Webber 3-20-00

18 Mar 2000 JRDG000320.tlk

ALMA Joint Receiver Design Group Meeting
Charlottesville, 20-21 March 2000

Balanced and Sideband Separating SIS Mixers for ALMA, and Some Thoughts on Vacuum Windows

A. R. Kerr
NRAO

Why Sideband Separating Mixers?

Why Balanced Mixers?

Realization of Balanced and Sideband Separating Mixers for 100-700 GHz
- Quasi-Optical
- Waveguide
  - W/G loss
- MMIC
  - MMIC Sideband Separating Mixer -- with JPL
  - MMIC Balanced Mixer -- with UVA
  - MMIC Balanced Sideband Separating mixer -- with UVA
  - A Building Block Mixer for 602-720 GHz

Implications of the ALMA IF requirements
- Building Block SIS Mixer with Low IF Parasitics

Vacuum Windows

Why Sideband Separating Mixers?

⇒ To eliminate atmospheric noise in the image band during spectral line observations.

In spectral line observations quadrature phase switching in the back end of an interferometer allows upper and lower sideband signals common to the whole array to be separated out, but atmospheric noise in the image sideband cannot be removed in this way and degrades the system sensitivity. This is because the atmospheric noise received at each antenna originates in the patch of atmosphere in the line of sight of that antenna and is not correlated with the atmospheric noise arriving at any other antenna.

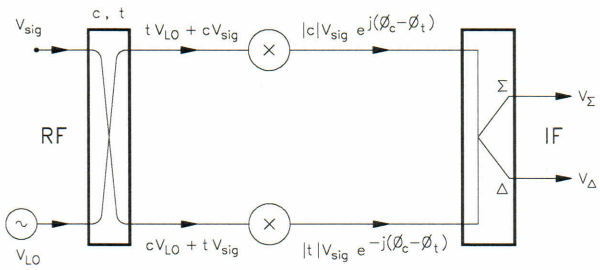
The benefits of sideband separating mixers in the ALMA context have been discussed in MMA Memo. 168, and I think there is now general agreement that sideband separating mixers should be used on ALMA if they are practical.

Note that an image rejection of ≥10 dB is sufficient to suppress atmospheric noise in the image band.

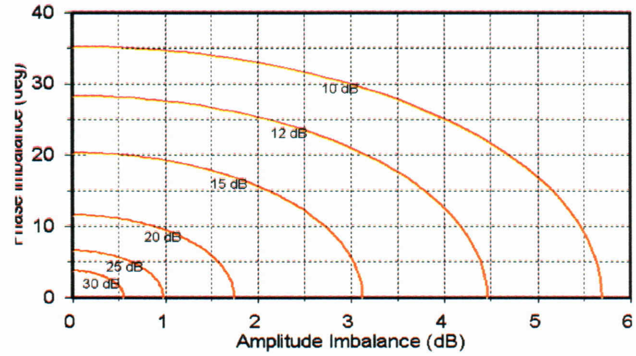
Why Balanced Mixers?

⇒ Balanced mixers have been used in commercial and military equipment since before WWII to:
- — eliminate the need for a LO diplexer
- — reduce LO power required by ~17 dB
- — obtain additional rejection of sideband noise accompanying the LO power

IF 180° hybrid not required if mixers are biased oppositely so IF's from the two mixers are in phase.



Amplitude and phase balance requirements of balanced and sideband separating mixers are not stringent.

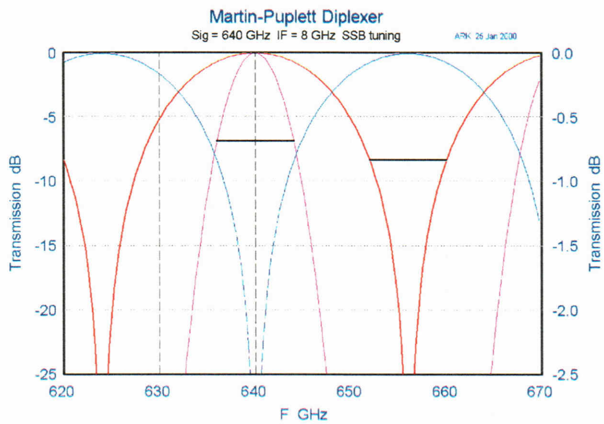


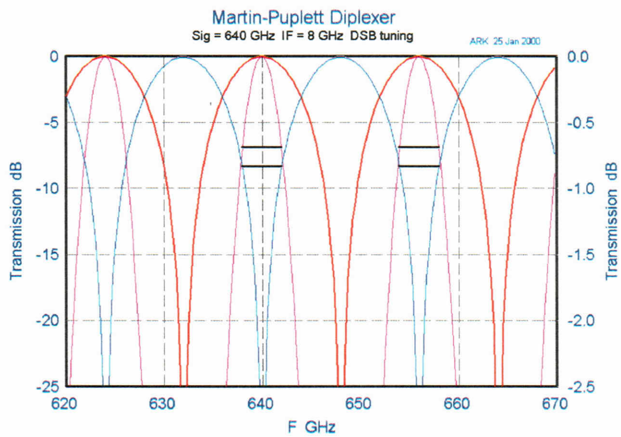
Conventional LO coupling schemes:

— Beam splitter or directional coupler
High LO power loss
Low signal loss
No LO noise rejection
Physically large

— Martin-Puplett interferometer
Efficient LO coupling only for DSB operation. In SSB operation the image must be terminated in a cold load, so *EITHER* a cold LO attenuator must be used, which requires ~20 dB more LO power, *OR* a second (tunable) MP interferometer and cold image load is required for efficient LO diplexing (but this gives reduced LO noise rejection bandwidth).

