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Indigenous Development of MIC-Based C-Band Dual Chain Down Converter Unit for GEOSAT-Spacecraft Checkout System

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Abstract: *As part of miniaturization, the development work for the C-band dual-chain down converter, which is extensively used in TM (Telemetry) data acquisition system in GEOSAT spacecraft checkout system has been taken up in MIC (Microwave Integrated Circuit) approach using microstrip line structure. A prototype unit is realized using standard surface mount devices (SMD) and few indigenously developed MIC components namely, the directional couplers, the power dividers etc. The MIC-based down converter module, which forms the heart of the unit is housed in an Aluminium milled box having the dimension of 150 x 150 x 25 mm^3. Except internal Local Oscillator (LO), RF Switches and Power supply, all other circuitry are mounted withinthis milled box which is housed in 1U chassis. It meets all the requirements of a conventional down converter. The paper describes the salient features of the unit, its detailed design approach and realization plan and finally the test and evaluation results of the prototype unit developed indigenously.*

Keywords: Microwave Integrated Circuit (MIC), Tracking, Telemetry and Command (TTC), Local Oscillator (LO), Conversion gain, Low Noise Amplifier (LNA), Gain characteristics, SSB (Single Sideband) phase noise

I. INTRODUCTION

C-band Dual Chain Down Converter is used in Ground Checkout, for receiving the two TTC Telemetry Downlinks from the GEOSAT spacecraft, down converts the signal from 4.2 GHz RF to 70 MHz IF and generates 70 MHz output for the further chain to establish the Telemetry link from GEOSAT spacecraft to checkout. The Local Oscillator (LO) required for down-conversion is taken from C-Band Frequency synthesizer module as internal LO, where LO frequency can be set in the synthesizer either by using push buttons or by Ethernet LAN control and the set frequency could be seen on the display and can be saved. The provision for providing external LO from a signal generator is also made. The selection between internal LO and external LO is done with the help of a manual RF switch mounted on the front panel of the unit. The entire unit, which consists of MIC-based down converter module, the C-band frequency synthesizer (which acts as an internal LO) and the DC power supply module is realized within a single 1-U chassis.

The salient features of the unit include the following:

- MIC (Microstrip Line) design using surface mount and indigenous components
- Reduced cost and size
- Better reliability and ease of fabrication

II. FUNCTIONAL DESCRIPTION

This unit comprises of C-Band RF band pass filter, front-end Low Noise Amplifier (LNA), power divider, frequency mixers and the IF portions. Device used for LNA is MAAM37000-A1 of MACOM make. It is a wideband low noise MMIC amplifier. RF band pass filter is a MIC-filter at the front end from Custom microwave, USA (TDRF-4200B100X). Output of this filter is fed to the LNA and LNA output is fed to indigenously designed microstrip line power divider, whose two outputs are connected to two mixers (corresponding to two IF chains) through an isolator (DII-4070-20) of Mesa Microwave make, each isolator provides 20dB isolation. The mixers used are SKY-7G+ of

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Mini-Circuits make. For each IF chain, LO input is fed to the individual mixer through indigenously developed microstrip line directional coupler and an isolator. Coupled port of the directional coupler in the LO path is used forLO Monitoring and its isolated port is terminated with 50 Ohm resistor. IF output of each mixer is taken through an IF band pass filter followed by an IF amplifier. IF band pass filter (BPF-C70+) ofMini-Circuits make and of bandwidth 1 MHz and insertion loss of 6dB is used. IF amplifiers used are also Mini-Circuit make (MAR-8-ASM). IF amplifier output is the final IF output for both the IF chains as shown in Figure 1.

The DC supply for the entire unit is given from AC-DC power supply of LAMDA make (+24V, 4.5A). Two DC-DC converter convert 24V output to +15V, 1.7A & +5V, 3A to provide supply to the frequency synthesizers, RF and IF amplifiers via feed thru's mounted on the chassis. Provision for monitoring of LO signals are available in the Front Panel of the unit. All the outputs and inputs are taken out using SMA connectors. The unit has:

- One RF Input port
- Two IF Output ports
- Two External LO Inputs port
- One LO Monitoring Port
- EXT LO/INT LO selection switch
- LO1/LO2 MON selection switch

The target specifications of the unit are shown in Table 1.

