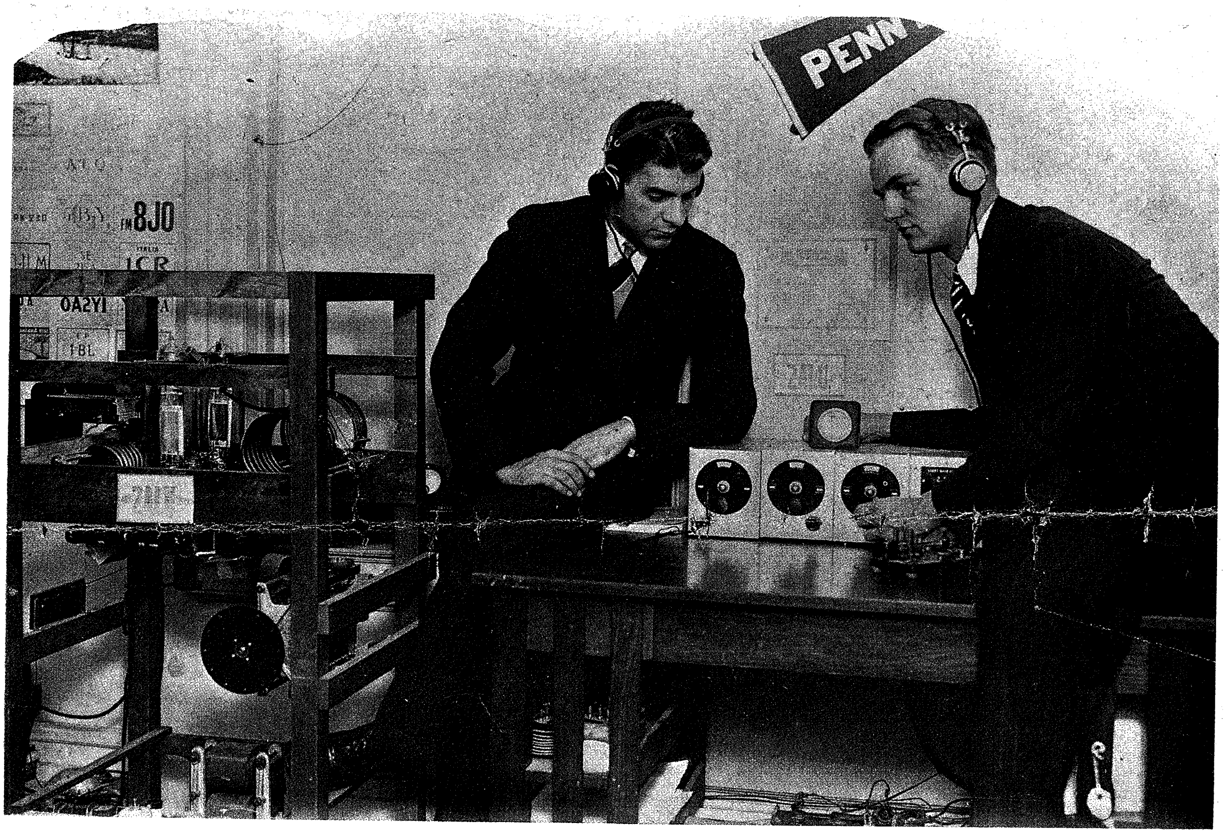
PROCEEDINGS OF

THE RADIO CLUB OF AMERICA, INC.

Founded 1909, New York, U.S.A.

Spring 1995



John B. Knight, W6YY, 1906-1995

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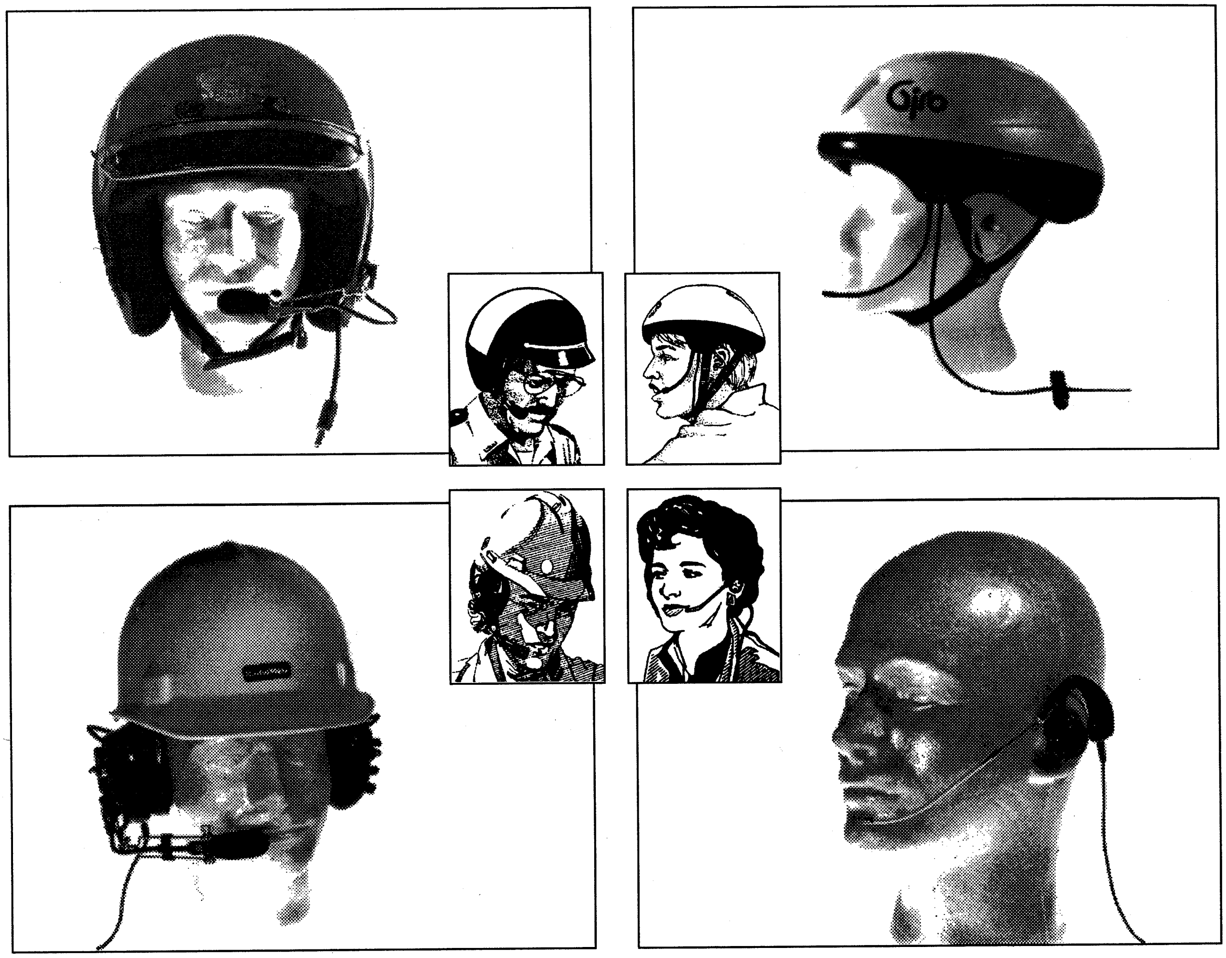
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THE RADIO CLUB OF AMERICA, INC.
Founded 1909, New York, U.S.A.
Executive Secretary: P.O. Box 68, Glen Rock, NJ 07452
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President's Message

By John Morrisey

The Future

We have been very fortunate in the quality of the individuals that we have attracted from the radio industry and academia. Now we are undertaking a new, long-range program under the leadership of President-Emeritus Mal Gurian. His committee is interacting with all levels of membership to plan for the Club's future.

For a successful future, we must strengthen our program for recruiting new members, as well as have attractive activities for our present members. Enhancement of our publications is of highest importance; so is the formation of additional Sections so each member may share in social as well as technical activities close to home.

In the years ahead, there will be changes in the Club as we know it for, as I recall from a sociological class, those human institutions that do not lend themselves to change provide for their own quick or slow death. Our mission and role is to provide challenging and interesting activities, and we face the problem of what activities to retain and which to shed. However, we must not fall into the trap of thinking that because something was done in a certain way in the past, it must continue to be done so in the future.

