LO Signal Generation Circuit for Power Amplifier in a 7 Tesla MRI System

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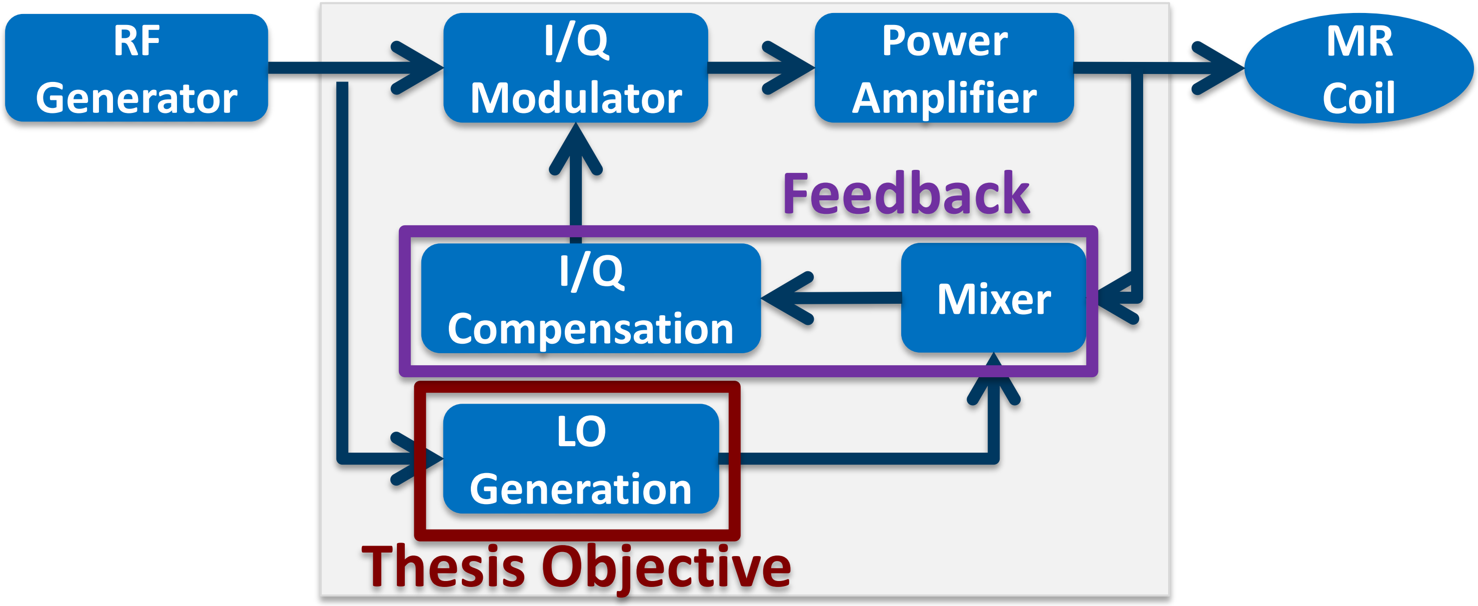
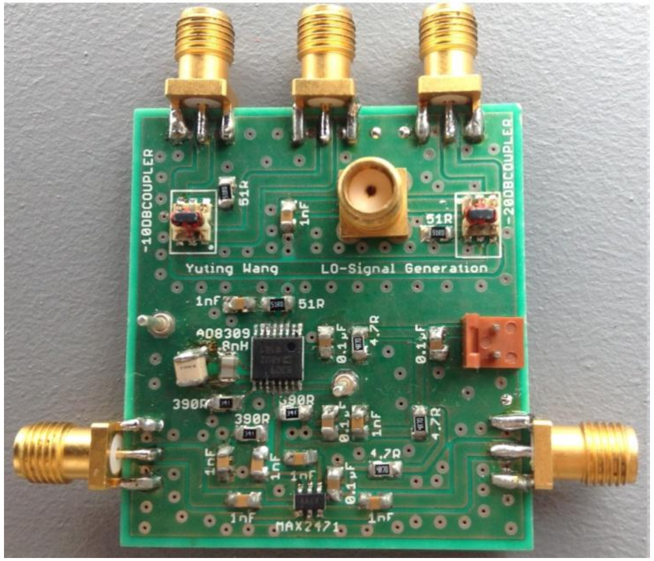
Background

- MRexcite project for 7-Tesal MRI
- 32-Channel RF transmit power amplifier

  = RF power amplifier + a Cartesian feedback loop
- Satisfactory LO → robust feedback → precise phase and amplitude



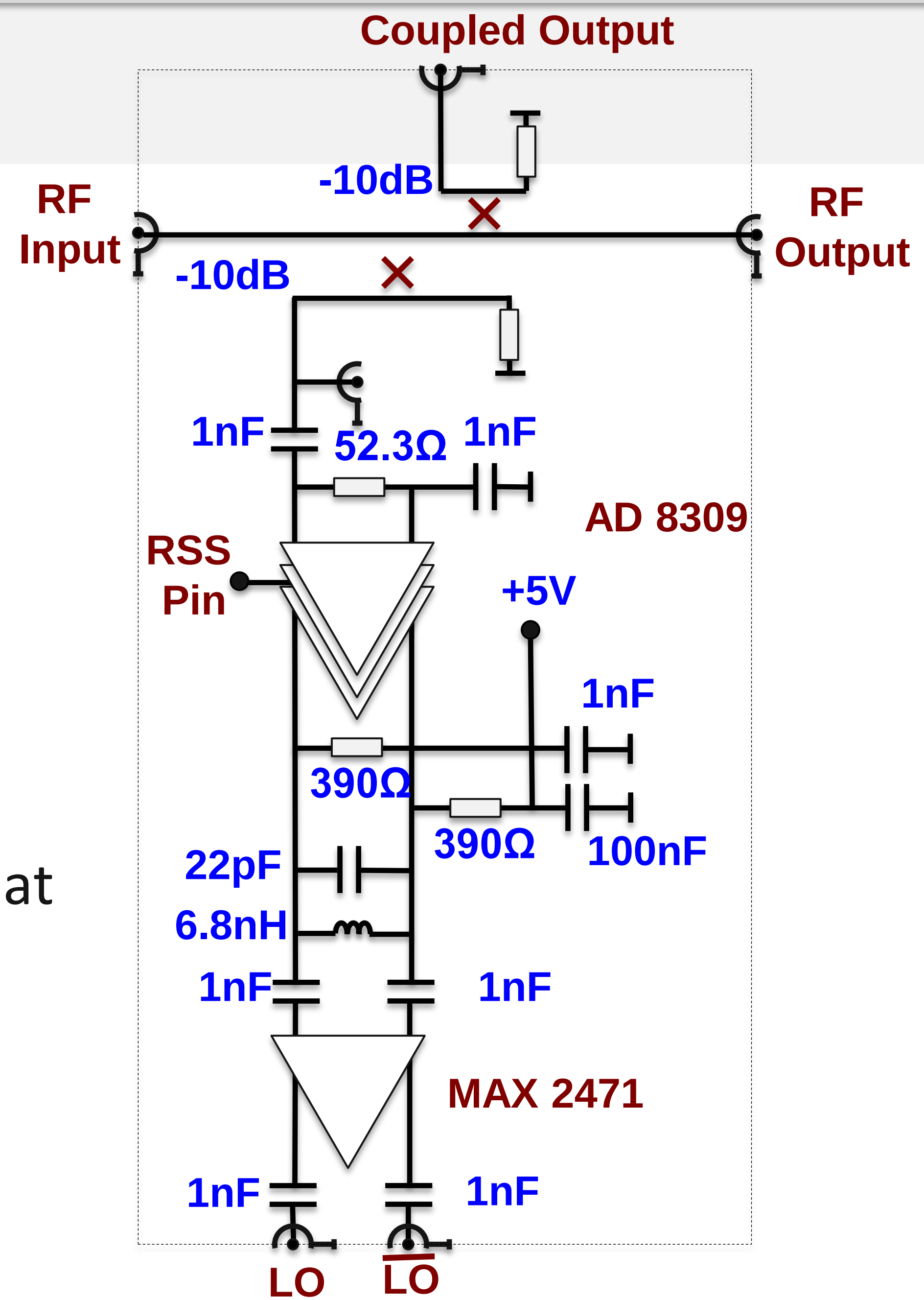
Outline



1. System Overview
2. Component Modules
3. PCB Design
4. PCB Assembly
5. Testing & Measurement
6. Conclusions

System overview

- **LO signal generation circuit**
- **Task objective:**
  - 1. Design
  - 2. Test DC current and DC voltage
  - 3. Check correct coupling level of directional coupler
  - 4. Check generated signals at limiting amplifier
  - 5. Check LO output signals

