INA Series RFIC Amplifiers

Application Note S012

Introduction

The INA series amplifiers are part of Hewlett-Packard's product line of silicon bipolar RF Integrated Circuits built with HP's ISOlated Self Aligned Transistor (ISOSAT™) process. These devices are 50 ohm cascadable gain blocks that feature high insertion gains and low noise figures. They represent an extension of the technology used in HP's MSA product family of RFIC amplifiers.

The INA Series Product Family

The INA part numbers impart information about the product. The prefix INA designates a standard (catalog) ISOSAT-based low Noise Amplifier. The first two digits following the hyphen designate die type. The third digit is reserved for performance selections. The last two digits designate package type.

The INA products covered in this note are:

INA-01:

Low noise:	1.7 dB
Low frequency:	500 MHz f_{3dB}
Very high gain:	32.5 dB
Higher power:	+11 dBm P_{1dB}
Moderate bias:	35 mA

INA-02:

Low noise:	2.0 dB NF
Moderate frequency:	1.0 GHz f_{3dB}
Very high gain:	31.5 dB
Higher power:	+11 dBm P_{1dB}
Moderate bias:	35 mA

INA-03:

Low noise:	2.5 dB NF
High frequency:	2.8 GHz f_{3dB}
High gain:	25 dB
Low power:	+1 dBm P_{1dB}
High efficiency bias:	12 mA

INA-10:

Moderate noise:	3.5 dB NF
High frequency:	1.8 GHz f_{3dB}
High gain:	25 dB
Higher power:	+10 dBm P_{1dB}
Moderate bias:	50 mA

The package options available are:
00 - chip form - unpackaged die

70 - "hermetic stripline" package - 70 mil surface mount gold/ alumina high reliability microstripline package for premium performance applications.

84 - surface mount "micro-plastic" package - 85 mil, low cost plastic microstripline package with superior microwave performance.

86 - surface mount "micro-plastic" package - 85 mil, low cost surface mountable plastic microstripline package with leads formed and trimmed for automated assembly; some high frequency performance is lost due to the higher parasitics of the formed leads.

Note: Some die-package combinations may not be available. Contact your HP representative for specific products.

Product Design and Performance Features

The INA Circuit

All amplifiers in the INA product line have similar circuit topologies. The design utilizes a two stage cascade consisting in general of a single input transistor driving a Darlington connected output pair. Resistive feedback is used to set the RF performance.

In the most typical realization, the first stage has minimal feedback supplied only by a shunt resistor. This yields the best noise performance, and also causes the first stage to provide most of the RFIC gain. The collector of the first stage directly drives the base of the output stage, without any interstage blocking capacitor that

would limit low frequency performance. The second stage is heavily fed back using both series and shunt resistors, and sets the match, gain, and flatness of the RFIC. Additional resistors complete the DC biasing network. A typical schematic is shown in Fig. 1.

Consequent Performance Features

The topology described above results in a number of significant performance characteristics for the INA series products.

The low noise figures of INAs result directly from the circuit design. The bias point of the first stage is selected to provide excellent noise performance. The omission of a first stage emitter resistor from the design also keeps the noise figure of the devices very low. INAs have noise figures as low as 1.7 dB at 500 MHz and 2 dB at 2 GHz.

INAs have high gains and excellent reverse isolation. The high gains of 25 to 35 dB in a single transistor package follow from the use of two stages of amplification in cascade. The reverse isolation results from the lack of a direct feedback path from the input of the RFIC to the output. This is in contrast to single stage feedback amplifiers, where the shunt feedback resistor provides a direct path from output to input, and necessarily reduces device $|S_{12}|$. Typical values for INA reverse isolation are on the order of 30 dB, compared to only 15 dB for most single stage feedback amplifiers.

The performance of INA RFICs is predominantly current controlled. This follows from the use of silicon bipolar transistors as the active devices. Device performance is consequently characterized and guaranteed at a certain current level, not at an applied voltage.

The performance parameter most affected by bias is P_{1dB}. In general, there is a relatively narrow range of current over which INAs function as designed. At low bias currents, one or more stages of the cascade will be turned off, causing low gain and poor match. High reflected powers and instability over temperature are symptomatic of operation in this "not quite-turned-on" region. Although there is no reliability risk inherent in low current operation, HP does not recommend this kind of use due to the unpredictability of performance. Once sufficient current is drawn for the device to be fully operative, adding more bias current predominantly effects P_{1dB} and has limited effect on gain. Representative performance for the INA-01170 shows a 4 dB increase in P_{1dB} but only a 1 dB gain variation over this product's recommended I_d range. The maximum allowable I_d is set by current density and thermal transfer; exceeding this limit can potentially damage the INA. A recommended operating current range is included on the data sheet of each INA series product.

The INA amplifiers have a bias point that is very temperature stable. This results from the resistive scheme used to DC bias these devices. Examination of the device current (I_d) versus device voltage (V_d) curves shows INAs have a much lower slope than do single stage resistive feedback amplifiers. Thus, INA series devices maintain a relatively constant bias current when operated over temperature at a fixed V_d. Test data reveals that although the least variation in gain occurs when the INA series RFICs are operated from a current source, it is possible to operate these devices directly from a voltage source (i.e. with no bias stabilization resistor) if the temperature range is not too broad. Data comparing current controlled performance to voltage controlled performance is given in Fig. 2. A further difference in bias characteristics between INA series and MSA series amplifiers is that the device voltage of an INA increases with temperature (dV/dT is positive), whereas single stage feedback amplifiers have negative temperature coefficients.

