Radio Transmitters

Amplifiers for Wireless Networks

by David B. Rutledge

In network jargon, the transmitter is part of the physical layer. It sends power to the other nodes through an antenna. In many wireless systems, transmitters are the most expensive components. One thing that increases the cost in cellular data and voice transmitters is that the power amplifiers are often made of gallium arsenide rather than silicon. Another is that traditional computer aided design software has not been adequate for transmitters. Instabilities are often discovered late in the development cycle when they are difficult to correct. In many wireless systems, the transmitter consumes most of the power and produces most of the heat. Yet another problem is that, historically, transistor-based transmitters have not produced enough power for high-speed satellite network uplinks. Our research has addressed many of these problems. Much of the work is in collaboration with Ali Hajimiri, Professor of Electrical Engineering at Caltech and Lee Center Visitor Professor Almudena Suarez.

In 2001, two of my students, Scott Kee and Ichiro Aoki, developed a new efficient class of switching amplifier called E/F (Figure 1). This work was followed by a series of papers with Scott Kee, Ichiro Aoki, and Ali Hajimiri that incorporated this class of switching amplifier into a power combining circuit that used a transformer with transistor pairs at the corners. This increased the power and efficiency to such an extent that we were able to demonstrate a silicon integrated circuit that had high enough output to act as power amplifier for a cellular telephone. Ali, Scott, and Ichiro founded a company called Axiom Microdevices to develop this power amplifier for the GSM cellular phone market. The company was eventually acquired by Skyworks, and this amplifier is one of their big sellers, with cumulative sales of over 50 million units.

Almudena Suarez from the University of Cantabria visited Caltech on sabbatical in 2004. Almudena is an expert in the development of computer software for non-linear microwave circuits. She had worked extensively with low-power mixers and oscillators, but until that time had not worked with high-power transmitters. Two of my students, Sanggeun Jeon and Feiyu Wang, had been developing high-power transmitter circuits for radar and industrial applications. Sanggeun and

Figure 1: Prototype E/F switching amplifier developed by Scott Kee and Ichiro Aoki[1]. This amplifier produced 1.1 kW at 7 MHz with 85% efficiency.

Feiyu had found that the circuits showed many instabilities that were not predicted by the computer-aided design software available at that time. There were oscillations away from the drive frequency, jumps in the output power, and increased noise in some drive power ranges. These instabilities have been known in industry for almost a hundred years. When the instabilities show up, they are a disaster, because solutions must be discovered by trial and error. Sanggeun and Feiyu had filled an entire shelf with these strange power amplifiers. I called it "the zoo." When Almudena arrived, the three of them set to work in analyzing and trying to understand each of the instabilities. Eventually they succeeded in tracking every one down, and developed a way to detect each instability in the design software before the transmitter was built. This led to a series of three papers in the IEEE microwave journals[2,3,4] that laid out a design approach to avoid these instabilities. For this and other work, Almudena Suarez has become extremely influential in the microwave community, and I believe that these techniques will see wide use as people become more familiar with them.

Frequencies above 15GHz are commonly used for mobile satellite uplinks because the antennas can be smaller than at lower frequencies. However, there is a serious challenge in using these frequencies. Specifi-

cally, to obtain high data rates, one needs more power than has traditionally been available from integrated circuits, typically 3Watts at these frequencies. While power levels in the range of 50Watts are available from a vacuum tube transmitter, making the data transmission faster, and giving better transmission through rain, vacuum transmitters are heavy and expensive. A vacuum-tube transmitter that we purchased for measurements in my lab cost $100,000 twenty years ago, and weighed over one hundred pounds. In addition, the vacuum-tube circuits often have burn-out problems. All of these difficulties have encouraged engineers to find an alternative to vacuum-tube transmitters in mobile satellite uplinks. What was needed was a way to combine the output power of a large number of transistors within an integrated circuit. Previous integrated circuits used transmission-line combiners that typically only allow the power from about eight devices to be combined efficiently. These transmission lines consume an increasing fraction of the power as the number of devices is increased, and that puts a stop to it. Students in my group invented a way to combine the outputs of several hundred or more transistors efficiently by letting

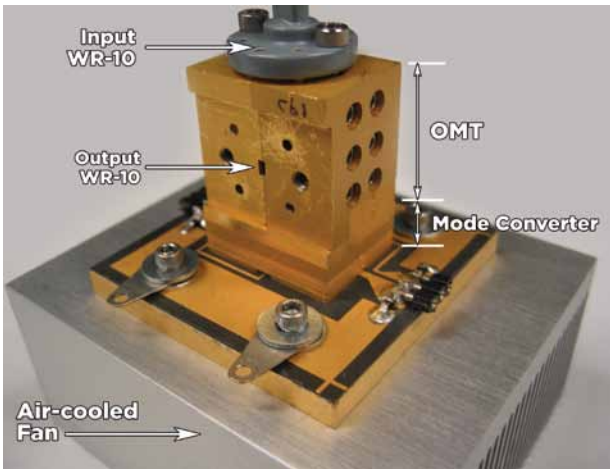

Figure 2: Grid amplifier operating at 79 GHz with an output power of 260 mW[5].

them radiate collectively into a metal waveguide. The device is called a grid amplifier. IST post-doctoral fellow Younkyu Chung, and Caltech students Chun-Tung (Lawrence) Cheung and Michael DeLisio showed that the approach could work at 79GHz, a very high frequency[5].

Lawrence, Mike, and another student from my group, Chad Deckman, started a company called Wavestream (see discussion of Wavestream later in this booklet) to develop and sell these grid amplifiers. The company is located in San Dimas and has 120 employees. Their best selling product is a 50-W, 30-GHz transmitter. Ten years ago, a transistor-based transmitter at this power level and frequency would have been inconceivable. **LEE**

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Read more at:

http://www.its.caltech.edu/~mmic/group.html

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