With f_{IF} = 8 GHz:
Limited signal bandwidth: SSB tuning: 0.7 dB signal loss with B = 8 GHz
DSB tuning: 0.7 dB signal loss with B = 4 GHz
Limited LO noise rejection bandwidth:
SSB tuning: 8 dB LO sideband rejection with B = 8 GHz
DSB tuning: 8 dB LO sideband rejection with B = 4 GHz
Physically large.
Requires precise mechanical tuning in cryogenic environment.

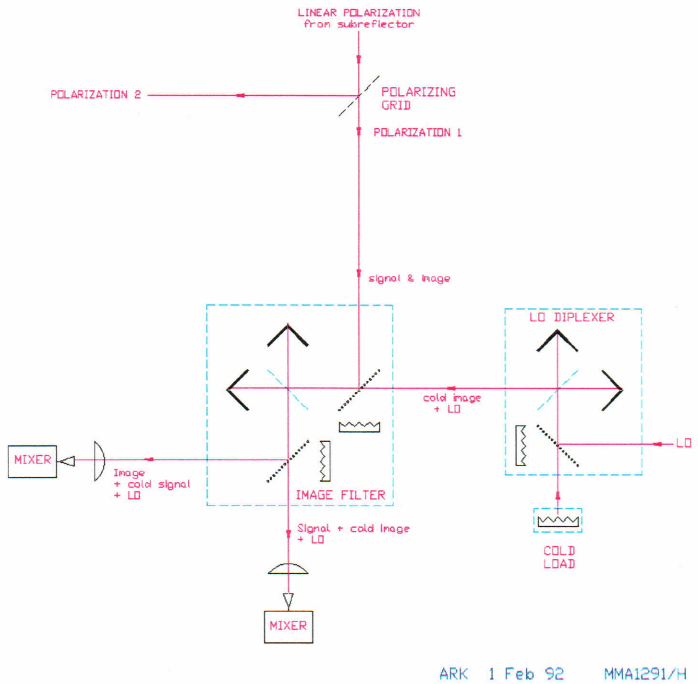


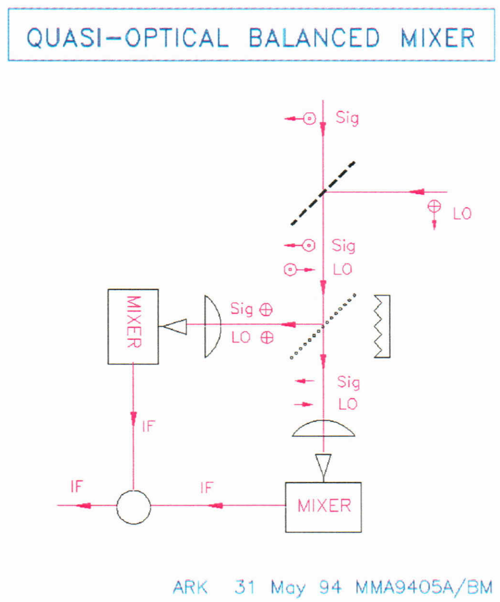


⇒ Question: Is the overall cost of making balanced SIS mixers less than the cost of either:
(a) a cold attenuator (beam splitter & cold load) and a LO with ~20 dB more power across the band, or
(b) a cryogenic MP diplexer with mechanical tuning AND a penalty in receiver performance, especially for continuum work (DSB tuning)?

Realization of Balanced and Sideband Separating Mixers for 100-700 GHz

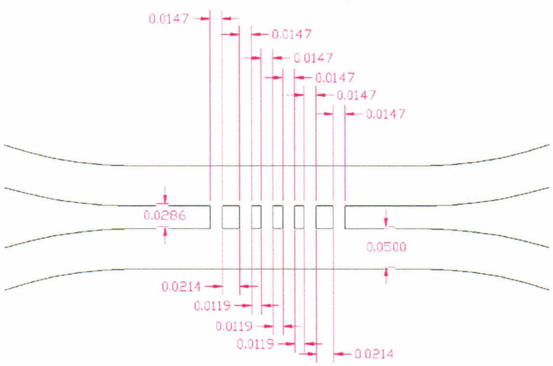
Quasi-Optical Balanced and Sideband Separating Mixers

