frequencies up to 14 GHz [18]. The fixed tuned down conversion mixers will be single frequency low phase noise version. The lock loop bandwidths will all be carefully chosen for optimal loop bandwidth and the loops will be designed with near critical damping to limit added noise at the loop bandwidth [19].

3.3 Optics

The primary task of the local oscillator optics is highly efficient coupling of the generated power to the mixers located inside the focal plane unit. There is close to a meter of optical path length between the focal plane unit and the local oscillator unit with a 34mm window with a 30mm guaranteed clear aperture at the cryostat shell. The other constraint on the system is the 50mm spacing between each local oscillator window. If the modular design philosophy is to be maintained, the largest optic available for manipulation of the local oscillator beam is 40mm in diameter. Due to thermal and gravitational movements between the focal plane unit and the local oscillator unit after launch, a misalignment tolerant optical interface between both units is required. With an 8mm beam waist for this interface, there is a margin of 0.8mm for a linear displacement, but a tilt of more than 2arcmin between local oscillator and focal plane introduces a significant optical loss. These tight constraints indicate that achievement of the alignment of the fourteen local oscillator beams will be a technical challenge. The alignment will be facilitated using kinematic mounts for each local oscillator chain of a receiver band assembly, a flat adjustable output mirror and a kinematic mount of each band assembly. The interface with the spacecraft is still being optimized; however, the angular constraints require that the local oscillator unit mounting standoffs be made of the same material, have the same angle between all support struts and be as symmetric as possible about the fourth of the seven windows. Several alignment aids such as extra optical windows in the cryostat are still under consideration.

Several focusing mirrors perform the optical beam transformation between the multiplier feedhorn output and the FPU optical input. It is highly desirable for the optics to be frequency independent after the interface with the multiplier feedhorn, so optical alignment tools can be used. Unfortunately, the number of focusing elements drives the required volume for and mass of the local oscillator assembly, the complexity of the alignment procedure and ultimately the cost of the unit. As a result there is an ongoing engineering discussion of system compromises, which would allow the design to be less complex and semi-independent of the frequency. The other important task of the optics is to deliver the correct polarization (45 degree with respect to either mixer) to the focal plane unit so that both E and H plane mixers are pumped equally by the single multiplier chain of a given local oscillator source band. For simplicity of qualification and design, all the multipliers will have their waveguide E-fields oriented perpendicular to the mounting surface. Since it is necessary to combine two multiplier chains in a single unit and co-align them with minimal loss, the plane of polarization for one of the outputs must be rotated before a polarizer can combine both beams along the same optical axis. The use of a polarizer combined with a retro-reflector (roof-top with the vertex at 45 degrees relative to the polarization) mirror as shown in figure 5 is the current baseline. A λ/4 plate (a grid at 45 degrees relative to either polarization located 1/8 wavelength in front of a mirror) will generate the desired circular polarization, which has the added benefit of some standing wave rejection. Figure 5 is one example of partially frequency independent design, which meets the other optical requirements and could be optically aligned. Regardless of the final optical configuration, the local oscillator optics will be required to launch seven precisely aligned beams with large beam waists, large f-numbers and the correct polarizations.

