COMPACT - Microwave Circuit Optimization Through Commercial Time Sharing

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***Abstract*—The SPICE program was developed at UC Berkeley in the early 1970s to computerize low-frequency analog circuit design. In those days, microwave designers did not have any significant commercially available CAD tools until the introduction of COMPACT (Computerized Optimization of Microwave Passive and Active CircuiTs) in 1973. Initially, the program was only available through commercial timesharing systems, but in a few years in-house versions were also offered. The ability to optimize complex microwave circuits eventually convinced many reluctant engineers to accept CAD as a practical design tool and as a result revolutionized circuit design.**

***Index Terms*—Computer-aided circuit design, CAD/CAE, Circuit optimization, Microwave circuits, COMPACT**

I. Introduction

Computerization of microwave design was relatively slow compared to the other EE design disciplines. Traditionally, microwave circuit design was more of an art than science. Designers often achieved results by tweaking, tuning, and shielding circuits on the bench, instead of using a systematic analytical approach. In the 1960's, introductions of Hewlett-Packard's s-parameter test instruments revolutionized microwave component testing and characterization. Soon after, related s-parameter design techniques became available, using measured data directly. However, even the state-of-the-art computers of the 1960's were large and extremely awkward to use. Consequently, they were rarely utilized in microwave circuit design. Lack of appropriate programming languages made things even more difficult.

By the late 1960s, the newly formed timeshare industry introduced more convenient computer operating systems and programming languages for engineers. Soon after, several software packages were also developed, and became commercially available to microwave designers. Still, due to the relatively high expense of computer time and the resistance of management, progress was extremely slow. Circuits were still "designed" on the bench and yield-oriented design was virtually non-existent.

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In the early 1970s, first-generation circuit design packages were offered through timesharing and also became available for in-house computer installations. Several of the progressive companies began to recognize the advantages of the computer aided approach and also installed design programs on their own computers. However, since most of the computers were initially bought by accounting or by production, they were often not suitable for scientific design. Availability was also a problem; the engineers had to take a second role in usage, and the early days of in-house computing were not as successful as most engineers had desired.

In the late 1970s, hardware manufacturers introduced powerful minicomputers and companies began to purchase them for dedicated scientific usage. Interestingly, software development for microwave design did not keep up with this progress. The worldwide "software industry" consisted of a relatively small firm whose product, COMPACT, was the only program commercially available to microwave circuit designers. To make matters worse, COMPACT only operated on large mainframe computers. Still, progress was made and the concept or microwave CAD was gradually accepted by the more progressive designers.

By 1980, most design managers recognized the importance of CAD and begun purchasing the newly developed mini-computers. Still the relatively large investment in computers and peripherals was extremely hard to justify. Computers also required controlled environments and only a few companies offered engineers the status symbol of individual computer terminals. In most cases, designers had to share terminals, often located elsewhere in their buildings. Despite all of these hardships, engineers began to rely more and more on CAD, and widespread usage was only a step away.

First-generation personal computers suddenly introduced a new era to design engineers. Inexpensive personal computers began "popping up" in various design departments, but suitable software was still not available commercially. Engineers began to write their own programs, which was an inefficient process. Generally, those in-house programs were undocumented and far from user-friendly, operated only by the author.

Finally IBM entered the market with a truly high-quality 16-bit personal computer and everything changed. The scientific

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community rapidly accepted the product and more and more engineers gained access to these machines. This was soon recognized by entrepreneurs and within a few years other CAD programs were offered for the IBM PCs and their clones. By then, even conservative microwave managers found it difficult to decline committing $10-20,000 to purchase a PC and all the related software. Engineers had their dreams fulfilled – they could design circuits on their own computers.

II. CIRCUIT ANALYSIS PROGRAMS

Most of the pioneer microwave CAD simulators, such as SPEEDY [1] and MAGIC, were based on two-port manipulations, where the program created the equivalent two-port parameters of each circuit element, converted the two-port parameters to the most appropriate type for handling interconnections, (y-parameters for parallel, z-parameters for series, etc.) and finally printed results for the overall circuit. These programs had significant limitations, since they could only handle circuits allowed by the two-port type of interconnections. The next generation of programs offered a nodal or n-port analysis with the capability of handling virtually unlimited circuit connections. This second approach initially required more computer time which became critical when the analysis was within an iterative loop. In the first commercially available optimization program [2]-[3], COMPACT, used a unique scheme where all interconnections were in terms of s-parameters, eliminating the need for matrix conversions. Later however, improved numerical algorithms led to a more universal approach that is now used in all modern simulators. Outputs were provided in tabular or (now) primitive character-printing graphical form.

