APPLICATION NOTE

# Gain Block Bias Networks

## Introduction

Skyworks gain block amplifiers are InGaP/GaAs HBT integrated circuits. They use a Darlington-pair transistor configuration with bias and feedback resistors properly selected to determine the gain, input and output impedances and bias parameters. A schematic representation of the amplifier is shown in Figure 1.

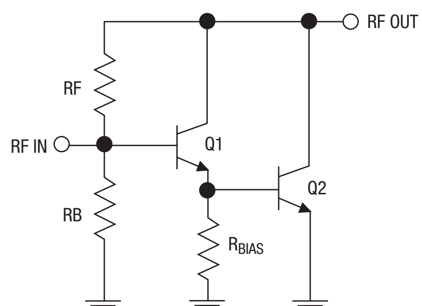


**Figure 1. Darlington Pair Amplifier**


## Abstract

As shown in Figure 2, the amplifier is a two-port device. C1 and C2 provide DC blocking in the RF input and output paths, respectively. RF ground is made through the remaining package pins. The RF output port is also used to provide bias to the amplifier through an external bias network (C4, R1 and L1). The values of the bias decoupling network components are selected based upon the frequency of operation and supply voltage available. This application note provides details on the proper selection of these components.


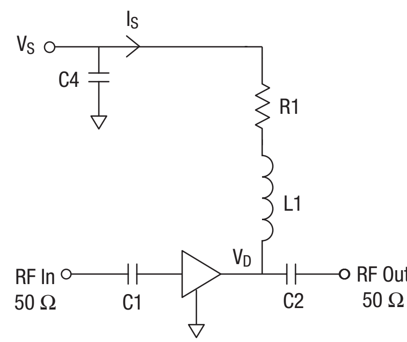


**Figure 2. Amplifier with Bias Network**

## Theory of Operation

Skyworks gain blocks are Darlington feedback amplifiers which feature a constant gain-bandwidth product for use as an RF gain block. They use a circuit topology in which two transistors are combined to form a configuration known as a Darlington pair. This transistor pair behaves like a single transistor with a current gain equivalent to the product of the current gain of the two transistors. Darlington transistors are connected in a common emitter configuration, while sharing the same collector contact.

The emitter current of the first transistor is applied to the base of the second transistor. This gives a high current gain (written $\beta$ or Hfe), and takes less space than two discrete transistors in the same configuration. As RF gain blocks, Darlington pairs are offered as integrated packaged devices, usable from very low frequency to over 10 GHz. They exhibit good broadband matching into 50 $\Omega$ and tight performance distributions.

The designed DC voltage that appears at the RF output of the amplifier, known as $V_D$, is fixed by the base-emitter voltages of Q1 and Q2, and by the voltage divider formed by RF and RB. The values of resistors RF and RB are selected to establish the necessary feedback to set the input and output impedances of the amplifier, as well as to set the base voltages and currents of the Darlington pair. Consequently, the amplifier is controlled by the current supplied to the output node. Thus, the amplifier is biased using a fixed current source rather than a fixed voltage source. The simplest current source is a resistor (R1) connected to a voltage source ($V_S$) as shown in Figure 2.

Figure 3 shows a simplified DC equivalent circuit of the Darlington pair gain block. The voltage that appears at the point labeled $V_D$, which is the RF output of the amplifier, is the series sum of the forward voltages of the base-emitter junctions of the transistors and the voltage drop across RF. The forward voltage of each of the base-emitter diodes is exponentially related to the current flowing through them, and is also affected by temperature.

Since the current through each of the base-emitter diodes directly controls the collector current for each of these transistors (these paths are not shown in this diagram), it is clearly important to control the bias current through each of the base-emitter junctions with a well-regulated current source. If a regulated voltage source is connected to the $V_D$ point in place of current source, the current through the transistors in the amplifier can vary widely in response to comparatively small changes in supply voltage. Additionally, due to the I-V characteristics of the base-emitter junction of each transistor, a small change in voltage or temperature can result in a large change in current.

