

ALM-32x20 series

2 Watt, 0.7GHz to 3.9GHz Base Transceiver Station Driver Amplifier Design
Using Avago Technologies ALM-32x20 series



Application Note 5402

Introduction

ALM-32x20 is a high linearity, 2 Watt driver amplifier series from Avago Technologies which consist of ALM-32120, ALM-32220 and ALM-32320. The ALM-32x20 series is designed to operate from 0.7GHz to 3.9GHz as shown in Table 1. With excellent OIP3, OP1dB and PAE at P1dB point performance; this amplifier series are well suited is well suited for WiMax, WLAN, GSM and 700MHz AWS BTS driver amplifier application. Figure 1 shows the target application of the ALM-32x20 series amplifier.

A modern digital wireless communication requires amplifier with superior linearity performance in order to support complex modulation schemes such as 64QAM,

OFDM & GMSK within a limited spectral bandwidth and at high data rates. These modulated signals tend to have high peak-to-mean power ratios and require highly linear amplifier.

This excellent performance is achievable through Avago Technologies' proprietary 0.25um GaAs Enhancement mode pHEMT (E-pHEMT) process^[2]. The enhancement mode technology provides superior performance in-term of low-noise and high linearity while allowing a direct DC grounding at the source pin with a single polarity power supply that is easily designed and built.

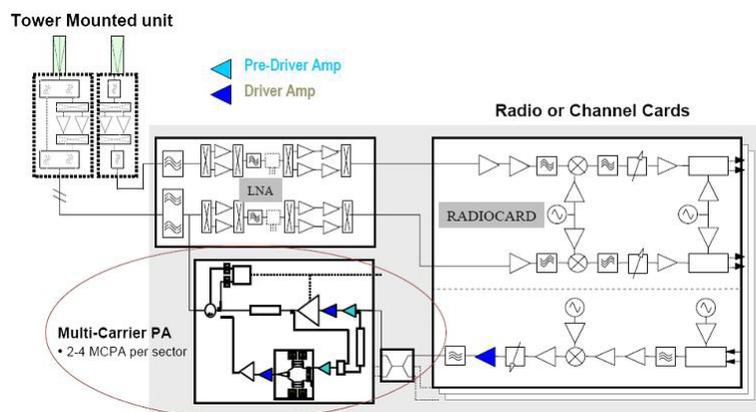


Figure 1. Application Examples for ALM-32x20 Driver Amplifier Series

Table 1. Avago Technologies Driver Amplifier Series

Output Power	Operating Frequency		
	0.7GHz to 1GHz	1.7GHz to 2.5GHz	3.3GHz to 3.9GHz
0.5W	MGA-30116	MGA-30216	MGA-30316
1W	ALM-31122	ALM-31222	ALM-31322
2W	ALM-32120	ALM-32220	ALM-32320

With all matching components are fully integrated within the ALM-32x20 module and the 50Ω RF input and output pins are internally AC-Coupled, this device is easy to use since the only external components need are DC bypass capacitors. This significantly reduces the bill of material and ultimately the total manufacturing cost. The device is internally biased for class A operation and with temperature compensated circuitry. The ALM-32x20 series is housed in a miniature 7.0 x 10.0 x 1.1 mm³ 22-lead multiple-chips-on-board (MCOB) package where the land pattern and footprint of the module are available from the ALM-32x20 datasheet^[5].

ALM-32x20 amplifier series is designed with a current and linearity adjustment features. The quiescent current, Idq is adjustable by varying the Vctrl. This allow the device to

be operated at either class A or AB. Indirectly, the features provide a degree of freedom for users to customize the PA's linearity and efficiency parameters to suit a different level of system requirement. The advantage of the linearity adjustment is by its ability to operate independently of other critical parameters (e.g. gain & output power).

Spectrum Allocation

With the complexity of the EM spectrum, perhaps it is useful to review the frequency allocation within the ALM-32x20 operating band as shown in Table 2. The uplink is defined as transmission from Mobile Station (MS) to Base Station (BTS), and the downlink is defined as transmission from the Base Station to Mobile Station.

Table 2. 0.7GHz to 3.8GHz Frequency Allocation

	Uplink (Reverse)	Downlink (Forward)
AMPS 800	824-849	869-894
CDMA 800	824-849	869-894
CDMA 800 (Japan)	887-924	832-869
CDMA (S.Korea)	1740-1770	1840-1870
CDMA (China)	2300-2400	
W-CDMA	1920-1980	2110-2170
TDMA 800	824-849	869-894
TDMA 1800	1710-1785	1805-1880
iDEN	806-821	851-866
GSM 850	824-849	869-894
GSM 900 (P-GSM)	890-915	935-960
GSM 900 (E-GSM)	880-915	925-960
GSM 900 (R-GSM)	876-880	921-925
DCS/GSM 1800	1710-1785	1805-1880
PCS/GSM 1900	1850-1910	1930-1990

Lower 700MHz	Uplink (Reverse)	Downlink (Forward)
Block A	698-704	728-734
Block B	704-710	734-740
Block C	710-716	740-746
Block D	716-722	
Block E	722-728	
Upper 700MHz	Uplink (Reverse)	Downlink (Forward)
Block A	757-758	787-788
Block B	775-776	805-806
Block C	746-757	776-787
Block D	758-763	788-793
WLAN (802.11b/g/n)	2405-2485	
WiBro I	2305-2320	
WiBro II	2345-2360	
WiMax	3300-3800	

Demonstration Board Design

A common demoboard is used to demonstrate the ALM-32x20 performance for the three frequency bands. Figure 2 and 3 are the actual ALM-32x20 top and bottom views of the demoboard image. The ALM-32x20 demoboard design provides plenty of plated-through via holes for good thermal and RF grounding. Coplanar Waveguides with Ground plane (CPWG) with characteristic impedance (Z_0) of 50 ohm are used as the transmission lines on the boards.