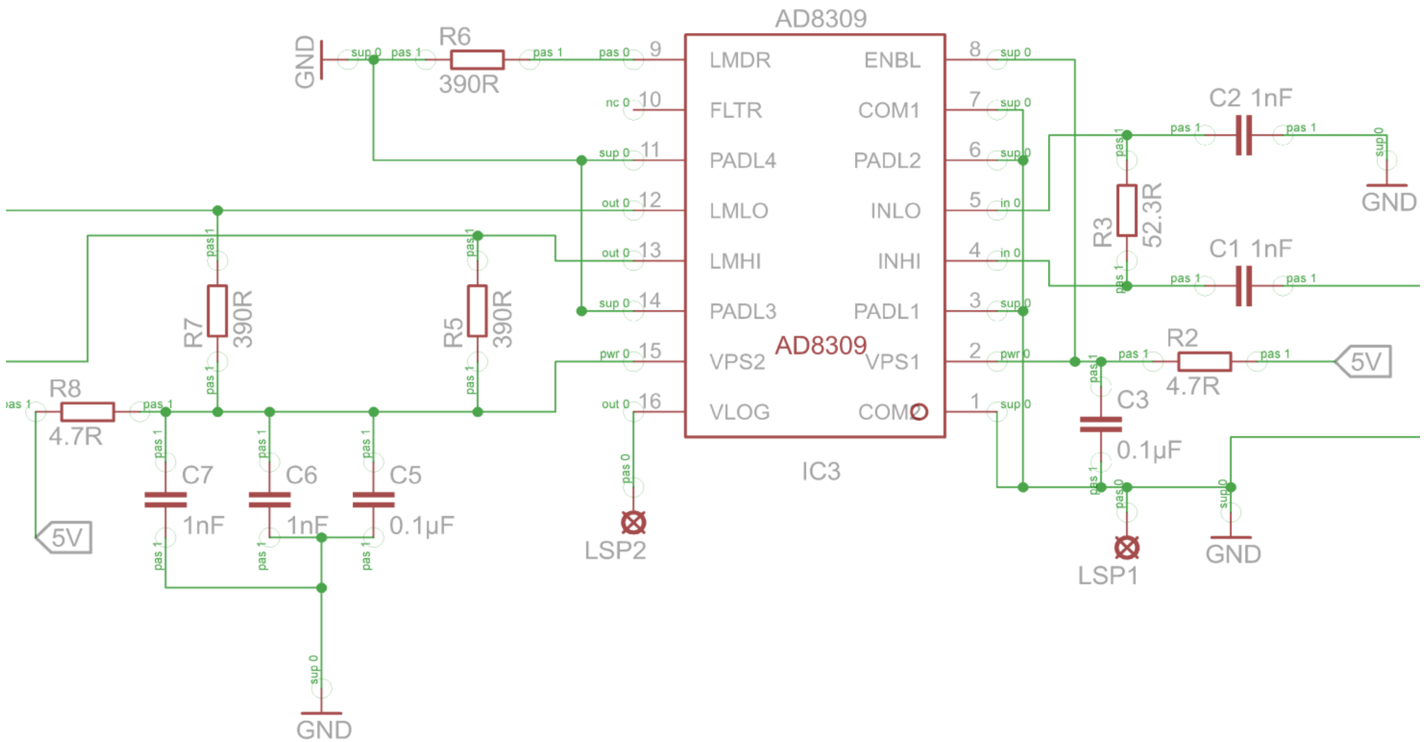


1. Logarithmic Limiting Amplifier AD8309

- **Logarithmic output & two limiter outputs**
- **Power supply: +2.7V to +6.5V (+5.00V)**

$$I_{out} = 400mV / R_{LIM}$$

$$V_{LIM} = V_S - 400mV \times R_{LOAD} / R_{LIM}$$



2. Resonant Filter

- L-C shunt
- Center frequency: 298MHz

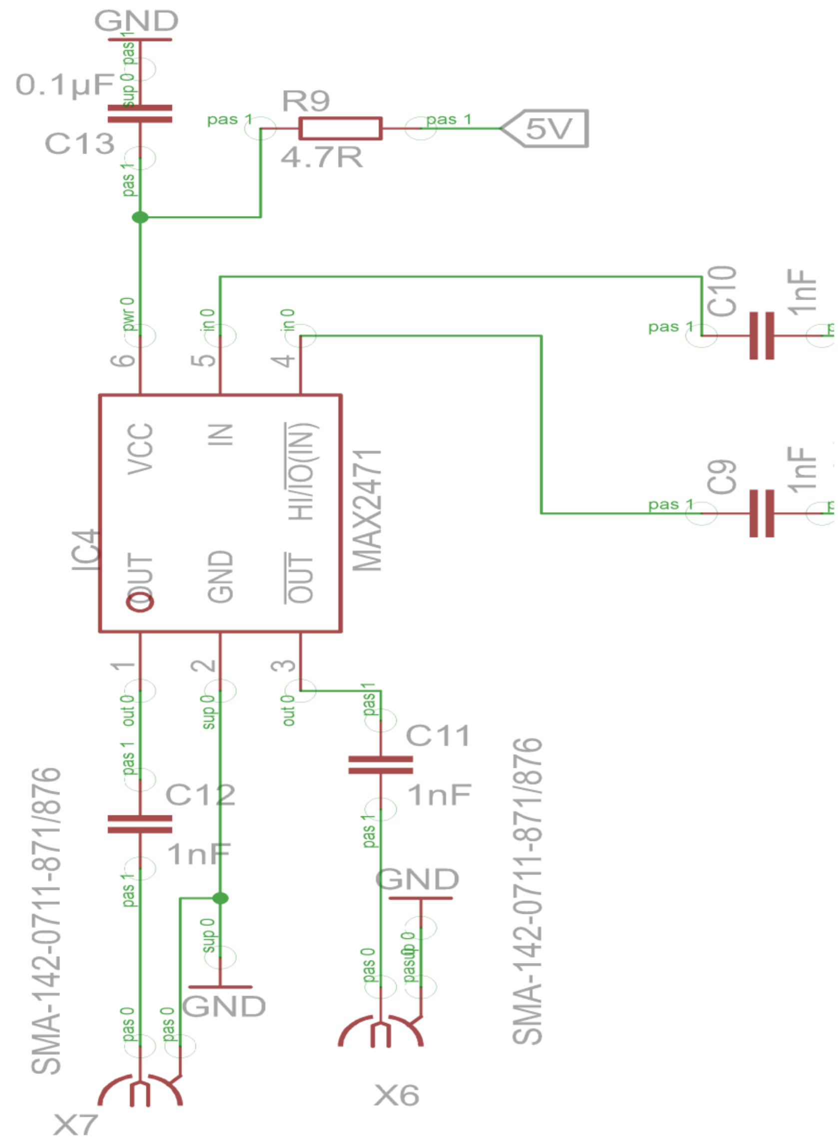
$$f_0 = \frac{1}{2\pi} \cdot \frac{1}{\sqrt{CL}}$$

- (Empirical) Assumption:

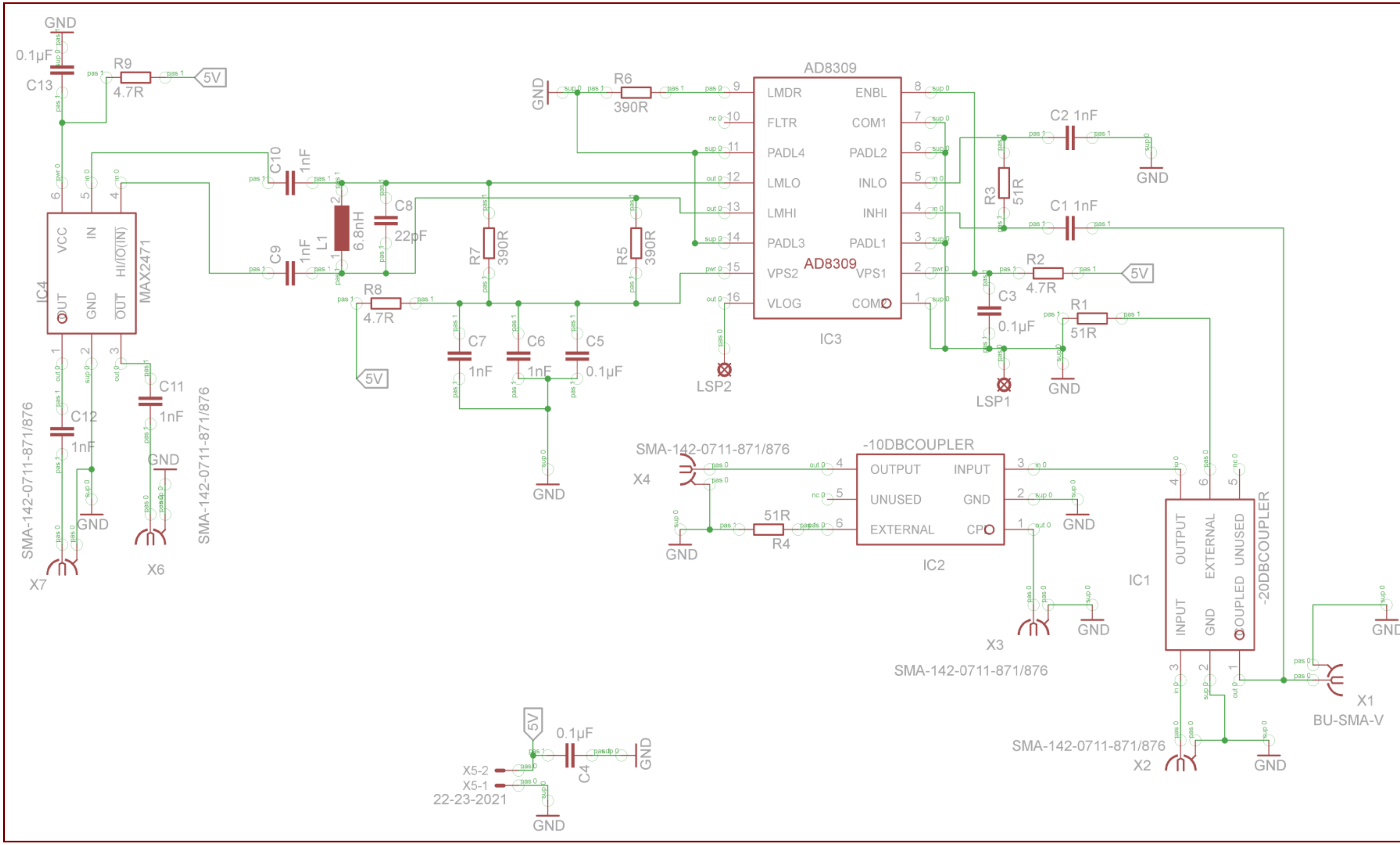
  Capacitor from the transistor in ICs = 20pF
- L=6.8nH, C=22pF
- 3dB Bandwidth depends on resistors
- Control bandwidth → Buffer amplifier