We shall face the stress of coping with financial difficulties that may impede our ability to expand the Club and to bring professional management into the leadership. With our independent staff of volunteers to bolster the scope and quality of activities, the progress may sometimes seem slow. The forum as the direction of our planning should belong to every member, and space in our publications should be made to everyone with an opinion. Undoubtedly, we shall differ amongst ourselves as to the proper paths to choose, but our concentration on the goal must not waiver.

In the forthcoming issues of the Club's *Proceedings* and *Newsletters*, we shall keep you informed on the progress of the long-range planning committee.

John Morrisey, Radio Club President

Editorial Comment

By Jane Bryant

This issue of the *Proceedings* is filled with interesting articles on radio communications and personalities in the radio industry. The Radio Club of America continues to support radio communications, history and innovators in the field.

If you missed the fall's annual banquet in New York City, you'll want to read our coverage on pages 4 to 10. The technical symposium was particularly interesting, and the papers delivered are covered in this edition for your reading enjoyment.

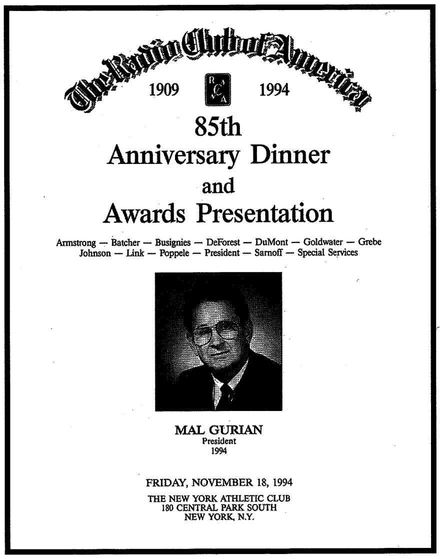
As the Club looks to the future, we need your input. Many Club members contribute to the *Proceedings*, but we need to hear from more of you. As the radio industry continues to evolve, members want technical information on personal communications services, high-definition television, digital broadcast services, satellite and more. Historical articles and features on Club members are favorites among readers as well.

We welcome your input; send articles for review to us or call us with your ideas. We look forward to continuing to provide you with interesting and informative articles. The editorial deadline for the next *Proceedings* is September. This will be our issue that comes out right before our annual meeting. It is not too early to begin planning to contribute to this issue now.

Jane Bryant, Editor

1994 RCA Banquet and 85th Anniversary Dinner

By Jane Bryant, *Proceedings* Editor



The Radio Club of America
1909 RCA 1994
85th
Anniversary Dinner
and
Awards Presentation

Armstrong — Batcher — Busignies — DeForest — DuMont — Goldwater — Grebe
Johnson — Link — Poppele — President — Sarnoff — Special Services

MAL GURIAN
President
1994

FRIDAY, NOVEMBER 18, 1994
THE NEW YORK ATHLETIC CLUB
180 CENTRAL PARK SOUTH
NEW YORK, N.Y.

The 85th Radio Club of America's Anniversary Dinner and Awards Presentation on Nov. 18, 1994 in New York City brought many club members and guests together for a diverse technical symposium and to witness the annual presentation of honors and awards.

Alfred H. Grebe Jr. (F), Gregory M. Stone, Ph.D. (F) and Albert D. Helfrick, Ph.D., P.E. (F) provided participants in the technical symposium with diverse information. Grebe discussed the history of Grebe Radio manufacturing and broadcasting, relating stories about his father, Alfred Henry Grebe. Helfrick discussed the global positioning system (GPS) and radionavigation, and Stone detailed bandwidth efficiency. A copy of Stone's presentation appears in this *Proceedings* on page 18.

Raymond C. Trott, Director, welcomed RCA members and guests to the annual awards ceremony and banquet. President Mal Gurian gave his president's report, followed by the election report by Secretary Gilbert R. Houck. Election results include officers Vice President William E. Endres, Vice President Counsel Joseph Rosenbloom, Esq., Vice President Co-Counsel David Weisman, Esq., Treasurer Eric Stoll and Secretary Houck. Elected directors for two years include Maxine Carter-Lome, John E. Dettra Jr., Arch Doty, Dr. Theodore S. Rapport, Raymond C. Trott, Ed Weingart and Don Bishop. John Hart was elected to a one-year director term.

The annual President's Award was bestowed to three club members: Frank A. Gunther, Jerry B. Minter and Francis H. Shepard Jr., who received the honor posthumously. The Annual Citation and Award winners are listed on page 7.

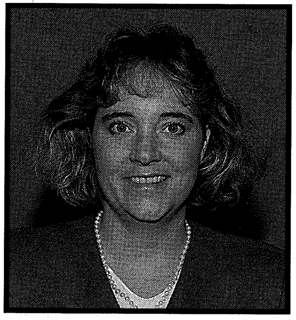
Following the presentation of the major awards, John N. Palmer, Mtel Corp. chairman and CEO, gave the keynote address, "Wireless Communications: Bringing America into the Twenty-First Century," which can be read on page 8.

RCA Banquet '94

In addition, among the honors at this annual event, 25 club members were elevated to the grade of Fellow with Director Jay Kitchen reading the names of these recipients and President Emeritus Fred M. Link handing out the plaques. New Fellows are Bentley G. Baker of Philadelphia; Beverly G. Baker, Esq., Washington, D.C.; Marion S. Campbell Jr., Plano, TX; Werner H. Freitag, D.Ed., New York; Lacy Goostree, P.E., Dallas; June S. Harris, Coral Springs, FL; Bobby J. Hudson, Bellevue, WA; Frank L. Huggins Jr., Swannanoa, NC; Bruce M. Karr, Fresno, CA; William P. Keel, Flint, MI; Oliver D. Kihchel, Jeannette, PA; Irving C. Klepper, Severna Park, MD; Julius P. Knapp, Ellicott City, MD; and John L. Koenreich, Palma de Mallorca, Spain.

Additional Fellow honors went to Peter L. Langer, Sag Harbor, NY; Donald Magrini, Wayne, NJ; James A. Maxwell, Ph.D., Redwood Estates, CA; Louis J. Meyer, P.E., Lewisville, TX; Emily C. Nelms, Potomac, MD; Paula Nelson-Shira, Englewood, CO; Ron R. Ross, Upland, CA; Patricia Schod, Schaumburg, IL; Robert L. Tonsfeldt, Atlanta; Malcolm M. Turdo, Wall, NJ; and Lewis D. Wetzel, Wenham, MA.

New Fellow Tonsfeldt responded for the Fellows in a short address, followed by the banquet's closing.



Jane Bryant, a Fellow of the Radio Club of America and editor of the *Proceedings*, is editorial director at Phillips Business Information.

Thank You to the 1994 RCA Banquet Contributors

American Mobile Systems Inc.
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Aurora Marketing Co.
Celwave RF Inc.
COMCAST Cellular Systems
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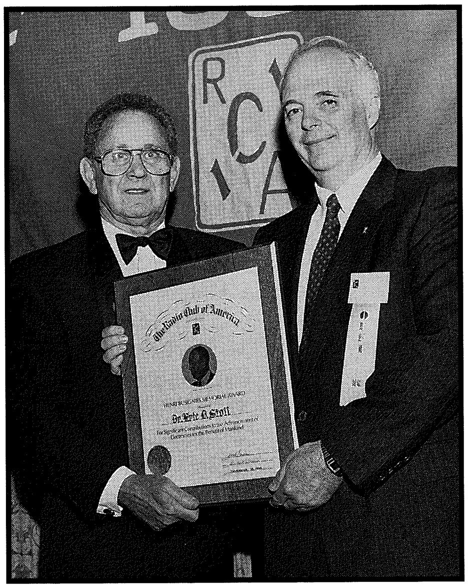
Eric D. Stoll, Ph.D., Treasurer
Tele-Measurements Inc.
Telewave Inc.
TROTT Communications Group

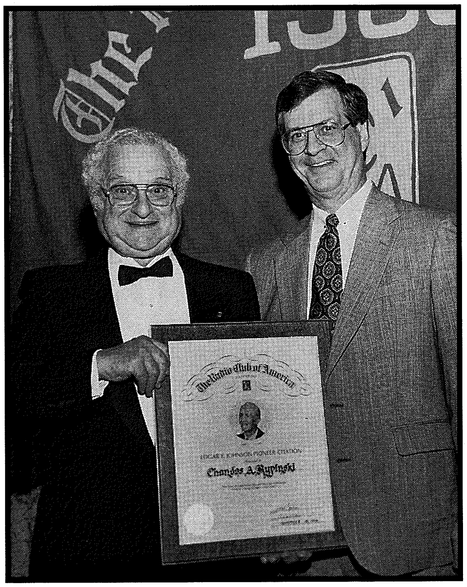
RCA Banquet '94

Frank A. Gunther (left) receives the Alfred H. Grebe Award in recognition of his achievement of excellence in the engineering and manufacturing of radio equipment.

