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# Using the MSA-0520 and MSA-1023 Medium-Power MODAMP Silicon MMIC Amplifiers

## Application Note S007

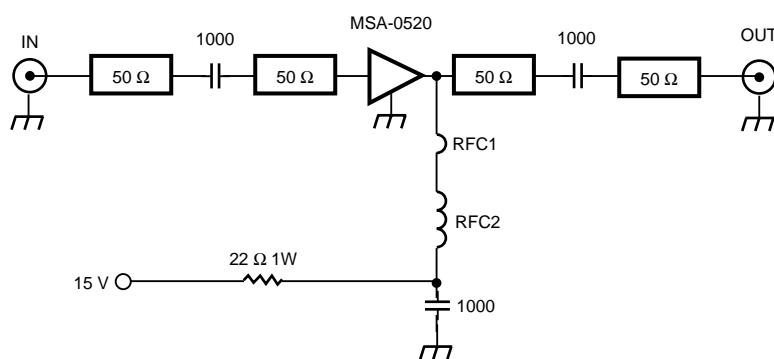
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### Introduction

This application note describes the use of medium-power MODAMP silicon MMIC amplifiers at frequencies up to 3 GHz. Single-ended, in-phase parallel and push-pull designs are discussed using models MSA-0520 and MSA-1023. Both MMICs used in the amplifiers are broadband, internally matched, unconditionally stable gain blocks with rated power outputs at 1 GHz of +23 dBm for the MSA-0520 and +27 dBm for the MSA-1023. Output power levels of up to +30 dBm at 500 MHz are possible with a single MSA-1023.

The MSA-0520 is designed for 50 ohm input and output impedances while the MSA-1023 is designed for 25 ohm impedances. The 25 ohm impedance allows the MSA-1023 to be used in a push-pull amplifier using very simple 1 to 1 baluns for matching the amplifier to 50 ohms over a broad frequency range.

Both MODAMP devices are designed to be run from current sources. The MSA-1023 requires 325 mA while the MSA-0520 requires 165 mA for maximum rated power. At room temperature, the device voltage will be



NOTES:  
RFC1 1 TURN 1/8" I.D. WOUND FROM LEAD OF RFC2  
RFC2 0.33  $\mu$ H MINIATURE MOLDED RFC  
ALL CAPACITORS ARE CHIPS IN pF  
LENGTH OF THE 50 OHM MICROSTRIP IS NOT CRITICAL

Figure 1. Single Stage MSA-0520

approximately 15 volts for the MSA-1023 and 11.5 volts for the MSA-0520. The MSA-1023 test circuits described in this note are driven from a 15 volt power supply. To help minimize current variation over temperature, a current source consisting of a resistor with a positive temperature coefficient in series with a 20 volt supply would be desirable. The MSA-0520 test circuits described in this note are driven by a 15 volt supply with appropriate series current limiting resistors.

## MSA-0520

The MSA-0520 is tested in the circuit shown in Figure 1. The 50 ohm microstriplines are 0.100 inch wide copper etched on 0.062 inch thick G-10 printed circuit material ( $\epsilon_r = 4.8$ ).

The amplifier is driven by a source of 15 volts through a 22 ohm resistor which drops the device voltage down to approximately 11.4 volts. Device current for all tests is 165 mA. The 22 ohm resistor also provides negative DC feedback which helps stabilize amplifier gain over temperature by varying device current.

Maintaining the inherent broad bandwidth of the MSA-0520 requires a broad-bandwidth bias decoupling network. The 1-turn RF choke used in the test circuit provides a high impedance to the higher frequencies while the 0.33  $\mu$ H choke offers a high impedance at VHF frequencies. RF chokes greater than 0.33  $\mu$ H will cause resonances to occur in the passband. A 1000 pF chip capacitor is used to bypass the cold end of RFC2 to ground.

As shown in Figure 2, amplifier gain varies from approximately 9 dB at 100 MHz to 8 dB at 1.0 GHz. At 2.0 GHz, the gain is still 6.5 dB and does not drop below 5 dB until the frequency is raised beyond 2.7 GHz. Input and output VSWR is less than 1.5:1 at 100 MHz and less than 2.2:1 at 2.0 GHz.

Power output performance is shown in Table 1. Power output at 1 dB gain compression varies from +27 dBm at 300 MHz to +23 dBm at 1.0 GHz. At 2.0 GHz the amplifier still delivers +19.4 dBm at 1 dB gain compression.