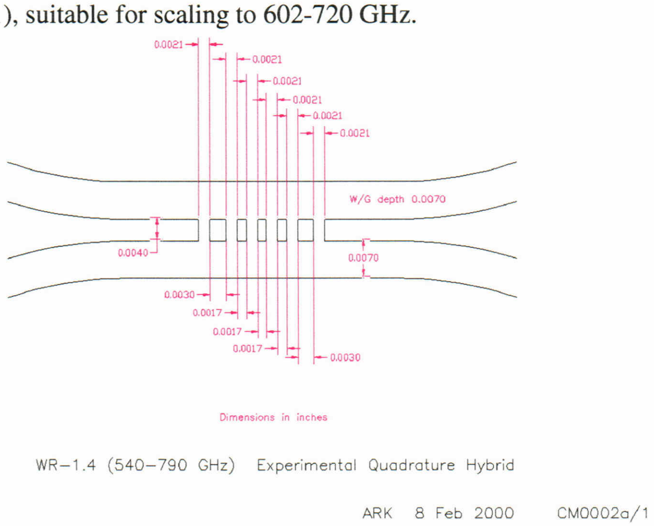




Waveguide Balanced and Sideband Separating Mixers

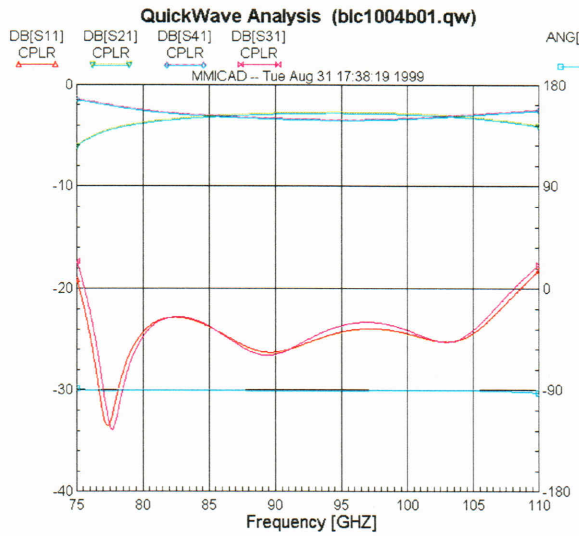
A waveguide quadrature hybrid for 82-107 GHz (1.31:1), suitable for scaling to 602-720 GHz.

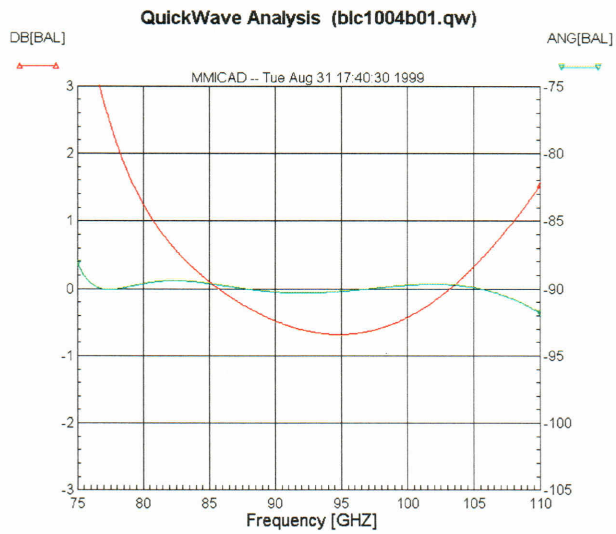


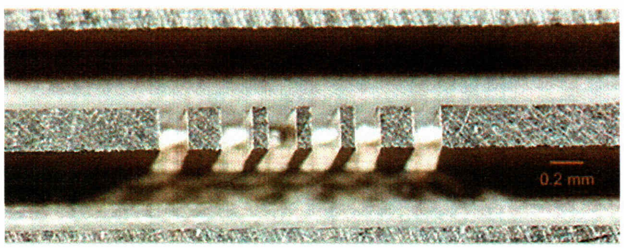


WR-10 coupler length = 0.167" (4.24 mm)

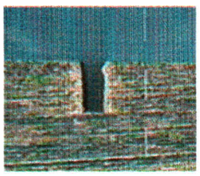
WR-1.4 coupler length = 0.023" (0.59 mm).



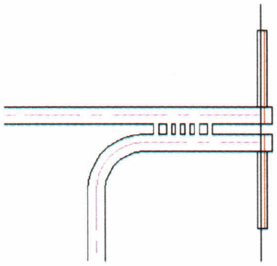




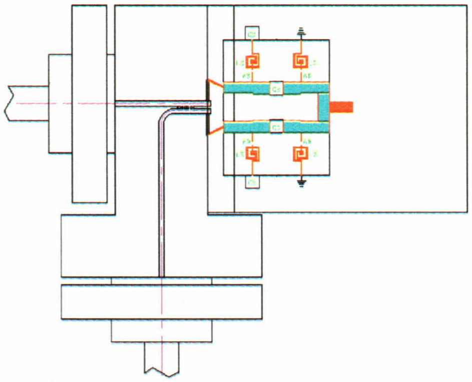
WR-3.7 (200-300 GHz) quadrature coupler.
(from Claude & Cunningham at HIA)

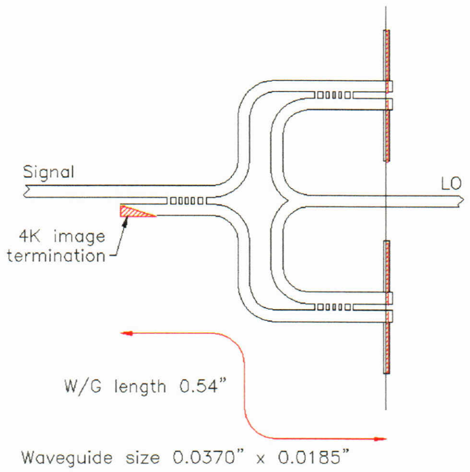


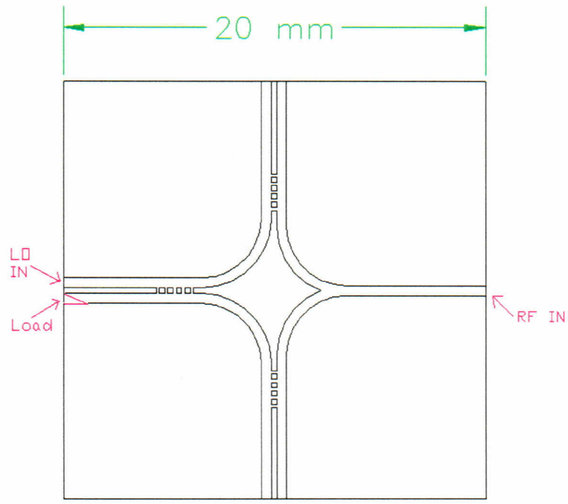
0.002" x 0.006" channel made with a 0.0018" end mill
(from Custom Microwave).



