

### Linear Arrays Have Advantages Over Discrete Transistors

Discrete transistors have been used to build RF up/down converters in the past because they were the only cost effective technology available. Linear semiconductor process improvements have increased the frequency response of ICs to the point where linear arrays are rapidly replacing discrete devices. Linear arrays are a group of transistors made with an IC process, and there can be both NPN and PNP transistors on one piece of silicon. The linear array is usually packaged in a PDIP or SOIC case, but the next generation arrays will be packaged in a SOT36 outline as well.

Discrete transistors are hard to use because each transistor is expensive and space consuming, so the design becomes an art of utilizing each transistor to its maximum limit, an art which can take years to master. Single transistor designs, see Figure 1, predominate in low cost equipment where the design requirements are not very severe. More transistors are required to meet the demanding specifications imposed by higher cost equipment, because each transistor is limited in the power gain it can supply. Also, all of the transistors must have a bias circuit which usually includes negative feedback for DC stability. Some gain is lost because of this bias circuitry, so multistage transistor designs are required for all but the simplest requirements.

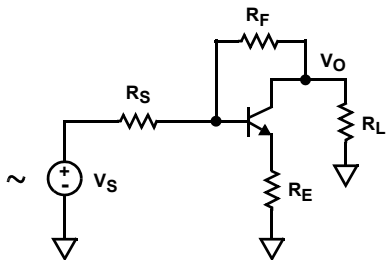


FIGURE 1. DISCRETE TRANSISTOR AMPLIFIER

The multistage transistor amplifier design shown in Figure 2 uses Q<sub>4</sub> and Q<sub>5</sub> for bias stability, while Q<sub>2</sub> does the amplification. This circuit nearly achieves the maximum transistor gain because the bias stability is achieved through transistor matching rather than negative feedback. This highlights another shortcoming of discrete transistor designs which is their lack of matching characteristics. Without matching most of the advantage gained by the amplifier shown in Figure 2 is lost. After the first transistor is paid for in a linear array, additional transistors cost little because they take little space on the same piece of silicon. This multistage circuit configurations can be employed with linear arrays at a small additional cost. Many transistors, some resistors, and sometimes capacitors can be included on the same piece of silicon thus further easing multistage circuit design.

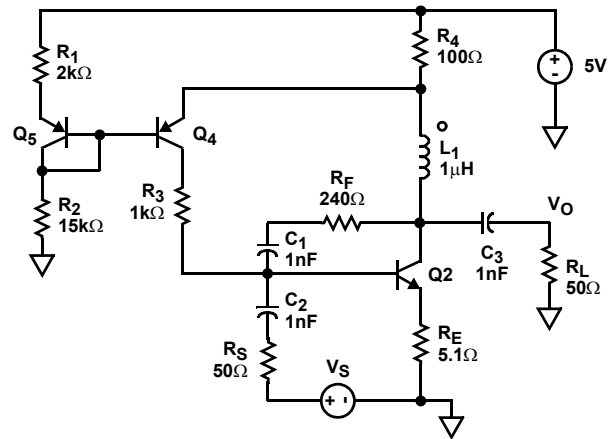


FIGURE 2. MULTISTAGE TRANSISTOR AMPLIFIER

The advantages of linear arrays over discrete transistors are less components, increased reliability, decreased incoming test time, lower cost, and better circuit performance. Discrete transistors retain one advantage over linear arrays because they can be fabricated for very special performance characteristics such as super high frequency response or high breakdown voltage.

### What Comprises A Linear Array

The two first items which are considered when designing a linear array are what semiconductor process and what package will be used. The process determines the parameters such as frequency response, gain, and breakdown voltage that the transistors in the linear array will have. The package determines the size of the linear array die and the number of leads (bond pads), hence it ultimately determines the number of transistors which can be put in the array.

The types of devices and how they will be bonded out are determined by product marketing. If the array is to be general purpose it will contain a block of NPN bipolar transistors, a block of PNP bipolar transistors, maybe some FET transistors if the process allows, and possibly some passive devices.

