
© Bob Turner

Mixer Diodes Millimeter??

NORTH TEXAS MICROWAVE SOCIETY

April 13, 2019

Chuck Clark, AF8Z

Goal: Make a MMW Mixer for ??

- How to use existing Avago Diodes to get a upconverter/downconverter.
- Diodes need to be solderable, SOT23, SOT143, SOT363
  - Pkg model HP AN1124
- Diodes: HSMS-282x C case style for antiparallel pair (harmonic mixing.).

Where to Start?

$$I_D = I_S\left(e^{\frac{qV_D}{nkT}} - 1\right)$$

Ideal Diode Equation

Where

I_D and V_D are the diode current and voltage, respectively

q is the charge on the electron

n is the ideality factor: n = 1 for indirect semiconductors (Si, Ge, etc.)
n = 2 for direct semiconductors (GaAs, InP, etc.)

k is Boltzmann's constant

T is temperature in Kelvin

kT/q is also known as V_{th}, the thermal voltage. At 300K (room temperature), kT/q = 25.9mV

Simplification

- When V_D is negative

$$I_D \sim -I_S$$

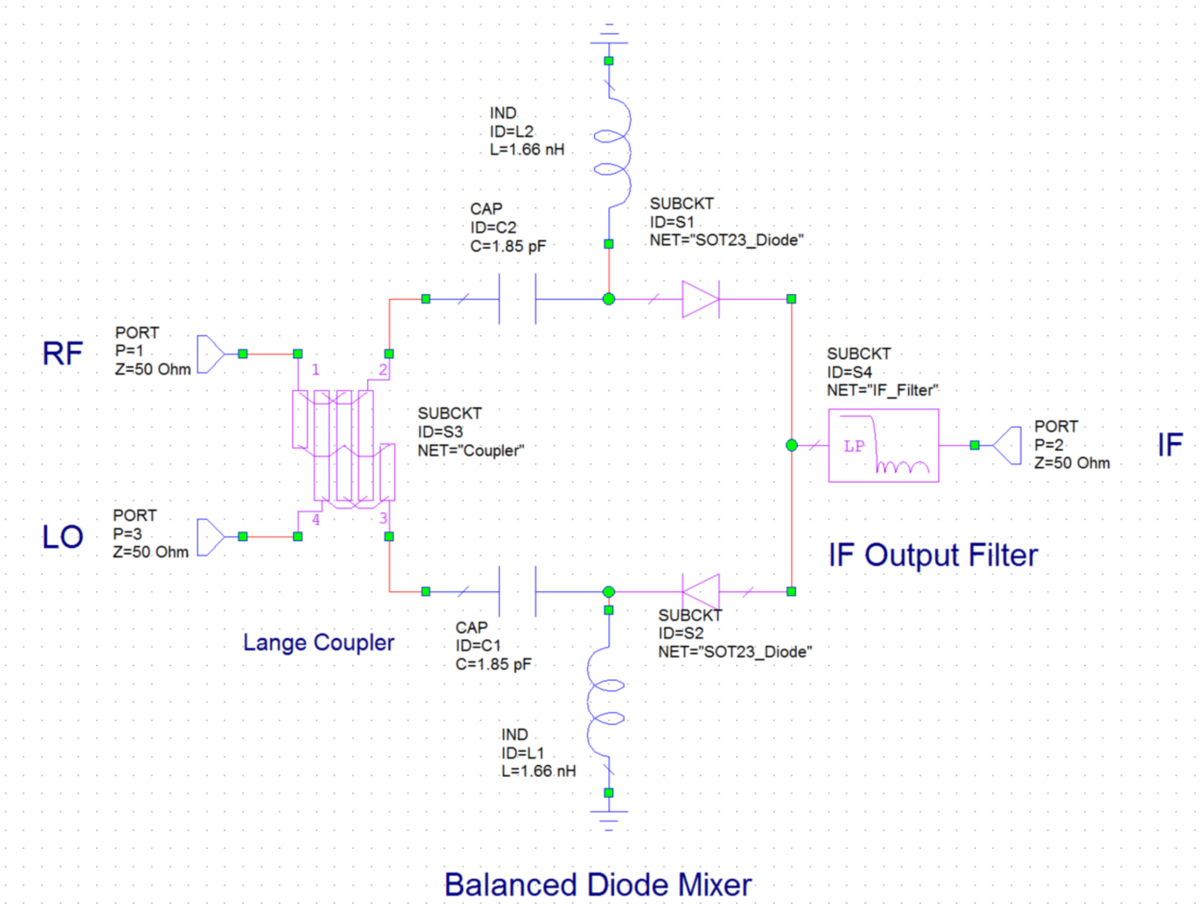
- When V_D is positive

$$I_D \sim I_S e^{\frac{qV_D}{nkT}}$$

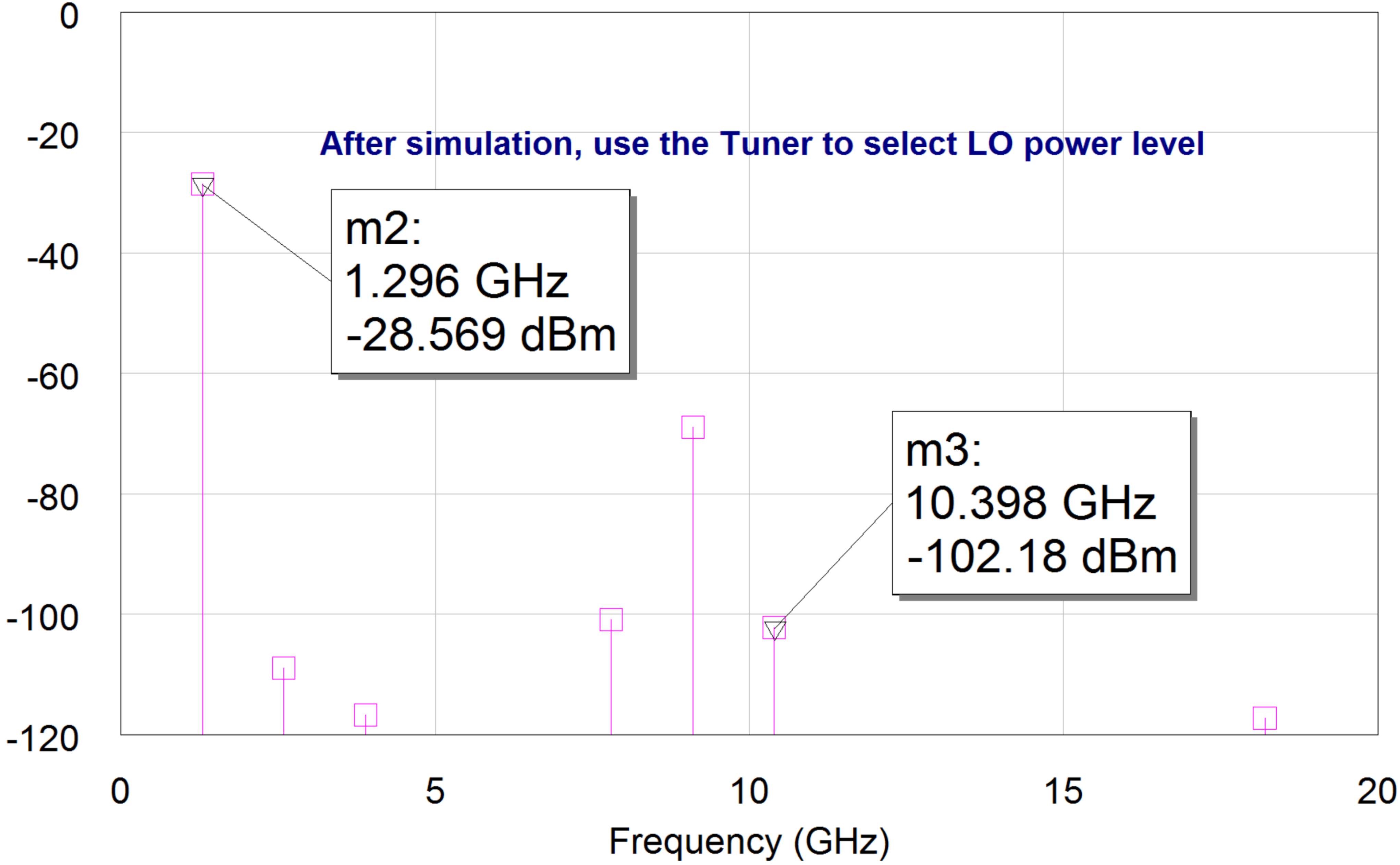
Where to Start?

- Microwave Office: Has a Diode Mixer Example file….
  - Uses SOT23 diode package
  - Balanced (quad hybrid) to isolate LO and RF
  - Frequency 4.25 GHz
  - Lange Coupler allows easy change in frequency.

MWO Model


IND
ID=L2
L=1.66 nH
CAP
ID=C2
C=1.85 pF
SUBCKT
ID=S1
NET="SOT23_Diode"
RF
PORT
P=1
Z=50 Ohm
SUBCKT
ID=S3
NET="Coupler"
SUBCKT
ID=S4
NET="IF_Filter"
LP
PORT
P=2
Z=50 Ohm
IF
LO
PORT
P=3
Z=50 Ohm
IF Output Filter
Lange Coupler
CAP
ID=C1
C=1.85 pF
SUBCKT
ID=S2
NET="SOT23_Diode"
IND
ID=L1
L=1.66 nH
Balanced Diode Mixer