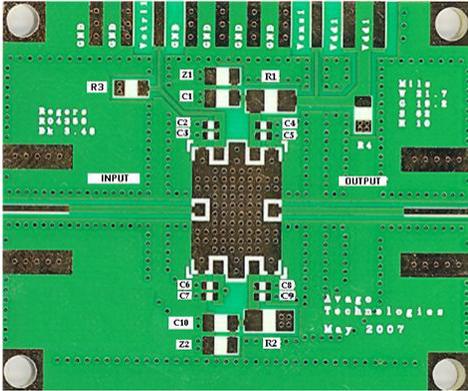


Figure 2. Top Layer of the ALM-32X20 Demoboard

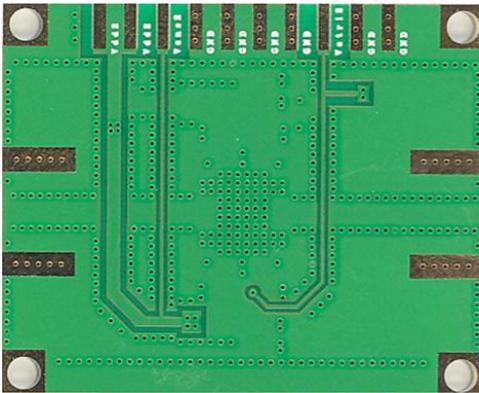


Figure 3. Bottom Layer of the ALM-32X20 Demoboard

Demoboard layout routing

Figure 2 and 3 are the actual ALM-32x20 demoboard image captured from the top and bottom view. As shown in Figure 2, the module is placed on the top layer of the demoboard. Both Vdd and sense lines are connected together. Vdd1, which can be seen from the top layer, is used to power up the upper FET while Vdd2 on the bottom layer is used to power up the lower FET (Please refer to Figure 4). Both FETs have to be turned on for the normal amplifier operation. By using a 0Ω jumper resistor (R4), both Vdd1 and Vdd2 are connected together and can power up simultaneously. As for the Control Voltage (Vctrl), users just have to provide a 5V of Vcontrol to either Vctrl1 or Vctrl2, since both are internally tied up together. In real application, users can simplify the layout by merging both Vdd lines together and the same goes for the Vcontrol where designers just have to use a single 5V control voltage.

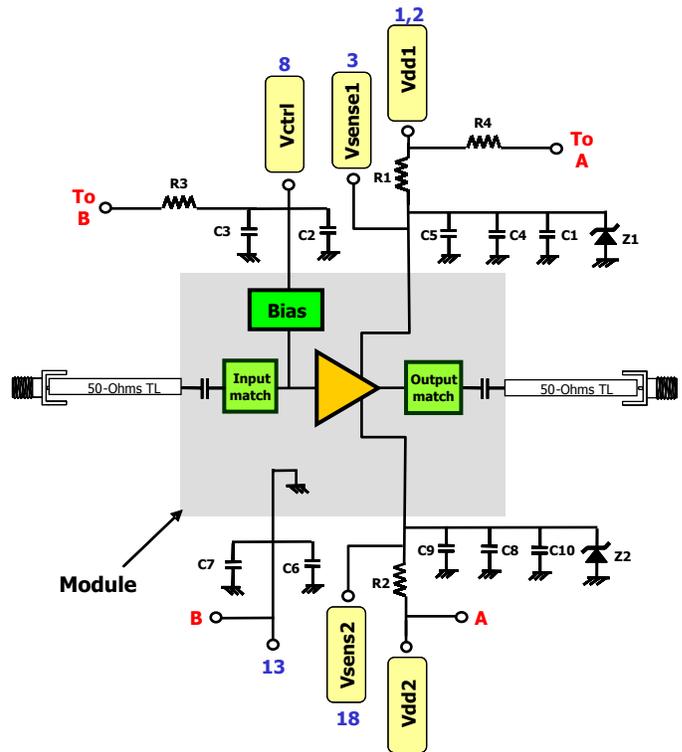


Figure 4. ALM-32x20 Demoboard Schematic Diagram

The internal module consists of a dual FET amplifier, a gate bias controller input and output matching network. The amplifier utilizes the internal bias FET that helps to provide the current adjustment feature. The bias circuit allows the Quiescent Current, I_{dq} to be adjustable by controlling the Control Voltage, V_{ctrl} . Dual FET design or split FET offers better compensation against the temperature variation and at the same time having a better thermal distribution performance. Designed for high linearity application, the stability criterion is assured with the integrated stabilization resistor. As a result, users just have to add a series of capacitors for DC bypassing purposes and Z1 and Z2 are the two optional Zener diodes to enhance the over voltage protection capability.

PCB Material and Layer Stack Design

ALM-32x20 demoboard is three-layer board with 0.5 oz of copper (0.7mils) for each layer. Every copper layer is separated with a dielectric material and the board cross sectional diagram is shown in Figure 5. First dielectric material is 10 mils Rogers, RO4350 with Dk of 3.48^[1]. The second dielectric material is for mechanical strength and stability which utilized FR4 with Dk of 4.2.

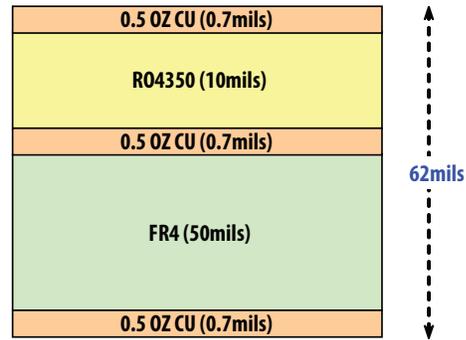


Figure 5. Demoboard Cross Sectional Diagram

Table 3. Is the ALM-32x20 demo board's Bill of Materials respectively.

Reference Designator	Size	Value	Description	Function
C1, C10	0805	2.2uF	Chip Capacitor	DC Bypass
C2, C4, C9	0402	0.1uF	Chip Capacitor	DC Bypass
C3, C5, C8	0402	10nF	Chip Capacitor	DC Bypass
C6, C7	0402	NU	Chip Capacitor	DC Bypass
R1, R2	1206	0W	Chip Resistor	Jumper Resistor
R3	0402	NU	Chip Resistor	Jumper Resistor
R4	0805	0W	Chip Resistor	Jumper Resistor
Z1, Z2	0805	5.6V	Zener Diode (Optional)	Overvoltage Protection
J1, J2	-	Johnson 142-0701-851	Edge Mount SMA Connector - EF Johnson (142-0701-851)	RF input & Output
PCB			10 mils Rogers, R04350 with FR4 backing	

50Ω Transmission Line Design

The dimension of the CPWG lines can easily be determined using AppCAD, free and handy RF simulation software from Avago (<http://www.avagotech.com>). The overall thickness of the board is 62 ± 0.002 mils, which allows SMA connectors from EF Johnson (142-0701-851) to be slipped at the both board edges. With the 20mils diameter of the center pin; this requires the demoboard transmission line width to be wider to accommodate the center

pin. In this demoboard, 22mils was chosen and the Z_0 at 2GHz is 51.6Ω . There is some degree of freedom for the designer to determine the transmission line width as long as the resultant Z_0 close to 50Ω and able to squeeze in for the design with a limited space. Table 4 shows the CPWG parameters for various frequency bands obtained using AppCAD software.

Table 4. CPWG parameters obtained using AppCAD

Parameters	Frequency Band					Unit
	700	900	1900	2100	2450	MHz
ϵ_r	3.48	3.48	3.48	3.48	3.48	-
L	600	600	600	600	600	mils
H	10	10	10	10	10	mils
T	0.7	0.7	0.7	0.7	0.7	mils
W	22	22	22	22	22	mils
G	19	19	19	19	19	mils
Elec. Length	0.058	0.074	0.157	0.174	0.203	λ
Z_0	51.6	51.6	51.6	51.6	51.6	Ω

The snapshot of the CPWG design using AppCAD for 1960MHz is illustrated in Figure 6.

