Millman and Taub's *Pulse and Digital Circuits*—A Pioneer Text in Its Field

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Abstract—In 1956 a new electrical engineering text entitled *Pulse and Digital Circuits* (New York: McGraw-Hill, 1956) appeared. The book, by Jacob Millman and Herbert Taub, was an immediate worldwide success. There are two reasons. It was one of the first American texts to open the door to pulse and digital waveforms and circuits—the brand new and very extensive technology acquired during the World War II development of radar. It was an outstanding teaching book. It broke new ground in presenting unconventional electrical engineering material with wide breadth and clarity, coupled with a large number of applied problems (more than 400).

The book's successor, *Pulse, Digital and Switching Waveforms* (New York: McGraw-Hill, 1965), by the same authors, is still in print—19 years after its initial publication.

This paper describes the genesis of *Pulse and Digital Circuits*.

Introduction

Electrical engineering educators today face a problem—how to select the best text from the avalanche of new publications regularly appearing on the market. A scant 30 years ago, however, the problem was quite the opposite. There were too few texts available, and the instructor's choice was limited.

It was during this period in the mid-1950's that a new textbook appeared, one that was destined to become a worldwide success. The book was titled simply *Pulse and Digital Circuits* [1], and what its authors had done was to distill much of the extensive theoretical and practical knowledge of pulse techniques developed during and immediately after World War II, and create from it a teaching book that broke new ground in organization, clarity of presentation, and depth of coverage. This paper describes the genesis of that text.

The World War II Period

The time was the early 1940's, the critical period immediately following the Japanese bombing of Pearl Harbor and the subsequent entrance of the U.S. into World War II. The entire nation was swept up in the war effort, and during those early years the outlook for the Allies appeared grim and uncertain. The potential contributions of science and technology to the national defense were just beginning to be realized, and starting in about 1941 many of the nation's leading scientists were quietly recruited and sent east to work on one of the war's vital engineering projects—the (then secret) development of microwave radar.

Among the select group was Jacob Millman,[1] a young electrical engineering professor, granted leave in 1941 from his teaching duties at the City College of New York, New York, NY, and assigned to the Radiation Laboratory of the Massachusetts Institute of Technology, Cambridge.[2] In discussing those days, Millman remembers that there were few graduate electrical engineers at the lab. Most staff members were physicists (as was Millman), together with a few mathematicians.

The work in which Millman found himself suddenly immersed involved problems in the generation and reception of sharp, narrow pulses of RF energy. These were crucial aspects of radar design, since the sharper and narrower the radar pulse, the higher the resolution of the system. That meant an increased ability to recognize enemy ships or aircraft. The work was in the forefront of electronic technology. "It was all quite new to me," Millman recalls. "There were no textbooks on nonsinusoidal waveforms, and we had to learn from one another. The radiation lab provided a marvelous learning experience."

The state of electrical engineering education at that time was such that most college curricula could be divided into two broad categories.[3] One was power (motors, generators, and also transformers) and the other communications, which included electronics. Electronics concerned itself, among other things, with the theory of conduction in

Manuscript received May 21, 1984; revised July 27, 1984.

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[1]Millman obtained his undergraduate degree in physics from the Massachusetts Institute of Technology, Cambridge, in 1932. After spending the following year on a fellowship at the University of Munich, Germany, he returned to M.I.T. and in 1935 was awarded the physics doctorate. Millman recalls that jobs in physics were very scarce then. When an electrical engineering teaching position at CCNY was offered, Millman—with the encouragement of Prof. J. A. Stratton (later to become M.I.T.'s President)—accepted.

[2]Spurred on by the growing threat of the conflict in Europe, and at the urging of its ally Great Britain, the U.S. government undertook the development of high-resolution radars to operate at the then barely explored microwave frequency range. To realize this goal, the M.I.T. Radiation Laboratory was established on November 10, 1949 under the supervision of the U.S. National Defense Research Committee. A very readable history of this enormous wartime research project can be found in the introductory sections to [2].

[3]J. Millman, private communication. Also [3].

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Fig. 1. Jacob Millman lecturing at City College of New York (1947-1948.).

Fig. 2. Herbert Taub in a recent photograph.

vacuum tubes. In the field of communications, radio circuits occupied the preeminent position, with the emphasis chiefly on sinusoidal waveshapes. What interest there existed in nonsinusoidal waveforms had to do mainly with rectifiers and filters. Saw-tooth time base generators were, of course, also known (they were already in use by 1936), but they apparently did not play a large role in the students' education. Even less of a role was played by pulse-type circuits. These were hardly known outside of a few scientific research laboratories.

