Mixer Development at ASIAA for HARP Upgrade

- New Spare Mixer Chips for Heterodyne Array Receiver Program (HARP)

Ming-Jye Wang, Tse-Jun Chen, Yen-Pin Chang, Wei-Chun Lu, Chuang-Ping Chiu, Ming-Tang Chen, Johnson Han, Shang-Fang Yen, and Kuan-Yu Liu* (ASIAA)
Jessica Dempsey, Per Friberg, Dan Bintley, Izumi Mizuno, Shaoliang Li, Kuan-Yu Liu* (EAO)
Edward Tong (SAO)
Su-Wei Chang (TMYTEK)

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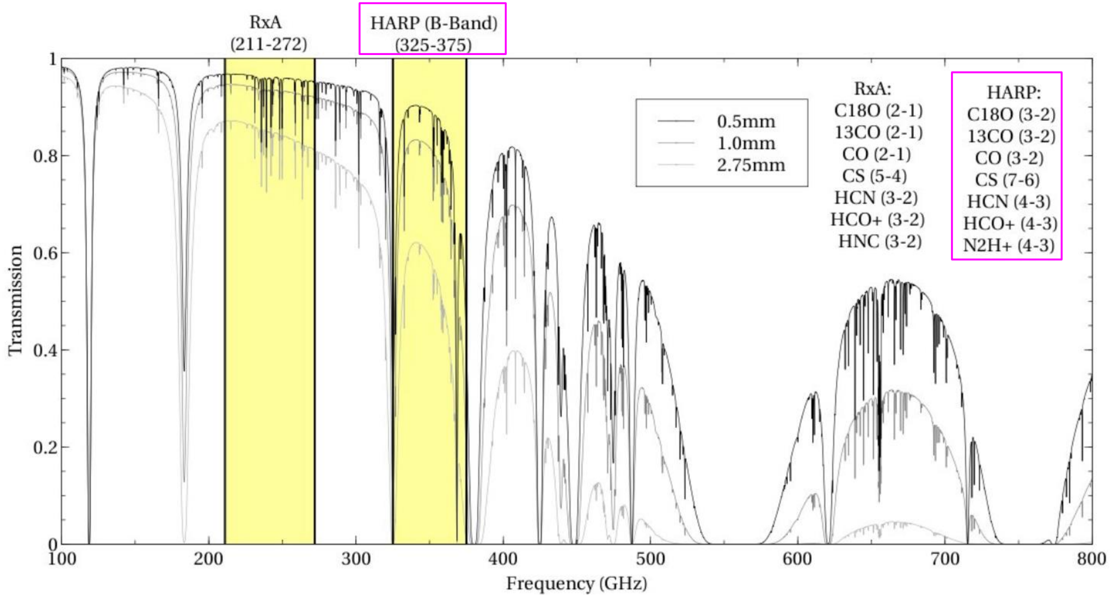
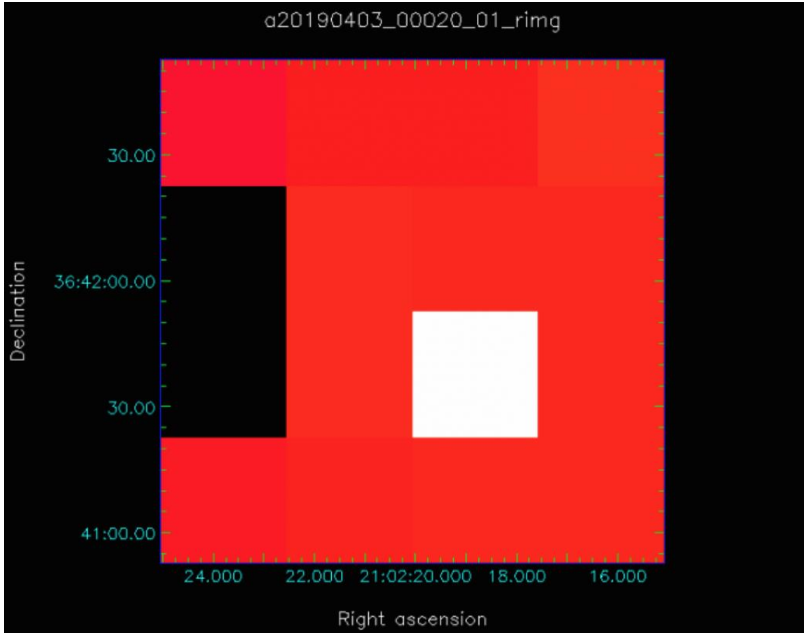
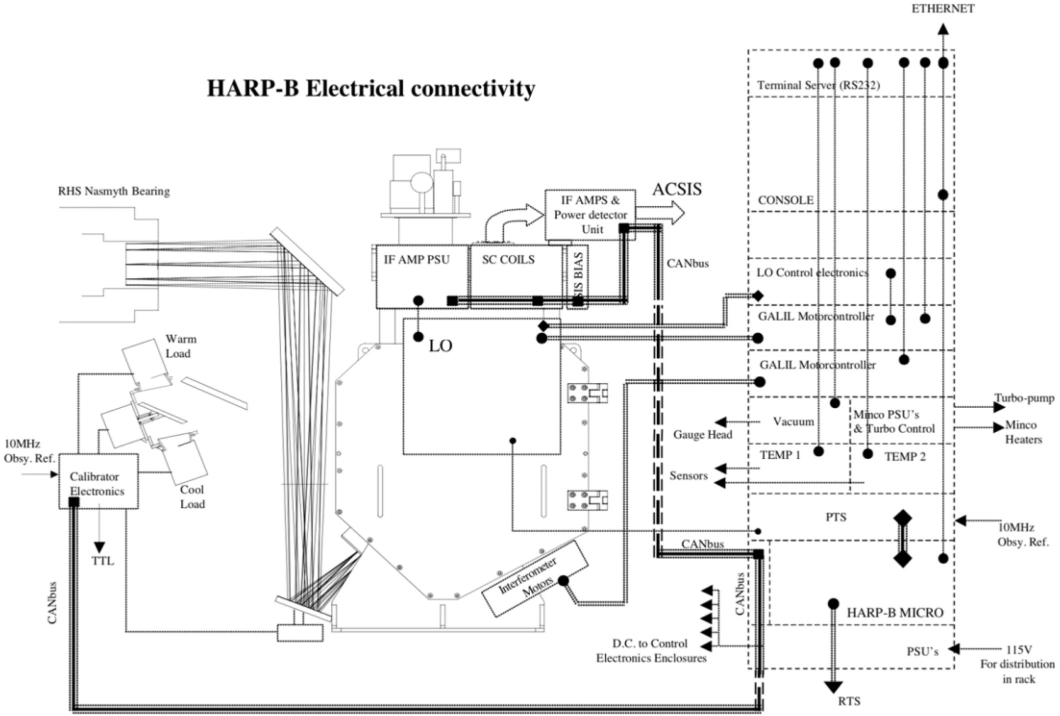
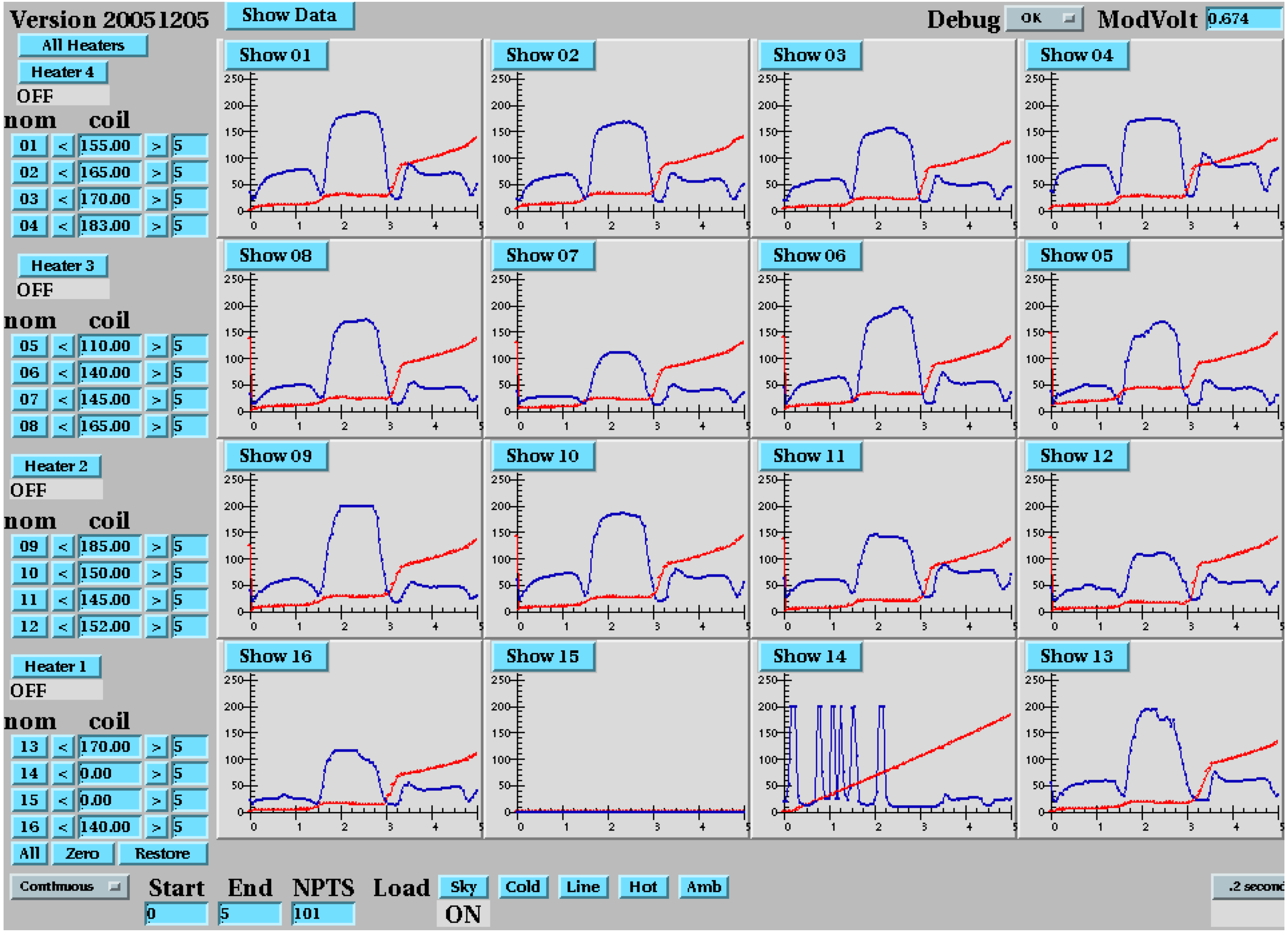
The JCMT currently has one heterodyne receivers in operation: **HARP**: 345 GHz, 16-pixel array receiver. The backend for the HARP receiver is the **ACSIS** correlating spectrometer. **Receiver A3** (also known as RxA): 230 GHz, single-pixel DSB receiver has been retired (as of June 27th 2018).