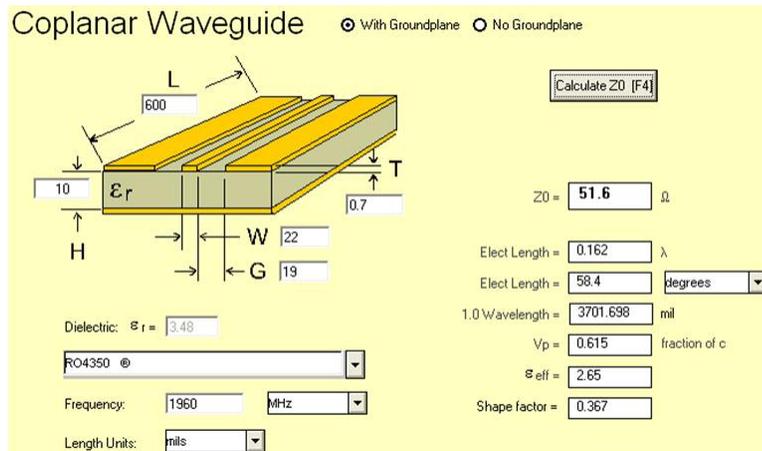


Figure 6. CPWG Design with AppCAD

Demoboard Performances

The following discussion will reveal the performance of the ALM-32x20 series amplifier across the regular 900MHz, 1900MHz and 2100MHz BTS frequency bands. Additionally, this application notes will extend the discussion across the latest standard such as 700MHz (AWS), 2450MHz (WLAN) and 3500MHz (WiMax).

Performance across the 700MHz band using ALM-32120

With V_{dd} of 5V and I_{dd} of 800mA, the device produces 15.2dB of gain and 49.7dBm of OIP3 and 34.0dBm of OP1dB across the band. Input and output return loss are both greater than 10 dB. As for the IP3 measurement, F_{Spacing} used was 10MHz and the P_{in} was -5dBm. Table 5 and series of figures below shows the performance summary of the demoboard across the band.

Table 5. Performance Summary across the 700MHz Band

Parameters	700MHz	Unit
V _{dd}	5.00	V
V _{ctrl}	5.00	V
I _{dd}	800.00	mA
S ₁₁	-18.70	dB
S ₂₁	15.20	dB
S ₁₂	-22.50	dB
S ₂₂	-11.20	dB
OIP3	49.67	dBm
OP1dB	33.95	dBm
PAE @ P1dB	47.00	%
K	> 1	-

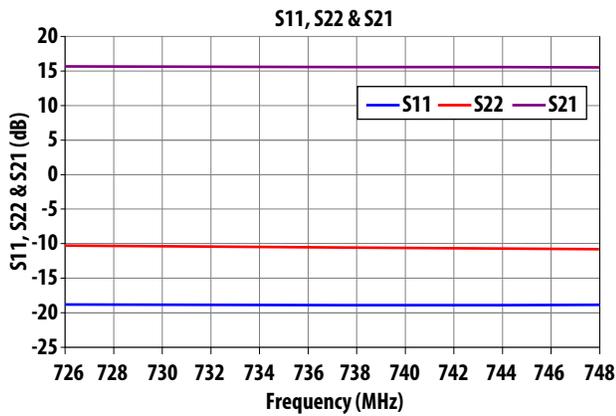


Figure 7. S11, S22 and S21 performance across the 700MHz band

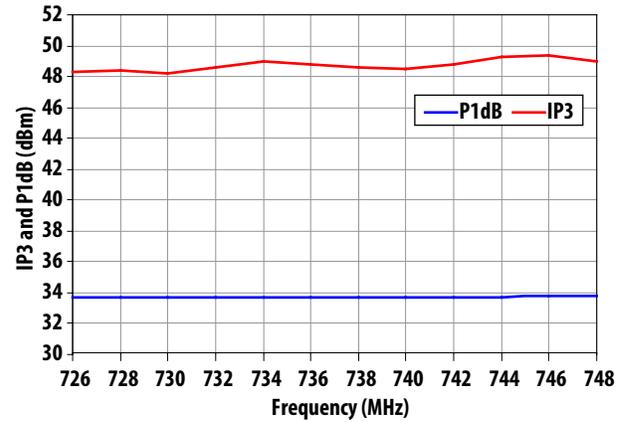


Figure 8. P1dB and IP3 across the 700MHz band

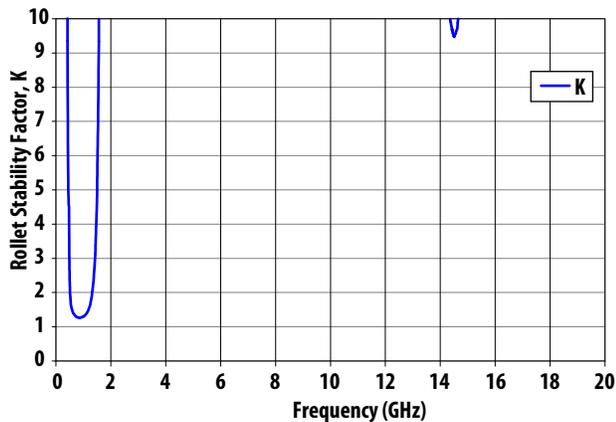


Figure 9. Rollet Stability Factor, K

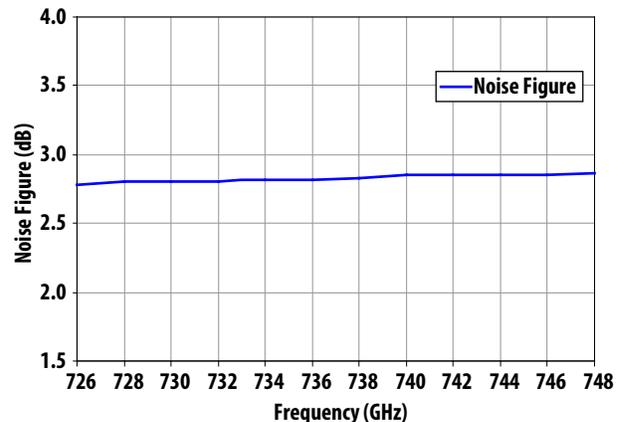


Figure 10. Noise Figure across the 700MHz band

Performances across the 900MHz band using ALM-32120

Transmitter designers typically looking for a driver amplifier stages in a BTS application with 1-dB gain compression levels between 20 to 33 dBm [3]. As for the ALM-32120, the OP1dB of 34.1dBm, OIP3 of 51.8dBm and the spectral re-growth behavior are within the limits as shown in Figure 15, this would make the devices well suited for the GSM900 and CDMA BTS application. Table 6 shows the performance summary of the demoboard across the 900MHz band.