Figure 3 shows the layout diagram for the basic die which is used to make the HFA3xxx series of linear arrays. Notice that there is a block of 15 NPN bipolar transistors, a block of 11 PNP bipolar transistors, and a block of 4 FET transistors. The process used to make the HFA3xxx die yields NPN transistors with an  $f_t$  of 9GHz and PNP transistors with an  $f_t$  of 5.5GHz. The parameter  $f_t$  is a measure of the transistor's high frequency performance, and it is often unsymmetrical (NPN vs PNP) as shown here. There are two metal layers with interconnections which can be used to connect the transistors contained in the HFA3xxx die into various circuit configurations.

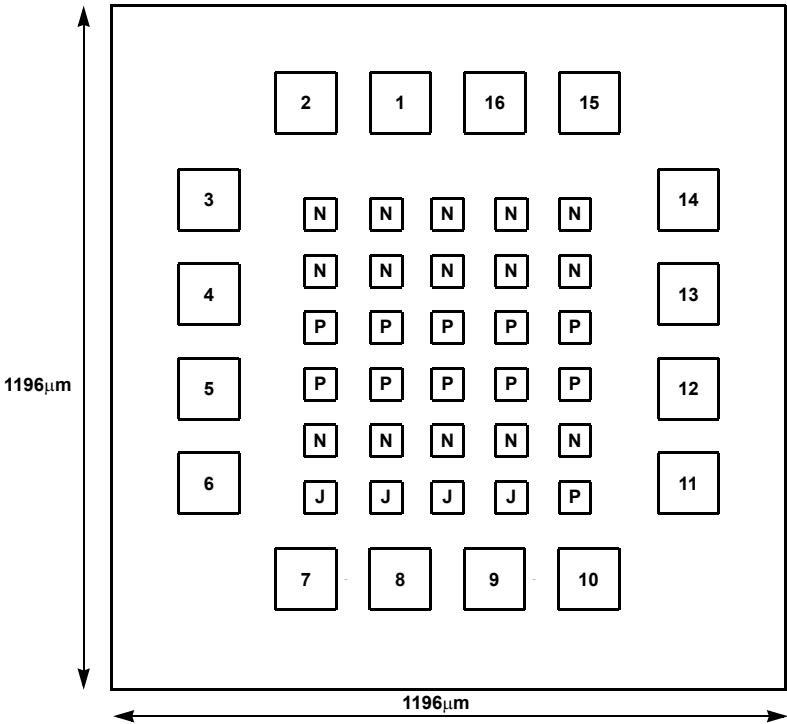


FIGURE 3. LAYOUT DIAGRAM FOR THE HFA3XXX LINEAR ARRAYS

Four different linear arrays are made from the same base HFA3xxx die by using the metal masks to connect different transistors to the bonding pads. These linear arrays, shown in Figure 4, are the HFA3046 and the HFA3127 linear arrays which contain all NPN transistors, the HFA3128 which contains all PNP transistors, and the HFA3096 which contains a mix of NPN and PNP transistors. These linear arrays have been available for design since 1993, and the multistage amplifier shown in Figure 2 is made from the HFA3096.