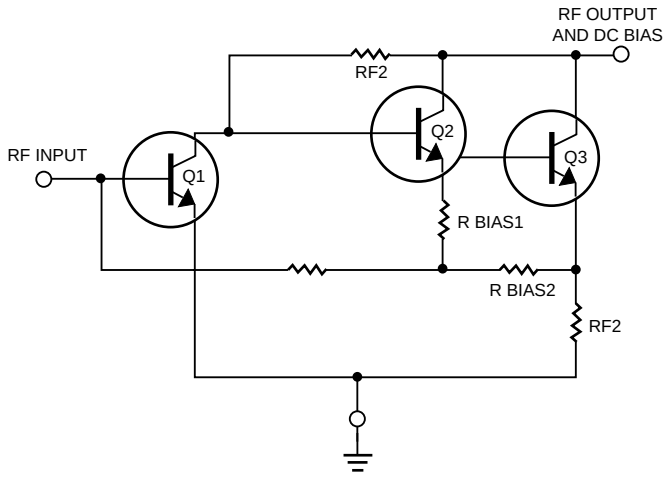


Figure 1. Typical Schematic for INA RFICs.

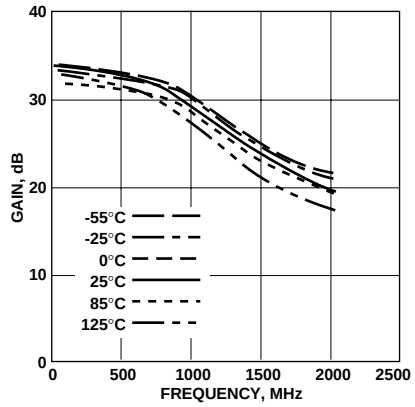


Figure 2a. Gain vs. Frequency Over Temperature INA-02170 Bias = 35 mA (Fixed).

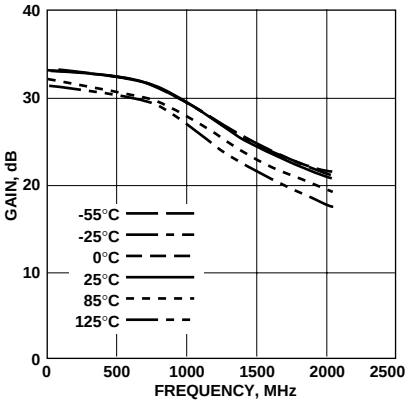


Figure 2b. Gain vs. Frequency Over Temperature INA-02170 Bias = 7.35 V (Fixed).

Emitter Inductance and Performance

As a direct result of their circuit topology, the performance of INAs is extremely sensitive to ground path ("emitter") inductance. The two stage design creates the possibility of a feedback loop being formed through the ground returns of the stages. If the path to ground provided by the external circuit is "long" (high in impedance) compared to the path back through the ground return of the other stage, then instability can occur (see Fig. 3). This phenomena can show up as a "peaking" in the gain versus frequency response (perhaps creating a negative gain slope amplifier), an increase in input VSWR, or even as return gain (a reflection coefficient greater than unity) at the input of the RFIC.

The "bottom line" is that *excellent grounding is critical* when using INAs. The use of plated through holes or equivalent minimal path ground returns *right at the device* is essential. A corollary is that designs should be done on the thinnest practical substrate. The parasitic inductance of a pair of via holes passing through .032" thick pc board is approximately 0.1 nH, while that of a pair of via holes passing through .062" thick board is closer to 0.5 nH. HP does not recommend using the INA family on boards thicker than 32 mils.

The various resistor values used in the designs make some members of the INA family more sensitive to this phenomena than others. The INA-03 geometry is most sensitive to this effect; the INA-01, INA-02 and INA-10 can tolerate somewhat higher inductance in the ground path. The package version selected also effects ground path sensitivity. Devices in the 70 style package, which has the lowest associated parasitic inductance, will be the least sensitive to ground path inductance. Devices in the 86 package, with its formed leads and higher associated inductances, will be less tolerant.

When used in chip form, the lengths of the bond wires become critical. As the bonds from the two emitter ground pads to system ground are made longer, the loop impedance increases and the tendancy towards oscillations diminishes. There is, however, a trade-off in that the gain-bandwidth of the amplifier decreases fairly rapidly as these wires are lengthened.