- 325 – 375 GHz 16 detector SSB SIS array receiver
- Currently HARP cannot be tuned to frequencies 325-329 GHz LSB and 335 – 339 GHz USB.
- 14 of the 16 receptors (detectors) are operational: H13 and H14 are not operational.
- Receptor H04/R05 is unusable at frequencies below 332.5 GHz






Version 20051205
Show Data
Debug
OK
ModVolt
0.674
All Heaters
Heater 4
OFF
nom coil
01 < 155.00 > 5
02 < 165.00 > 5
03 < 170.00 > 5
04 < 183.00 > 5
Heater 3
OFF
nom coil
05 < 110.00 > 5
06 < 140.00 > 5
07 < 145.00 > 5
08 < 165.00 > 5
Heater 2
OFF
nom coil
09 < 185.00 > 5
10 < 150.00 > 5
11 < 145.00 > 5
12 < 152.00 > 5
Heater 1
OFF
nom coil
13 < 170.00 > 5
14 < 0.00 > 5
15 < 0.00 > 5
16 < 140.00 > 5
All
Zero
Restore
Show 01
Show 02
Show 03
Show 04
Show 08
Show 07
Show 06
Show 05
Show 09
Show 10
Show 11
Show 12
Show 16
Show 15
Show 14
Show 13
Continuous
Start
End
NPTS
Load
0
5
101
Sky
Cold
Line
Hot
Amb
ON
.2 second

Show Array Data

Version 20051205

.2 second

38

Coil / SIS Bias / I/V Curves

Coil nom	Coil ctrl	Coil mon	Coil alarm	SIS nom	SIS ctrl	SIS mon	curr	IF Pwr
01	155.00	155.12	OK	01	2.00	1.99	29.55	179.28
02	165.00	164.93	OK	02	2.00	2.01	32.11	163.25
03	170.00	169.57	OK	03	2.00	1.98	22.95	150.73
04	183.00	183.21	OK	04	2.00	2.00	27.35	173.41
05	110.00	110.03	OK	05	1.90	1.91	43.10	144.28
06	140.00	140.06	OK	06	2.00	1.98	32.72	179.47
07	145.00	144.86	OK	07	1.85	1.85	23.20	103.42
08	165.00	165.00	OK	08	2.00	1.98	24.66	166.76
09	185.00	185.30	OK	09	2.00	2.01	28.45	200.00
10	150.00	149.95	OK	10	2.00	1.98	26.98	182.99
11	145.00	145.16	OK	11	2.00	2.00	20.63	146.04
12	152.00	151.90	OK	12	2.00	1.98	16.85	107.92
13	170.00	169.87	OK	13	2.00	2.01	18.56	186.51
14	0.00	0.30	OK	14	0.00	0.00	0.00	15.64
15	0.00	0.30	OK	15	0.00	0.00	0.00	0.59
16	140.00	140.66	OK	16	1.80	1.77	15.87	114.57
All	Zero	Restore	Reset	All		Mean	25.929	

Receptor 01 … Receptor 16

All Receptors

Sky · Cold · Line · Hot · Amb **Load**

ON

SimMode: Hardware

Monitor: On

Man/Auto
- Array: Auto
- Coil: enabled
- SIS: Auto
- IF: Auto

Coil
- async: Normal
- sleep: Normal
- debug: Normal

SIS
- sleep: Normal
- debug: Normal

IF
- sleep: Normal
- debug: Normal

HARP: a submillimetre heterodyne array receiver operating on the James Clerk Maxwell Telescope

Authors: H. Smith[1], J. Buckle[1], R. Hills[1], G. Bell[1], J. Richer[1], E. Curtis[1], S. Withington[1], J. Leech[1&4], R. Williamson[1], W. Dent[2], P. Hastings[2], R. Redman[3], B. Wooff[3], K. Yeung[3], P. Friberg[4], C. Walther[4], R. Kackley[4], T. Jenness[4], R. Tilanus[4], J. Dempsey[4], M. Kroug[5], T. Zijlstra[5], T. M. Klapwijk[5]

[1]Cavendish Astrophysics Group, Cavendish Laboratory, University of Cambridge, J J Thomson Ave., Cambridge CB3 0HE, UK
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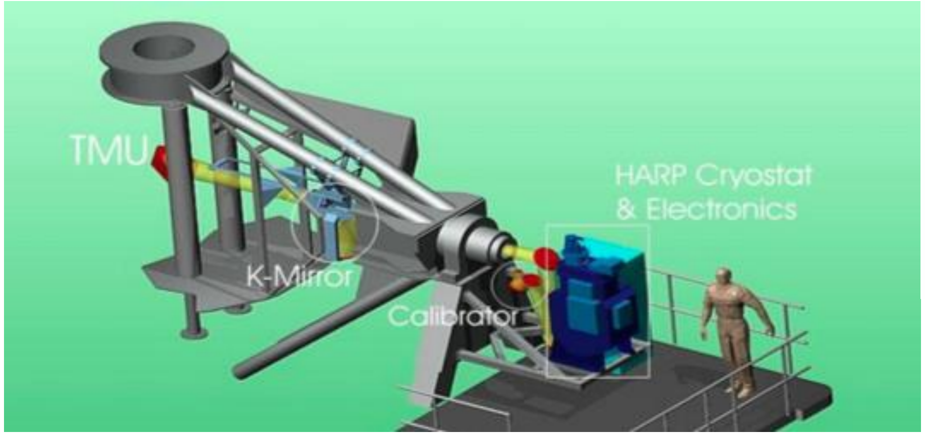
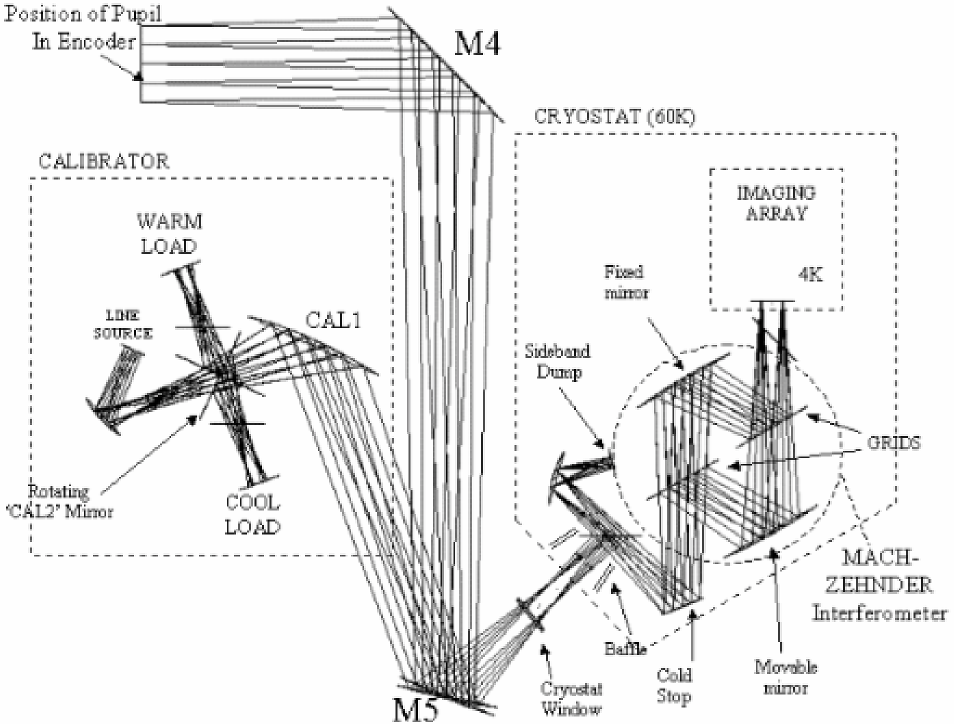
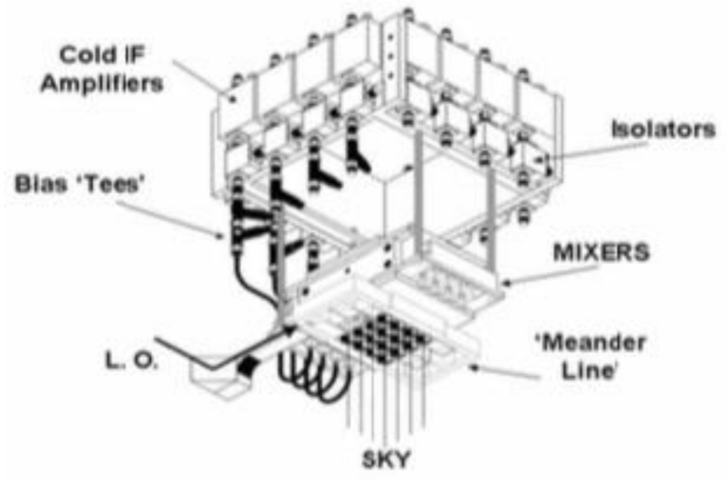
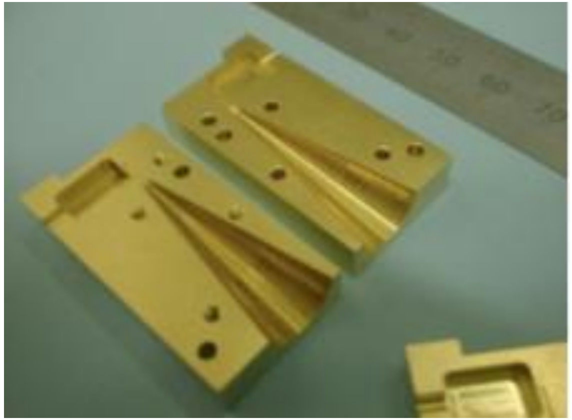
[5]Kavli Institute of Nanoscience, Faculty of Applied Sciences, Delft University of Technology, Lorentzweg 1, 2628 CJ Delft, The Netherlands

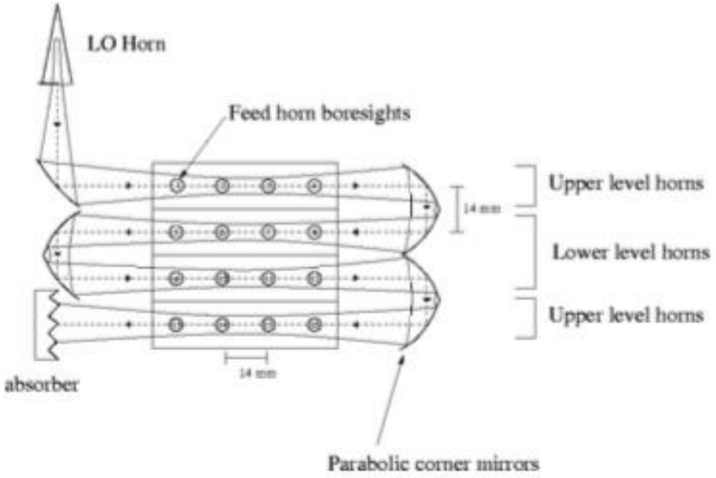
Millimeter and Submillimeter Detectors and Instrumentation for Astronomy IV
edited by William D. Duncan, Wayne S. Holland, Stafford Withington, Jonas Zmuidzinas
Proc. of SPIE Vol. 7020, 70200Z, (2008) · 0277-786X/08/$18 · doi: 10.1117/12.790707






