Second Semester Examination

2022/2023 Academic Session

July/August 2023

EEE 322 – RADIO FREQUENCY (RF) & MICROWAVE ENGINEERING

Duration: 2 hours

Please ensure that this examination paper consists of TWENTY (20) pages of printed appendix material before you begin the examination.

Instructions: This question paper consists of **FOUR (4)** questions. Answer **ALL** questions. All questions carry the same marks.

1. a) A microstrip line constructed on FR-4 with microstrip width w = 3.058 mm, FR-4 relative permittivity ε_r= 4.4, microstrip line thickness t = 0.1 mm, FR-4 substrate height h = 1.7 mm is terminated by load impedance of 400 ohms. The operating frequency is at f = 2.45 GHz.

Using the specifications given, evaluate:

(i) the characteristic impedance, Z_0 of the w = 3.058 mm line;

(10 marks)

(ii) the load reflection coefficient, ρ;

(10 marks)

(iii) the characteristic impedance of the quarter-wave transformer, Z_{0T} that could be used to match the load;

(10 marks)

(iv) the width of the quarter-wave transformer section

(10 marks)

(v) analyze and sketch the design of the microstrip line together with its matching circuit using the information in question 1(a)(i) – (iv) with appropriate labels.

(10 marks)

b) A microwave device has an impedance of Z = 10 + j 25 Ω.

(i) Find the reflection coefficient of the given impedance using Smith Chart.

(25 marks)

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(ii) Find the Voltage Standing Wave Ratio (VSWR) value of the impedance given in 1(b)(i) using Smith Chart.

(5 marks)

(iii) Find the admittance value of the impedance given in 1(b)(i) using Smith Chart.

(5 marks)

(iv) Based on findings from questions 1(b) (i) to (iii), is the impedance given a perfectly matched impedance? How do you know this based on the Smith Chart? If yes/no, what method would you recommend to increase the impedance matching?

(15 marks)

2. a) Microwave filter functions to selectively pass or attenuate a particular band of frequencies and is a crucial element of the receiver front end architecture.

(i) Design a 5-element low-pass filter with a 3dB point at 600 MHz using inductors (L) and capacitors (C). The filter is to have a Butterworth response and is to work between terminating impedances of 50 ohms.

(30 marks)

(ii) Design a 5-element high-pass filter with a 3dB point at 600 MHz inductors (L) and capacitors (C). The filter is to have a Butterworth response and is to work between terminating impedances of 50 ohms.

(30 marks)

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b) Directional coupler is normally used to split the input signal and distributed power by isolating, eliminating, or combining signals in microwave signal routing and radio frequency.

(i) Illustrate and describe a hybrid ring coupler showing all 4 ports and relevant information.

(20 marks)

(ii) Define the Scattering Parameter (S-parameter) of a reciprocal hybrid ring coupler.

(20 marks)

3. Referring to a block diagram in Figure 3, design a 2.5 GHz wireless transmitter having the specifications as in Table 3. The information for the components that is required for the design is attached in the Appendix section.

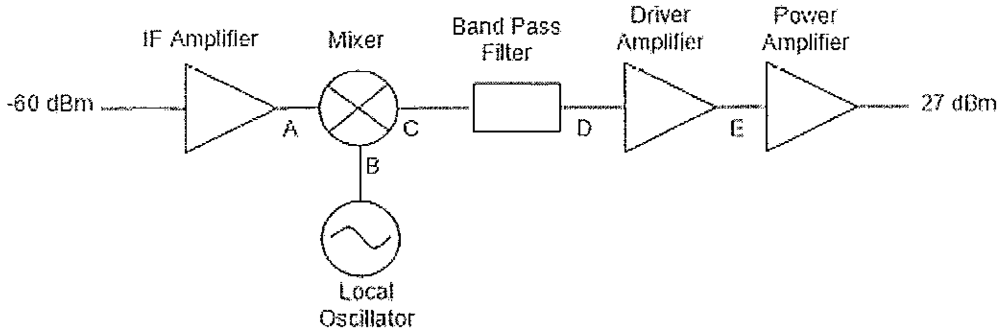

Figure 3: Block diagram of the 2.5 GHz wireless transmitter

Table 3: Specification for 2.5 GHz wireless transmitter

TX Frequency	IF Frequency	Bandwidth	TX Power
2.5 GHz	130 MHz	40 MHz	27 dBm

a) Determine the gain of the IF Amplifier and power level at point A (assume minimum input power to the mixer RF port is -45 dBm?

(20 marks)

b) What is the frequency of the Local Oscillator and typical output power of the Local Oscillator at point B?

(20 marks)

c) Based on the mixer specification and typical Local Oscillator drive power, what is the mixer output power at point C.

(20 marks)

d) Referring to the datasheet of the Band Pass Filter in the Appendix section, what is the power level at point D?

(15 marks)

e) How many Driver Amplifier are required to drive the Power Amplifier to produce 27 dBm of output power?

(15 marks)

f) How much gain is required for the Power Amplifier?

(10 marks)

4. The PHEMT ATF 36077 has the S-parameter and noise parameter as in Appendix 2. Design a Low Noise Amplifier operating at 6 GHz. Choose input reflection coefficient Γ_{in} on your own and using required noise figure F_r at 0.4 dB. Microwave laminate having the thickness of 0.813 mm with dielectric constant ε_r of 3.38 must be used. The following important formulas may be useful.

a) Calculate the center of the input noise circle point C_i.

(20 Marks)

b) Calculate the radius of the input noise circle R_i.