For operation principally at frequencies below 300 MHz, it is advisable to use a larger RFC (i.e. 1  $\mu$ H) to ensure that RF power output is not

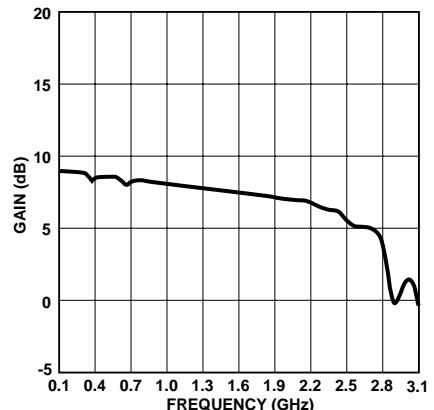


Figure 2. Single MSA-0520 Gain

**Table 1. Power Output Summary for Single MSA-0520**

Freq (GHz)	P <sub>Sat</sub> (+dBm)	P <sub>1dB</sub> (+dBm)	2nd (dBc)	3rd (dBc)	4th (dBc)	Harmonics at P <sub>1dB</sub>
0.3	28.0	27.0	-25	-14	-22	
0.5	27.0	26.4	-20	-16	$\geq 25$	
0.9	25.0	23.0	-20	-22	-34	
1.0	24.7	23.0	-20	-22	-35	
2.0	-	19.4	-	-	-	
2.3	22.3	17.5	-	-	-	

lost. When choosing a different RFC and bypass capacitor arrangement, be sure that inband resonances do not adversely affect amplifier operation.

With any broadband amplifier that covers over an octave bandwidth, there is concern with the amplitude of the second and higher-order harmonics. For the MSA-0520 amplifier, the second-order harmonics are less than -20 dBc when operating at the 1 dB gain compression point in the 300 MHz to 1.0 GHz frequency range. Higher order harmonic levels are summarized in Table 1.

Also shown in Table 1 is  $P_{sat}$  or maximum saturated power output. This level generally occurs at a power output level that is approximately 1 to 3 dB greater than the 1 dB gain compression power output. Of course, the gain of the device is severely reduced when driving the device to  $P_{sat}$ , i.e., approximately 3 dB gain compression, and the harmonic levels will have degraded significantly over those shown in Table 1.

As with any class-A amplifier, driving the amplifier to saturation will drive it out of its linear operating region, causing distortion and increasing harmonic output. A power MMIC driven to this level may be useful in applications such as power multipliers where nonlinearity is desirable to enhance harmonic output.

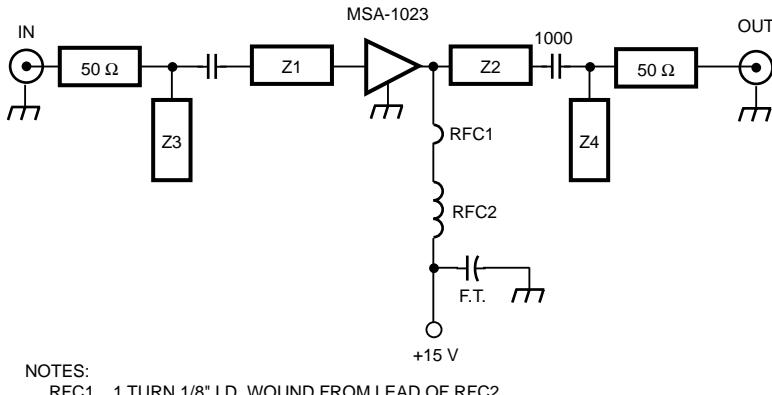
### MSA-1023

As previously discussed, the MSA-1023 is designed primarily for 25 ohm input and output loads. For applications that require moderate power, however, a single stage may be all that is required. For narrow bandwidths, quarter-wave transformers of characteristic impedance of  $Z_t$  will effectively match both the input and output to 50 ohms.

$$Z_t = \sqrt{50 \cdot 25} = 35 \text{ ohms}$$

For narrowband applications, i.e. up to 20% bandwidth, this approach works well. For broadband operation from 100 MHz to above 1.0 GHz, a different approach is necessary. With the help of the TUNE mode of Hewlett-Packard Touchstone™ it is found that a 25 ohm microstripline of 57.5 electrical degrees at 2.0 GHz produces greater than 7 dB of gain from 100 MHz to well above 1.0 GHz. In fact, the matching network actually enhances the high frequency response over that obtained with the device in a 25 ohm system with minimal deterioration in the lower frequency range.

The actual circuit is shown in Figure 3. The matching sections, Z1 and Z2, are simulated by microstriplines 0.25 inch wide by 0.65 inches in length. The dielectric is Duroid 5880, 0.031 inches thick,  $\epsilon_r = 2.2$ , manufactured by Rogers Corporation. Short sections of 50-ohm microstripline of 0.090 inches in width provide the transition from the matching sections to end-launch connectors. The open-circuited stubs, Z3 and Z4, located on the input and output 50 ohm lines, are used to boost the midband gain slightly – on the order of 0.5 to 1 dB. This



## NOTES:

RFC1 1 TURN 1/8" I.D. WOUND FROM LEAD OF RFC2  
 RFC2 0.33  $\mu$ H MINIATURE MOLDED RFC  
 F.T. 0.001  $\mu$ F, FEEDTHRU CAPACITOR  
 Z1, Z2 25 OHM MICROSTRIP, 0.25" WIDE BY 0.65" LONG  
 Z3, Z4 OPEN CIRCUITED. STUB, 0.1" WIDE BY 0.2" LONG -  
 ADJUST TO BRING GAIN UP AT 1.5 GHz  
 LENGTH OF THE 50 OHM MICROSTRIP IS NOT CRITICAL

**Figure 3. Single MSA-1023**

enhancement, originally found empirically, is later proven with computer simulation. The effect of the stubs is to better match the amplifier impedance to 50 ohms in the midband frequency range.