Cold IF
Amplifiers
Isolators
Bias 'Tees'
MIXERS
'Meander
Line'
L. O.
SKY

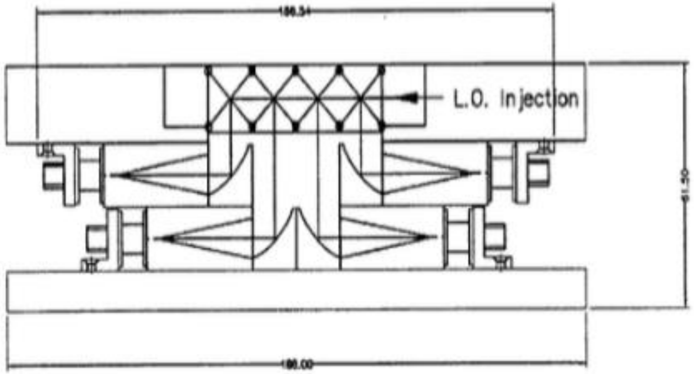



LO Horn
Feed horn boresights
Upper level horns
14 mm
Lower level horns
Upper level horns
absorber
14 mm
Parabolic corner mirrors

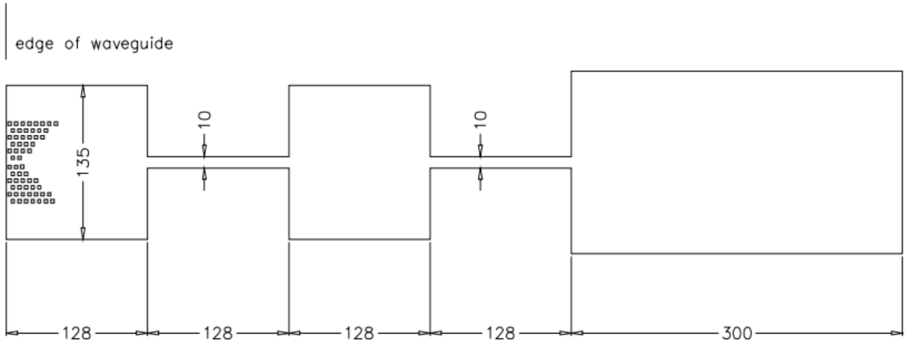
A 350 GHz SIS Imaging Module for the JCMT Heterodyne Array Receiver Programme (HARP)

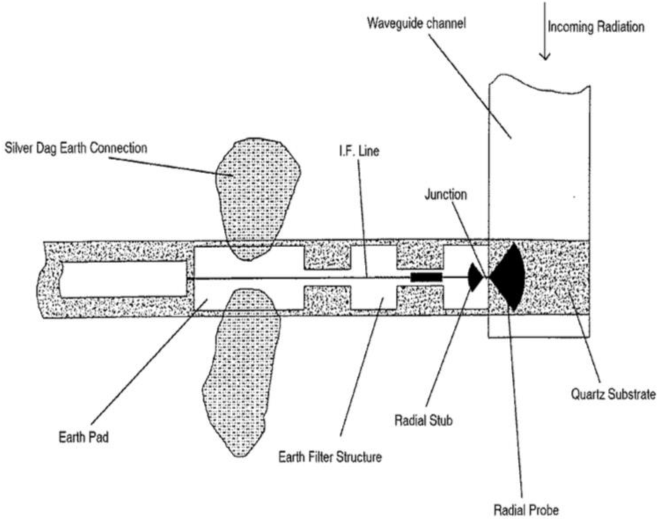
J. Leech[1], S. Withington[1], G. Yassin[1],
H. Smith[1], B.D. Jackson[2], J.R. Gao[2],
T.M. Klapwijk[3].

[1] Cavendish Laboratory, University of Cambridge, Madingley Road, Cambridge, UK.
[2]Space Research Organization of the Netherlands, Postbus 800, 9700 AV Groningen, The Netherlands.
[3]Department of Applied Physics (DIMES), The Delft University of Technology, Lorentzweg 1, 2628 CJ Delft, The Netherlands.



The meander line LO injection above the imaging module.





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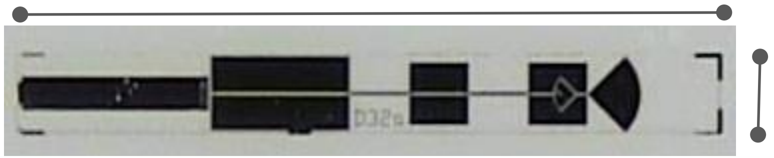
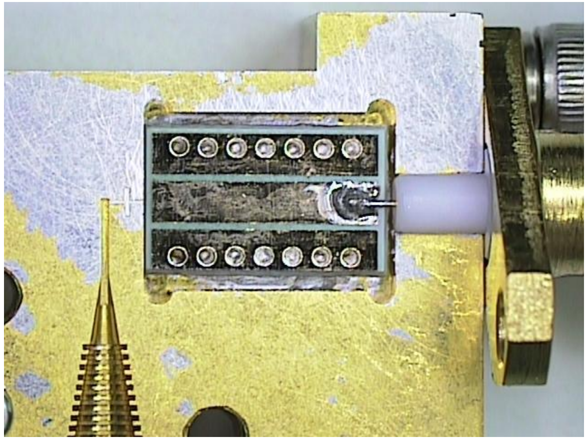
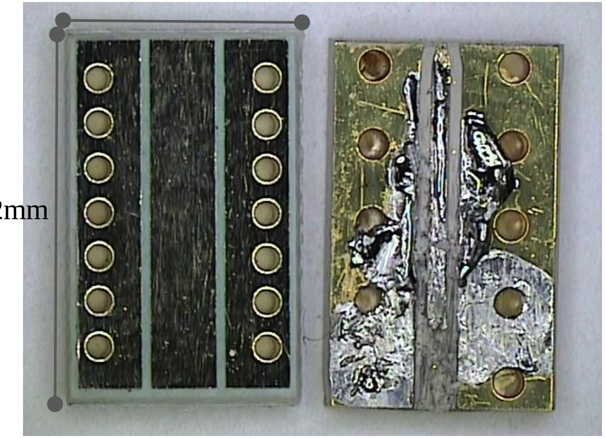


The Original Mixer Chip



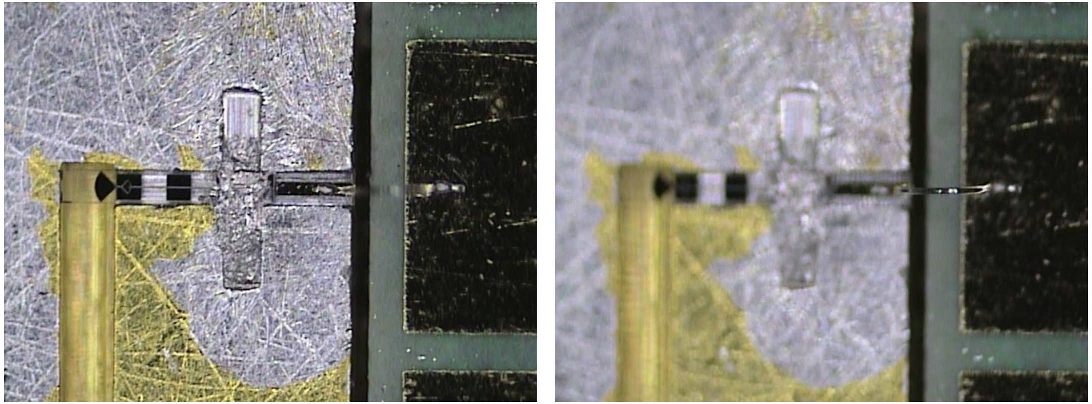
The IF Transmission Line to SMA Connector



New
(Designed by Su-Wei Chang)