Table 6. Performance Summary across the GSM900 Band

Parameters	900MHz	Unit
Vdd	5.00	V
Vctrl	5.00	V
Idd	800.00	mA
S11	-28.00	dB
S21	13.70	dB
S12	-21.00	dB
S22	-10.60	dB
OIP3	51.76	dBm
OP1dB	34.11	dBm
PAE @ P1dB	47.00	%
K	> 1	-

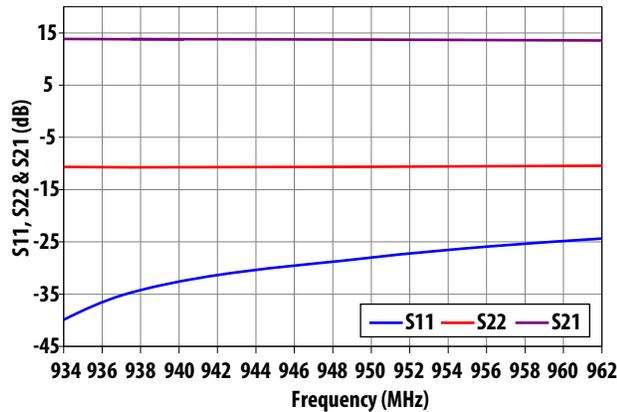


Figure 11. S11, S22 and S21 performance across the GSM900 band

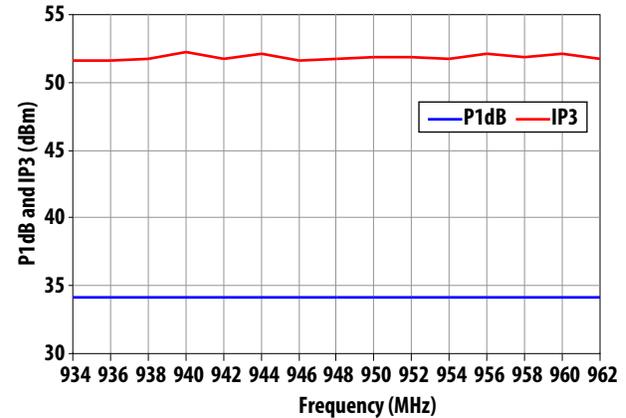


Figure 12. P1dB and IP3 across the GSM900 band

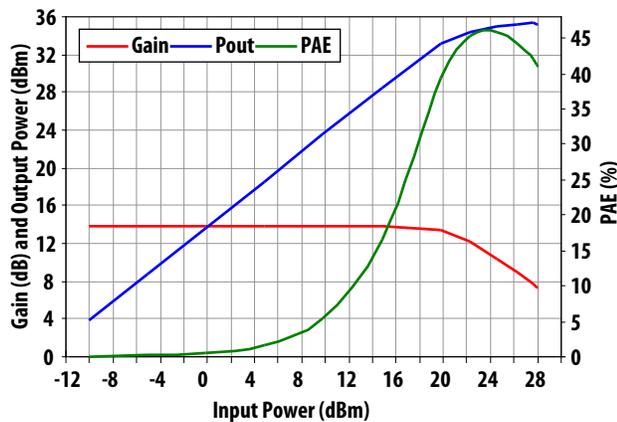


Figure 13. PAE versus Input Power at 900MHz

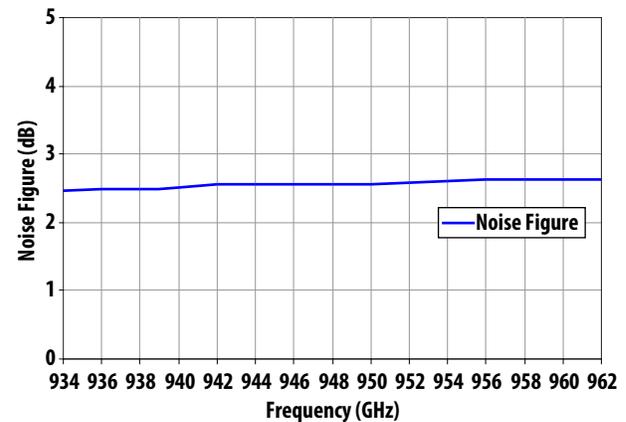


Figure 14. Noise Figure across the GSM900 band

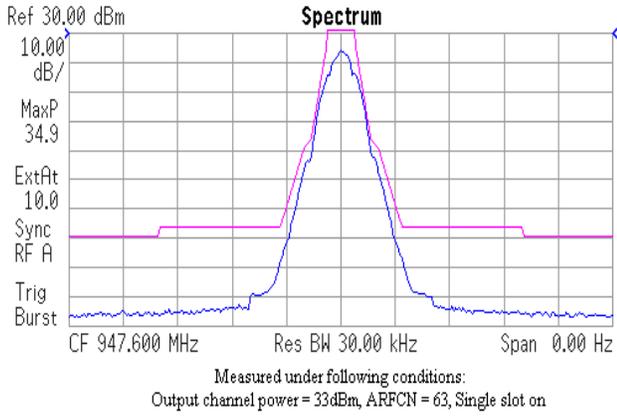


Figure 15. GSM900 spectral mask

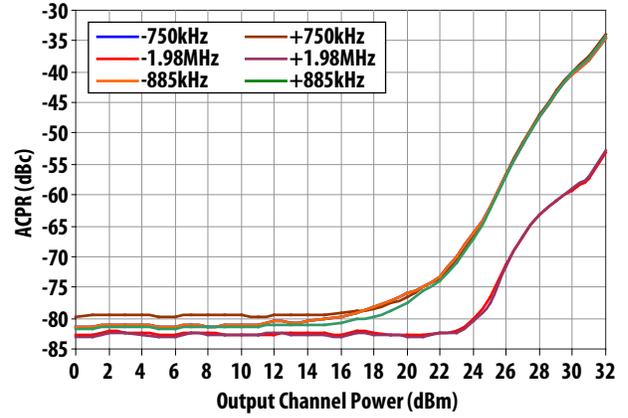


Figure 16. CDMA2000 ACPR performance at 881MHz

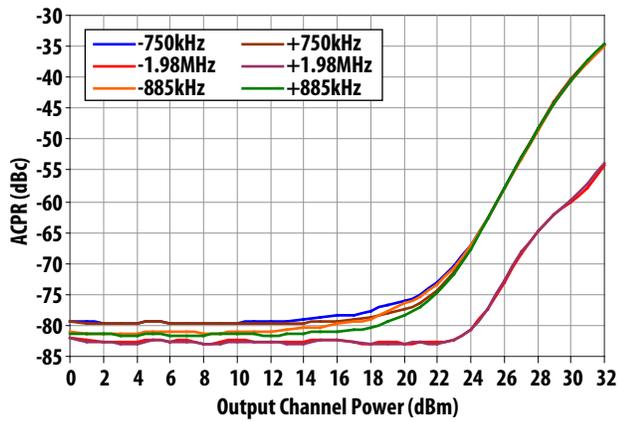


Figure 17. CDMA2000 ACPR performance at 940MHz

Performance across the 1900MHz band using ALM-32220

The ALM-32x20 has been specifically optimized for BTS driver applications where high linearity is required. With the bias condition of 5V and 830mA typical current consumption, the device able to produce 14.5dB of gain and 49.1 dBm of OIP3 and 34.0dBm of OP1dB respectively across the 1900MHz band. This make the ALM-32x20 well suited for 1900MHz wireless cellular BTS application such as PCS and CDMA. The demoboard performance summary across the 1900MHz band is shown in table 7.