These stability effects are entirely predictable. A circuit simulation using the data sheet S-parameters and including a description of the ground return path (via model or equivalent "emitter" inductance) will give an accurate picture of the performance that can be expected. Device characterizations are made with the ground leads of the INA directly contacting a solid copper block (system ground) at a distance of 2 to 4 mils from the body of the package. Thus the informa-

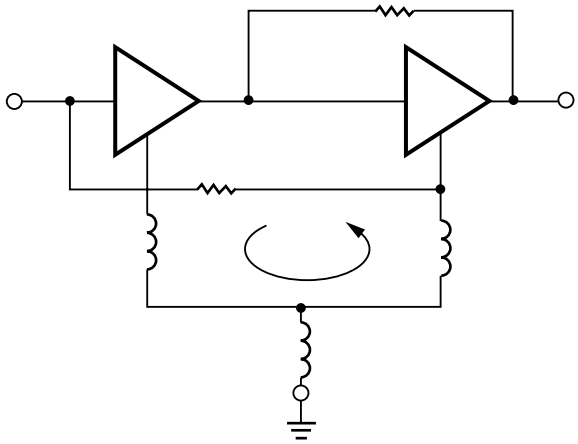


Figure 3. INA Potential Ground Loop.

tion in the data sheet is a true description of the performance capability of the RFIC, and contains minimal contributions from fixturing.

Circuit Design

RF Circuitry

Impedance Matching

The resistive feedback incorporated into each INA series device creates a gain block that is matched to 50 Ω on both input and output ports. In most cases the matches are sufficiently good that the benefit from additional matching is minimal. Improvements in gain from additional matching would typically be on the order of only tenths of a decibel. Thus the most common RF circuit consists simply of 50 Ω transmission lines.

Of course, if system requirements are for extremely low VSWRs, additional RF matching to achieve this could be devised using the device S-parameters. Arbitrarily good performance is achievable in narrow bands. It is also possible to design an input match for improved noise performance. Noise figure can typically be lowered by a few tenths of a dB at the cost of increased input reflection coefficient.

Note: Excess source inductance will significantly alter the match of the INA, causing an increase in S_{11}. Remember to include source inductance (such as a via hole description) in any simulations for predictions of performance.

INA-03xxx VSWRs

The VSWRs of the INA-03xxx are higher than those of other members of the INA family. In most cases, the match remains good enough that this is not a design issue. If, however, the designer wishes to improve the output match of this device, this can be done by placing an external resistor in parallel with the device output.

An appropriate circuit for improving the output match of the INA-03170 is shown in Fig. 4. In this circuit, the choke network consists of a resistor R_C of appropriate value well bypassed to ground at the terminal away from the RFIC. If an additional voltage drop is required to bias the INA-03170 from the available power supply, a resistor R_{BIAS} can be connected in series with R_C.

By varying the value of R_C, different circuit performance can be achieved. This has been demonstrated using an amplifier built on a 20 mil thick PTFE-fiberglass circuit board, into which various values of resistor were substituted. For the lower values of R_C tested. additional R_{BIAS} was added after the bypass capacitor to keep the overall voltage drop between supply and device constant.

An R_C value of 430 Ω (effectively no shunt resistive matching) yielded a circuit with 27 dB of low frequency gain, an f_{1dB} of 900 MHz, an input VSWR of 3.1:1 worst case and an output VSWR of 3.2:1 worst case. An R_C of 180 Ω had the effect of flattening the gain response, both by reducing low frequency gain and by peaking high frequency gain. For this circuit low frequency gain was 25.7 dB, f_{1db} was 2.4 GHz, worst input VSWR was 3.0:1 and worst output VSWR was 2.6:1. Reducing the value of R_C still further to 100 Ω yielded an ultra-flat gain response to 1 GHz, and an upward gain slope versus frequency between 1 GHz and 2 GHz. This circuit had a low frequency gain of 24.5 dB, a f_{1db} of 1.8 GHz, a worst input VSWR of 3.0:1 and a worst output VSWR of 2.2:1. Complete data for these amplifiers is shown in Figures 5 through 7.

A trade-off involved in using this technique is that output match is improved by absorbing some of the output power; consequently the P_{1dB} of the resulting amplifier will decrease by 1 to 2 dBm from the level specified on the data sheet.

DC Circuitry

Blocking Capacitors

The INA series amplifiers are designed to be used with DC blocking capacitors on both the input and output terminals. These capacitors ensure that the RF loads provided to the RFIC do not shift

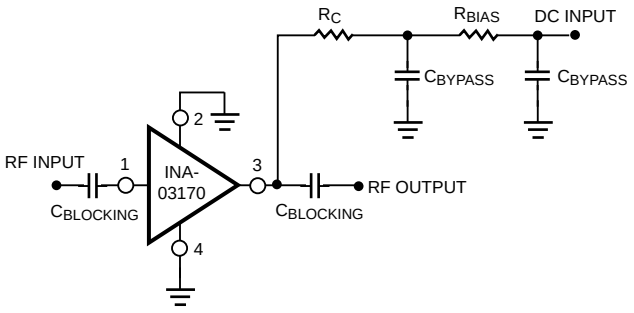


Figure 4. Using R_C to Adjust INA-03170 Output Match.

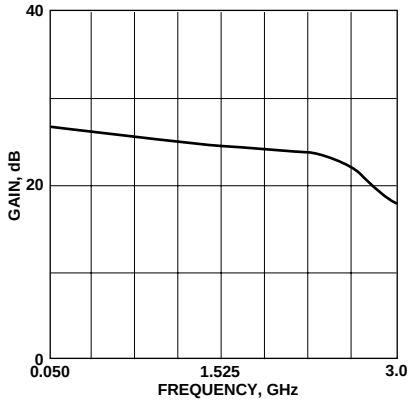


Figure 5a. Gain vs. Frequency INA-03170 with R_C = 430 Ω.

