Addvalue Communications Pte Ltd
750D Chai Chee Road #03-03 Technopark @ Chai Chee
Singapore 469004 Tel +65 244 4828 Fax +65 242 4555
www.addvaluetech.com

UT HARDWARE DESIGN DOCUMENT

Chapter 2: RF & Antenna

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Addvalue Communications Pte Ltd
750D Chai Chee Road #03-03 Technopark @ Chai Chee
Singapore 469004 Tel +65 244 4828 Fax +65 242 4555
www.addvaluetech.com

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Addvalue Communications Pte Ltd
750D Chai Chee Road #03-03 Technopark @ Chai Chee
Singapore 469004 Tel +65 244 4828 Fax +65 242 4555
www.addvaluetech.com

ACRONYMS

ACI	Adjacent Channel Interference
ADC	Analog to Digital Converter
ALC	Automatic Level Control
AUT	Antenna Under Test
AWGN	Additive White Gaussian Noise
AGC	Automatic Gain Control
ASIC	Application Specific Integrated Circuit
BER	Bit Error Rate
BB	Baseband signal processor
BGAN	Broadband Global Area Network
CIC	Cascaded Integrator Comb
CN	Core Network
CORDIC	Coordinate Rotation Digital Computer
CS	Circuit Switched
DAC	Digital to Analog Converter
DDC	Digital Down Converter
DUC	Digital Up Converter
DFT	Discrete Fourier Transform
DD	Decision directed
DA	Data aided
EVM	Error Vector Magnitude
EOF	End Of Frame
FEC	Forward Error Correction
FER	Frame Error Rate
FFT	Fast Fourier Transform
FIR	Finite Impulse Response
FPGA	Field Programmable Gate Arrays
GPS	Global Positioning System
GPRS	General Packet Radio Service
HPA	High Power Amplifier
IF	Intermediate Frequency
I/Q	In-Phase/Quadrature
ISI	Inter-Symbol Interference
IAI-2	Inmarsat Air Interface -2
LEO	Low Earth Orbit
LNA	Low Noise Amplifier
ME	Mobile Equipment
MODEM	MOdulator and DEModulator
MCU	MicroControl Unit
MMI	Man Machine Interface
MPU	Micro Processor Unit
MT	Mobile Terminal
NCO	Numerically Controlled Oscillator
NDA	Non-Data Aided
PER	Packet Error Rate
PFD	Power Flux Densities
POST	Power On Self Test

PUT	Pocket User Terminal
PS	Packet Switched
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shifted Keying
RAM	Random Access Memory
RAN	Radio Access Network
RHCP	Right-Hand Circular Polarization
RNS	Radio Network Subsystem
ROM	Read Only Memory
RF	Radio Frequency
ROM	Read Only memory
RRC	Root Raised Cosine
RX	Receiver
SFDR	Spur Free Dynamic Range
SIM	Subscriber Identity Module
SNR	Signal-to-Noise Ratio
SOF	Start Of Frame
TBD	To Be Done/Determined
TDM	Time Division Multiplexing
TDMA	Time Division Multiplexing Access
TE	Terminal Equipment
TX	Transmitter
UICC	Universal Integrated Circuit Card
USIM	Universal Subscriber Identity Module
UT	User Terminal
UW	Unique Word

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DOCUMENT STATUS PAGE

Issue	Update	Date	Amendment Summary
Draft	N/A	Apr 03	PDR Release
Rev 1.0	2	Sept 0 3	FDR Release
Rev 1.1	3	Oct 03	Update based on RIDs

1 INTRODUCTION

1.1 RF SYSTEM OVERVIEW

The entire RF system consists of RF front-end, RX down-converter, and TX up-converter as well as frequency synthesizer section. Refer to Figure 1 for overall block diagram.

RF front-end consists of a Duplexer followed by 2 stages of LNA and RF band pass filters. The RF signal will be down converted to 1st IF (248.6MHz) and then to 2nd IF (10.8MHz). The 2nd IF signal is fed to the baseband for demodulation. Analog ALC loops are implemented to ensure constant level of IF signal is present to the ADC at the baseband.

For the transmit path, IF signal of 71MHz from the baseband will be up-converted to 433.92MHz and then to TX frequency before going to the HPA. HPA with a total gain of approximately 45 dB is capable of boosting the TX RF signal to +38dBm. In actual operation, the HPA will be driven to produce an output of +34dBm at 4dB OBO so as to ensure that the UT is able to pass the ETSI radiation specification.

Two Fractional-N Frequency synthesizers will be use to generate the LOs for the up and down conversion. TCXO with a frequency stability of ±2.5ppm is used to generate the reference clock for both RF synthesizer and baseband demodulator.

Duplexer is employed to allow simultaneous transmission and reception of signal with minimum interference to each other. Patch antenna with a minimum gain of 8.5dBi is designed so that the transmit power (EIRP) of 10dBW can be achieve.

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Singapore 469004 Tel +65 244 4828 Fax +65 242 4555
www.addvaluetech.com

1.2 RF FRONT END BLOCK DIAGRAM

RF FRONT END (Rev 0.12)

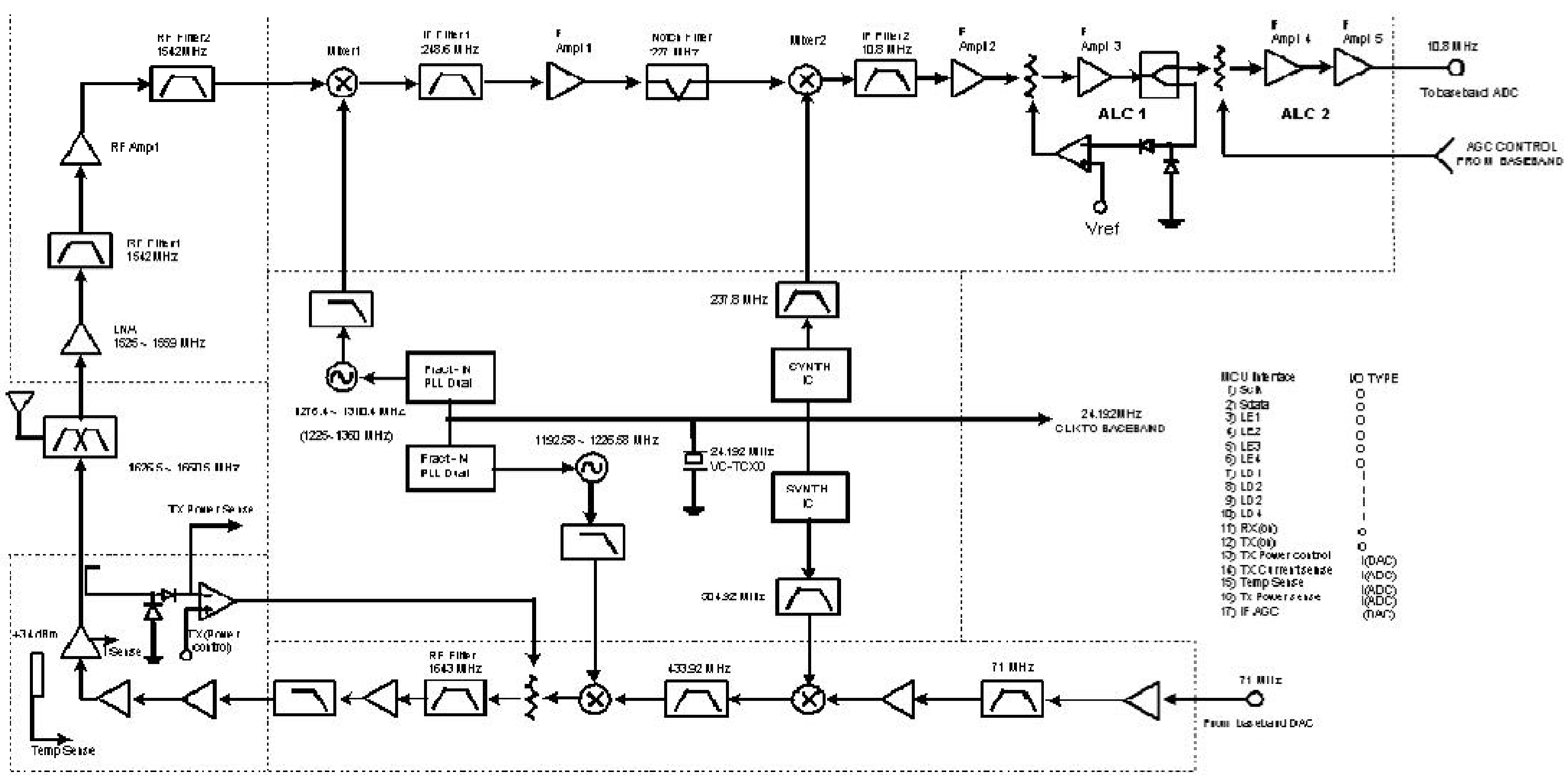


Figure 1: RF Front End Block Diagram

2 BGAN UT RF DESIGN TECHNICAL REQUIREMENTS

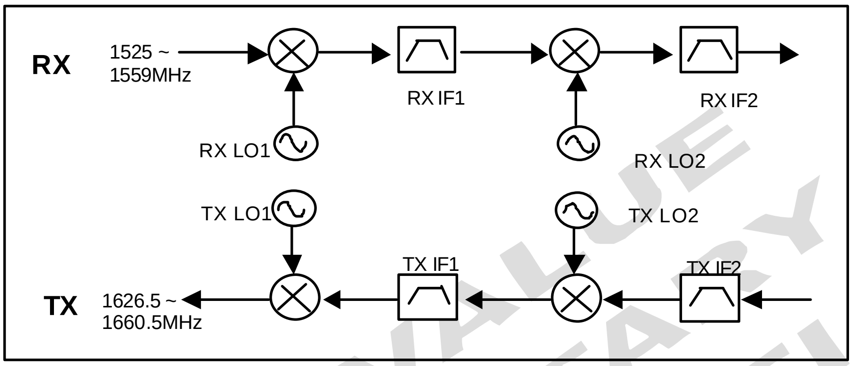
Item	Parameters	Test Condition	Limits			Unit
			Min	Typ	Max	
1	I4 Communication Antenna					
	Frequency	Receive band Transmit band	1525 1626.5		1559 1660.5	MHz
	Gain		8.5			dBic
	Polarization			RHCP		
	Noise Temperature				100	K
	Axial Ratio				4	dB
	Pattern Restriction		Gain < -5dB at angles below horizon			
	Size		140 × 160 × 10 Exclude thickness of base plate and ABS cover			mm
2	RF Receive Chain					
	G/T		-18.5			dB/K
	Receiver frequency		1525		1559	MHz
	System NF				3.5	dB
	LNA Gain		+18			dB
	LNA NF				0.6	dB
	LNA P1dB		+17	+19		dBm
	Receive Phase Noise	fc ± 10Hz	-36			dBc
		fc ± 50Hz	-54			dBc
		fc ± 100Hz	-61.5			dBc
		fc ± 500Hz	-74			dBc
		fc ± 1KHz	-78			dBc
		fc ± 5KHz	-79.5			dBc
		fc ± 10KHz	-80			dBc
		fc ± 50KHz	-89			dBc
		fc ± 100KHz	-89			dBc
	Receive ALC Dynamic Range			60		dB
3	RF Transmit Chain					
	EIRP				10	dBW
	Transmitter frequency		1626.5		1660.5	MHz
	HPA P1dB			+38		dBm
	HPA Chain Power added efficiency at P1dB			30		%
	Transmit Power Mask	See Appendix 1				

	Transmit Power Spectral Density Mask	Bearer Type T0.5:				
		fc ± 15.7 KHz	-20			dBc
		fc ± 32.7 KHz	-25			dBc
		fc ± 34.7 KHz	-30			dBc
		fc ± 65.5 KHz	-45			dBc
		Bearer Type T1:				
		fc ± 31.4KHz	-20			dBc
		fc ± 65.5 KHz	-25			dBc
		fc ± 69.4 KHz	-30			dBc
		fc ± 131 KHz	-45			dBc
		Bearer Type T2:				
		fc ± 62.9Hz	-20			dBc
		fc ± 131KHz	-25			dBc
		fc ± 138.8KHz	-30			dBc
		fc ± 262KHz	-45			dBc
		Bearer Type T4.5:				
		fc ± 133.6 KHz	-20			dBc
		fc ± 256 KHz	-25			dBc
		fc ± 282.6 KHz	-30			dBc
		fc ± 450 KHz	-45			dBc
		All PSD Mask must comply with ETSI 301 681 as well				
	Transmit Phase Noise	fc ± 10Hz	-35			dBc
		fc ± 100Hz	-55			dBc
		fc ± 1KHz	-73			dBc
		fc ± 10KHz	-75			dBc
		fc ± 100KHz	-90			dBc
		fc > 100KHz	-90			dBc
	Transmit Spurious Emission		Comply with ETSI EN 301 681			
	Transmitter Frequency Accuracy and Stability	Per 3 years			±5	ppm
4	Miscellaneous					
	Power supply (+5V_{DC})	Both RX and TX ON			600	mA
	Power supply (+5V_{DC})	Only TX ON			330	mA
	Power supply (+9V_{DC})	HPA supply only			1400	mA
	Operating Temperature		0	+25	40	°C

Table 1: BGAN UT RF Design Technical Requirement

3 BGAN UT RF DESIGN AND MEASUREMENT RESULTS

3.1 FREQUENCY PLAN



RX LO1	=	1276.4	~	1310.4	MHz
TX LO1	=	1192.58	~	1226.58	MHz
TX LO2	=	504.92	MHz		
RX LO2	=	237.8	MHz		
RX IF1	=	248.6	MHz		
RX IF2	=	10.8	MHz		
TX IF1	=	433.92	MHz		
TX IF2	=	71	MHz		
Image of Rx IF1	=	1027.8	~	1061.8	MHz
Image of Rx IF2	=	1503.4	~	1537.4	MHz

Harmonics	Ref Clk	TX LO2	RX LO2	RX IF1	RX IF2	TX IF1	TX IF2
Fundamental	**24.192**	**504.92**	**237.8**	**248.6**	**10.8**	**433.92**	**71**
2	48.384	1009.84	475.6	497.2	21.6	867.84	142
3	72.576	1514.76	713.4	745.8	32.4	1301.76	213
4	96.768	2019.68	951.2	994.4	43.2	1735.68	284
5	120.96	2524.6	1189	1243	54	2169.6	355
6	145.152	3029.52	1426.8	1491.6	64.8	2603.52	426
7	169.344	3534.44	1664.6	1740.2	75.6	3037.44	497
8	193.536	4039.36	1902.4	1988.8	86.4	3471.36	568
9	217.728	4544.28	2140.2	2237.4	97.2	3905.28	639
10	241.92	5049.2	2378	2486	108	4339.2	710
11	266.112	5554.12	2615.8	2734.6	118.8	4773.12	781
12	290.304	6059.04	2853.6	2983.2	129.6	5207.04	852
13	314.496	6563.96	3091.4	3231.8	140.4	5640.96	923
14	338.688	7068.88	3329.2	3480.4	151.2	6074.88	994
15	362.88	7573.8	3567	3729	162	6508.8	1065
16	387.072	14642.68	3804.8	3977.6	172.8	6942.72	1136

Table 2: Harmonics table (All in MHz)

		RX		TX		TX		RX	
m	N	mRX LO2 + nRX IF1	mRX LO2 - nRX IF1	mTX LO2 + nTX IF2	mTX LO2 - nTX IF2	mTX LO2 + nRX IF1	mTX LO2 - nRX IF1	mRX LO2 + nTX IF2	m RX LO2 - nTX IF2
1	1	486.4	-10.8	575.92	433.92	753.52	256.32	308.8	166.8
1	2	735	-259.4	646.92	362.92	1002.12	7.72	379.8	95.8
1	3	983.6	-508	717.92	291.92	1250.72	-240.88	450.8	24.8
1	4	1232.2	-756.6	788.92	220.92	1499.32	-489.48	521.8	-46.2
2	1	724.2	227	1080.84	938.84	1258.44	761.24	546.6	404.6
2	2	972.8	-21.6	1151.84	867.84	1507.04	512.64	617.6	333.6
2	3	1221.4	-270.2	1222.84	796.84	1755.64	264.04	688.6	262.6
2	4	1470	-518.8	1293.84	725.84	2004.24	15.44	759.6	191.6
3	1	962	464.8	1585.76	1443.76	1763.36	1266.16	784.4	642.4
3	2	1210.6	216.2	1656.76	1372.76	2011.96	1017.56	855.4	571.4
3	3	1459.2	-32.4	1727.76	1301.76	2260.56	768.96	926.4	500.4
3	4	1707.8	-281	1798.76	1230.76	2509.16	520.36	997.4	429.4
4	1	1199.8	702.6	2090.68	1948.68	2268.28	1771.08	1022.2	880.2
4	2	1448.4	454	2161.68	1877.68	2516.88	1522.48	1093.2	809.2
4	3	1697	205.4	2232.68	1806.68	2765.48	1273.88	1164.2	738.2
4	4	1945.6	-43.2	2303.68	1735.68	3014.08	1025.28	1235.2	667.2
5	1	1437.6	940.4	2595.6	2453.6	2773.2	2276	1260	1118
5	2	1686.2	691.8	2666.6	2382.6	3021.8	2027.4	1331	1047
5	3	1934.8	443.2	2737.6	2311.6	3270.4	1778.8	1402	976
5	4	2183.4	194.6	2808.6	2240.6	3519	1530.2	1473	905
6	1	1675.4	1178.2	3100.52	2958.52	3278.12	2780.92	1497.8	1355.8
6	2	1924	929.6	3171.52	2887.52	3526.72	2532.32	1568.8	1284.8
6	3	2172.6	681	3242.52	2816.52	3775.32	2283.72	1639.8	1213.8
6	4	2421.2	432.4	3313.52	2745.52	4023.92	2035.12	1710.8	1142.8

Table 3: Mixer product output table (All in MHz)

From the harmonics study in Table 2, none of the harmonics of L.O.s fall into TX and RX frequency band. TX IF has been selected such that its harmonics do not fall into any of the RX frequency band. Some of the mixer output products (Table 3) actually fall into the RX and TX frequency band. However, their signal level should be very weak. To further reduce the effect of these products, band pass filter has been added to LOs to suppress their harmonics level. Special attention will also be given to the PCB layout to avoid cross coupling of such signals into the TX/RX path.