Table 7. Performance Summary across the PCS Band

Parameters	1900MHz (PCS)	Unit
Vdd	5.0	V
Vctrl	5.0	V
Idd	830.0	mA
S11	-10.0	dB
S21	14.5	dB
S12	-31.0	dB
S22	-9.5	dB
OIP3	49.1	dBm
OP1dB	34.0	dBm
PAE @ P1dB	47.0	%
K	>1	-

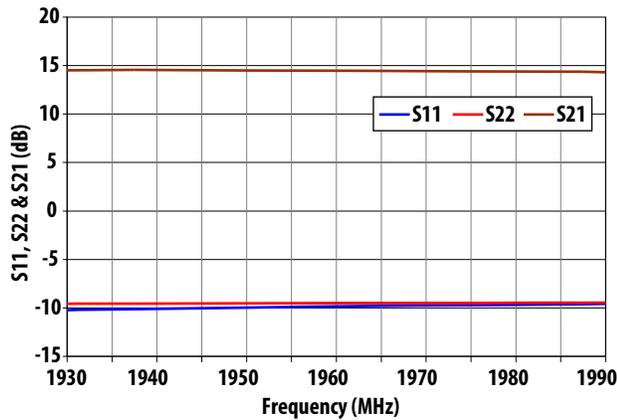


Figure 18. S11, S22 and S21 performance across the PCS band

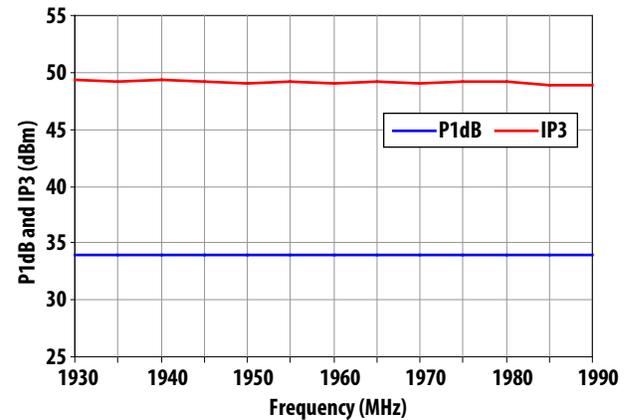


Figure 19. P1dB and IP3 across the PCS band

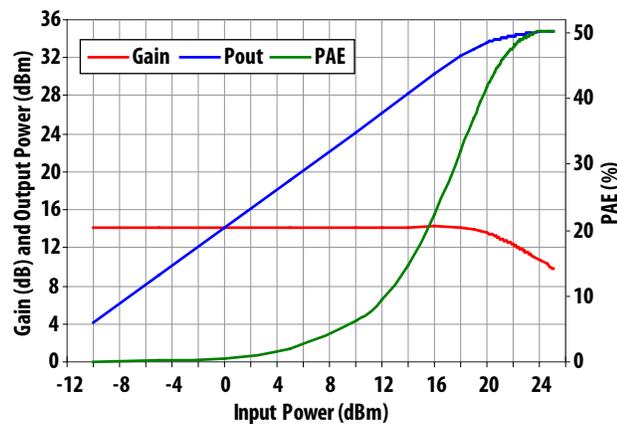


Figure 20. PAE versus Input Power at 2GHz

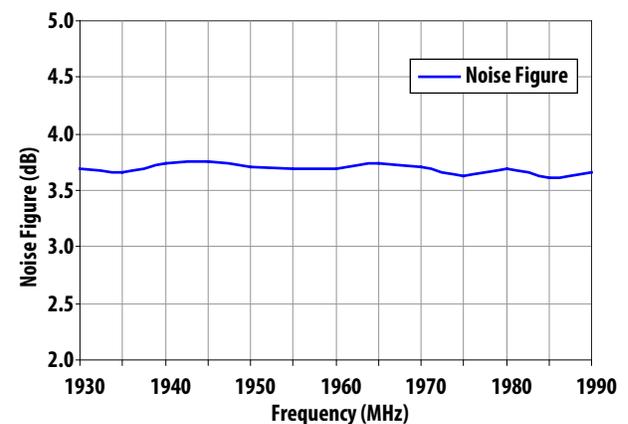


Figure 21. Noise Figure across the PCS band

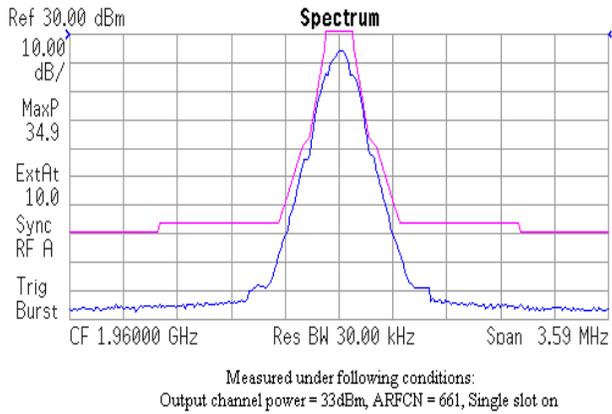


Figure 22. PCS band spectral mask

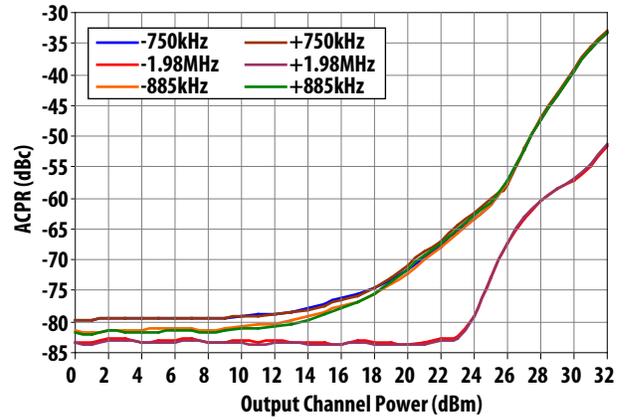


Figure 23. CDMA2000 ACPR performance at 1.88GHz

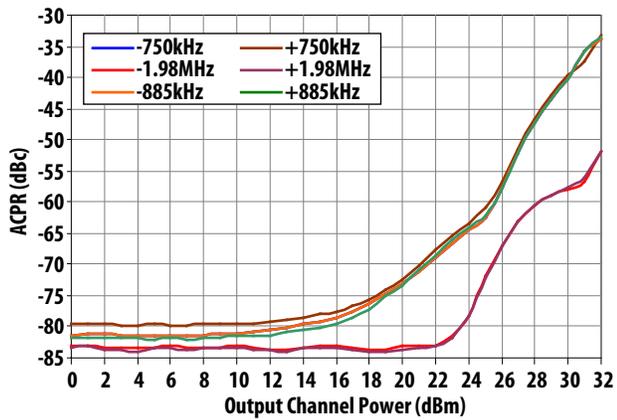


Figure 24. CDMA2000 ACPR performance at 1.96GHz

Performance across the 2.1 GHz W-CDMA band using ALM-32220

As for the WCDMA band, the ALM-32x20 series delivers an exceptional performance with the same biasing condition. The ALM-32x20 is capable of 14.0dB of gain, 48.8dBm of OIP3 and 33.9dBm of OP1dB across the band. Good linearity and more than 10dB of return loss performance; the ALM-32x20 is well suit for the WCDMA BTS application. Performance summary of the demoboard across band can be found in Table 8.