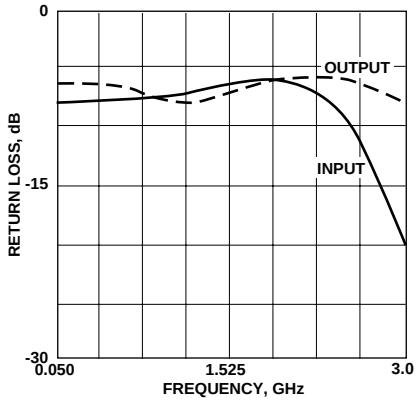


Figure 5b. Input and Output Return Loss vs. Frequency INA-03170 with R_C = 430 Ω.

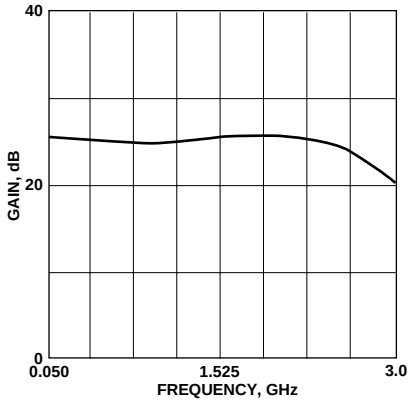


Figure 6a. Gain vs. Frequency INA-03170 with R_C = 180 Ω.

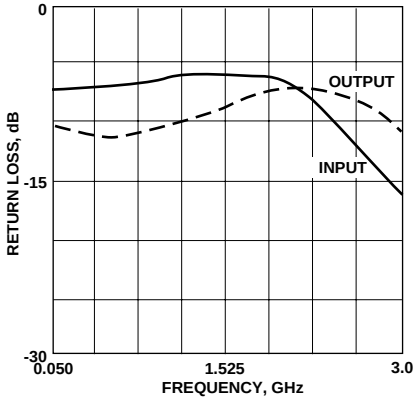


Figure 6b. Input and Output Return Loss vs. Frequency INA-03170 with R_C = 100 Ω.

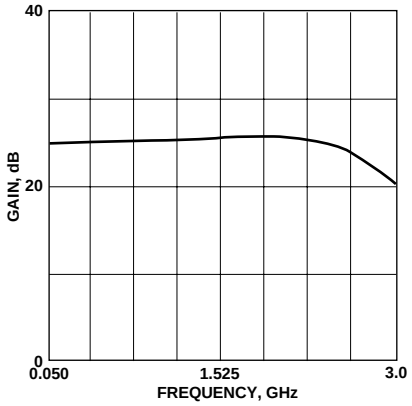


Figure 7a. Gain vs. Frequency INA-03170 with R_C = 100 Ω.

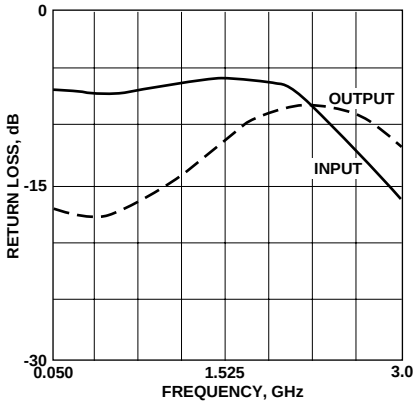


Figure 7b. Input and Output Return Loss vs. Frequency INA-03170 with R_C = 100 Ω.

the DC operating point set by the internal resistive networks. Blocking capacitors should provide a low series impedance (usually less than 10 Ω), throughout the frequency band over which the amplifier is to be used. Remember that at microwave frequencies, the reactive impedance of the blocking capacitor is the sum of the impedance provided by its capacitance [-1 / (2πfC)] and the impedance from its associated parasitic inductance (+2πfL). Dissipative loss (capacitor Q) will also contribute a resistive component to the impedance of the DC block. For best noise performance, high-Q capacitors should be used for input blocking, as any loss in front of the INA will add to the noise figure of the circuit.

Blocking capacitors may be used either above or below resonance, so long as their net series impedance is low. For narrow band applications, capacitors at resonance can be used, as this provides minimal insertion impedance [2πfL -1 / (2πfC) = 0 at resonance]. Typical values for blocking capacitors are on the order of 1000 pF, with associated parasitic inductances of 0.5 nH.

The value of blocking capacitor selected will usually determine the lowest frequency of operation of the circuit. As can be seen from the section on circuit topology, there is no internal low frequency limit inherent in the INA design.

One way to eliminate blocking capacitors is to separate DC and RF levels by "floating" the device using bypass capacitors. In this manner, an INA could be biased between a plus supply and a minus supply (Fig. 8), allowing a true DC input or output. Alternatively, the INA could be biased with the output at DC ground and the ground terminals at $-V_d$ (Fig. 9). The necessary criteria for any such configuration is that the input "base to emitter" voltage (1.6 V) and output "collector to emitter" voltage (V_d) are maintained. This constraint means that a cascade of two stages cannot be run at DC output. The sensitivity to

emitter inductance also necessitates excellent low parasitic bypassing if these schemes are used.