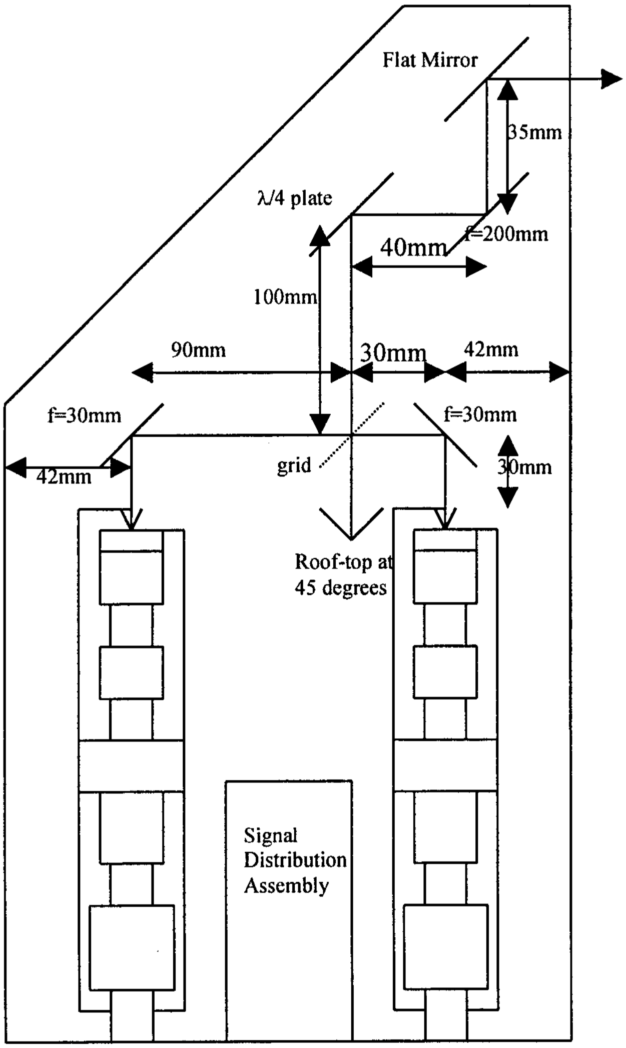

Figure 5. The optical configuration for one of the seven local oscillator assemblies is shown. The system performs generation of a large f number beam with circular polarization. The achieved compactness is implement at the expense of a frequency dependent waist at the interface to the focal plane unit. There are a number of technical issues remaining to be addressed before this design can be finalized including the distance to the focal plane unit. The maximum diameter of any optical element is 40mm due to the 50mm beam centers of each assembly. The final design will be the result of a combined thermal, mechanical and optical analysis involving ESA the focal plane unit and the local oscillator.

3.4 Modularity

The cost of space qualification of parts and mechanical structures in space systems is always expensive and time consuming. As a result the local oscillator system has been designed to use common parts and assemblies wherever possible in the design. In the high frequency part of the local oscillator there will be 24 different multiplier designs for a system with 44 (not counting parallel multipliers) multipliers. There will be five amplifier designs and six isolator designs each requiring only one qualification. The mechanical assembly for each local oscillator band will be identical, as will the as many parts as possible in each. The source unit will have only five sets of circuitry for the 14 outputs. The local oscillator control unit will benefit the most from modularity since the bias circuitry for each stage of multiplication will be the same as will circuitry for all other tasks common to each local oscillator assembly. This design philosophy minimizes the number of part types and circuit qualification tests necessary.

4. DEVELOPMENT STATUS

The development of the local oscillator has gotten off to a relatively slow start due a variety of funding problems in participating countries. The effort has been funded in the United States since 1998, but funding in Germany and Poland has only been available since the beginning of 2000. The Canadian contribution is still pending, but funding for preliminary engineering work has been available since February 2000. The technology development efforts in the United States has demonstrated the necessary bandwidth and power with power amplifiers, demonstrated the first broad-banded fixed tuned planar triplers, achieved first stage doubling efficiencies in excess of 40%, and achieved second stage doubling efficiencies near 30%.

The Max-Planck-Institute for Radio Astronomy, Bonn will take the lead in the thermal-mechanical and optical design of the local oscillator unit. The strong system engineering teams at SRON and ESA along with a spacecraft contractor will facilitate the final optimization of the spacecraft interfaces. The analog and digital circuit design for the source and control unit is now underway at MPB in Canada and Space Research Center in Poland. The feasibility of using planar diodes as multipliers at THz frequencies will be assessed during the summer of 2000 as will a number of decisions on the implementation details of the high frequency multipliers. The major milestone in the program is the development model, which will be assembled and tested in 2001. The development model will be a critical test of the system concept for noise control and will be the first opportunity to verify or fix the stability, alignment and control questions. Qualification of the subsystem components will be completed early in 2003. Final delivery of the instrument is scheduled for 2004. FIRST will be launched in 2007.

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