3. Buffer Amplifier MAX2471

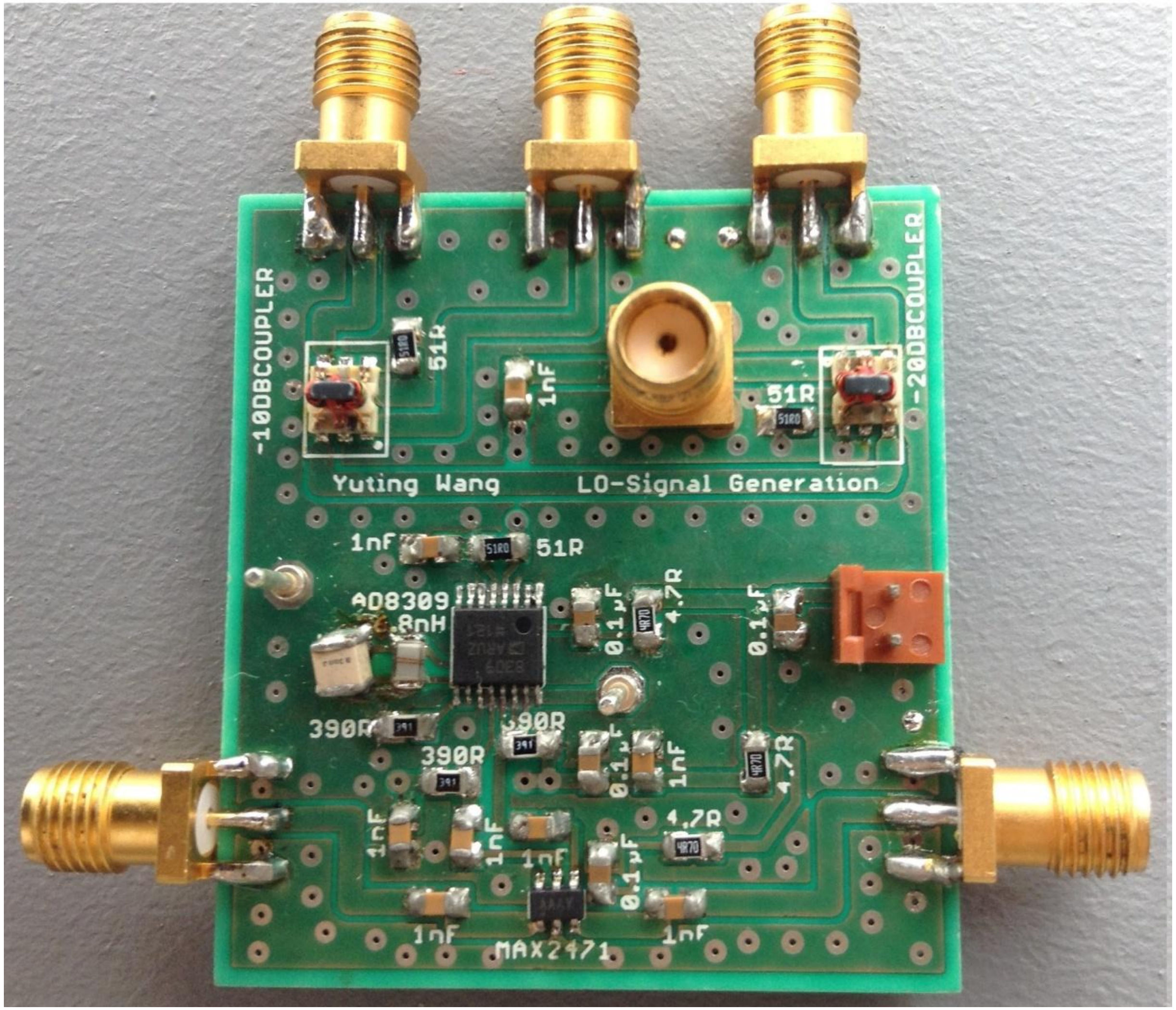
- High input impedance
- Voltage gain:
  16V/V
- Power supply:
  +2.7V to +5.5V (+5.00V)



PCB Design


GND
0.1µF
C13
R9
4.7R
5V
IC4
MAX2471
VCC
IN
HI/IO(IN)
OUT
GND
OUT
C10
1nF
C9
1nF
L1
6.8nH
C8
22pF
R8
4.7R
5V
R7
390R
R5
390R
C7
1nF
C6
1nF
C5
0.1µF
GND
C12
1nF
C11
1nF
GND
GND
SMA-142-0711-871/876
X7
X6
SMA-142-0711-871/876
R6
390R
GND
AD8309
LMDR
FLTR
PADL4
LMLO
LMHI
PADL3
VPS2
VLOG
ENBL
COM1
PADL2
INLO
INHI
PADL1
VPS1
COM2
AD8309
IC3
LSP2
LSP1
C2 1nF
GND
R3
51R
C1 1nF
R2
4.7R
5V
C3
0.1µF
R1
51R
GND
SMA-142-0711-871/876
X4
-10DBCOUPLER
OUTPUT
UNUSED
EXTERNAL
INPUT
GND
CP
IC2
51R
R4
GND
GND
X3
GND
SMA-142-0711-871/876
IC1
-20DBCOUPLER
OUTPUT
EXTERNAL
UNUSED
INPUT
GND
COUPLED
GND
X1
BU-SMA-V
SMA-142-0711-871/876
X2
GND
5V
0.1µF
C4
GND
X5-2
X5-1
22-23-2021
GND

PCB Assembly



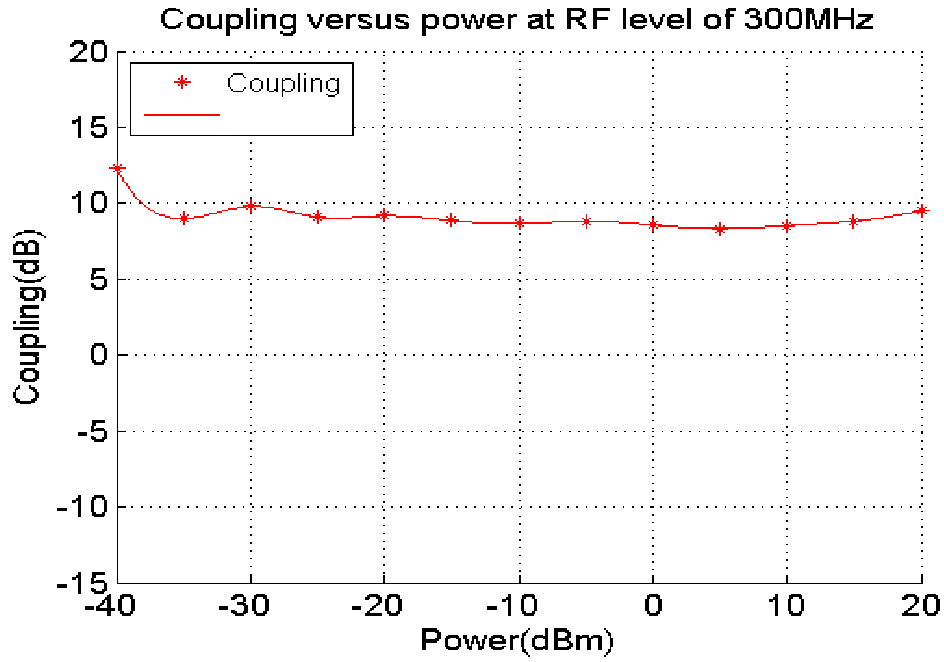
Testing & Measurement Scenarios

Test	Equipment	Result
1. Current consumption	+5.00V Power Supply Digital Multimeter	22.95mA
2. DC voltage at the power supply, input, output pins of ICs	+5.00V Power Supply Digital Multimeter	Vps1: 4.96V, Vps2: 4.97V Vcc: 4.98V, INHI&INLO: 1.768V LMHI&LMLO: 4.77V IN&$\overline{\text{IN}}$: 1.616V OUT&$\overline{\text{OUT}}$: 3.659V
3. Correct coupling levels of the directional coupler	RF Signal Generator -3dB Power Divider Oscilloscope/Network Analyzer	1. The directional coupler is a linear device. 2. My measurements verify the function of the couplers.
4. Generated signals at the limiting amplifier	RF Signal Generator +5.00V Power Supply Digital Multimeter	My measurements verify the logarithmic function of the AD8309.
5. Generated signals at the buffer amplifier (LO output signals)	RF Signal Generator +5.00V Power Supply -3dB Power Divider Oscilloscope	A balanced distorted sine wave signal with a fixed amplitude

