Compound Semiconductors in Wireless Communications Systems

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ABSTRACT

Over the past few years, the mobile wireless communications market has grown at an unprecedented rate and is expected to continue its phenomenal growth well into the next century. Along with this growth has come fierce competition among wireless service providers and equipment manufacturers. This competition has forced a cost reduction effort to be undertaken in the area of base station design. Base stations contain many compound semiconductor devices, but the largest single item in a typical base station, in terms of cost, physical size, and energy consumption, is the RF power amplifier. My talk will provide a general overview of wireless base station architecture and point out some requirements for compound semiconductors in each functional area, with an emphasis on the RF power amplifier. I will discuss cost requirements and possible market size for components, and also the role of emerging RF compound semiconductor technology in reducing the cost, physical size, and energy consumption of the power amplifier and hence, the base station.

FUTURE MARKET AND STANDARDS

The concept of cellular telephony was first proposed in 1947 by D.H. Ring in a Bell Laboratories Technical Memorandum [1], in which he stated "In this memorandum

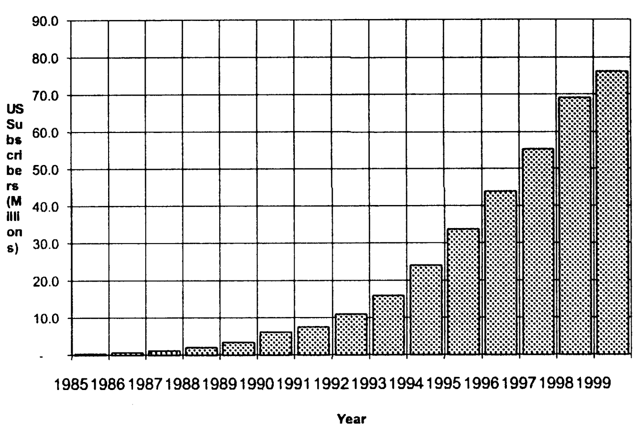

Figure 1: US wireless subscribers (millions) 1985 - 1999. [Source: CTIA]

it is postulated that an adequate mobile radio system should provide service to any equipped vehicle at any point in the whole country." Mainstream commercial usage of such a system with a significant subscriber base did not occur until the 1980s. In 1985, there were approximately 340,000 subscribers to wireless service in the United States. By 1999, there were 76 million subscribers. Figure 1 illustrates this explosive growth trend by plotting the number of wireless subscribers in the US from 1985 to 1999. Global subscriber trends are equally, if not more impressive. In 1999 there were 355 million wireless subscribers worldwide and by the end off 2000 it is projected that there will be 440 million subscribers. It is also projected that by 2004 there will be approximately 1.2 billion wireless subscribers globally. At this point, the number of wireless subscribers will begin to exceed the number of wireline subscribers. This switch to a wireless telephone infrastructure has already begun to occur in some developing countries where it is difficult and costly to install cables.

Worldwide mobile wireless network systems have progressed in generational stages since the mid 1980s. In the first generation of wireless service from the mid 1980s to early 1990s, voice was the dominant application and was adequately served by analog cellular technology. The frequency bands allocated for this use were between 824 MHz and 960 MHz, with channel bandwidths from 10–30 kHz. The majority of cells were large "macro" cells that ranged in size from 1 to 5 miles in diameter. The second generation of service (mid 1990s to 2000) saw the introduction of Personal Communication Services (PCS). These services are characterized by voice, combined with short messaging and limited data services. In order to easily provide messaging and data along with increased cell capacity, digital modulation techniques were implemented. There was also a trend toward cell size reduction, where "micro" and "pico" cells were increasingly deployed. The three dominant digital multiple access protocols in second generation systems are Code Division Multiple Access (CDMA), Time Division Multiple Access (TDMA), and Global System for Mobile Communication (GSM). Frequency bands allocated for these standards range from 1710 MHz to 1990 MHz, with channel bandwidths from 30 kHz to 1.25 MHz.

Third generation (3G) standards will provide higher data rates for data services through the use of wider channel bandwidths. Data services that are envisioned for 3G include wireless internet access and wireless home control. Frequency requirements for 3G systems can be anywhere from 824 MHz to 2200 MHz, with a typical channel bandwidth of 5 MHz.