3.2 RECEIVER INTERFERENCE REJECTION ANALYSIS

This section will study the filter response required at each stage of the receive chain in order to suppress the interfering signal i.e. 1626.5~1660.5MHz, 1520~1560MHz (-95dBW/m^2), 1500~1525 MHz (-69dBW/m^2), 100kHz~1400MHz(-45dBW/m^2), 1626.5~4000MHz (-45dBW/m^2) and 2.4GHz Bluetooth.

3.2.1 RECEIVE SIGNAL ANALYSIS (1525~1559 MHZ)

Calculation in section 3.4.4.6 shows that RF board is required to generate a –15dBm IF output signal to the ADC in order to meet the full-scale voltage required by the baseband.

			Min signal level (-143dBW/m2)	Max signal level (-113dBW/m2)	
Receiver Block	***Gain (dB)***	***$OP1_{dB}$ (dBm)***	***RX Signal strength (dBm)***	***RX Signal strength (dBm)***	***REMARKS***
			-138.5	-109.5	
Ant	8.5	-	-130	-101	
Cable	-0.5	-	-130.5	-101.5	
Duplexer	-1.5	-	-132	-103	
LNA	+18	+20	-114	-85	
RF Filter1 (1542MHz)	-3.5	-	-117.5	-88.5	
RF Ampl	+14	+16	-103.5	-74.5	
RF Filter2 (1542MHz)	-3.5	-	-107	-78	
Mixer1	+6	-4	-101	-72	
IF Filter1 (248.6MHz)	-6	-	-107	-78	
IF Ampl1	+20	0	-87	-58	
Mixer 2	+6	-4	-81	-52	
IF Filter2 (10.8MHz)	-8	-	-89	-60	
IF Ampl 2	+20	0	-69	-40	
Attenuator 1	-1	-	-70	-41	ALC 1 begins at attenuator 1. It will be activated when the output of splitter hit –13dBm so that the ADC will not saturate.
IF Ampl 3	+20	0	-50	-21	
Splitter	-3	-	-53	-24	
Attenuator 2	-2	-	-55	-26	ALC 2 begins at attenuator 2. It is controlled by baseband and for max signal level (-113dBw/m^2), attenuator 2 will be set to –31dB so that the output of IF Ampl 5 will be –15dBm.
IF Ampl 4	+20	0	-35	-6	
IFAmpl 5	+20	0	-15	+14	

Table 4: Receive signal analysis

3.2.2 TRANSMIT SIGNAL REJECTION ANALYSIS (1626.5~1660.5 MHZ)

The strongest signal at 1626.5 ~ 1660.5MHz that will be received by the UT is actually the signal (+32dBm) transmitted by the UT itself. There will be at least 65dB suppression by the Duplexer so that the signal will not drive the LNA into compression. 2 RF filters are placed after the LNA to give further rejection to the interfering signal. Each RF filter will have at least –38dB of rejection to 1626.5 ~ 1660.5MHz interference.

The resultant signal (Refer to Table 5) at output of IF stage is –49dBm and is more than 30dB below the wanted signal (with reference to the weakest RX signal strength of –143dBW/m^2).

Receiver Block	*Gain (dB)*	*OP1$_{dB}$ (dBm)*	*RX signal strength (dBm)*	*REMARKS*
			+32	The strongest signal at 1626.5 ~ 1660.5MHz that will be received by the UT is the signal (+32dBm) transmitted by the UT itself.
Duplexer	-65	-	-33	
LNA	+18	+20	-15	
RF Filter1 (1542MHz)	-38	-	-53	
RF Ampl	+14	+16	-39	
RF Filter2 (1542MHz)	-38	-	-77	
Mixer1	+6	-4	-71	
IF Filter1 (248.6MHz)	-48	-	-119	
IF Ampl1	+20	0	-99	
Mixer 2	+6	-4	-93	
IF Filter2 (10.8MHz)	-30	-	-123	
IF Ampl 2	+20	0	-103	
Attenuator 1	-1	-	-104	ALC 1 begins at attenuator 1. It will be activated when the output of splitter hit –13dBm so that the ADC will not saturate.
IF Ampl 3	+20	0	-84	
Splitter	-3	-	-87	
Attenuator 2	-2	-	-89	
IF Ampl 4	+20	0	-69	
IFAmpl 5	+20	0	-49	

Table 5: Transmit Signal Rejection Analysis (1626.5~1660.5 MHz)

3.2.3 IMAGE1 SIGNAL REJECTION ANALYSIS (1027.8~1061.8 MHZ)

Image1 frequency refers to image frequency of the RX IF1 that is 2 x 248.6MHz away from the RX frequency at the low side. Interfering signal in this frequency band will have a power level of -45dBW/m^2.

The analysis result shows that the output signal at IF stage produced by the image signal is –76.2dBm and is more than 30dB below the wanted signal (with reference to the weakest RX signal strength of –143dBW/m^2).

Receiver Block	*Gain (dB)*	*OP1$_{dB}$ (dBm)*	*RX signal strength (dBm)*	*REMARKS*
			-36.7	
Ant	-10	-	-46.7	There is approx. 10dB suppression of signal by the antenna at image frequency 1027.8 ~ 1061.8MHz.
Cable	-0.5	-	-47.2	
Duplexer	-70	-	-117.2	
LNA	+18	+20	-99.2	
RF Filter1 (1542MHz)	-29	-	-128.2	
RF Ampl	+14	+16	-114.2	
RF Filter2 (1542MHz)	-29	-	-143.2	
Mixer1	+6	-4	-137.2	
IF Filter1 (248.6MHz)	-6	-	-143.2	
IF Ampl1	+20	0	-123.2	
Mixer 2	+6	-4	-117.2	
IF Filter2 (10.8MHz)	-8	-	-125.2	
IF Ampl 2	+20	0	-105.2	
Attenuator 1	-1	-	-106.2	ALC 1 begins at attenuator 1. It will be activated when the output of splitter hit –13dBm so that the ADC will not saturate.
IF Ampl 3	+20	0	-86.2	
Splitter	-3	-	-89.2	
Attenuator 2	-2	-	-91.2	
IF Ampl 4	+20	0	-71.2	
IFAmpl 5	+20	0	-51.2	

Table 6: Image1 Signal Rejection Analysis (1027.8~1061.8 MHz, -45dBW/m^2)

Addvalue Communications Pte Ltd
750D Chai Chee Road #03-03 Technopark @ Chai Chee
Singapore 469004 Tel +65 244 4828 Fax +65 242 4555
www.addvaluetech.com

3.2.4 IMAGE2 SIGNAL REJECTION ANALYSIS (1503.4~1537.4 MHZ)

Image2 frequency refers to image frequency of the RX IF2 that is 2 x 10.8MHz away from the RX frequency at the low side. Interfering signal in this frequency band will have a power level of -69dBW/m^2.

When down converted to 1st IF stage, this image2 frequency will appear as 227MHz (248.6 –2X10.8MHz).

Analysis result (refer to Table 7) shows that there is insufficient rejection to the 2nd image signal. Therefore an additional notch or band pass filter is needed at the 1st IF stage to suppress the image (227MHz) by at least 35dB.

Receiver Block	*Gain (dB)*	*OP1$_{dB}$ (dBm)*	*RX signal strength (dBm)*	*REMARKS*
			-64	
Ant	8.5	-	-55.5	There is no rejection by the A5004 antenna at image frequency 1503 ~ 1537MHz.
Cable	-0.5	-	-56	
Duplexer	-1.5	-	-57.5	
LNA	+18	+20	-39.5	
RF Filter1 (1542MHz)	-3.5	-	-43	
RF Ampl	+14	+16	-29	
RF Filter2 (1542MHz)	-3.5	-	-32.5	
Mixer1	+6	-4	-26.5	
IF Filter1 (248.6MHz)	-66	-	-92.5	An additional notch filter is needed to give another 35dB suppression of image signal at 227MHz.
IF Ampl1	+20	0	-72.5	
Mixer 2	+6	-4	-66.5	
IF Filter2 (10.8MHz)	-8	-	-74.5	
IF Ampl 2	+20	0	-54.5	
Attenuator 1	-1	-	-55.5	ALC 1 begins at attenuator 1. It will be activated when the output of splitter hit –13dBm so that the ADC will not saturate.
IF Ampl 3	+20	0	-35.5	
Splitter	-3	-	-38.5	
Attenuator 2	-2	-	-40.5	ALC 2 begins at attenuator 2. It is controlled by baseband. In this analysis, attenuator 2 will be set to –16.5dB so that the output of IF Ampl 5 will be –15dBm.
IF Ampl 4	+20	0	-20.5	
IFAmpl 5	+20	0	-0.5	

Table 7: Image2 Signal Rejection Analysis (1503.4~1537.4 MHz, -69dBW/m^2)

3.2.5 BLUETOOTH SIGNAL REJECTION ANALYSIS (2.4 GHZ)

The Duplexer and RF filters at the RF front end have provided a very good rejection to the 2.4GHz Bluetooth signal (refer to Table 8). Therefore the Bluetooth signal at the surrounding of UT should not cause any degradation in the UT performance.

Receiver Block	***Gain (dB)***	***$OP1_{dB}$ (dBm)***	***RX signal strength (dBm)***	***REMARKS***
			-25	Bluetooth signal at 2.4GHz.
Ant	-10	-	-35	Assuming BT transmits at 0dBm. Antenna rejection at 2.4GHz is approx. 10dB
Cable	-0.5	-	-35.5	
Duplexer	-60	-	-95.5	
LNA	+18	+20	-77.5	
RF Filter1 (1542MHz)	-30	-	-107.5	
RF Ampl	+14	+16	-93.5	
RF Filter2 (1542MHz)	-30	-	-123.5	
Mixer1	+6	-4	-117.5	
IF Filter1 (248.6MHz)	-50	-	-167.5	
IF Ampl1	+20	0	-147.5	
Mixer 2	+6	-4	-141.5	
IF Filter2 (10.8MHz)	-50	-	-191.5	
IF Ampl 2	+20	0	-171.5	
Attenuator 1	-1	-	-172.5	ALC 1 begins at attenuator 1. It will be activated when the output of splitter hit –13dBm so that the ADC will not saturate.
IF Ampl 3	+20	0	-152.5	
Splitter	-3	-	-155.5	
Attenuator 2	-2	-	-157.5	
IF Ampl 4	+20	0	-137.5	
IFAmpl 5	+20	0	-117.5	

Table 8: Bluetooth Signal Rejection Analysis (2.4 GHz)

Addvalue Communications Pte Ltd
750D Chai Chee Road #03-03 Technopark @ Chai Chee
Singapore 469004 Tel +65 244 4828 Fax +65 242 4555
www.addvaluetech.com

3.2.6 IN-BAND INTERFERENCE REJECTION ANALYSIS (-95DBW/M ^{2})

In-band interference is in the frequency range of 1520 ~ 1560MHz having a composite flux density as high as -95dBW/m^2. The worst scenario will be that the interfering signal appears to be very near the wanted signal. An example will be adjacent channel rejection. Adjacent channel refers to signal at ±120kHz away from the wanted bearer center frequency.

Analysis of the result (refer to Table 9) shows that IF filters do not have sufficient rejection to the adjacent channel interference. The main reason is that in order to have good rejection, the IF filters need to have a very sharp response. The nominal bandwidth of the signal is 200KHz and to ensure that this 200KHz signal is being properly filtered, the passband of the IF filter has to be slightly wider i.e. ±135KHz to cater for response drift at extreme temperature condition. It is therefore not possible to achieve a 30 dB suppression of adjacent channel signal at IF stage. However, the RRC filter at the baseband will provide at least 35dB rejection to such interfering signal so as to meet the receiver selectivity specification stated in SDM V5C1 section 2.3.6.

Receiver Block	***Gain (dB)***	***$OP1_{dB}$ (dBm)***	***RX signal strength (dBm)***	***REMARKS***
Ant	8.5	-	-90.1 -81.6	Adjacent channel refers to signal at ±120KHz away from the wanted bearer center frequency.
Cable	-0.5	-	-82.1	
Duplexer	-1.5	-	-83.6	
LNA	+18	+20	-65.6	
RF Filter1 (1542MHz)	-3.5	-	-69.1	
RF Ampl	+14	+16	-55.1	
RF Filter2 (1542MHz)	-3.5	-	-58.6	
Mixer1	+6	-4	-52.6	
IF Filter1 (248.6MHz)	-6	-	-58.6	There is no rejection of adjacent channel signal by the 248.6MHz filter.
IF Ampl1	+20	0	-38.6	
Mixer 2	+6	-4	-32.6	
IF Filter2 (10.8MHz)	-9	-	-41.6	There is only approx. 1dB suppression of adjacent channel signal by 10.8 IF filter.
IF Ampl 2	+20	0	-21.6	
Attenuator 1	-1	-	-22.6	ALC 1 begins at attenuator 1. It will be activated when the output of splitter hit –13dBm so that the ADC will not saturate. In this analysis, attenuator 1 will be set to –6.4dB so that together with attenuator 2 (-42dB) it will produce a –15dBm signal at IF Ampl 5 output.
IF Ampl 3	+20	0	-2.6	
Splitter	-3	-	-5.6	
Attenuator 2	-2	-	-7.6	ALC 2 begins at attenuator 2. It is controlled by baseband. In this analysis, attenuator 2 will be set to –42dB so that the output of IF Ampl 5 will
IF Ampl 4	+20	0	+12.4	

IFAmpl 5	+20	0	+32.4	be –15dBm.

Table 9: In-Band Interference rejection analysis (-95dBW/m²)

3.2.7 NEAR IN-BAND INTERFERENCE REJECTION ANALYSIS (1524.625MHZ)

Near in-band interference appear in the 1500 ~ 1525 MHz band a having a composite flux density as high as -69dBW/m^2. One worst scenario will be wanted signal at 1525.1MHz with interfering signal at 1524.625MHz. Since the interfering signal is near in-band, there will be not rejection by the RF front-end filters. 1st IF filter (248.6MHz) will have more than 20dB rejection while 2nd IF filter (10.8MHz) will give another 30dB rejection minimum. As a result there will be more than 50dB suppression of interference at 1524.625MHz.

Analysis of the result (refer to Table 10) shows that the interfering signal at the IF stage appeared to be 14.4dB stronger than the wanted signal (with reference to the weakest RX signal strength of –143dBW/m^2).

Receiver Block	***Gain (dB)***	***OP1$_{dB}$ (dBm)***	***RX signal strength (dBm)***	REMARKS
			-64.1	Interfering signal = 1524.625MHz. There is no rejection of signal by the antenna at near band frequency 1524MHz.
Ant	8.5	-	-55.6	
Cable	-0.5	-	-56.1	
Duplexer	-1.5	-	-57.6	
LNA	+18	+20	-39.6	
RF Filter1 (1542MHz)	-3.5	-	-43.1	
RF Ampl	+14	+16	-29.1	
RF Filter2 (1542MHz)	-3.5	-	-32.6	
Mixer1	+6	-4	-26.6	
IF Filter1 (248.6MHz)	-30	-	-56.6	
IF Ampl1	+20	0	-36.6	
Mixer 2	+6	-4	-30.6	
IF Filter2 (10.8MHz)	-44	-	-74.6	
IF Ampl 2	+20	0	-54.6	
Attenuator 1	-1	-	-55.6	ALC 1 begins at attenuator 1. It will be activated when the output of splitter hit –13dBm so that the ADC will not saturate
IF Ampl 3	+20	0	-35.6	
Splitter	-3	-	-38.6	
Attenuator 2	-2	-	-40.6	ALC 2 begins at attenuator 2. It is controlled by baseband. In this analysis, attenuator 2 will be set to –16.4dB so that the output of IF Ampl 5 will be –15dBm.
IF Ampl 4	+20	0	-20.6	
IFAmpl 5	+20	0	-0.6	

Table 10: Near In-band Interference rejection analysis (1524.625MHz)

3.3 A5004 ANTENNA

3.3.1 MODELLED PERFORMANCE OF THE A5004 ANTENNA

PARAMETER	SPECIFICATION
Frequency	1525-1559.5 MHz, receive (Rx 1626-1660.5 MHz, transmit (Tx)
Gain	9 dBic, Rx and Tx
Polarization	RHCP, Rx and Tx
Noise Temperature	~100K
Axial Ratio	4 dB maximum, Rx and Tx patches
Return Loss	12 dB, nominal
Size	150mm × 200mm × 12mm deep
Construction	120 mil foam/5 mil FR4/250 mil foam/ 5mil FR4

Table 11: Modelled Performance of A5004 Antenna

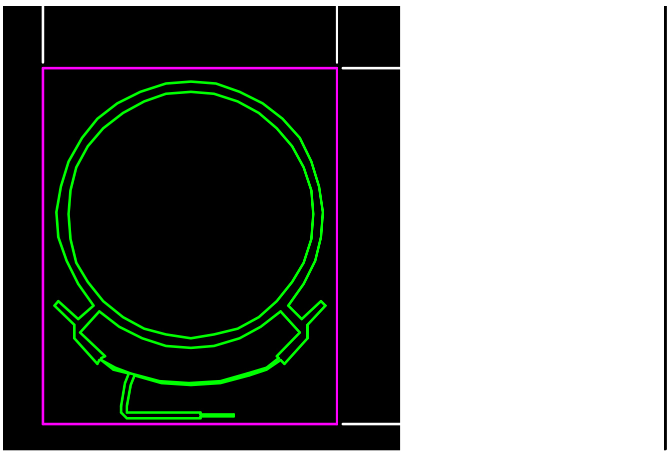


Figure 2: The A5004 Single Broadband CP Patch Antenna

3.3.2 ANTENNA A5004 ELECTRICAL PERFORMANCE

This section summarizes the electrical performance measured on the BGAN A5004 antenna. It includes a description of the Antenna Under Test (AUT), the procedure(s) used for making the measurements, and a summary of the measurement results including radiation patterns.