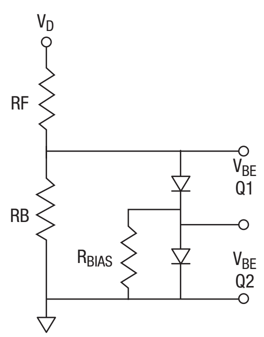


**Figure 3. Simplified DC Equivalent Circuit of Darlington Pair Gain Block**

Skyworks offers a series of gain block amplifiers in 3 different package styles (see Figure 4). These products differ by such parameters as gain, output power, frequency range and supply current draw, among others. Proper selection of a gain block depends upon the specific requirements of the application. Table 1 shows a list of gain blocks currently offered.

***NOTE:*** *For purposes of this application note, the SKY65015-92LF will be referenced. The information provided is common to other Skyworks gain block part numbers. Refer to the data sheets for specific part information.*


**Figure 4. Gain Block Package Styles**

## Table 1. Skyworks Gain Block Part List

| Part Number | Package | Frequency Range (GHz) | Test Frequency (GHz) | Gain Typ. (dB) | Quiescent Current Typ. (mA) | $V_{CC}$ (V) | Noise Figure Typ. (dB) | OIP3 (dBm) | $P_{1\ dB}$ (dBm) |
|---|---|---|---|---|---|---|---|---|---|
| SKY65013-70LF | SOT-89 | LF-7 | 2 | 12.5 | 40 | 5 | 5.5 | 29 | 12.5 |
| SKY65014-70LF | SOT-89 | LF-6 | 2 | 16 | 70 | 5 | 4.8 | 36 | 18 |
| SKY65015-70LF | SOT-89 | LF-6 | 2 | 18 | 70 | 5 | 4.2 | 35 | 17 |
| SKY65016-70LF | SOT-89 | LF-3 | 2 | 20 | 40 | 5 | 4.8 | 27 | 14 |
| SKY65017-70LF | SOT-89 | LF-6 | 2 | 20 | 100 | 5 | 4.5 | 35 | 20 |
| SKY65013-92LF | SC-88 | LF-12 | 2 | 12.5 | 40 | 5 | 5.8 | 29 | 12.5 |
| SKY65014-92LF | SC-88 | LF-9 | 2 | 15 | 70 | 5 | 5.4 | 36 | 15 |
| SKY65015-92LF | SC-88 | LF-6 | 2 | 18 | 70 | 5 | 4.8 | 35 | 18 |
| SKY65016-92LF | SC-88 | LF-3 | 2 | 20 | 40 | 5 | 5.4 | 27 | 20 |
| SKY65013-214LF | Micro-X | LF-6 | 2 | 11.5 | 40 | 5 | 5.4 | 29 | 11.5 |
| SKY65014-214LF | Micro-X | LF-6 | 2 | 13.5 | 70 | 5 | 4.6 | 36 | 13.5 |
| SKY65015-214LF | Micro-X | LF-6 | 2 | 16 | 70 | 5 | 5.2 | 24 | 16 |
| SKY65016-214LF | Micro-X | LF-3 | 2 | 19 | 40 | 5 | 6.5 | 20 | 19 |

The bill of materials for operation at 2 GHz for the SKY65015-92LF gain block amplifier circuit as shown in Figure 2 is shown in Table 2. Capacitors C1 and C2 are selected to provide DC blocking for the RF input and output. Capacitor C4 is used for a bias decoupling capacitor. This capacitor provides suppression of low frequency RF signals appearing across the DC bias lines.

The selection of inductor, L1 is based upon its self-resonant frequency (SRF) and its impedance in the band of operation ($F_0$). The inductor's SRF should be greater than $F_0$ and its impedance value should be approximately 10 times greater than Zo (50 Ω). Table 3 shows values for inductor L1 based upon the frequency of operation.