DC Bias

Since the performance of INAs is predominantly current controlled, it is anticipated that the typical bias of these devices will be from a current source. The most common realization of "current source" biasing is to use a dropping resistor from a fixed voltage source. This kind of biasing is shown in the "typical bias configuration" given on INA data sheets, and is repeated in Fig. 10. The value of the resistor R_{BIAS} sets the device operating current in that the volltage drop across this resistor must equal the difference between the supply voltage and the device operating voltage. Thus

$$I_d = \frac{V_{SUPPLY} - V_d}{R_{BIAS}}$$

Such a resistor also acts as a collector feedback element, and helps to stabilize the DC bias point of the INA over temperature. To provide effective feedback the voltage drop across R_{BIAS} should be at least 2 V, with higher voltage drops resulting in bias points that are even more stable over temperature. The temperature coefficient of R_{BIAS} will also play a role; resistors with positive temperature coefficients will provide more feedback versus temperature than will resistors with negative coefficients.

In cases where the designer does not have a 2 V difference between the supply voltage and the required device voltage, a simple PNP current source offers a reasonable biasing option. This circuit has the advantage of requiring only a 1 V difference between the supply

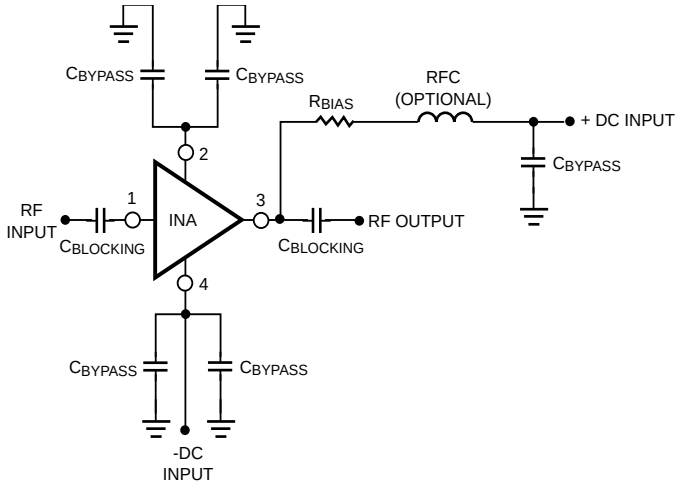


Figure 8. Biasing From ±Supply.

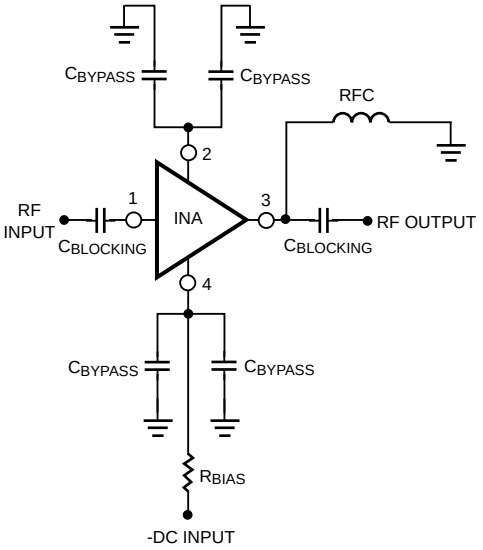


Figure 9. Biasing From a Negative Supply.

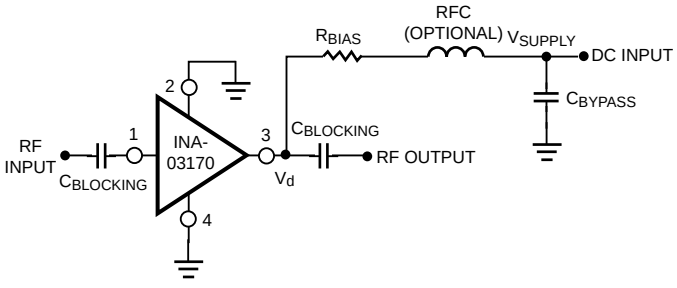


Figure 10. Biasing With a Stabilization Resistor.

voltage and the device operating voltage. A schematic for this circuit is shown in Fig. 11. Other biasing possibilities are discussed in Hewlett-Packard Application Note AN-S003: *Biasing MSA Series RFICs;* these circuits are also applicable to INA series RFICs.

Choke Networks

As with most microwave devices, RFCs or "chokes" must be used in conjunction with the DC biasing to prevent the very low AC impedance of the power supply from unduly loading the output of INAs. The important point to remember is that the choke network is a load appearing in parallel with the RF circuitry and termination. As a "rule of thumb," the total series impedance appearing between the INA output (bias) terminal and the power supply should be at least 10 times greater than that of the designed load impedance if the choke network is not to effect circuit performance. (The section on INA-03 VSWRs above is an example of a case where the choke network is specifically designed to alter circuit performance, and is therefore an exception to this rule.) In the typical bias stabilization resistor scheme, this means that the sum of the resistance of the stabilization resistor (R_{BIAS}) plus the impedance added by a series inductor acting as an RF choke ($2\pi fL$) should add up to at least 500 ohms (10 x nominal 50 Ω load).

