

# Silicon Microwave Broadband Amplifier MMICs

## Introduction

In the field of communications equipment, and particularly consumer equipment such as cable TV and super high frequency receivers or television tuners, there is a great demand for amplifiers in the range from UHF to microwave. Also, there has recently been an increased need to reduce the sizes of these amplifiers, which can be accomplished by the use of Silicon MMICs.

It is difficult to make Silicon MMICs for use in the UHF and higher bands. Therefore, by improving the processes used with conventional analog ICs, NEC developed a new Silicon MMIC technology based on the techniques used to attain the high frequency performance of their discrete silicon microwave transistors.

Generally speaking, when MMIC amplifiers are designed, their circuitry is usually based on a differential amplifier approach in which there is a high input and a low output impedance. This approach gives large variations of impedance at the high frequencies, and broadband matching is difficult. Therefore, for high-frequency all-purpose amplifiers, a single-ended feedback amplifier circuit is selected to reduce noise and distortion and to match the input/output impedance to 50 Ω.

## Development of the New Process Technology

Since the goal is an analog MMIC which can be used up to more than 1 GHz the basic goal of the new process design was the reduction of base resistance  $r_{BB}$ , such that the transistor would have a gain-bandwidth product (ft) of 5 GHz or higher, and therefore high insertion gain  $|S_{21}|^2$ . Figure 1 shows the sectional view of a transistor cell of the newly developed process. This process has the following characteristics:

- Dielectric isolation using oxide film is adopted to isolate a transistor from its neighbor, thereby reducing the parasitic capacitance.

- A thin epitaxial layer is used to reduce the collector resistance and also to facilitate dielectric isolation.
- Shallow bases produced by ion implantation and shallow emitters produced by diffusion from As-doped polysilicon are used in order to realize ft greater than 5 GHz.
- Reduction of noise and increase in gain are achieved by using an emitter stripe measuring 1 μm in width. This reduces the base resistance and also reduces the E-B junction capacitance.
- High reliability is achieved by adopting a Ti-Pt-Au metalization structure for the electrodes. This metalization increases the permissible current of the interconnections and also improves corrosion resistance.
- A DNP (Direct Nitride Passivated Base Surface) structure is adopted to improve the moisture resistance, and therefore improves the reliability when a plastic mold package is used.

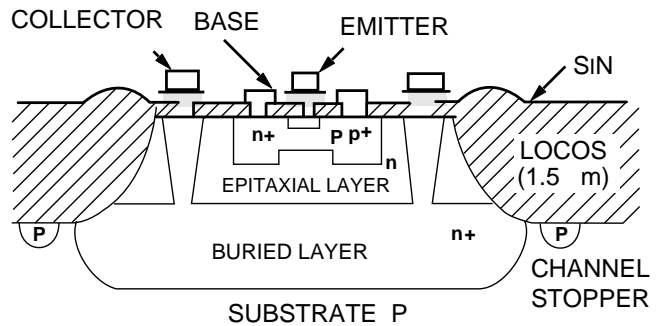


Figure 1. Sectional view of transistor cell.

## Circuit Characteristics

A study was made of the various types of circuits which might conceivably be used in broadband monolithic IC amplifiers, including the differential type and the single ended feedback type. A multiple negative-feedback amplifier

circuit, such as the UPCI651G shown as an example in Figure 2, was adopted. This circuit has the following characteristics:

- Good gain frequency characteristics. Since there are multiple feedback circuits, the circuit is stable with respect to variations in the source voltage and temperature.
- By selecting the feedback resistance, the gain and the input/output impedance can be adjusted easily.
- The noise characteristics are good because the resistance on the emitter side of the input-stage transistor is lower than the emitter resistance in the differential amplifier type circuit.
- There is low distortion because impedance matching with the external circuits is better, and there is a higher output efficiency than in the differential amplifier type circuit.