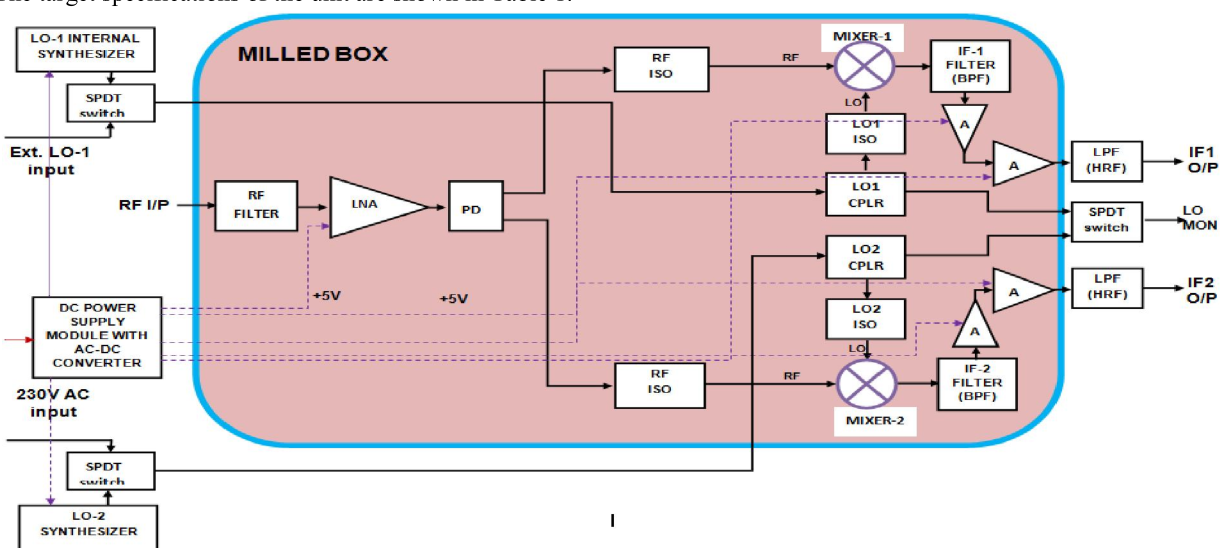

Fig. 1: **Basic Block diagram of C-Band Dual-Chain TTC down Converter Unit**

Table 1: Target Specifications of the MIC-Based C-Band Dual Chain Down Converter Unit

S/N	Parameters	Values
1	RF Input Frequency	4150 to 4250 MHz
2	IF Output Frequency	70 MHz at both the IF ports
3	LO frequency	4000 to 5000 MHz
4	External LO level	+10dBm (±1 dB)
5	Conversion gain	12 dB (approx.) for both the chains
6	Input dynamic range	-80 dBm to -30 dBm
7	Spurious & Harmonics	≤ -50dBc
8	Isolation (Typical) LO-RF LO-IF	 ≥ 50 dB ≥ 50 dB

	RF to IF	≥ 50 dB
9	Nominal Impedance	50 Ohms
10	Noise Figure	≤ 5 dB
11	Return Loss (magnitude) at all the ports	≥ 15 dB
12	Internal LO Phase Noise	-95 dBC/ HZ @1 KHz offset
13	Power supply	+15V 1.5 A, +5V 3A

III. REALIZATION PLAN

- Single down conversion technique is used
- Circuit is realized in RT-Duroid substrate of dielectric constant, 10.2 and substrate height, 50 mil
- Indigenously developed two-way microstrip line power divider (Wilkinsontype)and Parallel line LO directional couplers are used
- To achieve proper isolation between the ports (RF, IF & LO), the milled box is designed with partitions for all 3 chains (RF, IF1 & IF2)
- Each component is tested separately in a test jig and then incorporated in the final card

IV. DESIGN APPROACH

- MIC Card Design
- 10 dB Microstrip Parallel Line Directional Coupler Design
- C-Band Microstrip line-Two-way Power Divider Design
- Overall circuit Design

Before going to the design details, let us define the following parameters:

Z_o = Characteristic impedance of the microstrip line in Ohm

ϵ_r = Dielectric constant of the substrate material (dimension less)

w = Width of the metallic microstrip (in mil)

d = Height of the substrate (in mil)

$\frac{w}{d}$ = Width to height ratio of the microstrip line(dimension less)

4.1 MIC Card Design

It is realized using RT-Duroid substrate with a dielectric constant of 10.2 and thickness 50mil. PCB Layout design is done using AutoCAD. All the components and modules selected are 50-Ohm matched.

For the MIC card, first design of 50-Ohm microstrip transmission line is done. For this, inputs required are:

Characteristic impedance,Z_0 = 50 ohms

Height of the substrate,d = 50 mil

Dielectric constant of the substrate,ϵ_r = 10.2

For Calculation of width to height ratio $\left(\frac{w}{d}\right)$of the Microstrip line when Z_o&ϵ_r are known:

Case-1: For$\frac{w}{d} < 2$

$$\frac{w}{d} = \frac{8e^A}{e^{2A}-2} \quad (1)$$

Case-2: For $\frac{w}{d} > 2$

$$\frac{w}{d} = \frac{2}{\pi}\left[B - 1 - \ln(2B-1) + \frac{\epsilon_r - 1}{2\epsilon_r}\left\{\ln(B-1) + 0.39 - \frac{0.61}{\epsilon_r}\right\}\right] \quad (2)$$

where,

$$A = \frac{Z_o}{60}\sqrt{\frac{(\epsilon_r+1)}{2}} + \left(\frac{\epsilon_r-1}{\epsilon_r+1}\right)\left(0.23 + \frac{0.11}{\epsilon_r}\right) \qquad (3)$$

$$B = \frac{377\pi}{2Z_o\sqrt{\epsilon_r}} \qquad (4)$$

Using Equations (2) and (4) for Zo = 50 Ohm, d = 50 mil and ∈r = 10.2, the ratio, w/d is found be equal to 0.938. Hence, for the substrate height, d =50 mil, the width (w) of the 50-Ohmtransmission line*i.e.,* the track widthwill be equal to 0.938 x 50 mil = 46.9 mil= 46.9 x 0.0254 mm ≈**1.20 mm**(since, 1 mil = 0.0254 mm).

4.2 Design of 10dB Microstrip Parallel Line Directional Couplers at the LO Input Paths

These directional couplers are used to monitor the LO signals to the frequency mixers. There are two such directional couplers, one for mixer-1 and the other for mixer-2 as shown in Figure 1.These directional couplers of about 10 dB coupling are designed using microstrip line structure with the help of Keysight's Advanced Design System (ADS)software. The target specification of such directional coupler is shown in Table 2.The microstrip line PCB layout diagram of the directional coupler is shown in Figure 2.