3.3.2.1 TEST ARTICLE

A bottom-up material description of the AUT is as follows:

- Aluminum ground plane 150mm W × 200mm L × 1.5mm T.
- Foam spacer 150mm W × 200mm L × 3mm T.
- FR-4 printed circuit 150mm W × 200mm L × 0.127mm T.
- Foam spacer 150mm W × 200mm L × 6.4mm T.
- FR-4 printed circuit 150mm W × 200mm L × 0.127mm T.
- ABS cover 150mm W × 200mm L × 1.5mm T.
- OVERALL DIMENSIONS: 150mm W × 200mm L × 12.66mm T

The RF port uses an SMA (f) panel mounted connector located beneath the aluminum ground plane and its center conductor soldered to the lower FR-4 circuit. All measurement values are referenced to the output of this connector.

3.3.2.2 RANGE TESTS

The A5004 AUT was measured for return loss (VSWR), gain, x-pol level, and co-pol radiation patterns. Return loss measurements were taken using a scalar network analyzer and RF source sweeping 1525 – 1661 MHz. Gain, x-pol and radiation pattern measurements were taken in a 35-foot anechoic test chamber at four frequency points: 1525 MHz, 1559 MHz, 1626 MHz, and 1661 MHz. Patterns were recorded on a Scientific Atlanta receiver and rectangular chart recorder. To take co-pol radiation patterns, the AUT is placed on el-az test pedestal and bore sighted toward a transmitting antenna that was either a RHCP helix (for co-pol) or LHCP helix (for x-pol). For gain measurements the helix is replaced with a linear standard gain horn and the recorded amplitude level of the AUT is compared with that of a calibrated gain horn. The standard 3 dB adjustment is made to convert from linear to CP gain. The test results are summarized in Table 12.

Frequency	1525 MHz	1559 MHz	1626 MHz	1661 MHz
Gain	8.5 dBic	8.6 dBic	8.6 dBic	8.7 dBic
X-pol*	20 dB	23 dB	17 dB	16 dB
HPBW	60°	56°	54°	52°
Max gain below horizon	<-10 dB	<-10 dB	<-10 dB	<-10 dB
Var. at peak (Pointing loss)	0.1 dB	0.1 dB	0.1 dB	0.1 dB
Swept VSWR	<1.5:1			
Noise Temp (est)	88K	88K	N A	N A
Connector	SMA (f)			
Cover	1.5mm ABS			

Table 12: Summary of A5004 Antenna test result

** 20 dB X-pol level is equivalent to 1.8 dB axial ratio.*
16 dB X-pol level is equivalent to 3.0 dB axial ratio.

3.3.2.3 RECORDED DATA

Radiation patterns for each of the four test frequencies are shown in Figure 3 to Figure 6. The return loss plot is shown in Figure 7.

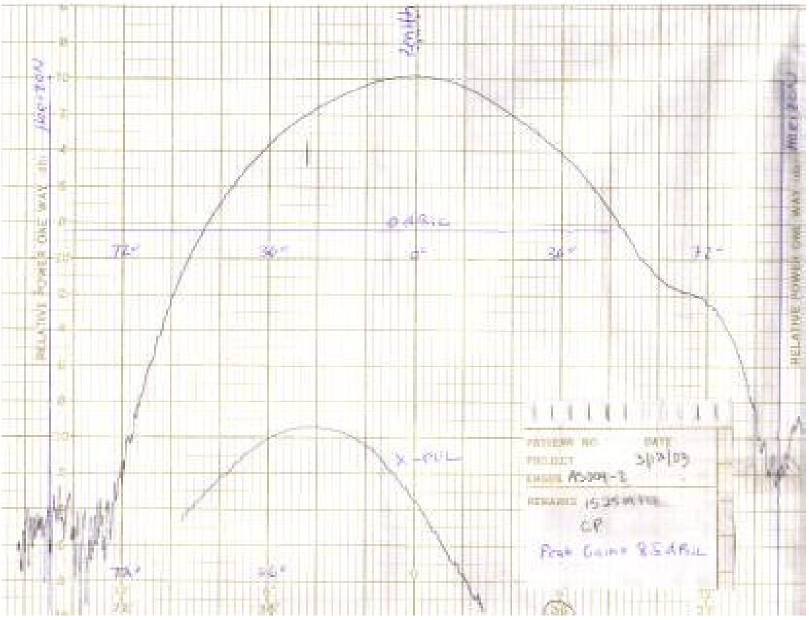


Figure 3: Radiation Pattern at 1525 MHz

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750D Chai Chee Road #03-03 Technopark @ Chai Chee
Singapore 469004 Tel +65 244 4828 Fax +65 242 4555
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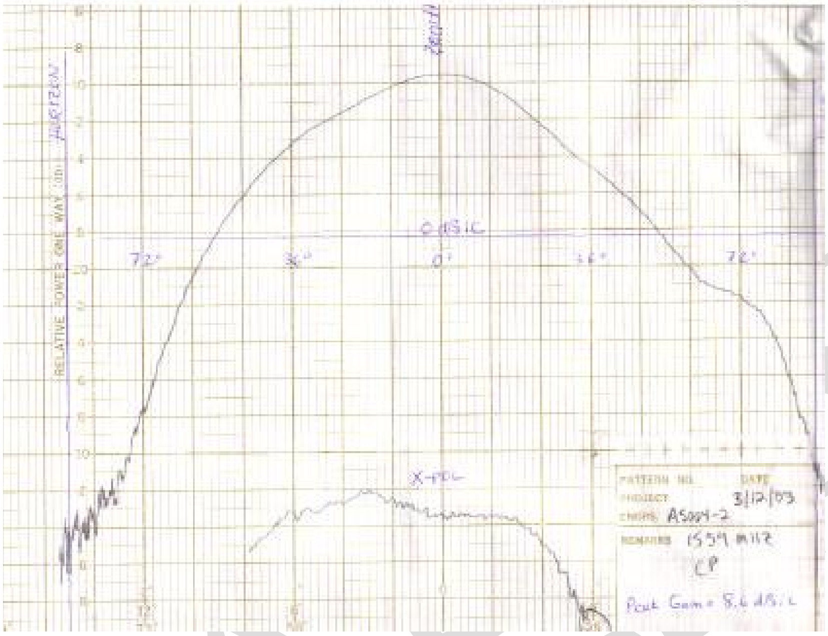


Figure 4: Radiation Pattern at 1559 MHz

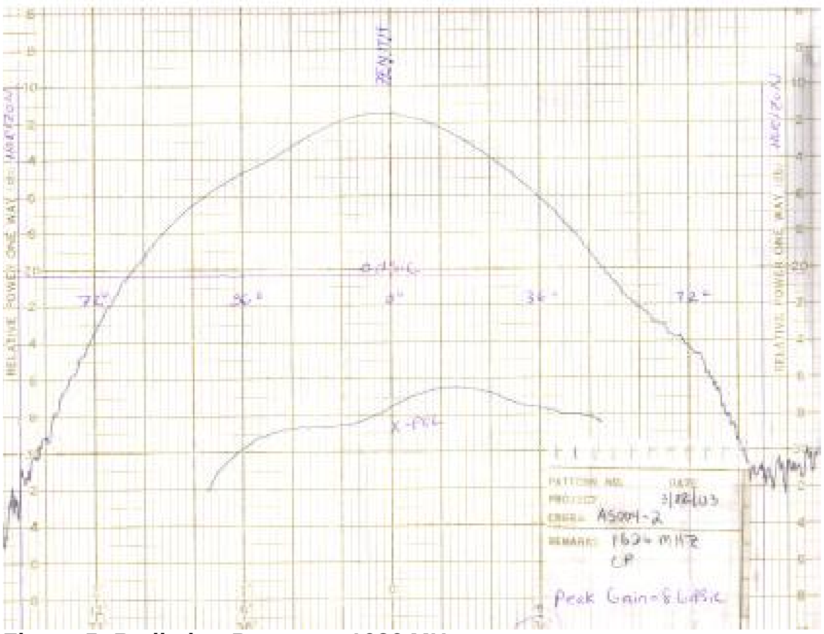


Figure 5: Radiation Pattern at 1626 MHz

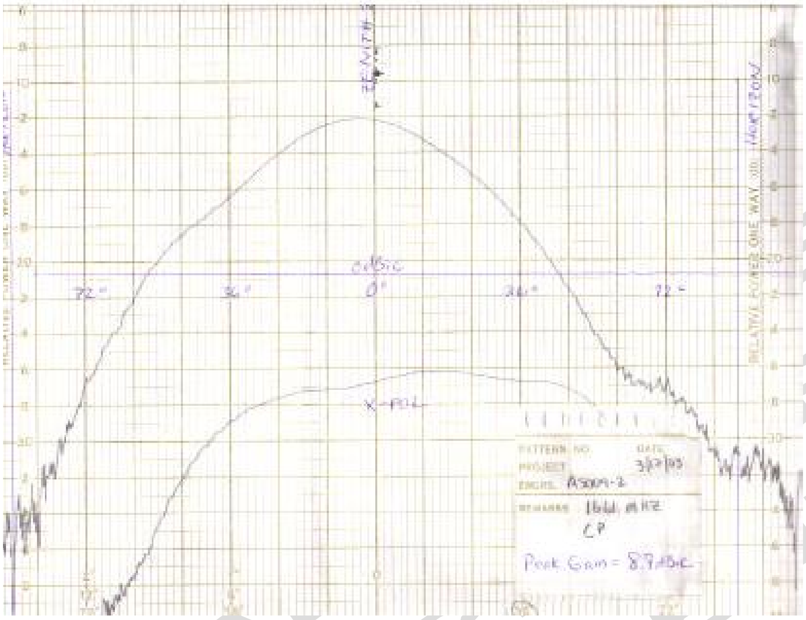


Figure 6: Radiation Pattern at 1661 MHz

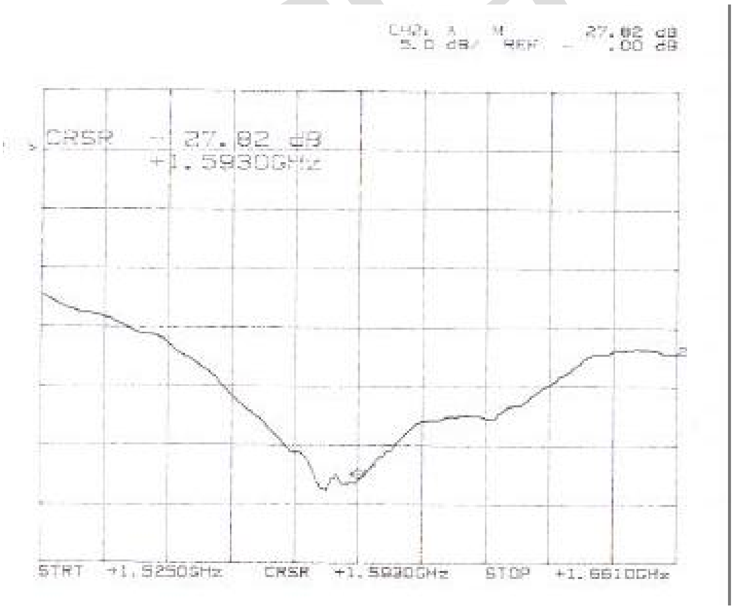


Figure 7: Swept Return Loss Plot

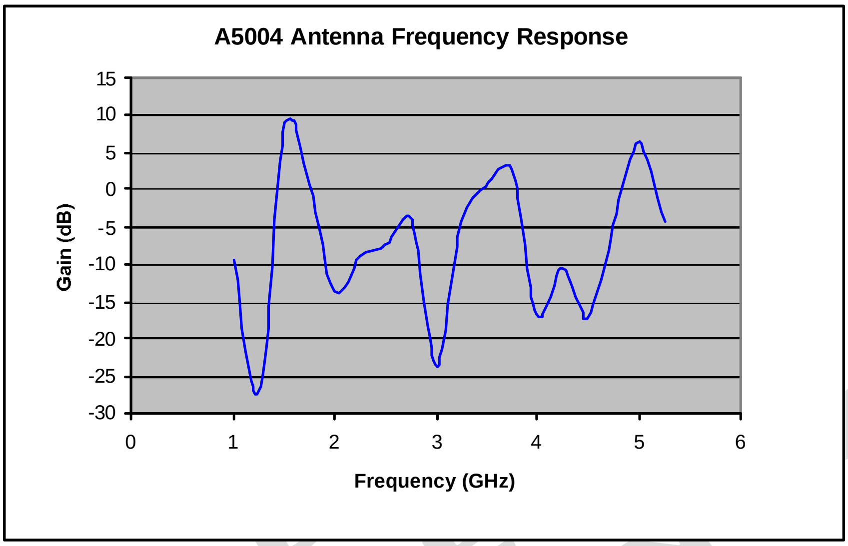


Figure 8: Frequency response of A5004 antenna 1GHz ~ 5 GHz

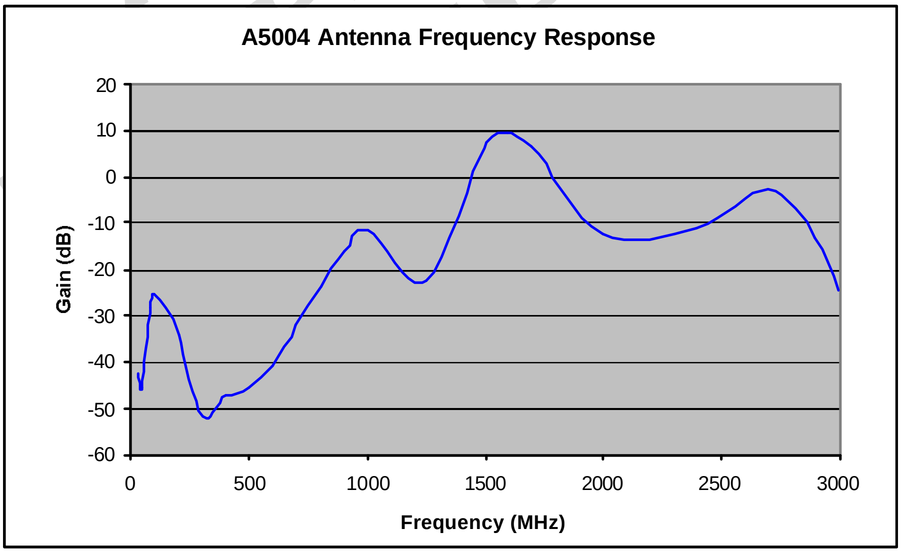


Figure 9: Frequency response of A5004 antenna 30MHz ~ 3GHz

Figure 8 & Figure 9 will be used to determine the amount of out of band signal rejection of the antenna. These plots were referenced during the receiver interference rejection analysis in section 3.2 as well as spurious signal suppression measurement in section 3.4.4.3.

3.4 RF RECEIVE CHAIN

3.4.1 SYSTEM G/T CALCULATION

From the antenna prototype (A5004) measurement result, the antenna gain is 8.5dBi. Base on this value, the maximum system Noise Figure to meet the minimum G/T ratio of -18.5dB/K is calculated as below:

G/T (dB/K) = Ant Gain (dB) – 10 Log [Total System Noise Temp] ----------- (3.1)

$$-18.5 = 8.5 - 10\text{Log}[T_{sys}]$$

$$T_{sys} = 501\ K$$

The total system noise temperature (Tsys) consists of antenna noise temperature (Tant) and system noise temperature (Te).

Taking maximum antenna noise temperature as 135K (135K is given in Action item #02, Pocket Size BGAN UT Development Program Feasibility Study Review – Action Log 22-24 July 02), maximum system noise temperature will be:

$$T_e = 501 - T_{ant} = 501 - 135\ K = 366\ K$$

$$NF = 10\text{Log}(1 + T_e/T_o) \quad \text{--} \ (3.2)$$

Where NF: System Noise Figure

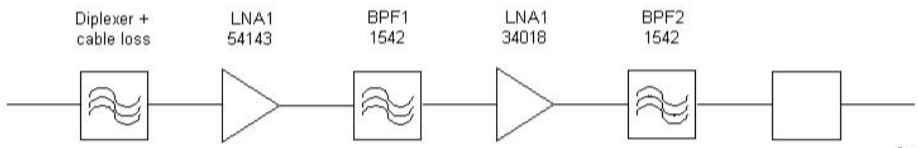
T_e: System Noise temperature

T_o: 290K

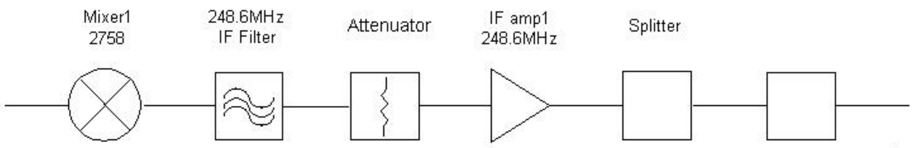
Therefore $NF = 10\text{Log}(1+ 366/290) = 3.545\text{dB}$

The design target will be set at 3.5dB which include LNA temperature variation, antenna gain variation and noise contributed by the UT transmitter in the receive band.