3. Checking the Correct Coupling Levels of the Direction Coupling at RF Level of 300MHz

- ## 3.1. Using Oscilloscope
- ## 3.1.1. Coupling

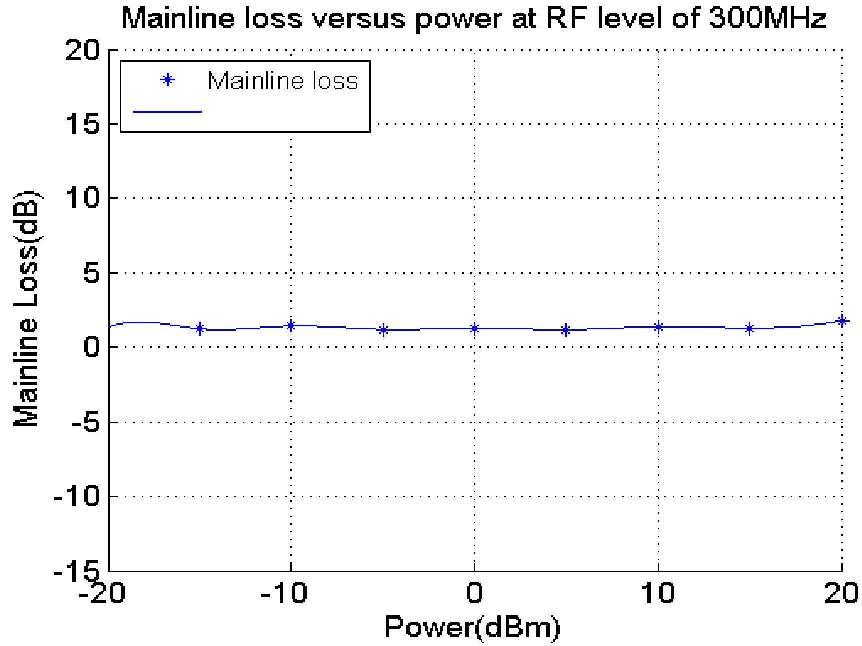
Symbol	Actual Coupling	Coupling in the Data Sheet	Relative Error
Value(dB)	8.91975	8.90	0.222%



3. Checking the Correct Coupling Levels of the Direction Coupling at RF Level of 300MHz

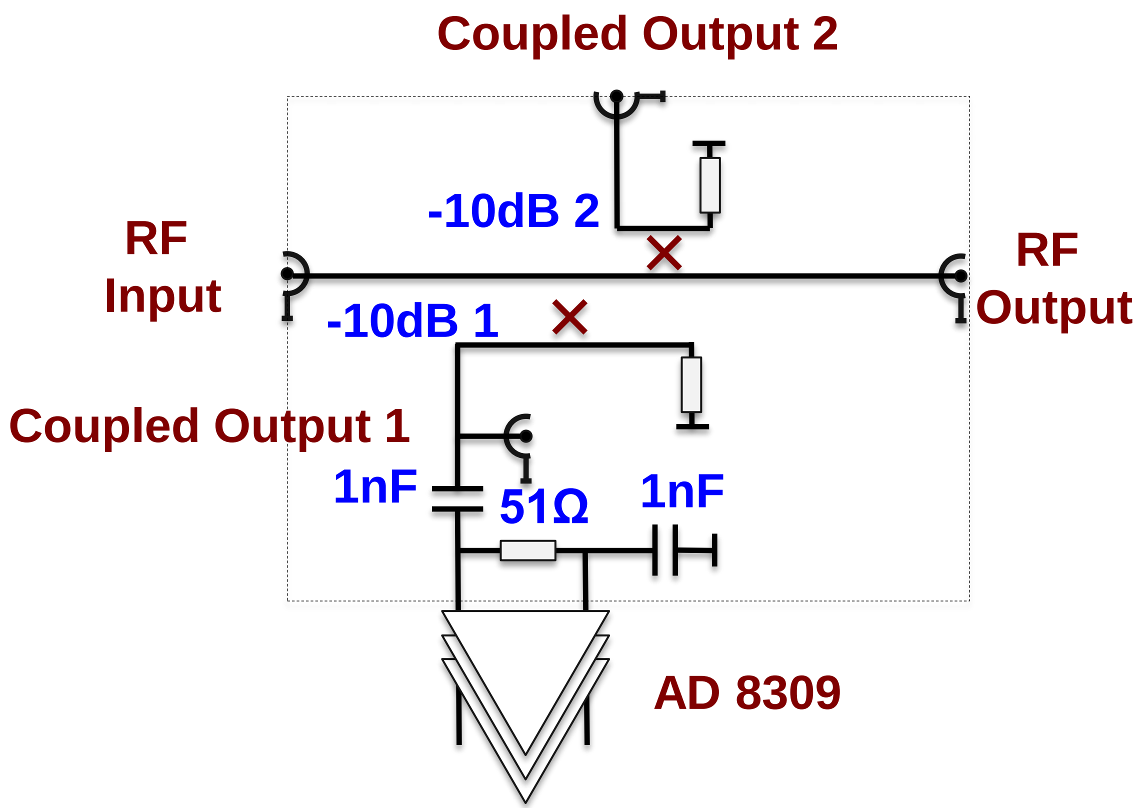
- **3.1. Using Oscilloscope**
- **3.1.2. Mainline Loss**

Symbol	Actual Mainline loss	Mainline Loss in the Data Sheet	Relative Error
Value(dB)	1.35895	1.24	9.59%



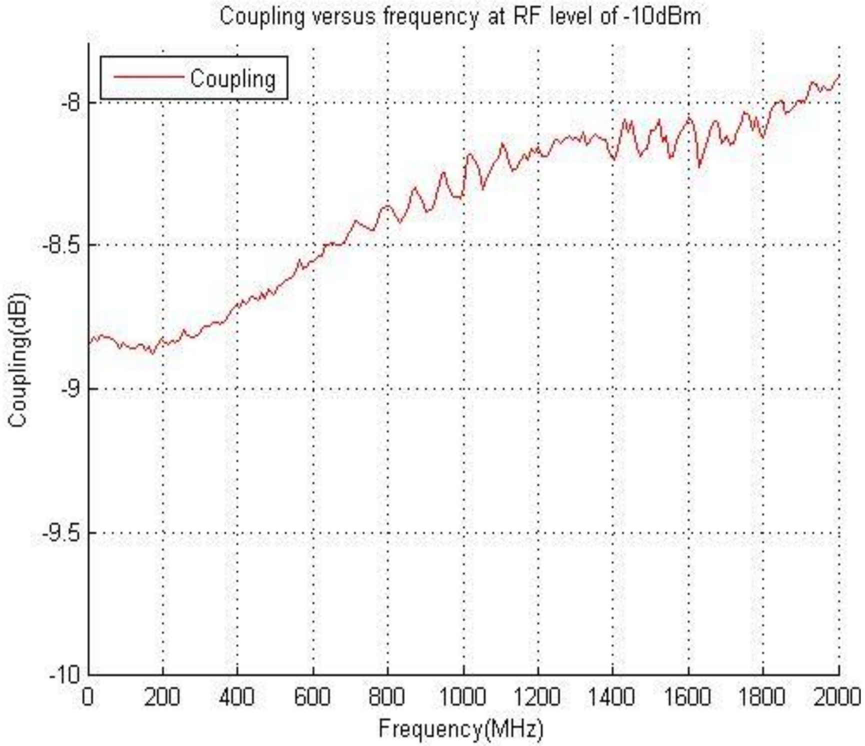
3. Checking the Correct Coupling Levels of the Directional Coupling