Table 2: Target Specifications of 10 dB Microstrip Parallel Line Directional Couplers

Parameters	Specifications
Freq. range (MHz)	4000 to 4300
Main line Insertion loss (dB)	<1.0
Return loss (dB) at all the ports	≥ 20
Coupling (dB)	10 (± 0.5 dB)
Directivity (dB)	15 (minimum)

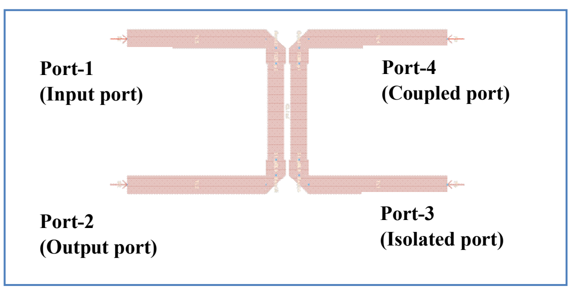

Fig. 2 microstrip line PCB layout diagram of the directional coupler

4.2.1 ADS EM Simulation results for 10 dB Directional coupler

The input to output insertion loss (S21) variation over C-band is shown in Figure 3. On the other hand, the return loss (S11,S22, S33 and S44) variations at all the four ports over C-band are shown in Figures 4(a) to 4(d).

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a) Insertion Loss - S21

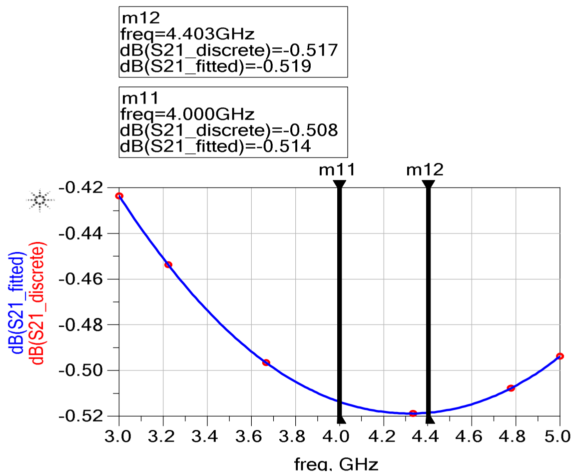
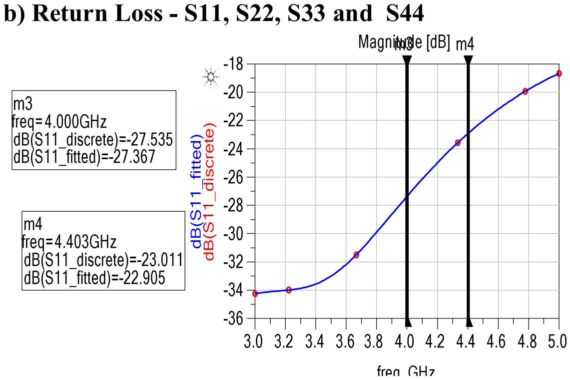
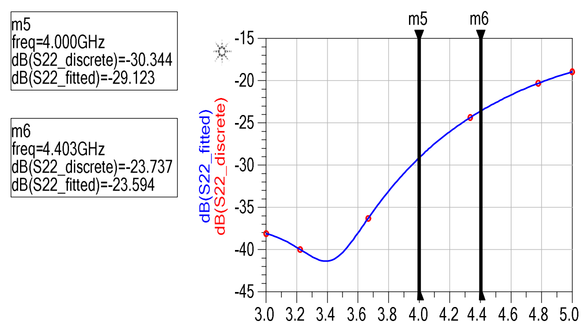


Fig. 3 Input to output Insertion loss variation

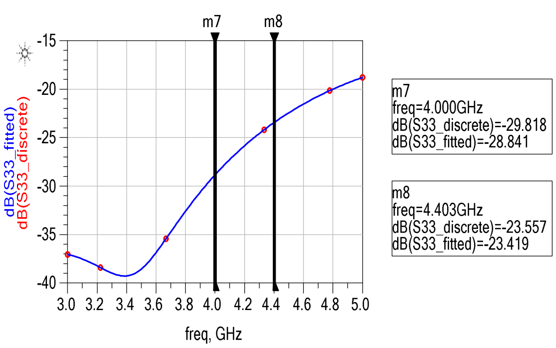
b) Return Loss - S11, S22, S33 and S44



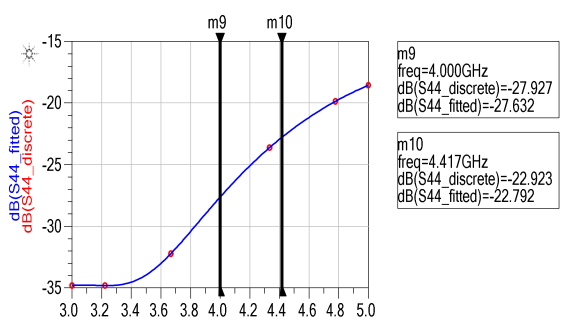
(a) Return loss variation at input port



(b) Return loss variation at output port



(c) Return loss variation at isolated port



(d) Return loss variation at coupled port

Fig. 4 Return loss variation at different ports

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c) Coupling (S41)

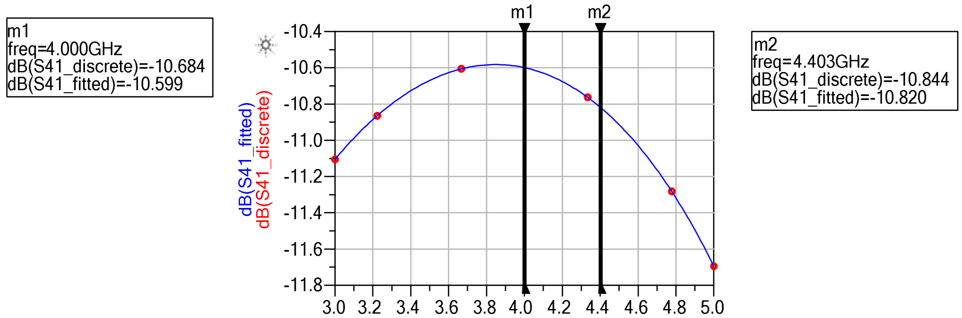

Fig. 5 Variation of coupling factor at the coupled port

d) Isolation (S31)