211-275 GHz Waveguide Balanced Mixer







Balanced sideband separating mixers for 211-275 GHz (1.30:1)

Stephane Claude, February 29, 2000
HIA/NRC

Waveguide loss

For room temperature copper or coin silver WR-10 at 100 GHz, 0.1 dB/in is typically measured. For a given f/fc (e.g., at midband), the loss of a waveguide goes as f^(3/2). Scaling from 100 GHz gives (for the appropriate size waveguide):

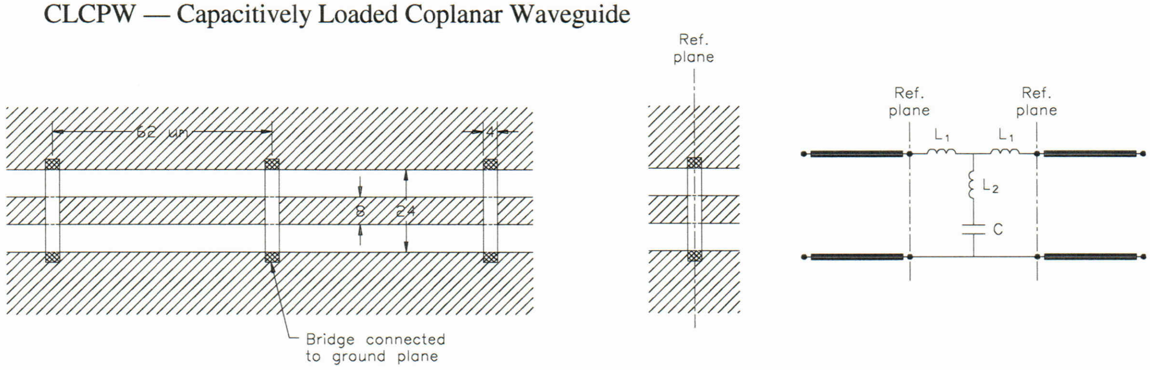
100 GHz	0.1 dB/in	0.012 dB/λ_0
200	0.28	0.017
300	0.52	0.020
600	1.5	0.030
700	1.9	0.032

The type of metal and the surface finish are important. For mixers, I like brass blocks (for stability and ease of machining) with good gold plating. Cooling reduces the loss but I don't have any data on that.

Waveguide loss should not be a problem for a 600-720 GHz mixer with gold plated w/g, as long as the w/g length less than ~1/4".

MMIC Balanced and Sideband Separating Mixers

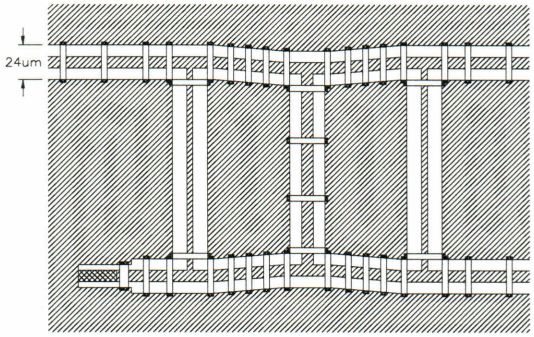
CLCPW — Capacitively Loaded Coplanar Waveguide



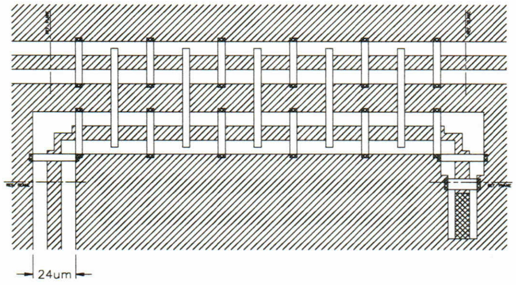
CLCPW Characteristics:

Thick substrate OK -- in contrast to conventional MMIC, CLCPW width << substrate thickness
All conductors on same side of the substrate
Bridges: (i) greatly reduce coupling between adjacent components
(ii) prevent odd-mode gap resonances in long CPW lines
(iii) give a convenient range of Z_0 which allows fabrication of CLCPW couplers, etc.

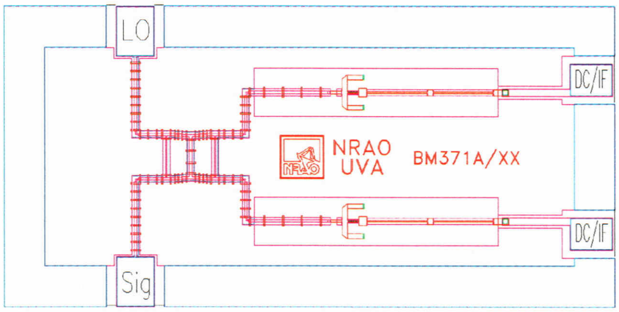
CLCPW Loss:
Nb CLCPW loss -- 12 dB/in at 720 GHz = 0.20 dB/λ_0 (Mattis-Bardeen + Sonnet).
cf: 10-Ω microstrip -- 51 dB/m at 720 GHz = 0.83 dB/λ_0.