(20 Marks)

c) By using the Smith chart, design the input noise figure matching circuit.

(30 Marks)

d) Based on your selection of the Γ_{in}, calculate the load reflection coefficient Γ_L and design the output matching.

(30 Marks)

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APPENDIX 1

APPENDIX FOR QUESTION 1 & 2: Design and Synthesis Formula for Microstrip

a. Impedance, Z_0

$$Zo \approx \frac{87}{\sqrt{\varepsilon_r + 1.41}} ln\left(\frac{5.98h}{0.8w + t}\right)$$

b. Width and Length

$$w/h = \frac{377}{Z_0\sqrt{\varepsilon_r}} - 2$$

$$Length = \frac{c}{2f_0\sqrt{\varepsilon_{reff}}} - 0.824h\left(\frac{(\varepsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{W}{h}+0.8)}\right) \text{ m}$$

c. Low-Pass Butterworth Filter

$$g_k = 2\ \sin\frac{(2k-1)\pi}{2n}$$

$$L_k = \frac{Z_0 g_k}{\omega_c} \quad C_k = \frac{g_k}{Z_0\omega_c}$$

d. High-Pass Butterworth Filter

$$g_k = 2\ \sin\frac{(2k-1)\pi}{2n}$$

$$L_k = \frac{Z_0}{g_k\omega_c}\ C_k = \frac{1}{Z_0 g_k \omega_c}$$

APPENDIX FOR QUESTION 3 & 4

$$C_i = \frac{\Gamma_{opt}}{(1+N_i)}$$

$$Zo \approx \frac{377}{\sqrt{\varepsilon_r}}\left(\frac{W}{h}+2\right)$$

$$R_i = \frac{1}{1+N_i}\sqrt{N_i^2 + N_i(1-|\Gamma_{opt}|^2)}$$

$$Ni = \frac{\left|(Fr - F\min)|1+\Gamma_{opt}|^2\right|}{4\frac{R_n}{Z_o}}$$

$$\Gamma_L = \left(S_{22} + \frac{S_{12}S_{21}\Gamma_{in}}{1-S_{11}\Gamma_{in}}\right)^*$$

APPENDIX 2:
USEFUL CONTANTS & EXPRESSIONS FOR TRANSMISSION LINE ANALYSIS

$\mu_0 = 4\pi 10^{-7} Henry\ per\ meter\ ;\ \varepsilon_0 = 8.85x10^{-12}\ Farad\ per\ meter$

Speed of light, m/s	$c = \frac{1}{\sqrt{\mu_0\varepsilon_0}}$	Input impedance, Z_{in} when $Z_{direction}$= length, l	$Z_{in(z=l)} = Z_0 \frac{Z_L + jZ_0 \tan\theta_l}{Z_0 + jZ_L \tan\theta_l}$
Wave Transmission	$V(z) - V^+e^{-\gamma z} + V^-e^{+\gamma z}$	Effective dielectric constant (Simple)	$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2}$
Wave Propagation in time domain	$\lvert V(z,t)\rvert = \lvert V^+ e^{-\alpha z}\cos(\omega t - \gamma z + \phi)\rvert + \lvert V^- e^{+\alpha z}\cos(\omega t + \gamma z + \phi)\rvert$	Complex Propagation Constant	$\gamma = \alpha + j\beta$ or $\gamma = \sqrt{(R + j\omega L)(G + j\omega C)}$
Dielectric Loss Tangent, (nepers/m)	$\alpha_D = \tan(\delta) . \frac{\omega C' Z_0}{2}$	Characteristic Impedance (Lossy)	$Z_0 = \sqrt{\frac{(R + j\omega L)}{(G + j\omega C)}}$
Voltage Standing Wave Ratio	$VSWR = \frac{V_{max}}{V_{min}}$	Standing Wave Ratio	$SWR = \frac{1 + \lvert\Gamma\rvert}{1 - \lvert\Gamma\rvert}$
Conductor loss (nepers/m)	$\alpha_c = \frac{R'}{2Z_0}$	Complex Reflection Coefficient (at any z position)	$\Gamma_z = \lvert\Gamma_z\rvert\angle\theta$
Resistivity	$\rho = \frac{1}{\sigma}$	Electrical Length (radians)	$\theta = \frac{4\pi l_{min}}{\lambda} - \pi\ or\ \theta = \beta l$
Dissipation factor	$Df = \tan\delta$	Minimum Physical Length to load @ V_{min}	$l_{min} = \frac{\lambda}{4\pi}\theta + \pi$
Skin depth	$\delta = \sqrt{\frac{2}{\omega\mu\sigma}}$	Load Reflection Coefficient	$\Gamma_L = \frac{Z_L - Z_0}{Z_L + Z_0}$
Conductivity (sheet)	$\sigma = \frac{G' \times length}{Area}$	Impedance @ distance in z-direction , l,	$Z(l) = Z_0 \frac{1 + \Gamma(l)}{1 - \Gamma(l)}$
Relative permeability	$\mu_r = \mu_0\mu_r$	Normalization (to Z_o)	$\bar{z}(l) = \frac{Z(l)}{Z_0}$
Complex Relative Permittivity (lossy dielectric)	$\varepsilon_r = \varepsilon_r' + j\varepsilon_r' \tan\delta$ $\varepsilon_r' = \varepsilon_0\varepsilon_r$	Reflection Coefficient (Amplitude)	$\lvert\Gamma\rvert = \frac{SWR - 1}{SWR + 1}$
Phase Velocity	$v = \frac{\omega}{\beta}$	Return Loss (dB) @ 1 port	RL= $10\ log(\frac{V^-}{V^+})$
Phase Constant	$\beta = \frac{2\pi}{\lambda}$	Transmission Coefficient	$T = 1 - \lvert\Gamma\rvert$