Mixer IF Output Power Spectrum

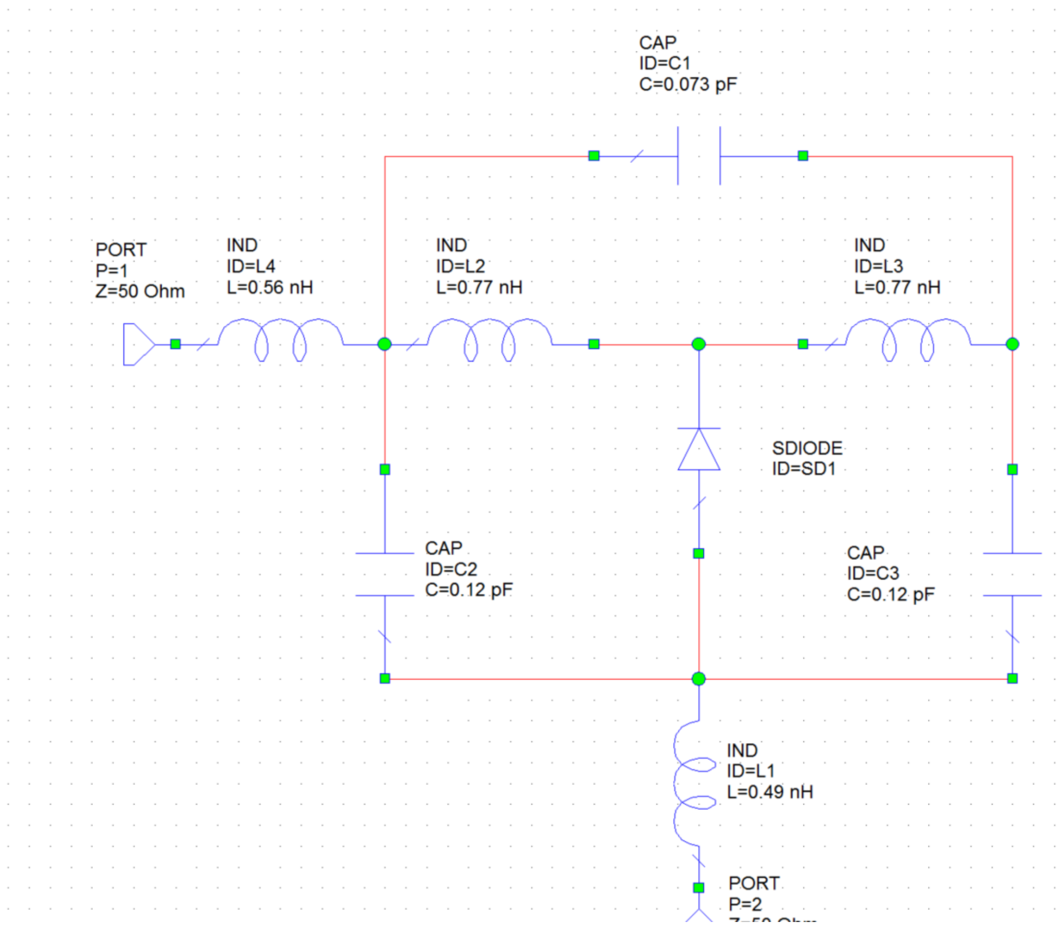


Results

- Input Signal -10 dBm….If selected to be 1296 MHz
- Loss

Frequency GHz	Loss dB
4.25	9.7
6.25	9.7
8.25	12.7
10.398	18.6 29.8 after fixing HMSX282x model

Why Does it fall apart at 10 GHz



The 4 inductors cause almost all of the excess loss!

The diode model hasn't been eliminated yet.

SC-79 package, smaller lower inductance?

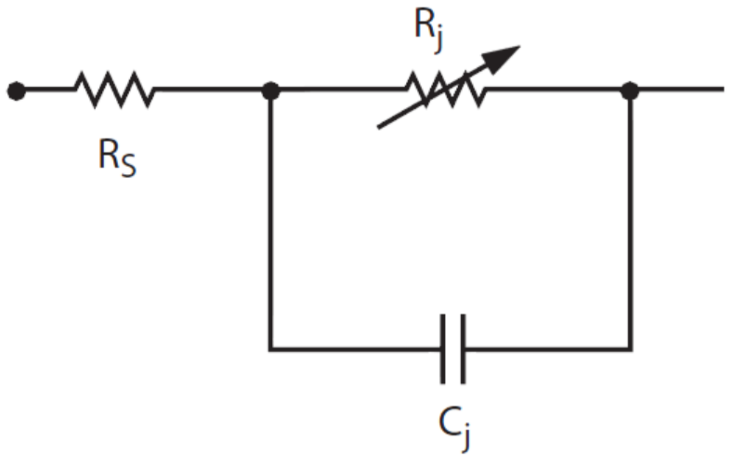
Beam Lead?