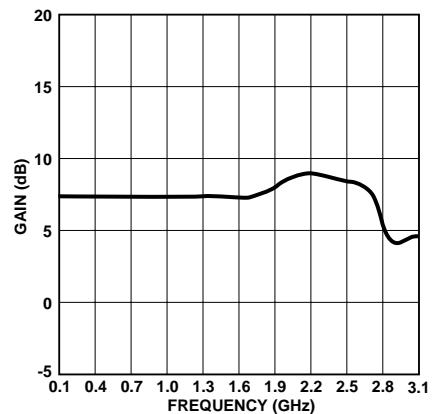
The bias decoupling network is optimized for operation from 300 MHz to 2.3 GHz. A broadband RF choke, consisting of a small molded choke of 0.33  $\mu$ H with a 1-turn coil formed from the lead of the choke, is bypassed to ground with a 1000 pF feedthrough capacitor. The device is driven from a 15 volt supply with a current drain of 325 mA.

The gain actually peaks at almost 9 dB at 2.3 GHz, with a gain of 5 dB still achieved at 2.8 GHz. Performance is shown in Figure 4. Actual performance compares very well to the response predicted by the computer (Table 2). The simulation also predicts unconditional stability from 100 MHz to 2.5 GHz, except at 2.1 GHz. The actual amplifier circuit is completely stable at all frequencies either by itself or when cascaded with other devices.

Data on the actual amplifier shows that input VSWR varies from 1.5:1 to 2.5:1 from 200 MHz to 2.5 GHz while peaking to 3.0:1 at 100 MHz. Output VSWR varies from 1.9:1 to 3.0:1 from 100 MHz to 3.1 GHz. The shape of the VSWR curve is similar to those predicted by computer simulation.

The matching network is effective in increasing the amplifier bandwidth with minimal gain degradation in the center of the band.

Power output at 1 dB gain compression is greater than +30 dBm at frequencies up to 500 MHz and is +28 dBm at 900 MHz and +26 dBm at 1.0 GHz. At 2.3 GHz, the power output drops to +24 dBm. Saturated power output is typically 1 to 2 dB greater than 1 dB gain compression power output. A complete summary including harmonic levels at 1 dB gain compression is shown in Table 3.

**Figure 4. Single MSA-1023 Gain**

**Table 2. Computer Simulation of a Single MSA-1023 Amplifier**

Freq (GHz)	S <sub>21</sub> (dB)	S <sub>12</sub> (dB)	K	Input VSWR	Output VSWR
0.1	7.01	-15.88	1.21	3.29	2.66
0.3	7.19	-15.68	1.21	2.88	2.49
0.5	7.46	-15.46	1.22	2.26	2.12
0.7	7.67	-15.33	1.24	1.72	1.79
0.9	7.77	-15.33	1.24	1.43	1.69
1.1	7.76	-15.49	1.25	1.47	1.81
1.3	7.74	-15.70	1.24	1.68	1.98
1.5	7.85	-15.75	1.23	1.82	2.05
1.7	8.23	-15.42	1.19	1.73	1.93
1.9	8.97	-14.65	1.05	1.48	2.04
2.1	9.32	-14.15	0.96	1.26	2.30
2.3	8.60	-14.59	1.06	1.50	2.19
2.5	7.36	-15.53	1.16	2.05	2.52

**Table 3. Power Output Summary for Single MSA-1023**

Freq (GHz)	P <sub>Sat</sub> (+dBm)	P <sub>1dB</sub> (+dBm)	Harmonics at P <sub>1dB</sub>		
			2nd (dBc)	3rd (dBc)	4th (dBc)
0.3	31.9	30.8	-26	-16	-24
0.5	31.2	30.2	-18	-13	-25
0.9	29.0	28.0	-15	-18	-23
1.0	28.4	26.0	-21	-23	-
2.3	26.8	24.0	≥ 23	-	-

### Low Frequency Operation

The “on-chip” capacitor that is part of the parallel feedback network in both the MSA-0520 and the MSA-1023 will limit the usefulness of the devices at low frequencies. A 45 pF capacitor is used in the MSA-0520 feedback network while an 80 pF capacitor is used in the MSA-1023 feedback network. As the reactance of the feedback capacitor increases, the effect of the feedback network on device performance is lessened. The result is that low frequency gain increases and input and output VSWR increases.