APPENDIX 3: COMPONENT DATASHEET

2–18 GHz Ultra Low Noise Pseudomorphic HEMT

Technical Data

ATF-36077

Features

- **PHEMT Technology**
- **Ultra-Low Noise Figure:**
  0.5 dB Typical at 12 GHz
  0.3 dB Typical at 4 GHz
- **High Associated Gain:**
  12 dB Typical at 12 GHz
  17 dB Typical at 4 GHz
- **Low Parasitic Ceramic Microstrip Package**
- **Tape-and-Reel Packing Option Available**

Applications

- **12 GHz DBS LNB (Low Noise Block)**
- **4 GHz TVRO LNB (Low Noise Block)**
- **Ultra-Sensitive Low Noise Amplifiers**

Note: 1. See Noise Parameter Table.

Description

Hewlett-Packard's ATF-36077 is an ultra-low-noise Pseudomorphic High Electron Mobility Transistor (PHEMT), packaged in a low parasitic, surface-mountable ceramic package. Properly matched, this transistor will provide typical 12 GHz noise figures of 0.5 dB, or typical 4 GHz noise figures of 0.3 dB. Additionally, the ATF-36077 has very low noise resistance, reducing the sensitivity of noise performance to variations in input impedance match, making the design of broadband low noise amplifiers much easier. The premium sensitivity of the ATF-36077 makes this device the ideal choice for use in the first stage of extremely low noise cascades.

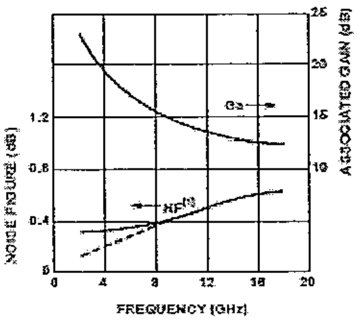
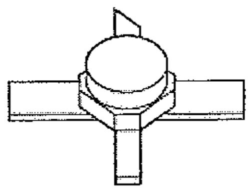
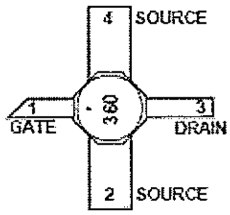


Figure 1. ATF-36077 Optimum Noise Figure and Associated Gain vs. Frequency for V_{DS} = 1.5 V, I_D = 10 mA.

77 Package



Pin Configuration



The repeatable performance and consistency make it appropriate for use in Ku-band Direct Broadcast Satellite (DBS) Television systems, C-band Television Receive Only (TVRO) LNAs, or other low noise amplifiers operating in the 2-18 GHz frequency range.

This GaAs PHEMT device has a nominal 0.2 micron gate length with a total gate periphery (width) of 200 microns. Proven gold based metalization systems and nitride passivation assure rugged, reliable devices.

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ATF-36077 Typical Scattering Parameters,
Common Source, $Z_O = 50\,\Omega$, $V_{DS} = 1.5\,V$, $I_D = 10\,mA$

Freq. GHz	S_{11} Mag.	S_{11} Ang.	S_{21} dB	S_{21} Mag.	S_{21} Ang.	S_{12} dB	S_{12} Mag.	S_{12} Ang.	S_{22} Mag.	S_{22} Ang.
1.0	0.99	-17	14.00	5.010	163	-36.08	0.016	78	0.60	-14
2.0	0.97	-33	13.81	4.904	147	-30.33	0.030	66	0.59	-28
3.0	0.94	-49	13.53	4.745	132	-27.25	0.043	54	0.57	-41
4.0	0.90	-65	13.17	4.556	116	-25.32	0.054	43	0.55	-54
5.0	0.86	-79	12.78	4.357	102	-24.04	0.063	33	0.53	-66
6.0	0.82	-93	12.39	4.162	88	-23.17	0.069	24	0.50	-78
7.0	0.78	-107	12.00	3.981	75	-22.58	0.074	16	0.48	-89
8.0	0.75	-120	11.64	3.820	62	-22.17	0.078	8	0.46	-99
9.0	0.72	-133	11.32	3.682	49	-21.90	0.080	1	0.44	-109
10.0	0.69	-146	11.04	3.566	37	-21.71	0.082	-6	0.42	-119
11.0	0.66	-159	10.81	3.473	25	-21.57	0.083	-13	0.40	-129
12.0	0.63	-172	10.63	3.401	13	-21.44	0.085	-19	0.38	-139
13.0	0.61	175	10.50	3.349	1	-21.32	0.086	-25	0.37	-149
14.0	0.60	161	10.41	3.315	-12	-21.19	0.087	-32	0.35	-160
15.0	0.58	147	10.36	3.296	-24	-21.04	0.089	-39	0.33	-171
16.0	0.57	131	10.34	3.289	-37	-20.87	0.091	-47	0.31	177
17.0	0.56	114	10.34	3.289	-50	-20.69	0.092	-55	0.29	164
18.0	0.57	97	10.35	3.291	-64	-20.53	0.094	-65	0.26	148

ATF-36077 Typical "Off" Scattering Parameters,
Common Source, $Z_O = 50\,\Omega$, $V_{DS} = 1.5\,V$, $I_D = 0\,mA$, $V_{GS} = -2\,V$