Dr. William E. Good (left) receives the Allen B. DuMont Citation in recognition of his pioneering work in color-television video display technology.



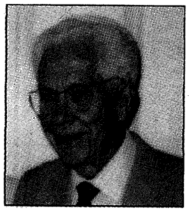
Dr. Eric D. Stoll (right) receives the Henri Busignies Memorial Award in recognition of his significant contributions to the development and advancement of electronic communications. Mal Gurian was the presenter.



Chandos A. Rypinski (left) receives the Edgar Johnson Pioneer Citation in recognition of his contributions in fields of signal processing, access protocol and LAN system architecture.

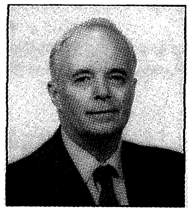
RCA Banquet '94

HONORS AND AWARDS 1994



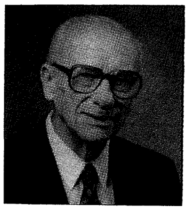
SARNOFF CITATION
Jack McCullough

Awarded in recognition of his leadership in the development and production of high-powered vacuum tubes.



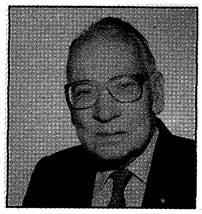
BUSIGNIES MEMORIAL AWARD
Eric D. Stoll, Ph.D.

Awarded in recognition of his significant contributions to the development and advancement of electronic communications.



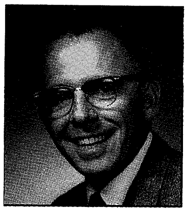
ALFRED H. GREBE AWARD
Frank A Gunther

Awarded in recognition of his achievement of excellence in the engineering and manufacturing of radio equipments.



FRED M. LINK AWARD
Robert M. Mattingly

Awarded in recognition of his contributions toward the successful development of cellular radio techniques.

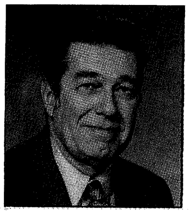


ALLEN B.DuMONT CITATION
William E. Good, Ph.D.

Awarded in recognition of his pioneering work in color-television video display technology.

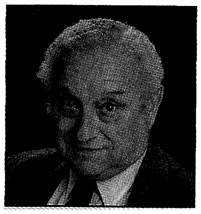
POPPELE BROADCAST AWARD
John B. Knight

Awarded in recognition of his long-term contributions to the development of radio broadcasting at N.B.C.



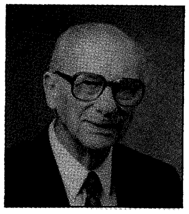
BARRY GOLDWATER AWARD
Stuart F. Meyer (*)

Awarded in recognition of his long record of service to the public through the use of Amateur radio.

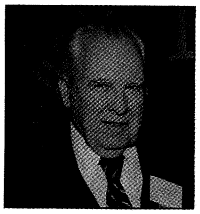


JOHNSON PIONEER CITATION
Chandos A. Rypinski

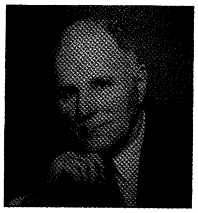
Awarded in recognition of his contributions in fields of signal processing, access protocol, and LAN system architecture.



Frank A. Gunther



Jerry B. Minter



Francis H. Shepard, Jr. (*)

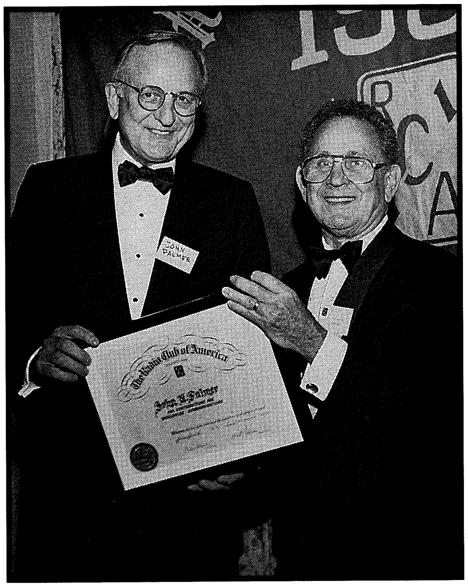
PRESIDENT'S AWARDS

Awarded in recognition and appreciation of their extended services rendered to The Radio Club of America, Inc.

(*) Awarded Post-humously

Wireless Communications: Bringing America into the 21st Century

By John Palmer



John Palmer (left), CEO of Mtel, receives a citation from RCA President-Emeritus Mal Gurian at the Radio Club of America annual banquet in New York on Friday, Nov. 18. His keynote address is printed here in its entirety.

You know, Groucho Marx used to say, "I'll make my speech in a minute, but first I have something important to say."

Before beginning my remarks, I'd like to pay tribute to a few people [at the banquet]: First, there is our [Radio Club] president...and my friend, Mal Gurian. His commitment and tireless leadership have made this a remarkable successful year for the Radio Club. All of us who value the Radio Club and its guiding ideals owe Mal a tremendous debt of gratitude.

I'd also like to salute the award winners and the Club's new Fellows—congratulations to all of you.

In a larger sense, though, I think it's also fitting to salute all the members of Radio Club. Through your generosity, the club is able to sustain its far-reaching grant and scholarship programs. These help the next generation of entrepreneurs and visionaries continue the very communications revolution that many of us began.

You know, standing before you like this, I'm reminded of the story about the Congressman who's asked to speak at a local PTA dinner. The day before the event, he calls the PTA's director and asks how long the speech should be. And the director thinks for a moment and then responds, "Congressman, your job is to teach, and our job is to listen...and if we're done before you are, we'll let you know."

Tonight, I would like to speak with you about communication and how it is changing the world we know. I want to share with you a remarkable item I recently came across during some research for this speech. In his book *Turmoil and Triumph*, former Secretary of State George Shultz recounts a meeting he had with Soviet leader Mikhail Gorbachev in April 1987—a meeting ostensibly devoted to arms reductions. However, midway through the meeting, the subject turned to economics—more specifically, how technology is changing the world economy.

I'd like to read for you Secretary Shultz's statement to Gorbachev, which is not only remarkably prescient, but also important for every one of us who is involved in radio or communications. Shultz told Gorbachev, "There are big changes going on in the world economy. It's not just bipolar to multipolar; the world is in the midst of a highly complicated evolution. Scientific and chemical processes now replace minerals in the ground. This is good news for some nations and bad for others. But for all, it is a spur to move beyond the industrial age to the information age."

The secretary continued: "There was a time when a government could control its scientific establishment. No longer. To keep up today and in the future means that scientists will have to be in constant touch with the thinking community around the world. The key is going to be knowledge-based productivity."

Secretary Shultz concluded: "In our GNP accounts, we have classifications that distinguish between capital and labor. But that dichotomy is becoming obsolete because we have entered a world in which the truly important capital is human capital, what people know, how freely they exchange information and knowledge, and the intellectually creative product that emerges."

Now, as one who has spent his whole life in communications, I find Secretary Shutlz's statement a vibrant testimony to the power of communications in the 20th century. After all, when you think about it, what finally brought down the Berlin Wall and liberated Eastern Europe was...communication. Not soldiers or planes or tanks, but communication. The foundation of those closed societies—that government was the sole repository of the truth—was torn asunder by advances in communication.

Some people are calling the period we're in now the "Information Age." I'd like to disagree with that. I would submit to you that it is not the information that is new...what's new is our ability to deliver the information.

Moreover, the hallmark of the communications revolution that started in the 1980s is the degree to which everyone—not just the rich or powerful—but everyone can reap the benefits.

Driving this revolution is the wireless industry, with its explosive growth during the past several years. Wireless companies have helped to make beepers, pagers and cellular phones so commonplace today that we have difficulty conceiving of life without them. And yet—believe it or not, the oldest public cellular communications system in the United States is only 11 years old.