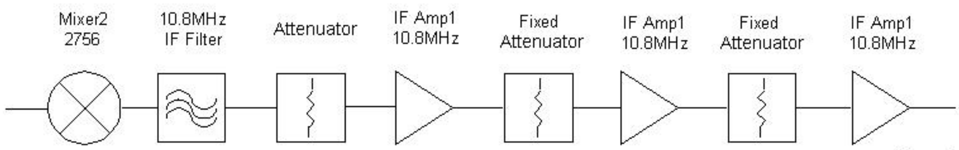
3.4.2 SYSTEM GAIN AND NF SIMULATION



	Diplexer + cable loss	LNA1 54143	BPF1 1542	LNA1 34018	BPF2 1542	IF (248.6MHz)	Cascade Total
NF (dB)	2.0	0.6	3.5	1.0	3.5	12.85	2.92
Gain (dB)	-2	18	-3.5	14	-3.5	67.00	90.00
OIP3 (dBm)	100	35	100	28	100	9.91	9.91
Pout (dBm)	-133.0	-115.0	-118.5	-104.5	-108.0	-41.0	
NF+ (dB)		0.55	0.07	0.03	0.01	0.21	
OIP3+ (dB)	0.00	0.00	0.00	0.00	0.00		
Input Power (dBm)		-131					



	Mixer1 2758	248.6MHz IF Filter	Attenuator	IF amp1 248.6MHz	Splitter	IF (10.8MHz)	Cascade Total
NF (dB)	12	6	1	4	3	13.16	12.85
Gain (dB)	6	-6	-1	20	-3	51.00	67.00
OIP3 (dBm)	11	100	100	10	100	9.91	9.91
Pout (dBm)	-102.0	-108.0	-109.0	-89.0	-92.0	-41.0	
NF+ (dB)		0.17	0.06	0.45	0.00	0.11	
OIP3+ (dB)	0.00	0.00	0.00	0.00	0.00		
Input Power (dBm)		108.00					



	Mixer2 2756	10.8MHz IF Filter	Attenuator	IF Amp1 10.8MHz	Fixed Attenuator	IF Amp1 10.8MHz	Fixed Attenuator	IF Amp1 10.8MHz	Cascade Total
NF (dB)	12	8	1	4	3	4	3	4	13.16
Gain (dB)	6	-8	-1	20	-3	20	-3	20	51.00
OIP3 (dBm)	4	100	100	10	100	10	100	10	9.91
Pout (dBm)	-86.0	-94.0	-95.0	-75.0	-78.0	-58.0	-61.0	-41.0	
NF+ (dB)		0.29	0.09	0.68	0.00	0.01	0.00	0.00	
OIP3+ (dB)	0.00	0.00	0.00	0.00	0.00	0.09	0.00		
Input Power (dBm)		-92.00							

The system NF simulation result shows that the overall system noise figure is 2.92dB and compared to design target of 3.5dB, there will be 0.58dB allowance for LNA temperature variation, antenna gain variation as well as amplified noise from the UT transmitter falling in the receive band. Amount the 0.58dB margin, 0.2 dB will be set for LNA temperature variation and the remaining 0.38dB will be given to antenna gain variation and transmitter noise in the receive band.

Measurement result shows that the noise contributed by the transmit section in the receive band is insignificant. Therefore the 0.38dB margin is given to antenna manufacturing tolerance.

The main contribution to the antenna gain variation during production will be the PCB fabrication tolerance. Giving 5% tolerance to the antenna fabrication will cause an approximately 0.22 dB variation in the antenna gain. The entire antenna is made up of different materials. 5 mils FR-4 PCB is used for the antenna and its property should not vary over wide temperature range. Other materials like foam (for air-gap) and Polycarbonate (for cover) will have insignificant change over temperature range 0°C to +40°C. As a result, antenna gain is independent of the temperature variation from 0°C to +40°C.

3.4.3 LOW NOISE AMPLIFIER (LNA) DESIGN

A Low Noise Amplifier with low noise figure and high gain is desirable at the receiver front end in order to achieve a good satellite link. Two stages of Low Noise amplifier will be employed in this design to achieve the calculated noise figure and gain.

The first stage LNA design is based on the state of art PHEMT transistor from Agilent (AT54143) with a minimum noise figure of 0.5dB and a realizable gain of as high as 20dB. The desired input P1dB of the LNA should be as high as possible so as to prevent strong RF input signal from saturating the entire receiver chain. AT54143 has output P1dB of as high as 19dBm.

Addvalue Communications Pte Ltd
750D Chai Chee Road #03-03 Technopark @ Chai Chee
Singapore 469004 Tel +65 244 4828 Fax +65 242 4555
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3.4.3.1 DESIGN SIMULATION USING ANSOFT

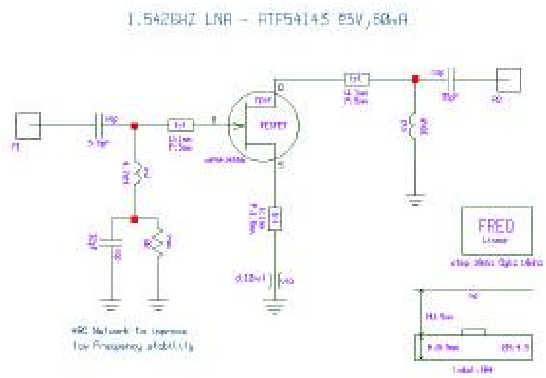

Figure 10: Schematic diagram of the LNA

Figure 10 shows the simulation circuit used for LNA design. The LNA design is optimized to achieve a good noise figure. The result is plotted inFigure 11, showing a noise figure of 0.38dB in the 1525 ~ 1559MHz band. However, there is a tendency that LNA will oscillate at low frequency near 700MHz, where both input and output return loss exceeded the 0dB line, and the transducer gain coming near to its Maximum Stable Gain. Hence, the low frequency stability of the LNA is ensured by placing a parallel RC network at the input matching network, as shown in Figure 10. The result is plotted in Figure 12 showing that the NF of 0.59dB can be achieved.

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750D Chai Chee Road #03-03 Technopark @ Chai Chee
Singapore 469004 Tel +65 244 4828 Fax +65 242 4555
www.addvaluetech.com

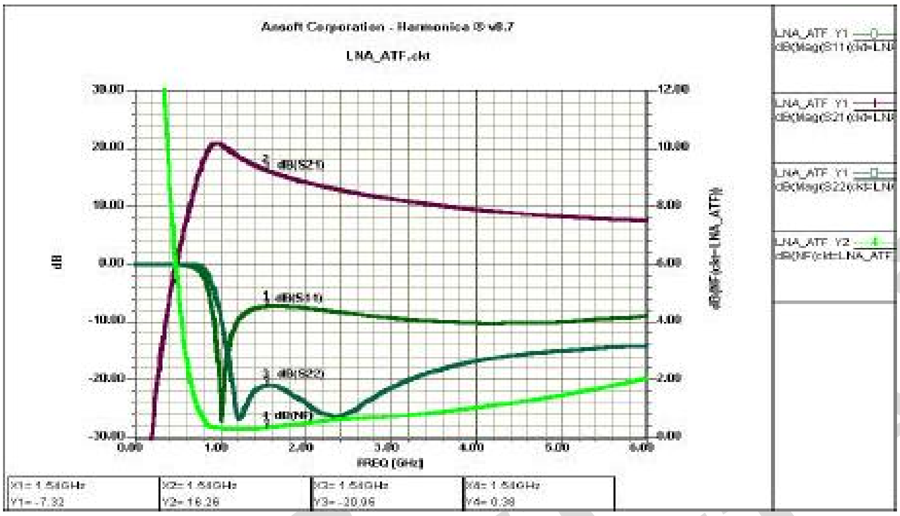


Figure 11: S21, S22 and S11 plots of the LNA circuit simulation

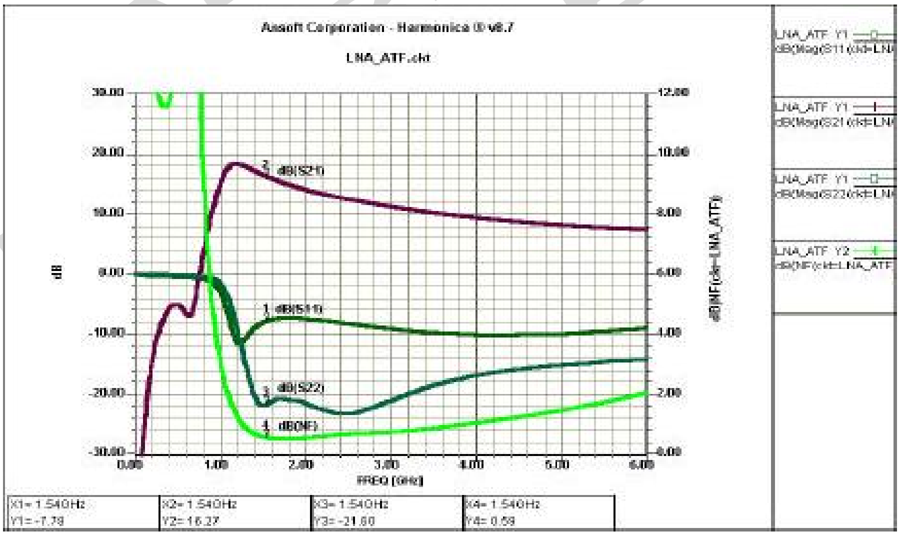


Figure 12: Improved Low Frequency Stability with RC Matching Network.

3.4.4 RECEIVE CHAIN EVALUATION RESULT

The evaluation of receive chain performance is based on RF Evaluation Board V0.11. The simulated LNA circuit has been implemented and result is shown in Figure 13 and Figure 14. The result shows that LNA has a gain of around +18dB and P1dB is approximately +19dBm while the maximum noise figure is 0.67 dB. The noise figure is slightly lower than the desired value of 0.6dB.

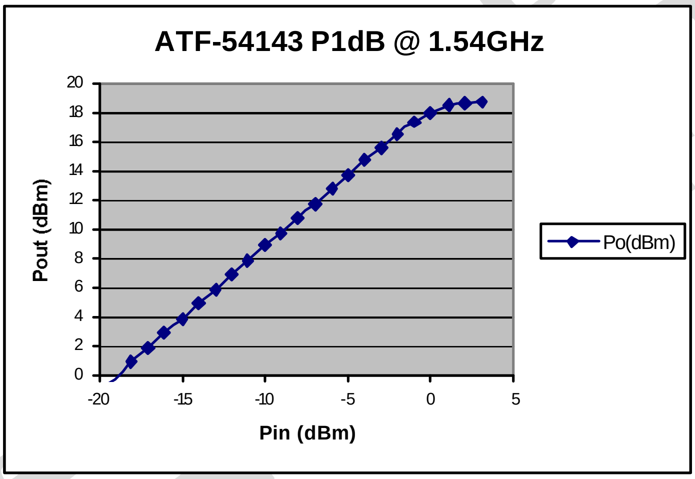


Figure 13: P1dB curve of LNA

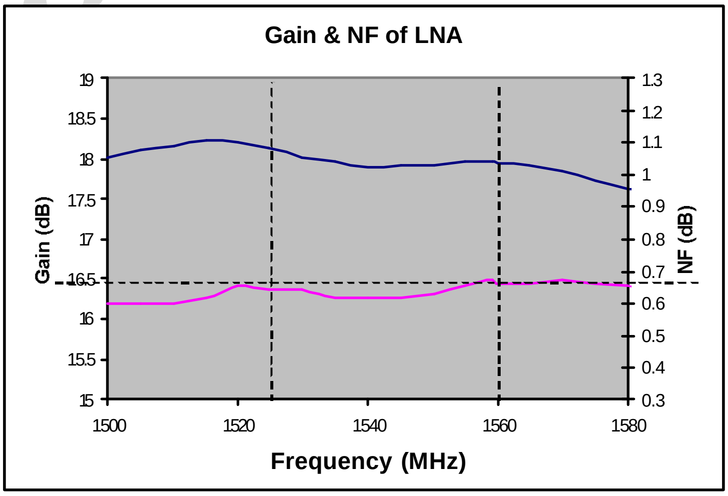


Figure 14: Gain and NF plot of LNA

3.4.4.1 SYSTEM NOISE FIGURE MEASUREMENT RESULTS

The measured system noise figure curve is shown in Figure 15. It can be seen that the maximum system noise figure of receiver is approximately 2.7dB. This noise figure is measured at output of the RF amplifier with noise source connected directly at the Duplexer input. Adding a 0.5dB cable loss between the antenna and the Duplexer will yield a 3.2dB total system noise figure. With the 0.2dB temperature variation included, the total system noise figure will be 3.4dB and is able to meet the design target of 3.5dB. Circuit will be further optimised to lower the NF.

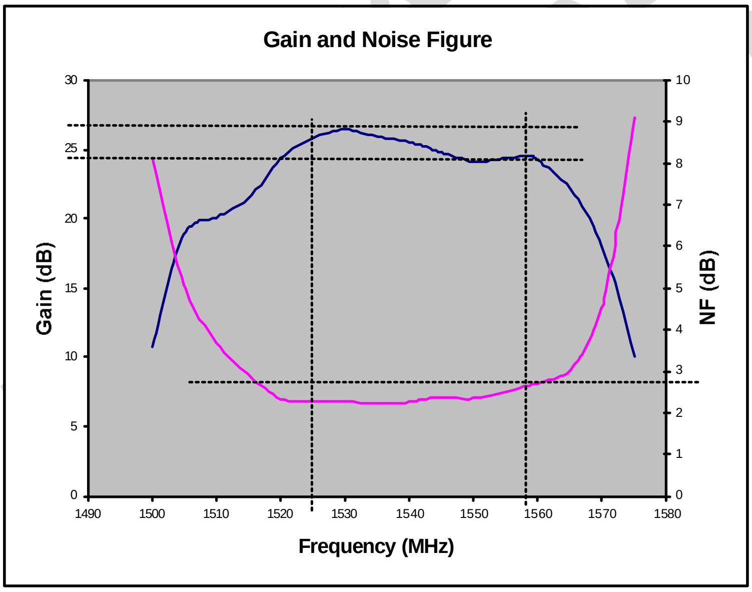


Figure 15: Measured Gain and NF of RX chain at output of RF amplifier.

3.4.4.2 RECEIVE PHASE NOISE

The measured SSB phase noise performance of the RX IF (248.6 MHz) is shown in Figure 16. Results in Table 13 show that receive phase noise have just passed the specification. Further optimisation on the circuit will be carried out to improve the receive phase noise. Figure 17 and Figure 18 show the phase noise of the receive LO1 and LO2.

Offset Frequency (Hz)	***Specification (dBc)***	***248.6 MHz (dBc)***
10	-36	-60
50	-54	-70
100	-61.5	-73
500	-74	-80
1000	-78	-82
5000	-79.5	-85
10000	-80	-86
50000	-89	-90
100000	-89	-90

Table 13: RX phase noise measurement results.

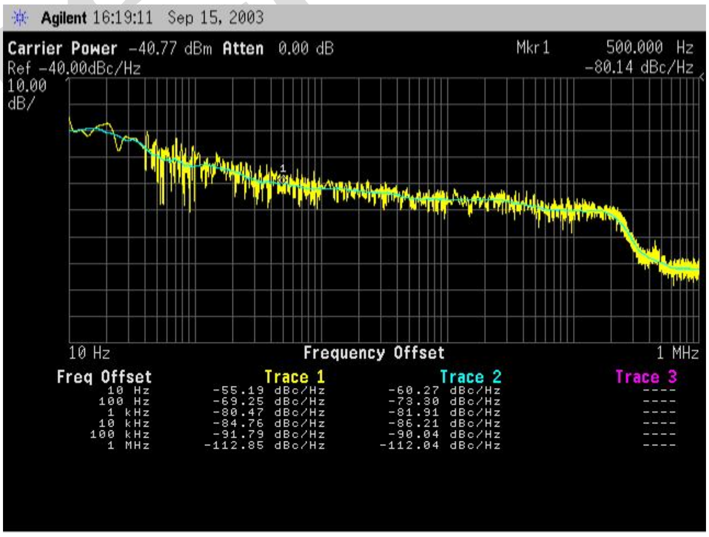


Figure 16: Phase noise plot of 248.6MHz IF signal

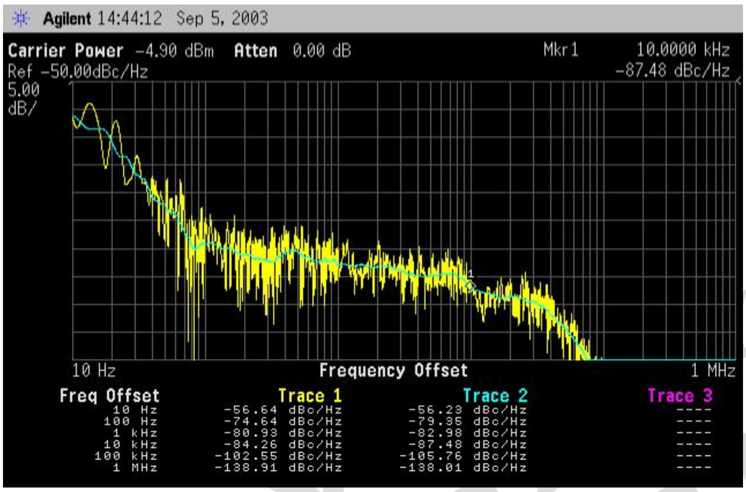


Figure 17: RX LO1 phase noise

Figure 18: RX LO2 phase noise

3.4.4.3 SPURIOUS SIGNAL SUPPRESSION MEASUREMENT RESULT

3.4.4.3.1 IMAGE FREQUENCY

1st image (1027.8~1061.8MHz, -45dBW/m^2) refers to image frequency of the RX IF1 that is 2 x 248.6MHz away from the RX frequency at the low side. Synthesize Signal Generator (SSG) 2 is used to produce the image signal and its output has already offset with the antenna gain in that frequency band. SSG1 is used to generate the wanted signal in the L-band. Refer to Table 14 for results.

2nd image (1503.4~1537.4 MHz, -69dBW/m^2) refers to image frequency of the RX IF2 that is 2 x 10.8MHz away from the RX frequency at the low side. The image signal is near in-band and therefore there is no suppression by the A5004 antenna. In fact it will experience a gain of +8.5dBi from the antenna.

	SSG1		SSG2 (Image)		RX IF	Interference	Rejection	Remarks
	(MHz)	(dBm)	(MHz)	(dBm)	(dBm)	(dBm)	(dB)	
1st Image	1525.1	-129.6	1027.9	-46.7	-60	-110	132.9	SSG2 output has already included the antenna gain of -10dB.
	1542.1	-129.6	1044.9	-46.8	-60	-110	132.8	
	1558.9	-129.6	1061.7	-47	-60	-110	132.6	
2nd Image	1525.1	-129.6	1503.5	-55.5	-60	-55	69.1	SSG2 output has already included the antenna gain of +8.5dB.
	1542.1	-129.6	1520.5	-55.6	-60	-55	69	
	1558.9	-129.6	1537.3	-81.7	-60	-110	97.9	

Table 14: Image rejection result

From Table 14, we can see that IF signal created by the 1st image is –110dBm and is 50dB lower than the wanted signal (-60). The 1st image has been suppressed to a level that will not interfere the demodulation of the wanted signal. As for 2nd image, the signal strength of this unwanted signal appeared to be 5dB higher than the wanted signal. This shows that there is insufficient rejection for this image signal. Since the 2nd image (1503.4~1537.4MHz) is near in-band, there will be no rejection by the RF front end i.e. Antenna, Duplexer, RF filters. As a result, a notch filter is needed at 1st IF stage to suppress this image signal. The image will appear as 227MHz in the 1st IF stage and a suppression of at least 35dB is needed in order to bring the interfering signal 30dB below the wanted signal at the 2nd IF output.