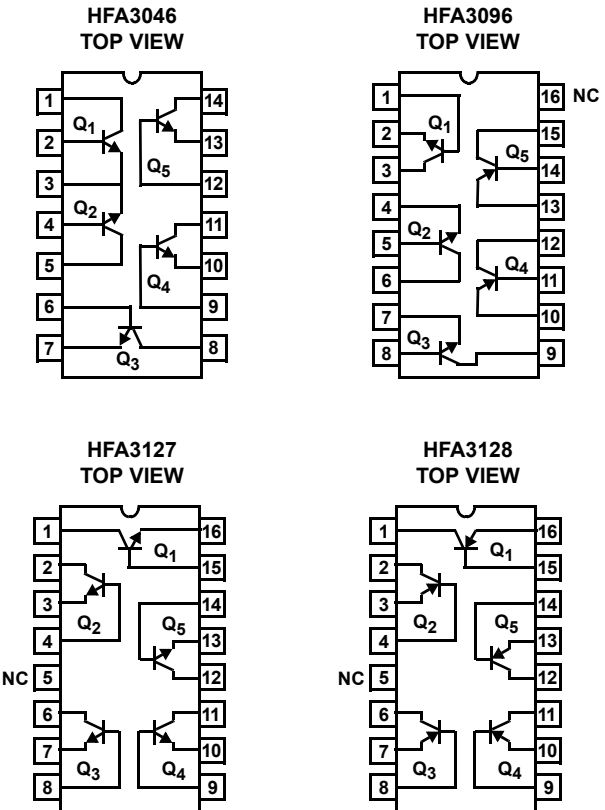


FIGURE 4. CIRCUIT DIAGRAMS FOR THE HFA3046, HFA3096, HFA3127 AND HFA3128

Figure 5 shows the HFA3101 and HFA3102 linear array schematics, both which have been made from the HFA3xxx die. The HFA3102 is a dual-long tailed transistor pair; a configuration often used to make voltage controlled gain and differential amplifier circuits. The HFA3101 is configured as a Gilbert cell which is often used for multipliers.

**Discussion of the HFA3101 Gilbert Cell**

The metallization diagram for the HFA3101 is shown in Figure 6. The HFA3101 is a very versatile RF building block, which has been carefully laid out to improve its matching properties. Notice that the layout is as symmetrical as possible which minimizes distortion due to area mismatches, thermals, betas, and ohmic resistance. The symmetry insures that both long tailed pairs will track when the IC is subjected to temperature or stress, and consequently the whole cell will remain stable.