Table 8. Performance Summary across the W-CDMA band

Parameters	2100MHz (W-CDMA)	Unit
Vdd	5.0	V
Vctrl	5.0	V
Idd	830.0	mA
S11	-9.8	dB
S21	14.0	dB
S12	-30.9	dB
S22	-10.0	dB
OIP3	48.8	dBm
OP1dB	33.9	dBm
PAE @ P1dB	47.0	%
K	>1	-

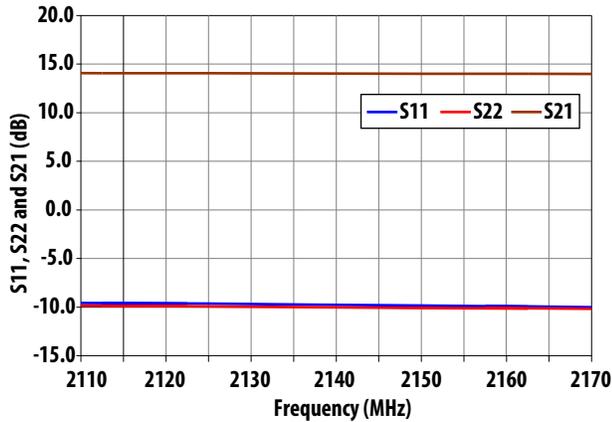


Figure 25. S11, S22 and S21 performance across the W-CDMA band

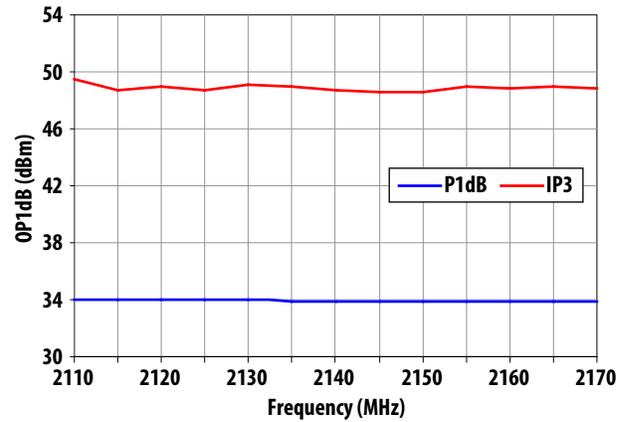


Figure 26. P1dB and IP3 across the W-CDMA band

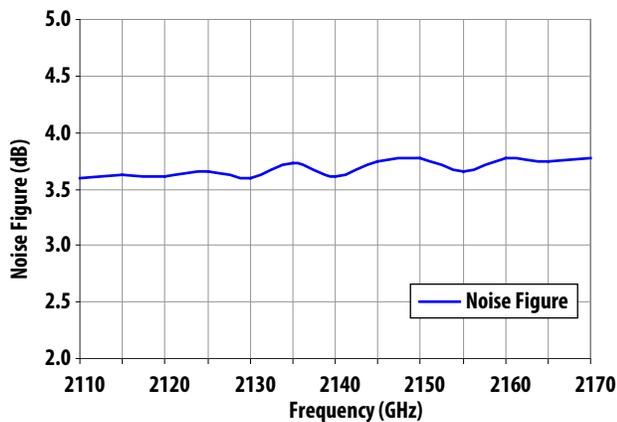


Figure 27. Noise Figure across the W-CDMA band

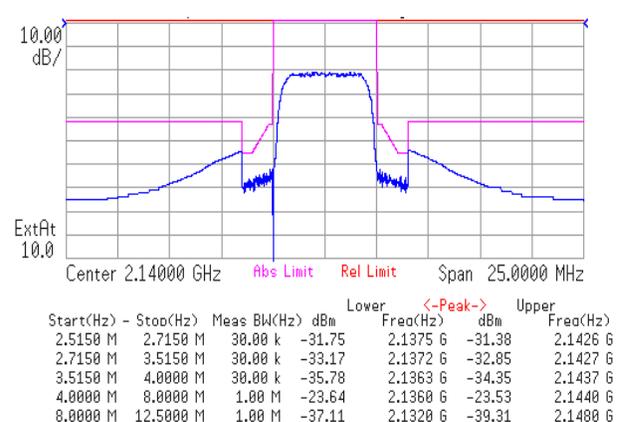


Figure 28. Spectrum mask measurement for WCDMA band

Performance across the 2.45GHz band (WLAN – 802.11b/g/n) using ALM-32220

The ALM-32220 delivers excellent performance with Vdd of 5V and Idd of 800mA across the 2.45GHz WLAN band. As shown in table 8, the device able to produce 13.5dB of gain, 48.7dBm of OIP3 and 33.9dBm of OP1dB respectively across band. With good linearity and return loss performance with both are greater than 10dB, the ALM-32x20 series is well suit for the WLAN BTS application. As typical linearity measure parameters for WLAN, the 802.11g spectral mask is shown in Figure 27 while the EVM data can found from the datasheet^[5].