Freq. GHz	S_{11} Mag.	S_{11} Ang.	S_{21} dB	S_{21} Mag.	S_{21} Ang.	S_{21} dB	S_{21} Mag.	S_{21} Ang.	S_{22} Mag.	S_{22} Ang.
11.0	0.96	-139	-14.2	0.19	-43	-14.2	0.19	-43	0.97	-125
12.0	0.95	-152	-14.0	0.20	-56	-14.0	0.20	-56	0.97	-137
13.0	0.94	-166	-13.8	0.20	-69	-13.8	0.20	-68	0.96	-149

ATF-36077 Typical Noise Parameters,

Common Source, $Z_O = 50\,\Omega$, $V_{DS} = 1.5$ V, $I_D = 10$ mA

Freq. GHz	F_{min}[1] dB	Γ_{opt} Mag.	Ang.	R_n/Z_o -
1	0.30	0.95	12	0.40
2	0.30	0.90	25	0.20
4	0.30	0.81	51	0.17
6	0.30	0.73	76	0.13
8	0.37	0.66	102	0.09
10	0.44	0.60	129	0.05
12	0.50	0.54	156	0.03
14	0.56	0.48	-174	0.02
16	0.61	0.43	-139	0.05
18	0.65	0.39	-100	0.09

Note:
1. The F_{min} values at 2, 4, and 6 GHz have been adjusted to reflect expected circuit losses that will be encountered when matching to the optimum reflection coefficient (Γ_{opt}) at these frequencies. The theoretical F_{min} values for these frequencies are: 0.10 dB at 2 GHz, 0.20 dB at 4 GHz, and 0.29 dB at 6 GHz. Noise parameters are derived from associated s parameters, packaged device measurements at 12 GHz, and die level measurements from 6 to 18 GHz.

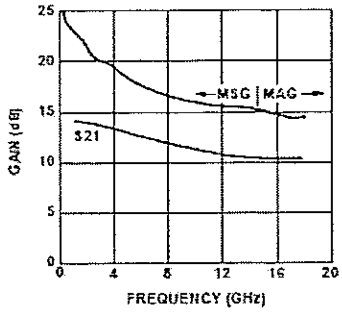
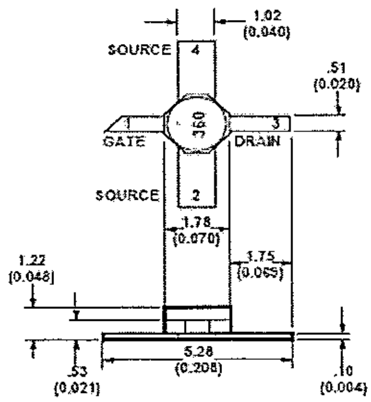


Figure 2. Maximum Available Gain, Maximum Stable Gain and Insertion Power Gain vs. Frequency. V_{DS} = 1.5 V, I_D = 10 mA.

77 Package Dimensions



TYPICAL DIMENSIONS ARE IN MILLIMETERS (INCHES).

Part Number Ordering Information

Part Number	No. of Devices	Container
ATF-36077-TR1[2]	1000	7" Reel
ATF-36077-STR	10	strip

Note:
2. For more information, see "Tape and Reel Packaging for Semiconductor Devices," in "Communications Components" Designer's Catalog.

MIXER

Data Sheet ADL5363

SPECIFICATIONS

V_S = 5 V, I_S = 100 mA, T_A = 25°C, f_{RF} = 2535 MHz, f_{LO} = 2738 MHz, LO power = 0 dBm, Z_O = 50 Ω, unless otherwise noted.

Table 2.

Parameter	Test Conditions/Comments	Min	Typ	Max	Unit
RF INPUT INTERFACE					
Return Loss	Tunable to >20 dB over a limited bandwidth		16		dB
Input Impedance			50		Ω
RF Frequency Range		2300		2900	MHz
OUTPUT INTERFACE					
Output Impedance	Differential impedance, f = 200 MHz		33||-0.3		Ω||pF
IF Frequency Range		dc		450	MHz
DC Bias Voltage[1]	Externally generated	3.3	5.0	5.5	V
LO INTERFACE					
LO Power		−6	0	+10	dBm
Return Loss			15		dB
Input Impedance			50		Ω
LO Frequency Range		2330		3350	MHz
POWER-DOWN (PWDN) INTERFACE[2]					
PWDN Threshold			1.0		V
Logic 0 Level				0.4	V
Logic 1 Level		1.4			V
PWDN Response Time	Device enabled, IF output to 90% of its final level		160		ns
	Device disabled, supply current <5 mA		220		ns
PWDN Input Bias Current	Device enabled		0.0		μA
	Device disabled		70		μA

[1] Apply the supply voltage from the external circuit through the choke inductors.
[2] The PWDN function is intended for use with $V_S \leq 3.6$ V only.

5 V PERFORMANCE

V_S = 5 V, I_S = 100 mA, T_A = 25°C, f_{RF} = 2535 MHz, f_{LO} = 2738 MHz, LO power = 0 dBm, VGS0 = VGS1 = 0 V, and Z_O = 50 Ω, unless otherwise noted.

Table 3.