3.4.4.3.2 IN-BAND INTERFERENCE REJECTION

Measurement has been performed to determine the amount of rejection that the receiver has to the in-band interference and strength of interfering signal is as high as -95dBW/m^2. Measurement is done in every 200KHz step size away from the wanted bearer frequency (Refer to Table 15). Result shows that as the interference gets nearer to the wanted signal, the amount of rejection reduces. This is the limitation faced by the 10.8MHz IF filter. The rejection to interfering signal at 200KHz away is only 9dB. It is therefore difficult to achieve a 30dB suppression to interfering signal at ±120kHz away at IF stage.

SSG1		SSG2 (Interference)		RX IF	Interference	Rejection	Remarks
(MHz)	(dBm)	(MHz)	(dBm)	(dBm)	(dBm)	(dB)	
1528	-99.6	1527.8	-81.6	-29	-20.3	9.3	
1528	-99.6	1527.6	-81.6	-29	-58	47	
1528	-99.6	1527.4	-81.6	-29	-100	89	
1528	-99.6	1528.2	-81.6	-29	-22.5	11.5	
1528	-99.6	1528.4	-81.6	-29	-64	53	
1528	-99.6	1528.6	-81.6	-29	-100	89	
1542	-99.6	1541.8	-81.6	-29	-20.7	9.7	
1542	-99.6	1541.6	-81.6	-29	-58	47	
1542	-99.6	1541.4	-81.6	-29	-100	89	
1542	-99.6	1542.2	-81.6	-29	-21.7	10.7	
1542	-99.6	1542.4	-81.6	-29	-64	53	
1542	-99.6	1542.6	-81.6	-29	-100	89	

Table 15: In-Band interference rejection

Addvalue Communications Pte Ltd
750D Chai Chee Road #03-03 Technopark @ Chai Chee
Singapore 469004 Tel +65 244 4828 Fax +65 242 4555
www.addvaluetech.com

3.4.4.3.3 OUT OF BAND INTERFERENCE REJECTION

Test has been conducted to determine the amount of rejection to signal in the frequency range of 100KHz ~ 1400MHz and 1600MHz ~ 4000MHz at power of -45dBW/m^2. Result from Table 16 shows that there is more than 130dB rejection to the interfering signal and is sufficient to prevent interference to the demodulation.

SSG1		SSG2 (Interference)		RX IF	Interference	Rejection	Remarks
(MHz)	(dBm)	(MHz)	(dBm)	(dBm)	(dBm)	(dB)	
1525.1	-99.6	0.1	18.55	-29	-110	199.15	
1525.1	-99.6	1	-1.45	-29	-110	179.15	
1525.1	-99.6	10	-21.45	-29	-110	159.15	
1525.1	-99.6	100	-41.55	-29	-110	139.05	
1525.1	-99.6	1000	-61.45	-29	-110	119.15	
1525.1	-99.6	1400	-31.37	-29	-110	149.23	
1525.1	-99.6	1600	-32.03	-29	-110	148.57	
1525.1	-99.6	2000	-34.47	-29	-110	146.13	
1525.1	-99.6	3000	-38	-29	-110	142.6	
1525.1	-99.6	4000	-40.5	-29	-110	140.1	

Table 16: Out of band interference rejection

3.4.4.3.4 NEAR IN-BAND INTERFERENCE REJECTION

Near in-band refers to interference in the 1500 ~ 1525MHz having signal strength of 69dBW/m^2. Result in Table 17 shows that there is about 55dB rejection to the interfering signal at 1524.625MHz.

SSG1		SSG2 (Interference)		RX IF	Interference	Rejection	Remarks
(MHz)	(dBm)	(MHz)	(dBm)	(dBm)	(dBm)	(dB)	
1525.1	-99.6	1524.625	-55.6	-29	-40.7	55.7	
1525.1	-99.6	1523.875	-55.6	-29	-100	115	
1525.1	-99.6	1523.125	-55.6	-29	-100	115	
1525.1	-99.6	1522.375	-55.6	-29	-100	115	

Table 17: Near Band interference rejection

3.4.4.3.5 INTER-MODULATION DISTORTION (IMD)

The inter-modulation product of the out-of-band interference has been tested. When two signals separated at 248.6MHz apart received by the UT, their inter-modulation product will fall into the 1st IF signal. The worst scenario is when both signals are very strong. One of the strongest signal in this case will be the TX signal generated by the UT itself and the other one from the interference in the 100kHz ~ 1400MHz band having a power flux density of -45dBW/m^2.

The same scenario will happen to 2nd IF but in this case, one of the strongest interference come from the UT TX signal while their other one from interference in the 1600MHz ~ 4000MHz band having a power flux density of -45dBW/m^2.

	SSG1 (Interference)		SSG2 (Interference)		RX IF	Interference	Rejection	Remarks
	(MHz)	(dBm)	(MHz)	(dBm)	(dBm)	(dBm)	(dB)	
1st IF	1626.5	32	1377.9	-39.32	-60	-110	-50dB reference to wanted signal at IF output	SSG2 output has already included the antenna gain of 0dB.
2nd IF	1626.5	32	1615.7	-87.1	-60	-110	-50dB reference to wanted signal at IF output	SSG2 output has already included the antenna gain of +8.5dB.
	1525.1	-81.6	1535.9	-81.6	-60	-110	-50dB reference to wanted signal at IF output	
	1524.625	-55.6	1513.825	-55.6	-60	-110	-50dB reference to wanted signal at IF output	

Table 18: Examples of Inter-modulation distortion rejection results

3.4.4.4 RX FILTERS RESPONSE

3.4.4.4.1 DUPLEXER

The Duplexer has a maximum insertion loss of 1.5dB at the passband (TX & RX). For the RX band, it provides as high as 68dB rejection of the transmit signal (1626.5 ~ 1660.5MHz). This will prevent the transmitted signal from saturating the receiver LNA during a full duplex communication mode. The typical response of the Duplexer is shown in Figure 19, Figure 20, Figure 21 and Figure 22.

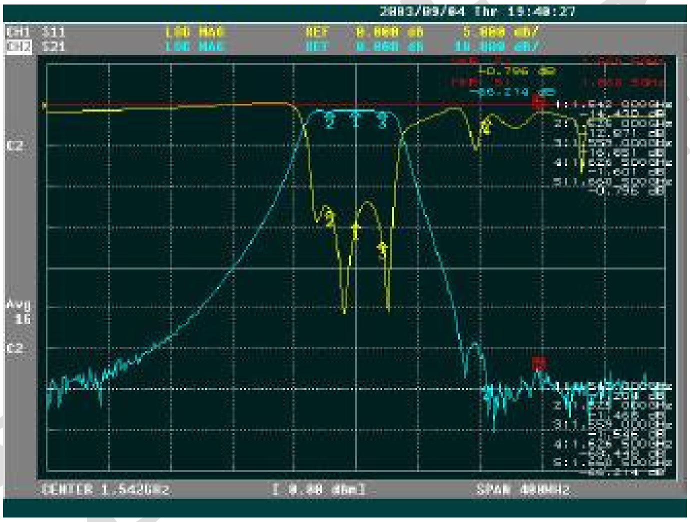


Figure 19: Duplexer – RX response at 400MHz span

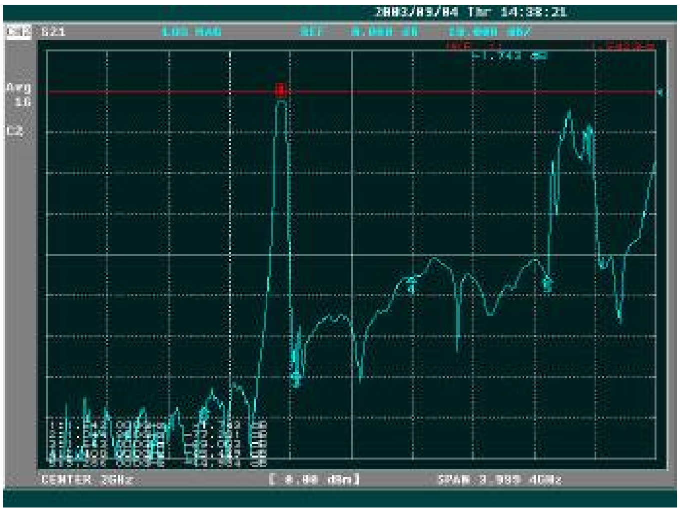


Figure 20: Duplexer –RX Response in 4000MHz

Addvalue Communications Pte Ltd
750D Chai Chee Road #03-03 Technopark @ Chai Chee
Singapore 469004 Tel +65 244 4828 Fax +65 242 4555
www.addvaluetech.com

Figure 21: Duplexer – TX response at span 400MHz

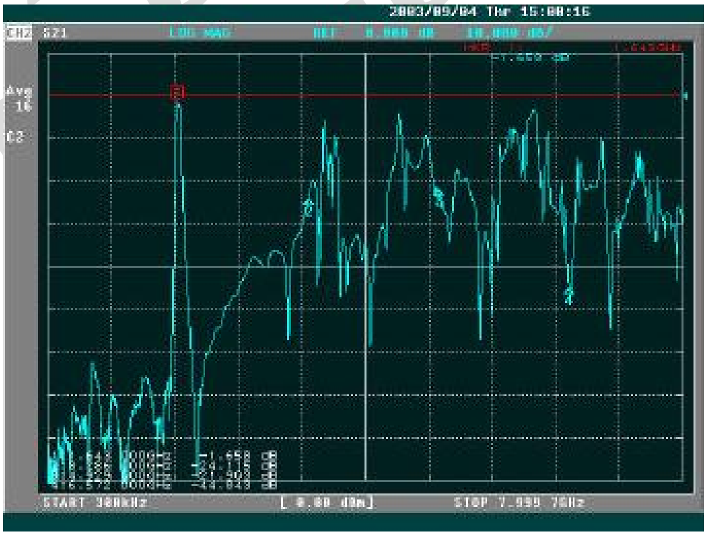


Figure 22: Duplexer – TX response at span 8000MHz

3.4.4.4.2 RECEIVE 1542 MHZ BPF

A BPF is placed immediately after the 1st LNA stage as image rejection filter. The receive BPF has a pass band of 34MHz centered at 1542MHz. It provides more than 30dB suppression to the transmit signal. Besides that, the rejection to the 1st image signal is greater than 30dB. The typical response is shown in Figure 23, Figure 24 and Figure 25

Figure 23: 1542MHz BPF response at span 200MHz

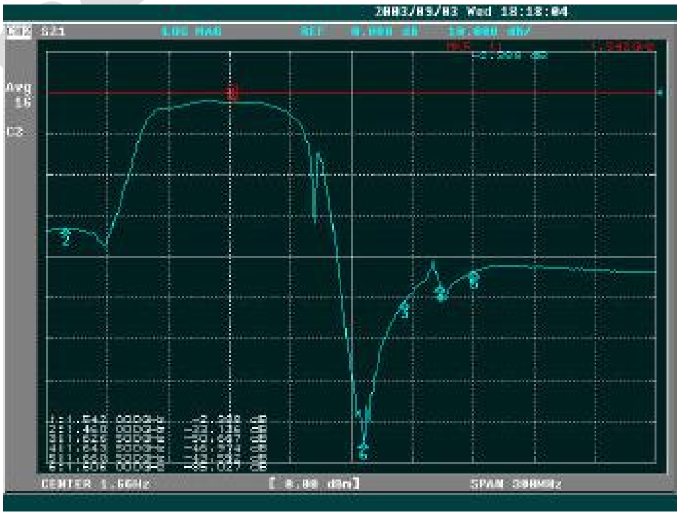


Figure 24: 1542MHz RF filter response indicating rejection to TX signal.

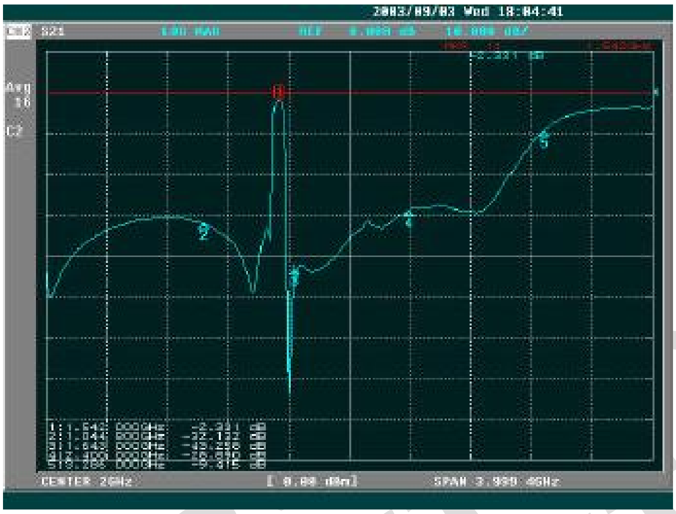


Figure 25: 1542MHz RF filter response at span 4000MHz

3.4.4.4.3 RECEIVE IF FILTER

Receive 248.6 IF filter response is shown in Figure 26 and Figure 27. The 3dB pass bandwidth is ±200KHz. It can be seen from the response that the 2nd image rejection at 227MHz is more then 65dB. Figure 28 and Figure 29 shows the response of 2nd RXIF (10.8MHz) filter. It can be seen that there is almost no rejection at ±120KHz away from the centre frequency.

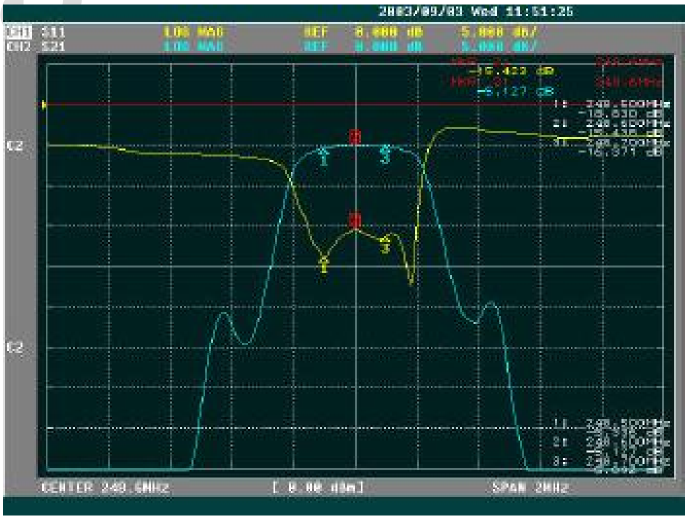


Figure 26: RX 248.6MHz IF filter response at 2MHz span

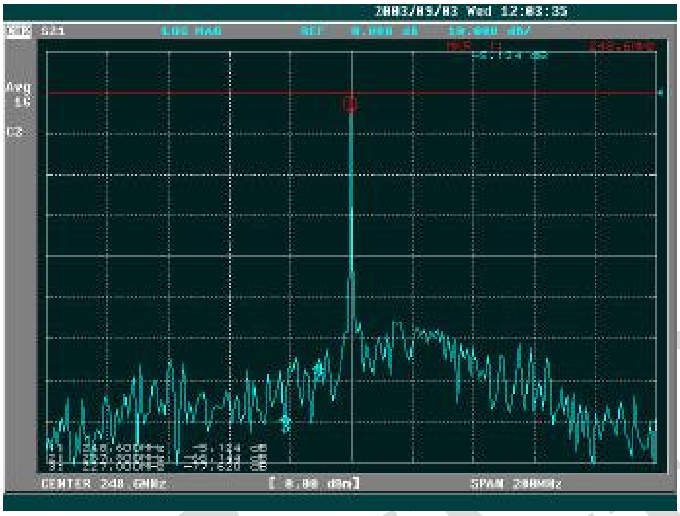


Figure 27: RX 248.6MHz IF filter response at 200MHz span

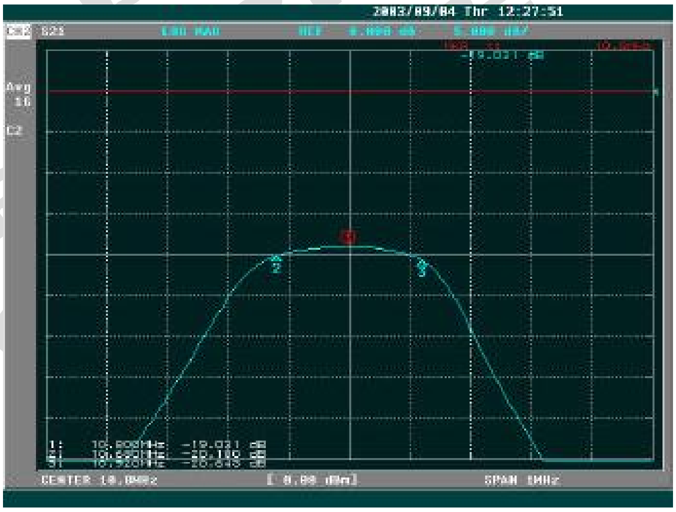


Figure 28: 2nd RXIF (10.8MHz) filter response at 1MHz span.