With the wireless industry, the numbers can certainly speak for themselves: Since 1983, companies in the wireless industry have spent more than $16 billion in capital investment. By 1997, that figure will be more than $25 billion.

In the process, the industry has created nearly 50,000 jobs—and if you count related service and manufacturing jobs, it's created more than 160,000 jobs. Nearly 20 million Americans are now wireless customers, and each day, on average, more than 17,000 new subscribers sign up.

Looking to the future, things get even more bright: By the year 2000, according to a study by Donaldson, Lufkin and Jenrette, there will be some 66 million subscriber units in the United States alone. A Market Intelligence study projects global revenue for services and handsets will top $13 billion in the year 2000. By comparison, in 1992, that figure was only $70 million.

Yet numbers alone cannot tell the whole story. They cannot even begin to show the wonderful diversity that has taken hold in the wireless market—and my company, Mtel, is proof of that.

Our market is the mobile professional—the 2.7 million Americans working outside their offices. These mobile professionals are comprised of traveling executives, sales people, white collar technicians and the "informationally disenfranchised," who need a solution to bridge the gap between mobility and connectivity.

In 1987, we set out to fill that need—and I believe we have. Permit me to say "We" because I could not have done this alone. The most worthwhile part of working at Mtel has always been the team itself—Jai Bhagat, president of Mtel Technologies, and others.

Through all of our efforts—the brainstorming sessions, the search for technology, the late nights, the weekends, even the occasional arguments—through it all, we never wavered from our core conviction that we could make our vision a reality. In the process, we created an institution that is helping people compete and win in today's global economy.

Mtel's success demonstrates something important about the wireless industry. It shows that the wireless market is now large enough to sustain a rich diversity of competitors. Some companies are prospering through appeals to the general public. Others, such as Mtel, concentrate on business. Even within those two broad categories, there is a dazzling array of plans to choose from.

Speaking personally, I can say that the business climate today is much more competitive than it once was. For a few years, Mtel had no real competition for our target market. Now we have several formidable competitors. And by the way, I report that given choice, it's a lot more fun to run a business without competition.

But that's the nature of business, and we wouldn't be competing if we thought for a moment that we weren't going to win.

I'd like to finish with a few thoughts about where the wireless industry is headed.

To do that, I'd like to quote a wise old American philosopher—that great catcher for the New York Yankees, Yogi Berra. Now some of you may remember that Yogi had a penchant for saying memorable things: "Baseball is 90 percent physical; the other half is mental;" "No one goes there anymore; it's too crowded;" or my favorite, "I can't believe that pitcher thinks he's good, considering the stuff he strikes me out with."

But the Yogi line [for this banquet] is a remark he once made to a reporter during spring training. The reporter asked about the Yankees' prospects for the season, and Yogi responded, "We are faced with insurmountable opportunities."

In a way, that summarizes the wireless industry as it looks to the future. Not just my company or your companies, but the totality of the industry in all of its glorious splendor.

The insurmountable opportunities that lie before us are at once daunting and humbling. We see how far we've come during the last decade and are tempted to believe that our industry is well developed.

Yet, stop a moment. Take a step back. Take two steps back. Look at the wireless industry as an outsider. In many important respects, our industry is still in its infancy. Everything we have accomplished to date will pale in comparison with what's in store during the coming decade. In the words of author economist George Gilder, the wireless communications devices of the future will be "as mobile as a watch and as personal as a wallet. [It] will recognize speech, navigate streets, take notes, keep schedules, collect mail, manage money, open the garage door and start the car."

This evolution will not be easy. In the coming years, the wireless industry will have to contend with a variety of challenges—not just technological, but also regulatory and cultural. Congress' failure to pass a telecommunications reform bill this year is a prime example of how difficult it will be for many companies to overcome outdated government regulation. Likewise, integrating our systems internationally will require extraordinary patience and negotiation.

[Here are] some predictions about the wireless industry and where it's headed. First, in the coming years, the wireless industry will conquer its insurmountable opportunities—and second, we will all be right there when it does.

John B. Knight, W6YY, 1906-1995

By Don Bishop

Amateur radio experimentation led to a career in TV broadcast engineering and to the construction of unique, contest-winning amateur radio stations by the 1994 winner of the Jack Poppele Broadcast Award.

John B. Knight at his contest-winning amateur radio station, W6YY, in 1957.

Capt. John B. Knight (USNR-ret.) died March 29, 1995, of heart failure. A member of the Radio Club of America since 1978, John became a Fellow in 1980 and received the Jack Poppele Broadcast Award in 1994.

John was born in Augusta, GA, on Oct. 18, 1906. His family later moved to South Carolina, where he was issued a license for amateur station 4DX in 1920. John began amateur operations with a Ford spark coil, then a UV-201 and, later, a UV-203 50W transmitter given to him as a high school graduation present.

Using a 60-jar lead-aluminum chemical rectifier in a borax solution, a combination called at the time a "slop jar," he worked all states by 1925 on the old 150-meter band. John was the first amateur in South Carolina to work Europe.

His antenna was a 6-inch-diameter twin cage strung between two 90-foot poles made from 10-foot sections of 3-inch gutter pipe. Plenty of guy wires held the poles erect. By 1925, one of the poles was used as a vertical antenna on 40 meters.

He attended school at the Citadel in Charleston, SC, and at the U.S. Naval Academy in Annapolis, MD.John was in the academy's class of 1929, but he resigned in 1927 and went to work forAT&T at the Western Electric factory in Kearny, NJ, as a transfer of manufacture engineer. It wasn't long before John was reassigned to anotherAT&T affiliate, Electrical Research Products Inc. NewYork, which made sound equipment for theaters. For two years, he installed equipment in theaters around New York before transferring back to the Kearney works.

One of John's frequent amateur contacts, Fred M. Link, 3BVA, from York, PA, also went to work for AT&T. His assignment was with New York Telephone as a transmission engineer. Through their radio communication, John and Fred knew that they both were moving to New York, and they arranged to share rooms at the Prospect Park YMCA in Brooklyn. Together they built a new station, jointly licensed to them as 2ALU, with the main objective of competing in the American Radio Relay League's second annual DX competition in 1927.

The contest lasted two weeks, but 2ALU was forced to cease operation after the first few days because of complaints about broadcast reception interference. The discovery of the station as the source of the interference made front-page news in New York. Despite the abbreviated operation, John and Fred made so many contacts in the early part of the contest that their station took second place. Were it not for lack of proof of a contact with the *Nielsen Alonso,* an icebound Norwegian whaler near Antarctica, the station would have placed first. Proof in the form of a postcard from the vessel's radio operator could not be mailed until 18 months later after the the ship broke free of the ice and reached port.

John described the YMCA transmitter as using a UV-204 "250-watter" with a mercury vapor rectifier. He recalled a special feature of the transmitter: The primary power input was diverted from the transmitter to an electric heater when the Morse-code key was open, keeping the power drain relatively constant whether the key was open or closed. This kept the lights in the YMCA from flickering, which might draw unwanted attention from other residents or the building management. Fred recalled that the YMCA transmitter used power tapped from ac lines in the elevator shaft and developed in excess of 1kW of power output.

The newspaper publicity about the interference led to the next step in John's career, because it attracted the attention of Allen B. DuMont, the chief engineer and manager of De Forest Radio Company, and also a radio amateur. DuMont hired both John and Fred, initially to help with the design and construction of TV transmitters. John was in charge of the transmitter equipment division, where he built radio broadcast and communications transmitters for the U.S. Department of Commerce, the Hearst newspaper radio division, the Michigan state police, and the cities of New York, Philadelphia and Los Angeles. He built and operated the first TV sound transmitter, 2XCD, at the De Forest factory in Passaic, NJ. Cast out by the YMCA following the contest episode, the two operators reconstructed their amateur transmitter in an apartment at 583 Riverside Drive that faced the Hudson River. A third version of the station retained the receiver at the apartment, and the transmitter was rebuilt at De Forest Radio's Passaic Park, NJ, factory. The transmitter was operated by remote control via a leased telephone line from the apartment. Although it was under remote control, the high voltage was left on during operation. The remote control served only to key the signal, but it was a first for amateur radio. That of the transmitter used a halfwave, three-phase rectifier that gave it a distinctive 180 Hz modulation. It used two 1kW tubes as a push-pull amplifier.

When the federal government added the "W" prefix to amateur calls and combined station and operator licenses, Fred retained the W2ALU call sign. John was assigned W2JJ. John left De Forest Radio to join the National Broadcasting Company (NBC) in 1933 at the Radio City studio and switchbank. Except for seven years' active Navy duty during and after World War II, John remained with NBC until retiring in 1971.

