## Bias Scheme for NBB-Series Amplifiers

### Introduction

RFMD's NBB-series amplifiers are monolithic integrated circuits (IC's) using InGaP/GaAs HBT technology. The NBB-series uses a Darlington-pair transistor configuration with bias and feedback resistors properly selected to determine the gain, input and output match and bias (both voltage and current) parameters. A schematic representation of the NBB-series amplifier is shown in Figure 1.
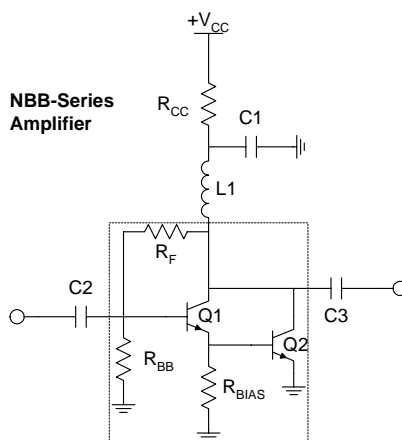


**Figure 1. Schematic representation of Darlington-pair feedback amplifier used in the NBB-series amplifiers.**
(On-chip components are shown inside the dotted outline.)

The amplifier may be analyzed as a two-port network with the input (left) and output (right) as shown in Figure 1. The output node is also used to provide bias to the amplifier through the bias network (top), which is shown in the figure. The packaged part has a total of four ports: input, output and bias, and two ground connections for minimization of ground inductance.

### Bias Circuit Topology

The input voltage of the amplifier is fixed by the base-emitter voltage of $Q_1$ and $Q_2$, and the output voltage is determined by the voltage divider established by $R_{BB}$ and $R_F$. Hence, the output voltage is a designed parameter and the amplifier is controlled by the current supplied to the output node. Thus, the amplifier is biased using a current source rather than a voltage source. The simplest current source is a resistor ($R_{CC}$) connected to a voltage source ($V_{CC}$) as shown in Figure 2.

The current source, comprising voltage source $V_{CC}$ and resistor $R_{BIAS}$, should be selected such that the designed amplifier voltage ($V_D$) appears at the output with the desired current ($I_{CC}$) flowing into the amplifier. The governing relationship for the bias circuit shown in Figure 2 is:

$$I_{CC} = \frac{(V_{CC} - V_D)}{R_{BIAS}}$$

Eq. 1

The recommended amplifier current ($I_{CC}$) and design value of the amplifier voltage ($V_D$) for each NBB-series amplifier is specified on the data sheet. Hence, if a $V_{CC}$ is selected, then the desired $R_{CC}$ may be calculated from Equation 1. A bias resistor table is provided with each datasheet which is calculated using this method.

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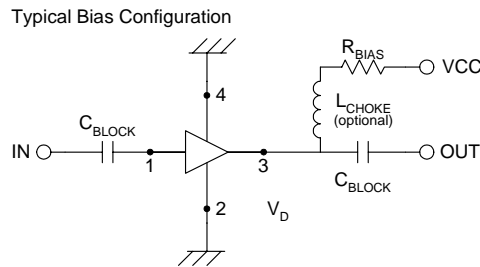
Typical Bias Configuration



**Figure 2.  Typical bias configuration for the NBB-series amplifier.**
The device is current-controlled due to the nature of the circuit. The simplest current source which can be connected is a resistor (RBIAS) and voltage supply (VCC) as shown. Two blocking capacitors (CBLOCK) are shown to prevent DC-loading of the circuit by an adjacent component.

Alternatively, a current steering circuit (see Sedra and Smith, *Microelectronic Circuits*, 2nd Edition, page 508) may be used to bias the amplifier as shown in far right of Figure 3. Such circuits are commonly used to bias various stages of an IC. The circuit uses one positive power supply ($V_{CC}$). The DC reference current $I_{REF}$ is generated in the branch that consists of the diode-connected transistor, $Q_1$, resistor $R_1$, and the diode-connected transistor $Q_2$. Assuming all transistors have high current gain and hence the base currents are negligibly small, then the reference current is given by:

$$I_{REF} = \frac{V_{CC} - V_{BE1} - V_{BE2}}{R_1}$$

Eq. 2

Diode-connected transistor $Q_1$ forms a current mirror with $Q_3$. Thus $Q_3$ will supply a constant current $I_{CC}$ equal to $I_{REF}$. Transistor $Q_3$ can supply this current to any load as long as the voltage that develops at the collector does not exceed that at the base ($V_{CC}$-$V_{BE3}$).
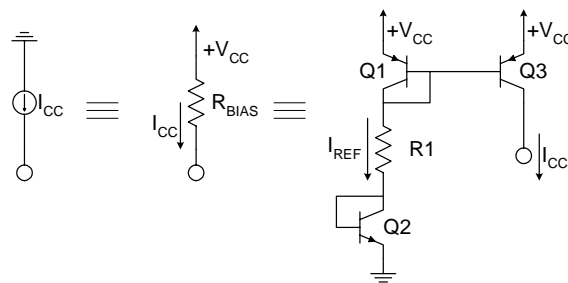


**Figure 3.  The family of NBB-series amplifiers is biased using a current source (left).**
The simplest current source is a resistor connected to a voltage source (middle). Alternatively, a current steering circuit (right) may be used as well to produce a constant current (see Sedra and Smith, *Microelectronic Circuits*, 2nd Ed., page 508).