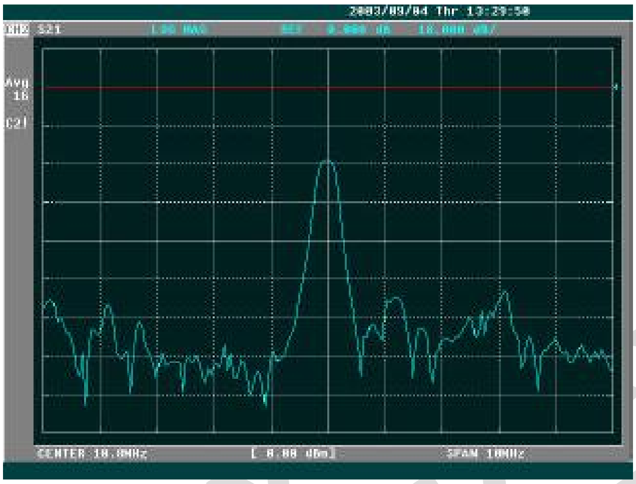


Figure 29: 2nd RXIF (10.8MHz) filter response at 10MHz span.

3.4.4.5 RECEIVE AUTOMATIC LEVEL CONTROL

Two Automatic Level Control (ALC) loop have been implemented on the receive chain to maintain a constant signal level into the A/D converter at the baseband. The dynamic range of the two loops is approximately 60dB. Refer to Figure 1, the first ALC loop is an analogue loop located at the 10.8MHz IF stage (after the 10.8MHz IF filter2) while the second loop is at the end of 10.8MHz IF stage (just before ADC). The second ALC loop will have a dynamic range of about 40dB with time constant of approx. 2 to 3 msec and will be digitally controlled by baseband through an 8-bit DAC. The worst case LSB step size is 0.05dB with fixed step voltage of 4mV. The attenuator response versus control voltage is shown in Figure 30.

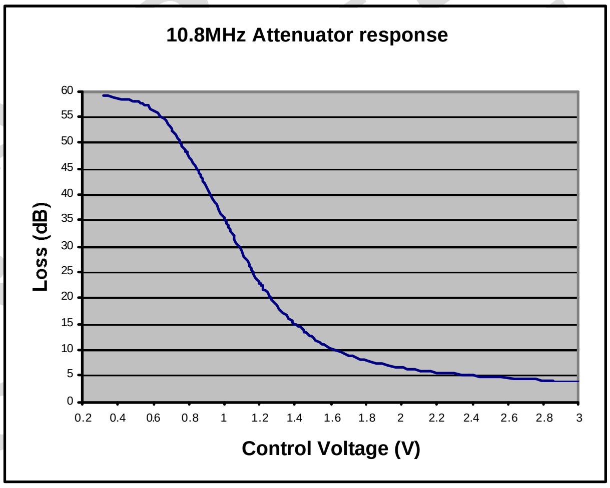


Figure 30: Attenuator response at 10.8MHz

3.4.4.6 10.8 MHZ ANALOG TO DIGITAL CONVERTER (ADC)

A 10-bit ADC has been selected to perform the conversion of 10.8Mhz IF analog signal to digital format for baseband procession. The 10.8MHz IF signal is applied to a single-ended to differential analog input RF transformer (refer to Figure 31). The impedance ratio of the RF transformer is 16:1. The input of the ADC is a ac-coupled differential input and full scale is achieved when the Vin+ and Vin- input signals are 0.5Vp-p, with Vin- being 180° out of phase with Vin+.

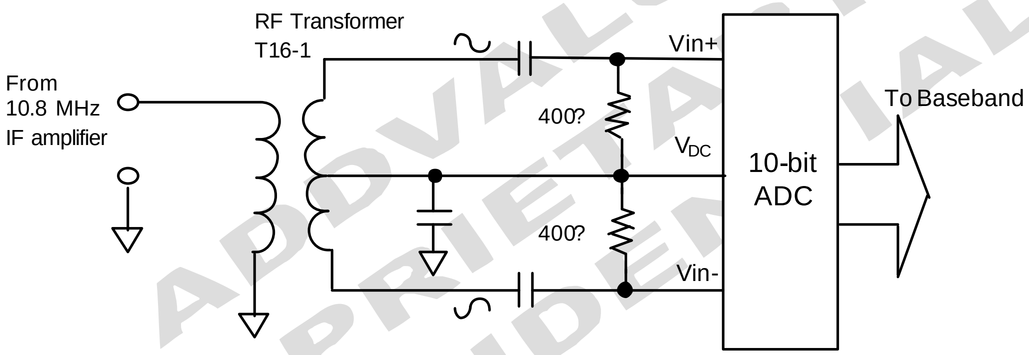


Figure 31: ADC with a.c. coupled differential input

Baseband team has performed a calculation to determine the Vrms required at the input of the ADC. Calculation of Vrms is based on pseudo random data for QAM and at the same time taking into consideration of the constellation effect. The calculated value is (Vp/4) where Vp is the full-scale peak input voltage (0.5V) of the ADC. Therefore the desired input Vrms to the ADC is 0.125V.

Based on input Vrms of 0.125V, the input power required by the ADC will be ($Vrms^2$/800) i.e. –17dBm. However, due to 2dB (approx.) insertion loss encountered at the transformer network, the actual power required at the input of the transformer will be -15dBm. As a result, power output from the last stage of 10.8MHz IF amplifier will be maintained at -15dBm in order to meet the Vrms required by the baseband.

3.5 RF TRANSMITTER CHAIN

Two IF frequencies have been employed for transmit up conversion. This will make the transmit Local Oscillator (LO) frequency further away from the transmit band, hence allow a better LO rejection by the Band Pass Filter and Duplexer. 71MHz modulated IF signal from the baseband will first mixed with 504.92MHz LO to produce a 433.92MHz signal. This 433.92MHz signal will then go through a second mixing and up converted to 1626.5 ~ 1660.5 MHz. A 1643MHz BPF is placed after the mixer to suppress LO and second harmonics of the RF signal. High Power Amplifier (HPA) chain will amplify the RF signal to a desired power level before radiation through the antenna.

3.5.1 HPA DESIGN

The HPA chain consists of three stages, two drivers followed by the High Power Amplifier (refer to Figure 32). The driver amplifier will have a Noise Figure of less than 2dB and this will ensure that the amplified noise from the transmitter falling in the RX band will be insignificant. This HPA chain is capable of generating an output power of +38dBm (P1dB) at the power amplifier output. Automatic Level Control (ALC) has been employed to ensure the transmit power maintain at less than ±0.5dB fluctuation. The ALC reference level is controlled by micro-controller so as to vary the transmit power within a range of –6dB down from the nominal power.

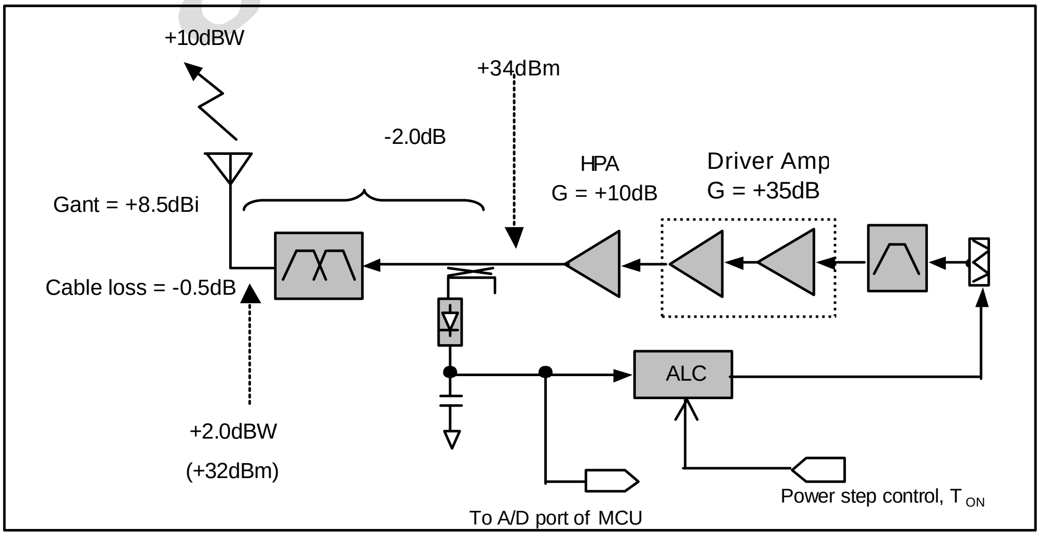


Figure 32: HPA Chain power budget.

3.5.2 TRANSMITTER FAIL SAFE PROTECTION CIRCUIT

RF power detector will be included to monitor transmit level so as to indicate when the transmitter is operating. The detector will convert RF power into dc voltage and should there be an unwanted transmission, the micro-controller will be alerted and further action can be taken.

Heat sensing device will also be added to monitor the temperature around the final HPA. When the temperature exceeds a pre-determined value, the circuit will output a voltage to alert the micro-controller. The micro-controller will then take immediate action to turn OFF the transmitter chain and issue a warning to the user. This is to prevent the excess heat from damaging the HPA.

Besides the heat sensing device, current sensing circuit will be used to monitor the amount of current drawn by the final HPA. When the current exceeds a pre-determine value, the circuit will output a voltage to alert the micro-controller. Further action will be taken to shut down the transmission. This is to prevent the transmitter from drawing excessive current from the switch mode supply.

3.5.3 HPA CHAIN EVALUATION RESULT

3.5.3.1 P1dB OF HPA CHAIN

Evaluation is based on RF Evaluation Board V0.11 and result in Figure 33 shows that the P1dB point of the HPA chain is approximately at +38dBm. During normal operation, the HPA will be operating at 4dB OBO so as to produce +10dBW EIRP.

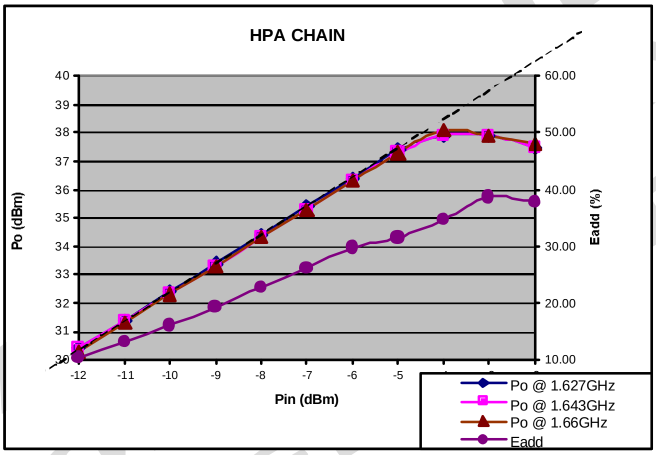


Figure 33: Pout Versus Pin curve of the HPA chain

3.5.3.2 TX POWER STEP CONTROL

Figure 34 shows that by changing the reference voltage to the analogue ALC loop, we can easily control the transmit output power step. EIRP setting range (Nominal EIRP to nominal EIPR –6dB) can be controlled by micro-controller in step of 1dB. This is achieved by controlling the reference voltage of the comparator through a DAC. When the output varies over temperature, the analogue ALC will perform an automatic compensation to maintain the output level to within 0.5dB variation. Calibration of EIRP level control will be carried out at different frequency points across the transmit band. The response at different frequency will be stored in EEPROM and form a look-up table. Data will be collected when more prototypes are built so as to decide how many frequency points are needed. Production testing document will include procedures for calibration.

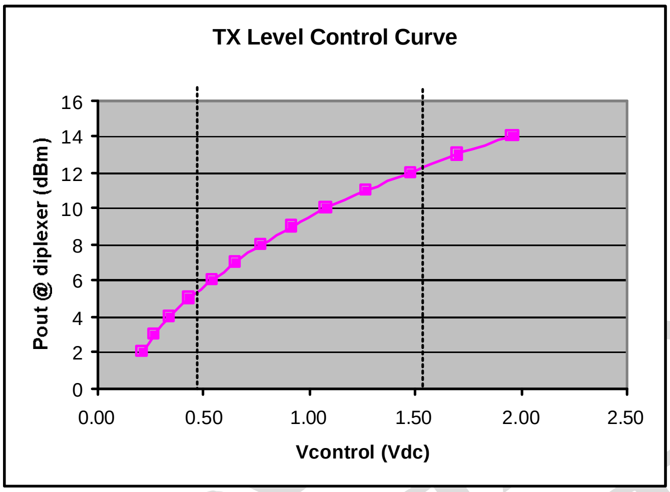


Figure 34: Pout Versus DC control voltage curve

3.5.3.3 TRANSMIT POWER PROFILE

An example of the TX power profile is shown in Figure 35. The measurement is conducted using 71MHz TXIF from the BPLT as the source. This IF signal is up converted to L-band using RF Evaluation board V0.11. The output of the Duplexer is fed back to the BPLT for evaluation. The UT is transmitting at maximum power (+32dBm at Duplexer output) that will produce a +10dBW EIRP when connected to the A5004 antenna. Result shows that the power variation within the burst is less than 0.5dB.

The transmit power ramp-up and ramp-down response is shown in Figure 36 and Figure 37. This is just a preliminary study on the HPA performance and is taken such that the HPA is always at the ON state. In order to determine the actual performance of the HPA in terms of ramp up/down timing, the micro-controller has to control the ON/OFF timing of the entire transmit chain. Since the micro-controller board is not ready at this stage, detail measurement will be carried out during UT integration test.

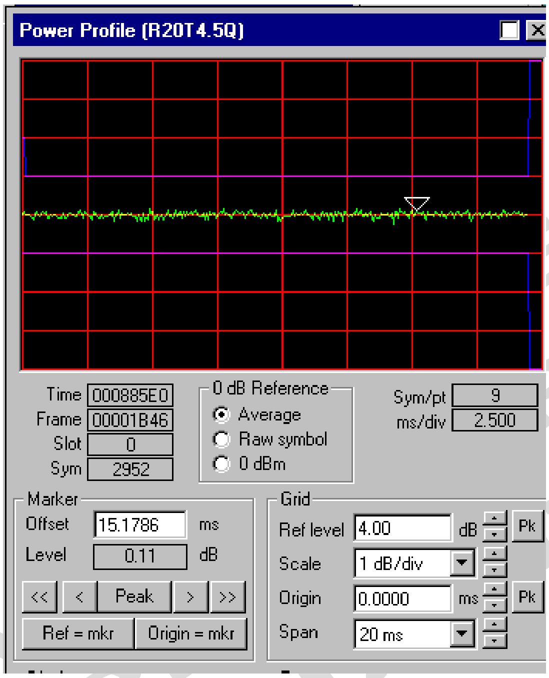


Figure 35: Example of TX power profile

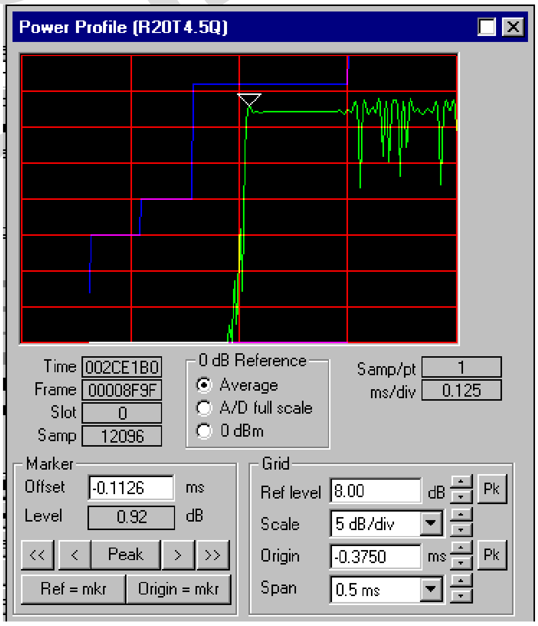


Figure 36: Transmit Rampup

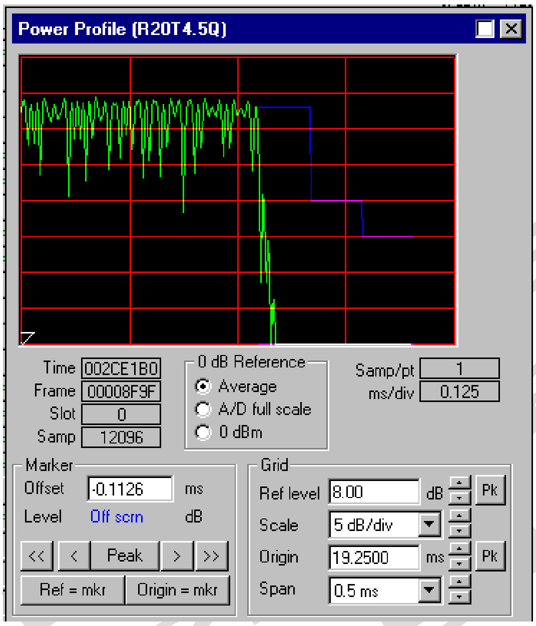


Figure 37: Transmit Rampdown

3.5.3.4 TRANSMIT POWER SPECTRAL DENSITY (PSD) MASK

Conducted measurement has been taken using TXIF (71MHz) generated by the BPLT. This IF signal is fed into the transmit chain of the RF Evaluation Board V0.11 and then up-converted to L-band. The output power at the Duplexer is set to +32dBm that will produce an EIRP of 10dBW when connected to the A5004 antenna (Gain=8.5dBi). The output of the Duplexer is fed back to the BPLT through the RF connector at the RF unit. Power Spectral Density (PSD) of 4 bearer type i.e. R20T0.5Q, R20T1Q, R20T2Q and R20T4.5Q has been captured and result is shown in Figure 38 to Figure 41. Relative PSD at various offset frequency (F1~F4) is measured with respect to the signal PSD at the bearer centre frequency. The result is shown in Table 19 to Table 22. An example of the constellation result is shown in Figure 42.

3.5.3.4.1 BEARER TYPE R20T0.5Q TRANSMIT PSD MASK

Refer to Figure 38 for the transmit signal analysis result of bearer type R20T0.5Q.