In 1936, he worked as a senior TV engineer for transmitters. "I worked at Radio City for a while," John said during a 1990 interview, "and then at the Empire State Building for the first field test of RCA TV in 1936." The Empire State Building was the TV transmitter location. "RCA built 100 TV receivers and distributed them among its executives in New York. The company built one TV studio in Radio City to see how it would go. Just before World War II began, the FCC decided that TV could begin commercial operation."

Shortly before WWII began, John, then a lieutenant in the U.S. Naval Reserve, was called to active duty. He was and assigned as a senior assistant at the Underwater Sound Desk of the Electronics Division at the Bureau of Ships in Washington, DC. The Bureau of Ships was looking for a technical officer to work with anti-submarine underwater sound. The U.S. Navy Underwater Sound Laboratory was was established at New London, CT, and John he served as the officer in charge, rising to the rank of commander. The laboratory was unique in that it was located at an old Army fort, Fort Trumbull, which was operated as a Coast Guard base. In 1943, he also served as a technical consultant at the Harvard Sound Laboratory and at Woods Hole Oceanographic Institution.

Although still with the Navy, he returned on transfer to NBC to work as the assistant station engineer at the Empire State Building TV transmitter in 1946. The next year, he moved to Washington, DC, to build and open WNBW, the first commercial TV station there. (His amateur call sign during this period was W3JJ.) "The network had coaxial cable connecting New York, Philadelphia and Washington," John said. "I worked there for one-and-a-half years."

Later in 1947, he was attached to the Naval Reserve Research Unit No. 1 at Chavez Ravine, Los Angeles. "I came back to California where I was promised a job as chief engineer of the Los Angeles station if I would leave the Navy," John said. "I returned to NBC and stayed there until mandatory retirement in '71."

In 1948, John was named engineer-in-charge at KNBC, Los Angeles. His amateur radio station call sign was changed to W6YY. From 1951 to 1971, he was manager of technical operations at KNBC. He was promoted to captain in the U.S. Naval Reserve in 1951.

"As chief engineer, I spent half the time at the transmitter on Mt. Wilson and half the time at the studio in Burbank," John said. He made his home halfway between them on the road to Mt. Wilson.

"NBC built the biggest tower on the mountain. Demand for antenna space from mobile radio users was so great, we leased space on the tower and in the metal transmitter building. Each lessee had a cubicle for equipment and a panel on the tower to hang antennas. The station earned a good income from those leases," John said.

"I asked the general manager, 'How about giving me a little space for my ham station, and I'll operate by remote control from my house?' He said OK. I put my antennas on two wooden poles already in place. For 10 years I operated from home by remote control." John's amateur operation was about 75% AM voice, 25% Morse code.

"So far as I know, it was the only remotely controlled amateur receiver and transmitter. Several hams had remote-controlled transmitters, but few of them ever had remote-controlled receivers," he said.

"At first, I used UHF control links. But as more and more transmitters were placed on the mountain, the interference became too great. By the time about 2,000 transmitters were in use on Mt. Wilson, finally I leased a telephone line for use in both directions," John explained.

"I used composite, home-assembled AM equipment. Some of it included exciters and receivers made by Collins and Racal. I was one of the first to get a Racal receiver from Britain. The rest was mostly Collins or surplus WWII equipment and parts you somehow got hold of, tubes and power supplies—like broadcast transmitters used to be.

> ***"NBC built the biggest tower on the mountain. Demand for antenna space from mobile radio users was so great, we leased space on the tower and in the metal transmitter building."***

"I used maximum power, 1kW. The transmitter used an Eimac 4-1000 tube, which gave me enough leeway so I didn't need to retune when I changed frequencies. The transmitter and receiver frequencies were locked together for transceive, which was a convenient arrangement for the mountaintop operation," John said.

"The VFO was driven by a 1 rpm motor and a sprocket-and-chain arrangement. At the house I had a dummy variable VFO with a frequency scale on it. As the motor turned clockwise or counterclockwise, the scale showed me the frequency.

"To verify the frequency independently, I used a receiver at the house to show me the frequency I was transmitting on. As I moved frequency 2 or 3 kHz I could read it on receiver," he said.

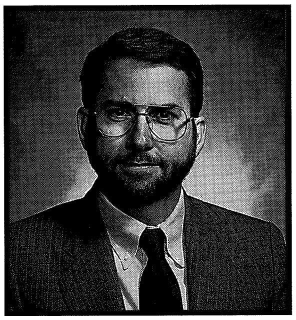
"Two rotary antennas covered the 15-meter and 20-meter bands. The remote directional indication was inferred by measuring the time the rotor was in operation. The rotor had a limit switch that stopped it when the antennas pointed north. Activating the rotor long enough to ensure it would hit the limit switch calibrated the antennas to north. Then, if I wanted to point the antennas to a specific direction, I would rotate them for the number of seconds required. A full rotation took 60 seconds," John said.

A year before he retired, John spent three weeks' vacation in Eastern Europe. "I visited central radio clubs in each satellite country," he said. "I lined up many people I talked to and knew me and knew who I was. It was quite an education." When he retired, John began traveling the world, visiting amateurs in foreign countries he had spoken with but never met.

"When I retired in 1971, I got permission to keep equipment on the mountain until NBC needed the space. Eventually someone who didn't know me succeeded to the top management post. I got the word third-hand in 1983 that the manager wanted to use the ham equipment's space for more mobile radio equipment. I have been off the air since," John said. John's amateur radio operation placed him on the ARRL's DX Century Club Honor Roll for many years. He took first place in the single-operator multiband CQ DX phone contests in 1955 and 1957 and won the ARRL DX contest in 1957. In addition to belonging to the Radio Club of America and ARRL, he was a member of the Radio Society of Great Britain, the Society of Television Engineers (Los Angeles), the Southern California DX Club and the Radio Amateur Society of Thailand.

After leaving NBC, John was employed as a radio engineering consultant by various Thailand manufacturers in connection with the contracts with the Signal Corps and with the Navy of the Kingdom of Thailand. He engaged in similar consultation with the broadcasting division of Radio Sofia (Bulgaria), including engineering and procurement.

John is survived by Peggy, his wife of 61 years, and a sister, Katherine Coe, of Birmingham, AL. A daughter, Jean Ellen, preceded him in death.



Don Bishop (LF) is co-editor of the *Proceedings* and a Club director. He is a member of IEEE and a life member of QCWA and ARRL. He is the editorial director of *Mobile Radio Technology, Dealers' Product Source* and *Cellular & Mobile International* magazines.

August J. Link Preserves Radio History by Collecting and Displaying Equipment

By Don Bishop

In Carlsbad CA, to the north of San Diego, a display of military radio equipment manufactured from 1907 to 1945 is maintained by August J. Link (M). Link began collecting the equipment in 1972, concentrating OR World War I vintage equipment. Later, he expanded the scope of the collection to include the period between the world wars and once again to include World War II equipment.

Most equipment in the Collection was made in the United States, but there are plans to include representative units of foreign manufacture.

Link was born in Tartu, Estonia, in 1940. He immigrated to the United States from Germany in 1949. From an early age, he was interested in historical items and eventually that interest, plus years of selling military surplus while attending school, led to collecting military radios. This endeavor began with a WWI Signal Corps SCR-68 aircraft transceiver. The start of the dedicated military equipment display began with the addition of a Navy 1917 CF-99 tubetype motorboat set manufactured by the de Forest Telephone and Telegraph Company. The die had been cast for a lifelong quest.

Link earned a B.S.E.E. from the University of California at Los Angeles and worked as an EMI/EMC engineer for Sprague Electric and later North American Rockwell. Projects that he worked on included the F-111 and B-1 aircraft. He founded Surcom Associates in Los Angeles in 1970.

Link is an active collector who considers himself to be a preservationist. "I don't necessarily study the equipment or learn the the history of the people who made it," he explained. "I'll leave that to others who come along after me. But if nothing else, I save the equipment for the future."

Link seeks information and equipment to add to his collection, and he is willing to provide information to others, too. He sometimes sells pieces of equipment when he finds duplicates in better condition. Eventually, though, he plans to sell it all.