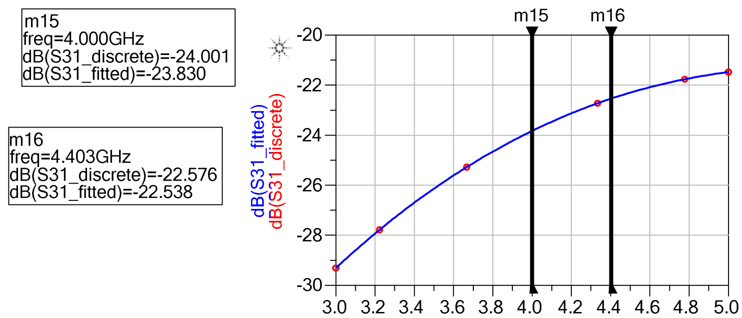

Fig. 4 Variation of isolation at the isolated port

4.3 Design of Microstrip line C-Band Two-way Power Divider (Wilkinson type)

This power divider is used to divide the combined input RF signal (received collectively from both the telemetry transmitters onboard GEO satellite)

into two RF paths, each of which will beat with the individual LO signal at the respective frequency mixer and will provide two 70 MHz IF chains. Each IF chain will drive individualdemodulator for further processing of the telemetry signals in GEOSAT-Spacecraft Checkout System.The target specification of the power divider is shown in Table 3.

Table 3: Target specification of the two-way power divider (Wilkinson type)

Parameters	Specifications
Freq. range (MHz)	4150 to 4250
Insertion loss(dB)	0.15 (max)
Return loss(dB)	≥ 20
Isolation (dB)	≥ 20
Amplitude balance (dB)	< 0.1
Phase balance (deg)	< 1

Circuit Simulation in ADS

Simulation for this circuit is done using ADS for the frequency range of 3 to 5 GHz. The MIC-PCBLayout diagram of the circuitis shown in Figures 7(a) and 7(b) respectively.

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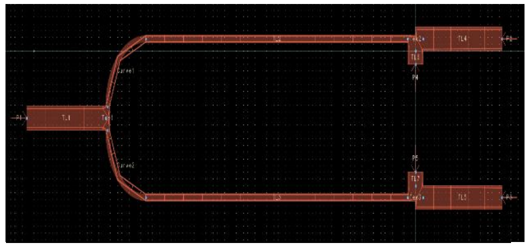
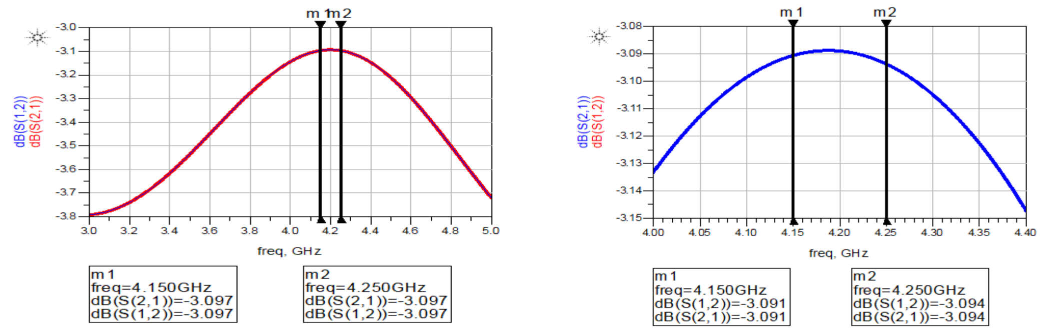


Fig. 7 Microstrip line PCB layout diagram of the power divider (Wilkinson type)

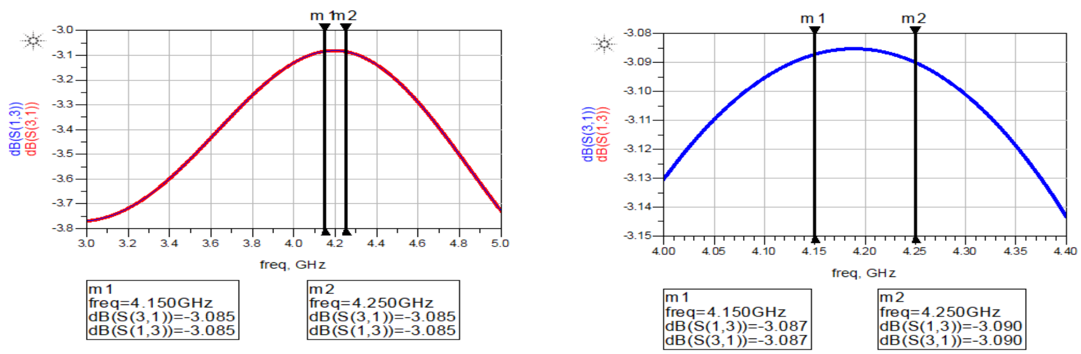
ADS Simulation Results

Using ADS software simulation, the S-parameterplots of the power divider are shown Figures 8to 10.