Original

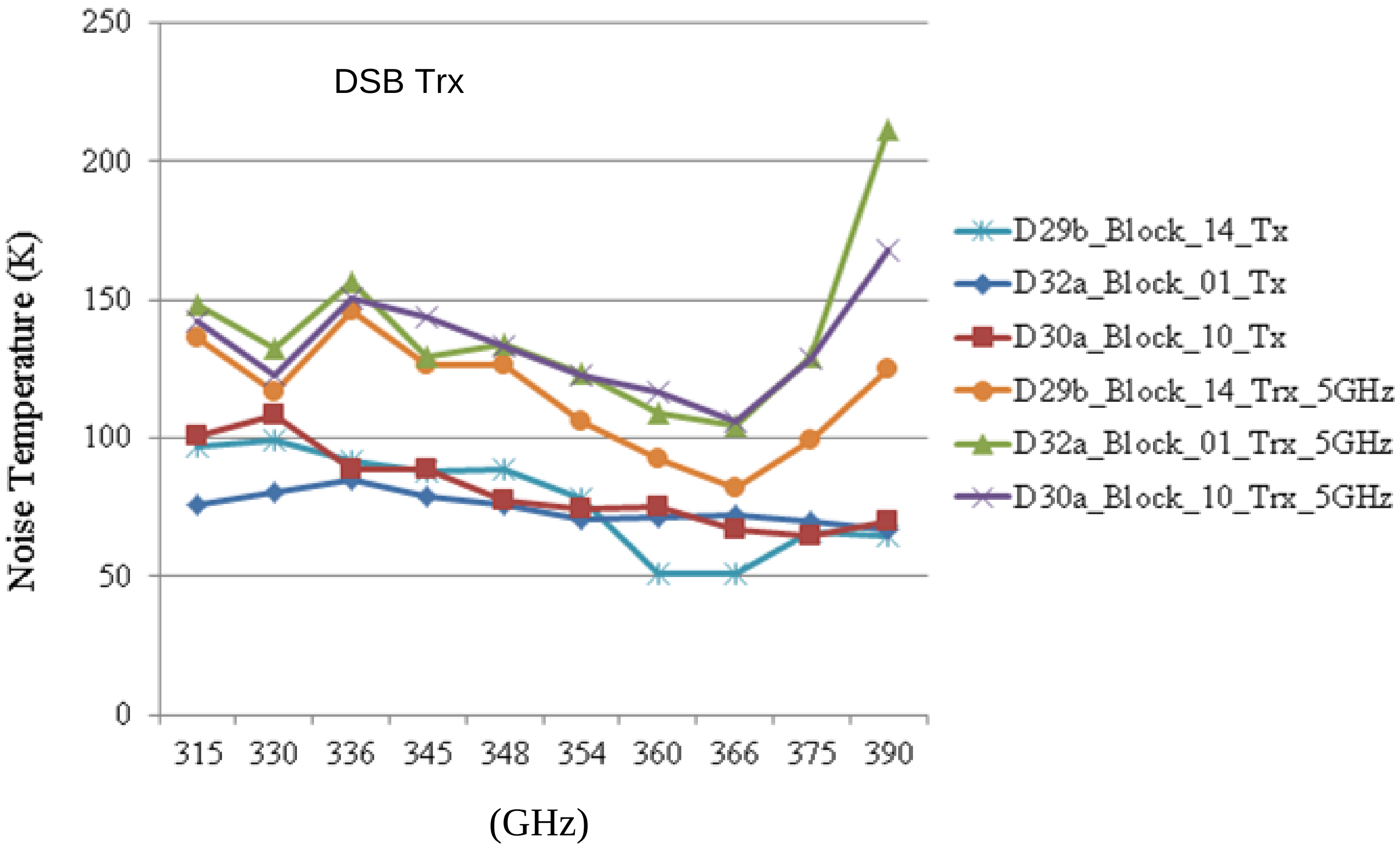
CPW IF Transmission Line



Focus on Mixer Chip

Focus on Bonding Wire

The Wire Bonding



Credit: Sheng-Feng

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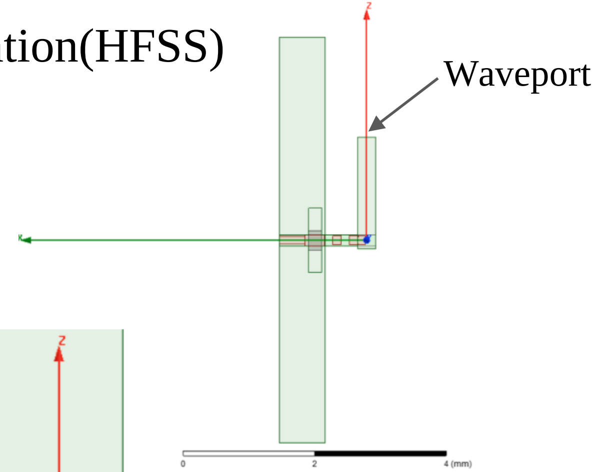
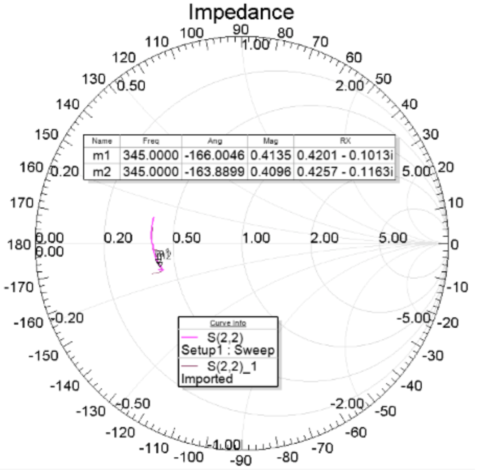
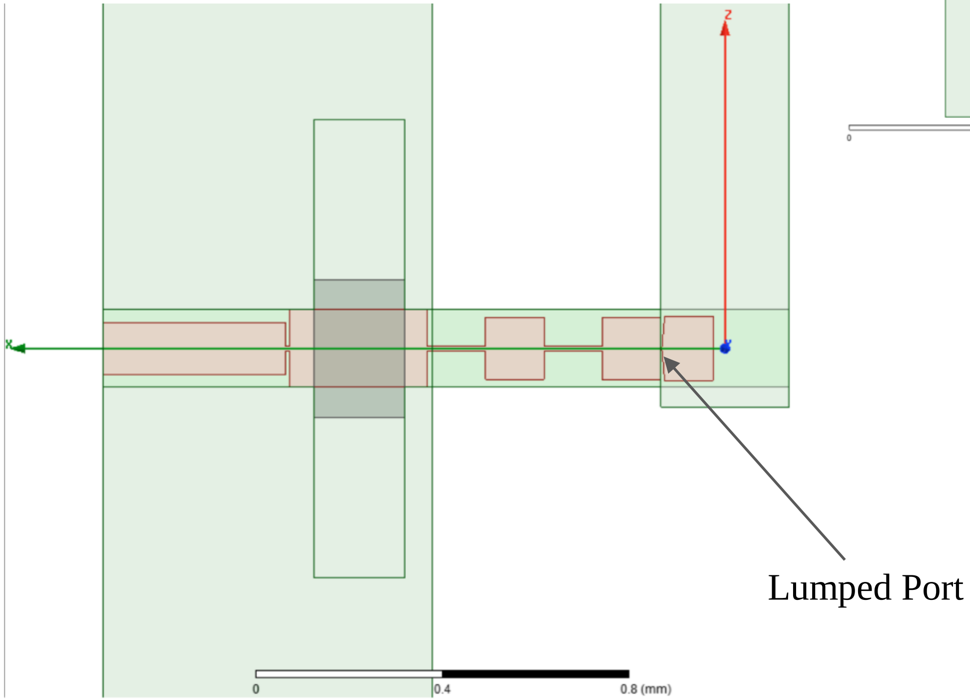
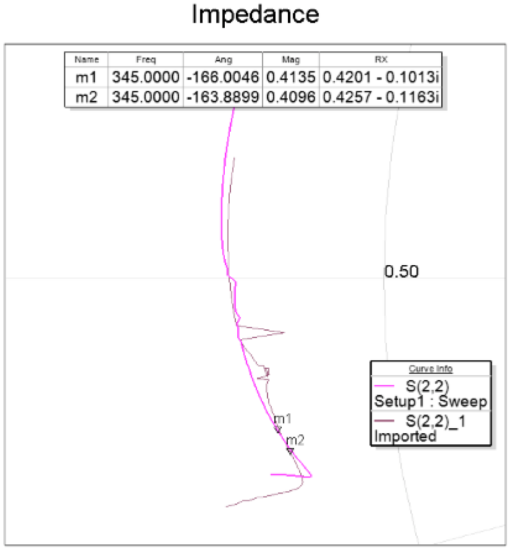
High Frequency Structure Simulation(HFSS)









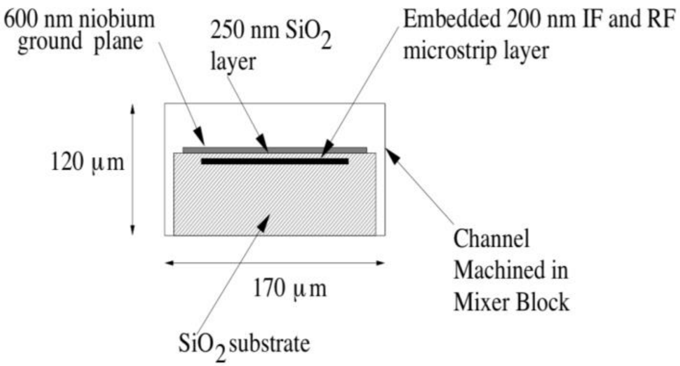


Figure 4.2: Cross-section of the HARP mixer chip showing embedded IF and RF microstrip beneath the ground plane filter layer.

Leech's Thesis

Material	relative permittivity				
Quartz	3.78				
		Z0 with textbook Model	Z0 with HFSS Simulation	Z0 (ET model)	% difference
W = 1um	d = 0.25um	36.60	28.83	30.72	6.60%
W = 2um	d = 0.25um	20.44	17.32	18.45	6.50%
W = 2.5um	d = 0.25um	16.78	14.54	15.84	8.90%
W= 3um	d = 0.25um	14.25	13.02	13.23	1.60%
W= 4um	d = 0.25um	10.96	10.04	10.34	3.00%
W= 5um	d = 0.25um	8.91	8.33	8.49	1.90%

Formulas for Effective Dielectric Constant, Characteristic Impedance, and Attenuation

The effective dielectric constant of a microstrip line is given approximately by

$$\epsilon_e = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \frac{1}{\sqrt{1 + 12d/W}}.$$

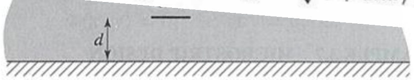


FIGURE 3.26 Equivalent geometry of quasi-TEM microstrip line, where the dielectric slab of thickness d and relative permittivity ϵ_r has been replaced with a homogeneous medium of effective relative permittivity, ϵ_e.

Given the dimensions of the microstrip line, the characteristic impedance can be calculated as

$$Z_0 = \begin{cases} \frac{60}{\sqrt{\epsilon_e}} \ln\left(\frac{8d}{W} + \frac{W}{4d}\right) & \text{for } W/d \leq 1 \\ \frac{120\pi}{\sqrt{\epsilon_e}\,[W/d + 1.393 + 0.667 \ln(W/d + 1.444)]} & \text{for } W/d \geq 1. \end{cases} \quad (3.196)$$

For a given characteristic impedance Z_0 and dielectric constant ϵ_r, the W/d ratio can be found as

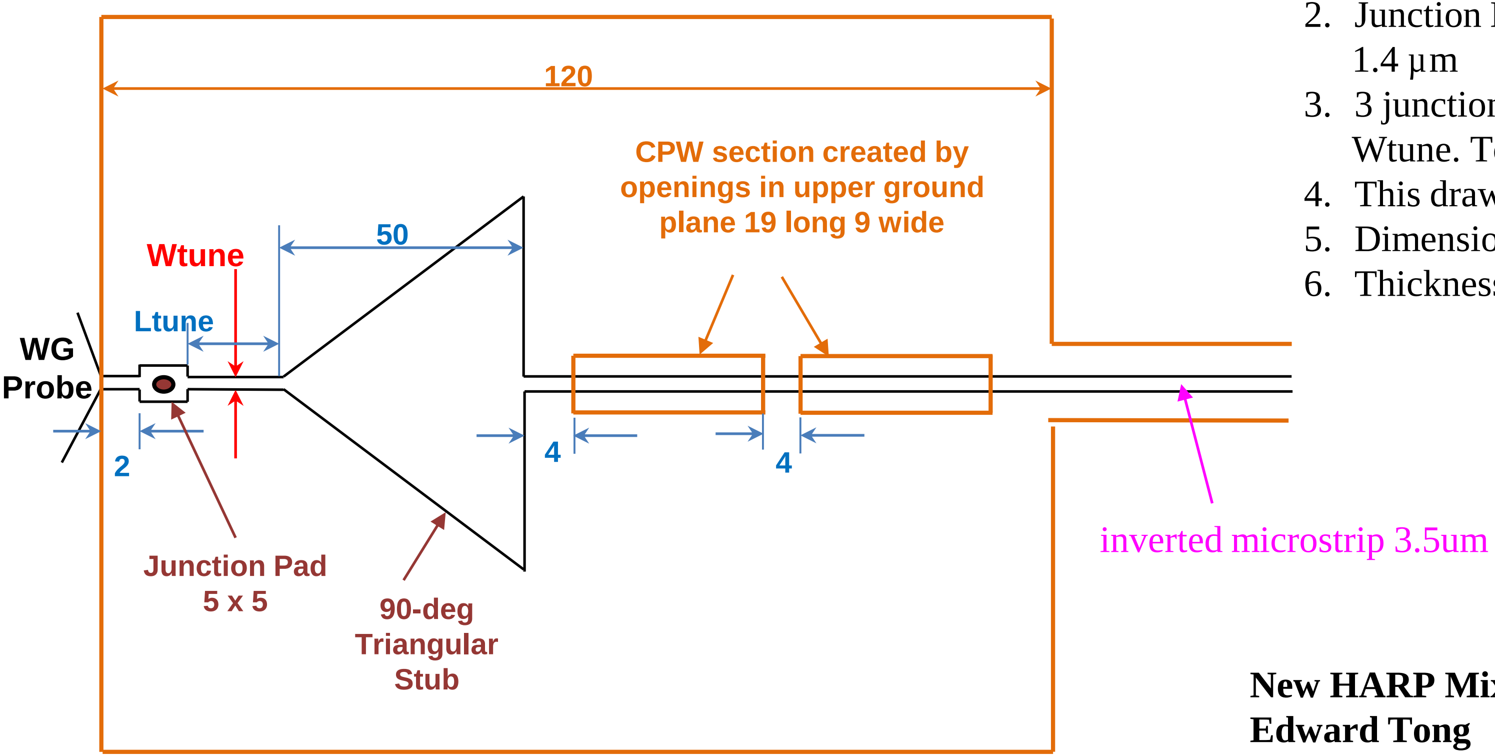
$$\frac{W}{d} = \begin{cases} \frac{8e^A}{e^{2A} - 2} & \text{for } W/d < 2 \\ \frac{2}{\pi}\left[B - 1 - \ln(2B - 1) + \frac{\epsilon_r - 1}{2\epsilon_r}\left\{\ln(B - 1) + 0.39 - \frac{0.61}{\epsilon_r}\right\}\right] & \text{for } W/d > 2, \end{cases} \quad (3.197)$$