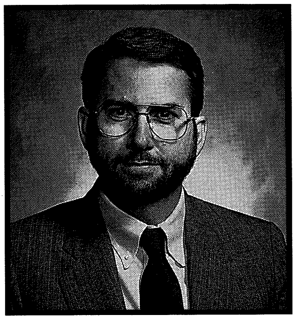
"I hope to double the size of the collection in the next 10 years, and then auction it off," he said. "I like the wheeling and dealing part of collecting. It would be fun to see it redistributed when the time comes."

Link finds the equipment by advertising. by attending the Antique Wireless Association (AWA) convention and by communicating with other collectors. To limit his acquisition of WWII equipment, these days he only collects brand-new, in-the-box, mint WWII equipment. "Every once in a while, a whole set shows up as issued, and regardless of the price, it's a bargain," he said. "With equipment from the later years of the period I collect, the search and travel expenses are usually greater than what the piece of equipment sells for."

He remembers seeing two pieces of equipment sold for $400 at an AWA auction. He looked for the same pieces of equipment at a lower price but never found them. Eight years later, he paid $1,200 for the same pieces of equipment after the collector who bought them at the auction had sold them to a dealer.

Link said that equipment from the WWII era became more popular with collectors during the 50th anniversary of the war.

The collection is on display at Link's company, Surcom Associates Inc., 2215 Faraday Ave., Suite A, Carlsbad, CA 92008. Link suggests calling at 619-438-4420 to arrange to see the display during business hours. After-hours appointments can be arranged, too. The 1,000-square-foot display includes 13 glass-enclosed cases and a library.



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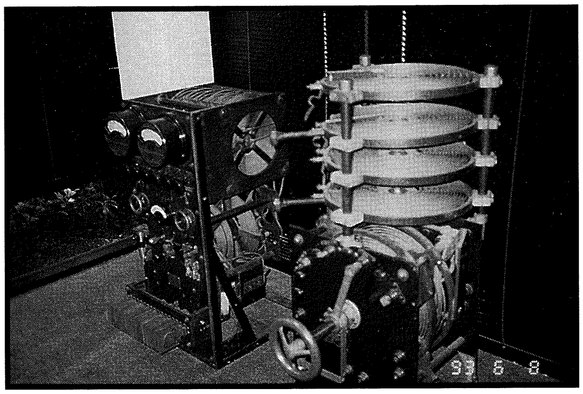
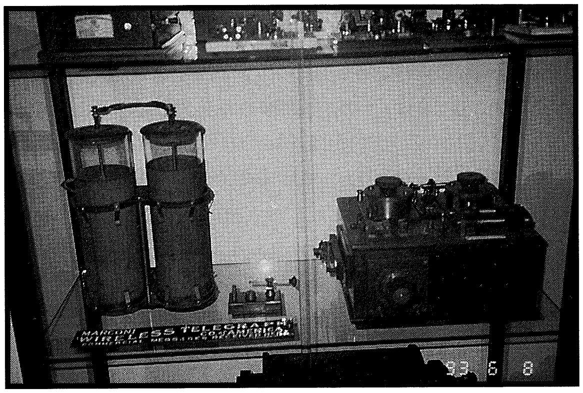
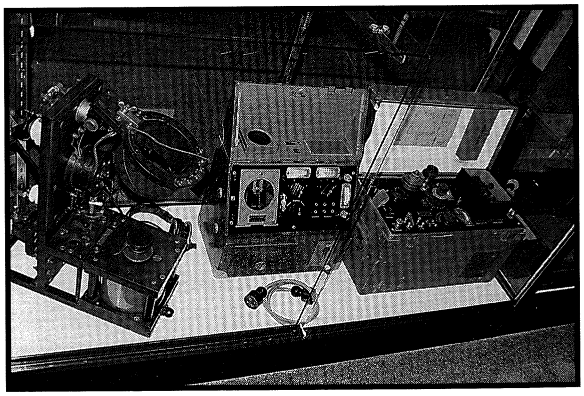


At the left, a Navy CR1126 quenched-gap, 1/2-kW transmitter made by Wireless Specialty Apparatus Company, c. 1918. At the right, a Navy type SE89 2kW inductive coupler and wavechanging shortwave transmitter made by Marconi Wireless Telegraph Company of America, c. 1917.

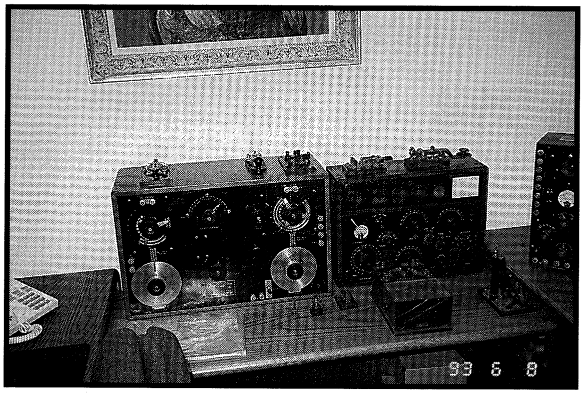
The storage, miscellaneous display and library includes a complete set of Signal Corps supply catalogs (Sig 5) of 1945.



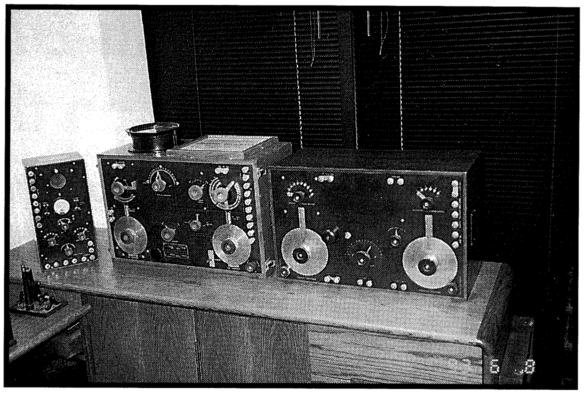
Items in this case were made by Marconi Wireless Telegraph Company of America, including the jar condensers on the left, the carborundum and cervsite crystal detector in the center and the 107A receiver with a carborundum detector on the right c. 1912-1915.



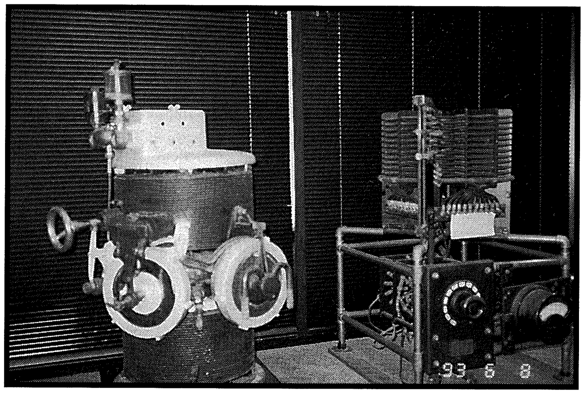
On the left, a Telefunken Wireless Telegraph Company of America type E5 with electrolytic detector, c. 1914-1915. Center and right, World War I German military field sets.



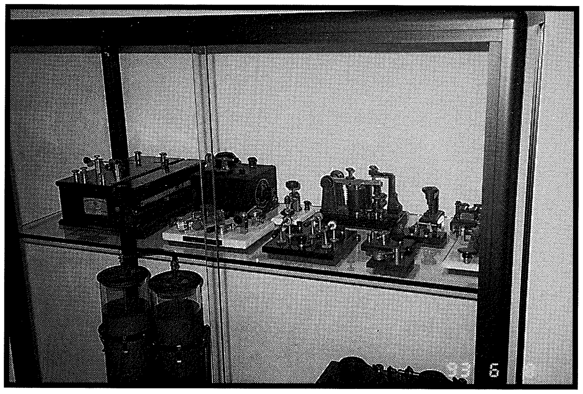
On the left, a National Electric Supply CN 239 receiver for 1,000m-10,000m reception c. 1917 made for the Navy. On the right, a BC-32-A T/R uses two VT-1 vacuum tubes in the receiver and three VT-2 vacuum tubes in the transmitter. This unit is c. 1919, and this design continued to be produced into the late 1920s.



On the left, a Western Radio SE-1071 audion control box c. 1918 made for the Navy. In the center, a National Electric Supply CN-240 receiver for 1,000m-10,000m reception c. 1917 made for the Navy. To the right, a National Electric Supply receiver SE 899 for 300m-12,000m reception c. 1918 made for the Navy.



A Federal 5kV arc transmitter c. 1918 made for the Navy.