Insertion Losses Between Ports



Insertion loss - S12and S21



Insertion loss - S13 and S31

Fig. 8 Insertion losses between ports

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Isolation Between Output Ports:

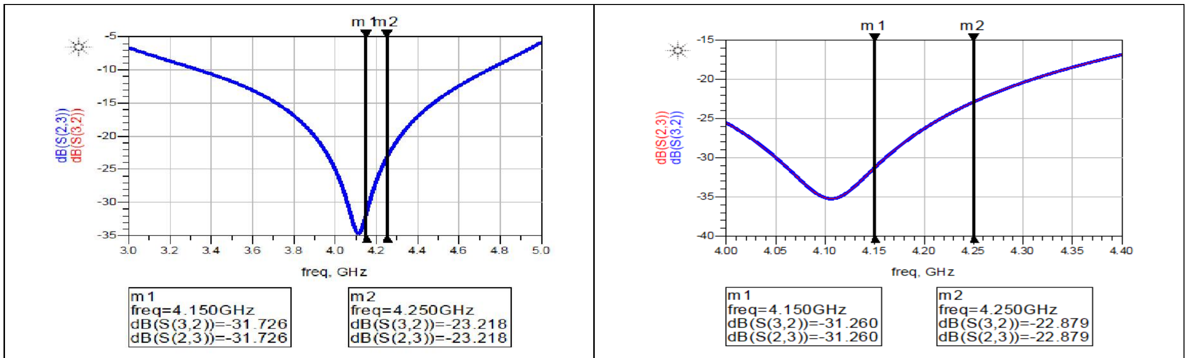

Fig. 9 Isolation between output ports

Return Loss at the Input Port (S11)

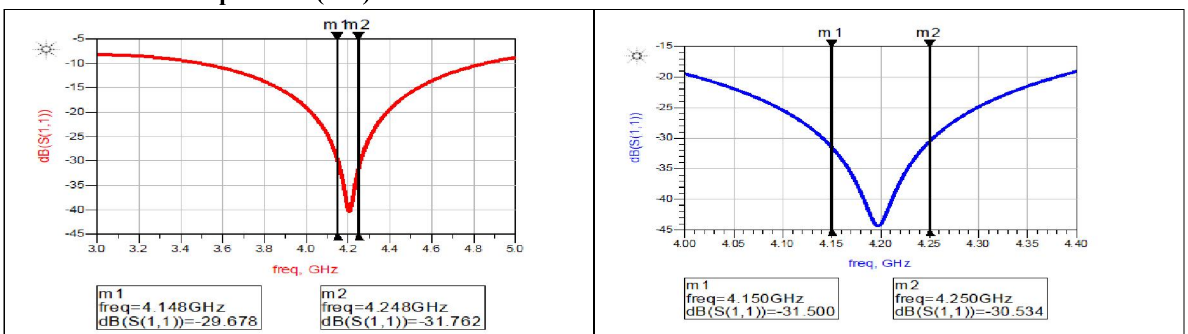

Fig. 10 Return Loss at the input Port (S11)

V. OVERALL CIRCUIT DESIGN

The detailed list of components used in the realization of the proto-model of a MIC-based C-band dual chain down converter unit is shown in Table 4

Table 4: Component List

S/N	Component name	Component Type	Make/Part No.	Qty. reqd.
1	RF Amplifier	Surface mount	MAKOM/MAAM37000-A1	1No.
2	IF Amplifiers	Surface mount	Mini Circuits/MAR-8-ASM	4 No.s
3	C-band Mixer	Surface mount	Mini Circuits/SKY-7G	2 No.s
4	RF Filter	Surface mount	ALS Associates /TDRF4200B100X	1 No.
5	IF Filters	Surface mount	Mini Circuits/BPF-C70+	2 No.s
6	Isolators	Surface mount	Mesa Microwave/DI0407T-2	4 No.s
7	Attenuation pads	Surface mount	Mini Circuits/PAT-3	2 No.s
8	Chip resistors	Surface mount	22 ohms	4 No.s
9	Chip resistors (Termination)	Surface mount	50Ω	2 No.s
18	Chip capacitors	Surface mount	0.1uF	6 No.s
19	Harmonic reject filter	Surface mount	Mini Circuits/	2 No.s
20	Manual SPDT switches	Co-axial	RLC Electronics	3 No.s
21	Frequency Synthesizers	Co-axial	ROPET/ SYNTH040050LE	2 No.s

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5.1 Overall Circuit Simulation in ADS

The overall circuit schematic of the MIC module of the C-band down converter unit is shown in Figure 12. On the other hand, the ECAD PCB layouts of the unit's MIC module are shown in Figures 13(a) to 13(c)