Parameter	Test Conditions/Comments	Min	Typ	Max	Unit
DYNAMIC PERFORMANCE					
Power Conversion Loss	Including 1:1 IF port transformer and PCB loss		7.7		dB
SSB Noise Figure			7.6		dB
Input Third-Order Intercept (IIP3)	f_{RF1} = 2534.5 MHz, f_{RF2} = 2535.5 MHz, f_{LO} = 2738 MHz, each RF tone at 0 dBm		31		dBm
Input Second-Order Intercept (IIP2)	f_{RF1} = 2535 MHz, f_{RF2} = 2585 MHz, f_{LO} = 2738 MHz, each RF tone at 0 dBm		62		dBm
Input 1 dB Compression Point (IP1dB)[1]	Exceeding 20 dBm RF power results in damage to the device		25		dBm
LO-to-IF Leakage	Unfiltered IF output		−22		dBm
LO-to-RF Leakage			−32		dBm
RF-to-IF Isolation			−44		dBc
IF/2 Spurious	−10 dBm input power		−61		dBc
IF/3 Spurious	−10 dBm input power		−70		dBc
POWER SUPPLY					
Positive Supply Voltage		4.5	5	5.5	V
Quiescent Current	V_S = 5 V		100		mA

[1] Exceeding 20 dBm RF power results in damage to the device.

3.3 V PERFORMANCE

V_S = 3.3 V, I_S = 60 mA, T_A = 25°C, f_{RF} = 2535 MHz, f_{LO} = 2738 MHz, LO power = 0 dBm, R9 = 226 Ω, VGS0 = VGS1 = 0 V, and Z_O = 50 Ω, unless otherwise noted.

Table 4.

Parameter	Test Conditions/Comments	Min	Typ	Max	Unit
DYNAMIC PERFORMANCE					
Power Conversion Loss	Including 1:1 IF port transformer and PCB loss		7.4		dB
SSB Noise Figure			6.8		dB
Input Third-Order Intercept (IIP3)	f_{RF1} = 2534.5 MHz, f_{RF2} = 2535.5 MHz, f_{LO} = 2738 MHz, each RF tone at 0 dBm		26		dBm
Input Second-Order Intercept (IIP2)	f_{RF1} = 2535 MHz, f_{RF2} = 2585 MHz, f_{LO} = 2738 MHz, each RF tone at 0 dBm		56		dBm
POWER SUPPLY					
Positive Supply Voltage			3.3		V
Quiescent Current	V_S = 5 V		60		mA

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5 V PERFORMANCE

V_S = 5 V, I_S = 100 mA, T_A = 25°C, f_{RF} = 2535 MHz, f_{LO} = 2738 MHz, LO power = 0 dBm, VGS0 = VGS1 = 0 V, and Z_O = 50 Ω, unless otherwise noted.

Table 3.

Parameter	Test Conditions/Comments	Min	Typ	Max	Unit
DYNAMIC PERFORMANCE					
Power Conversion Loss	Including 1:1 IF port transformer and PCB loss		7.7		dB
SSB Noise Figure			7.6		dB
Input Third-Order Intercept (IIP3)	f_{RF1} = 2534.5 MHz, f_{RF2} = 2535.5 MHz, f_{LO} = 2738 MHz, each RF tone at 0 dBm		31		dBm
Input Second-Order Intercept (IIP2)	f_{RF1} = 2535 MHz, f_{RF2} = 2585 MHz, f_{LO} = 2738 MHz, each RF tone at 0 dBm		62		dBm
Input 1 dB Compression Point (IP1dB)[1]	Exceeding 20 dBm RF power results in damage to the device		25		dBm
LO-to-IF Leakage	Unfiltered IF output		−22		dBm
LO-to-RF Leakage			−32		dBm
RF-to-IF Isolation			−44		dBc
IF/2 Spurious	−10 dBm input power		−61		dBc
IF/3 Spurious	−10 dBm input power		−70		dBc
POWER SUPPLY					
Positive Supply Voltage		4.5	5	5.5	V
Quiescent Current	V_S = 5 V		100		mA

[1] Exceeding 20 dBm RF power results in damage to the device.

3.3 V PERFORMANCE

V_S = 3.3 V, I_S = 60 mA, T_A = 25°C, f_{RF} = 2535 MHz, f_{LO} = 2738 MHz, LO power = 0 dBm, R9 = 226 Ω, VGS0 = VGS1 = 0 V, and Z_O = 50 Ω, unless otherwise noted.

Table 4.

Parameter	Test Conditions/Comments	Min	Typ	Max	Unit
DYNAMIC PERFORMANCE					
Power Conversion Loss	Including 1:1 IF port transformer and PCB loss		7.4		dB
SSB Noise Figure			6.8		dB
Input Third-Order Intercept (IIP3)	f_{RF1} = 2534.5 MHz, f_{RF2} = 2535.5 MHz, f_{LO} = 2738 MHz, each RF tone at 0 dBm		26		dBm
Input Second-Order Intercept (IIP2)	f_{RF1} = 2535 MHz, f_{RF2} = 2585 MHz, f_{LO} = 2738 MHz, each RF tone at 0 dBm		56		dBm
POWER SUPPLY					
Positive Supply Voltage			3.3		V
Quiescent Current	V_S = 5 V		60		mA

OSCILLATOR

ANALOG DEVICES

HMC385LP4 / 385LP4E

v02.0705

MMIC VCO w/ BUFFER AMPLIFIER, 2.25 - 2.5 GHz

Typical Applications

Low noise MMIC VCO w/Buffer Amplifier for:

- Wireless Infrastructure
- Industrial Controls
- Test Equipment
- Military

Features

Pout: +4.5 dBm

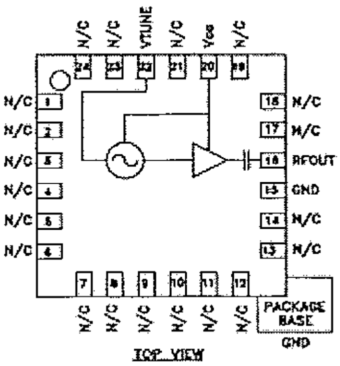
Phase Noise: -115 dBc/Hz @100 KHz

No External Resonator Needed

Single Supply: 3V @ 35 mA

QFN Leadless SMT Package, 16 mm²

Functional Diagram



General Description

The HMC385LP4 & HMC385LP4E are GaAs InGaP Heterojunction Bipolar Transistor (HBT) MMIC VCOs with integrated resonators, negative resistance devices, varactor diodes, and buffer amplifiers. Covering 2.25 to 2.5 GHz, the VCO's phase noise performance is excellent over temperature, shock, vibration and process due to the oscillator's monolithic structure. Power output is 4.5 dBm typical from a single supply of 3V @ 35mA. The voltage controlled oscillator is packaged in a low cost leadless QFN 4x4 mm surface mount package.

Electrical Specifications, T_A = +25° C, Vcc = +3V

Parameter	Min.	Typ.	Max.	Units
Frequency Range		2.25 - 2.5		GHz
Power Output	1.5	4.5		dBm
SSB Phase Noise @ 100 kHz Offset, Vtune= +5V @ RF Output		-115		dBc/Hz
Tune Voltage (Vtune)	0		10	V
Supply Current (Icc) (Vcc = +3.0V)		35		mA
Tune Port Leakage Current			10	µA
Output Return Loss		2		dB
Harmonics 2nd 3rd		 -7 -33		 dBc dBc
Pulling (into a 2.0:1 VSWR)		2.0		MHz pp
Pushing @ Vtune= +5V		-2		MHz/V
Frequency Drift Rate		0.25		MHz/°C

AMPLIFIERS

ANALOG DEVICES

HMC680LP4 / 680LP4E

v03.0609

BiCMOS MMIC 5-BIT DIGITAL VARIABLE GAIN AMPLIFIER, 30 - 400 MHz

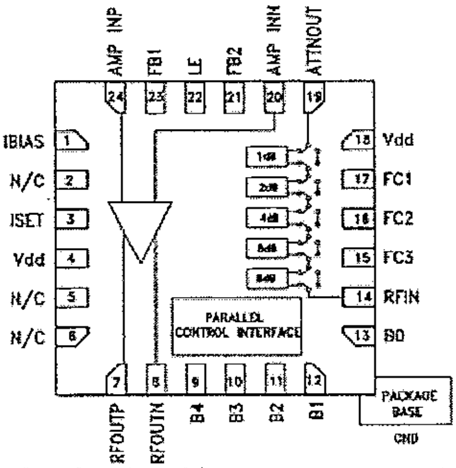
RoHS✓ EARTH FRIENDLY

Typical Applications

The HMC680LP4(E) is ideal for:

- Cellular/3G Infrastructure
- WiBro / WiMAX / 4G
- Microwave Radio & VSAT
- Test Equipment and Sensors
- IF & RF Applications

Functional Diagram



Features

TTL/CMOS compatible parallel or latched parallel control interface

High Output IP3: +40 dBm (At all gain settings)

Low Noise Figure: 5 dB

Wide Gain Control Range: 23 dB

24 Lead 4x4 mm SMT Package: 16 mm²

Excellent State & Step Accuracy (±0.05 dB)

General Description

The HMC680LP4(E) is a digitally controlled variable gain amplifier which operates from 30 to 400 MHz, and can be programmed to provide -4 dB to +19 dB of gain, in 1 dB steps. The HMC680LP4(E) delivers noise figure of 5 dB in its maximum gain state, with output IP3 of up to +40 dBm in any state. This high linearity DVGA also provides a differential RF output which can be used to interface directly with SAW filters in Tx and Rx applications, and with digital to analog converters in Rx chains. The HMC680LP4(E) is housed in a RoHS compliant 4x4 mm QFN leadless package, and is CMOS/ TTL compatible.

Electrical Specifications, T_A = +25° C, 50 Ohm System, Vdd = +5V

Parameter		Min.	Typ.	Max.	Units
Frequency Range		30 - 400			MHz
Gain (Maximum Gain State)		17	19		dB
Gain Control Range			23		dB
Input Return Loss			12		dB
Output Return Loss			13		dB
Gain Accuracy: (Referenced to Maximum Gain State) All Gain States		±(0.15 + 2% of Gain Setting) Max.			dB
Output Power for 1dB Compression		23	25		dBm
Output Third Order Intercept Point (Two-Tone Output Power= +5 dBm Each Tone) [1]			40		dBm
Output Second Order Intercept Point (Two-Tone Output Power= +5 dBm Each Tone) [1]			65		dBm
Harmonics	2nd Order		70		dBc
	3rd Order		75		dBc
Step Accuracy (Referenced to Maximum Gain State)			±0.2		dB
Noise Figure (max gain state)			5		dB
Switching Characteristics	tRise, tFall (10/90% RF)		11		ns
	tON, tOFF (50% CTL to 10/90% RF)		13		ns
Control Supply Current Idd			4	5	mA
Amp Supply Current (RFOUTP)			122	135	mA
Amp Supply Current (RFOUTN)			122	135	mA

[1] Test frequency 50 MHz

...17/-

ANALOG DEVICES

2.3 GHz to 4.0 GHz ¼ Watt RF Driver Amplifier

Data Sheet **ADL5321**

FEATURES

- Operation: 2.3 GHz to 4.0 GHz
- Gain of 14.0 dB at 2.6 GHz
- OIP3 of 41.0 dBm at 2.6 GHz
- P1dB of 25.7 dBm at 2.6 GHz
- Noise figure: 4.0 dB at 2.6 GHz
- Power supply voltage: 3.3 V to 5 V
- Power supply current: 37 mA to 90 mA
- Dynamically adjustable bias
- No bias resistor required
- Thermally efficient, MSL-1 rated SOT-89 package
- Operating temperature range: −40°C to +105°C
- ESD rating of ±2 kV (Class 3A)

FUNCTIONAL BLOCK DIAGRAM

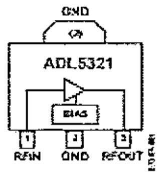


Figure 1.