Diode Parameters

SPICE Parameters

Parameter	Units	HSMS-282x
B_V	V	15
C_{J0}	pF	0.7
E_G	eV	0.69
I_{BV}	A	1E - 4
I_S	A	2.2E-8
N		1.08
R_S	Ω	6.0
P_B	V	0.65
P_T		2
M		0.5

Linear Equivalent Circuit Model Diode Chip



R_S = series resistance (see Table of SPICE parameters)

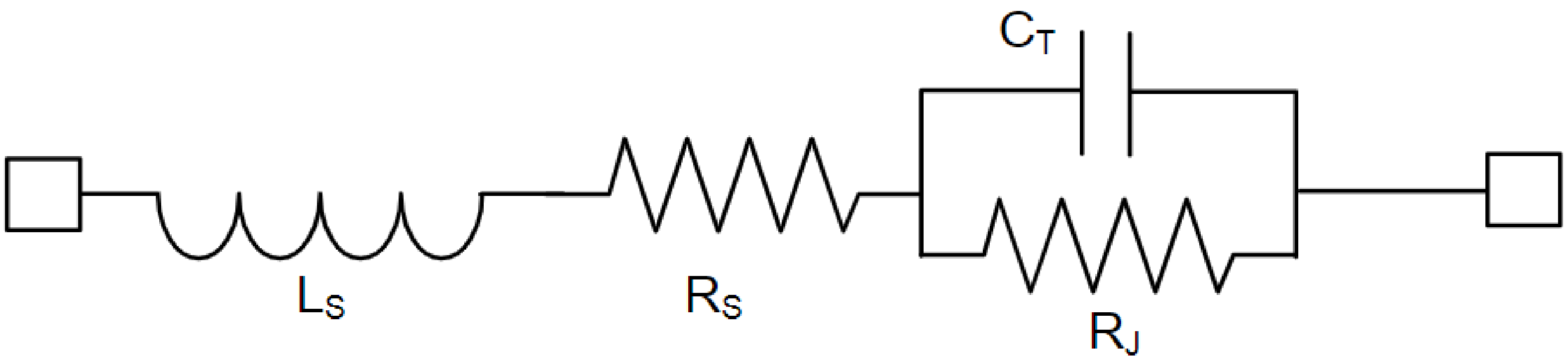
C_j = junction capacitance (see Table of SPICE parameters)