where

$$A = \frac{Z_0}{60}\sqrt{\frac{\epsilon_r + 1}{2}} + \frac{\epsilon_r - 1}{\epsilon_r + 1}\left(0.23 + \frac{0.11}{\epsilon_r}\right)$$

$$B = \frac{377\pi}{2Z_0\sqrt{\epsilon_r}}.$$

Microwave Engineering, David M. Pozar

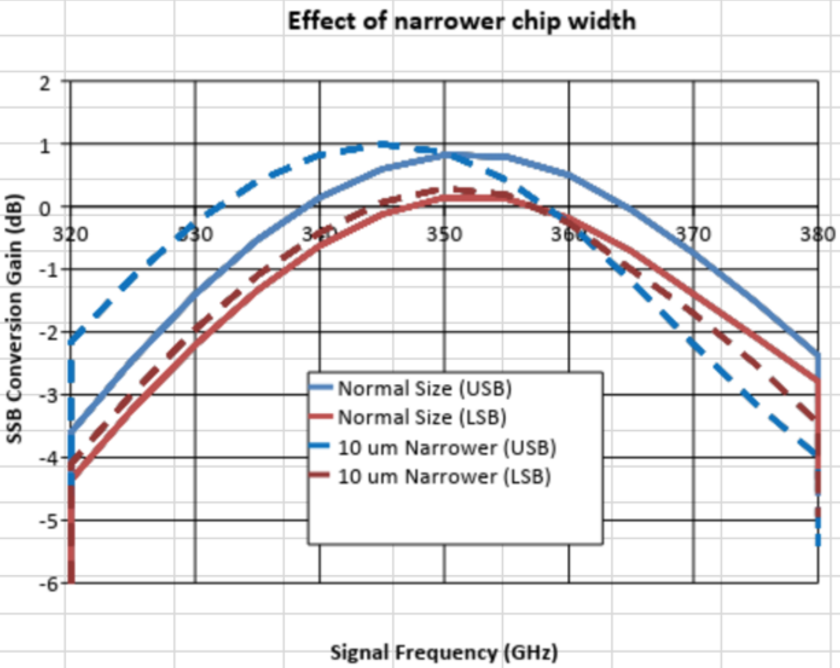


Design Notes:

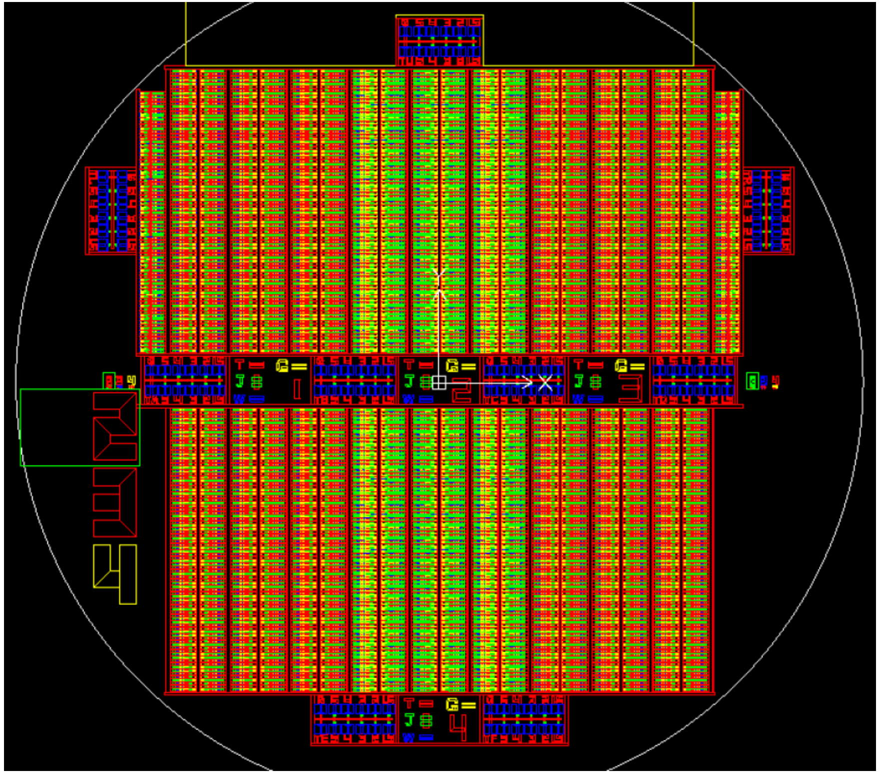
1. Target RnA = 25 Ω-μm^2
2. Junction Diameters: 1.2, 1.3 & 1.4 μm
3. 3 junction sizes & 3 values of Wtune. Total of 9 combinations
4. This drawing is not to scale.
5. Dimensions given in μm.
6. Thickness of SiO2 250 nm

New HARP Mixer Chip
Edward Tong
March 13, 2018

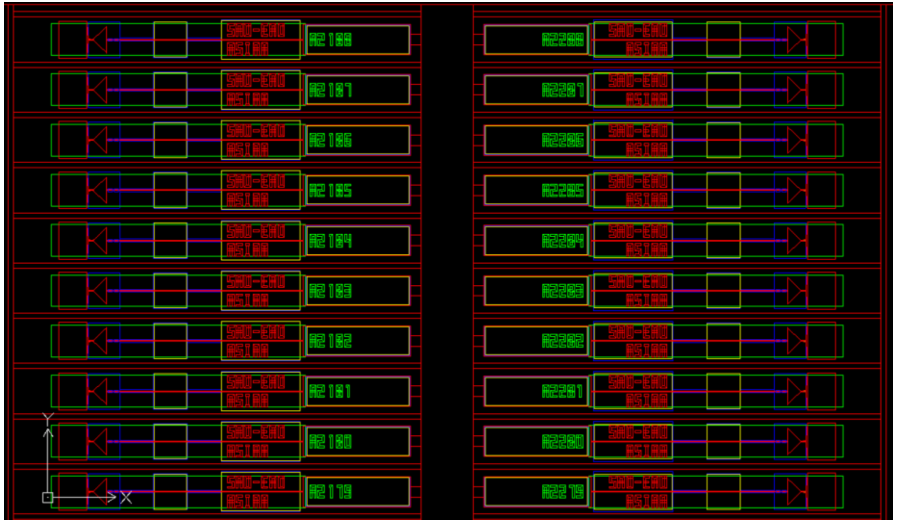
	normal size			10 um narrower	
Fsignal	Gusb (dB)	Glsb (dB)		Gusb (dB)	Glsb (dB)
305		-6.94			-6.66
310		-5.62			-5.35
315	-4.87	-4.37		-4.60	-4.11
320	-3.61	-3.22		-3.34	-2.97
325	-2.44	-2.21		-2.16	-1.96
330	-1.40	-1.34		-1.12	-1.10
335	-0.53	-0.63		-0.25	-0.42
340	0.14	-0.12		0.40	0.07
345	0.60	0.15		0.82	0.29
350	0.82	0.13		0.99	0.18
355	0.79	-0.19		0.87	-0.26
360	0.50	-0.71		0.42	-1.00
365	-0.05	-1.40		-0.26	-1.70
370	-0.74	-2.08		-1.19	-2.52
375	-1.52	-2.78		-2.20	-3.45
380	-2.37	-4.35		-3.15	-4.94
385	-3.13	-4.14		-3.98	-4.80
390	-4.61			-5.40	
395	-4.43			-5.21	



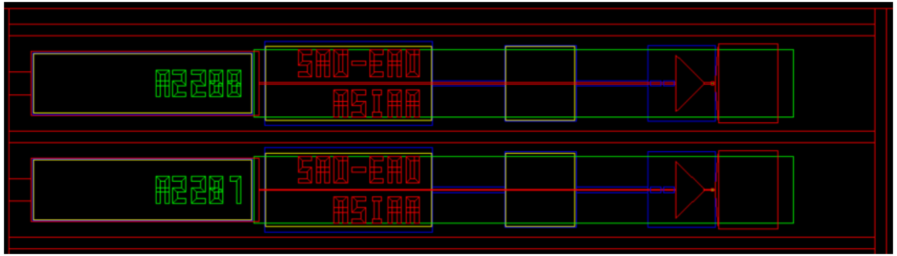
Credit: Edward Tong



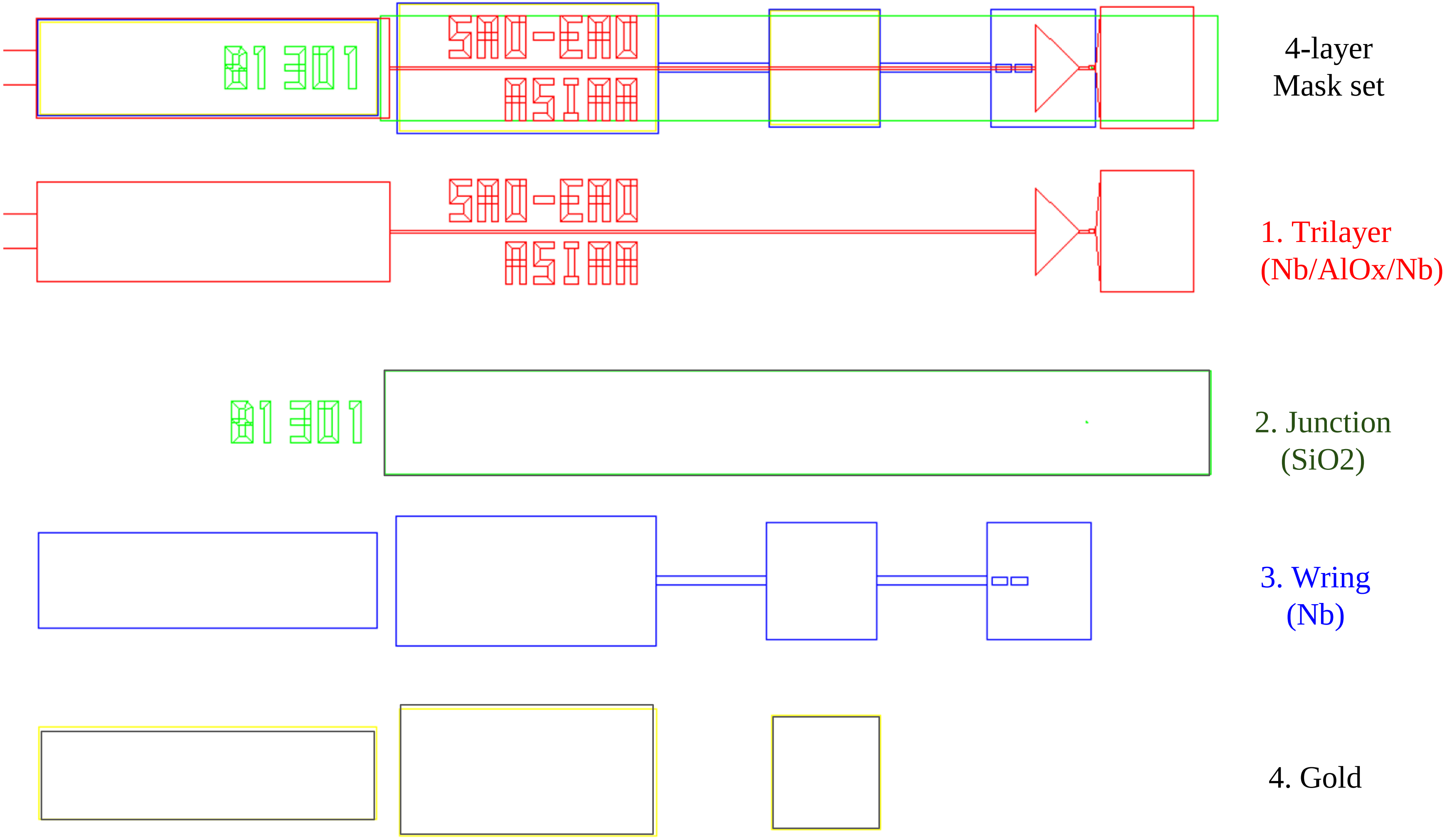
Mask Design



Chip Arrangement

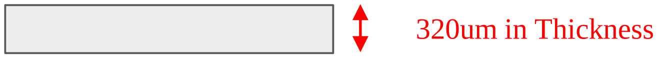


Zoomed-in

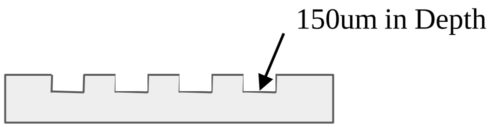


SAO-EAO
ASIAA
01 301
4-layer Mask set
1. Trilayer (Nb/AlOx/Nb)
2. Junction (SiO2)
3. Wring (Nb)
4. Gold