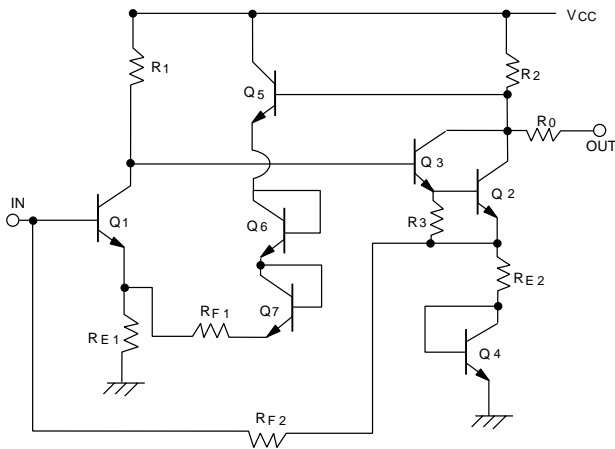
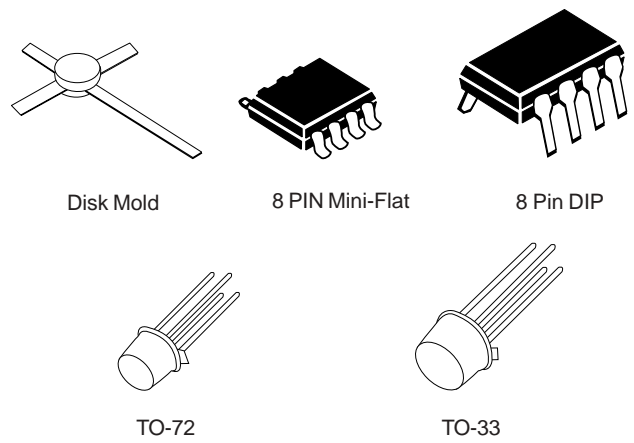


Figure 2. Circuitry of UPCI651G



Drawing 1. Packages of Si-MMIC series.

**Overview of Characteristics**

Drawing 1 shows the various packages available for silicon microwave monolithic IC (Si-MMIC) products. A large range of products are available in a variety of packages, including a disk mold (UPCI651G), a miniflat (UPCI652G), general purpose 8-pin DIPs (UPCI655C, UPCI656C) and canned types for the communications industry (TO-72 UPCI653A and TO-33 UPCI654A). Table 1 classifies the various packages and part numbers by the source voltages they use, and Table 2 shows the characteristics of each part number. Drawing 2 shows the UPCI651G chip for 5 V use. Models for 10 V use, such as the UPCI656C, apply the master slice approach in order to change the parts of the internal wiring.

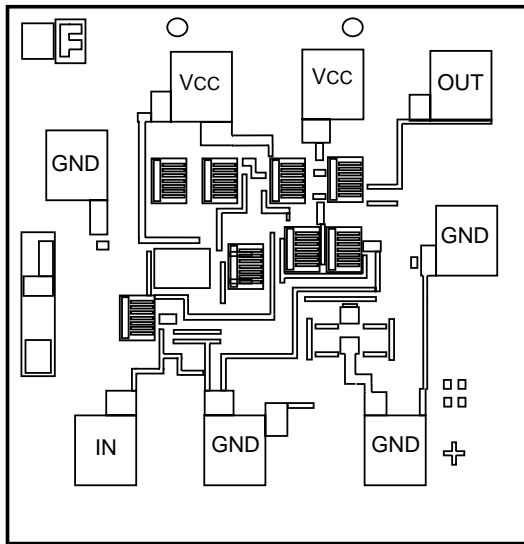
Source Voltage	Package and Product Names				
	Disk Mold	8-Pin Mini-flat	TO-72 Can	TO-33 Can	8-Pin DIP
Vcc = 5 V	UPC1651G	UPC1652G	UPC1653A		UPC1655C
Vcc = 10 V				UPC1654A	UPC1656C

Table 1. List of Products of Si-MMIC series.

Part Number	DEVICE CHARACTERISTICS									
	V <sub>cc</sub> (V)	I <sub>cc</sub> (mA)	B.W (MHz)	S <sub>21</sub>   <sup>2</sup> (dB)	S <sub>11</sub>   <sup>2</sup> (dB)	S <sub>22</sub>   <sup>2</sup> (dB)	S <sub>12</sub>   <sup>2</sup> (dB)	NF (dB)	P <sub>o</sub> (dBm)	Package
UPC1651G	5	20	1,200	19	15	10	24	5.5	+5	Disk Mold
UPC1652G	5	20	1,200	18	20	15	26	5.5	+5	8Pin Mini Flat
UPC1653A	5	20	1,300	19	23	16	28	5.5	+5	TO-72
UPC1654A	10	45	1,100	19	18	12	27	5.5	+10.5	TO-33
UPC1655C	5	20	1,000	18	25	10	24	5.5	+5	8 Pin DIP
UPC1656C	10	45	850	20	20	7	27	5.5	+10.5	8 Pin DIP

Table 2. List of Characteristics.