Fourth generation system may blur the distinction between wireless and wireline services by offering customers a single phone number that is associated with them no matter where they are (home, office, car, etc.). Frequency requirements for fourth generation systems are not known at this point. However, in order to accommodate very high bandwidth applications, such as teleconferencing, a high carrier frequency may be necessary.

SYSTEM ARCHITECTURES AND REQUIREMENTS

The basic building blocks of a typical digital transmitter system are shown in Figure 2. The transmit process starts with an information source, such as voice or data which is then formatted in such a way as to make digital transmission most efficient. The data is then modulated using one of the many digital modulation techniques. The modulation technique is chosen to maximize spectral efficiency by transmitting as many bits per symbol as possible, while maintaining an acceptable error rate, among other criteria. Once the data has been modulated onto an intermediate frequency carrier (IF), it can then be mixed to a high enough frequency for efficient transmission through air by the radio. To overcome the large losses introduced by propagation through a complex environment, a power amplifier stage is placed before the antenna. The receiver chain looks the same as the transmitter, only in reverse order.

Each stage in the transmitter/receiver chain contains many, many semiconductor devices. Currently, however, the only parts of the link to contain a significant numbers of compound semiconductors are the power amplifier stage in handsets and driver stages in base station amplifiers. Most power amplifiers in base stations now use either Silicon BJTs or lateral MOS technologies. The main reason for the absence of compound semiconductors in wireless systems is cost. There is much pressure on base station and handset manufacturers to reduce cost of goods sold (COGS) in their products. Silicon technologies are currently less expensive and meet the performance needs of today's systems. This does not rule out the use of compound semiconductors in future systems where data rates as well as frequency of operation may increase. Recently, GaAs MESFET devices have been introduced for use in high-speed digital communications networks. These chips are designed for clock rates to 10 GHz in order to be compatible with 10 Gb/s optical networks. As data rates increase in wireless networks, more of these types of devices will be necessary.

By far, the largest portion of a wireless base station in terms of cost, size, and power consumption is the RF power amplifier and associated components. The total RF portion of a base station (radio, power amplifier, and associated power supplies) can account for 25–65% of the total cost, 60% of the total power consumption, and more than 50% of the total size. Within the base station RF subsystem, the RF power amplifier is the largest section in terms of cost, power consumption, and size. Cost reduction efforts need to be concentrated on the RF subsystem in order to achieve significant savings.

The major drivers in RF power amplifier design for base stations are strict linearity specifications and high peak-to-average ratio signals. These two design factors combined, force the power amplifier to operate very inefficiently. For a CDMA-type system, peak-to-average ratios can be 10–12 dB. This high peak-to-average ratio combined with an out of band power ratio requirement of -45 dBc (i.e., the power in a channel outside the desired band must be at least 45 dB less than the in-channel power) produces multi-carrier power amplifiers that typically achieve less than 10% DC–RF efficiency. Another design factor of importance for base station amplifiers is the average/peak power rating. A standard multi carrier power amplifier (MCPA) for use in a base station must deliver in excess of 20 W average (~200 W peak, for a 10 dB peak-to-average signal) power. Since combiner losses may become significant at these powers, a small number of large devices are typically combined to achieve this power. Typical final stage devices range form 60 to 120 W at 1 dB compression.

Many efficiency enhancement techniques exist and have been used effectively in handsets where output power requirements are low and only single channel data is being transmitted. Base station MCPAs, as previously mentioned have higher output power requirements and must be able to amplify multiple channels of data. Transmitting multi-channel data obviously requires a wider bandwidth than transmitting a single channel, but it can also create a signal with a higher peak-to-average ratio. The wide bandwidth, high output power, high peak-to-average ratio signal make implementing standard efficiency enhancement techniques extremely challenging.