Fx	*Offset (KHz)*	*SDM Spec (dBc)*	*ETSI Spec (dBc)*	*Measured Amp (dBc)*
F1	15.7	-20	-10	-32.36
F2	32.7	-25	-10	-42.26
F3	34.7	-30	-10	-42.97
F4	65.5	-45	-10	-50.5
F1	-15.7	-20	-10	-30.82
F2	-32.7	-25	-10	-43.55
F3	-34.7	-30	-10	-43.62
F4	-65.5	-45	-10	-50.85

Table 19: R20T0.5Q Transmit Power Spectral Density Mask

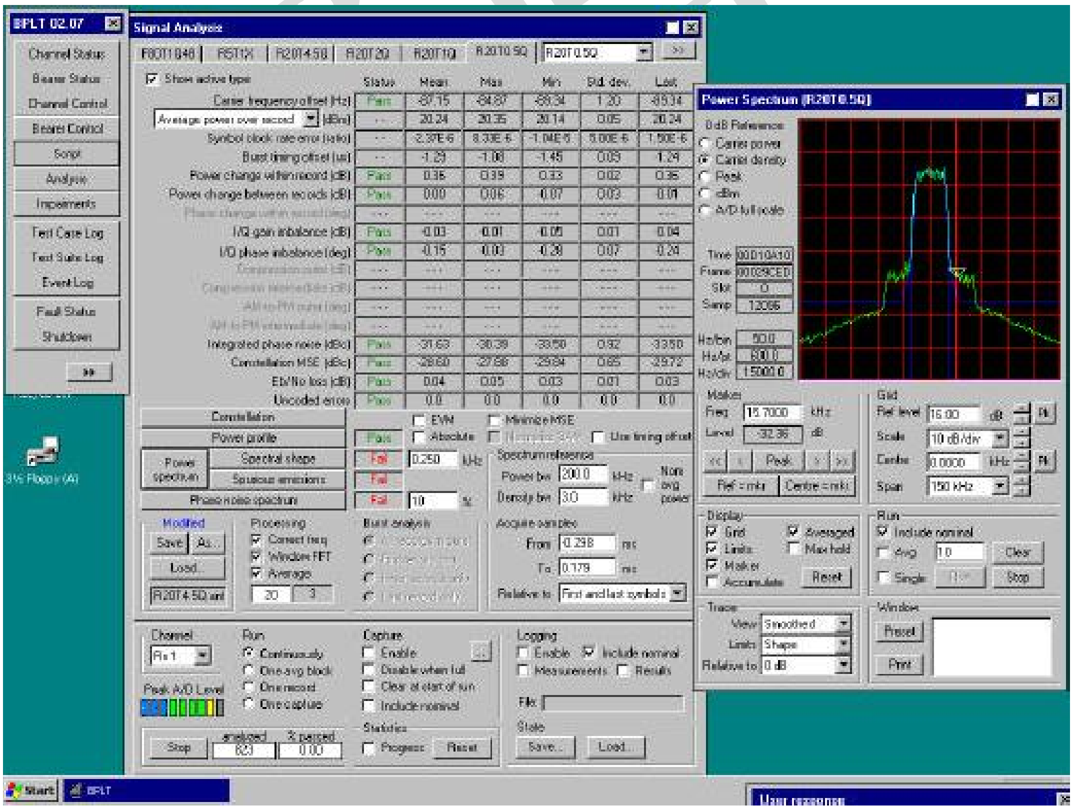


Figure 38: R20T0.5Q Transmit Signal Analysis

3.5.3.4.2 BEARER TYPE R20T1Q TRANSMIT PSD MASK

Refer to Figure 39 for the Transmit signal analysis result of bearer type R20T1Q.

Fx	*Offset (KHz)*	*SDM Spec (dBc)*	*ETSI Spec (dBc)*	*Measured Amp (dBc)*
F1	31.4	-20	10	-32.1
F2	65.5	-25	-10	-46.4
F3	69.4	-30	-10	-46.79
F4	131	-45	-30	-52.7
F1	-31.4	-20	-10	-29.94
F2	-65.5	-25	-10	-46.26
F3	-69.4	-30	-10	-47.4
F4	-131	-45	-30	-52.9

Table 20: R20T1Q Transmit Power Spectral Density Mask

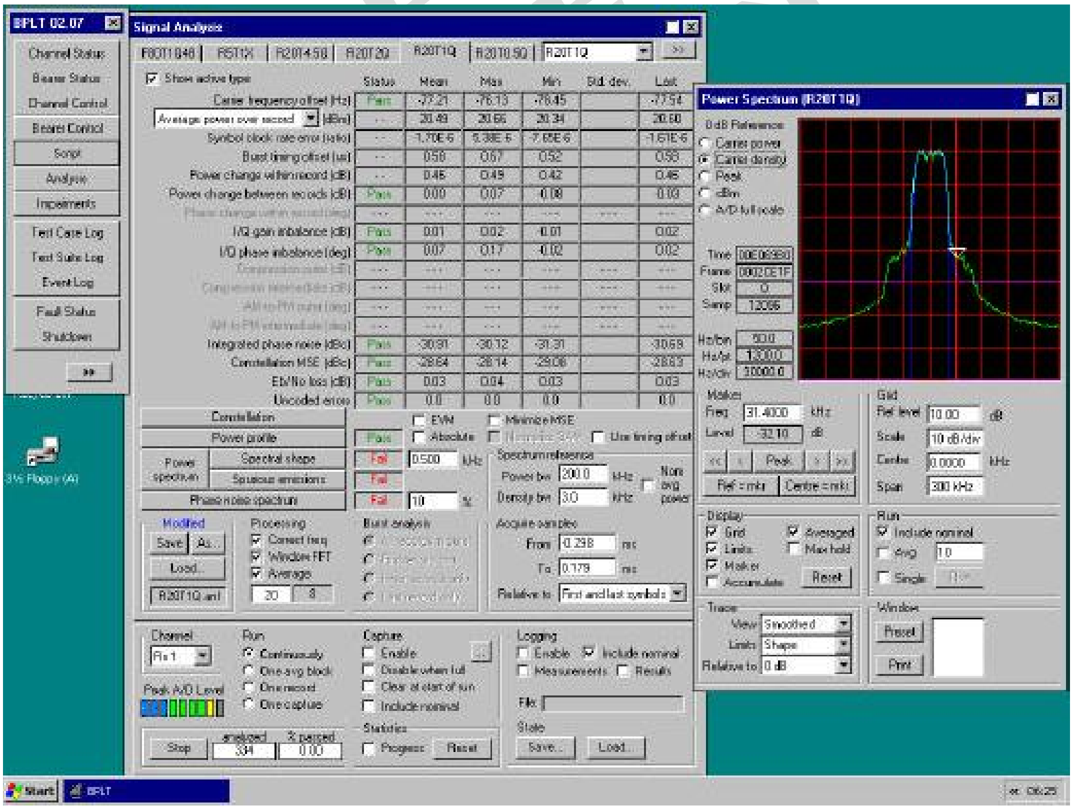


Figure 39: R20T1Q Transmit Signal Analysis

3.5.3.4.3 BEARER TYPE R20T2Q TRANSMIT PSD MASK

Refer to Figure 40 for the transmit signal analysis result of bearer type R20T2Q.

Fx	*Offset (KHz)*	*SDM Spec (dBc)*	*ETSI Spec (dBc)*	*Measured Amp (dBc)*
F1	62.9	-20	-10	-50
F2	131	-25	-30	-62
F3	138.8	-30	-32	-62.7
F4	262	-45	-60	-72
F1	-62.9	-20	-10	-47
F2	-131	-25	-30	-61.7
F3	-138.8	-30	-32	-62.4
F4	-262	-45	-60	-71.24

Table 21: T2Q Transmit Power Spectral Density Mask

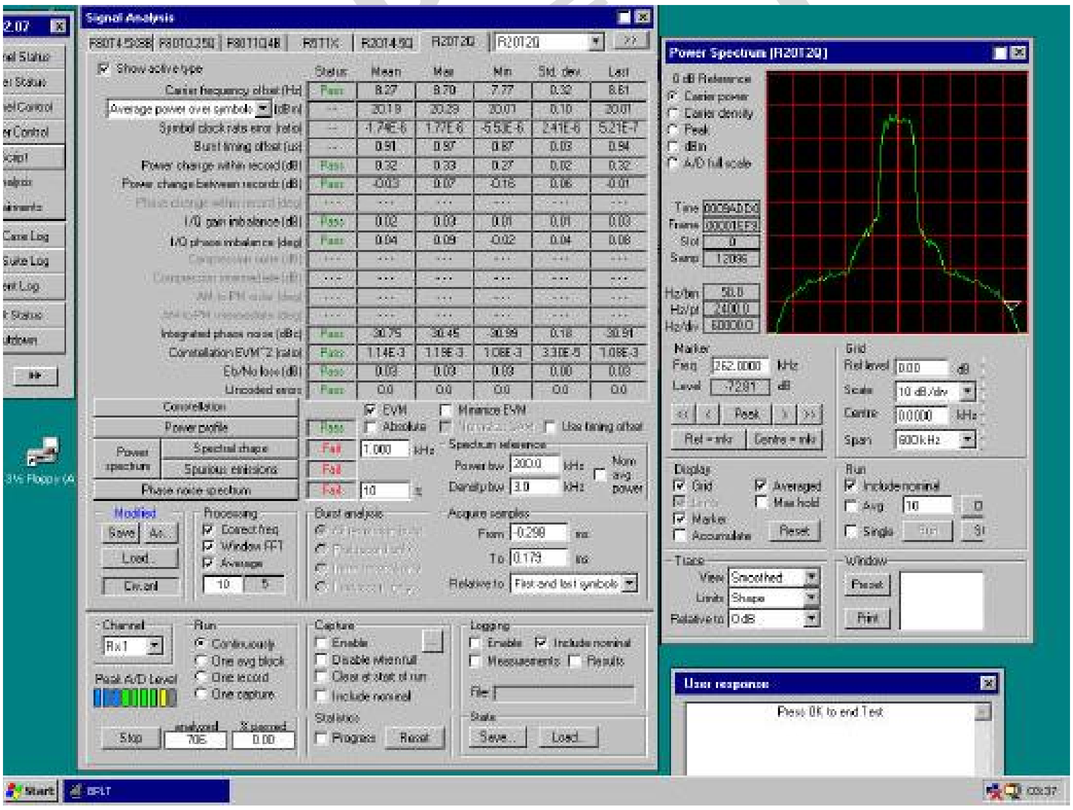


Figure 40: Bearer Type R20T2Q Transmit Signal Analysis

3.5.3.4.4 BEARER TYPE R20T4.5Q TRANSMIT PSD MASK

Refer to Figure 41 for the transmit signal analysis result of bearer type R20T4.5Q.

Fx	*Offset (KHz)*	*SDM Spec (dBc)*	*ETSI Spec (dBc)*	*Measured Amp (dBc)*
F1	133.6	-20	-31	-50.7
F2	256	-25	-60	-70.4
F3	282.6	-30	-60	-82
F4	450	-45	-60	<-82
F1	-133.6	-20	-31	-50.8
F2	-256	-25	-60	-69.9
F3	-282	-30	-60	-81.3
F4	-450	-45	-60	<-81

Table 22: Bearer Type R20T4.5Q Transmit Power Spectral Density Mask

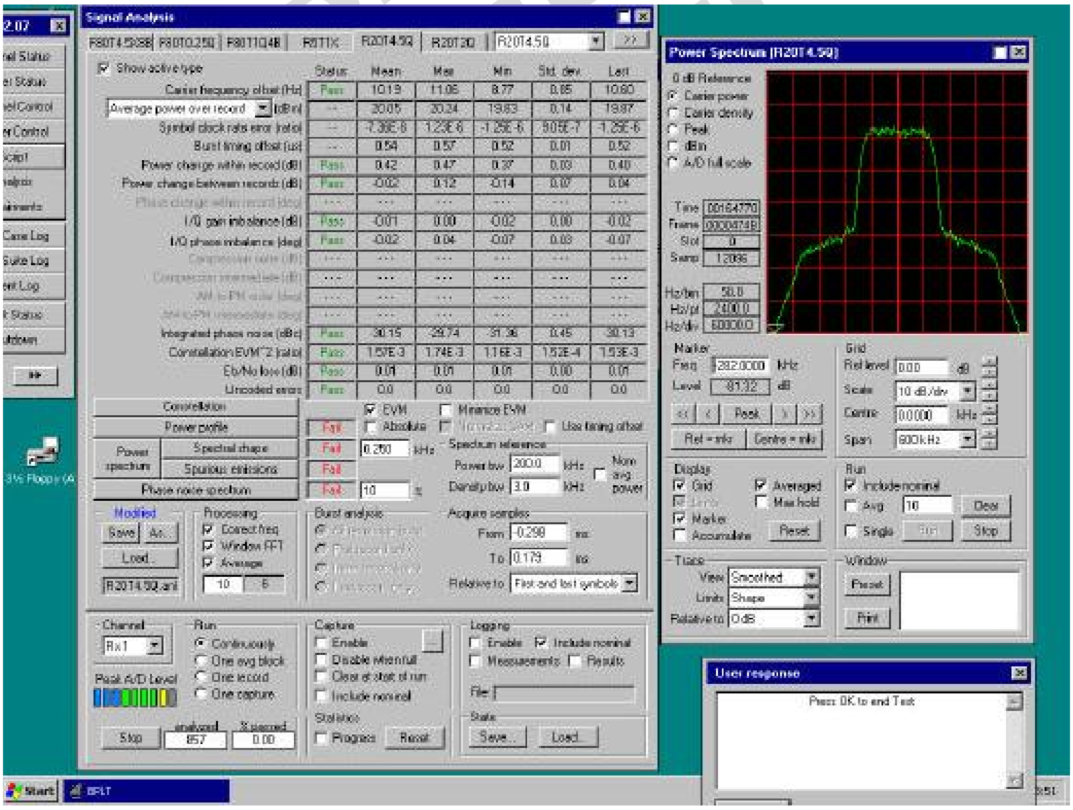


Figure 41: R20T4.5Q Transmit Signal Analysis

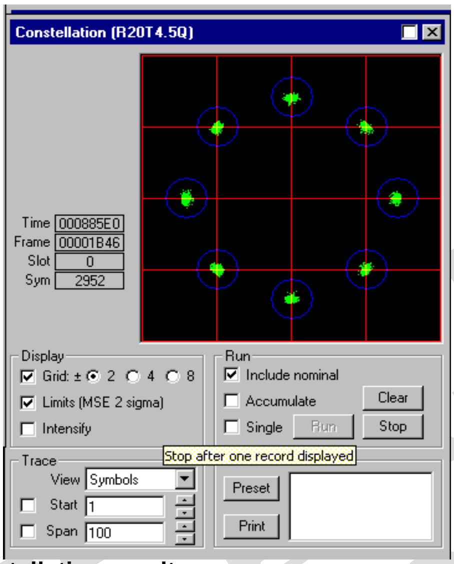


Figure 42: Example of constellation result

3.5.3.4.5 TRANSMIT PHASE NOISE PERFORMANCE

TX phase noise measurement is taken using a CW signal from TXIF output of BPLT at 71MHz. This 71MHz CW is injected to the TX chain of the RF Evaluation board V0.11 then up-converted to 1626.5 ~ 1660.5 MHz. The RF output from the Duplexer is returned back to BPLT for analysis. Result is shown in Figure 43.

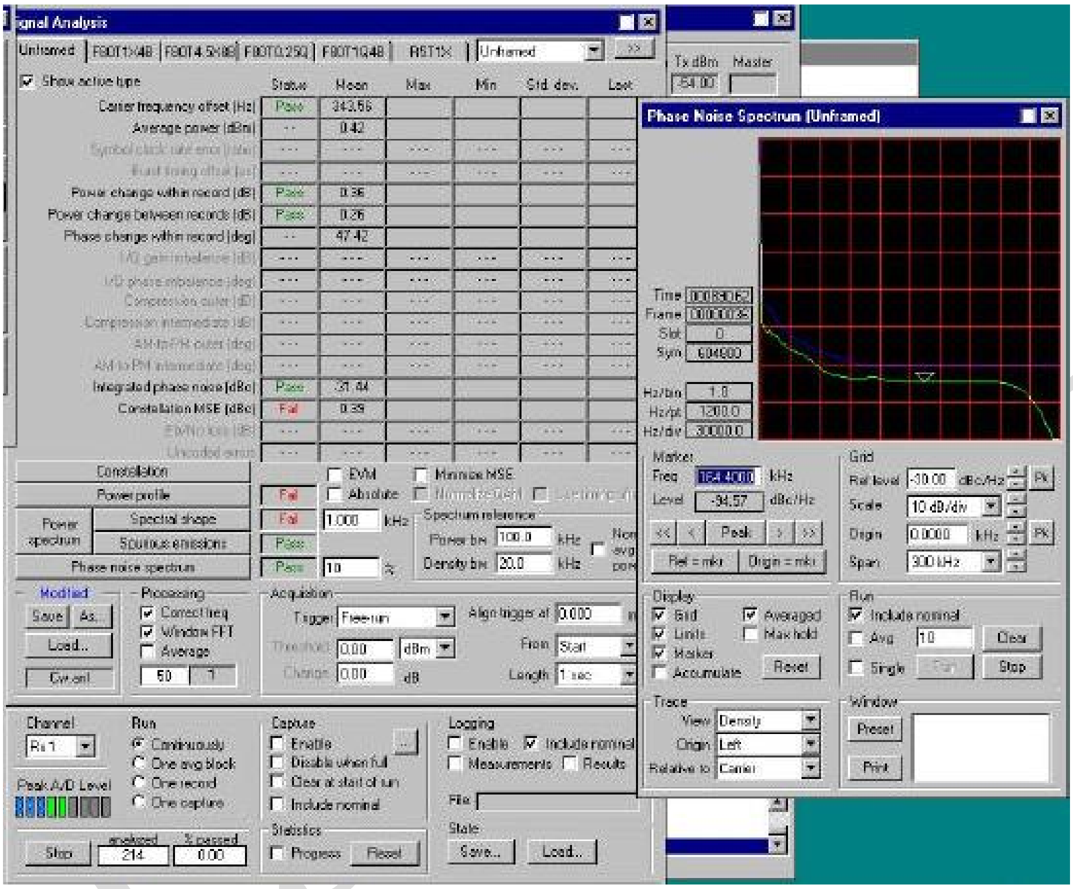


Figure 43: CW Transmit signal analysis

3.5.3.5 TRANSMIT FILTERS RESPONSE

3.5.3.5.1 TRANSMIT 1643 MHZ BAND PASS FILTER

The measured TX BPF response is shown in Figure 44 and Figure 45. This filter is able to suppress the TX LO by more than 60dB. Besides that, suppression of second harmonic of TX LO and TX signal is more than 30dB. This will help to provide a clean transmit signal to the HPA chain before being radiated out through the antenna. The rejection to GPS signal (1575.42MHz) is –25dBc while rejection to Bluetooth signal (2.4GHz) is –50dB.