Below are the high frequency characteristics for some of these silicon MMICS. Figure 3 illustrates the high frequency characteristics of the gain |S<sub>21</sub>|<sup>2</sup>, using the UPC1653A as an example. At a source voltage V<sub>cc</sub> of 5 V, a gain |S<sub>21</sub>|<sup>2</sup> of 19 dB is obtained. The 3 dB roll-off frequency is 1.3 GHz. Figure 3 also gives the input/output return loss |S<sub>11</sub>|<sup>2</sup>, |S<sub>22</sub>|<sup>2</sup> and the isolation |S<sub>12</sub>|<sup>2</sup> characteristics. Throughout the 1 GHz band, both input and output are matched to 50 Ω, with an input/output return loss of 10 dB or more. There are also excellent isolation characteristics of 25 dB or more. The packages make a difference as to the 3 dB bandwidth, but in the low frequency flat gain area, about 19 dB is obtained in all the part numbers. Similar characteristics are also true for |S<sub>11</sub>|<sup>2</sup>, |S<sub>22</sub>|<sup>2</sup> and |S<sub>12</sub>|<sup>2</sup>.



Drawing 2. UPC1651G chip.

The frequency characteristics of the noise figure (NF) are shown in Figure 4. A noise figure of 5 dB is obtained at 500 MHz. The input/output power characteristics of the UPC1654A are shown in Figure 5. An output power of +10.5 dBm is obtained at V<sub>cc</sub> of 10 V at the 1 dB compression point. Figure 6 shows the third order intermodulation distortion characteristics of the UPC1654A. It is clear that the third order intermodulation distortion of -44 dB is obtained when there is an output of 0 dBm per frequency.

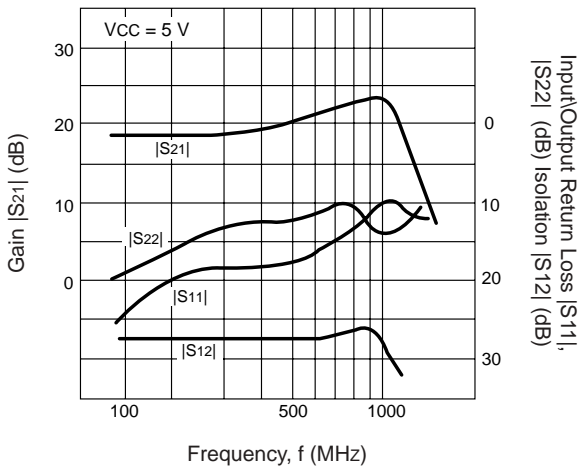


Figure 3. S-Parameters of UPC1653A.

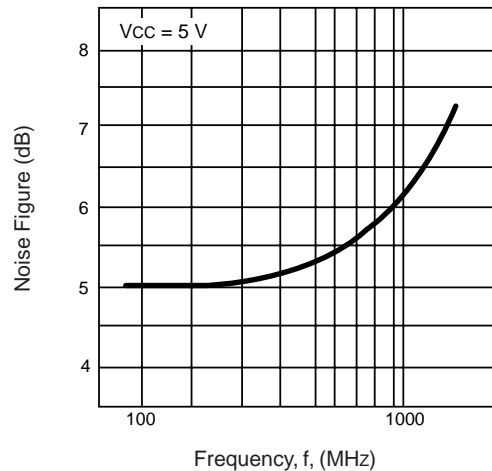


Figure 4. Noise Figure (NF) of UPC1653A.

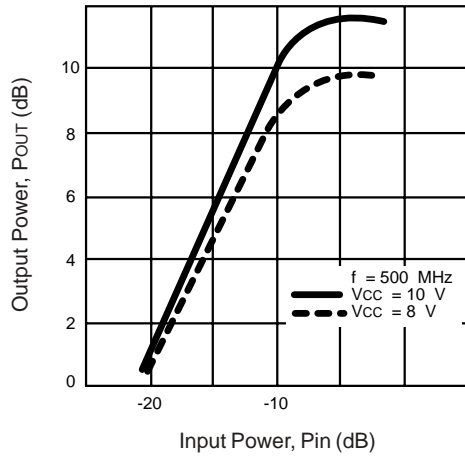


Figure 5. Input/Output Power of UPC1654A.