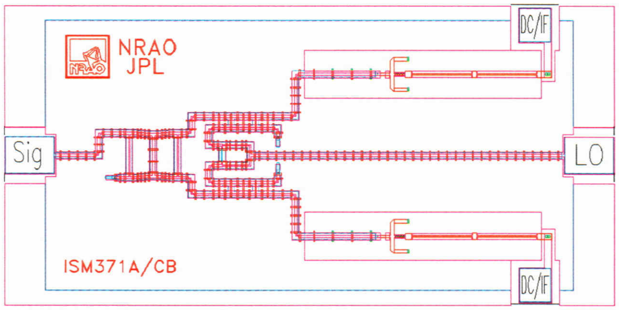
Quadrature hybrid for 200-300 GHz with integral 4 K image termination.



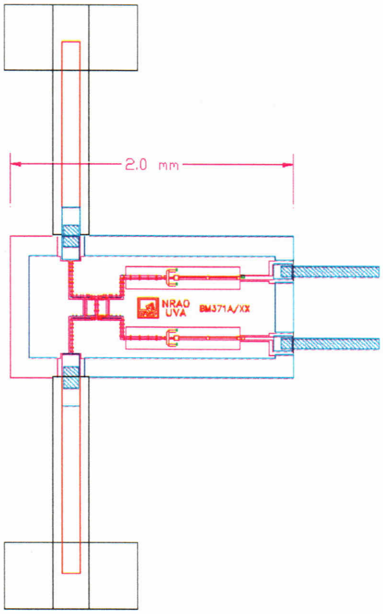
17-dB LO coupler for 200-300 GHz.

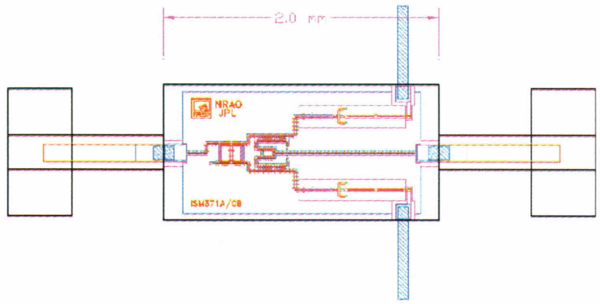


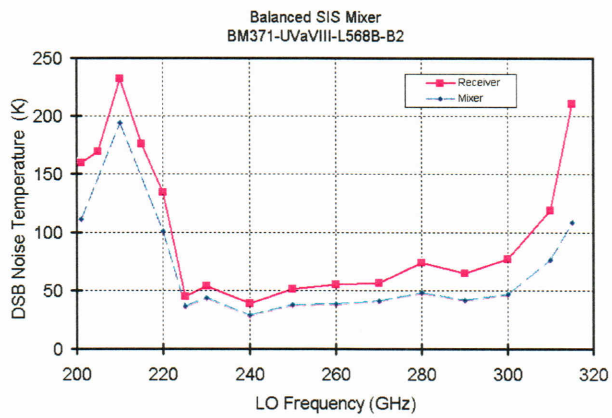
Balanced SIS mixer for 200-300 GHz.
Size 2 x 1 mm.

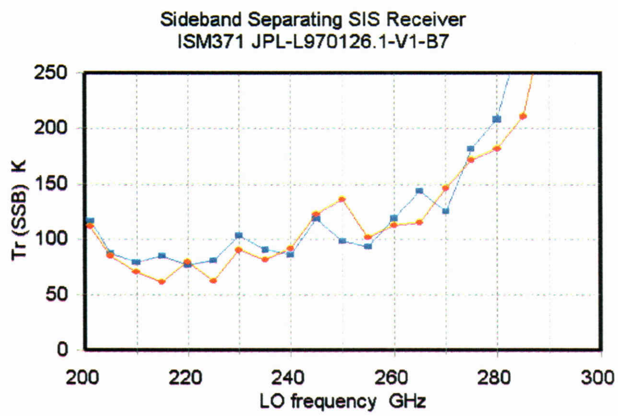


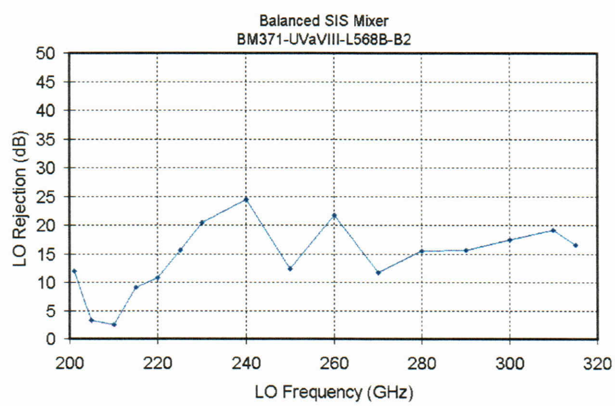
Sideband separating SIS mixer for 200-300 GHz.
Size 2 x 1 mm.