To evaluate the MSA-0520 at low frequencies, the circuit shown in Figure 1 is modified. 0.01 µF chip capacitors are substituted for the blocking capacitors. RFC1 and RFC2 are replaced by a single 10 µH RF choke with the supply end of the choke bypassed with a 0.01 µF and a 2 µF capacitor.

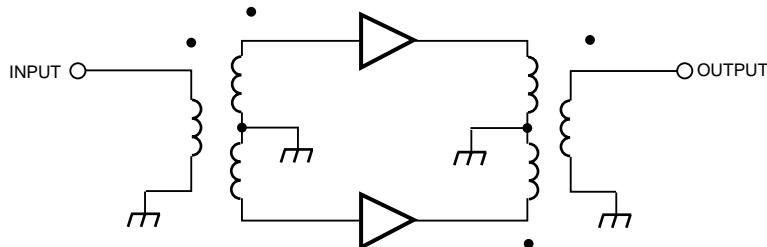
Test results indicate that the gain will increase to 11.5 dB at 10 MHz. The input return loss has only degraded to 12.5 dB while the output return loss has decreased to 5 dB.

## Push-Pull MSA-1023

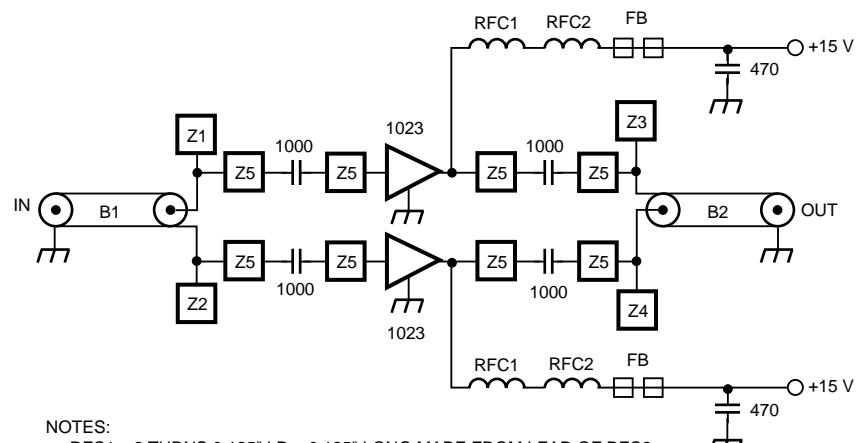
In push-pull operation, a balun (balanced-to-unbalanced) transformer is used to generate two signals 180 degrees out of phase to drive two devices (Figure 5). The outputs of both devices are then recombined with another 180-degree transformer which sums the output power of both devices. (Balun operation is covered in depth in several articles listed in references 2, 3, and 4.

The schematic of the push-pull amplifier is shown in Figure 6. The baluns used in the amplifier are made from two pieces of 0.085-inch diameter semirigid cable (Micro-Coax UT85 series, Precision Tube 0.085 series, or small braided coaxial cable, such as RG-174/U). Each balun is 1.25 inches long and offers good performance down to 100 MHz. The shield of each cable is connected to the groundplane at the ends opposite the devices. The shield at the opposite end remains ungrounded and connects to the input of one of the devices with the center conductor connected to the second device.

When combining the outputs, the balun center conductor must be attached to the device opposite of the one that was fed with the center conductor. This will ensure proper balance between the devices. To



**Figure 5. Push-Pull Operation**



NOTES:

- RFC1 2 TURNS 0.125" I.D., 0.125" LONG MADE FROM LEAD OF RFC2
- RFC2 1.0 μH MINIATURE MOLDED RFC
- FB FERRITE BEADS
- Z1-4 0.1" WIDE BY 0.15" LONG OPEN CIRCUITED STUB
- Z5 25 OHM MICROSTRIP, 0.1" LONG BY 0.2" WIDE
- B1, B2 50 OHM BALUN, 1.25" LONG

**Figure 6. Push-Pull MSA-1023**

ensure a smooth transition to the devices, short sections, i.e. 0.1 inch, of 25 ohm microstripline are used as transitions from the cable to each device. The coax cable balun should be dressed so that the shield has minimal stray capacitance to ground, since stray capacitance will upset the balance between devices, thereby reducing amplifier efficiency. It was found empirically that the open circuited stubs Z1 through Z4 enhanced gain at 2.0 GHz with no adverse effect on low frequency response.

The bias decoupling network consists of two RF chokes in series to enhance the broadband performance. RFC1 is a small 2-turn RF choke for high frequency isolation while RFC2 is a 1  $\mu$ H RF choke which provides decoupling in the VHF region. Ferrite beads added to the cold lead of RFC2 help low frequency decoupling. 470 pF feedthrough capacitors provide an effective bypass on the power supply side.