APPLICATIONS

- Wireless infrastructure
- Automated test equipment
- ISM/AMR applications

GENERAL DESCRIPTION

The ADL5321 incorporates a dynamically adjustable biasing circuit that allows for the customization of OIP3 and P1dB performance from 3.3 V to 5 V without the need for an external bias resistor. This feature gives the designer the ability to tailor driver amplifier performance to the specific needs of the design. This feature also creates the opportunity for dynamic biasing of the driver amplifier, where a variable supply is used to allow for full 5 V biasing under large signal conditions and then can reduce the supply voltage when signal levels are smaller and lower power consumption is desirable. This scalability reduces the need to evaluate and inventory multiple driver amplifiers for different output power requirements from 22 dBm to 26 dBm output power levels.

The ADL5321 is also rated to operate across the wide temperature range of −40°C to +105°C for reliable performance in designs that experience higher temperatures, such as power amplifiers. The ¼ watt driver amplifier covers the 2.3 GHz to 4.0 GHz wide frequency range and only requires a few external components to be tuned to a specific band within that wide range. This high performance, broadband RF driver amplifier is well suited for a variety of wired and wireless applications including cellular infrastructure, ISM band power amplifiers, defense equipment, and instrumentation equipment. A fully populated evaluation board is available.

The ADL5321 also delivers excellent adjacent channel leakage ratio (ACLR) vs. P_{OUT}. For output powers up to 10 dBm rms, the ADL5321 adds very little distortion to the output spectrum. At 2.6 GHz, the ACLR is −59 dB and a relative constellation error of −46.6 dB (<0.5% EVM) at an output power of 10 dBm rms.

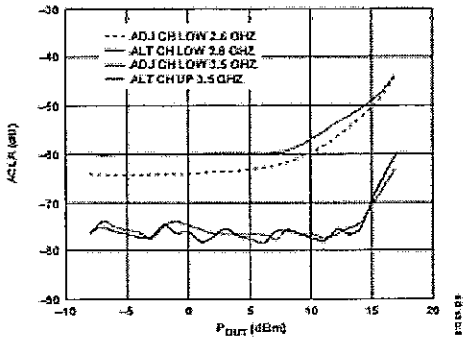


Figure 2. WiMAX 64 QAM, 10 MHz Bandwidth, Single Carrier

TYPICAL SCATTERING PARAMETERS

VCC = 5 V and T_A = 25°C; the effects of the test fixture have been de-embedded up to the pins of the device.

Table 2.

Frequency (MHz)	S11		S21		S12		S22	
	Magnitude (dB)	Angle (°)	Magnitude (dB)	Angle (°)	Magnitude (dB)	Angle (°)	Magnitude (dB)	Angle (°)
2400	−4.54	129.60	11.90	21.92	−26.72	−33.83	−8.18	−166.39
2450	−4.65	126.65	11.89	18.30	-26.63	−36.64	−8.27	−169.02
2500	−4.79	123.62	11.88	14.57	-26.55	−39.62	−8.37	−171.83
2550	−4.92	120.44	11.87	10.68	−26.48	−42.70	−8.45	−175.32
2600	−5.04	117.31	11.85	6.80	−26.42	−45.95	−8.44	−179.11
2650	−5.17	114.43	11.83	2.90	−26.37	−49.25	−8.39	177.31
2700	−5.33	111.78	11.80	−1.06	−26.34	−52.65	−8.33	173.43
2750	−5.50	109.21	11.77	−5.17	−26.31	−56.16	−8.15	169.22
2800	−5.70	106.84	11.74	−9.36	−26.30	−59.84	−7.90	165.46
2850	−5.94	104.85	11.71	−13.64	−26.30	−63.64	−7.63	161.87
2900	−6.25	103.23	11.66	−18.05	−26.31	−67.63	−7.31	158.01
2950	−6.61	101.91	11.62	−22.58	−26.34	−71.77	−6.83	154.58
3000	−7.03	101.06	11.56	−27.18	−26.37	−76.13	−6.44	151.64
3050	−7.53	100.92	11.50	−31.98	−26.44	−80.76	−6.00	148.53
3100	−8.12	101.82	11.40	−36.95	−26.55	−85.61	−5.53	145.65
3150	−8.78	104.04	11.29	−42.09	−26.68	−90.69	−5.03	143.14
3200	−9.47	107.91	11.15	−47.34	−26.85	−95.96	−4.56	140.74
3250	−10.07	113.72	10.97	−52.74	−27.06	−101.50	−4.08	138.36
3300	−10.45	121.55	10.76	−58.29	−27.32	−107.30	−3.61	136.16
3350	−10.45	130.87	10.49	−63.95	−27.65	−113.32	−3.19	133.97
3400	−10.02	140.04	10.17	−69.56	−28.05	−119.45	−2.80	131.77
3450	−9.25	147.61	9.80	−75.16	−28.49	−125.70	−2.43	129.85
3500	−8.28	153.06	9.39	−80.70	−29.00	−132.04	−2.13	128.08
3550	−7.27	156.76	8.92	−86.04	−29.58	−138.45	−1.89	126.22
3600	−6.34	159.01	8.39	−91.20	−30.20	−144.79	−1.66	124.51
3650	−5.51	160.11	7.83	−96.07	−30.88	−151.12	−1.48	123.23
3700	−4.76	160.43	7.26	−100.64	−31.57	−157.36	−1.37	122.16
3750	−4.14	160.36	6.66	−104.97	−32.29	−163.69	−1.27	121.07
3800	−3.60	160.07	6.04	−108.96	−33.02	−170.01	−1.19	120.25
3850	−3.16	159.62	5.43	−112.61	−33.74	−176.34	−1.14	119.79
3900	−2.78	158.95	4.82	−116.07	−34.44	177.21	−1.12	119.31
3950	−2.45	158.24	4.20	−119.27	−35.12	170.60	−1.10	118.94
4000	−2.17	157.64	3.60	−122.18	−35.74	163.89	−1.09	118.86