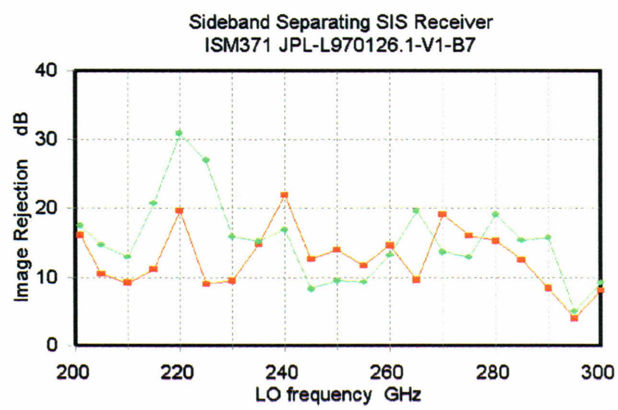

2.0 mm


2.0 mm

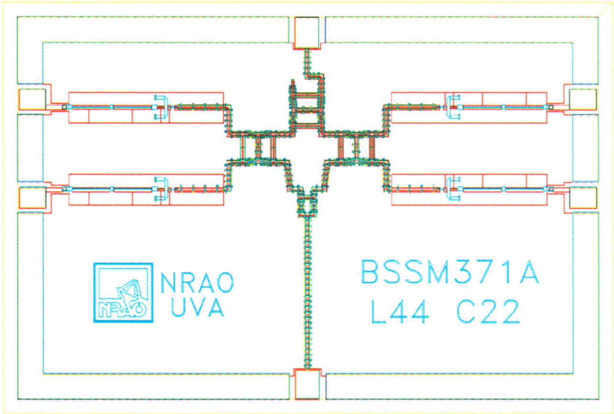

Balanced SIS Mixer
BM371-UVaVIII-L568B-B2
Receiver
Mixer
DSB Noise Temperature (K)
LO Frequency (GHz)


Sideband Separating SIS Receiver
ISM371 JPL-L970126.1-V1-B7
Tr (SSB) K
LO frequency GHz

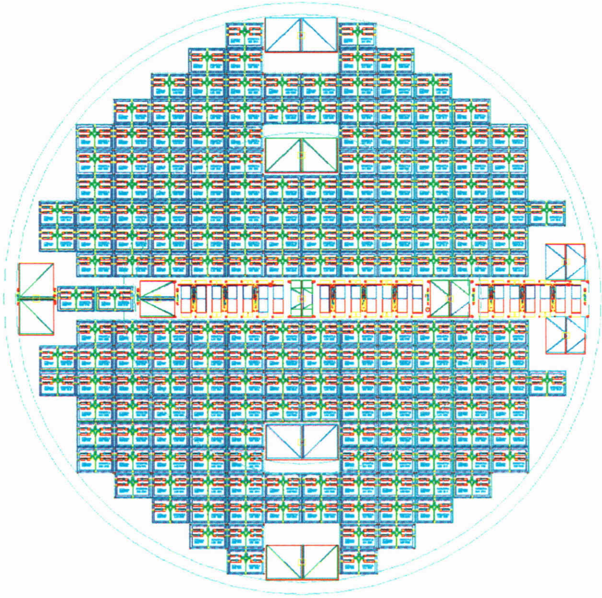

Balanced SIS Mixer
BM371-UVaVIII-L568B-B2
LO Rejection (dB)
LO Frequency (GHz)


Sideband Separating SIS Receiver
ISM371 JPL-L970126.1-V1-B7
Image Rejection dB
LO frequency GHz

Balanced sideband separating mixer for 211-275 GHz.

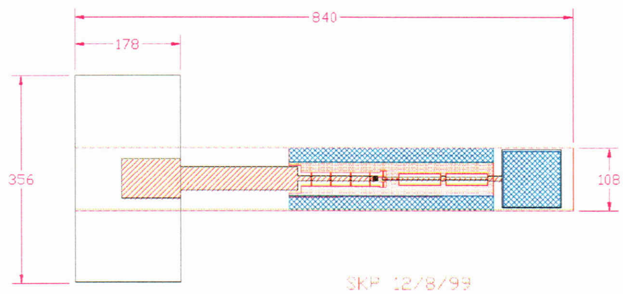


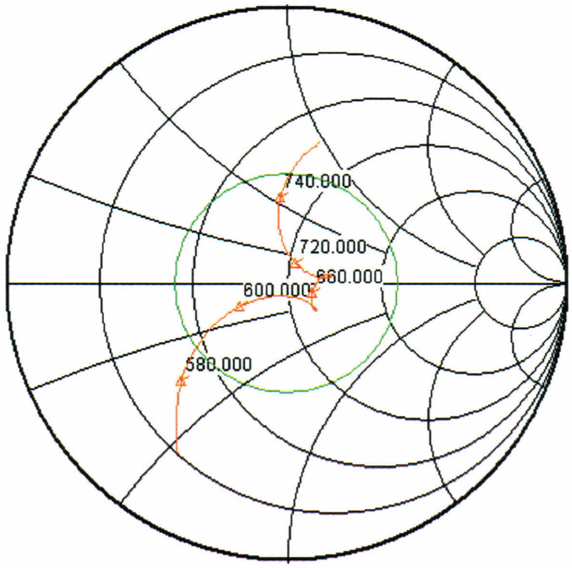
50-mm wafer containing 184 balanced sideband separating SIS mixers.