Consider as an example an INA-03170 biased from a 12 V supply. From the data sheet, this device has a nominal device voltage V_d of 4.5 V. The device operating current is 12 mA, so the bias stabilization resistor has a value of (12 V - 4.5 V) / 0.012 A = 625 Ω. Since this value is greater than 500 Ω, no inductor needs to be used with this circuit.

As a second example, consider biasing the INA-01170 from a 12 V supply, for operation down to 10 MHz. The INA-01170 operates at a device current of 35 mA and has a typical device voltage of 5.5 volts. Now R_b = (12 V - 5.5 V)/.035 A = 186 Ω. An RFC providing (500 Ω - 186 Ω) = 314 Ω additional impedance must now be added to the choke system to avoid loading the output of the INA. Worst case will be at 10 MHz, so the value of the inductor should be at least 314 Ω / [2π(10 x 10^6 Hz)] = 5 μH. Since the 5 μH inductor is needed to add additional choke impedance, the bypass capacitor to ground must be attached on the power supply end of this element, not between it and R_{BIAS}. In theory the RFC can either precede or follow the bias resistor with identical results; empirical observations show that placing the resistor as the first element from the INA often yields better performance results.

Note that the appropriate value for the RF choke will be determined by the lowest frequency of operation required. For very low frequency operation, lossy elements such as ferrite beads can also be used to provide additional choke impedance.

INA Applications

50 Ω Gain Block/Low Noise Amplifier

The INA series was designed to function as low noise 50 Ω gain blocks. A circuit board to demonstrate their performance has been laid out using the circuit considerations discussed above. The substrate selected was epoxy-glass, having a dielectric constant of 4.8. Board of 32 mil thickness was used to minimize the parasitic inductance of the via holes. The layout is shown to scale in Fig. 11.

An assembly drawing (including component values) for an INA-02170 circuit using this board is shown in Fig. 12. The performance of the resulting amplifier is given in Table 1; this data is in good agreement with the expected performance from the data sheet characterization.

Multiplier/Harmonic Generator

The output spectrum of any amplifier will include harmonically

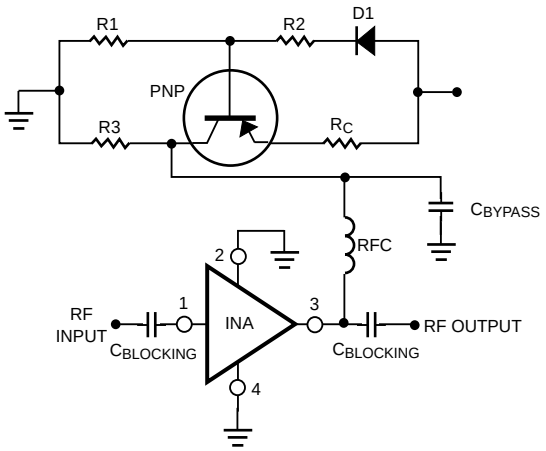


Figure 11. PNP Active Bias.

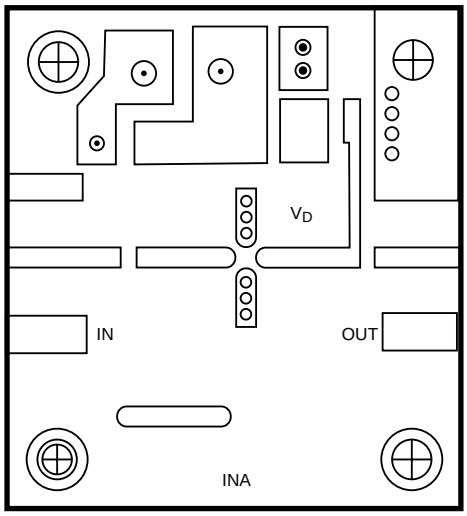


Figure 12. INA Circuit Board 2x Actual Size.

Table 1. INA-02170 Demonstration Amplifier Performance 12 V, 35 mA bias.

Freq MHz	S_{21} dB	S_{12} dB	Input VSWR	Output VSWR	k Factor	A_Z dB
100	33.56	-38.96	1.22	1.64	1.15	66.84
200	33.23	-41.11	1.41	1.61	1.37	65.88
300	32.88	-40.36	1.62	1.62	1.32	65.04
400	32.48	-39.68	1.84	1.59	1.28	64.54
500	32.09	-39.89	2.07	1.63	1.30	64.58
600	31.64	-39.07	2.30	1.64	1.24	65.10
700	31.09	-41.18	2.50	1.70	1.47	66.33
800	30.44	-37.58	2.64	1.76	1.18	68.02
900	29.57	-38.89	2.70	1.81	1.34	68.87
1000	28.62	-38.40	2.65	1.86	1.39	66.79
1100	27.59	-38.68	2.55	1.94	1.56	63.54
1200	26.44	-36.05	2.44	1.97	1.39	60.55
1300	25.30	-35.92	2.25	2.02	1.54	58.21
1400	24.12	-34.46	2.11	2.01	1.53	56.28
1500	22.93	-35.59	1.97	2.01	1.92	54.75
1600	21.76	-34.33	1.83	1.99	1.94	53.54
1700	20.59	-33.15	1.71	1.99	1.96	52.58
1800	19.48	-33.85	1.58	1.95	2.39	51.87
1900	18.51	-33.15	1.50	1.92	2.49	51.28
2000	17.53	-32.42	1.44	1.91	2.57	50.68
2100	16.46	-32.22	1.38	1.94	2.81	50.06
2200	15.40	-33.10	1.35	1.97	3.46	49.33
2300	14.41	-32.54	1.31	1.96	3.63	48.61
2400	13.43	-33.57	1.29	1.96	4.54	47.87
2500	12.85	-33.84	1.26	1.95	5.01	47.30
2600	12.04	-33.16	1.32	1.95	5.04	46.65
2700	10.86	-32.79	1.36	2.07	5.38	45.90
2800	10.20	-35.23	1.43	2.06	7.62	45.55
2900	8.94	-33.22	1.50	2.22	6.75	44.80
3000	8.24	-34.99	1.52	2.08	9.10	44.24