Amplifier gain performance is shown in Figure 7. The amplifier provides approximately 7 dB gain from 100 MHz to 1.9 GHz. The bias decoupling network is chosen for optimum performance in the 300 MHz to 1.9 GHz frequency range and has some inherent gain rolloff at 100 MHz.

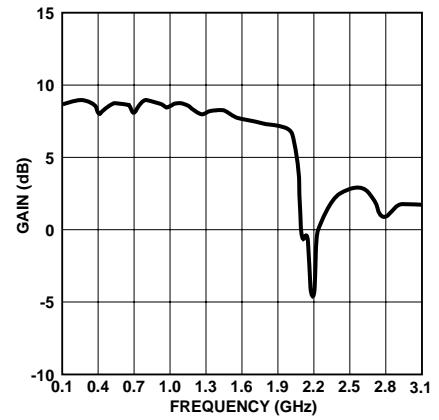
Power output is summarized in Table 4. Power output at 1 dB gain compression is +32.4 dBm at 100 MHz, +33.4 dBm at 300 MHz, +30.6 dBm at 1.0 GHz, and +27.1 dBm at 1.5 GHz. At 2.0 GHz the amplifier is still putting out +24.7 dBm, but drops off rather quickly above 2.0 GHz. This is due to the discontinuities associated with the transformation between the coaxial baluns and the devices themselves.

Harmonic level at 1 dB gain compression level for frequencies in the 100 to 900 MHz range is also shown in Table 4.

The level of intermodulation distortion levels (IMD) is of importance when high linearity is desired. IMD is measured by injecting two equal amplitude CW signals into the amplifier at a level 6 dB below the maximum peak output obtained with the amplifier when driven with a single carrier. The spacing in frequency of the two signals is not critical as long as they are both in the passband of the amplifier. Typically, the

**Table 4. Power Output Summary for Push-Pull MSA-1023**

Freq (GHz)	P <sub>Sat</sub> (+dBm)	P <sub>1dB</sub> (+dBm)	Harmonics at P <sub>1dB</sub>		
			2nd (dBc)	3rd (dBc)	4th (dBc)
0.1	34.7	32.4	-9	-12	-20
0.3	35.3	33.4	-14	-22	-27
0.5	34.0	32.8	-17	-18	-27
0.9	32.7	31.2	-22	-32	-36
1.0	31.8	30.6	-	-	-
1.5	30.0	27.1	-	-	-
2.0	28.5	24.7	-	-	-
2.3	21.8	18.4	-	-	-



**Figure 7. Push-Pull MSA-1023 Gain Performance**

two signals should be close enough in frequency that the gain and power output would be similar (i.e. 100 MHz or less).

When the push-pull amplifier is injected with two signals at the appropriate level at 1 GHz, the IMD is measured to be -26 dBc and -28 dBc at a peak output of +30.6 dBm. The third order intercept point is calculated with the aid of the following formula:

$$I.P. = P_{out} + (IMD/2)$$

where the IMD level is the absolute value of the average of the two third-order products.

For the push-pull amplifier, this equates to an intercept point of +44.1 dBm. With the aid of the preceding formula, the IMD at any power level can be calculated. As an example, the IMD at +30 dBm output power will be -28.2 dBc and -34.2 dBc at +27 dBm.

Input and output VSWR is less than 2.0:1 between 100 MHz and 1.0 GHz and is typically 1.5:1 in midband.

### **Other Paralleling Techniques**

Although push-pull operation is simple and offers the greatest bandwidth at frequencies up to 1.5 GHz, another paralleling approach using two MSA-1023 MMICs is demonstrated. In-phase power dividers and combiners are used to drive each stage in-phase and to recombine them in-phase to get maximum power output. This approach is nominally narrowband – on the order of 10% to 20% bandwidth – but has the added advantage of working very well at higher frequencies, especially if microstripline techniques are utilized.

To verify the power combining technique with the MSA-1023, a test amplifier is built for use at 750 MHz. Shown schematically in Figure 8, the amplifier uses four transmission lines, each a quarter-wavelength long, at 750 MHz. The transmission lines are conveniently three-quarter-waves long at approximately 2.2 GHz, allowing device evaluation at the higher frequency. Each transmission line is of an impedance equal to the square root of the product of the two impedances to be matched. For example:

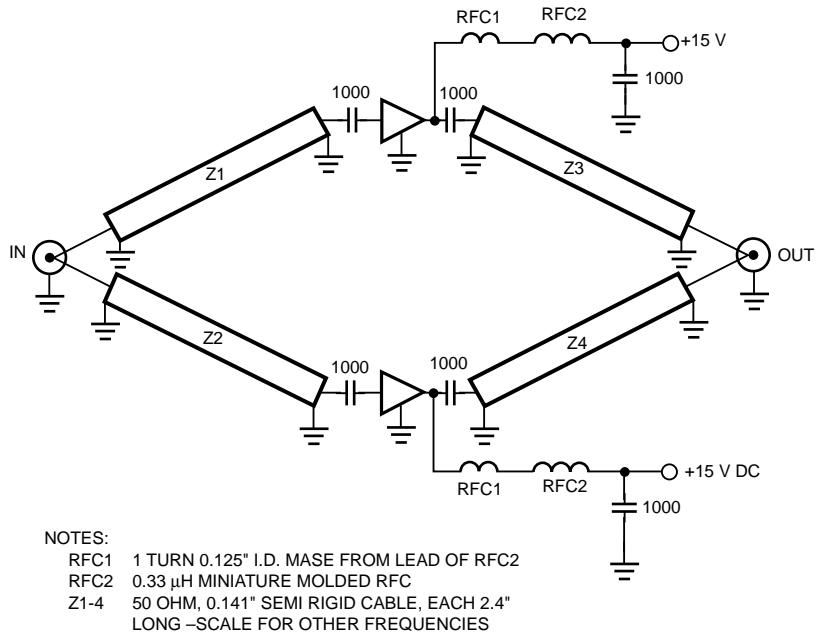
$$Z_t = \sqrt{25 \cdot 100} = 50 \text{ ohms}$$

This impedance is available in standard 0.141-inch 50 ohm semi-rigid cable (i.e. MicroCoax UT141 series, Precision Tube 0.141 series).

Since the impedance of each device is now transformed to 100 ohms\*, input and output impedance. This same concept works for both the input and output match.

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\* The two circuits can be paralleled to give 50 ohms.



**Figure 8. Parallel MSA-1023**

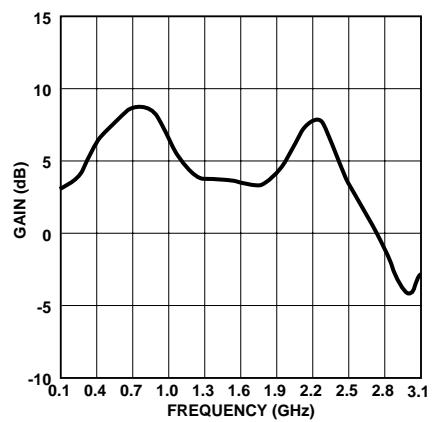
**Table 5. Power Output Summary for 2 MSA-1023 MMICs in Parallel**

Freq (GHz)	P <sub>Sat</sub> (+dBm)	P <sub>1dB</sub> (+dBm)	Harmonics at P <sub>1dB</sub> (dBc)
0.750	32.6	31.3	-22
2.2	27.8	25.3	-25

The results are shown in Table 5. As expected, the amplifier also provides acceptable power output where the lines are three quarter-waves long. At 750 MHz, the 1 dB gain compression output power is +31.3 dBm; only dropping to +25.3 dBm at 2.2 GHz.

Harmonic output at 1 dB gain compression is less than -22 dBc when operating at a frequency of 750 MHz and harmonic suppression is greater than 25 dB when operating at 2.2 GHz. The swept gain plot in Figure 9 shows a 1 dB gain bandwidth of 400 MHz at 750 MHz and 160 MHz at 2200 MHz. The 3 dB gain bandwidths are 700 MHz at 750 MHz and 450 MHz at 2.2 GHz. Peak gain at 750 MHz is 8 dB and 7 dB at 2.2 GHz. Input and output VSWR at 750 MHz is 1.26:1 maximum while the VSWR at 2.2 GHz is 2.25:1 on the input and 1.9:1 on the output.

The parallel amplifier provides comparable performance to the push-pull amplifier at 750 MHz and does provide better performance at 2.2 GHz. This may be due to the in-phase dividers radiating less than the 1:1 coax baluns.



**Figure 9. Parallel MSA-1023 Gain**

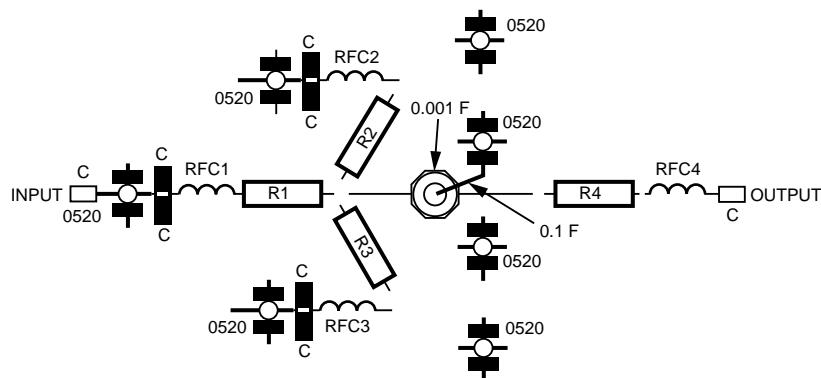
## Cascaded and Paralleled MSA-0520 Amplifier

Cascading MMICs for increased power output requires careful review of the individual gain and power output capabilities of each stage. Assuring that the overall amplifier will retain the 1 dB gain compression point of the last stage requires that none of the preceding gain stages be driven into compression – i.e. that they be operated several dB below their 1 dB gain compression points.