$$R_j = \frac{8.33 \times 10^{-5}\, nT}{I_b + I_s}$$

More Complete Spice Diode Model

Name	Value	Unit	Tune	Optimize	Constrain	Lower	Upper	Step Size	Use Statistics	Yield Optimize	Tolerance	Distribution	Tolerance2	Hide	Hide Label	Description
ID	SD1													☐	☐	Diode ID
IS	1e-14	mA	☐	☐	☐				☐	☐				☑	☐	Reverse saturation current
JSW	0	mA												☑	☐	Periphery reverse saturation current
MULT	1.0		☐	☐	☐				☐	☐				☑	☐	Scaling factor
AFAC	1		☐	☐	☐				☐	☐				☑	☐	Junction area
PJFAC	0.0													☑	☐	Junction periphery
RS	11	Ohm												☑	☐	Series resistance
N	1.115		☐	☐	☐				☐	☐				☑	☐	Bottom ideality factor
TT	0	us	☐	☐	☐				☐	☐				☑	☐	Storage time
CJ0	0	pF	☐	☐	☐				☐	☐				☑	☐	Zero-voltage bottom junction capacitance
CJP	0	pF												☑	☐	Zero-voltage periphery junction capacitance
VJ	1	mV	☐	☐	☐				☐	☐				☑	☐	Bottom built-in voltage
PHP	800	mV	☐	☐	☐				☐	☐				☑	☐	Periphery built-in voltage
M	0.5		☐	☐	☐				☐	☐				☑	☐	Bottom junction grading coefficient
MJSW	0.33		☐	☐	☐				☐	☐				☑	☐	Periphery junction grading coefficient
FC	0.5		☐	☐	☐				☐	☐				☑	☐	Bottom depletion capacitance linearization parameter
FCS	0.5		☐	☐	☐				☐	☐				☑	☐	Periphery depletion capacitance linearization parameter
BV	15000	mV	☐	☐	☐				☐	☐				☑	☐	Breakdown voltage
IBV	0.0005	mA	☑	☐	☐				☐	☐				☑	☐	Current at breakdown voltage
IKF	0	mA	☐	☐	☐				☐	☐				☑	☐	Forward knee current
IKR	0	mA	☐	☐	☐				☐	☐				☑	☐	Reverse knee current
EG	1.11		☐	☐	☐				☐	☐				☑	☐	Energy gap @ TNOM; default is Si
XTI	3.0		☐	☐	☐				☐	☐				☑	☐	Temp scaling coefficient; default is Si PN
TEXT	26.85	DegC	☐	☐	☐				☐	☐				☑	☐	Temperature at which diode params were determined
T	27	DegC	☐	☐	☐				☐	☐				☑	☐	Temperature
KF	0		☐	☐	☐				☐	☐				☑	☐	Flicker noise coefficient
AF	1.0		☐	☐	☐				☐	☐				☑	☐	Flicker noise exponent
FFE	1.0		☐	☐	☐				☐	☐				☑	☐	Flicker noise frequency exponent
KB	0.0		☐	☐	☐				☐	☐				☑	☐	Burst noise coefficient
AB	1.0		☐	☐	☐				☐	☐				☑	☐	Burst noise exponent
FB	1.0		☐	☐	☐				☐	☐				☑	☐	Burst noise cutoff frequency
NFLAG	Spice Model		☐	☐	☐				☐	☐				☑	☐	Noise model
DCAP	1		☐	☐	☐				☐	☐				☑	☐	Capacitance model selector
TLEV	0		☐	☐	☐				☐	☐				☑	☐	I/V temperature model
TLEVC	0		☐	☐	☐				☐	☐				☑	☐	Capacitance temperature model
CTA	0.0		☐	☐	☐				☐	☐				☑	☐	Temperature coefficient for CJ0
CTP	0.0		☐	☐	☐				☐	☐				☑	☐	Temperature coefficient for CJP
GAP1	7.02E-4		☐	☐	☐				☐	☐				☑	☐	First bandgap correction factor
GAP2	1108		☐	☐	☐				☐	☐				☑	☐	Second bandgap correction factor
TCV	0.0		☐	☐	☐				☐	☐				☑	☐	Breakdown voltage temperature coefficient
TM1	0.0		☐	☐	☐				☐	☐				☑	☐	First-order temperature coefficient for M
TM2	0.0		☐	☐	☐				☐	☐				☑	☐	Second-order temperature coefficient for M
TPB	0.0		☐	☐	☐				☐	☐				☑	☐	Temperature coefficient for VJ
TPHP	0.0		☐	☐	☐				☐	☐				☑	☐	Temperature coefficient for PHP
TRS	0.0		☐	☐	☐				☐	☐				☑	☐	Parasitic resistance temperature coefficent
TTT1	0.0		☐	☐	☐				☐	☐				☑	☐	First-order temperature coefficient for TT
TTT2	0.0		☐	☐	☐				☐	☐				☑	☐	Second-order temperature coefficient for TT
IMAX	1e+006	mA	☐	☐	☐				☐	☐				☑	☐	Maximum device current (for improving convergence)
COMPAT	AWR													☑	☐	Model compatibility selector
NS														☑	☐	Periphery ideality factor
RSW		Ohm												☑	☐	Sidewall series resistance
NZ														☑	☐	Emission coefficient for Zener diode
TRS2	0.0		☐	☐	☐				☐	☐				☑	☐	Quadratic temperature coefficient for parasitic resistanc
GLEAK		S												☑	☐	Bottom junction leakage conductance
GLEAKSW		S												☑	☐	Sidewall junction leakage conductance
TGS	0.0		☐	☐	☐				☐	☐				☑	☐	Linear temperature coefficient for leakage conductance
TGS2	0.0		☐	☐	☐				☐	☐				☑	☐	Quadratic temperature coefficient for leakage conducta
CD	0	pF	☐	☐	☐				☐	☐				☑	☐	Linear capacitance
ISR	0	mA	☐	☐	☐				☐	☐				☑	☐	Recombination current
NR	2.0		☐	☐	☐				☐	☐				☑	☐	Recombination current ideality factor
JTUN	0	mA	☐	☐	☐				☐	☐				☑	☐	Tunneling saturation current per area
NTUN														☑	☐	Reverse tunneling new ideality factor
KEG														☑	☐	EG correction factor for tunneling
XTITUN														☑	☐	Exponent for the tunneling current temperature
EGTUN														☑	☐	Tunneling Energy gap @ TNOM
JTUNSW	0	mA	☐	☐	☐				☐	☐				☑	☐	Sidewall tunneling saturation current per unit junction pe

MA4E2502 Diode Schematic



Schematic Values

Model Number	Ls (nH)	Rs (Ω)	Rj (Ω)	Ct (pF)
MA4E2502L	0.45	12.8	26 / Idc (mA)	0.10
MA4E2502M	0.45	9.6	26 / Idc (mA)	0.10
MA4E2502H	0.45	6.5	26 / Idc (mA)	0.10

MA4E2502L Low Barrier SPICE PARAMETERS

Is (nA)	Rs (Ω)	N	Cj0 (pF)	M	Ik (mA)	Cjpar (pF)	Vj (V)	FC	BV (V)	IBV (mA)
26	12.8	1.20	1.0 E-2	0.5	14	9.0 E-2	8.0 E-2	0.5	5.0	1.0 E-2

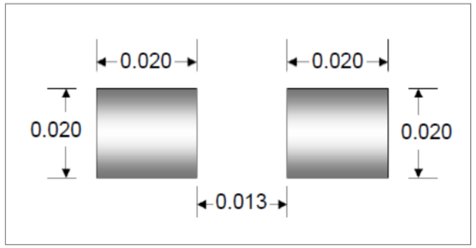
MA4E2502M Medium Barrier SPICE PARAMETERS

Is (mA)	Rs (Ω)	N	Cj0 (pF)	M	Ik (mA)	Cjpar (pF)	Vj (V)	FC	BV (V)	IBV (mA)
5 E-1	9.6	1.20	1.0 E-02	0.5	10	9.0 E-2	8.0 E-2	0.5	5.0	1.0 E-2