## RF Choke Selection

The RF choke in series with the bias resistor is recommended as the bias line will effectively load the output of the amplifier. When considering power delivered from the amplifier to a load, it is useful to model the output of the amplifier as a Thevenin equivalent: a voltage $V_{th}$ with internal impedance $Z_O$ (50Ω for a matched amplifier). When an amplifier is driven in a 50Ω load, only half the Thevenin voltage ($V_{th}/2$) appears across the load resistor. If a RF choke is not used then the voltage across the load reduces to $V_{th} \times R_{BIAS}/(2R_{BIAS}+50)$. The power deliver to the load is reduced by the reduction in the voltage which appears across the load resistor. Taking this ratio, the reduction in power (in dB) by not using an RF choke can be expressed by:

$$P_{REDUCTION} = 20 \times LOG\left(\frac{(V_{th}/2)}{V_{th}R_{BIAS}/(2R_{BIAS}+50)}\right)$$

Eq. 3

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$$P_{REDUCTION} = 20 \times LOG\left(\frac{(2R_{BIAS} + 50)}{2R_{BIAS}}\right)$$

Eq. 4

In the case of the NBB-300 with a bias resistor of $120\Omega$ ($V_{CC}$=10V), the reduction in power delivered to a $50\Omega$ load is 1.64dB.

In order to prevent loading of the output of the amplifier, a reactance of five to 10 times the characteristic impedance is desired. At upper microwave frequencies where lumped element chokes are not available, a microstrip bypass circuit is desirable. Such as choke circuit would consist of a 90° high-impedance line with a short-circuit radial stub. If the tolerances are an issue with the short-circuit stub, a short circuit may be provided from a suitable capacitor instead. In such instances the self-resonance frequency of the capacitor must be considered.

### Bias Resistor Selection

The output voltage of the amplifier ($V_D$) varies as a function of both the bias current ($I_{CC}$) and the temperature. The variation of device voltage versus current is supplied on each data sheet. From this data, a coefficient may be calculated for the change in $V_D$ versus current (see Figure 4). Notice that all coefficients are positive, indicating that the device voltage increases with increasing current. A large bias resistor is desirable because it reduces the variation in bias current, reducing the change in important amplifier parameters such as P1dB and IP3. Selecting a large bias resistor, $R_{BIAS}$, requires selecting a higher voltage supply ($V_{CC}$) to maintain the desired bias current ($I_{CC}$). The current steering circuit (see Figure 3) provides a steady current and minimizes variations in amplifier parameters as well.

**Table 1. Summary of the coefficient of the change in device voltage ($V_D$) versus amplifier current ($I_{CC}$).**
*The data is calculated from the plot provided with each datasheet. The positive coefficient indicates that the device voltage increases with increasing current.)*

| NBB Amplifier Model Number | Typical Device Voltage Variation with Current, $\delta V_D/\delta I_{CC}$ (in V/A) |
|---|---|
| NBB-300 NBB-301 | +4 |
| NBB-400 NBB-401 | +4 |
| NBB-410 | +7 |
| NBB-500 | +3 |

Device voltage ($V_D$) decreases with increasing temperature as shown in Figure 5. An average rate of change of the device voltage versus temperature is calculated and provided in the table. The device voltage can be expressed as a function both current and temperature as follows.

$$V_D(I_{CC}, T) = V_O + \left(\frac{\delta V_D}{\delta I_{CC}}\right) \times I_{CC} + \left(\frac{\delta V_D}{\delta T}\right) \times (T - T_O)$$

Eq. 5

**Table 2. Summary of the dependence of the amplifier output voltage ($V_D$) versus temperature.**
*The coefficient of the change in device voltage ($V_D$) versus ambient temperature is calculated from the tabular data. The negative coefficient indicates that the device voltage decreases with increasing current.*

| Model Number | Amplifier Current (mA) | Device Voltage ($V_D$) versus Temperature | | | Temp. Coef. (mV/°C) |
|---|---|---|---|---|---|
| | | -45°C | +25°C | +85°C | |
| NBB-300 NBB-301 | 50 | 4.03 | 3.86 | 3.70 | -2.75 |
| NBB-400 NBB-401 | 50 | 4.09 | 3.90 | 3.74 | -2.80 |
| NBB-410 | 65 | 4.19 | 4.00 | 3.88 | -2.85 |
| NBB-500 | 35 | 4.12 | 3.94 | 3.78 | -2.70 |

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Equation 5 may be substituted into Equation 1 and solved for $I_{CC}$ to get:

$$I_{CC} = \frac{V_{CC} - \left(\frac{\delta V_D}{\delta T}\right) \times (T - T_O)}{R_{BIAS} + \left(\frac{\delta V_D}{\delta I_{CC}}\right)}$$

Eq. 6

Equation 6 may be differentiated with respect to temperature to get an expression which is useful to observe the effect of the bias resistor (and supply voltage) selected by the user:

$$\frac{\delta I_{CC}}{\delta T} = \frac{-\left(\frac{\delta V_D}{\delta T}\right)}{R_{BIAS} + \left(\frac{\delta V_D}{\delta I_{CC}}\right)}$$

Eq. 7

For example, an NBB-400 biased from a 5V supply ($V_{CC}$) using a 22Ω resistor ($R_{CC}$) will exhibit the following current change with respect to temperature,

$$\frac{\delta I_{CC}}{\delta T} = \frac{-(-2.8)}{(22 + 4)} = 0.108 mA/°C$$

Eq. 8

which translates into a variation of 14mA over the temperature range from -40°C to +85°C. By comparison, if a 12V supply rail is with a 162Ω bias resistor, then a change in current with respect to temperature reduces to 0.016mA/°C. This translates into a current variation of only 2.2mA over the same operating temperature range.