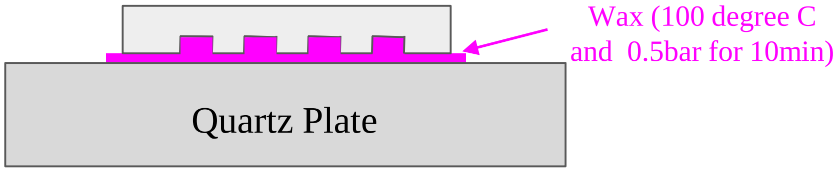
Lapping Process



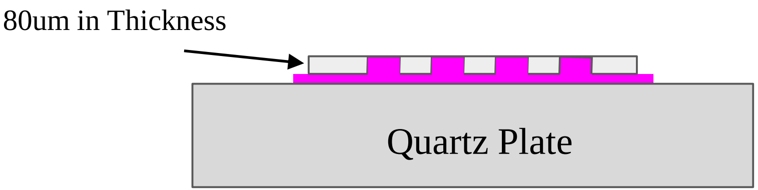
Mixer Chip Wafer
(Cross-Sectional)



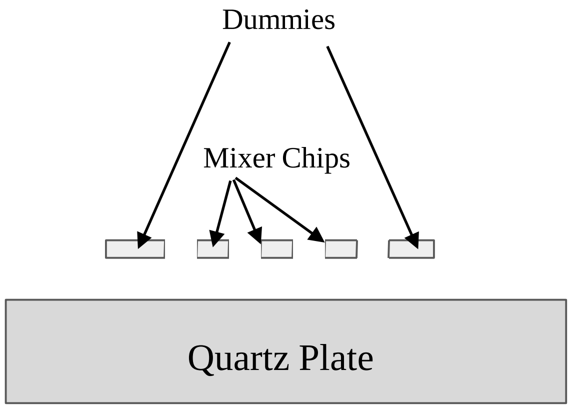
Grooves on Chip Front with
Dicing Saw



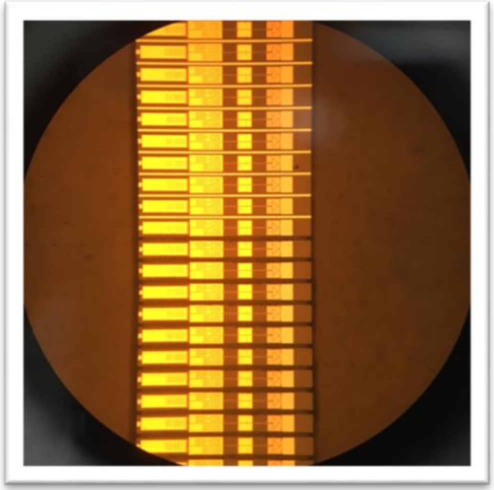
Preparation for Chip Backside Lapping



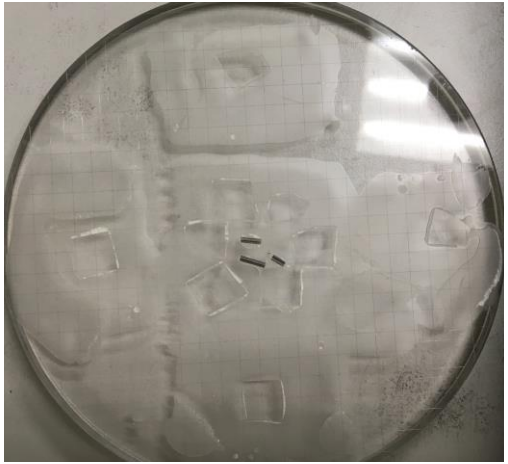
Lapping to the Target Thickness of 80um



De-wax/Acetone/IPA Clean

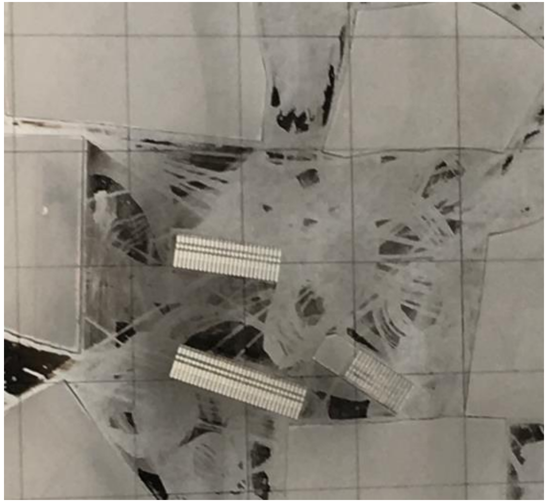


Dicing

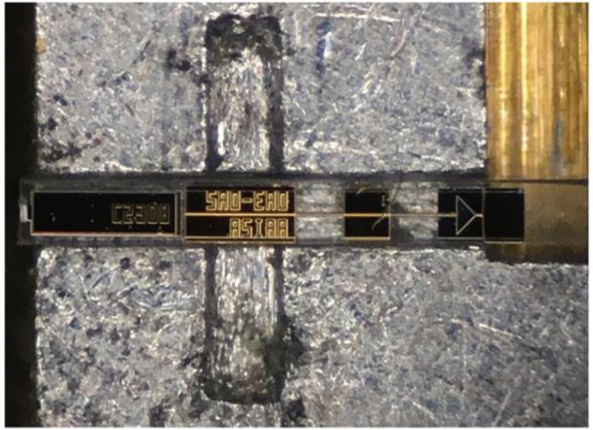


Lapping

Thickness Measurement



End of Lapping



Chip Assembly

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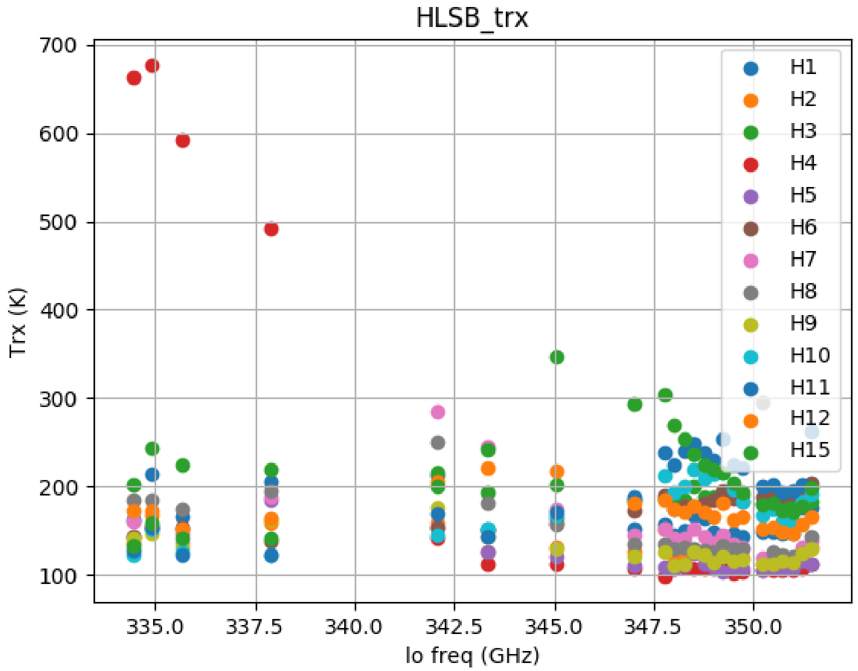
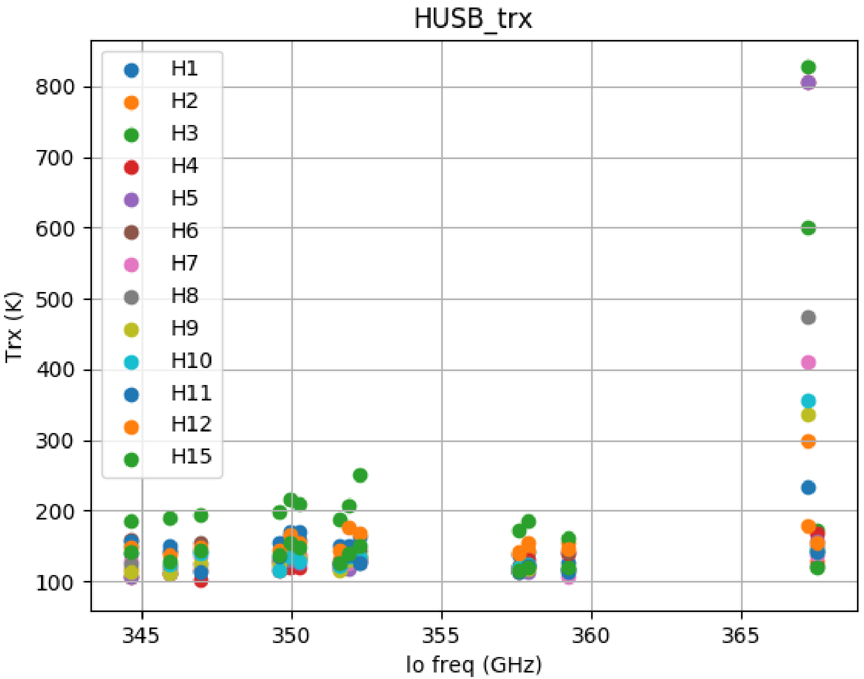
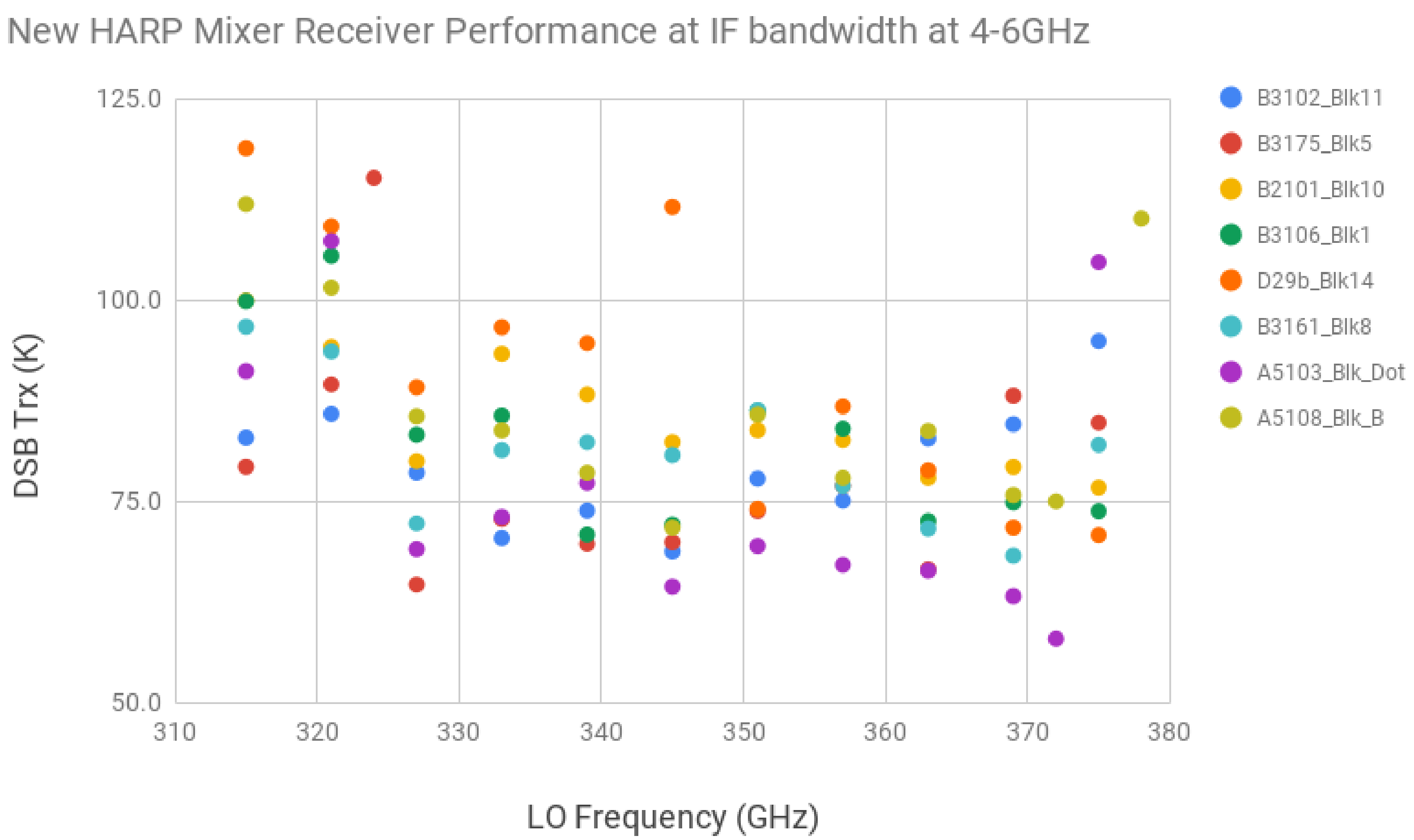
HARP Running Receptors SSB Trx