Millman continued his work at the radiation labs for the remainder of the war. He was made Project Engineer of the "V-Beam," the largest ground radar system in existence, and his work increasingly involved pulse and digital waveforms. In 1945, with the surrender of the axis powers and the ending of the conflict, he returned to the City College of New York (CCNY) to resume his teaching career.

The Groundwork

It was at CCNY that Millman met and began his fortuitous collaboration with another young electrical engineering professor—Herbert Taub.[4] Taub had just received the Ph.D. degree from Columbia University, New York, NY, (also, coincidentally, in physics), and it became quickly apparent to these two that 1) the newly acquired body of knowledge of pulse and digital waveforms should be introduced into the curriculum as soon as possible, and 2) they were the individuals at CCNY best suited and most prepared to do it. They were formally assigned such a task by the CCNY Department of Electrical Engineering, that is, to develop a course in the new radar-type circuits.

The actual work began, inauspiciously enough, in the time-honored tradition of the teaching profession, with Millman and Taub writing lecture notes. These were then mimeographed (no fast copying machines then) and handed out to the students. Although there was some initial apprehension whether sufficient material would be available for an entire course, slowly and steadily the subjects began to accumulate.

The emphasis throughout was on waveforms and waveshaping circuits. In describing that early work, Taub points out the essential distinction between the digital waveforms of today's computer era and the pulse-type waveforms employed in those early days of radar. "Nowadays, pulse work is all on a yes-or-no basis," he emphasizes. "Today we couldn't care less about the details of whether there are wiggles (ringing) at the top or not—all those concerns we were so worried about then. In fact, the very word 'pulse' has gone out of vogue. These are now binary or digital waveforms."

Collaboration between two authors doesn't always necessarily guarantee success—especially if there are wide differences in personality, style, or goals. One of the serendipitous aspects of the Millman–Taub collaboration was that both followed a similar style of writing. Each believed strongly in paying scrupulous attention to detail and in striving for maximum understanding on the part of the reader, even at the expense of more words or more diagrams.

Millman recalls, "I would revise the material he (Taub) wrote and it would then go back to him. He might agree or not, and we would discuss it and finally agree on a com-

[4]Herbert Taub graduated from City College of New York, New York, NY, in 1940, with the bachelor's degree in physics. In 1945 he earned the Ph.D. degree at Columbia University, New York, NY, and that same year began his teaching career at the City College School of Engineering. At Columbia, working under Nobel Laureate Polykarp Kusch, Taub succeeded in measuring the magnetic moment of the proton to an accuracy greater than ever before achieved. Taub's reason for switching from physics to engineering was similar to that of Millman's, namely, "opportunities in engineering were more readily available than in physics."

promise. The converse was true with respect to what I wrote. This was often a lengthy process, but the end result was so homogeneous that later we ourselves could not tell which portions of prose (or ideas) were Taub's and which were mine. However, through all these labors Herb and I remained warm friends."

In this fashion, the material grew from a set of mimeographed hand-out notes eventually to a complete bound set, stapled together, running to some 200 pages. The notes were, indeed, meticulously crafted. They described in step-by-step logic the operation of such circuits as multivibrators (bistable, monostable, and astable), linear pulse amplifiers, and delay lines. Few of these circuits had been so carefully described before. The style was simple and direct, giving a physical explanation of the operation first, but never hesitating to use equations where it was felt they would clarify the discussion. A large number of circuit diagrams, tables, and graphs also helped to explain the material.

The Technical Environment at the Time

It must be borne in mind that at that time the only data available on the new radar technology were in highly specialized technical journals. There were few textbooks on the subject.[5]

There is one special book to which both Millman and Taub do acknowledge a debt. The book is *Waveforms* [5], the 19th volume of the historic 28-volume *Radiation Laboratory* series, published a few years after the war. *Waveforms* and its 27 companion volumes contained a wealth of material—indeed, they summarized much of the entire wartime research effort at the radiation lab. Many technical libraries still maintain this set on their open shelves. But these were not teaching books in any sense of the word. The material was highly mathematical and not readily understandable to the average undergraduate. There were no end-of-chapter problems. Moreover, *Waveforms* was not published until 1949, so that even that book was not available when the first set of lecture notes was prepared.