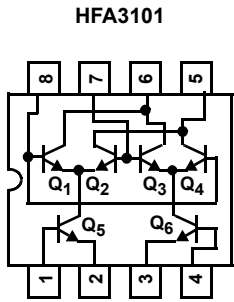


FIGURE 5A. GILBERT CELL  
HFA3102

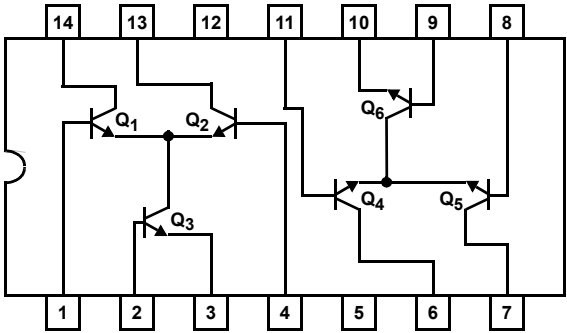


FIGURE 5B. DUAL LONG-TAILED TRANSISTOR PAIR  
FIGURE 5. COMPLEX CIRCUITS MADE FROM LINEAR ARRAYS

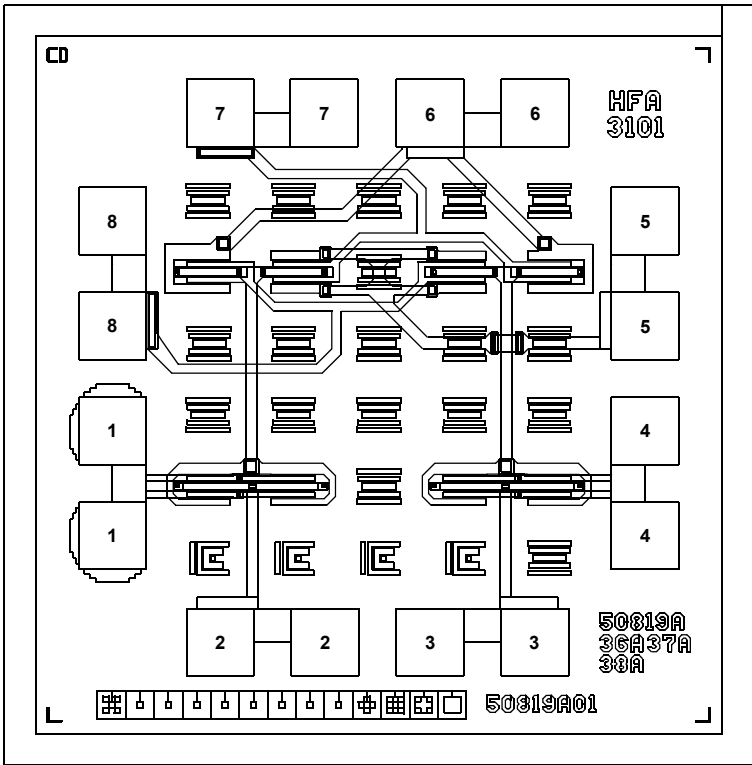


FIGURE 6. METALLIZATION MASK LAYOUT DIAGRAM FOR THE HFA3101

The cell is made from two long-tailed pair stages built as two variable transconductance multipliers in parallel with their outputs cross coupled. This configuration is known in the industry as a Gilbert cell (see Figure 5A), and it enables four quadrant multiplier operation. The cell has restricted use as a linear four quadrant multiplier because there are input dynamic range restrictions for the upper differential pair and lower tail transistors. The input range restrictions are confined to the input signal levels, thus this configuration is quasi-confined to applications where it's linear response is only required at one input. Such as in modulator or mixer circuits. Up converters, down converters, frequency doublers, and frequency/phase detectors often use this configuration with great success. Emitter degeneration, gained by adding an external emitter resistor, improves the dynamic range and linearity, so the lower pair emitters have been brought out to leads for this purpose.

The upper quad transistors are used as switches in modulator applications (see Figure 5A).  $Q_1/Q_2$  and  $Q_3/Q_4$  are used as on/off switches so they do not saturate, consequently the modulator will have a very high frequency response. The upper switches are controlled by the carrier input signal, while the modulating signal is applied to the lower tail transistors,  $Q_5/Q_6$ . If the modulation is to be linear, the modulating signal must be significantly below the threshold voltage of 26mV to keep the lower tail transistors in their linear region. Higher input modulating signals can be handled by adding an emitter degeneration resistor. The waveforms for the modulator are shown in Figure 7.

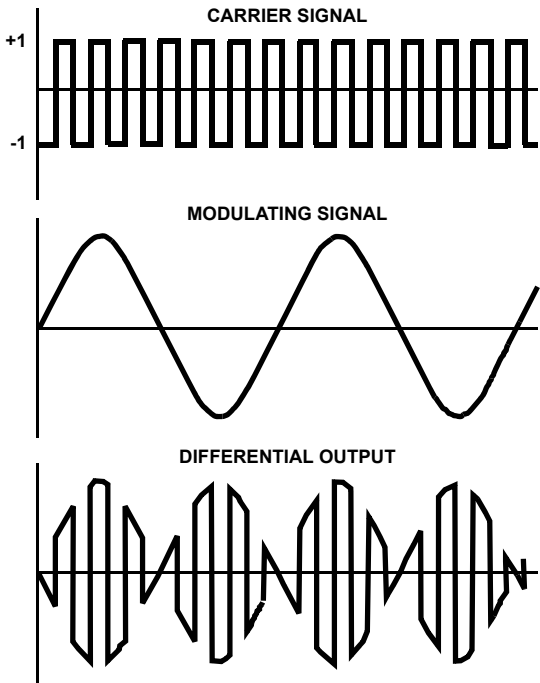


FIGURE 7. MODULATOR INPUT/OUTPUT SIGNALS

When the upper quad and lower tail transistors are both operated in their linear region the cell functions as a linear multiplier. If the carrier frequency,  $f_C$ , and the modulating frequency,  $f_M$ , are put into the different inputs they will be multiplied together by the equation  $f_{AM} = f_C +, -f_M$ . The circuits which perform this function are called mixers, and the result is known as AM modulation as shown in Figure 8.

