How we have continued GaAs RFIC business in Japan; Survival History of New Japan Radio

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Abstract

We will describe the history of New Japan Radio Co. Ltd.,(NJR), and our continuing presence in the business of making GaAs RF front end components. We will also present tips for how our company survived, and prospered, despite the changing markets. We will compare NJR strategies with those of competing RF IC makers in Japan.

The HJFET technology which plays a key role in the success of NJR's RFIC business will be briefly described. The unique underlying technologies have enabled the implementation of unique circuit types which are rarely seen in conventional GaAs ICs.

I. INTRODUCTION

New Japan Radio has about 25 years history of GaAs RFIC business in Japan. When we first started the GaAs RFIC business, there were many other competing GaAs RFIC manufacturers in Japan. However, most of these companies have now either been reduced in size, or have exited the RFIC business entirely. In contrast, New Japan Radio is still expanding its GaAs RFIC sales, and its related technology offerings. Why and how have we been able to continue and grow in this business? In this paper, we will show the New Japan Radio survival history. We will compare this with the actions of other GaAs RFIC companies in Japan, with a perspective that may be slightly colored by our own experience and prejudices within NJR.

We will also present our key GaAs HJFET technologies, which have been developed by New Japan Radio for RF front-end devices. We will briefly review the development history, with emphasis on the process technology, as well as on unique circuit approaches, which are rarely seen in conventional GaAs RFICs.

II. NJR HISTORY and BACKGROUND

New Japan Radio started its GaAs RFIC business in 1996, by selling SPDT switches for PHS applications. We entered this market around five years after the first Japanese companies. Demand for GaAs RFICs was rapidly growing in Japan at that time, being driven by the rapidly expanding Japanese cell phone market.

The Japanese cell phone market has some unique characteristics. Firstly, cell phones in Japan are usually manufactured by large vertically integrated companies. These cell phone manufacturers usually have internal groups to develop and produce the GaAs RFICs which are needed, so they do not purchase RFICs from the outside. Similarly, these large companies generally do not sell their GaAs RFICs to other outside companies. An advantage of this arrangement is that the GaAs RFIC business can expand as the cell phone business grows. This is because the cell phone manufacturer and GaAs RFIC manufacturer are one and the same company. Secondly, the carrier companies in Japan specified the overall architecture for the cell phones used in Japan. This externally defined platform architecture constrained the detailed specifications of the cell phone hardware, including those of the GaAs RFICs. The cell phone manufacturers, and their internal GaAs RFIC subsidiaries, were forced to follow the specifications defined by the carrier companies, which, unfortunately, caused enormous development costs for the final cell phone products.

More recently the cellular market situation has changed significantly. Users required their phones to operate in diverse cellular networks worldwide, and also needed to use their phones for internet connection; the smart phone was born. This smart phone business and technology are strongly dependent on the chip set maker reference design, and this requires a worldwide supply chain. However, Japanese cell phone manufacturers did not follow this market trend, and could not respond to the changing market demand. Instead, they persisted in following the architectures which had been defined by the Japanese carrier companies, and they failed to evolve their cell phone designs to fit the changing market. Furthermore, unfortunately after Lehman shock (the financial collapse of 2008), the financial health of the whole Japanese electronics industry sharply declined. This was especially true for the IC business, and consequently for the Japanese cell phone manufacturers. Consequently, the Japanese GaAs RFIC business also sharply declined.

How about New Japan Radio? We are essentially an IC manufacturer, and not a cell phone manufacturer. Of course, New Japan Radio suffered a large loss from the decline of the cell phone market. However, our other GaAs RFIC businesses remained strong. This is because we have both domestic customers, and also overseas customers, including chip set makers. We also continued producing high performance switches and LNA ICs in our own HJFET process. While certain applications have migrated from GaAs switches to SOI, many of our customers still require the high performance of our HJFET GaAs switch ICs.