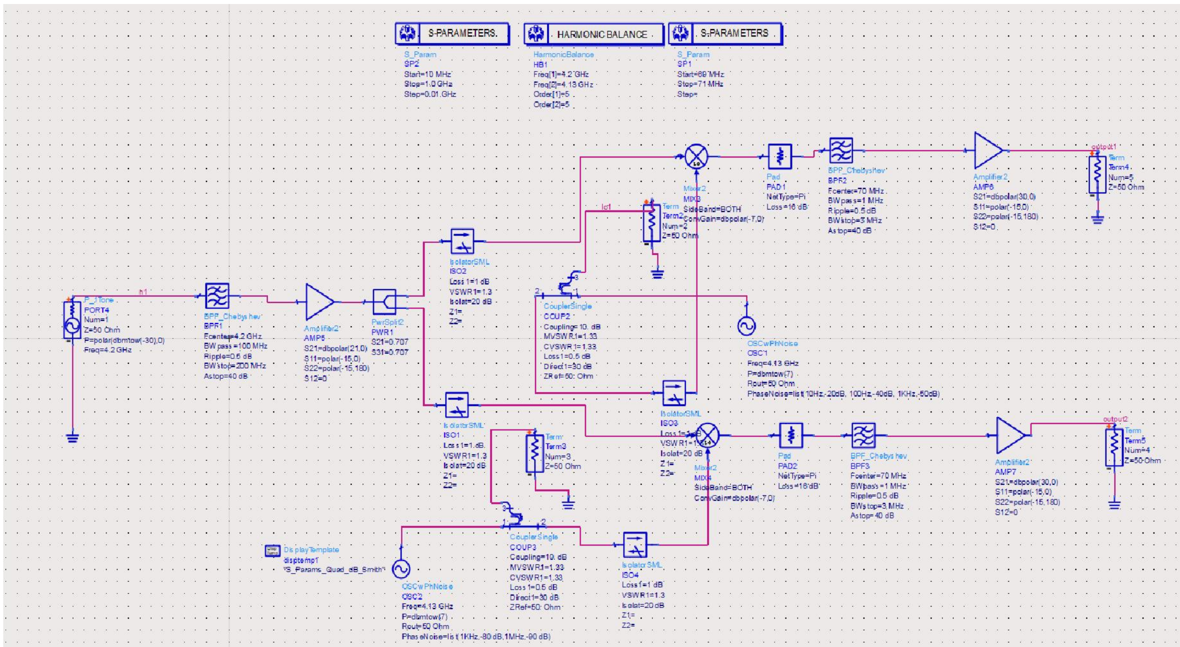
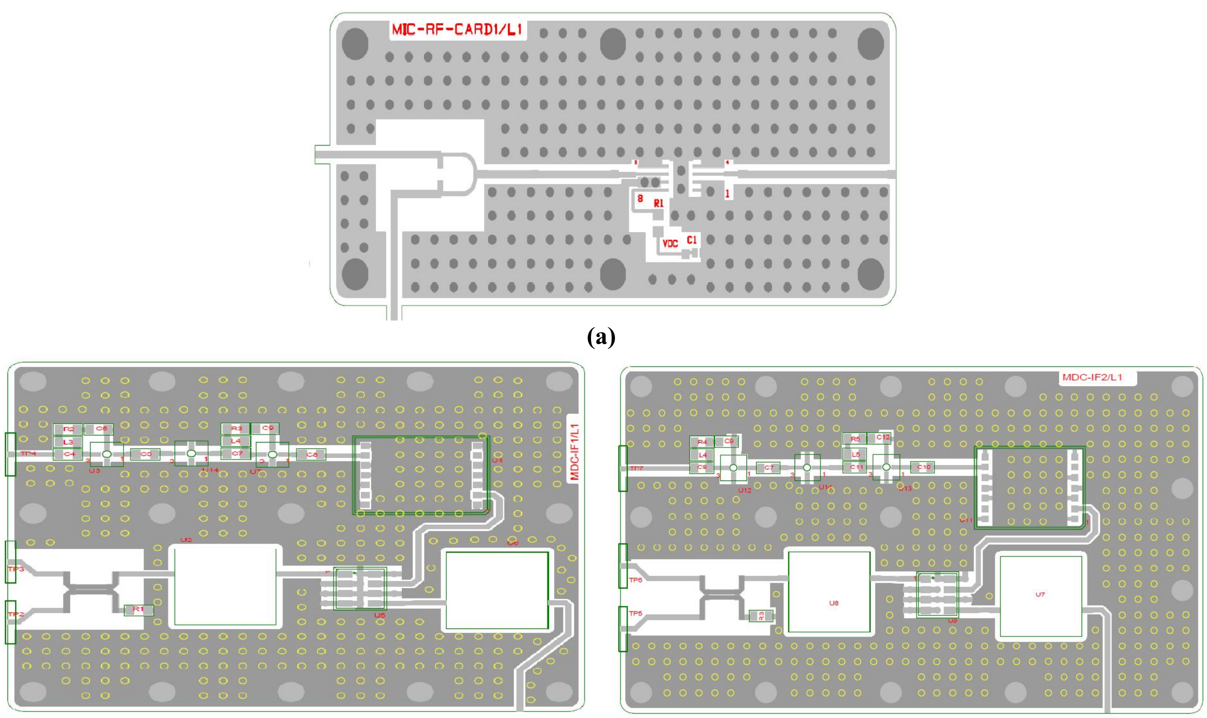


Fig. 12 C-Band Dual Chain Down Converter Schematic



(a)

(b) (c)

Fig. 13 ECAD PCB Layout of (a) RF card (b) IF1 card and (c) IF2 card of the MIC module

5.2 ADS Simulated Results

Overall gain of the unit

Here, the RF input to the system is -30dBm, with unit's gain of around 18 dB the simulation results show about-12dBmof IF power at both the IF1 and IF2 outputs as shown in Figure 14 .This shows that the gain of the unit is about 18 dB (for both the IF chains). This is checked for the full dynamic range of -30dBm to -80dBm.