Did Millman and Taub plan right from the start to write a book? Both authors acknowledge that, in time, as the volume of material began to grow, the idea of writing a book seemed more and more the obvious direction to go. At first, however, back in 1945, there was no such idea—nothing more ambitious than preparing a worthwhile, new electrical engineering course.

To check out many of the circuits described in the first set of notes, the CCNY electronics lab was used extensively. One of the most important items of test equipment was the oscilloscope—not the simple, easy-to-use 'scopes' available today. Millman remembers some of the earliest ones. "Many were huge monsters," he recalls. "There was one that consisted of two separate units, the 'scope' itself and a separate power supply section. Each unit was enormously heavy."

In gathering material for this paper, one special question was put to both collaborators: "Was there anything unique in the City College environment at that time that fostered pioneer undertakings such as the writing of your book?" The reply was that the CCNY engineering school always had a reputation for first-rate teaching. Instruction was the primary objective.[6] The weekly contact hour load, 15 classroom hours, was rather heavy by today's standards. But neither author was required to do research, and thus could devote full energies to pedagogic activities. (Herbert Taub, who is still teaching at CCNY, continues to follow this precept. He spends his time teaching and writing, rather than in research.)

By the early 1950's, some seven or eight years after the initial collaboration, enough material had been assembled to produce a quite extensive book. The manuscript was submitted to McGraw-Hill Publishing Company in 1955 and finally appeared in print one year later as a 687-page textbook. During that time (in 1952) Millman had assumed a professorship at Columbia University (about a mile down the street from the CCNY campus), but the close collaboration between the two authors continued.

Development of the book did not go completely smoothly. In 1955, the year prior to publication, a potentially serious problem arose. The entire text of *Pulse and Digital Circuits* had been delivered to the publisher. All that was lacking were the problems. The authors felt—and McGraw-Hill agreed—that since it required about one year from the time the manuscript was submitted until the book was finally set up in type, that interval would be used to write all the problems. This was no small task, but it was assumed by all concerned that it would be manageable. But just about that time it was becoming evident that a major revolution was quietly taking place in the electronic industry. The recently developed transistor had proved its worth beyond a doubt, and the new device was steadily and relentlessly beginning to replace vacuum tubes in many applications. The manuscript for *Pulse and Digital Circuits,* begun in the late 1940's, was based strictly on vacuum

[5]When *Pulse and Digital Circuits* was finally printed in 1956, it turned out that it was not the first textbook on that subject. Three years earlier, L. W. Von Tersch and A. W. Swago of Iowa State College, Ames, published a 399-page text [4] that discussed a selected number of basic pulse circuits. The book grew out of a course in pulse circuits given at Iowa State as early as 1946, in a pattern similar to that at CCNY. Although the Von Tersch and Swago text addressed itself to practical aspects as well as theory, it was not as comprehensive nor did it achieve as wide a circulation as the Millman and Taub book.

[6]Millman, whose teaching career at CCNY began in 1936, recalls that in the 1930's and 1940's, "students worked like dogs." It was a time when the aftereffects of the Depression were still being felt. People were poor and jobs were scarce. "They (the students) knew they had to be pretty darn near the top of the class to get a job—anywhere. Many came to school on empty stomachs and some couldn't even afford the subway fare and would walk a great distance just to attend classes."

Although that era of economic distress ended early in the 1940's, the atmosphere of intense, survival-like competition among the undergraduates did not die out. It remained, and continued to foster an accompanying spirit of dedication among the teaching staff.

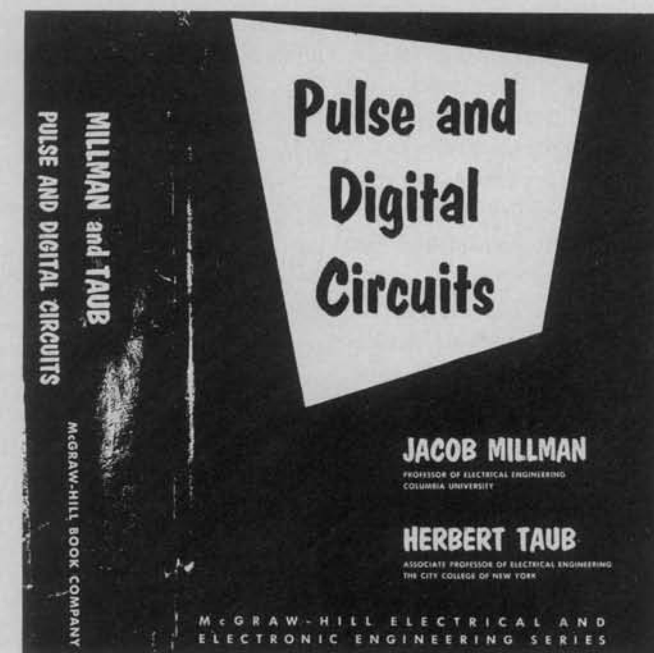

Fig. 3. The cover of *Pulse and Digital Circuits,* familiar to many students in the 1950's and 1960's.