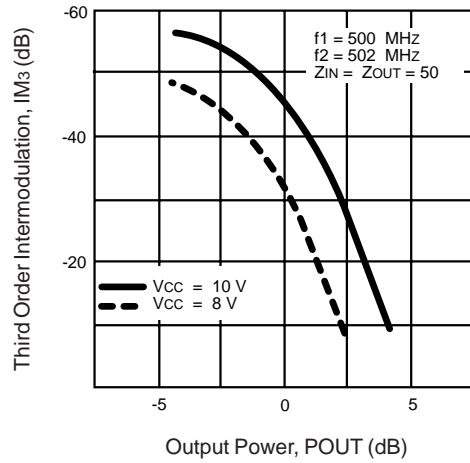


Figure 6. Third Order Intermodulation Distortion of UPC1654A.

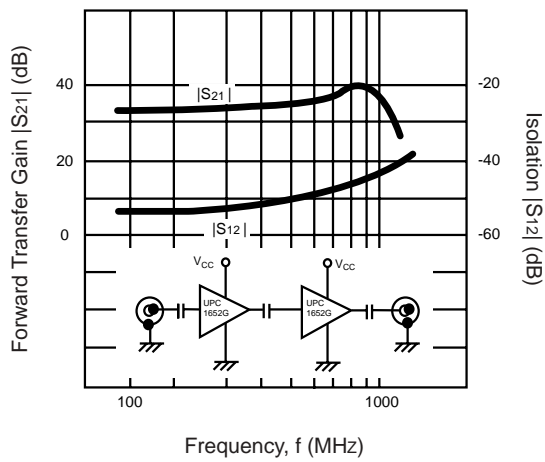


Figure 7. |S<sub>21</sub>|<sup>2</sup> and |S<sub>12</sub>|<sup>2</sup> when two stages of UPC1652G are connected.

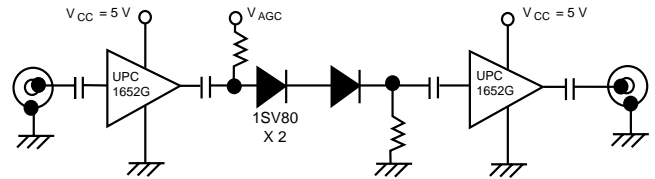


Figure 8. Configuration of AGC Amplifier Using UPC1652G.

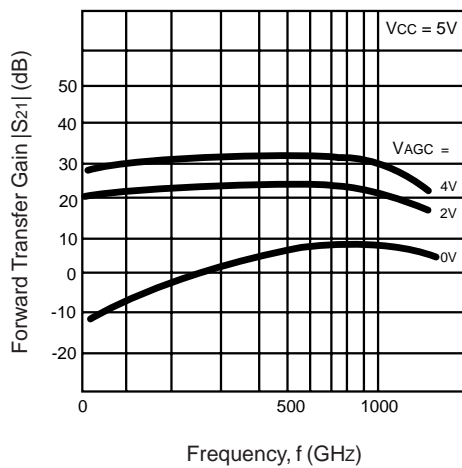


Figure 9. Gain (|S<sub>21</sub>|) of AGC Amplifier.

### Examples of Applications

As was mentioned in the previous section, the distinctive features of this series of Silicon MMICs are that the input/output impedance is matched to 50  $\Omega$ , and there is good isolation between input and output. Therefore, if this IC is cascaded, broadband amplification with an extremely high gain will be possible. An example of this is given in Figure 7 which shows the  $|S_{21}|^2$  and  $|S_{12}|^2$  when two UPCI652G devices are connected. It is clear that a broadband amplifier with an extremely high gain and good isolation can easily be configured. Figure 8 shows an AGC amplifier configured by cascading two UPCI652Gs with PIN diodes. Figure 9 shows its AGC characteristics. An AGC amplifier with a dynamic range of 25 dB can easily be produced using these ICs.

### Precautions During Use

- Choose a ground pattern that is as broad as possible, and avoid increases of the grounding impedance (since this can cause oscillations).

- Since these MMICs are designed to have an input/output impedance of 50  $\Omega$ , match the signal sources and the load impedance to 50  $\Omega$ . These are feedback type amplifiers, therefore oscillations can occur if they are used with input/output in a nearly open state.

- Use input/output capacitors for AC coupling. Select the capacitor values so that the impedance will be sufficiently low over the frequency band of interest, e.g., 1,000 pF or 2,200 pF.

- Use bypass capacitors at the Vcc terminals (e.g., 1,000 pF or 2,200 pF).

- When using the can packages, ground the cases in order to prevent oscillations and to reduce the thermal resistance.

The circuits listed in this application note are not aimed at mass-production designs, which take into consideration the deviations or the temperature characteristics of the parts. Please note that our company does not assume the responsibility for patents on the circuits listed here.

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