A single MSA-0520 can be used to drive two or four MSA-0520s to achieve a 3 or 6 dB increase in output power. At 1.0 GHz, a single device can drive a pair of devices very well. Driving four devices in parallel from a single device requires that the gain of the individual device be great enough to keep the driver device from being driven into compression when the final devices are compressing. Since the gain at 1 dB compression is 7 dB, the driver device is starting to go into compression. A more optimum situation would be to have a single device driving a pair of devices instead of four. This would insure that the only stage driven to compression will be the final stage, especially at higher frequencies where the gain is below 7 dB.

This technique is verified by designing an amplifier in which one MSA-0520 drives two MSA-0520s which then drive four devices. The design uses quarter-wave microstripline power dividers for feeding and combining power (Figure 10). The quarter-wave lines are 70 ohm microstriplines of 0.060 inches in width etched on Rogers RT-DUROID™ 5880 material. Dielectric thickness is 0.031 inch,  $\epsilon_r = 2.2$ .

The amplifier is designed for a frequency of 2.0 GHz but, as the swept plot shows (Figure 11), it also has acceptable gain down to 100 MHz. This is due in part to the low-pass nature of the in-phase power dividers. The gain over the entire 400 MHz to 2.8 GHz frequency range is within 2 dB of that predicted by the computer analysis (Table 6). Some of the gain rolloff at 100 MHz is due to the small-value RF choke, however, the choice of value is based on an attempt to get broadband performance without resonances



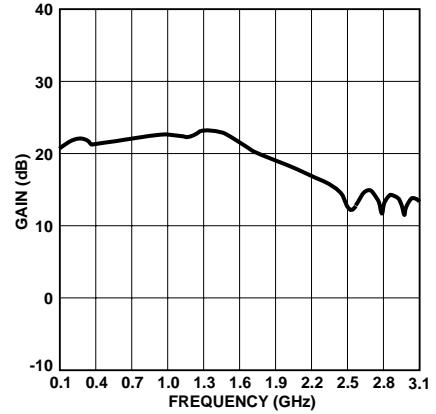
NOTES:

- RFC1-4 6 TURNS #24 GAUGE, 1/8" I.D. SWD
- R1-3 22 OHM 1/2 WATT CARBON RESISTOR
- R4 FOUR 22 OHM, 1/2 WATT RESISTORS IN PARALLEL
- C 1000 pF CHIP CAPACITOR

**Figure 10. Cascade/Parallel MSA-0520**

**Table 6. Computer Simulation of the Cascade/Parallel MSA-0520 Amplifier**

Freq (GHz)	S <sub>21</sub> (dB)	S <sub>12</sub> (dB)	K	Input VSWR	Output VSWR
0.1	20.1	-50.8	8.0	1.70	5.89
0.3	22.1	-46.4	3.9	1.18	6.09
0.5	22.1	-45.9	3.7	1.68	5.89
0.7	22.6	-45.1	3.5	2.11	4.75
0.9	23.1	-44.4	3.0	2.36	4.20
1.1	23.5	-43.5	2.2	2.73	4.16
1.3	24.0	-42.1	1.7	3.50	3.49
1.5	24.4	-40.9	2.0	3.45	2.33
1.7	23.8	-40.4	2.8	2.23	1.64
1.9	22.5	-40.7	3.7	1.61	1.57
2.1	21.1	-40.8	4.1	1.64	1.86
2.3	19.9	-40.7	4.3	1.76	2.10
2.5	18.8	-40.3	4.6	1.85	2.20
2.7	17.7	-40.0	5.1	1.92	2.19
2.9	17.1	-39.1	4.9	2.08	2.13
3.1	17.5	-37.0	3.4	2.59	2.19
3.3	19.2	-33.3	1.0	5.59	3.03



**Figure 11. Parallel MSA-0520 Gain**

in the passband. For narrower bandwidths, the bias decoupling circuit can be optimized to enhance gain and power output.

The computer simulation predicts unconditional stability over the 100 MHz to 3.3 GHz frequency range. No problems have been encountered when cascading this assembly with other stages.

**Table 7. Power Output Summary for Cascade/Parallel MSA-0520**

Freq (GHz)	P <sub>Sat</sub> (+dBm)	P <sub>1dB</sub> (+dBm)	Harmonics at P <sub>1dB</sub>		
			2nd (dBc)	3rd (dBc)	4th (dBc)
0.1	31.9	30.2	-22	-18	-26
0.3	30.5	29.7	-13	-20	-24
0.5	28.5	28.1	-14	-18	-25
0.9	27.3	26.8	-18	-18	-32
1.0	27.2	27.0	-23	-22	-
1.5	27.8	26.0	-	-	-
2.0	25.2	24.0	≥ 27	-	-
2.3	24.0	21.9	≥ 27	-	-

As expected, power output at the design frequency of 2.0 GHz is approximately 5 dB over that available from a single device. At frequencies lower than 2.0 GHz, the mismatches between devices and dividers limit the power output to about 4 dB over a single device. Complete power output data and harmonic levels are shown in Table 7.