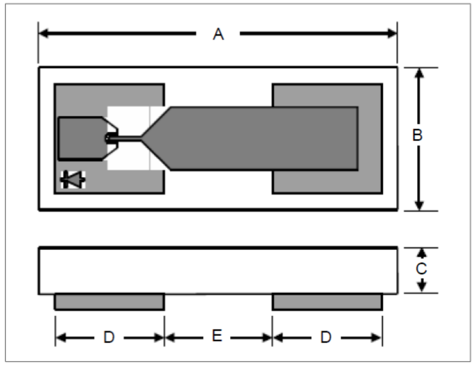
MA4E2502H High Barrier SPICE PARAMETERS

Is (mA)	Rs (Ω)	N	Cj0 (pF)	M	Ik (mA)	Cjpar (pF)	Vj (V)	FC	BV (V)	IBV (mA)
5.7 E-1	6.5	1.20	1.0 E-02	0.5	4	9.0 E-2	8.0 E-2	0.5	5.0	1.0 E-2

Circuit Mounting Dimensions (Inches)



Case Style 1246



DIM.	INCHES		MILLIMETERS	
	MIN.	MAX.	MIN.	MAX.
A	0.0445	0.0465	1.130	1.180
B	0.0169	0.0189	0.430	0.480
C	0.0040	0.0080	0.102	0.203
D Sq.	0.0128	0.0148	0.325	0.375
E	0.0128	0.0148	0.325	0.375

AmScope 3.5X-90X Zoom Trinocular Stereo Microscope with Table Pillar Stand

Brand New

★★★★★ 20 product ratings

$286.99

List price: ~~$545.99~~

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Free Shipping

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Brand New

$496.99

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2 new & refurbished from $496.99

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$65.98

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Free shipping

Arrives by Tuesday, Apr 16 Options

Add a Walmart Protection Plan powered by Allstate

None	2 Year - $6.00	3 Year - $8.00

Qty:

1

Add to Cart

Pickup not available

Sold & shipped by E-STORE ATC | Return policy

Results

- Input Signal -10 dBm….If selected to be 1296 MHz
- Loss

Frequency GHz	Loss dB
4.25	9.7
6.25	9.7
8.25	12.7
10.398	18.6 29.8 after fixing HMSX282x model 10.4 using MA4E2502L diode….

MA4Exxxx Series

MACOM

GaAs Flip Chip
Schottky Barrier Diodes

Rev. V11

Electrical Specifications @ +25°C

Parameters and Test Conditions	Symbol	Units	MA4E1317			MA4E1318		
			Min.	Typ.	Max.	Min.	Typ.	Max.
Junction Capacitance at 0 V at 1 MHz	Cj	pF	-	.020	-	-	.020[3]	-
Total Capacitance at 0 V at 1 MHz[1]	Ct	pF	.030	.045	.060	.030[3]	.045[3]	.060[3]
Junction Capacitance Difference	DCj	pF	-	-	-	-	.005	.010
Series Resistance at +10 mA[2]	Rs	Ohms	-	4	7	-	4	7
Forward Voltage at +1 mA	Vf1	Volts	.60	.70	.80	.60	.70	.80
Forward Voltage Difference at +1 mA	DVf	Volts	-	-	-	-	.005	.010
Reverse Breakdown Voltage at -10 µA	Vbr	Volts	4.5	7	-	-	-	-
SSB Noise Figure	NF	dB	-	6.5[4]	-	-	6.5[4]	-

Parameters and Test Conditions	Symbol	Units	MA4E1319-1 or -2			MA4E2160		
			Min.	Typ.	Max.	Min.	Typ.	Max.
Junction Capacitance at 0 V at 1 MHz	Cj	pF	-	.020[3]	-	-	-	.020[3]
Total Capacitance at 0 V at 1 MHz[1]	Ct	pF	.030[3]	.045[3]	.060[3]	.060[3]	.030[3]	.045[3]
Junction Capacitance Difference	DCj	pF	-	.005	.010	.010	-	.005
Series Resistance at +10 mA[2]	Rs	Ohms	-	4	7	7	-	4
Forward Voltage at +1 mA	Vf1	Volts	.60	.70	.80	.80	.60	.70
Forward Voltage Difference at +1 mA	DVf	Volts	-	.005	.010	.010	-	.005
Reverse Breakdown Voltage at -10 µA	Vbr	Volts	4.5	7	-	-	4.5	7
SSB Noise Figure	NF	dB	-	6.5[4]	-	-	-	6.5[4]

- Still about $2.00
- Even smaller…..
- Special solder/epoxy to mount
- Vendor claims 80 GHz performance.

- Why it works:
  - Low junction capacitance
  - Low series inductance

For the Massocist.

VIRGINIA Diodes Inc.