At the top left is a United Wireless type C tuner c. 1908. To its right are assorted detectors c. 1913-1922.

Grants-in-Aid Funds Go to 11 Groups

The RCA board of directors approved the establishment of 14 financial aid grants to 11 organizations at the RCA annual meeting. The grants total $10,650 and are made to "provide a scholarship fund for the needy and worthy students for the study of radio communications."

Grants from the general fund include Southern Methodists, Capitol College, Polytech University, Stevens Institute of Technology, Virginia Polytechnic Institute, Georgia Institute of Technology and the Embry-Riddle University.

From the Finch Fund, a grant was bestowed to the University of Cincinnati, and from the Grebe Fund, a grant was made to the Armstrong Foundation. The Foundation for Amateur Radio received a grant from the Poppele, Meyerson, Biggs and General GIA Funds. Ranken Technical College received a grant from the Poppele Fund.

Grants-In-Aid Committee Chairman Kenneth Miller recognized donations provided by Jack Poppele's family.

Miller said the club witnessed "major activity" in 1994, which allowed the club's financial aid grants in fiscal year 1995 to increase 10 percent.

Bandwidth-Efficient Technology: A Report on the Art 1994

By Gregory M. Stone, Ph.D., FRCofA
and Karen Bluitt

FORWARD

In 1984 we presented at the Radio Club of America a work entitled, Bandwidth Efficient Technology--A Report on the Art. In our 1984 paper, we addressed *bandwidth efficiency, information formatting and coding, modulation, radio frequency transmission, radio frequency detection and demodulation*, and we offered our thoughts on the future of bandwidth efficient technology.

In 1984, we made the following pronouncements:

- Linear technology and systems architectures would predominate.
- LSI and VLSI technology would facilitate the implementation of bandwidth efficient technologies.
- Digital signal processing (DSP) technology would permit the deployment of high-quality low bit rate vocoders, development of robust channel linearizing technologies, highly linear power efficient radio frequency amplification systems and high-performance linear detection systems, all of which may be integrated into handheld/portable and mobile equipment.
- Microwave integrated circuitry (MIC) and monolithic microwave integrated circuitry (MMIC) would facilitate the implementation of advanced radio frequency amplifier designs.
- In a 5.0 kHz channel, we stated that data rates of 4.8 kb/s were available, rivaling traditional 25 kHz FM systems, and that 9.6 kb/s data rates were possible within the existing art.
- There are no scientific barriers to the implementation of bandwidth efficient technology.

In the 10 years since then, dramatic technological advancements have occurred, eclipsing many of our projections. What we reported in 1984 as practicable is now commercially available. Such companies as Ericsson-GE, Motorola and Linear Modulation Technology Ltd. (Securicor) have commercially viable communications products that employ digitally derived bandwidth efficient technologies.

This current paper presents a 10-year update to our previous work and will examine the progress that has been made since November 1984 in the area of bandwidth efficient technologies.

Most importantly, it is hoped that the reader will learn that bandwidth efficient technologies are on the verge of becoming the state-of-common usage and universally deployable throughout the land mobile community.

Furthermore, looking forward, we have new projections based upon logical extrapolations of the current art, presenting an aggressive outlook for what is likely to occur during the next 10 years, just past the turn of the century into the next millennium.

The Bandwidth Controversy

Before we move into 1994, let us address an issue that has become a profound impediment to the proliferation of bandwidth efficient technology and to the fundamental understanding of the transfer of information itself. It is alleged that such modern multimedia services as motion video, high-fidelity audio and high-resolution graphics require "more bandwidth" or "higher bandwidth" than traditional voice-only services.

Although we are engulfed in a digital revolution, and the advent of computerization has brought many advantages to our society, it also has brought along terrible baggage, especially as it concerns the notion of "bandwidth." In the computer industry, "bandwidth" is used incorrectly to denote the information transfer rate. In communications, bandwidth conveys no such meaning--or at least it should not.

Thus, what exists today is a continuing confusion and general lack of understanding over bandwidth (how many hertz [Hz] wide a channel is) and the information transfer capacity of a channel in terms of bits-per-second (b/s). Unfortunately, this is the crux of our problem: misinformation, improper definition and a lack of understanding fundamental tenets of science.

In attempting to correct this misunderstanding, we turned to *The New IEEE Standard Dictionary of Electrical and Electronics Terms*, Fifth Edition. Here we find definitions for bandwidth, channel capacity and for the terms baud and data rate.

The IEEE dictionary defines bandwidth as: (signal transmission system) The range of frequencies within which performance, with respect to some characteristic, falls within specific limits.

Channel capacity is defined as the maximum possible information rate through a channel subject to the constraints of that channel.

Information transfer rate may be expressed in term of a channel's baud rate (symbol rate) and its bit rate. In binary systems, the baud rate and bit rate are equivalent. However in *m-ary* or *multilevel systems*, they are different. Thus, many categorizations in the computer industry of modems and channels operating at certain baud rates are suspect, when in reality most incorrectly are referring to the information transfer rate in bits-per-second. In multilevel systems, the symbol rate is important to determine compliance with the Nyquist criteria. However, the Shannon channel capacity usually is not expressed in terms of symbol rate but in the context of bit rate, that is information transfer rate.

In practical terms, if we subscribe to the notion that bandwidth efficient technologies are desirable, future multimedia digital services that are likely to demand greater information transfer capacities of our systems, in terms of greater b/s values, can be accommodated. This may be achieved not necessarily by means of additional bandwidth (Hz) but through the proliferation of bandwidth efficient technologies that support large b/s transfer rates per given unit bandwidth (Hz).

Unfortunately, this issue is not trivial and gets to the root of much of the opposition and misinformation concerning bandwidth efficient technology.

Additionally, the land mobile community is inundated with marketing hype today from manufactures that use bandwidth as the magic potion needed to support wireless multimedia services. Under this hype, multimedia is a voracious consumer of "bandwidth," and its development will be stifled unless more "bandwidth" is allocated for these emerging services.

As technical practitioners, we must let ourselves be deceived by this hype, but most focus on the scientific facts appertaining to the underlying physics of the narrowband/bandwidth efficient technologies themselves.

Thus, the challenge we face in selecting the appropriate communications technology is to discern beforehand what information is to be conveyed between the sender and receiver and put in place the necessary channel, be it wireless or cable based, that has the appropriate capacity to support information transfer at a rate consistent with the service requirements.

Detractors of bandwidth efficient technology have asserted incorrectly that reducing channel bandwidth, per se, reduces a channel's information capacity. This is not true. Likewise, as stated above, these same parties assert that future multimedia digital services will require "increasing amounts of bandwidth." This notion is absurd and represents a fundamental lack of understanding the Shannon Channel Capacity theorem, which addresses the relationship between information transport capacity in b/s, energy density per transmitted bit vs. noise power (carrier-to-noise C/N in dB) and what we refer to as bandwidth in Hz.

In the wireless world, spectrum is a precious and limited resource that must be used correctly and efficiently. To accommodate ever-increasing demands for higher and higher information transfer rates, attention must be directed to the judicious application of Bandwidth efficient technologies. That is, to technologies that efficiently use bandwidth.

It should be obvious that reducing the occupied bandwidth of a signal vis-á-vis narrowbanding results in demonstrative improvements in bandwidth efficiency and spectrum use efficiency if properly implemented.

There is no real mystery to bandwidth efficiency as the science behind it is straightforward. According to Shannon, in situations where bandwidth is limited, a more sophisticated channel coding (modulation) is required that requires more power, or more exactly, a higher C/N value per unit bandwidth. Thus, if the Federal Communications Commission and other government regulators are serious about improving spectrum efficiency, power level authorization must be linked to bandwidth efficiency. Thus, a more bandwidth efficient technology would be allowed to employ greater power levels than relatively less bandwidth efficient technologies. In the future, with anticipated major gains in DSP capabilities, other means of improving C/N than merely increasing desired signal power will become common.

The Proliferation of Bandwidth Efficiency

Although many issues associated with the universalization of bandwidth efficient technology are technologically intense, they are neither insurmountable nor beyond the scope of the current art.

Today, we are on the verge of seeing a deluge of advanced technology deployment that will accommodate this nation's ever-expanding wireless communications and information transport requirements well past the turn of the century.

But first, let us clear up some myths concerning bandwidth efficient technology:

1) Narrowbanding that is reducing the authorized and occupied channel bandwidth in wireless services, per se, is not an impediment to the efficacious future use of wireless multimedia digital services.