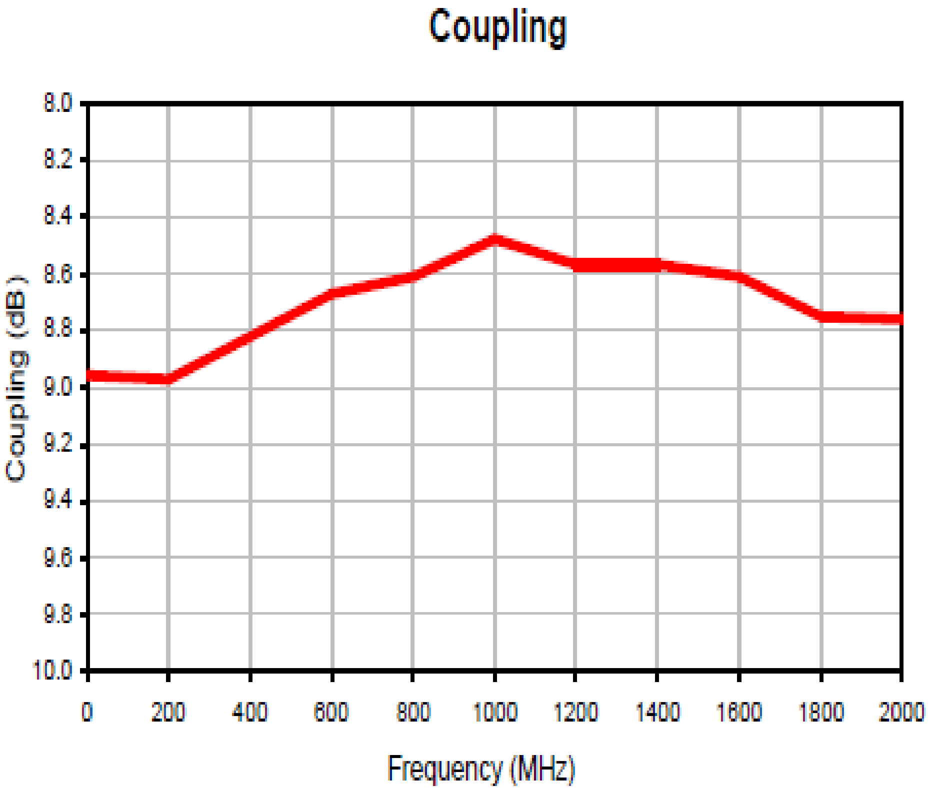
- **3.2. Using Network Analyzer**
- **Matching System**
- **Coupling, Mainline Loss, Directivity, &Return Loss**



3. Checking the Correct Coupling Levels of the Directional Coupling

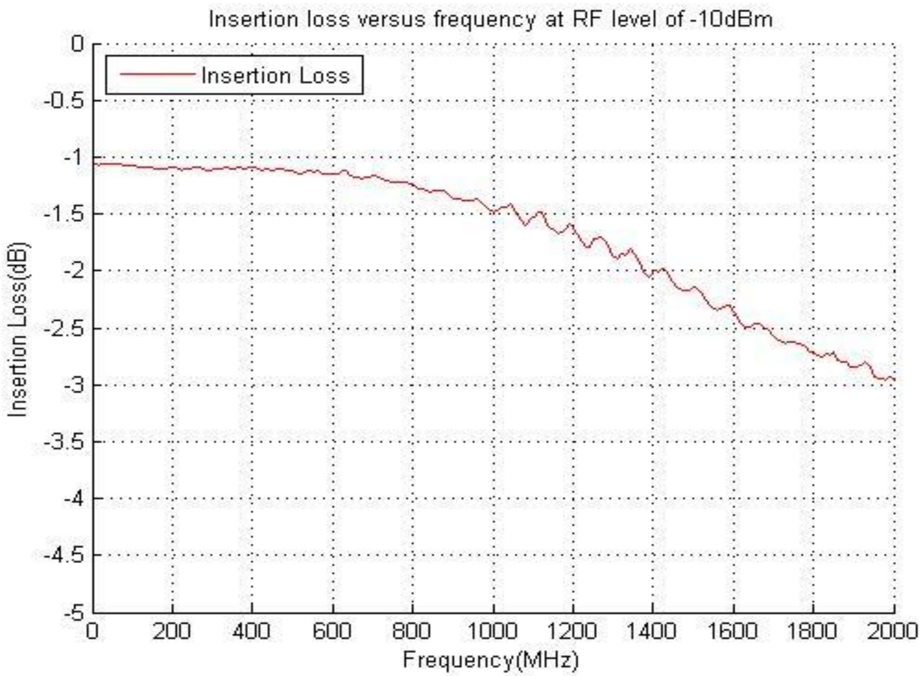
- **3.2.1. Coupling**
- **8.8315 ⇔ 8.90 (300MHz, -10dBm) ε=5.2%**

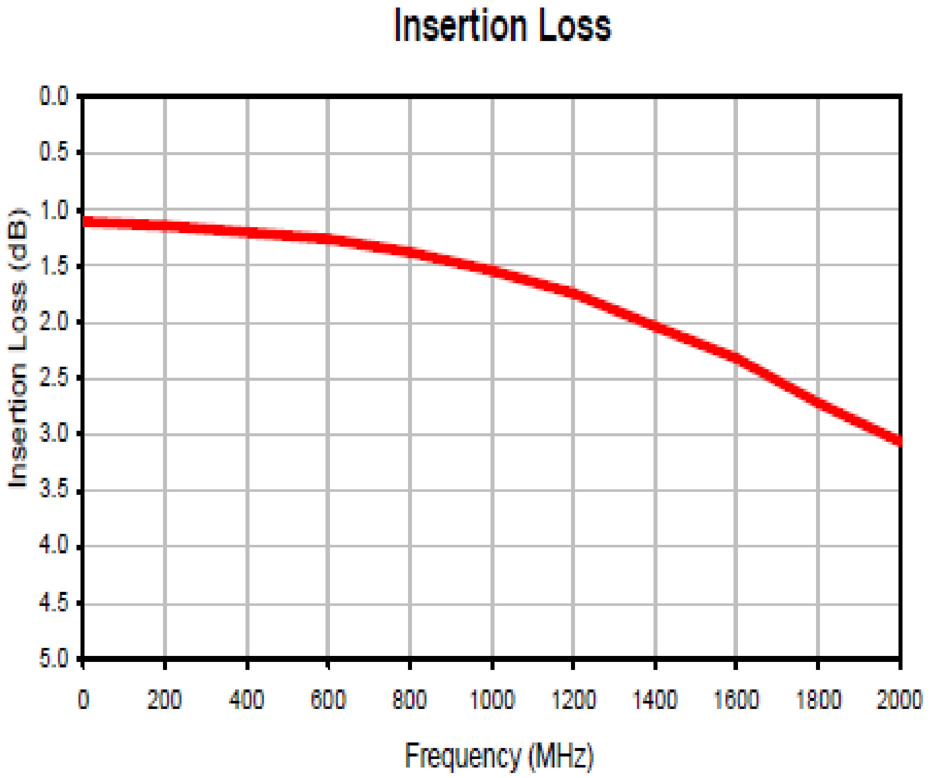




3. Checking the Correct Coupling Levels of the Directional Coupling

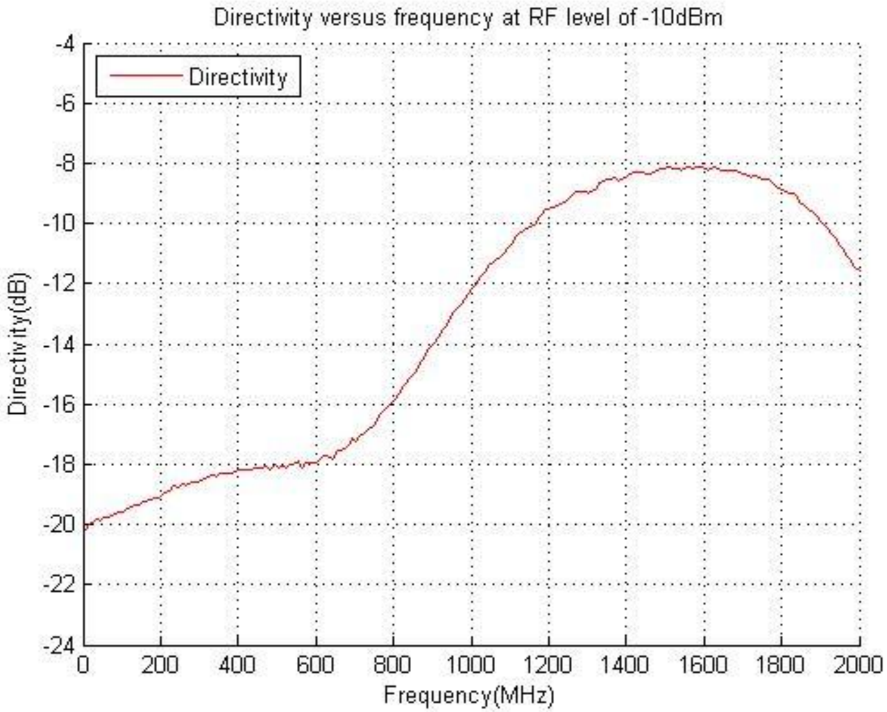
- **3.2.2. Mainline Loss**
- **1.1055 ⇔ 1.24 (300MHz, -10dBm) ε=10.8%**

