



A Brief History of UWB Communications

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The majority of the initial concepts and patents for ultra wideband (UWB) technology originated in the late 1960's at the Sperry Research Center (Sudbury, MA), then part of the Sperry Rand Corporation, under the direction of Dr. Gerald F. Ross. At that time, this technology was alternately referred to as *baseband*, *carrier-free* or *impulse*. The term "ultra wideband" was not applied to this technology until approximately 1989; and by this time, UWB theory, techniques and many hardware approaches had experienced well over 30 years of extensive development. (See below for Dr. Ross' views on the *Early Motivations and History of UWB Technology*. Dr. Ross is a Fellow of the IEEE and a Member of the National Academy of Engineering, both honors awarded for his long history of contributions to time-domain electromagnetics and ultra wideband technology. Also below is a *History of Ultra Wideband (UWB) Radar & Communications: Pioneers and Innovators*, provided to MSSSI by UWB researcher Dr. Terence W. Barrett.)

By 1989, Sperry had been awarded over 50 patents in the field covering UWB pulse generation and reception methods, and applications such as communications, radar, automobile collision avoidance, positioning systems, liquid level sensing and altimetry. Sperry was also awarded the earliest UWB communications patent ([U.S. Patent No. 3,728,632 dated 17 April 1973](#) 1.72Mb).

Interestingly, much of Dr. Ross' early work in UWB was an outgrowth of his 1963 doctoral dissertation on "The Transient Analysis of Multiple Beam Feed Networks for Array Systems," under the guidance of Professor Athanasios Papoulis, an internationally known expert in the field of systems analysis. (Portions of this thesis can be found in "The Transient Analysis of Certain TEM Mode Four-Port networks," *IEEE Trans. Microwave Theory and Tech.*, Vol. MTT-14, No. 11, November 1966, pp. 528-547.)

In 1984, recognizing the value of UWB technology in the development of low probability of intercept and detection (LPI/D) communications systems, Dr. Ross prepared a seminal paper entitled "Comments on Baseband or Carrier-Free Communications". Collaborating with Dr. Robert Fontana, currently MSSSI President, Ross and Fontana designed, developed and implemented an LPI/D communications system which was funded by the U.S. Government in 1986 and fielded in September 1987.

Unique to the Ross-Fontana approach was the use of a single-pulse detection strategy utilizing the negative resistance properties of a quantum tunneling device. The tunnel diode, invented in 1958 by Nobel Laureate Leo Esaki, was originally conceived for the detection of subnanosecond pulses by Ken Robbins ("Short Base-band Pulse Receiver," U.S. Patent No. 3,662,316, May 9, 1972). An early implementation of this single-pulse detector has been described in detail in an article by Bennett and Ross "Time-Domain Electromagnetics and Its Applications," *Proceedings of the IEEE*, Vol. 66, No. 3, March 1978, pp. 299-318. This article is highly recommended reading for those interested in applications of UWB technology. A modern implementation of this receiver can be found in [U.S. Patent No. 5,901,172, "Ultra Wideband Receiver with High Speed Noise and Interference Tracking Threshold,"](#) dated 4 May 1999.

After the initial success of the first UWB communications system, several classified follow-on programs ensued, and Drs. Fontana and Ross continued collaboration on UWB system development from 1986 through the end of 1997.

Since its inception, MSSI has been actively involved in UWB system development. Through over 11 years of collaboration with Dr. Ross, and with independent developments over the past 10 years, MSSI has developed an ultra wideband capability which is unique and proven. To date, MSSI has received over 28 contracts worth in excess of \$14M to develop UWB systems primarily for military and government agencies. Many of these contracts involved direct competition against other UWB companies. As such, MSSI has proven to be the industry leader in the UWB hardware field. While MSSI has focused primarily on UWB development for the Government and military, a recent Dual Use Science & Technology program award has prompted MSSI to seek outside investment for commercialization purposes.

For an excellent compendium of patents, papers, essential book references and bibliography on ultra wideband technology, please see Æther Wire & Location, Inc.'s CD-ROM collection at <http://www.aetherwire.com/CDROM/Welcome.pdf>.

Early Motivations and History of Ultra Wideband Technology

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In the late 1950's, there was an effort made by Lincoln Laboratory and Sperry to develop phased array radar systems. Sperry's Electronic Scanning Radar (ESR) employed a so called Butler Hybrid Phasing Matrix which was an interconnection of 3 dB branch line couplers connected in such a manner that it formed a 2-N port network. Each input port corresponded to a particular phase taper across the output N-ports which, when connected to antenna elements, corresponded to a particular direction in space.

In attempting to understand the wideband properties of this network, efforts were made to reference the properties of the four port interconnection of quarter wave TEM mode lines which formed the branch line coupler. It was astonishing to find that no such analysis existed. And so it began.