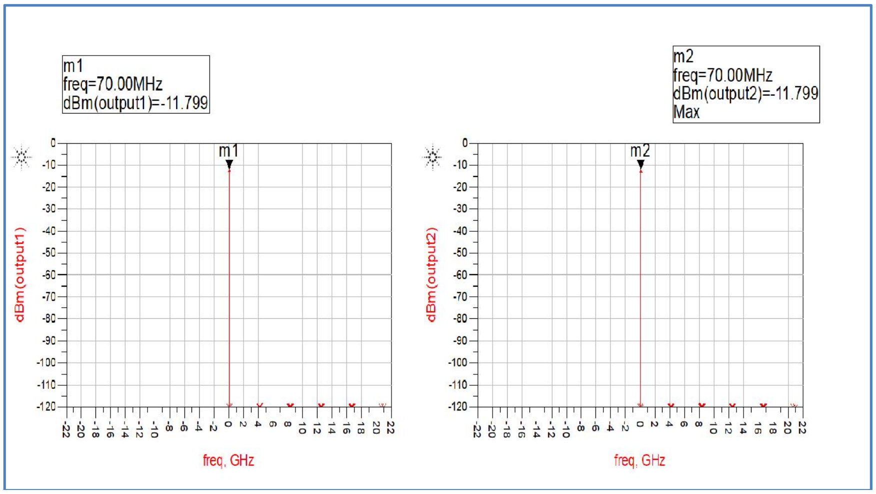


Fig. 14 Output power at (a) IF1 port and (b) IF2 port corresponding to the RF input of -30 dBm

VI. TEST AND EVALUATION RESULTS

Test Results of Unit's IF Chain-1 :

RF Input Frequency **:**4200 MHz

LO Frequency : 4130 MHz

LO level@ mixer port : +8dBm

IF Output Frequency **:**70 MHz

Gain Characteristics withInt LO1– IF Chain-1

SL NO.	RF INPUT (dBm)	IF OUTPUT (dBm)	CONVERSION GAIN (dB)
1	-80	-64.9	Around 15 dB
2	-70	-54.9	
3	-60	-44.9	
4	-50	-34.9	
5	-40	-24.9	
6	-30	-15.0	

Gain Characteristics withExtLO1–IF Chain-1

SL NO.	RF INPUT (dBm)	IF OUTPUT (dBm)	CONVERSION GAIN (dB)
1	-80	-64.5	15.5 dB
2	-70	-54.5	
3	-60	-44.5	

4	-50	-34.5	
5	-40	-24.5	
6	-30	-14.5	

Input Dynamic Range **:** -80 dBm to -30dBm
Conversion Gain **:** 15.5 dB (min)
I/P Power @ Ext LO Port**:**+10 dBm

Signal Leakage/ Isolation
RF : 4200 MHz, RF level: -40dBm,
LO: 4130 MHz, LO level at mixer port : +8 dBm
LO leakage at RF Input port: -74 dBm
LO leakage at IF1 Output port: -82 dBm
RF leakage at IF1 Output port :-94 dBm

Mon Port Measurement (Chain-1)
LO MON@ LO drive of +10 dBm : -2.8 dBm
Harmonics for -40 dBm RF I/P :
(2^{nd} harmonics) = -73 dBm @ 140 MHz
(3^{rd} harmonics) = Nil
Spurious for -40 dBm RF I/P :Nil

Test Results of Unit's IF Chain-2 :
RF Input Frequency **:** 4200 MHz
LO Frequency : 4130 MHz
LO level @ mixer LO port : +8dBm
IF Output Frequency **:** 70 MHz

Gain Characteristics with Internal LO2–IF Chain-2

SL NO.	RF INPUT (dBm)	IF OUTPUT (dBm)	CONVERSION GAIN (dB)
1	-80	68.2	Around 12 dB
2	-70	58.2	
3	-60	48.2	
4	-50	38.2	
5	-40	28.2	
6	-30	18.2	

Input Dynamic Range**:** -80 dBm to -30dBm
Conversion Gain**:** 12 (min)

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Gain Characteristics with External LO2–IF
Chain-2

SL NO.	RF INPUT (dBm)	IF OUTPUT (dBm)	CONVERSION GAIN (dB)
1	-80	-67	13 dB
2	-70	-57	
3	-60	-47	
4	-50	-37	
5	-40	-27	
6	-30	-17	

Input Dynamic Range **:** -80dBm to - 30dBm
Conversion Gain **:** 13.0 dB (min)
Input Power @ Ext LO port **:** +10 dBm

Signal Leakage/Isolation
RF :4200 MHz, RF level**:** -40dBm
LO: 4130 MHz, LO level at mixer port**:** +8 dBm
LO leakage at RF Input port : -70.6 dBm
LO leakage at IF2 Output port : -84.9 dBm
RF leakage at IF2 Output port: Nil
Mon Port Measurement (Chain-2)
LO MON@ LO drive of +10 dBm: -0.73 dBm
Harmonics For -40 dBm RF I/P : NIL
Spurious for -40 dBm RF I/P : NIL