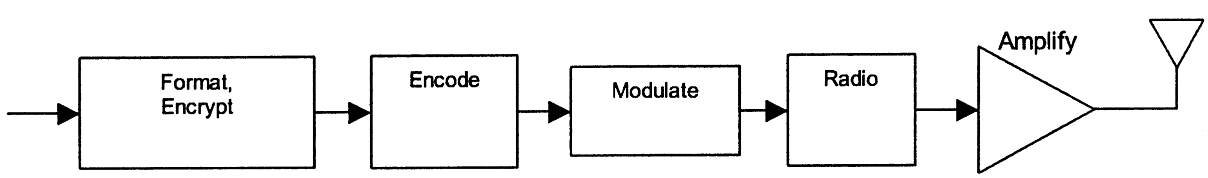

Figure 2: Simplified block diagram of a wireless transmitter

One method of achieving high efficiency operation is to employ class D,E, or F operation. Devices with high f_T are necessary for these classes due to the switching nature of their operation. Using new materials, such as GaN, SiC, SiGe, InP, GaAlAs, amplifiers employing these high-efficiency classes have been demonstrated to 10 GHz. However, these exotic materials are still too expensive for introduction into current generation, or even next generation products.

There are many other circuit level techniques for efficiency enhancement or linearization (the two are very closely related) that have been proposed, but never find their way into commercial systems. One of the reasons these techniques fail to become commercialized in high power systems is that the efficiency gains are not appreciable enough to outweigh the cost, in terms of complexity, they usually introduce. Something as simple as reducing internal losses to improve inherent device efficiency can lead to significant improvements in overall system power consumption.

DEMANDS ON FUTURE DEVICES

As has been mentioned numerous times throughout this paper, probably the biggest single reason any one device is chosen over another is cost. Of course, this assumes that these different devices meet approximately the same specifications. A more expensive device must far outperform a less expensive device to be considered. This cost consciousness is the reason why so many designers of high power amplifiers in the wireless industry have started using Si lateral MOS devices. A reasonable cost target today for any RF power device considered for use in wireless base stations is approximately $1 per peak Watt ($P_{1dB}$). One way in which some device manufacturers have reduced cost is to enclose lower power devices in plastic packaging.

Two more important considerations for devices intended for use in RF power amplifiers for wireless systems are efficiency and linearity. Any device efficiency improvements translate directly to system wide efficiency improvements. A device is more attractive from a linearity standpoint if it behaves more like an ideal limiting device. This type of saturation characteristic is shown in Figure 3. Signals with a time varying envelope can be amplified more efficiently since, on average, the amplifier can operate closer to saturation without becoming nonlinear. Figure 3 also shows the range over which a typical amplitude modulated signal may vary. It is obvious from the figure that in order to remain linear with the non-ideal transfer characteristic, the average input power must be reduced, hence reducing efficiency. For signals with large peak-to-average ratios, this back-off is very significant. Through the use of linearization techniques, the non-ideal characteristic is made to look like the ideal characteristic. Any linearization technique, however, adds cost without improving efficiency. Using a device that is as linear as possible from the outset, even though it may be more expensive, may result in lower overall system cost.

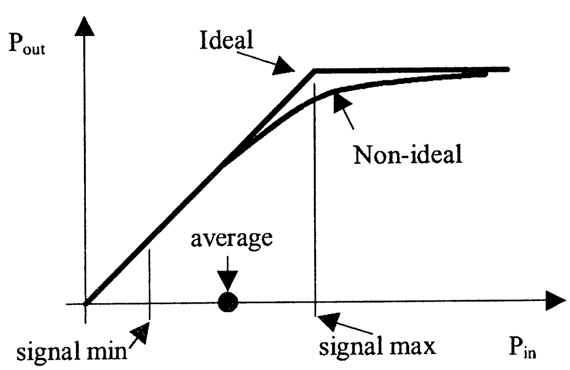

Figure 3: Transfer characteristic for an ideal and non-ideal amplifier.

CONCLUSION

The mobile wireless telephony industry has seen very rapid growth and aggressive competition in the recent past. Increased demand for data services is expected in the near future, with ultra high-speed data services further outCurrent wireless systems do not employ large numbers of compound semiconductors, but increasing data rates will necessitate high-speed digital switching circuits and wider bandwidths as well as higher carrier frequencies. These high frequency applications will most likely require many compound semiconductor devices. If current subscriber growth trends continue, the wireless sector could possibly represent a very large market for compound semiconductor devices.

REFERENCES

[1] Ring, D.H., "Mobile Telephony – Wide Area Coverage", *Bell Laboratories Technical Memo # TM 47-160-37*, 11 December 1947.