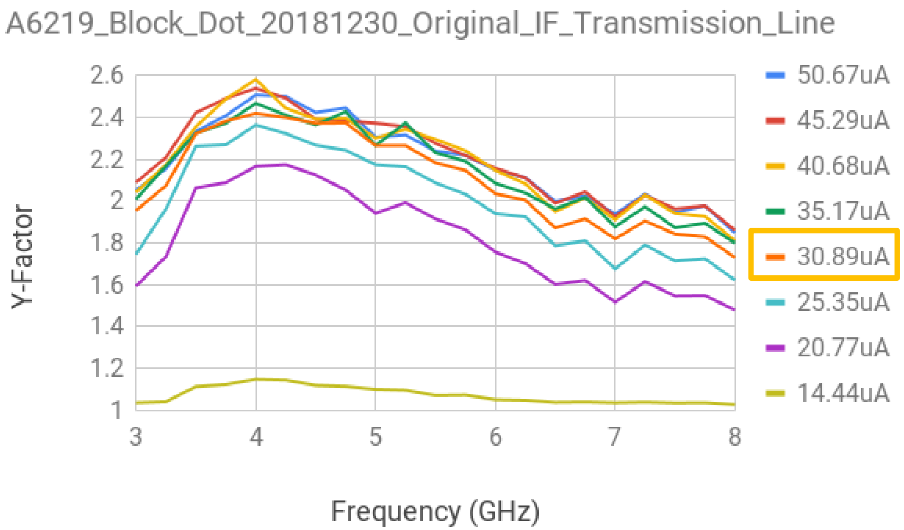


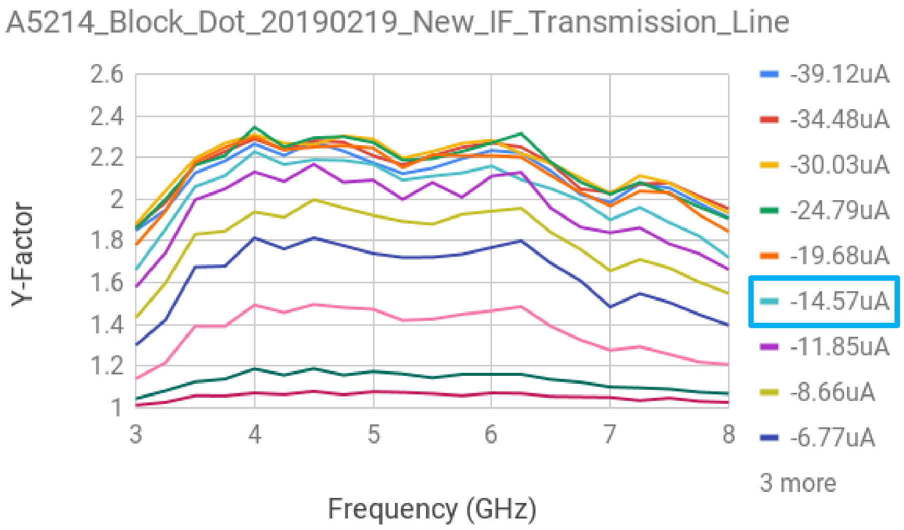


Credit: Izumi Mizumo


New HARP Mixer Receiver Performance at IF bandwidth at 4-6GHz
DSB Trx (K)
125.0
100.0
75.0
50.0
310
320
330
340
350
360
370
380
LO Frequency (GHz)
B3102_Blk11
B3175_Blk5
B2101_Blk10
B3106_Blk1
D29b_Blk14
B3161_Blk8
A5103_Blk_Dot
A5108_Blk_B