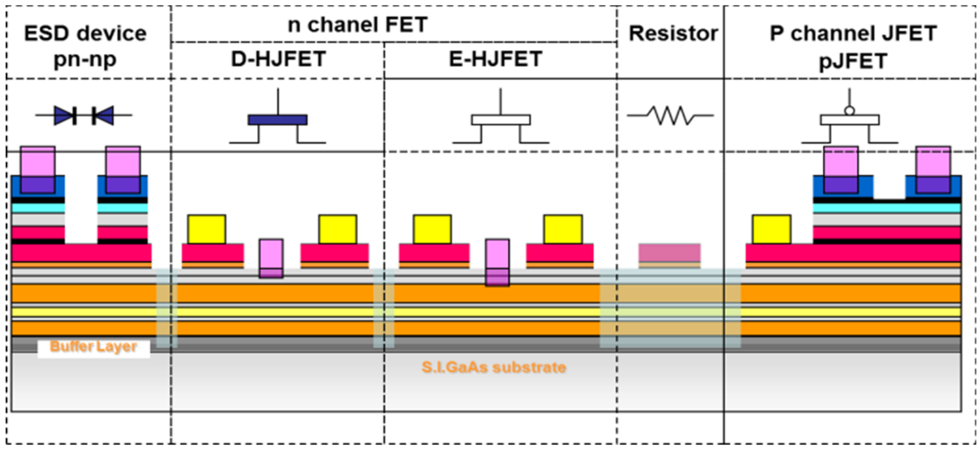


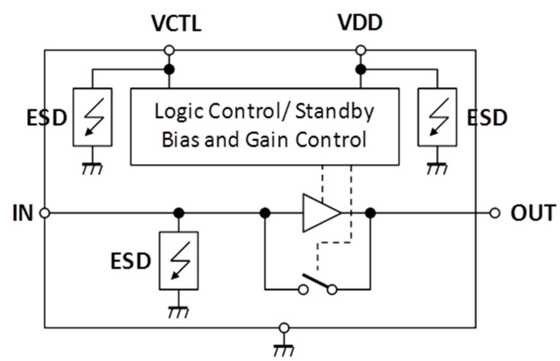
Figure1. Various devices used in New JRC GaAs HJFET process; pn-np ESD device, D-HJFET, E-HJFET, Boron-implanted Resistor and pJFET.

III. HJFET PROCESS AND PRODUCTS IN NEW JAPAN RADIO

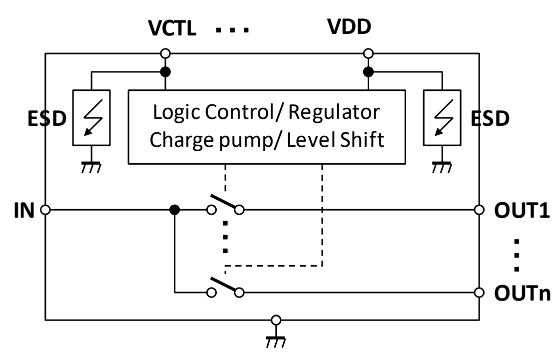
When NJR started making RFICs in 1996, we were using an ion-implanted GaAs FET process. This process which supported several kinds of RF switches, low noise amplifiers (LNA) and power amplifiers (PA). These ICs were used in Personal Digital Cellular (PDC) and Personal Handy-phone System (PHS) applications. Over the subsequent two decades, our primary GaAs FET process has evolved into high performance HJFET process, which supports a variety of different device types, as shown in Figure 1. The modern HJFET process includes combination of depletion mode HJFETs (D-HJFET) , enhancement mode HJFETs (E-HJFET) [1], a pn-np ESD protection device [2], P channel JFETs (pJFET) [3], and high resistivity Boron-implanted resistors. This portfolio of device types, and the optimization of their performance have enabled the design and release of various fascinating products. It has enabled the integration of various types of analog and logic circuits into the LNA and Switch IC as shown in Figure 2.

One of the key devices is the ESD protection device, which is simply two pn diodes connected in series as a pn-np pair. This ESD device shows good RF distortion characteristics, especially for even order harmonics distortions, because of its symmetry. This device easily shows ESD robustness of greater than 2kV HBM, which is the standard criteria needed for RF front end devices. The addition of this ESD device has enhanced the acceptance of our products in the RF front end market significantly.

Other key devices are the combination of D-HJFET and E-HJFET. The E/D-HJFET technology has been very effective for practical RF devices, because we can make various kinds of analog and digital circuits by the combination of these devices. The analog circuits include voltage regulators, constant current sources, current mirrors, clock oscillators, charge-pumps for high voltage or negative voltage sources, and so on. The digital circuits are logic



(a) Low Noise Amplifier (LNA) with logic control for standby and bypass function.



(b) RF switch with logic control/ regulator/ charge pump and Level shifter.

Figure 2. Schematic block diagram of (a) LNA and (b) Switch

interface, logic inverters and decoders, level shifters, and so on. Boron implanted resistors have been widely used in our products to form DC path with RF isolation, resistive load for logic circuits. The sheet resistance is typically 3.3 kOhm/squares.

We have two types of capacitors, namely the MIM capacitor and the MIMIM capacitor. The MIMIM cap has significantly contributed to the chip size and cost reduction.

The GaAs pJFET has played an important role in our process. The P-channel transistors have been extensively used in Si bipolar transistors and CMOS processes. However, in GaAs FETs, the much lower mobility of P-channel FETs (compared with N-channel FETs). This low P-channel mobility limited the usefulness of GaAs P-Channel FETs, especially in the RF path for RFICs. As a key innovation in NJR, we applied the GaAs pJFET to our GaAs IC for negative voltage control circuit. The pJFET is much better suited to this bias control task than an N-channel FET. With this breakthrough of utilizing both P-channel and N-channel devices, we have been able to utilize unique circuits, which cannot be made when only using N-channel FETs. The pJFET has found widespread use, and is used in about 40 % of our switch products, which have been shipping for about 9 years.