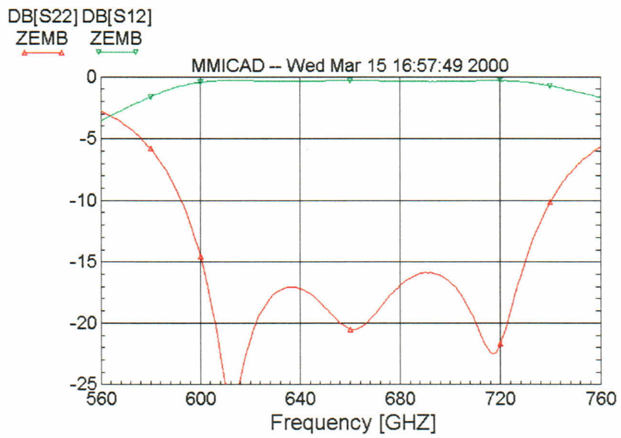


A building Block SIS Mixer for 600-720 GHz

- —Fully integrated (MMIC) fixed-tuned waveguide mixer with feed horn build into the mixer block
- —Design can be used as the building block in balanced and sideband separating mixers
- —Return loss of the waveguide probe better than 25db
- —Uses capacitively-loaded coplanar waveguide (CLCPW) as transmission line medium
- —Uses twin-junction tuning circuit to tune out the junction capacitance
- —Uses 0.8 μm^2 junction, Jc ~ 12,000 A/cm^2: compatible with SUNY/Stony Brook process
- —Do not need lossy multisection microstrip transformer for matching
- —Low output capacitance (~175 fF) and inductance (~85 pH): compatible with proposed 4-12 GHz IF





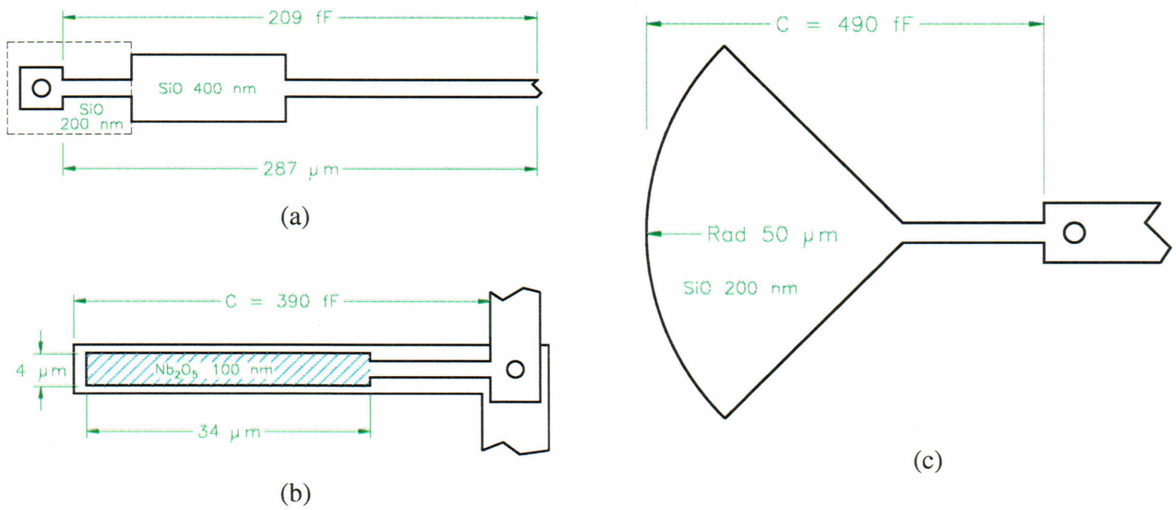


Implications of the ALMA IF requirements

Isolator needed if IF amplifier is not in the mixer block.

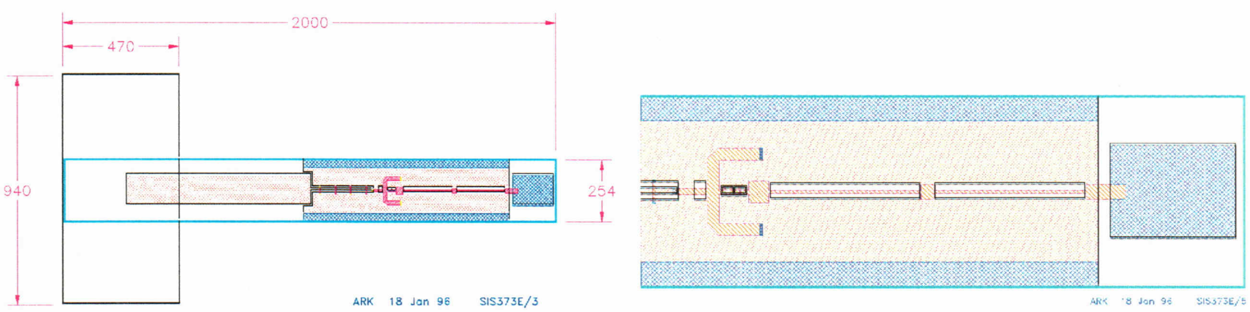
Disadvantages of an IF isolator:
- Max isolator bandwidth ~1 octave⇒ 8-16 GHz IF or higher.
- Noise from 4 K termination reflected from SIS mixer degrades T_{IF}.

IF preamp integrated into mixer block (Padin) allows wide fractional IF bandwidth as long as mixer parasitic L and C are small.



Three RF tuning circuits used in SIS mixers. Dimensions and capacitances indicated are for a center frequency of ~230 GHz. (a) End loaded matching circuit. (b) Tuning inductor with λ/4 microstrip stub. (c) Tuning inductor with radial microstrip stub. (Diagrams not to scale.)