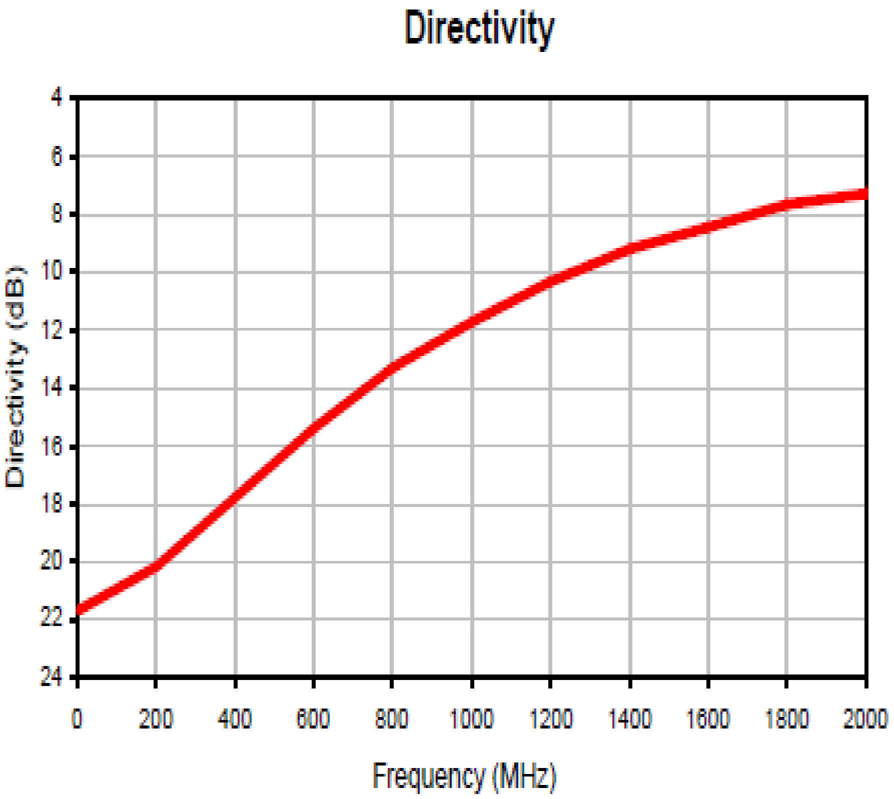




3. Checking the Correct Coupling Levels of the Directional Coupling

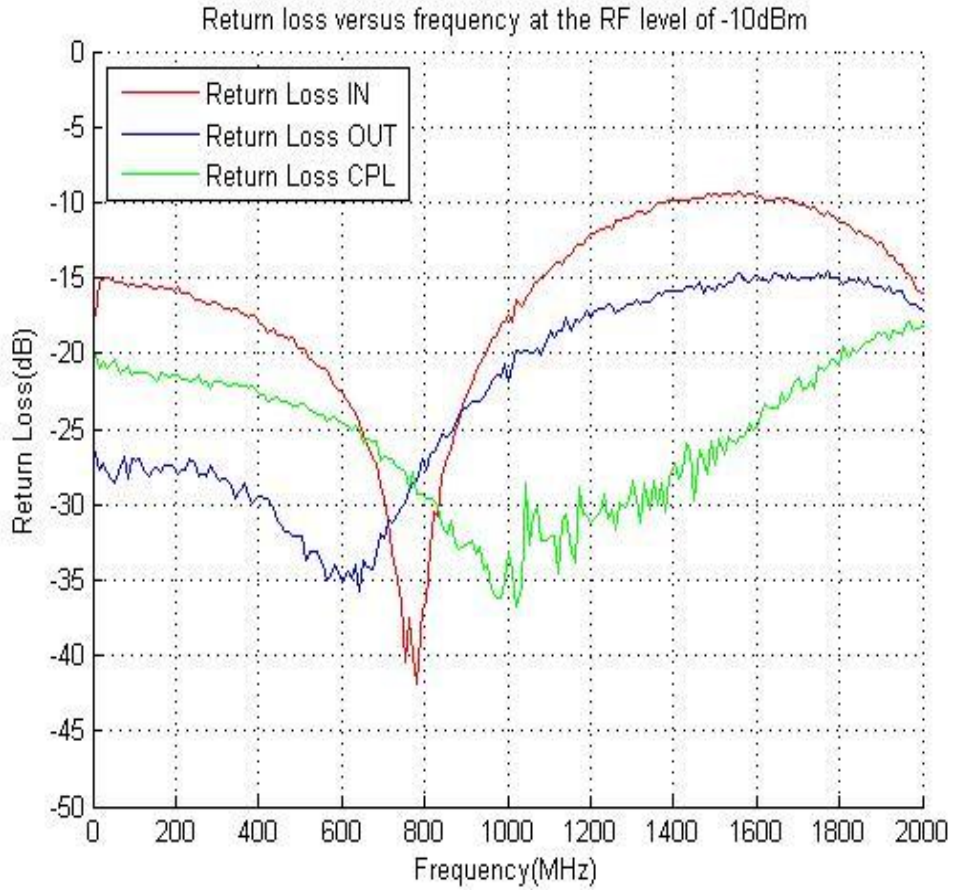
- **3.2.3. Directivity**
- **18.5125 ⇔ 19.20 (300MHz, -10dBm) ε=3.58%**

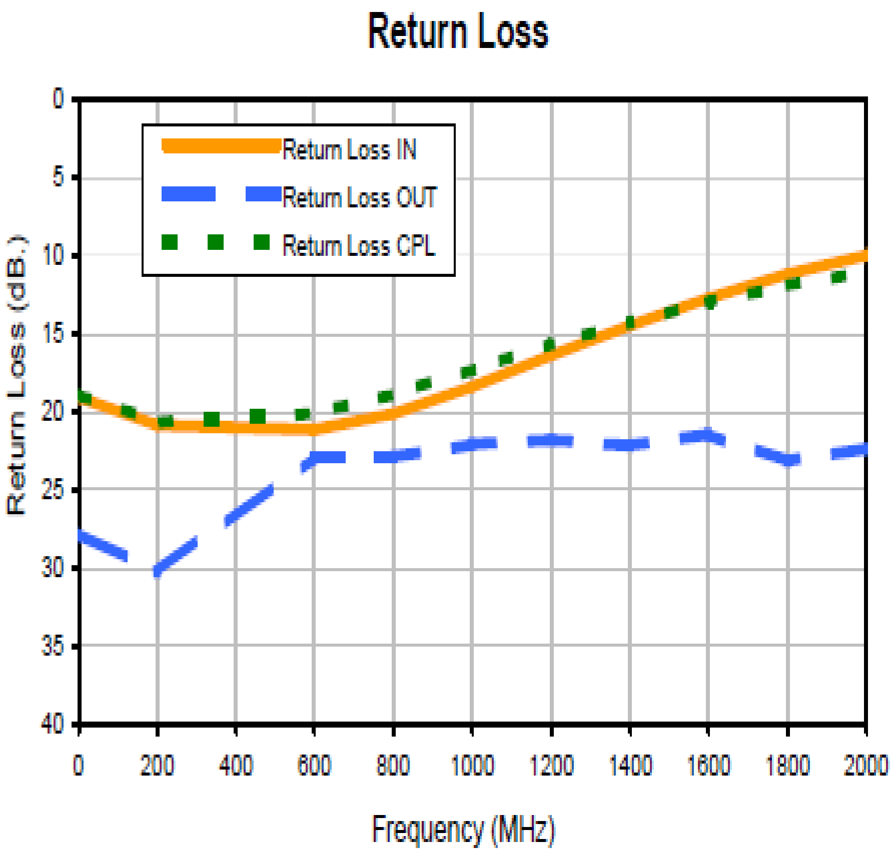




3. Checking the Correct Coupling Levels of the Directional Coupling

- **3.2.4. Input Return Loss, Output Return Loss, & Coupled Return Loss**

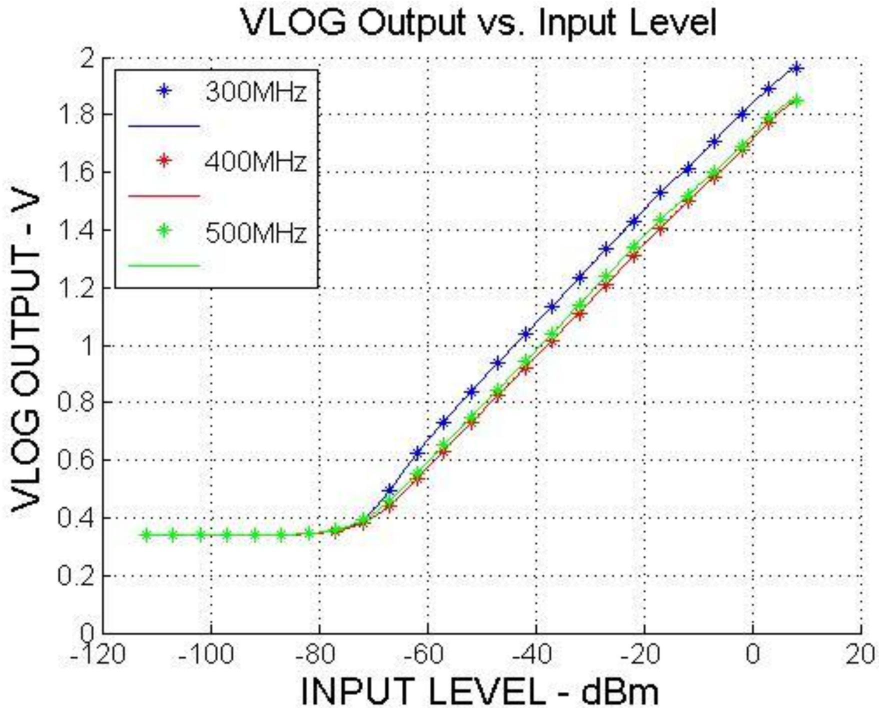




4. Checking the Generated Signals at the Limiting Amplifier

- **VLOG at RF level of 300MHz-500MHz**

Slope 300MHz (mV/dB)	Intercept 300MHz (dBm)	Slope 400MHz (mV/dB)	Intercept 400MHz (dBm)	Slope 500MHz (mV/dB)	Intercept 500MHz (dBm)	Ideal slope (mV/dB)	Ideal Intercept (dBm)
15.3	-109.49	14.0	-109.34	14.2	-109.72	20.0	-95