DIODE SPECIFICATION

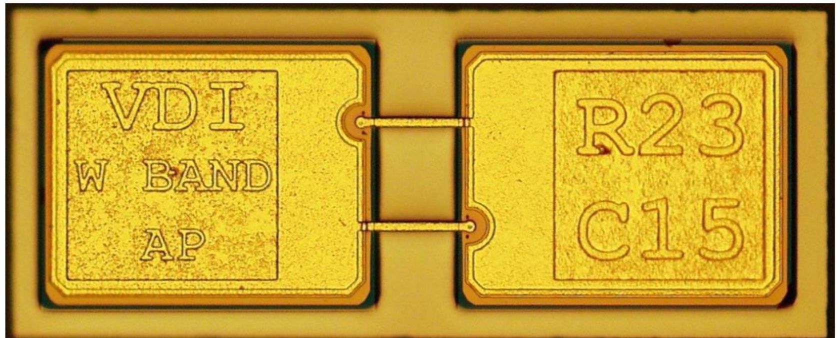
W Band Anti-Parallel

Table I ELECTRICAL CHARACTERISTICS

	Test Conditions	Minimum Value	Maximum Value	Maximum δ side to side	Units
R_s Series Resistance	I_{max}=10 mA		4	0.5	Ω
V_F Forward Turn-on Voltage	I_F = 1 μA	470	520	10	mV
ΔV	100 μA – 10 μA		70	1	mV
C_T Total Capacitance Both Anodes	V = 0V	56	62	N/A	fF
C_{PP} Pad to Pad Capacitance	V = 0V		15		fF

Table II PHYSICAL DIMENSIONS

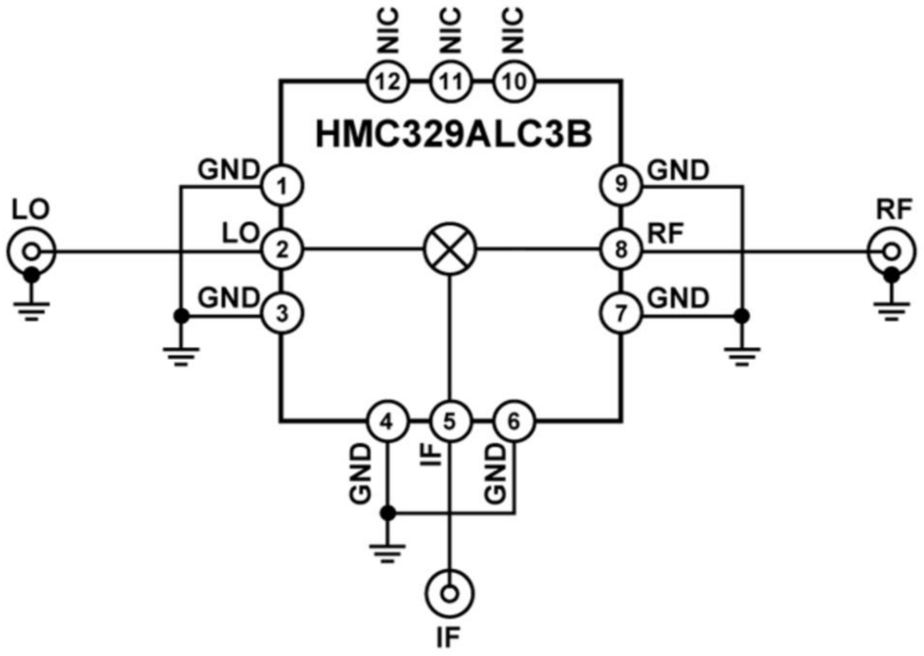
	Minimum Value	Maximum Value	Units
Chip Length	580	630	μm
Chip Width	230	280	μm
Substrate Thickness	90	100	μm



- These are very EDS sensitive.
- There are higher frequency diodes, try Hughes Research, tunnel/back diodes.

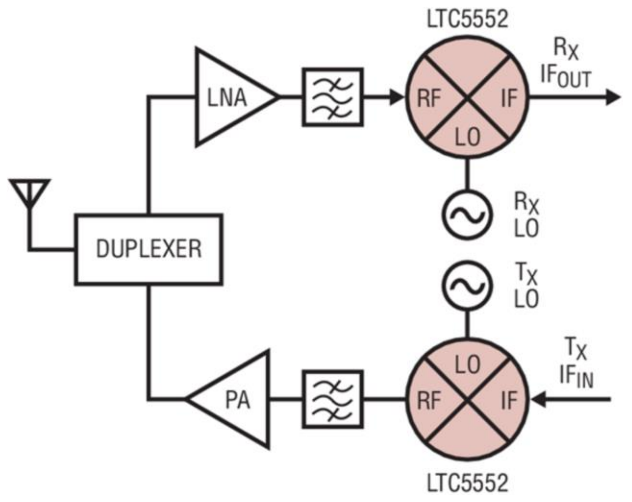
Alternative Approach

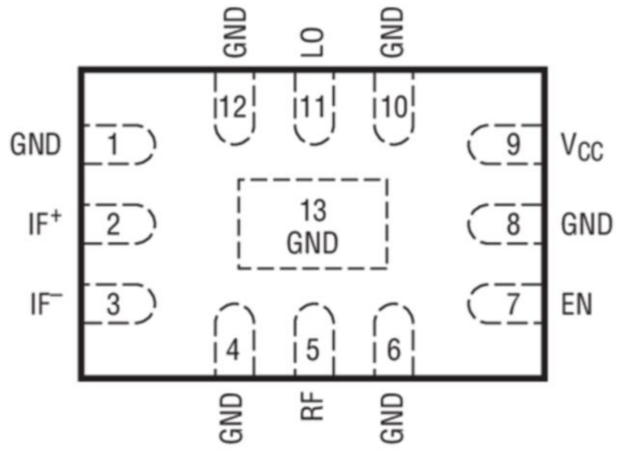
- **Let the semiconductor vendor do the hard stuff…**
  - Diode mounting
  - Quadrature hybrid.