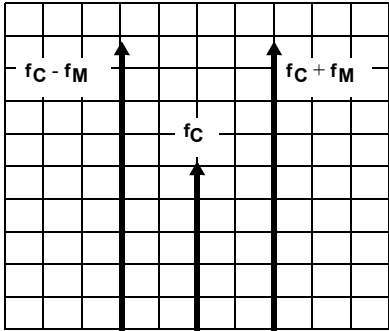


FIGURE 8A. UP CONVERSION OR SUPPRESSED CARRIER AM

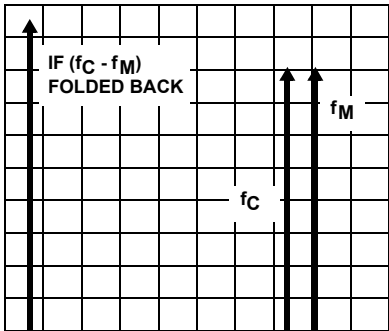


FIGURE 8B. DOWN CONVERSION

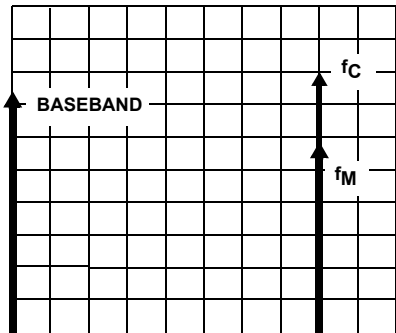


FIGURE 8C. ZERO IF OR DIRECT DOWN CONVERSION

FIGURE 8. AM MODULATION WITH A GILBERT CELL

**Downconverter and Upconverter Design**

This section describes the design of a downconverter shown in Figure 9, and an upconverter shown in Figure 10. Both converters operate in the 900MHz frequency range, and both are powered from a three volt power supply. The heart of the both converters is the Gilbert cell linear array, and the local oscillator signal will always be connected to the bases of the upper quad pairs, Q<sub>1</sub> through Q<sub>4</sub>. Also, the RF signal for the downconverter and the modulating signal for the upconverter are applied to the base of the lower tail transistor, Q<sub>6</sub>. Essentially the circuits are the same because they perform the same multiplication function in the same manner with the same transistors; the major difference is the output coupling networks which act as filters to select the output signal.

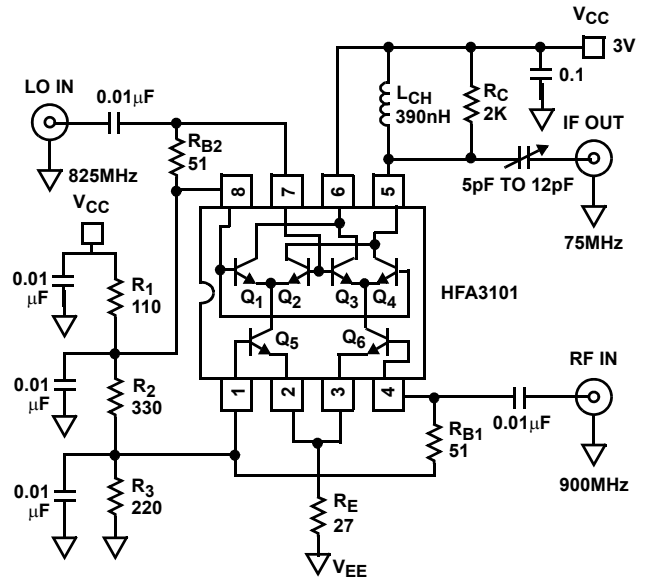


FIGURE 9. 3V DOWN CONVERTER APPLICATION

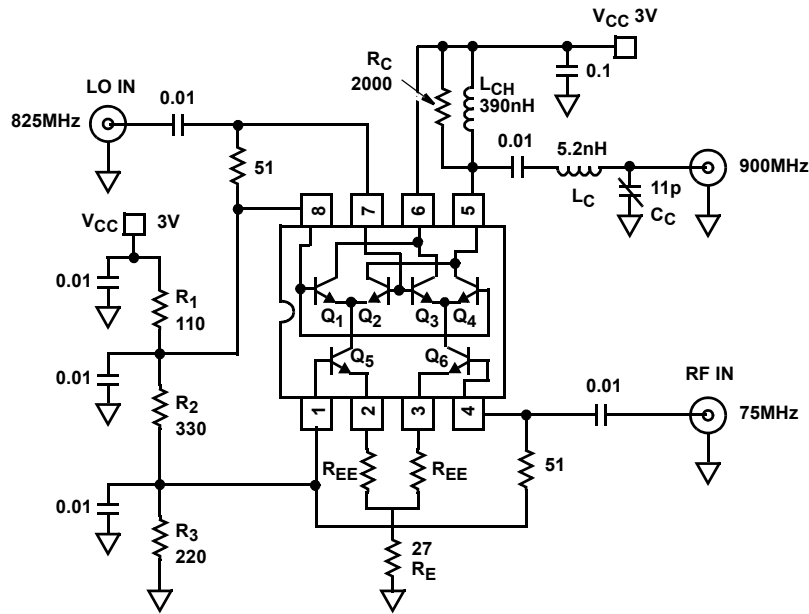


FIGURE 10. 3V UP CONVERTER APPLICATION

**Summary**

Linear arrays are comprised of many transistors, NPN, PNP or a combination on a single die. Because putting all of the transistors on the same die gains excellent matching characteristics and reduces cost, the design of multistage high frequency circuits is simplified. The manufacturers utilize the base die to make many different linear arrays.