Measured input and output VSWR ranges from 2.0:1 to 2.5:1 at 2.0 GHz. As the operating frequency deviates from the optimum frequency at which the in-phase dividers are a quarter-wavelength, the match will get worse. The actual VSWR response is similar to the computer simulation with the exception that the actual VSWR is somewhat higher between 2.0 and 2.5 GHz.

## Amplifier Efficiency

Most medium-power narrowband class A amplifiers have 20 to 25% DC-to-RF conversion efficiencies. The medium-power MODAMP MMIC amplifiers have similar efficiencies, but with much greater bandwidth. Amplifier efficiency is summarized in Table 8. Typical efficiencies of the MSA-0520 and MSA-1023 amplifiers are 22% to almost 27% at 300 MHz and from 8% to almost 12% at 1.0 GHz. When a bias resistor is used with the MSA-0520, the DC to RF conversion efficiency decreases to 20% at 300 MHz and 8% at 1.0 GHz. The parallel MSA-1023 amplifier has an efficiency of 13.8% at 750 MHz.

The efficiency of the cascade/parallel MSA-0520 amplifier at low frequencies is less than that achieved with a single device. This is due to the amplifier being designed for operation at 2.0 GHz. If the matching sections were scaled for the lower frequencies, the efficiency would be comparable to that obtained with the single MSA-0520.

**Table 8. Comparison of Power Amplifier Efficiency**

Device Efficiency	Device & Bias Resistor Efficiency
Single MSA-0520 $V_D = 11.4 \text{ V}$ $I_D = 0.165 \text{ A}$	26.7%/10.7% 20.2%/8.1 %
Single MSA-1023 $V_D = 15 \text{ V}$ $I_D = 0.325 \text{ A}$	24.7%/8.2% N/A
Push-Pull MSA-1023 $V_D = 15 \text{ V}$ $I_D = 0.650 \text{ A}$	22.4%/11.8% N/A
Parallel MSA-1023 $V_D = 15 \text{ V}$ $I_D = 0.650 \text{ A}$ Test Frequency = 750 MHz	13.8% N/A
Quad MSA-0520 $V_D = 11.4 \text{ V}$ $I_D = 0.66 \text{ A}$	12.4%/6.7% 9.4%/5.1 %
Test conditions: Frequency: VCC: POUT:	300 MHz/1 GHz 15 VDC $P_{1\text{dB}}$

## Cascading Stages

There are a number of factors to consider when choosing a driver for either the push-pull or parallel MSA-1023 amplifier. If a high degree of linearity is desired, the driver stage should be chosen so that when the final stage is driven nearly into gain compression the driver stage is several dB below its compression point. As an example, at 1.0 GHz, when the MSA-0520 is used to drive the pair of MSA-1023s, both stages will simultaneously reach their 1 dB gain compression point. This is because the gain of the final amplifier stage at +30.6 dBm output is only 7 dB. Slightly less compression will occur at a final output power level of +30 dBm. An alternative is to use the MSA-1023 as a driver stage. The single MSA-1023 will develop +26 dBm at 1 dB gain compression point. At the +23 dBm required to drive the final pair of devices, the single MSA-1023 will be operating at a level 3 dB below its 1 dB gain compression point.

## Conclusion

This note has demonstrated several techniques for achieving moderately high power output from the Hewlett-Packard MSA-0520 and MSA-1023 MODAMP MMICs.

The single stage MSA-0520 produces +23 dBm at 1 GHz while a single stage MSA-1023 produces +28 dBm at 900 MHz. The simple matching network used with the single stage MSA-1023 has extended its useful frequency range to 2.7 GHz. The note also shows that with the appropriate bias decoupling, the MSA-0520 provides acceptable performance down to 10 MHz.

Two parallel approaches are demonstrated using the MSA-1023: push-pull baluns and in-phase power dividers. The first approach is the more broadband and delivers good gain to almost 2.0 GHz and produces a minimum of +30 dBm output power at 1 dB gain compression at frequencies up to 1.0 GHz. The single section in-phase power divider approach provides better performance above 2.0 GHz, but is inherently less broadband.

The second design example demonstrates that the MSA-0520 can be paralleled and cascaded for increased power output and increased gain while still retaining stability. Although the test circuit is designed for a center frequency of 2.0 GHz, the actual circuit exhibits excellent broadband gain from 100 MHz through 2.0 GHz. The example also shows the importance of insuring that the driver stages do not compress prior to the final stages. This is necessary to achieve rated power output while retaining a high degree of linearity.



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