It started with the analysis of the general microwave 2-N port, the so called biconjugate network. Since the impulse response of these networks was a train of weighted and equally spaced impulses, the response resembled what one would find at the output of a sampled data system. About the same time, Schmidt and RWP King were measuring the impulse response of the dipole and resonant ring radiating elements in the time-domain. Here, too, the response in the far field and the driving ports was approximately a train of uniformly spaced impulses. This correlated well with the work of Hallen who found in the frequency domain that this class of radiating element had a periodic amplitude spectrum when measured by a swept frequency source.

It was clear that working in the time domain, where the responses of these microwave networks were "compact", was correct for analysis. The laboratory measurement of these responses in the time domain, however, proved a real challenge. With the help of Dr. Barney Oliver at Hewlett Packard, who had just developed the sampling oscilloscope, and the generation of very short pulses using avalanche transistors and tunnel diodes, a whole new world began developing.

The work was then moved to the former Sperry Research Center (SRC), Sudbury, MA in 1965 where this writer formed a group of very talented engineers to help with the further development of "time domain electromagnetics".

Dr. J. Lamar Allen expanded the analysis of linear and non-reciprocal microwave networks and antennas to ferrite devices. Dr. Harry Cronson later extended the work to time domain metrology where the frequency domain properties of passive microwave networks were found via their impulse response and Fourier transforms. Both the US Air Force at Rome Labs and the US Army in Huntsville, Alabama supported this work. At about the same time, Drs. David Lamensdorf and Leon Susman started the analysis of antennas using time domain techniques. Once impulse sources and antennas capable of radiating impulse-like and step functions (at least over a narrow time window of 20-30 ns) were developed, Drs. C. Leonard Bennett and Joseph D. DeLorenzo began studying the impulse response of targets directly in the time domain. Dr. DeLorenzo invented the time domain scattering range, which proved to be a powerful tool for both the scattering analyses of targets and antennas. Ohio State investigators using individual frequencies and combining the amplitude and phase data by computer also did a significant amount of work on scattering using DeLorenzo's scattering range concepts.

The last element that needed to be developed before real system development began was the threshold receiver. In the early 1970's both avalanche transistor and tunnel diode detectors were constructed in an attempt to detect these very short duration signals (e.g., 100 ps). This work culminated in the development by Dr. A. Murray Nicolson of the tunnel diode constant false alarm rate (CFAR) receiver. An improved version of the CFAR detector is still in use today.

With all the system blocks in place, a short range radar sensor was developed as a pre-collision sensor for the airbag then being touted for use in cars (1972). The range of this sensor was about 8 feet. Later improvements in power generation techniques resulted in a space docking radar (25-30 feet) and an aircraft runway traffic sensor with a range of 300 feet. Indeed, dozens of systems requiring different range requirements were developed, including a new class of altimeters.

In the metrology area (1970-1980), this writer together with Dr. Nicolson developed a narrow baseband pulse fixture in conjunction with FFT techniques to measure the stealthy properties of microwave absorbing materials directly from a single pulse measurement. Most of the development of stealthy materials done at Wright Patterson AFB used this approach until the Hewlett Packard network analyzer became available. The use of a single wire transmission line (e.g., a Gaubau line) was used to develop an anti-collision system for unmanned vehicles in work sponsored by UMTA and performed for the Boeing Aircraft Company. Later this technique was expanded to measure liquid levels in a tank. It appears others have recently rediscovered this work.

Work in radar continued in the 1990's with the development of synchronized arrays of short pulse sources. Peak powers in the order of 100 kW (peak baseband power) were achieved using low cost sources designed to radiate and scan in space microwave pulse packets having pulse durations on the order of 1-3 ns. These systems were used for intrusion detection applications.

In 1978 efforts turned toward the communication of these signals. Intelligible voice signals were communicated over hundreds of feet without the need for synchronization and demonstrated to the government. In 1979, data signals were communicated over much greater ranges using the 19 kHz subcarrier from classical music FM stations in urban areas. During the period 1984-1994, the work in communications was considerably expanded working together with Dr. Robert J. Fontana, now President of MSSSI. ANRO continues to be developing sophisticated UWB radar systems for anti-terrorist applications.

During the period 1960-1999, over 200 papers were published in accredited IEEE journals and more than 100 patents were issued on topics related to ultra wideband technology. And this work continues today with many more investigators having joined the field. The business interests for what is now called Ultra-Wideband (UWB) technology are growing exponentially.

History of Ultra Wideband (UWB) Radar & Communications: Pioneers and Innovators

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Magna est veritas, et praevallet.