A. *COMPACT capabilities*

Between its introduction and subsequent updates, COMPACT offered the following features:

1. Accepting two-, three-, and four-port, measured s-, y-, and z-parameters (polar and rectangular forms); and measured noise parameters for various device configurations.
2. Flexible and efficient interconnection schemes.
3. On-line editor.
4. A library of commonly used lumped and distributed circuit elements. The later ones could be defined either by electrical parameters (Z_o, θ, α) or by physical dimensions, realized in several forms (microstrip, stripline, suspended substrate, etc.)
5. Noise analysis with lossy and lossless matching as well as feedback components.
6. RF stability analysis.
7. Plotting rectangular and Smith Chart outputs, circles of stability, constant gain and constant noise (character plots).
8. Impedance mapping (character plots).
9. Element "tuning" by specified step-size.
10. Accepting dependent parameters, functional inputs and element labels.
11. Various Q definitions for lumped elements and transmission line, including dielectric losses.
12. Dispersive transmission lines models and discontinuities.
13. Directional elements (couplers, circulators, etc.)
14. Transistor noise and s-parameter databanks.
15. Advanced gradient and random circuit optimization.
16. Sensitivity and statistical (Monte-Carlo) analysis.
17. Illustrative examples

Of these features, perhaps circuit optimization was the most significant since many of the microwave circuits, particularly active circuits, did not have any convenient close-form solution. Equipped with a modified Davidon-Fletcher-Powell and an adaptive random search algorithm, COMPACT could quickly find optimum solution to complex projects, such as a multi-stage low-noise amplifier. Interestingly, some people opposed using circuit optimization. In fact, one well known MIT professor prohibited students from using circuit optimization, stating that a "good engineer should always be able to derive a closed-form equation instead of relying on such a crutch." Although at that time I strongly disagreed with his statement, I must now admit that optimization has encouraged some engineers to bypass estimating the initial component values. "Blind optimization," an approach I have always disapproved, can lead to sloppy engineering. Designers should always use all available tools, such as Smith Chart manipulations and circuit synthesis, to obtain reasonable initial component values before submitting a project to optimization.

Next to optimization, the most frequently used feature was the transistor databank. Although it was limited initially to a handful of device manufacturers, it allowed designers to immediately evaluate the capabilities of new parts. (I realize that today, with easy access to the Internet, such a feature does not sound very impressive, but remember that 35 years ago data did not travel around so conveniently.) Having access to noise parameters, in addition to s-parameters greatly helped low- noise amplifier designers in their work.

Of course commercial timesharing also played a very important in introducing microwave engineers to CAD. Having local access to design software through remote terminals, even though it was at snail-pace, was attractive enough to try it. Recognizing the time-saving this approach offered to lengthy manual computations, attracted open-minded engineers to this new alternative. As success stories began to circulate through publications [6]-[32] in trade magazines and conferences, a solid core of users switched to the computerized approach. In addition to becoming more effective designers, they also provided feedback and suggestions for new features that later appeared in the program.

B. *Microwave CAD maturing*

In 1976, after providing technical support to COMPACT in addition to my full-time job, I made the big step of quitting my day job and continuing with COMPACT full-time. Next, I hired the first employee. I still remember my father-in-law's concerns; he could not believe that I could make a living by "selling computer programs." Fortunately, the new company was profitable from day one and gradually grew to be an accepted entity of the microwave industry.

Supporting COMPACT became a significant problem. By 1979 there were over hundred and fifty users on six different international timeshare systems worldwide, in addition to a significant number of on-site installations. Many of the in-house computers also had different operating systems. Since a large number of the users were defense contractors or government agencies with high security concerns, troubleshooting problems was extremely difficult. Even if we had direct access to the customer's circuit file, the problem may have been caused by user error, program bug, or incompatibility with the computer's operating system. The last category was the hardest to fix since we could not simply dial into their computer systems; problems had to be solved by lengthy trials. We had a small room filled with source codes of every computer installation. If a reported problem required a change in the program, we had to figure out how to implement the change for the various systems. This required a lot of tedious work.

In 1980 I was approached by Communication Satellite Corporation (Comsat) with an offer to convert COMPACT to the newly developed Digital Equipment VAX PDP-10 minicomputer used in one of Comsat's projects. Our cooperative work led to a merger, forming a new California-based company named Comsat General Integrated Systems. Our aim was automation of engineering departments. One of the products of this new venture was SuperCOMPACT; a complete rewrite for the PDP-10. We chose that computer after careful competitive evaluation and decided that all future customers must buy a PDP-10 if they want to use SuperCOMPACT. Since our program was the only one on the market, we figured all companies must follow our condition.

Six months later we released SuperCompact and several customers immediately bought the program with PDP-10 computers. However, one of our major customer's vice president called and informed me that they were not about to drop their multi-million dollar large-scale IBM computer, and since they were the most important U.S. defense contractor, he wanted to see SuperCOMPACT running on their system. Not wanting to interfere with defense project developments, I promised to make an exception. A few days later two other large company bosses called with the same argument. I caved in again, promising to convert the program for their CDC and Cray computers. Fortunately, after the merger we hired some professional programmers who predicted such issue and used software switches in the program, making the conversions much easier. Another industry first product was AutoArt [4] that converted circuit files to circuit layout.