Table 9. Performance Summary across the 2.45GHz band

Parameters	2.45GHz (802.11b/g/n)	Unit
Vdd	5.0	V
Vctrl	5.0	V
Idd	830.0	mA
S11	-17.1	dB
S21	13.5	dB
S12	-30.6	dB
S22	-11.7	dB
OIP3	48.7	dBm
OP1dB	33.9	dBm
PAE @ P1dB	47.0	%
K	>1	-

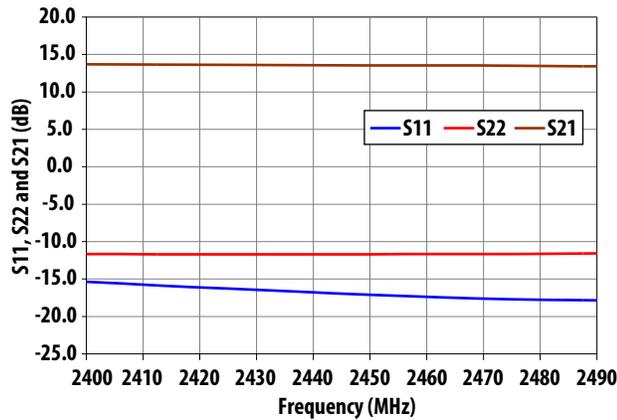


Figure 29. S11, S22 and S21 performance across the 2.45GHz band

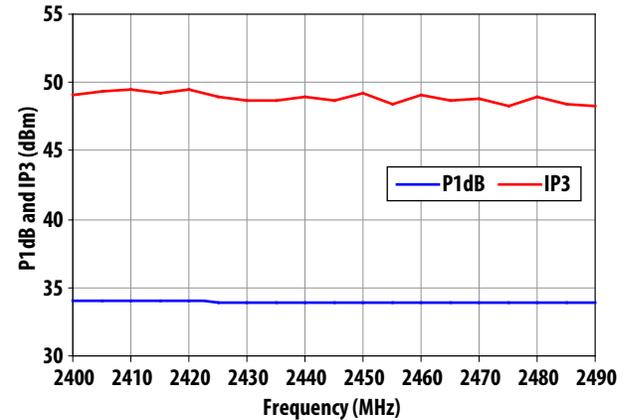


Figure 30. P1dB and IP3 across the 2.45GHz band

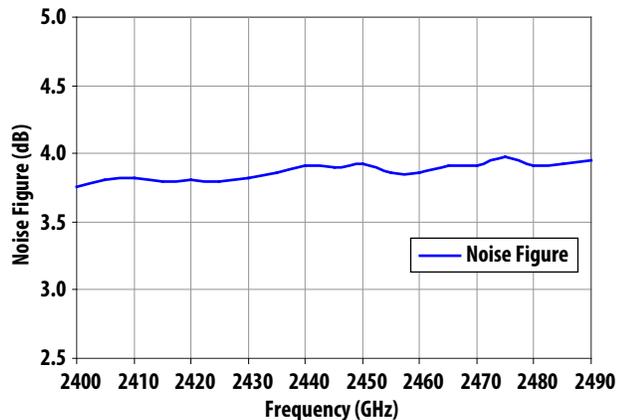


Figure 31. Noise Figure across the 2.45GHz band

Performance across the 3.5GHz band using ALM-32320

ALM-32x20 delivers excellent performance within the 3.5GHz WiMAX band. With a V_{dd} of 5V and a typical I_{dd} of 830mA, ALM-32320 is able to produce 12.6dB of gain at 3.5GHz. With 1-dB gain compression levels of 34.5dBm, the device is a good candidate for WiMAX BTS driver amplifier application. As for the IP₃ measurement, the two tone spacing used was 10MHz and the input power per tone was -5dBm. Table 3 shows the performance summary of the demoboard across the band.

OFDMA modulation schemes require high modulation accuracy due to a number of bits of information coded onto each carrier signal. A WiMAX transmitter operates with some linearity back-off. It is well understood that operating a PA at a power much lower than its maximum capability reduces the efficiency of conversion of DC power to RF power. As shown in Figure 35, the PAE plot will help WiMAX transmitter designers to compromise between linearity and efficiency requirements.

Table 10. Performance Summary across the 3.5GHz band

Parameters	3.5GHz (WiMax)	Unit
V _{dd}	5.00	V
V _{ctrl}	5.00	V
I _{dd}	820.00	mA
S ₁₁	-10.30	dB
S ₂₁	12.60	dB
S ₁₂	-26.70	dB
S ₂₂	-14.00	dB
OIP ₃	49.25	dBm
OP1dB	34.45	dBm
PAE @ P1dB	46.00	%