related components (2f, 3f, etc.) as well as the fundamental signal. By maximizing the harmonic output of an INA , the device becomes useful as a comb generator or frequency multiplier. As a comb generator, the entire output spectrum is used; for frequency multiplier use filters are typically added at the output of the INA to select the desired harmonic component.

To maximize harmonic output, the INA should be operated in hard saturation, with the RF input level approximately equal to the rated output power of the device. Note that each INA amplifier has a maximum RF input signal level listed in the ratings table on its data sheet; driving at input levels greater than this value can potentially shorten the operating lifetime of the INA. The bias point (device current) can also be adjusted to maximize harmonic output. Most commonly, bias current is increased from the nominal operating point, though this may vary with frequency of use and drive level. For use as a multiplier, the phasing of (electrical distance to) the filter used at the output is also a variable that will effect harmonic signal strength.

For maximal signal strength, the output (multiplied) signals should occur at frequencies within the normal 3 dB passband of the INA amplifier. The high f_{3dB} and relatively low P_{1dB} of the INA-03 geometry make it particularly appropriate for use as a multiplier. Typical output spectra for this device are shown in Fig. 14. No filters were used in the generation of this data. Figure 14a shows the output spectrum for an input signal of -2 dBm at 100 MHz with the bias optimized to 25 mA. Useful signals (30 dB down from input) occur to

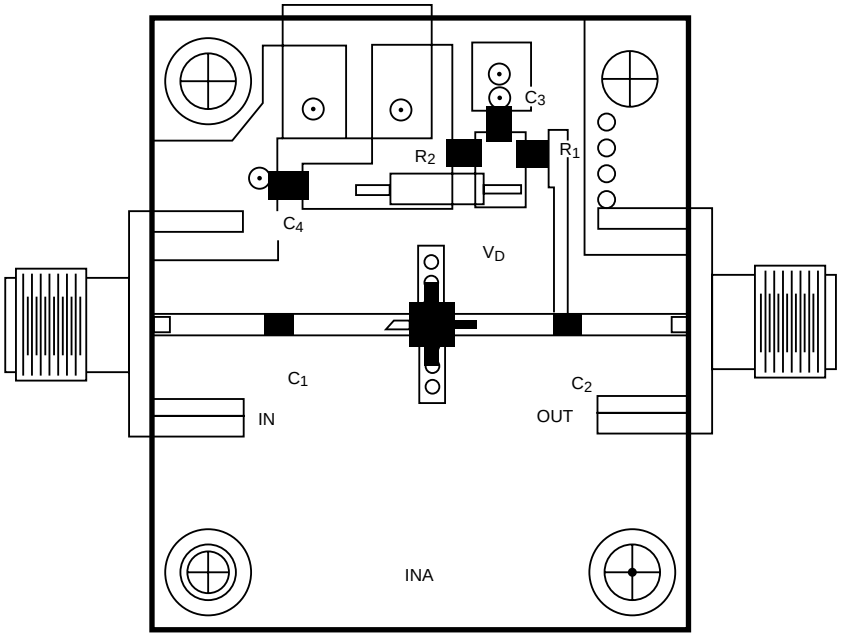
past 1 GHz. Figure 14b shows the output spectrum for an input signal of +10 dBm at 1 GHz; for this data the bias was optimized to 12 mA. Useful signals occur to 10 GHz.

Limiting Amplifier

The output power of a limiting amplifier should be constant over a wide range of input signal levels. The high gain and hard saturating characteristics of the INA family amplifiers make them appropriate for this kind of application.

The bias current at which an INA is operated will determine the power level at which it saturates. Thus for proper limiting, the bias point cannot be allowed to shift as a function of RF drive. The DC bias network must therefore provide a stiff current source for best results in limiting applications. An active bias circuit based on a pnp transistor is preferable to a simple dropping resistor as it will hold the bias current more constant. The cleanest output signal with lowest harmonics is obtained when the amplifier is operated at bias levels near its typical operating level.

RF output vs. RF input curves for an INA-02170 operated at 100 MHz, 1 GHz, and 2 GHz, with a bias current of 35 mA, are shown in Fig. 15. The flat saturation characteristic shown indicates that this INA can be successfully used as a limiting amplifier. Best limiting performance occurs within the 3 dB passband of the device. Again, remember that the input drive level into the INA should not exceed the maximum rating listed on the data sheet.