C. *HandyCOMPACT, MiniCompact, SuperCOMPACT PC*

Not having any commercial competition, we got carried away and created several versions of the program for hand-held and desktop calculators, but the return on their sales did not justify development cost. It wasn't until one of our key engineers left to form a competitor by writing a relatively simple program for the new IBM PC. Their product, TouchStone was an immediate success and opened a new era in microwave circuit design. Unique features of TouchStone were interactive tune mode and color graphics, at a reasonably low price. Companies where we previously tried unsuccessfully selling a PDP-10 with SuperCOMPACT for $70-80,000, suddenly bought a half dozen PCs with TouchStone installed for the same price. Microwave engineers learned to type, also wrote reports, used spreadsheets and other applications, in addition to circuit design. Office automation, the task we couldn't successfully achieve with minicomputers, was done with networked PCs. Although the 100,000+ lines of SuperCOMPACT code was later also converted for PCs by partitioning it into a large number of small segments, it could not compete with the TouchStone, that was written specifically for PCs. Thus ended COMPACT's monopoly.

D. *Emergence of new circuit simulators*

Although SuperCOMPACT was still used heavily by a large number of companies on their mainframe computers, new products gradually appeared on the market for PCs and workstations. The most significant of these were HP's Microwave Design System (MDS) for Unix-based workstations and Circuit Buster's Super Star (later version called Genesys under a new company name, Eagleware) for PCs. SuperCOMPACT added nonlinear simulation via harmonic-balance technique [5] in the mid-80's, to be followed by TouchStone (its version called Libra) and MDS. HP then bought the TouchStone group, merging their programs into Advanced Design System (ADS). After the HP break-up, Agilent bought Eagleware; Ansoft bought Compact Software, releasing a revised simulator under the name of Ansoft Designer. In the late 1990s, a new company, AWR appeared with a highly user-friendly product called Microwave Office.

Electro-Magnetic (EM) simulation begun to take off in the 1980s with Ansoft and Sonnet leading the way. They were followed by other groups in the 1990s. Today, the three major competitive circuit simulators include linear/nonlinear analysis and optimization, EM and system simulation, large vendor-supported active and passive component libraries, as well as other useful tools, such as filter synthesis, transmission line analysis/synthesis, Smith Chart manipulation, and load-pull tuners. Some of the major universities offer courses on the use of the simulators, enabling young graduates to be familiar with their use.

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Les Besser (S'64, M'66–SM'75–F'93, Life F'01) **A native of Hungary, he began his engineering career in 1966 in Hewlett Packard's Microwave Division, developing broadband microwave components, receiving a patent for the first thin-film amplifier circuitry used in the CATV industry. Next, he concentrated on MICs, GaAs FET amplifiers, and CATV systems at the Microwave and Optolectronics Group of Fairchild. During this time he became interested in CAD and wrote the SPEEDY program that offered a transistor database with high-frequency device parameters. He later joined Farinon Electric Company to direct their microcircuit design and development effort. During that period he authored COMPACT, the first commercially successful microwave circuit optimization routine, soon to become the industry standard. He then founded Compact Software, a pioneer CAD software company (now part of Ansoft), and was active in serving the engineering design needs of the RF/Microwave industry during the next ten years. In 1980, his company merged with Communication Satellite Corporation, where he served as a Senior Vice President.**

In 1985 he formed Besser Associates, an organization dedicated to continuing education through instructor-led and Internet-based short courses, CD- and video-taped presentations. The company now has over 50 Associates and has provided live training to more than 45,000 engineers, managers, and technicians world-wide. He was instrumental in the formation of the RF EXPO Short Course program between 1986 and 1991. From 1988 to 1990 he also served as Editorial Director of Microwave Systems News (MSN) magazine. He retired from the Besser Associates in 2001, but still teaches courses occasionally.

Dr. Besser has published over 70 technical articles, developed three one-week short courses, contributed to and co-authored several textbooks. His latest two-volume books, *Practical RF Circuit Design for Modern Wireless Systems* were published in 2003. During the past 30 years, he delivered short courses at several major universities, including UCLA, Stanford, MIT, Oxford and Cambridge (UK). He has also been involved in numerous IEEE activities. In 1983 he received the IEEE MTT "Microwave Applications Award," the IEEE RFTG "Career Award" in 1987, the IEEE Third Centennial Medal" in 2000, and the IEEE Education Activities Board's, "Meritorious Achievement Award in Continuing Education," in 2006and the IEEE MTT "Distinguished Educator" award in 2007, with the citation, "For Outstanding Achievements as an Educator, Mentor and Role Model of Microwave Engineers and Engineering Students." He is listed in Marquis' (1995) "*Who Is Who In The World*," "*Microwave Hall of Fame*" and recently also in "*Microwave Legend.s*"