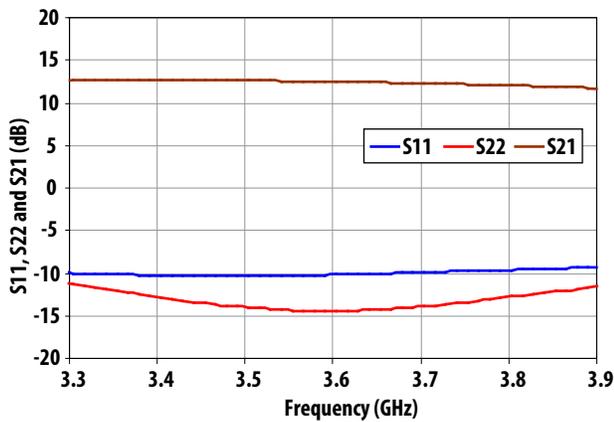


Figure 32. S11, S22 and S21 performance across the 3.5GHz band

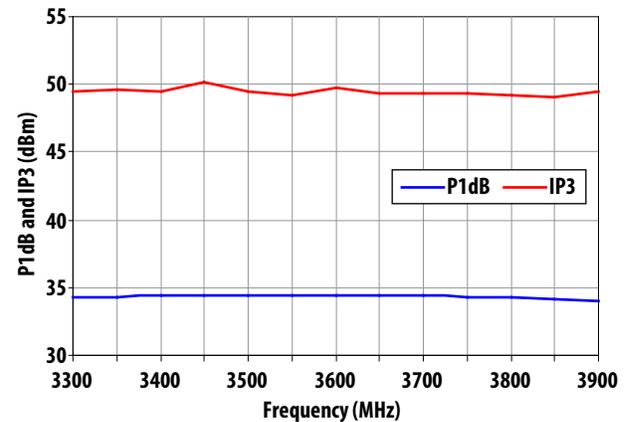


Figure 33. P1dB and IP3 across the 3.5GHz band

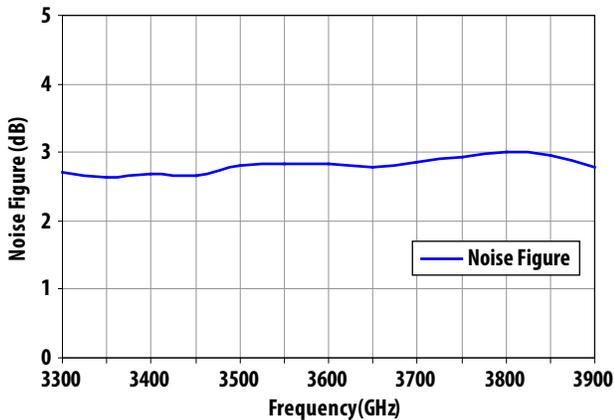


Figure 34. Noise Figure across the 3.5GHz band

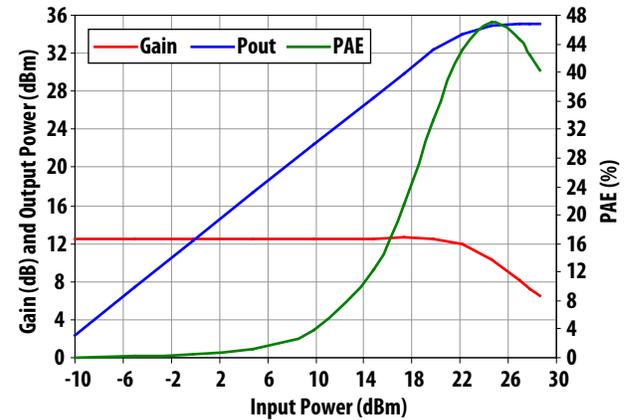


Figure 35. PAE versus Input Power at 3.5GHz

Thermal Management

Working with high dissipation device like ALM-32x20 amplifier series, thermal management should be taken into considerations. This is to ensure for a given ambient temperature, the transistor's junction temperature does not exceed the maximum rating, $T_{j, \max}$ on the data sheet. As for the ALM-32x20 series, the $T_{j, \max}$ are 150°C and a channel to case thermal resistance (θ_{jc}) of 12°C/W (ALM-32120), 14°C/W (ALM-32220) and 15°C/W (ALM-32320).

A heat sink helps keeping a device at a junction tempera-

ture below its specified recommended operating temperature. With a heat sink, heat from a device flows from the die junction to the case, then from the case to the heat sink, and lastly from the heat sink to ambient air. Since the goal is to reduce overall thermal resistance, designers can determine whether a device requires a heat sink for thermal management by calculating thermal resistance using thermal circuit models and equations. These thermal circuit models are similar to resistor circuits using Ohm's law. Figure 28 shows a thermal circuit model for a device with and without a heat sink, reflecting the thermal transfer path via the top of the package.

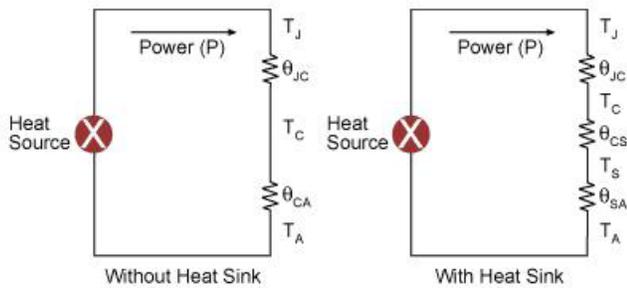


Figure 36. Thermal Circuit Parameters

Table 11. Thermal Circuit Parameters Description

Parameter	Name	Units	Description
θ_{JA}	Junction-to-ambient thermal resistance	°C/W	Specified in the data sheet
θ_{JC}	Junction-to-case thermal resistance	°C/W	Specified in the data sheet
θ_{CS}	Case-to-heat sink thermal resistance	°C/W	Thermal interface material thermal resistance
θ_{CA}	Case-to-ambient thermal resistance	°C/W	Specified by the heat sink manufacturer
θ_{SA}	Heat-sink-to-ambient thermal resistance	°C/W	
T_J	Junction temperature	°C	"The junction temperature as specified under recommended operating conditions for the device"
$T_{j, \max}$	Maximum junction temperature	°C	The maximum junction temperature as specified under recommended operating conditions for the device
T_A	Ambient temperature	°C	Temperature of the local ambient air near the component
T_S	Heat sink temperature	°C	
T_C	Device case temperature	°C	
P	Power	W	The total power from the operating device. Use the estimated value for selecting a heat sink

Determine the heat sink type for ALM-32x20 demoboard (i.e. ALM-32220)

- Using the heat-sink-to-ambient equation (and a θ_{CS} of $0.1^{\circ}\text{C}/\text{W}$ for typical thermal interface material), calculate the maximum required heat-sink-to-ambient thermal resistance.

$$\theta_{SA} = (T_{j,max} - T_A) / P - \theta_{JC} - \theta_{CS}$$

$$\theta_{SA} = (150 - 85) / 4 - 14 - 0.1$$

$$\theta_{SA} = 2.15^{\circ}\text{C}/\text{W}$$

Where

P = Power Dissipated (5V, 800mA typical)

- Select a heat sink that meets the θ_{SA} requirement of $2.15^{\circ}\text{C}/\text{W}$ or lower. The lower the heat sink thermal resistance, the device will have a lower junction temperature. The heat sink must also physically fit onto the device.

Using a heat sink with $\theta_{SA} = 2.15^{\circ}\text{C}/\text{W}$, and re-verifying for $T_{j,max}$:

$$T_J = T_A + P \cdot \theta_{JA}$$

$$T_J = 85 + 4 * (\theta_{JC} + \theta_{CS} + \theta_{SA})$$

$$T_J = 85 + 4 * (14 + 0.1 + 2.15)$$

$$T_J = 150^{\circ}\text{C}$$

Using a heat sink with $\theta_{SA} < 2.15^{\circ}\text{C}/\text{W}$: i.e. HT170006 (Heat Technology Inc [4]) with $\theta_{SA} = 1.42 @ 400 \text{ LFM}$

$$T_J = T_A + P \cdot \theta_{JA}$$

$$T_J = 85 + 4 * (\theta_{JC} + \theta_{CS} + \theta_{SA})$$

$$T_J = 85 + 4 * (14 + 0.1 + 1.42)$$

$$T_J = 147.08^{\circ}\text{C}$$

Using a heat sink with $\theta_{SA} > 2.15^{\circ}\text{C}/\text{W}$: i.e. HT170005 (Heat Technology Inc) with $\theta_{SA} = 2.91 @ 400 \text{ LFM}$

$$T_J = T_A + P \cdot \theta_{JA}$$

$$T_J = 85 + 4 * (\theta_{JC} + \theta_{CS} + \theta_{SA})$$

$$T_J = 85 + 4 * (14 + 0.1 + 2.91)$$

$$T_J = 153.04^{\circ}\text{C}$$

Table 11 shows θ_{SA} for the ALM-32x20 series based on the typical power consumption performance as a threshold point for the users to choose the suitable heat sink.

Table 12. θ_{SA} for ALM-32x20 Series

	ALM-32120	ALM-32220	ALM-32320	Unit
P	4	4	4	W
$T_{j,max}$	150	150	150	$^{\circ}\text{C}$
T_A	85	85	85	$^{\circ}\text{C}$
θ_{JC}	12	14	15	$^{\circ}\text{C}/\text{W}$
θ_{CS}	0.1	0.1	0.1	$^{\circ}\text{C}/\text{W}$
θ_{SA}	4.15	2.15	1.15	$^{\circ}\text{C}/\text{W}$

Summary

A high linearity driver amplifier for BTS application has been presented and designed using Avago Technologies ALM-32x20 amplifier series. This includes RF, DC and good thermal management practices for reliable lifetime operation.

References

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- [5] http://www.avagotech.com/products/parametric/rficsdiscretes/rfics/gaas_amplifiers%2C_switches/

For product information and a complete list of distributors, please go to our web site: www.avagotech.com

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