VIA HOLES: 0.031; 1/2 OZ. COPPER (EDC) TO FILL PLATED THRU HOLES
SCREW HOLES: 0.110
MATERIAL: 0.031 THICK FR-4 OR G-10, 1/2 OZ. COPPER BOTH SIDES
PLATING; 1 OZ. TIN LEAD BOTH SIDES

C_1 = 0.015 µF	L_1 = 10 µF
C_2 = 0.015 µF	R_1 = 180 Ω
C_3 = NOT USED	R_2 = NOT USED
C_4 = 0.015 µF	DEVICE = INA-02170

Figure 13. Assembly Drawing for INA-02170 Demonstration Amplifier.

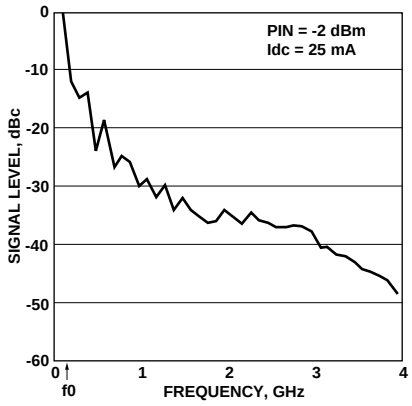


Figure 14a. Harmonic Generation vs. Frequency INA-03170, fo = 100 MHz.

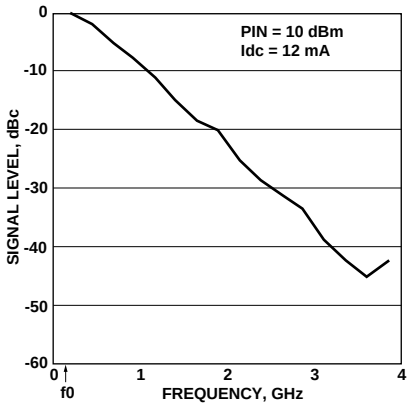


Figure 14b. Harmonic Generation vs. Frequency INA-03170, fo = 1 GHz.

Gain Control Amplifier

If the insertion power gain of an amplifier is a strong function of its bias current, then by adjusting I_d the gain may also be controlled, creating a variable gain amplifier. Although the gain of the INA amplifiers is a function of bias current, only a limited range of gain control, typically 10 dB or less, is practical. If this amount of control is sufficient, it can be obtained using a bias scheme which provides for current adjustment. Such a circuit is described in

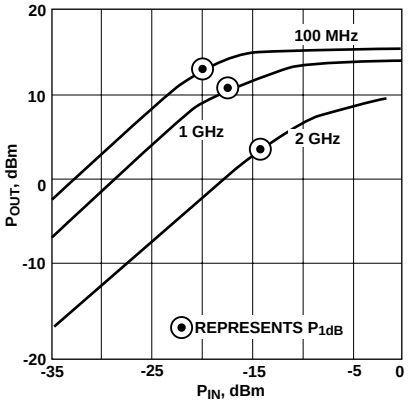


Figure 15. INA-02170 Limiting Characteristics I_d = 35 mA.

HP Application Note AN-S003: *Biasing MSA Series RFICs*. For applications requiring a wider range of gain control, a member of the HP IVA series of variable gain RFIC amplifiers is appropriate.

Transimpedance Amplifier

A transimpedance amplifier takes a current input and creates a voltage output. A very common use of such a circuit is in the receiving end of a fiber optics system, where the output current from a photodiode must be translated into usable RF energy. The low noise figure and high gain of the INA product make it a candidate for this function.

The circuitry for using an INA as a transimpedance amplifier is virtually identical to that for use as a conventional amplifier. The current from the photodiode is fed directly into the input of the INA amplifier, without the use of a blocking capacitor. The output of the INA usually drives a limiting or AGC amplifier before regeneration and de-multiplexing into the individual data channels. (Note that INA RFICs are also candidates for use in this conventional amplification role.)

The member of the INA family with the greatest potential as a transimpedance amplifier is the INA-02170. It has wider bandwidth than the INA-01170, better phase margin than the INA-03170, and lower noise performance than the INA-10386. Representational performance for this device includes a 65 dB transimpedance gain, a 600 MHz bandwidth, and 145 degrees of phase margin. Its equivalent input noise current is typically 7 pA/√Hz. It can handle input currents of ±1000 μA, and works well with photodiodes with 1 pF typical input impedances. A typical system application would be for the 622 Mb/s SONET system. For more information on the use of Hewlett-Packard gain blocks as transimpedance amplifiers, refer to Hewlett-Packard Application Note AN-S011: *Using Si MMIC Gain Blocks as Transimpedance Amplifiers.*

For technical assistance or the location of your nearest Hewlett-Packard sales office, distributor or representative call:

Americas/Canada: 1-800-235-0312 or (408) 654-8675

Far East/Australasia: Call your local HP sales office.

Japan: (81 3) 3335-8152

Europe: Call your local HP sales office.

Printed in U.S.A. 5965-8670E (6/97)