Building Block SIS Mixer with Low IF Parasitics



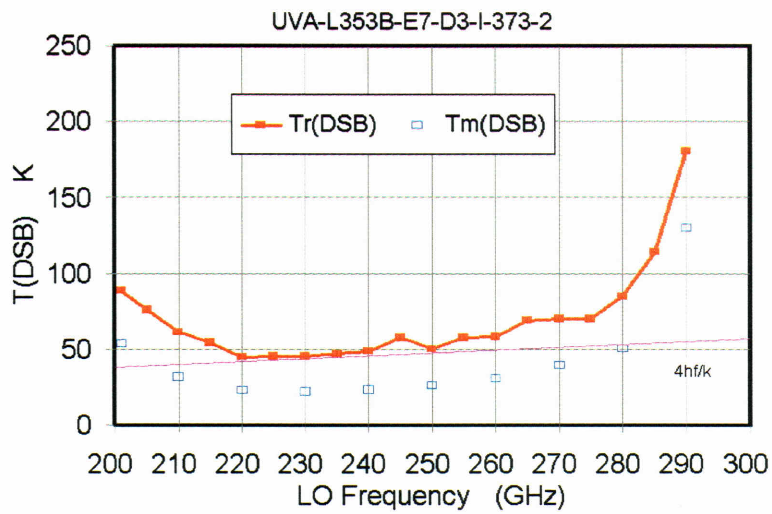
(a)

The low-parasitic SIS mixer for 200-300 GHz. (a) The whole mixer, showing the suspended stripline probe which couples to the signal/LO waveguide at the left. The ground plane contacts the mixer block along gold plated contact strips on the upper and lower edged of the substrate. The bonding pad for the IF connection is at the right end of the substrate. (b) The right-hand end of the substrate, showing the RF tuning circuit at the left, the two-section RF choke, and the DC/IF bonding pad.

CAPACITANCE	SAO Mixer	NRAO-373 2-section RFC	NRAO-373 1-section RFC
RFC	200 fF	137 fF	68 fF
RF circuit	210 fF	66 fF	66 fF
SIS junction	60 fF	38 fF	38 fF
TOTAL	**470 fF**	**241 fF**	**172 fF**

INDUCTANCE	SAO Mixer	NRAO-373 2-section RFC	NRAO-373 1-section RFC
RFC	1660 pH	235 pH	115 pH
RF circuit	42 pH	59 pH	59 pH
SIS junction	--	--	--
TOTAL	**1702 pH**	**294 pH**	**174 pH**

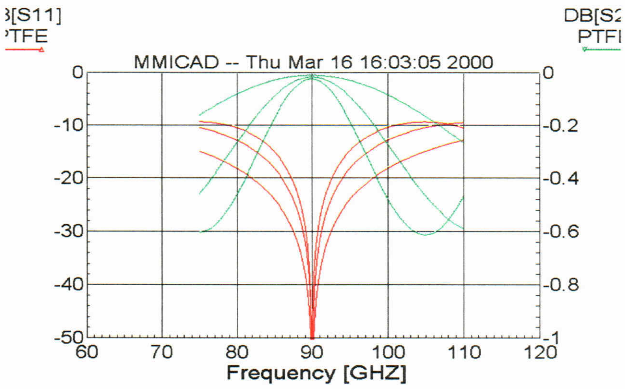
DSB receiver noise temperature (solid line) and mixer noise temperature (open squares). Shown for reference is the line 4hf/k.



Vacuum Windows

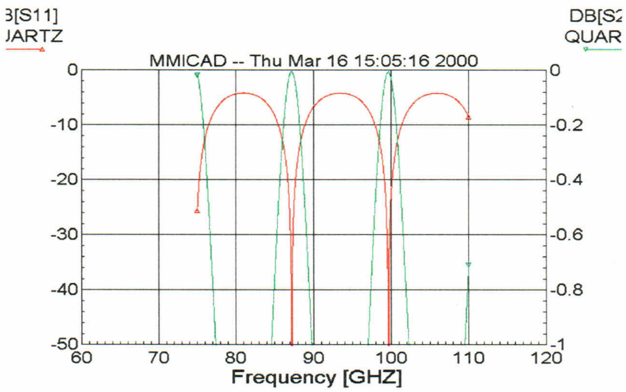
PTFE

Thickness	f_2/f_1 (0.1 dB)	f_2/f_1 (-20 dB)
0.0453"	1.29	1.18
0.0906"	1.13	1.09
0.1360"	1.08	1.06



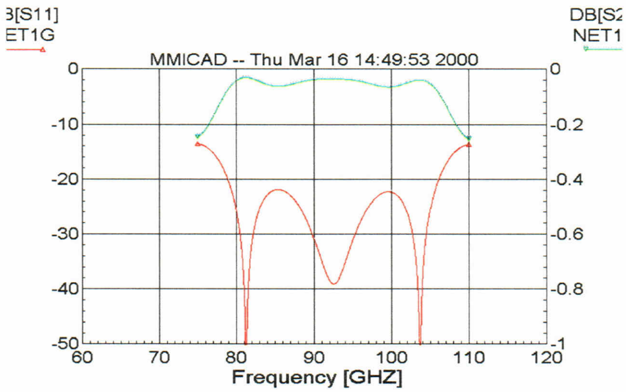
z-Quartz 0.223"

Clear aperture 3.5"



PTFE 0.022"
z-Quartz 0.223"
PTFE 0.022"

Clear aperture 3.5"



XPTFE 0.032"
HDPE 0.022"
z-Quartz 0.241"
HDPE 0.022"
XPTFE 0.032"

Clear aperture 3.5"