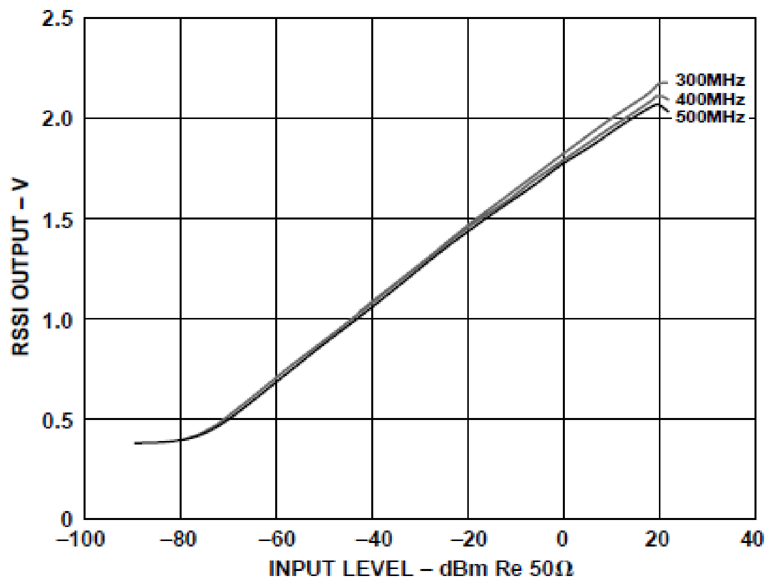


Figure 9. RSSI Output vs. Input Level, at $T_A = +25°C$, for Frequencies of 300 MHz, 400 MHz and 500 MHz

5. Checking the Generated Signals at the Buffer Amplifier

- Error-Correct Procedure:
- Original Resonant Capacitor as 22pF (Empirical Assumption)

↓ Unfortunately...

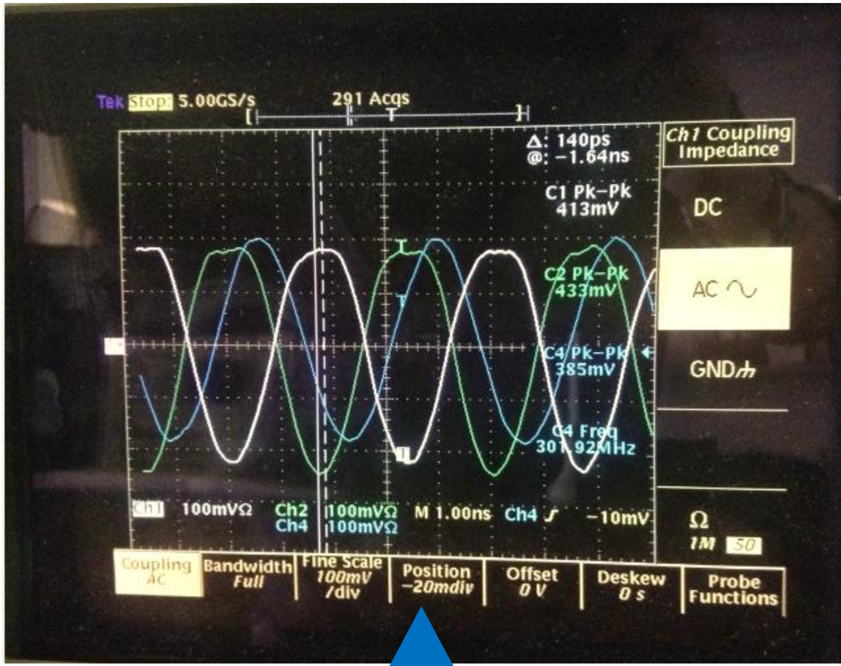
Test the Resonant Frequency 345MHz

↓

Change the Capacitor to 30pF

↓

Retest the Resonant Frequency 300MHz



A balanced distorted sine Signal with a fixed amplitude (300MHz, 0dBm) Good!

5.1. Checking the Generated Signals at the Buffer Amplifier – How It Comes Out

- **Limiter output signal of AD8309 – basically square**
- **Fourier series of an ideal square wave signal**

$$x_{square}(t) = \frac{4}{\pi}\sum_{k=1}^{\infty}\frac{\sin\left(2\pi(2\mathrm{k}-1)\,\mathrm{ft}\right)}{2k-1} = \frac{4}{\pi}\left(\sin(2\pi\,\mathrm{ft}) + \frac{1}{3}\sin(6\pi\,\mathrm{ft}) + \frac{1}{5}\sin(10\pi\,\mathrm{ft}) + \cdots\right)$$

Both even and odd harmonic sines would exist here

- **Resonant filter – "Restore" signal**

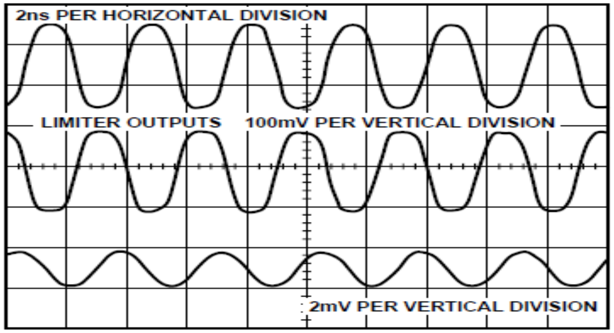
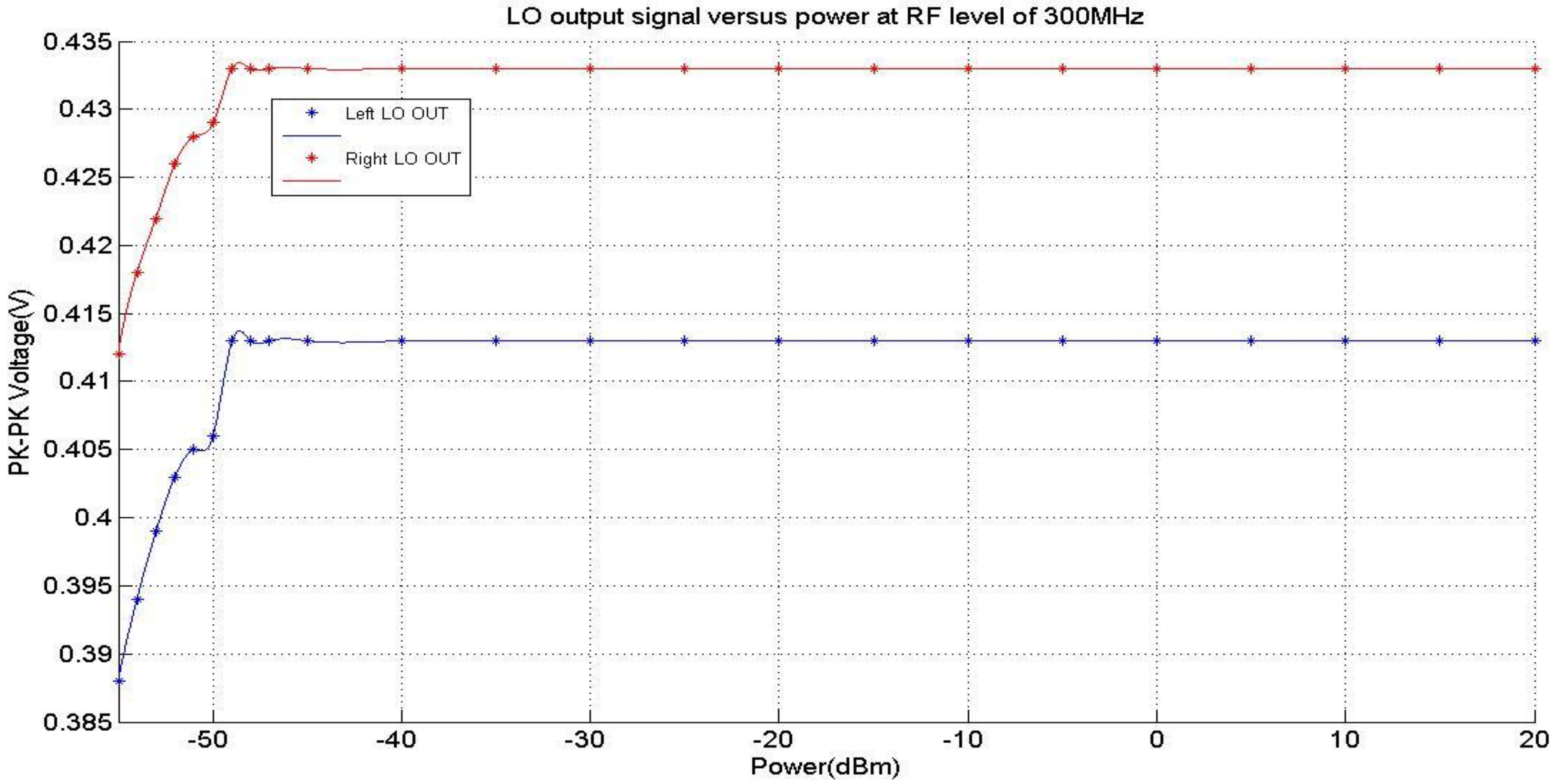