Comparison with IF Transmission Line





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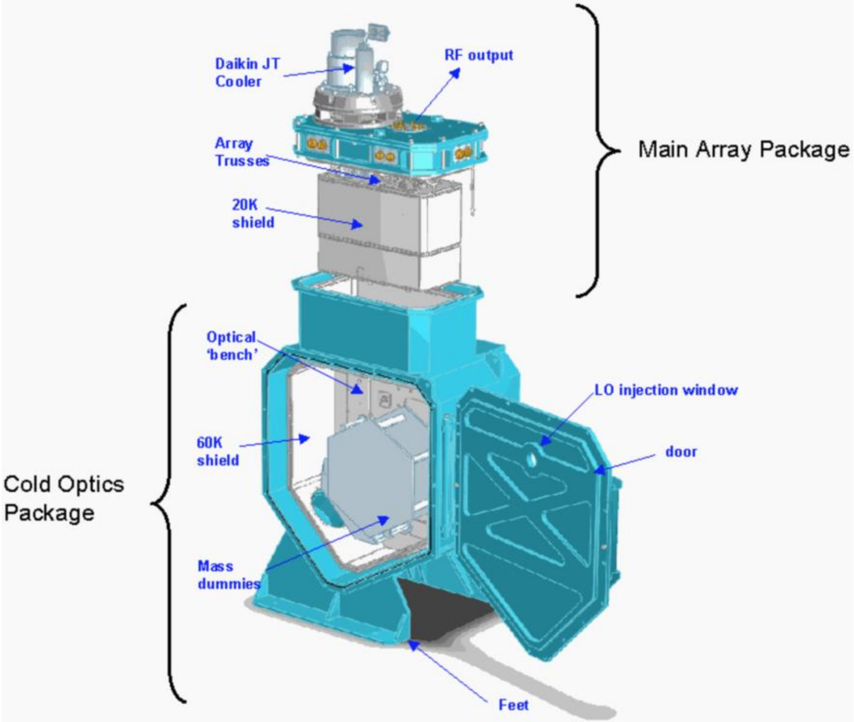
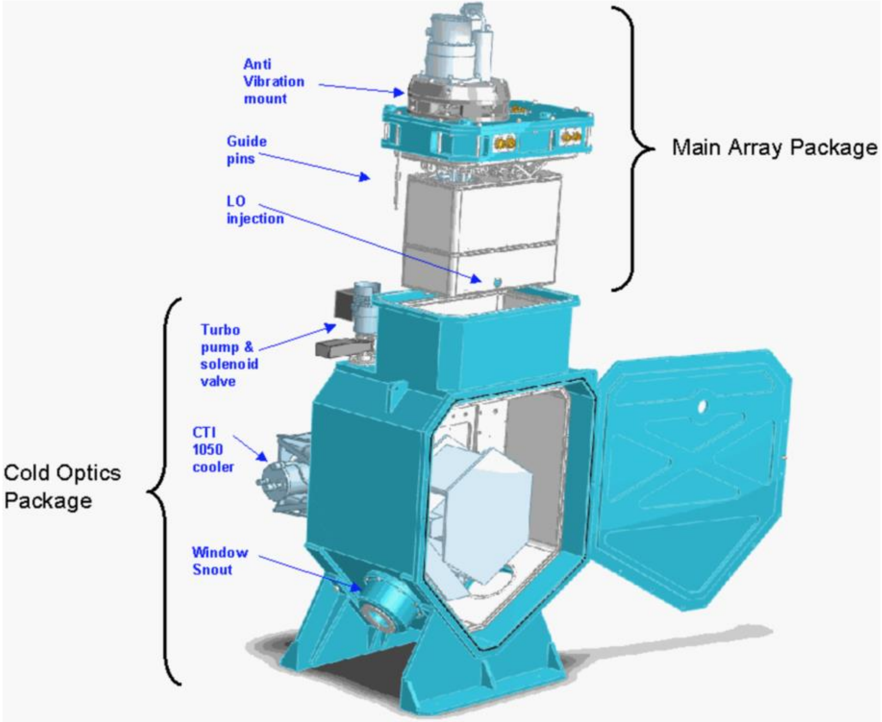
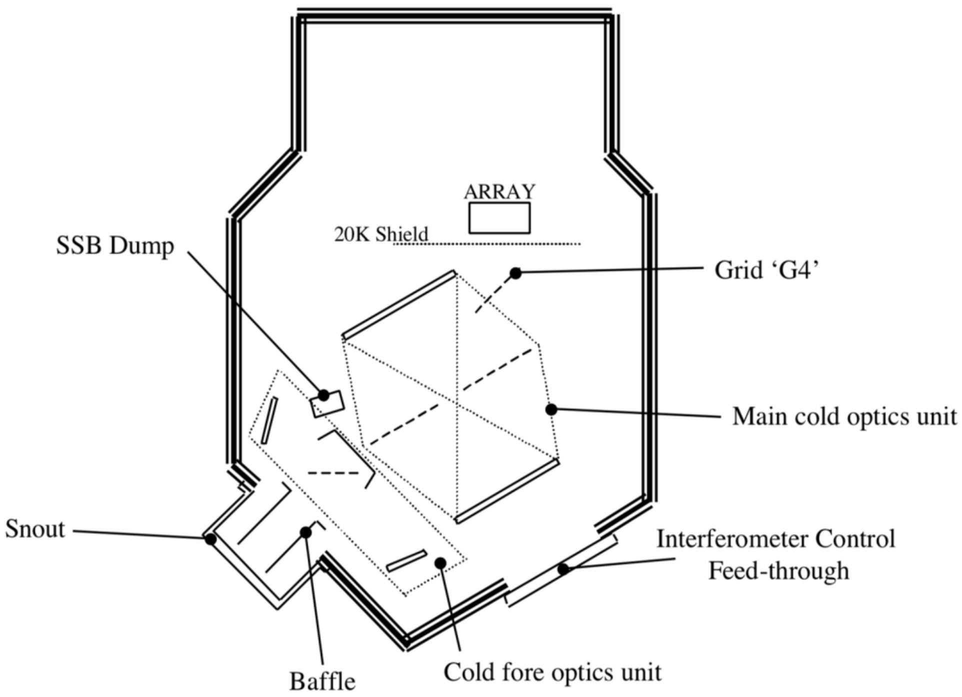
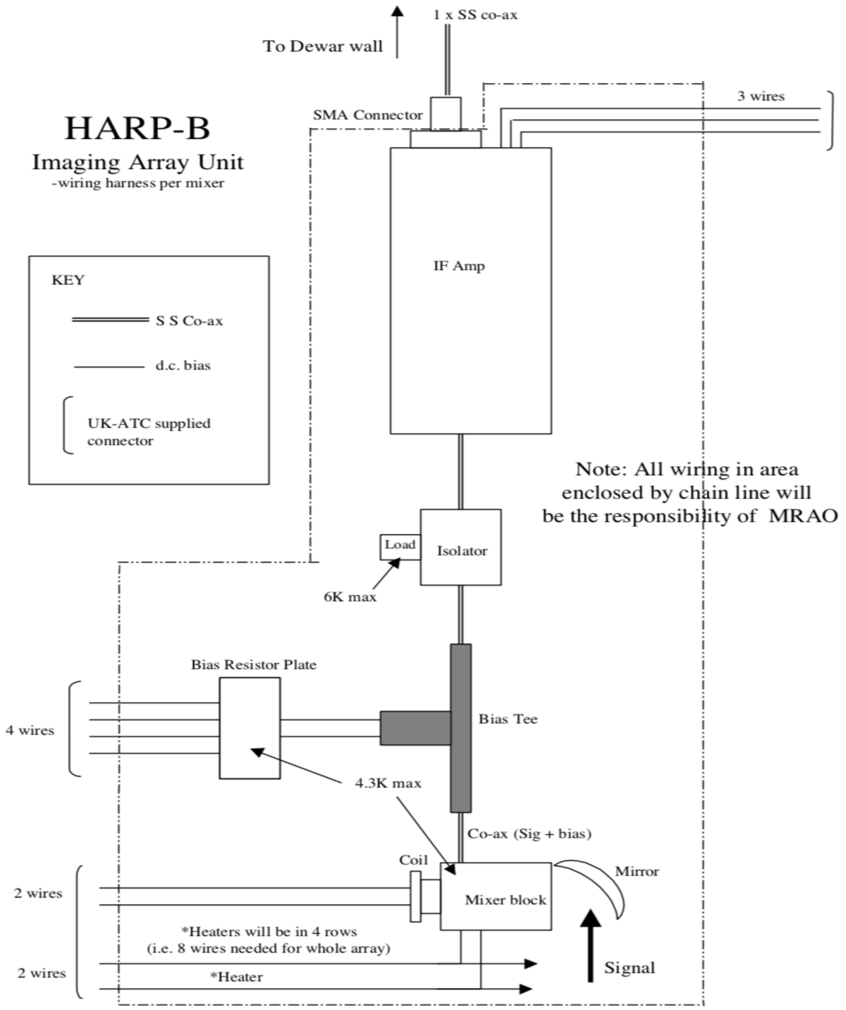
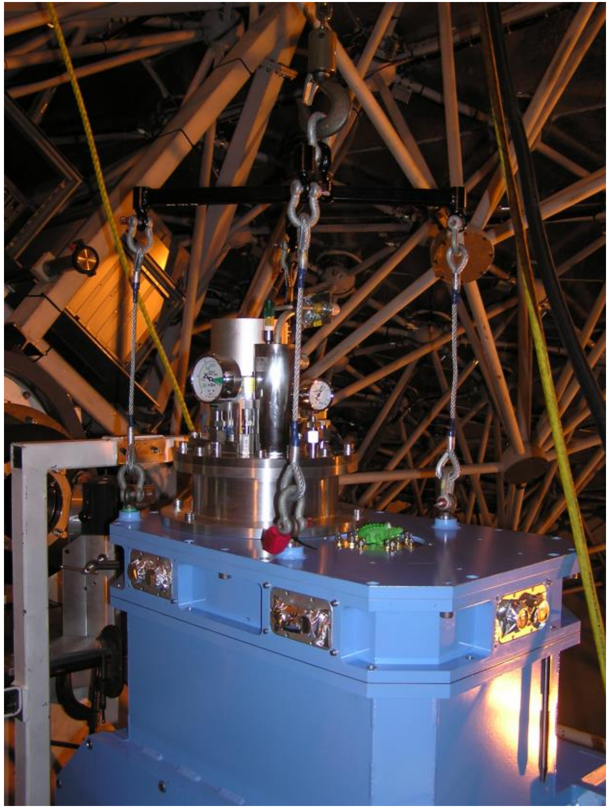
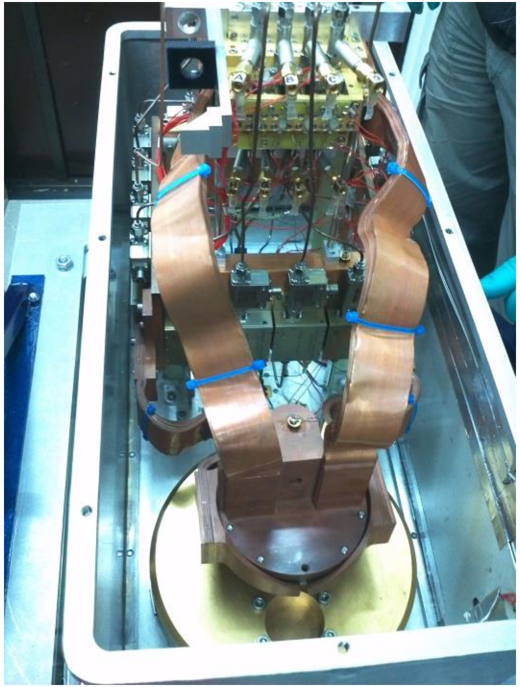

Daikin JT Cooler
RF output
Array Trusses
20K shield
Main Array Package
Optical 'bench'
LO injection window
60K shield
door
Cold Optics Package
Mass dummies
Feet

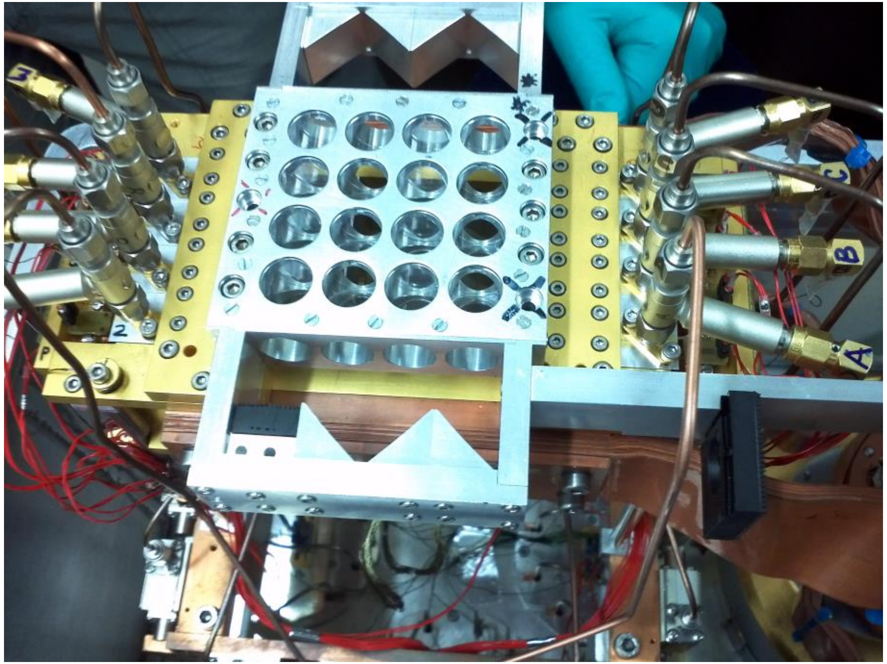

Anti Vibration mount
Guide pins
LO injection
Main Array Package
Turbo pump & solenoid valve
CTI 1050 cooler
Cold Optics Package
Window Snout


ARRAY
20K Shield
SSB Dump
Grid 'G4'
Main cold optics unit
Snout
Interferometer Control
Feed-through
Baffle
Cold fore optics unit

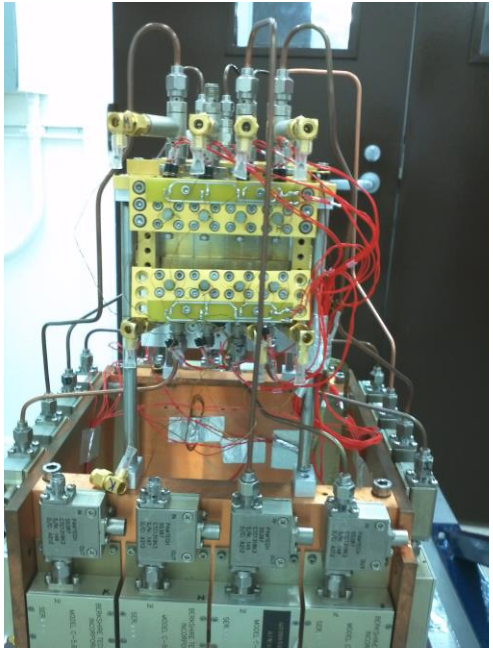

HARP-B
Imaging Array Unit
-wiring harness per mixer
To Dewar wall
1 x SS co-ax
SMA Connector
3 wires
KEY
S S Co-ax
d.c. bias
UK-ATC supplied connector
IF Amp
Note: All wiring in area enclosed by chain line will be the responsibility of MRAO
Load
Isolator
6K max
Bias Resistor Plate
Bias Tee
4 wires
4.3K max
Co-ax (Sig + bias)
Coil
Mirror
Mixer block
2 wires
*Heaters will be in 4 rows
(i.e. 8 wires needed for whole array)
2 wires
*Heater
Signal







C
B
A
2



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Summary

- New spare mixers for HARP have been designed, fabricated, and tested.
- The performance of the new mixers are compatible with the running mixers.
- Five receptors are ready for the replacement.
- The MAP service is aimed in August or later.