Linear arrays and their spin-offs such as the HFA3101 Gilbert cell enable the fast and efficient design of many different low and high frequency circuits such as up and down converters. This linear array offers the designer flexibility, lower cost, improved reliability, and improved performance. They are powerful RF building blocks.

## Notice

1. Descriptions of circuits, software and other related information in this document are provided only to illustrate the operation of semiconductor products and application examples. You are fully responsible for the incorporation or any other use of the circuits, software, and information in the design of your product or system. Renesas Electronics disclaims any and all liability for any losses and damages incurred by you or third parties arising from the use of these circuits, software, or information.
2. Renesas Electronics hereby expressly disclaims any warranties against and liability for infringement or any other claims involving patents, copyrights, or other intellectual property rights of third parties, by or arising from the use of Renesas Electronics products or technical information described in this document, including but not limited to, the product data, drawings, charts, programs, algorithms, and application examples.
3. No license, express, implied or otherwise, is granted hereby under any patents, copyrights or other intellectual property rights of Renesas Electronics or others.
4. You shall not alter, modify, copy, or reverse engineer any Renesas Electronics product, whether in whole or in part. Renesas Electronics disclaims any and all liability for any losses or damages incurred by you or third parties arising from such alteration, modification, copying or reverse engineering.
5. Renesas Electronics products are classified according to the following two quality grades: "Standard" and "High Quality". The intended applications for each Renesas Electronics product depends on the product's quality grade, as indicated below.  
"Standard": Computers; office equipment; communications equipment; test and measurement equipment; audio and visual equipment; home electronic appliances; machine tools; personal electronic equipment; industrial robots; etc.  
"High Quality": Transportation equipment (automobiles, trains, ships, etc.); traffic control (traffic lights); large-scale communication equipment; key financial terminal systems; safety control equipment; etc.  
Unless expressly designated as a high reliability product or a product for harsh environments in a Renesas Electronics data sheet or other Renesas Electronics document, Renesas Electronics products are not intended or authorized for use in products or systems that may pose a direct threat to human life or bodily injury (artificial life support devices or systems; surgical implantations; etc.), or may cause serious property damage (space system; undersea repeaters; nuclear power control systems; aircraft control systems; key plant systems; military equipment; etc.). Renesas Electronics disclaims any and all liability for any damages or losses incurred by you or any third parties arising from the use of any Renesas Electronics product that is inconsistent with any Renesas Electronics data sheet, user's manual or other Renesas Electronics document.
6. When using Renesas Electronics products, refer to the latest product information (data sheets, user's manuals, application notes, "General Notes for Handling and Using Semiconductor Devices" in the reliability handbook, etc.), and ensure that usage conditions are within the ranges specified by Renesas Electronics with respect to maximum ratings, operating power supply voltage range, heat dissipation characteristics, installation, etc. Renesas Electronics disclaims any and all liability for any malfunctions, failure or accident arising out of the use of Renesas Electronics products outside of such specified ranges.
7. Although Renesas Electronics endeavors to improve the quality and reliability of Renesas Electronics products, semiconductor products have specific characteristics, such as the occurrence of failure at a certain rate and malfunctions under certain use conditions. Unless designated as a high reliability product or a product for harsh environments in a Renesas Electronics data sheet or other Renesas Electronics document, Renesas Electronics products are not subject to radiation resistance design. You are responsible for implementing safety measures to guard against the possibility of bodily injury, injury or damage caused by fire, and/or danger to the public in the event of a failure or malfunction of Renesas Electronics products, such as safety design for hardware and software, including but not limited to redundancy, fire control and malfunction prevention, appropriate treatment for aging degradation or any other appropriate measures. Because the evaluation of microcomputer software alone is very difficult and impractical, you are responsible for evaluating the safety of the final products or systems manufactured by you.
8. Please contact a Renesas Electronics sales office for details as to environmental matters such as the environmental compatibility of each Renesas Electronics product. You are responsible for carefully and sufficiently investigating applicable laws and regulations that regulate the inclusion or use of controlled substances, including without limitation, the EU RoHS Directive, and using Renesas Electronics products in compliance with all these applicable laws and regulations. Renesas Electronics disclaims any and all liability for damages or losses occurring as a result of your noncompliance with applicable laws and regulations.
9. Renesas Electronics products and technologies shall not be used for or incorporated into any products or systems whose manufacture, use, or sale is prohibited under any applicable domestic or foreign laws or regulations. You shall comply with any applicable export control laws and regulations promulgated and administered by the governments of any countries asserting jurisdiction over the parties or transactions.
10. It is the responsibility of the buyer or distributor of Renesas Electronics products, or any other party who distributes, disposes of, or otherwise sells or transfers the product to a third party, to notify such third party in advance of the contents and conditions set forth in this document.
11. This document shall not be reprinted, reproduced or duplicated in any form, in whole or in part, without prior written consent of Renesas Electronics.
12. Please contact a Renesas Electronics sales office if you have any questions regarding the information contained in this document or Renesas Electronics products.  
(Note 1) "Renesas Electronics" as used in this document means Renesas Electronics Corporation and also includes its directly or indirectly controlled subsidiaries.  
(Note 2) "Renesas Electronics product(s)" means any product developed or manufactured by or for Renesas Electronics.