Layout shrink is also a key technology for NJR. The minimum gate pitch in the present process is 3.2 um. The metal lines are drawn with 2 um line and 3um space. For example, a SPDT switch configured with a series FET and a shunt FET on both RF paths, now has a size much smaller than 0.4 mm squares, even when we include ESD protection diodes on the chip. This shrink technology has brought us cost reduction as well as an increase in production capability.

Figure 3 shows a multi-gain stage LTE LNA for Ultra High Band (UHB: 3.5 GHz Band). The LNA has control logic circuits, reference current source and matching circuit components for both input and output. It has a size of about 0.6 mm squares. It exhibits the NF of as low as 0.6 dB with a small signal gain of 19.6 dB at a bias current of 3.6 mA. Figure 4 shows a 1 bit control high power SPDT switch with an integrated negative voltage generator (NVG). The NVG has enhanced the power handling capability, and removed the external DC blocking capacitors, which are commonly needed for RF FET switches. It features the insertion loss as low as 0.18 dB at 0.9 GHz and 0.23 dB at 2.7 GHz. These are, to our knowledge, the lowest insertion loss values which are available for commercially available RF switches, including SOI CMOS switch since 2012. The chip size of this SPDT switch IC is about 0.8 mm x 0.6 mm.

The robustness against high level input power is one of the major advantages of GaAs HJFET LNA. We have recently measured the performance deviation for the LTE LNA with an input power level of about 23 dBm. Even though the LNA shows P-1dB of only -4 to -8 dBm, the gain performance is stable against the 23dBm power level without any protection device.

It is important to manufacture products steadily, even if we need to keep the process target within very narrow window in order to satisfy high electrical performances. Test technology for screening is also another important factor for keeping the quality level as high as possible.

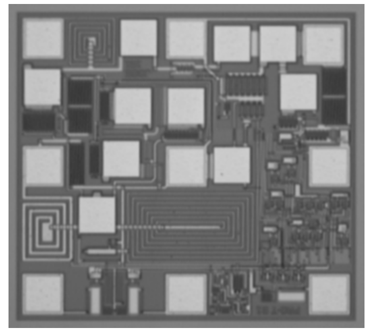


Figure 3. Chip photograph of a GNSS LNA with ESD protection devices.

The concept of our wafer process and test procedure is

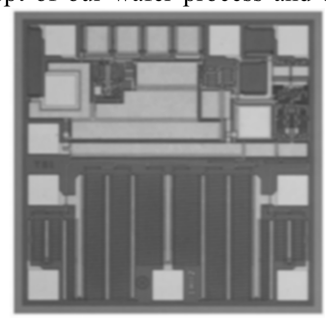


Figure 4. Chip photograph of 1-bit control SPDT switch with negative voltage generator. No external DC block capacitors are required for RF ports.

that "Good process output and good DC performance result

In good RF performance". There are around one hundred on-wafers DC-test terms, even if it is a simple SPDT switch. This has contributed to achieve a high built-in quality as well as to reduce the failure rate as low as possible.

There are some misunderstandings on the circuit feasibility and variety in GaAs HJFET [5]. Most of the circuits are available as in the case of Si-CMOS IC's. As we have shown here, our GaAs technology has enabled to form various types of circuit element. A few years ago, we developed a proto type chip consisting of a multiple port RF switch, negative voltage generator, voltage regulator, SPI (Serial Peripheral Interface) core with SRAM for state hold buffer memories. We are sorry that the chip was not used in practical application, though the EVB's were delivered to our customers.

We are continuously improving the performance of our HJFET devices. The next generation of HJFETs have much higher Gm, and lower Ron characteristics, in spite of keeping the same breakdown voltage and off-state leakage currents. The feasibility of these new HJFETs has already been proven for LNA and switch applications. For example, the insertion loss of our the new HJFET based SPDT switches is significantly lower than our released production SPDT switches. This is impressive, given that the released SPDT switches already have such low insertion loss! [4]. The results will be reported elsewhere in the near future.

IV. CONCLUSION

In this way, we brought up a company's original technology carefully, without being seized with the technology of other companies. We are always keeping a venture spirit for the GaAs RFIC business. Furthermore, recently we have created a GaAs HBT PA design technology, an SOI process, and a SAW filter technology. With this broad technology portfolio, we can supply all RF front-end devices to any customer. Basically, we are just an IC manufacturer, and not a module maker. This means our customers are chip set makers, module makers, handset makers, and also similar IC makers or SAW makers, and everything else. It means our customers will be sometimes our competitors, or our suppliers, but always they will be our partners. By such a business for all directions, we intend to continue conducting RFIC business from now on towards the future.

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