VII. UNIT LEVEL RETURN LOSS PLOTS AT ALL PORTS (RF, LO & IF)

RF Port RL = 20.5dB

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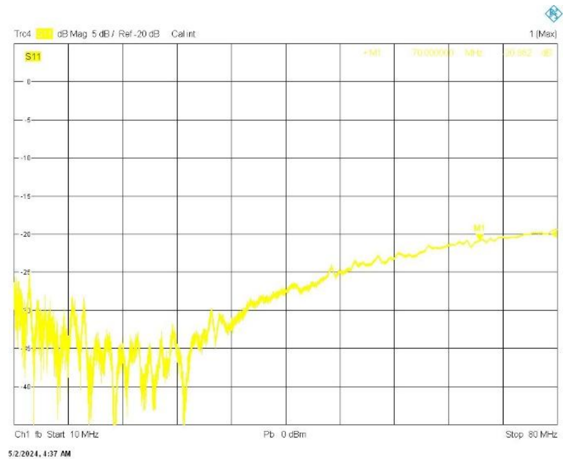
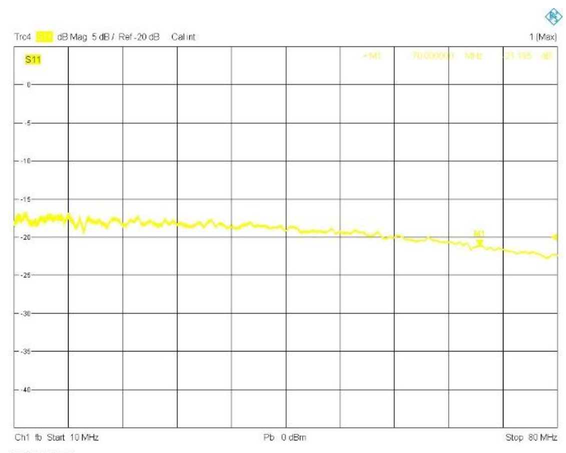
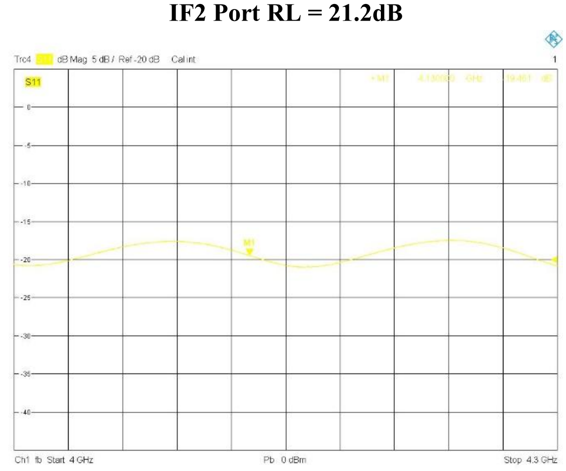


IF1 Port RL = 20.8dB



IF2 Port RL = 21.2dB



Ext LO1 Port RL = 19.5dB

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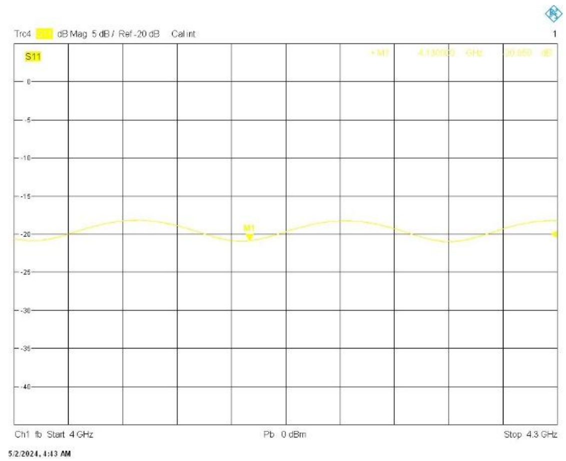
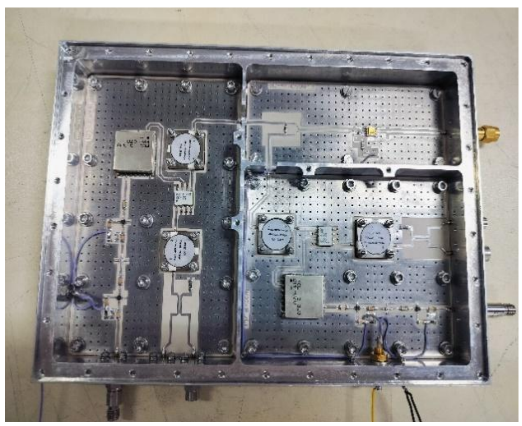
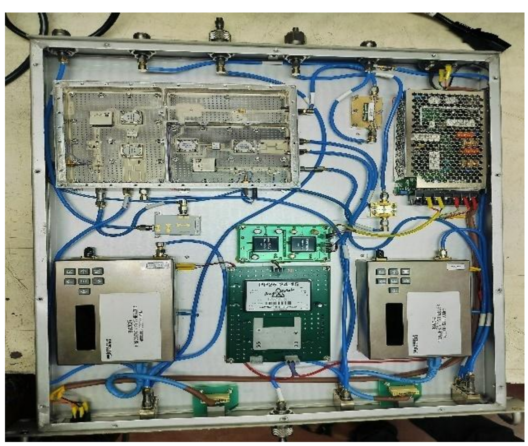


Ext LO1 Port RL = 20.8dB

VIII. FINAL UNIT PHOTOS



MIC DOWN CONVERTER MILLED BOX



FINAL PROTO UNIT INSIDE DETAILS

IX. DISCUSSIONS AND OBSERVATIONS

Loss of all the modules which are used ≈ 32dB

Gain of the amplifiers used (RF+IF) = 17+30 ≈ 47dB, **conversion gain** of the unit for both the chains expected ≈ 15dB

Bandwidth of the system is selected based on the transmission of PSK PM Signal for TTC RF downlink.

Bandwidth, $B = 2f_m(1 + m_p)$

where, f_m (Modulating frequency) = 128 KHz, m_p (PM mod index) = 1 rad,

hence, Bandwidth, B = ~ 600 KHz

Therefore, IF filter bandwidth selected for the system is 1.0 MHz for both the IF-1 and IF-2 chains.

Considering PM TM receiver's inputdynamic range and conversion gain of the down converter unit, the Input Dynamic range of the down converter unit's specification has been chosen as

-80 dBm to -30 dBm.

The unit level gain in ADS simulation is around 18dB but when actual hardware is fabricated in RT Duroid substrate, so many factors will come into picture which leads to loss of the signal level ex. Substrate losses, radiation losses and dielectric losses. With this we could get 15dB gain with the final unit.

X.0 FUTURE SCOPE

Design and development of Ku-Band MIC based Down converter for TTC-RF checkout requirements.

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