Figure 44: 1643 MHz filter response at 400MHz span

Figure 45: 1643 MHz filter response at 6000MHz span

3.5.3.5.2 TRANSMIT 433.92MHZ TXIF1 FILTER

A typical 433.92MHz TXIF1 filter response is shown in Figure 46 and Figure 47. The pass bandwidth is ±2MHz and is able to suppress 504.92MHz LO by more than 60dB.

Figure 46: TX 433.92MHz IF filter response at 40MHz span.

Figure 47: TX 433.92MHz IF filter response at 100MHz span.

3.5.3.5.3 TRANSMIT 71MHZ TXIF2 FILTER

A typical 71MHz transmit TXIF2 filter response is shown in Figure 48 and Figure 49. It has a pass bandwidth of at least 200kHz.

Figure 48: TX 71MHz IF filter response at 2MHz span.

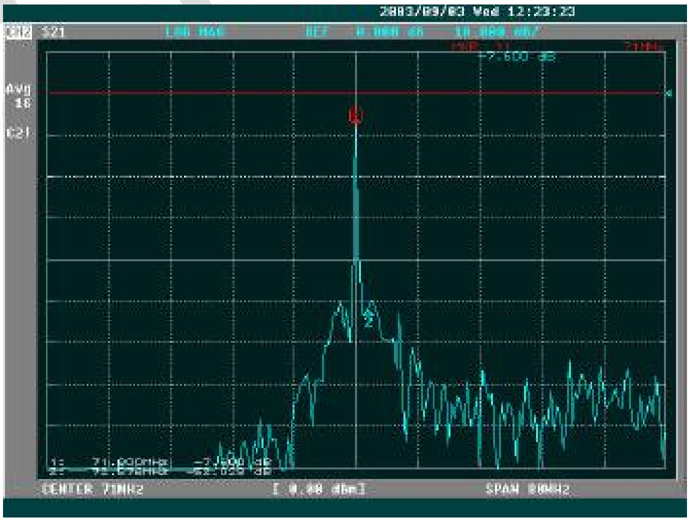


Figure 49: TX 71MHz IF filter response at 80MHz span.

3.6 FREQUENCY SYNTHESIZER

Conexant Fractional-N synthesizer (CX72300) has been selected to generate the RX and TX local oscillator frequency. This synthesizer is capable of providing ultra-fine frequency (< 100Hz) resolution, fast switching speed (< 100µsec), and low phase-noise (-90dBc/Hz up to 2.1GHz) performance. Refer to Figure 50 for the block diagram of the PLL IC.

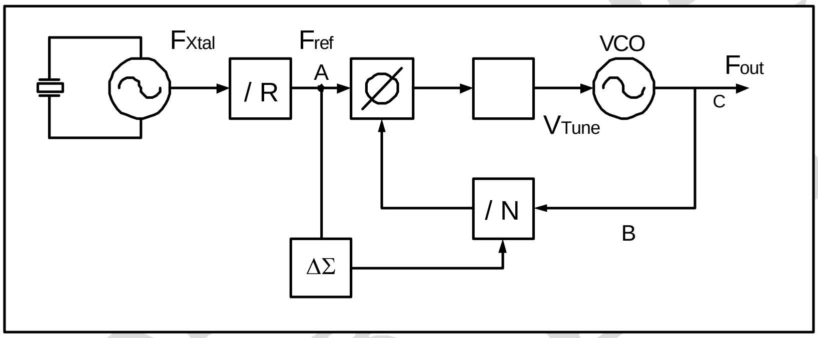


Figure 50: PLL Synthesizer loop

3.6.1 STEP SIZE

With the 18-bit Fractional-N mode selected for the Main Synthesizer and a Reference Divider Value (R) of 1, the step size is calculated as follow:

$$\text{Step size [Hz]} = \frac{F_{Xtal}/R}{2^{18}} \quad \text{-------------------------------- (4.1)}$$

Using a 24.192 MHz crystal yields,

$$\text{Step size} = \frac{24.192\,MHz/1}{262{,}144}$$

$$= 92.285 \text{ Hz}$$

Base on the resolution of 92.285Hz, the theoretical maximum frequency error encountered during channel tuning will be ± 46Hz.

3.6.2 RX CHANNEL TUNING

Receive frequency range is 1525 MHz to 1559MHz. The tuning of the receive frequency is controlled by the RXLO1. The tuning range of RXLO1 is 248.6MHz below the receive frequency i.e. 1276.4 MHz to 1310.4 MHz.

Measurement has been taken to determine the offset encountered when tuning in step of 1.25KHz in the RX frequency band. The receiver on the RF evaluation board V0.11 is tuned to the RX signal generated by Synthesized Signal Generator (SSG). Tuning is done at low, center and hi frequency of the RX band and result is shown in Table 23. The preliminary result shows that the offset encountered is less than the theoretical value of ±46Hz. More tests are needed to cover the entire frequency range of the RX band in order to determine the maximum error in the RX tuning.

Channel Frequency (MHz)	***RX IF (MHz)***	***Offset (Hz)***
1525.00000	10.79963	Reference
1525.00125	10.79964	2
1525.00250	10.79964	8
1543.00625	10.79961	-29
1543.00750	10.79961	-26
1543.00875	10.79961	-21
1558.00375	10.79961	-24
1558.00500	10.79962	-19
1558.00625	10.79962	-16

Table 23: RX channel tuning accuracy

3.6.3 TX CHANNEL TUNING

Transmit frequency range is 1626.5 MHz to 1660.5MHz. The tuning of the transmit frequency is controlled by the TXLO1. The tuning range of TXLO1 is 433.92MHz below the transmit frequency i.e. 1192.58 MHz to 1226.58 MHz.

Measurement has been taken to determine the offset encountered when tuning in step of 1.25KHz in the TX frequency band. Table 24 shows the result of frequency offset encountered when the unit is tuning in the LO, center and hi frequency of the TX band. The error encountered when tuning in step of 1.25KHz is less than ±46Hz. Similarly more data is needed to determine the maximum error.

Channel Frequency (MHz)	*Measured Frequency (MHz)*	*Offset (Hz)*	*Error with ref to 1627MHz (Hz)*
1627.00000	1627.000012	12	Reference
1627.00125	1627.001294	44	32
1627.00250	1627.002509	9	-3
1627.00375	1627.003789	39	27
1643.00000	1643.000053	53	41
1643.00125	1643.001269	19	7
1643.00250	1643.002549	49	37
1643.00375	1643.003805	55	43
1659.00000	1659.000049	49	37
1659.00125	1659.001293	43	31
1659.00250	1659.002539	39	27
1659.00375	1659.003793	43	31

Table 24: TX channel tuning accuracy

3.6.4 TRANSMIT SETTLING TIME

Zero span method has been employed to measure the settling time of the transmit path. The spectrum analyser is triggered at the moment when the LE line of the PLL IC is pulled low by the micro-controller during data transfer. 71MHz IF signal is injected at the input of the transmit chain. The settling time for the two extreme transmit frequencies has been taken. Result in Figure 51 and Figure 52 how that it takes less than 1msec for the loop to settle down.

Figure 51: Switching time from 1660.5MHz to 1626.5MHz

Figure 52: Switching time from 1626.5MHz to 1660.5MHz

3.6.5 RECEIVE LO SETTLING TIME

The same method of measuring the Transmit Settling time is applied to the receive path but the signal measured is the Local Oscillator. The settling time for the two extreme receive LO frequency has been taken. The results shown in Figure 53and Figure 54show that the settling time is less than 1msec.

Figure 53: Switching time from 1276.4MHz to 1310.4MHz

Figure 54: Switching time from 1310.4MHz to 1276.4MHz

3.7 REFERENCE CLOCK

The frequency accuracy of the modem depends on the stability of the reference clock over temperature and time. A 24.192MHz Voltage Tuned Temperature Compensated Crystal Oscillator (VC-TCXO) with a frequency stability of ±2.5ppm will be used as the reference clock for the entire system. A typical TCXO response is shown in Table 25. The VC-TCXO will be tuned to an accuracy of ±1Hz during the initial calibration at the production. It is done manually using a mechanical trimmer and will be tuned only once, no more re-tuning during operation. Description of the frequency correction can be found in UT Hardware Document Chapter 3.1 section 2.3.1.

Parameter	***Min***	***Typ***	***Max***	***Units***
Operating Frequency		24.192		MHz
Frequency stability (-30 to +75°C)			±2.5	ppm
Aging per 3yr			±3.0	ppm
Output voltage (Clipped Sinewave)	0.8			Vp-p
Phase Noise				
10Hz			-75	dBc/Hz
100Hz			-113	dBc/Hz
1KHz			-135	dBc/Hz
10KHz			-145	dBc/Hz
Operating current			2	mA

Table 25: 24.192 MHz TCXO specifications

The temperature gradient of the TCXO is not constant over the operating range of 0°C to +40°C. The accuracy is ±2.5ppm over the temperature range -30 to +75°C. In fact the frequency variation over the temperature range of 0°C to +40°C is less than ±1ppm. The aging specification is ±3ppm (max) per 3yrs. Therefore the maximum error after 3 years is ±4ppm but baseband design is using ±5ppm as reference and therefore there will be 1ppm margin.

4 GLOBAL POSITIONING SYSTEM (GPS) RECEIVER

An Off-the-shelf GPS receiver module will be used to provide accurate (i.e. within ±100m) position determination using the GPS in 2 dimensions with 2-sigma variation and within the limits of the GPS system. The GPS receiver module is capable of reporting 2D/3D positioning as well as providing the HDOP level information. It will first track for 3 satellites and report the 2D position information, then continue to search for the 4th satellite to give the 3D positioning. The minimum setup is shown in Figure 55. Active Patch antenna will be used together with the GPS receiver module. The typical radiation pattern of the patch antenna is shown in Figure 56. The specification of the patch antenna and LNA is shown in Table 27 and Table 28.

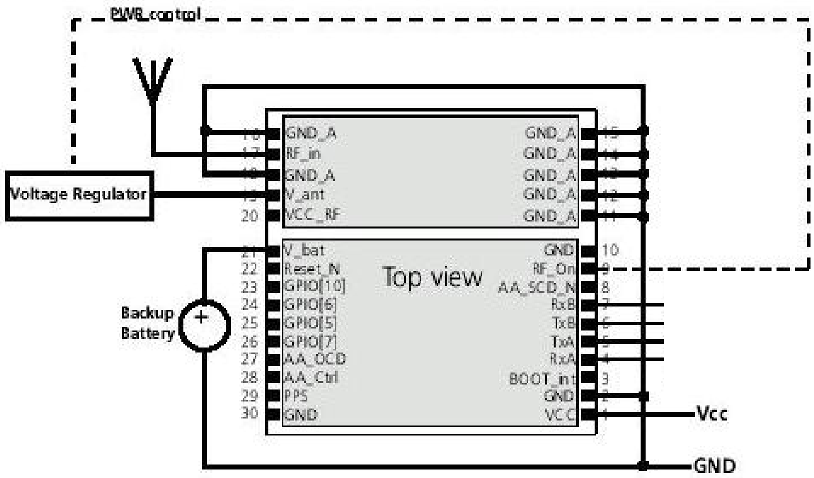
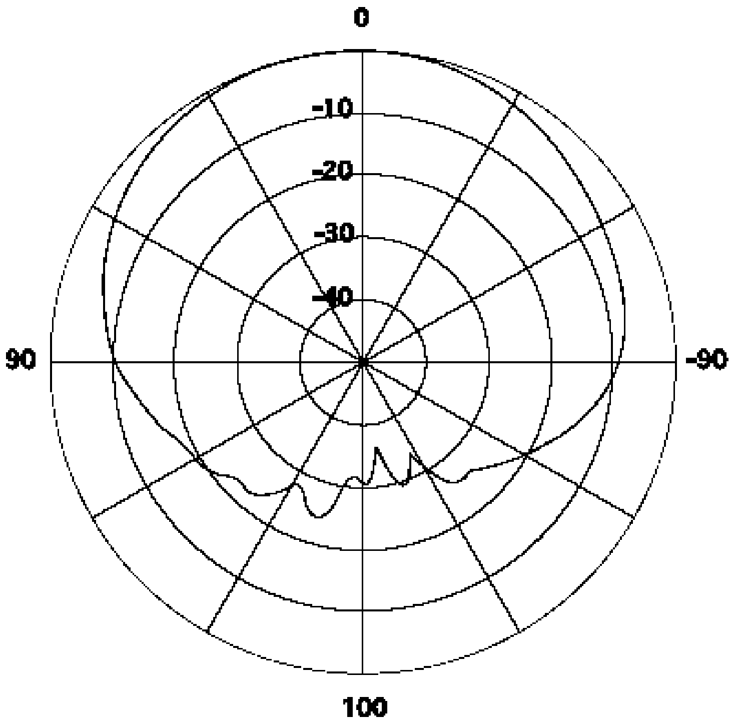


Figure 55: Minimal External wiring for GPS receiver.

Receiver Sensitivity	37 dB*Hz C/No @ -130 dBm RF input
Receiver Type	12 channels, L1 frequency, C/A code
Max. Update Rate	1 Hz
Accuracy	Position 4m CEP Position (DGPS) 2m CEP* (*Depending on accuracy of correction data)
Start-up Times	Hot start 2-8 s Warm start 38 s Cold start 45 s
Signal Reacquisition	100ms
Dynamics	< 4g
Operational Limits	COCOM restrictions apply
Operating Temperature	-40°C to 85°C
Power Consumption	<160 mA (continuous, 3.3V)

Table 26: GPS Receiver Module Specifications



Typical Radiation Pattern (10dB/div)

Figure 56: Typical Radiation Pattern of the Patch Antenna.

Outline Dimension	25x25x4 mm
Frequency	1582.42 ±4MHz
Bandwidth (at 10dB return loss)	15MHz min.
VSWR	1.5 max.
Impedance	50Ω
Polarisation	RHCP
Gain	@Zenith +5dBi typical @10° Elevation -1dBi typical
Axial Ratio	2 dB max.
Operating Temperature	-40°C to +105°C
Center frequency maybe offset to compensate for changes in ground plane and radome.	

Table 27: GPS Patch Antenna Specifications

GPS Low Noise Amplifier will be used and the specification is as follows:

Centre Frequency	1575.42MHz
Power Gain	30dB typically
Bandwidth	2MHz min.
Noise Figure	1.5dB max.
Outer Band Attenuation	20dB min @ F_0 ± 50MHz
VSWR	1.5 or less
Output Impedance	50Ω
Supply Voltages	3 ~ 5 V
Current Consumption	20mA

Table 28: GPS Low Noise Amplifier Specifications

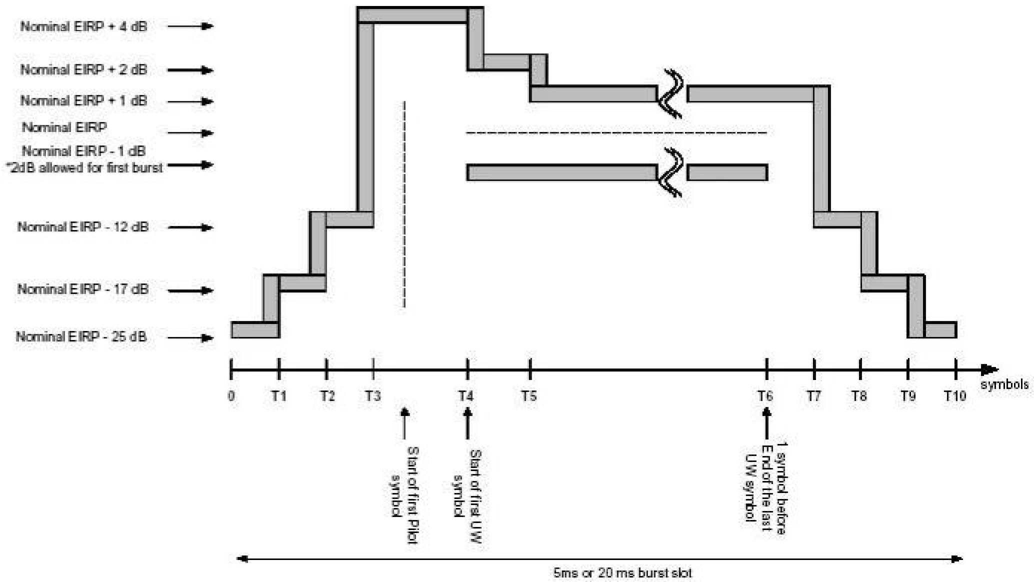
Addvalue Communications Pte Ltd
750D Chai Chee Road #03-03 Technopark @ Chai Chee
Singapore 469004 Tel +65 244 4828 Fax +65 242 4555
www.addvaluetech.com

5 CONCLUSIONS

Measurements have been taken using RF Evaluation Board V0.11 and the results prove that all of the specifications in the SDM can be fulfilled. Circuit board will be improved and optimised to create more margins for production. More data will be collected before integration test with the baseband and control unit.

Addvalue Communications Pte Ltd
750D Chai Chee Road #03-03 Technopark @ Chai Chee
Singapore 469004 Tel +65 244 4828 Fax +65 242 4555
www.addvaluetech.com

Appendix 1 : Transmit Power Mask



Symbol rate	16.8 Ksym/s	33.6 Ksym/s		67.2 Ksym/s		151.2 Ksym/s	
Burst duration	20ms	5ms	20ms	5ms	20ms	5ms	20ms
T1	0	3		9		24	
T2	1	4		10		25	
T3	2	5		11		26	
T4	5	10		20		45	
T5	7	12		22		47	
T6	332	161	665	323	1331	728	2996
T7	334	164	668	326	1334	731	2999
T8	335	164	668	326	1334	731	2999
T9	336	165	669	327	1335	732	3000
T10	336	168	672	336	1344	756	3024