(Rev.4.0-1 November 2017)



### SALES OFFICES

Renesas Electronics Corporation

<http://www.renesas.com>

Refer to "<http://www.renesas.com/>" for the latest and detailed information.

**Renesas Electronics America Inc.**  
1001 Murphy Ranch Road, Milpitas, CA 95035, U.S.A.  
Tel: +1-408-432-8888, Fax: +1-408-434-5351

**Renesas Electronics Canada Limited**  
9251 Yonge Street, Suite 8309 Richmond Hill, Ontario Canada L4C 9T3  
Tel: +1-905-237-2004

**Renesas Electronics Europe Limited**  
Dukes Meadow, Millboard Road, Bourne End, Buckinghamshire, SL8 5FH, U.K.  
Tel: +44-1628-651-700, Fax: +44-1628-651-804

**Renesas Electronics Europe GmbH**  
Arcadiastrasse 10, 40472 Düsseldorf, Germany  
Tel: +49-211-6503-0, Fax: +49-211-6503-1327

**Renesas Electronics (China) Co., Ltd.**  
Room 1709 Quantum Plaza, No.27 ZhichunLu, Haidian District, Beijing, 100191 P. R. China  
Tel: +86-10-8235-1155, Fax: +86-10-8235-7679

**Renesas Electronics (Shanghai) Co., Ltd.**  
Unit 301, Tower A, Central Towers, 555 Langao Road, Putuo District, Shanghai, 200333 P. R. China  
Tel: +86-21-2226-0888, Fax: +86-21-2226-0999

**Renesas Electronics Hong Kong Limited**  
Unit 1601-1611, 16/F., Tower 2, Grand Century Place, 193 Prince Edward Road West, Mongkok, Kowloon, Hong Kong  
Tel: +852-2265-6688, Fax: +852-2886-9022

**Renesas Electronics Taiwan Co., Ltd.**  
13F, No. 363, Fu Shing North Road, Taipei 10543, Taiwan  
Tel: +886-2-8175-9600, Fax: +886-2-8175-9670

**Renesas Electronics Singapore Pte. Ltd.**  
80 Bendemeer Road, Unit #06-02 Hyflux Innovation Centre, Singapore 339949  
Tel: +65-6213-0200, Fax: +65-6213-0300

**Renesas Electronics Malaysia Sdn.Bhd.**  
Unit 1207, Block B, Menara Amcorp, Amcorp Trade Centre, No. 18, Jln Persiaran Barat, 46050 Petaling Jaya, Selangor Darul Ehsan, Malaysia  
Tel: +60-3-7955-9390, Fax: +60-3-7955-9510

**Renesas Electronics India Pvt. Ltd.**  
No.777C, 100 Feet Road, HAL 2nd Stage, Indiranagar, Bangalore 560 038, India  
Tel: +91-80-67208700, Fax: +91-80-67208777

**Renesas Electronics Korea Co., Ltd.**  
17F, KAMCO Yangjae Tower, 262, Gangnam-daero, Gangnam-gu, Seoul, 06265 Korea  
Tel: +82-2-558-3737, Fax: +82-2-558-5338