24-32 GHz input DC-8 GHz IF
11 dB conversion loss
20 dBm IIP3
9 dBm LO
3mmx3mm LCC Package
That damn soldering problem again.

Others



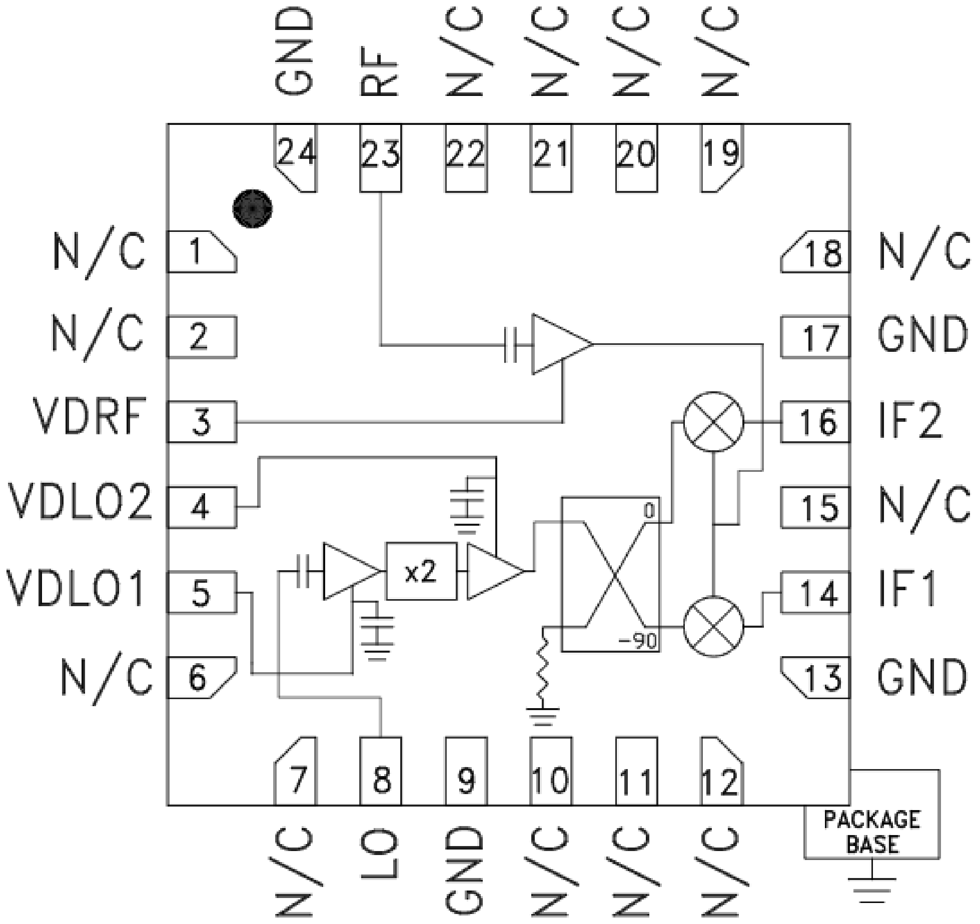


UDB PACKAGE
12-LEAD (3mm × 2mm) PLASTIC QFN

3-20 GHz RF Range DC-6 GHz IF
0 dBm LO drive
8 dB conversion loss
$44.00 Mouser
118x78 mils

I/Q   Well We do Want Direct Conversion!

- 21-24 GHz IF DC-3.5GHz
- Conversion Gain 15 dB
- LO Multiplication
- 4x4mm package
- HMC967LP4E
- $35.42
- HMC7912 matching up converter



Higher Bands

- OOPS ! They are die
  - Epoxy parts down
  - Wire bond.
    - I am known to be bad at wirebonding.
    - Some techs are quite good on primitive equipment….

Soldering Tools

- My First

Soldering in College

Current Tools

For The Next Level

Price

Under $350.00 | $350.00 - $3,500.00 | Over $3,500.00

West Bond 7316A Wire Bonder

Pre-Owned

$999.99

Buy It Now

+$52.73 shipping

Guaranteed by **Fri, Apr. 19**

References

- https://www.microwaves101.com/encyclopedias/branchline-couplers
- MWO Examples Diode Mixer
- https://filebox.ece.vt.edu/~LiaB/ECE2204/Lectures/Diodes/Ideal%20Diode%20Equation.pdf
- HP AN1124