tube technology. Realizing all this, the editors at McGraw-Hill expressed the view that in order to keep up with the changing times, there should be included at least one chapter on the new technology of transistors.

After nearly eight years of hard labor, this was a major setback to the writers. Neither Millman nor Taub (nor too many others, in fact) had acquired much experience with transistors. Very few books had been published, and what knowledge there was resided mainly in scattered technical articles and in a select number of internal Bell Laboratories reports.

To see their way through this unexpected obstacle, Millman and Taub worked out a special arrangement. Millman would assume the responsibility for writing all the problems while Taub would undertake the chapter on transistors (chapter 18). Neither task was enviable. The total number of problems ultimately ran to over 400, each one a solid "thinking type." Each problem required a great deal of time and effort to make up. As for the chapter on transistors, Taub still recalls the assignment with a certain amount of awe. "Starting absolutely from nothing," he recalls, he began intensively studying the available literature. He also began taking trips to Bell Laboratories, fortunately located not too far away in nearby New Jersey. At Bell Labs he tried to obtain whatever nonproprietary documents were then available.

After that, there came a period of mentally digesting the literature, none of it very simple. (It should be noted that in the early days of transistors many of today's simplifying assumptions were not yet widely understood. Consequently, much of the literature was burdened with ponderous equations. Transistor theory did not make light reading then.) Taub spent many hours in the laboratory testing transistor operation and building transistor circuits. Perseverance ultimately prevailed, and when the text was finally published, readers were able to find a full 59-page chapter describing and *explaining* much of what was then known about transistors.

Taub enjoys recalling that, soon after publication, a request came to McGraw-Hill from the IBM laboratory in Peekskill, NY: Could they be allowed to reprint the transistor chapter for an IBM in-house transistor training program. The request was granted, thus providing IBM with a brand new teaching tool, and Herbert Taub with immediate and respected recognition for his labors.

Conclusion

Pulse and Digital Circuits proved to be an immediate success, both in the United States and worldwide. It was reprinted in six languages: Russian, Hebrew, German, Italian, Spanish, and Japanese, and it ran to many printings. Pirated copies (the sure sign of success) also appeared, printed abroad illegally.

As a text, *Pulse and Digital Circuits* reigned virtually supreme for nearly a decade. By the early 1960's, however, it was readily apparent that the transistor was more than just another passing technology. It was here to stay, and so the two authors once again combined their talents and undertook the writing of another text, a successor to their 1956 pioneering classic. This new volume, *Pulse, Digital and Switching Waveforms* [6], came out in 1965 and enjoyed even greater success. Millman and Taub did not abandon vacuum tubes completely, but presented semiconductor and tube circuits side by side, with the emphasis, however, on transistors.

An indication of the popularity of this successor text may be gained from the fact that even today, in 1984, 19 years after its publication, the book is still in print, this despite the fact that much of its technology is already obsolete. A large fraction of the current sales are from abroad where an international student edition—a soft cover version—is sold. All in all, the combined sales of both pulse books in hard cover (the 1956 original and the 1965 sequel) have reached 160 000 copies.

Today the galaxy of electrical engineering authors is growing rapidly. But Millman and Taub continue[7] to be recognized as among the world's best, a recognition that spans more than three decades.

Addendum

The author of this paper was an electrical engineering student at City College of New York in the early 1950's. He was fortunate in having Professor Taub as one of his teachers. Later on, as a graduate student at Columbia University in the late 1950's, he was again fortunate in being in Professor Millman's class for three consecutive semesters of the pulse circuits sequence. The book *Pulse and Digital Circuits* was used throughout.

Material for this paper was obtained through phone conversations, correspondence, and personal interviews with Jacob Millman and Herbert Taub—all during the period January–July 1984. The author's own college notes and recollections also provided a source of information.

[7]Millman has authored eight books, the last of which is *Microelectronics* [7]. Taub has five books to his credit, the most recent being *Digital Circuits and Microprocessors* [8].

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