## Table 2. SKY65015-92LF Bill of Materials

| Part | ID | Description | Qty. | Size | Value | Units | Product Number | Manufacturer |
|---|---|---|---|---|---|---|---|---|
| 1 | C1, C2, C4 | Capacitor | 3 | 0603 | 47 | nF | GRM188R71E473K | Murata |
| 2 | L1 | Inductor | 1 | 0603 | 33 | nH | 0603CS-33NX_LU | CoilCraft |
| 3 | R1 | Resistor | 1 | 0603 | | Ω | See Current Limiting Res. Table | |

## Table 3. Recommended Chokes by Application Band

| Frequency[1] (GHz) | Inductance (nH) | SRF[2] (GHz) | Impedance ($X_L$)[3] | Mfg. Part Number | Manufacturer |
|---|---|---|---|---|---|
| 0.4 | 220 | 0.82 | 553 | 0805CS-221X_L_ | CoilCraft |
| 0.8 | 120 | 1.10 | 603 | 0805CS-121X_L_ | CoilCraft |
| 0.9 | 110 | 1.10 | 622 | 0805CS-111X_L_ | CoilCraft |
| 1.2 | 91 | 1.33 | 686 | 0805CS-910X_L_ | CoilCraft |
| 1.6 | 47 | 1.70 | 472 | 0805CS-470X_L_ | CoilCraft |
| 1.8 | 56 | 1.90 | 633 | 0603CS-56NX_L_ | CoilCraft |
| 1.9 | 47 | 2.00 | 561 | 0603CS-47NX_L_ | CoilCraft |
| 2.1 | 39 | 2.20 | 514 | 0603CS-39NX_L_ | CoilCraft |
| 2.2 | 33 | 2.30 | 456 | 0603CS-33NX_L_ | CoilCraft |
| 2.4 | 27 | 2.80 | 407 | 0603CS-27NX_L_ | CoilCraft |
| 3 | 22 | 4.60 | 414 | LQW18AN22NJ00 | Murata |
| 3.6 | 22 | 4.60 | 497 | LQW18AN22NJ00 | Murata |
| 4.2 | 22 | 4.60 | 580 | LQW18AN22NJ00 | Murata |
| 4.9 | 18 | 5.50 | 554 | LQW18AN18NJ00 | Murata |
| 6 | 15 | 6.00 | 565 | LQW18AN15NJ00 | Murata |

1. Evaluation board L1 nominal value = 33 nH (2.2 GHz). At high microwave frequencies, where no lumped element inductors are available, a ¼ wave length line with a stub may be used.
2. Self-resonant frequency
3. Choke selection is based upon SRF > $F_0$ and impedance ($X_L = 2*\pi*F*L$) value 10 times greater than $Z_0$ (50 $\Omega$). For extreme wideband operation 2 chokes may be combined, i.e. (33 nH and 110 nH).

In most electronic systems, the power supply produces a fixed voltage, rather than a fixed current to the devices comprising the system. The selection of R1 is based upon the system supply voltage available and the value of $V_D$ that occurs when the correct supply DC current is present, as well as the power dissipated by the resistor. The resistor value is derived from the following equation: $R = (V_S - V_D)/I_S$. The minimum resistor power dissipation rating is based upon the power dissipated across the resistor ($P_{DISS} = V^2 * R1$). It is recommended to use resistors rated for at least twice the calculated value of $P_{DISS}$; otherwise, use parallel or a series split of several resistors that are each easily capable of dissipating their dissipated power levels. For the evaluation circuit as supplied by Skyworks, the default resistor size is '0603' with a power rating of 1000 mW. Check the manufacturer's power rating when using smaller sized resistors.

## Table 4. Current Limiting Resistor Values

| $V_S$ (V) | R1 Resistance ($\Omega$) | Mimimum Resistor Power Dissipation Rating (mW) | Product Number | Manufacturer |
|---|---|---|---|---|
| 4.4 | 0.5[1] | – | ERJ-3GEY0R00V | Panasonic |
| 5 | 8.2 | 125 | ERJ-3GEYJ8R2V | Panasonic |
| 6 | 24 | 250 | ERJ-3GEYJ240V | Panasonic |
| 7 | 36 | 500 | ERJ-3GEYJ360V | Panasonic |
| 8 | 51 | 500 | ERJ-3GEYJ510V | Panasonic |
| 9 | 68 | 1000 | ERJ-3GEYJ680V | Panasonic |
| 10 | 82 | 1000 | ERJ-3GEYJ820V | Panasonic |
| 12 | 110 | 1000 | ERJ-3GEYJ111V | Panasonic |

1. At $V_S$ = 4.4 V, the series resistance (R1) is the DC resistance of the bias inductors (L1, L2 and L3) and trace lines.