Figure 14. Limiter Output at 300 MHz for a Sine Wave Input of –60 dBV (–47 dBm), Using an R_{LOAD} of 50 Ω and an R_{LIM} of 100 Ω

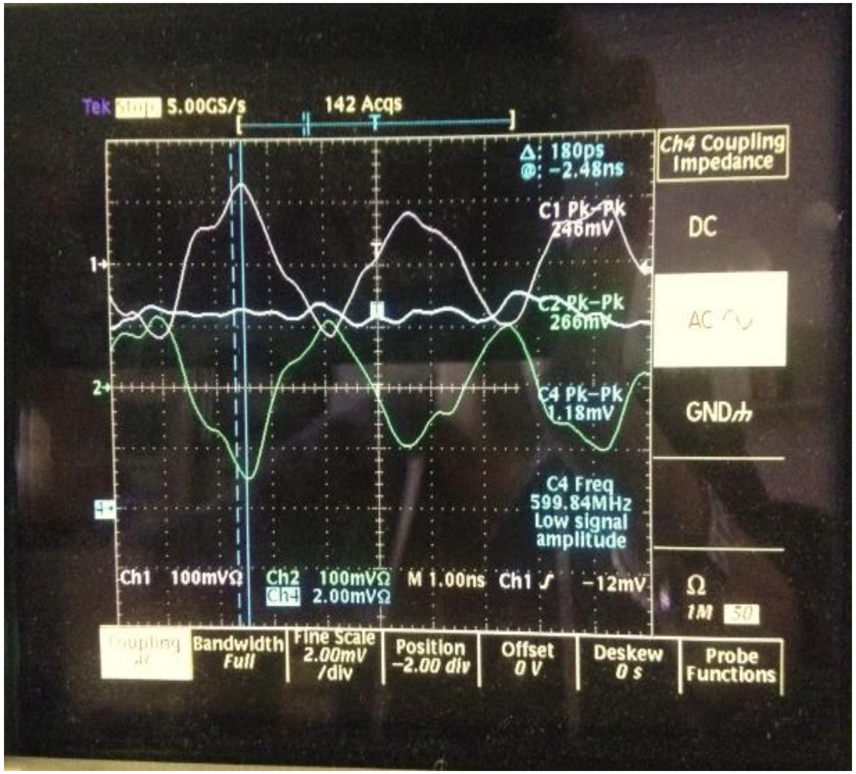
5.2. Checking the Generated Signals at the Buffer Amplifier – at RF Level of 300MHz

- **LO output signals Vpk-pk**
- **300MHz, -49dBm-20dBm ➡ Limiting (0.413V, 0.433V)**

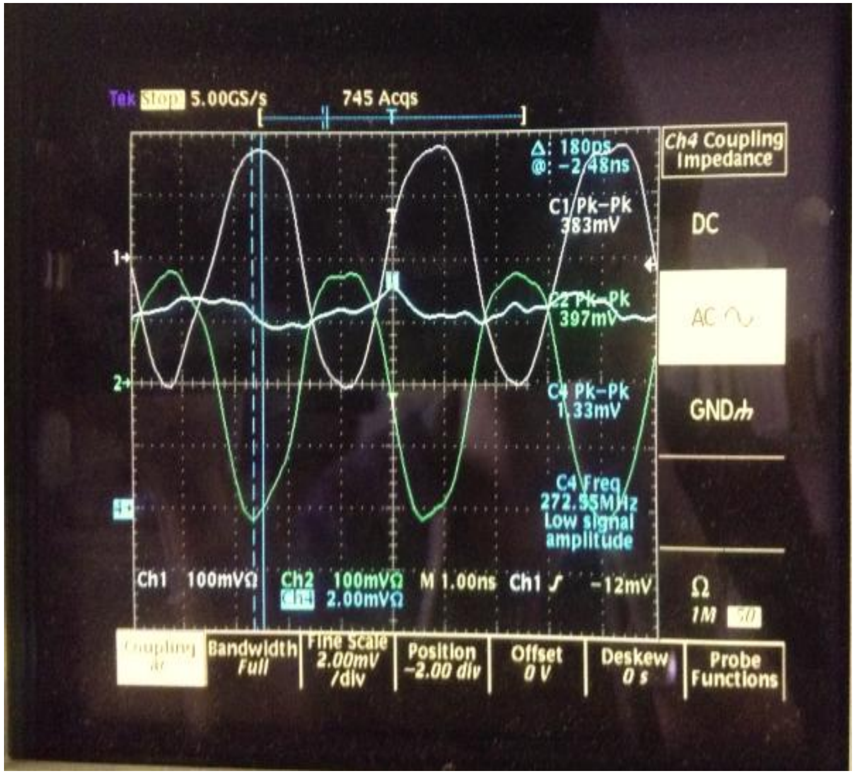


5.2. Checking the Generated Signals at the Buffer Amplifier – at RF Level of 300MHz

- 300MHz, -63dBm (Distorted due to transistor in ICs)

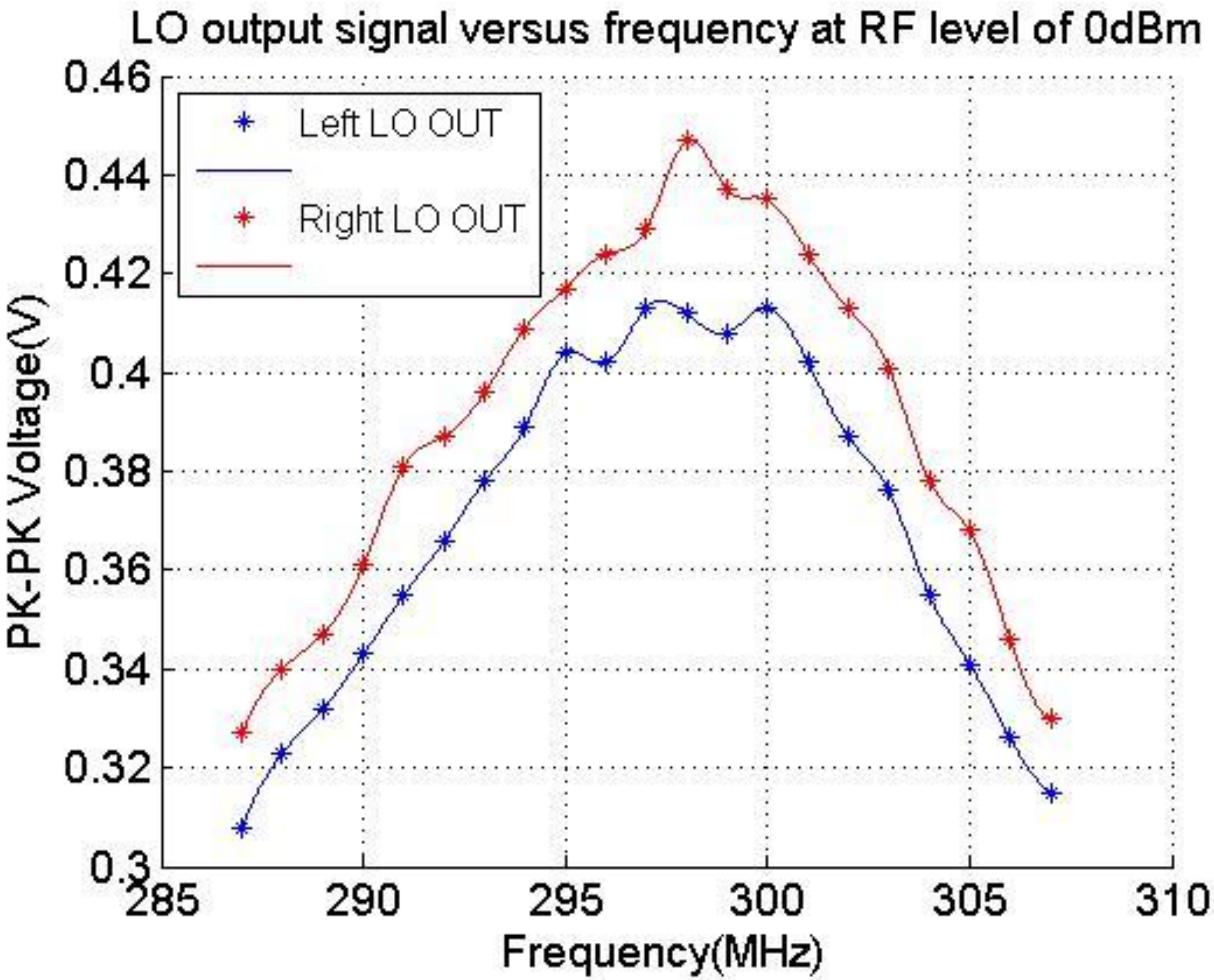


- 300MHz, -55dBm (Start)



5.3. Checking the Generated Signals at the Buffer Amplifier – at RF Level of 0dBm

- **3dB Bandwidth: 287Mhz-307MHz, 20MHz**



Conclusions

- I: The LO output signal = a balanced local oscillator signal with a fixed amplitude
  → Achieve the Objective
- II: -49dBm – 20dBm → Limiting
- III: 3dB bandwidth → 20MHz.
- IV: VLOG → 15mV/dB Slope , -109dBm Intercept
- V: Power Gain of the RF output and RF input port
  → -2.211dB

THE END

Thank You !