The term: Ultra Wideband or UWB signals has come to signify a number of synonymous terms such as: impulse, carrier-free, baseband, time domain, nonsinusoidal, orthogonal function and large-relative-bandwidth radio/radar signals. Here, we use the term "UWB" to include all of these. (The term "ultra wideband", which is somewhat of a misnomer, was not applied to these systems until about 1989, apparently by the US Department of Defense). Contributions to the development of a field addressing UWB RF signals commenced in the late 1960's with the pioneering contributions of Harmuth at Catholic University of America, Ross and Robbins at Sperry Rand Corporation and Paul van Etten at the USAF's Rome Air Development Center. The Harmuth books and published papers, 1969-1984, placed in the public domain the basic design for UWB transmitters and receivers. At approximately the same time and independently, the Ross and Robbins (R&R) patents, 1972-1987, pioneered the use of UWB signals in a number of application areas, including communications and radar using coding schemes. Ross' US Patent 3,728,632 dated 17th April, 1973, is a landmark patent in UWB communications. Both Harmuth and R&R applied the 50 year old concept of matched filtering to UWB systems. Van Etten's empirical testing of UWB radar systems resulted in the development of system design and antenna concepts. In 1974, Morey designed a UWB radar system for penetrating the ground, which was to become a commercial success at Geophysical Survey Systems, Inc. (GSSI).

The development of sample and hold receivers commercially in the late 1960s, e.g., at Tektronix Corp., was also, unwittingly, to aid the developing UWB field. For example, the Tektronix Time Domain Receiver plug-in, model 7S12, utilized a technique which enabled UWB signal averaging - the sampling circuit is a transmission gate followed by a short-term integrator (Tektronix, 1968). Other advances in the development of the sampling oscilloscope were made at the Hewlett Packard Company. This approach was imported to UWB designs. Commencing in 1964, both Hewlett Packard and Tektronix produced the first time domain instruments for diagnostics. In the 1960s both Lawrence Livermore National Laboratory (LLNL) and Los Alamos National Laboratory (LANL) performed original research on pulse transmitters, receivers and antennas. In the 1970s LLNL expanded its laser-based diagnostics research into pulse diagnostics.

Thus, by the early 1970s the basic designs for UWB signal systems were available and there remained no major impediment to progress in perfecting such systems. After the 1970s, the only innovations in the UWB field could come from improvements in particular instantiations of subsystems, but not in the system concept itself. The basic components were known, e.g., pulse train generators, pulse train modulators, switching pulse train generators, detection receivers and wideband antennas. Moreover, particular instantiations of the subcomponents and methodologies were also known, e.g., avalanche transistor switches, light responsive switches, use of "subcarriers" in coding pulse trains, leading edge detectors, ring demodulators, monostable multivibrator detectors, integration and averaging matched filters, template signal match detectors, correlation detectors, signal integrators, synchronous detectors and antennas driven by stepped amplitude input.

In 1978 Bennett & Ross summarized the known pulse generation methods. Since that time there have been numerous sessions at conferences, at SPIE meetings, at meetings held by Brooklyn University and at other national meetings, where the many approaches to pulse generation techniques have been, and, continue to be, discussed.

During the period, 1977-1989, the USAF had a program in UWB system development headed by Col. J.D.

Taylor. By 1988 the present author was able to organize a UWB workshop for the US DoD's DDR&E attended by over 100 participants (Barrett, 1988). At this time, there was already substantial progress in UWB in the former Soviet Union and China, which in a number of ways antedated and exceeded the progress in the US (cf. Glebovich et al, 1984; Varganov et al, 1985; Meleshko, 1987; Astanin & Kostylev, 1989; Kostylev et al, 1994). There were also very active academic programs (e.g., at LLNL, LANL, University of Michigan, University of Rochester and Brooklyn University) which focused on the interesting physics of short pulse transmissions that differed from the physics of continuous or long pulse signals, especially with respect to interactions with matter (cf. Miller, 1986; Barrett, 1991; Bertoni et al, 1993; Carin & Felsen, 1995; Baum et al, 1997).

In 1990 LANL hosted a conference which provided a forum for the burgeoning developments in UWB systems and subsystems. In 1994, T.E. McEwan, then at LLNL, invented the Micropower Impulse Radar (MIR) which provided a UWB operating at ultralow power, besides being extremely compact and inexpensive.

In summary, the pioneering work of Harmuth, Ross, Robbins, van Etten, and Morey defined UWB systems and did so in a very practical manner. Others have contributed to particular instantiations of the subsystems described by these pioneers, but after the pioneering contributions, no one can, or should, claim to have invented the field of UWB radio, radar or communications, nor to have invented a particular component or components which made it practical. There never was a time such that a particular subcomponent invention was required for UWB systems to become possible, except, perhaps, the sample-and-hold oscilloscope. In the commercial arena, UWB systems have been utilized and commercialized beginning in the 1970s.

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