ANALOG DEVICES

HMC414MS8G / 414MS8GE

v04.0607

RoHS✓ EARTH FRIENDLY

GaAs InGaP HBT MMIC POWER AMPLIFIER, 2.2 - 2.8 GHz

Typical Applications

This amplifier is ideal for use as a power amplifier for 2.2 - 2.7 GHz applications:

- BLUETOOTH
- MMDS

Features

Gain: 20 dB

Saturated Power: +30 dBm

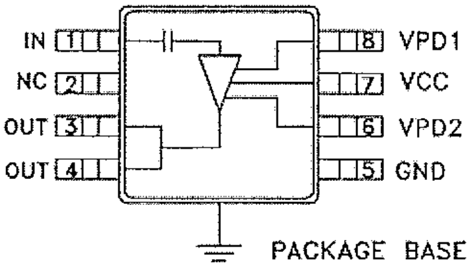
32% PAE

Supply Voltage: +2.75V to +5V

Power Down Capability

Low External Part Count

Functional Diagram



General Description

The HMC414MS8G & HMC414MS8GE are high efficiency GaAs InGaP Heterojunction Bipolar Transistor (HBT) MMIC Power amplifiers which operate between 2.2 and 2.8 GHz. The amplifier is packaged in a low cost, surface mount 8 leaded package with an exposed base for improved RF and thermal performance. With a minimum of external components, the amplifier provides 20 dB of gain, +30 dBm of saturated power at 32% PAE from a +5V supply voltage. The amplifier can also operate with a 3.6V supply. Vpd can be used for full power down or RF output power/ current control.

Electrical Specifications, $T_A = +25°$ C, As a Function of Vs, Vpd = 3.6V

Parameter		Vs = 3.6V			Vs = 5V			
		Min.	Typ.	Max.	Min.	Typ.	Max.	Units
Frequency Range			2.2 - 2.8			2.2 - 2.8		GHz
Gain		17	20	25	17	20	25	dB
Gain Variation Over Temperature			0.03	0.04		0.03	0.04	dB/ °C
Input Return Loss			8			8		dB
Output Return Loss			9			9		dB
Output Power for 1 dB Compression (P1dB)		21	25		23	27		dBm
Saturated Output Power (Psat)			27			30		dBm
Output Third Order Intercept (IP3)		30	35		35	39		dBm
Noise Figure			6.5			7.0		dB
Supply Current (Icq)	Vpd = 0V / 3.6V		0.002 / 240			0.002 / 300		mA
Control Current (Ipd)	Vpd = 3.6V		7			7		mA
Switching Speed	tON, tOFF		45			45		ns

...20/-

FILTER

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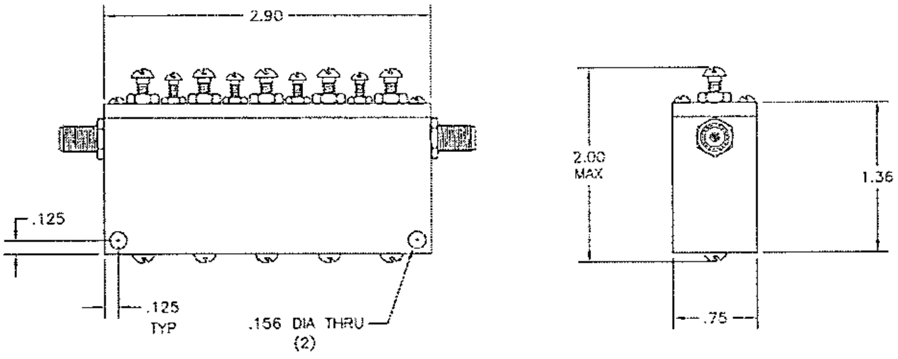

SPECIFICATIONS

CENTER FREQUENCY (Fo):	2500 MHz
INSERTION LOSS AT Fo:	2 dB TYP
3 dB RELATIVE BANDWIDTH:	44 MHz MIN, 60 MHz MAX
REJECTION:	60 dB TYP @ 2400 MHz
	30 dB TYP @ 2450 MHz
	30 dB TYP @ 2550 MHz
IMPEDANCE:	50 OHMS
CONNECTORS:	SMA FEMALE

UNLESS SPECIFIED
ALL TOLERANCES ±.025

ENVELOPE DRAWING

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