## Low Frequency Operation

For operation with signals below 300 MHz, Ferrite Bead (L2) and Inductor (L3) may be added. Figure 5 shows the schematic for low frequency applications below 300 MHz. Resistor R1 must also be added in series with the inductors to limit the power supply current when the power supply provides a constant voltage, as discussed above.

The modified bill of materials for extreme low frequency performance of the SKY65015-92LF is shown in Table 5. Gain (lS21l) performance using the bill of materials from Table 2 and Table 5 is shown in Figure 6. The ferrite bead and inductor L3 improve the frequency response below 300 MHz and reduce the variation in bias current, at the cost of degraded performance at 1 GHz and the monetary cost of the components themselves.

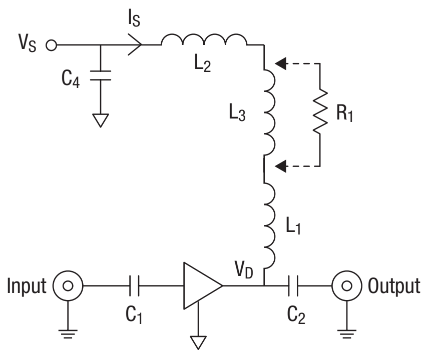


**Figure 5. Amplifier with Low Frequency Bias Network**

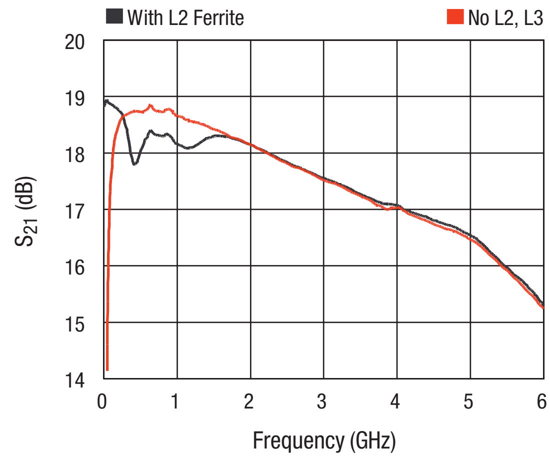


**Figure 6. SKY65015-92LF $S_{21}$ vs. Frequency, $I_S$ =70 mA, $T_A$ = 25 °C**

### Table 5. SKY65015-92LF Bill of Materials for Low Frequency Applications

| Part | ID | Description | Qty. | Size | Value | Units | Product Number | Manufacturer |
|---|---|---|---|---|---|---|---|---|
| 1 | C1, C2, C4 | Capacitor | 3 | 0603 | 47 | nF | GRM188R71E473K | Murata |
| 2 | L1 | Inductor | 1 | 0603 | 33 | nH | 0603CS-33NX_LU | CoilCraft |
| 3 | L2 | Ferrite Bead | 1 | 1810 | 1600 | Ω | FBMH4525HM162N-T | Taiyo-Yuden |
| 4 | L3 | Inductor | 1 | 0805 | 110 nH | nH | 0805CS-111X_L_ | CoilCraft |
| 5 | R1 | Resistor | 1 | 0603 | | Ω | See Current Limiting Res. Table | |

## Summary

Skyworks gain block amplifiers are InGaP/GaAs HBT integrated circuits using the Darlington-pair transistor configuration which requires a constant DC current applied to the output port to bias the device. Factors such as voltage supply level, system characteristic impedance, frequency of operation and cost should be taken into account when selecting the proper DC current limiting and RF decoupling bias components and RF DC blocking components in the signal path. The information provided in this application note addresses these tasks. Further information about specific gain block amplifiers may be found in the appropriate data sheets at www.skyworksinc.com.