2) Future digital multimedia services (NCIC 2000, telephoto, high-resolution, motion video with voice) are not voracious consumers of bandwidth (in Hz) as some incorrectly state but rather may impose demanding requirements on information transport capacity (in terms of b/s).

3) In bandwidth limited channels, the information transport capacity is a function of channel coding efficiency (bandwidth efficiency) and carrier-to-noise (C/N) not of bandwidth as many incorrectly assert.

4) Broadband emissions that permit overlay on existing services or support comparable user densities (Erlangs traffic load per square kilometer area per Hertz bandwidth E/km/Hz) are also spectrally efficient and pose semantic difficulties in comparison with narrowband/bandwidth efficient techniques that look only at the dimensions b/s per Hz.

Bandwidth Efficient Technology--1994

Technology Baseline:

The technologies that follow are substantive evidence that supports our assertion that today, linear systems employing multilevel (m-ary) (i.e., 4-QAM, 16-QAM) technologies represents a mature commercially available baseline in the private and public land mobile communities.

Bandwidth efficiency has indeed improved during the last 10 years. Assuming a 1984 baseline, high-performance digital land mobile systems of the era operated at a 12.0 kb/s data rate and used delta modulation for the voice source coding in conjunction with 2-FSK modulation operating in a 25 kHz channel. The bandwidth efficiency of such a scheme was .48 b/s/Hz.

Now, in 1994, the technology baseline dramatically has advanced bandwidth efficiency. Ranging from the Association of Public Safety Officials International's (APCO) Project 25 Phase-I standard predicated upon 12.5 kHz channel spacing and a 9.6 kb/s data rate, up to Linear Modulation Technology (LMT) LTD's 16 QAM implementation, bandwidth efficiencies in 1994 range from .768 b/s/Hz with the APCO Project 25 standard to 1.92 b/s/Hz with the LMT 16-QAM implementation.

APCO 25 technology, which is under current deployment, represents almost a two-fold (100%) improvement in bandwidth efficiency. As the Project 25 standard evolves and embraces 6.25 kHz channelization in the future, its bandwidth efficiency will increase to 1.535 b/s/Hz, while maintaining full backward compatibility with predecessor 12.5 kHz APCO 25 systems.

In spite of these commercial advancements, detractors of narrowband and bandwidth efficient technologies represent that a mobile communications channel is characterized by phase and amplitude distortions of such a degree that they make the use of "high" level very bandwidth efficient modulations, such as 16 QAM or better, impossible. Practical commercial realizations of 1984 technology promise have shown this to be untrue.

Such positions are indefensible and ignore the tremendous advancements in phase and amplitude perturbation correction made during the last 20 years that permit a complex Rayleigh/log normal channel to become a first order time invariant Gaussian channel. Such channel linearization techniques as feed forward signal regeneration (FFSR) and transparent tone in-band (TTIB), developed in the early 1980s by Dr. Joseph McGeehan and Dr. Andrew Bateman, and other techniques based upon pilot symbol insertion are the best examples today of such practices and are proven in their effectiveness.

In McGeehan's 1980s FFSR/TTIB research, using 16 QAM modulation very low error (10-6 BER) transmission at approximately 13 kb/s in a 3.4 kHz occupied bandwidth was demonstrated at 400 MHz under Rayleigh faded conditions approximating a vehicle velocity of approximately 100 km/h. McGeehan obtained this performance level without using any error-detection and correction (EDAC) and simply relied upon the FFSR/TTIB channel linearization techniques to provide a solid time invariant channel. Today, this technology can be purchased on the open market.

The Commercialization of Bandwidth Efficient Technology

Linear Modulation Technology Ltd. (LMT):

LMT headquarters in the United Kingdom has commercialized a bandwidth efficient linear system for use in 5.0 kHz channels; LMT commercialized McGeehan's TTIB/FFSR linear system. The LMT implementation possesses bandwidth efficiency at passband comparable to its baseband component. With TTIB/FFSR, there is a slight bandwidth expansion of approximately 600 Hz. Thus, with 16 QAM employed, its occupied bandwidth at passband is approximately 3.6 kHz at the -20 dB point. This equates into a bandwidth efficiency of 2.67 b/s/Hz.

Table LMT-1
LMT's 16-QAM Nomenclature

Access Methodology	FDMA
Channel Rate	9.6 kb/s (7.2 kb/s with trellis coding)
Symbol Rate	2.4 Ks/s
Channel Spacing	5 kHz
Vocoder Line Rate	4.8 kb/s IMBE
Vocoder EDAC (FEC)	2.4 kb/s
Modulation	Linear Frequency Translated 16-QAM
Premodulation Filter	Raised Cosine 0.35 alpha
C/N Static	6.0 dB
C/N dynamic @ 5% BER	14.0 dB
Peak/Mean Ratio	6.0 dB
TTIB Notch Width	600 Hz
Effective Noise BW	3.0 kHz
Bandwidth Efficiency	2.67 b/s/Hz @ 3.6 kHz occupied bandwidth 1.92 b/s/Hz @ 5 kHz channel bandwidth
Occupied Bandwidth	3.6 kHz (-20 dB point)

Ericsson GE:

Ericsson GE (EGE) has commercialized a modern bandwidth efficient, two-slot time division multiple access (TDMA) technique employing pi/4 differential quadrature phase shift keying. This technique referred to as F-TDMA operates at a gross bit rate of 16 kb/s in a 12.5 kHz channel.

In the F-TDMA concept, EGE employs a high-quality vocoder, for example improved multiband excitation (IMBE), operating at a line rate of 4.1 kb/s. Vocoder error detection and correction (EDAC) comprises another 3.0 kb/s to correct for the phase perturbations commonly encountered in a land mobile environment.

A spectrogram of the F-TDMA waveform is presented in Figure EGE-1. It may be seen that the occupied bandwidth is 10 kHz and the bandwidth efficiency at the occupied bandwidth is 1.6 b/s/Hz or 1.28 b/s/Hz at the 12.5 kHz channel bandwidth. A summary of the F-TDMA parameters is presented in Table EGE-1 below.

Table EGE-1
F-TDMA Nomenclature

Access Methodology	2-slot TDMA
Channel Rate	16.0 kb/s
Channel Spacing	12.5 kHz
Vocoder Line Rate	4.1 kb/s IMBE
Vocoder EDAC	3.0 kb/s
Modulation	pi/4 DQPSK
Premodulation Filter	Raised Cosine 0.3 alpha
C/N dynamic @ 5% BER	12.3 dB
Peak/Mean Ratio	2.6 dB
Bandwidth Efficiency	1.6 b/s/Hz @ 10.0 kHz occupied bandwidth 1.2 b/s/Hz @ 12.5 kHz channel bandwidth
Occupied Bandwidth	10.0 kHz (-20 dB point)

Motorola

Likewise, Motorola Inc. commercialized two bandwidth efficient technologies, one employing FDMA and a second based upon TDMA.

C4FM:

In Motorola's FDMA offering, two distinct modulations are provided. Initially for use in a 12.5 kHz channel, Motorola employs Compatible Four (4) Frequency Modulation, a four-level FM technique that is the digital modulation format specified in APCO Project 25. It employs four level constant envelop FM. The gross information rate is 9.6 kb/s and is transmitted at symbol rate of 4.8 kilo-symbols per second (Ks/s).

Table Motorola-1
C4FM Nomenclature

Access Methodology	FDMA
Channel Rate	9.6 kb/s
Symbol Rate	4.6 Ks/s
Channel Spacing	12.5 kHz
Vocoder Line Rate	4.8 kb/s IMBE
Vocoder EDAC (FEC)	2.4 kb/s
Modulation	C4FM
Premodulation Filter	Raised Cosine 0.2 alpha
C/N Static	9 dB
C/N dynamic @ 5% BER	17 dB
Peak/Mean Ratio	1.0 dB
Bandwidth Efficiency	1.158 b/s/Hz @ 8.1 kHz occupied bandwidth 0.768 b/s/Hz @ 12.5 kHz channel bandwidth
Occupied Bandwidth	8.1 kHz (-20 dB point)

C4FM is compatible with quadrature phase shift keying-compatible (QPSK-c), which is specified in APCO Project 25. A compatible receiver that is designed to conform with Project 25 can recover either C4FM or QPSK-C. This compatibility extracted an approximate 1.0 dB penalty over non-compatible detection schemes but facilitates migration from 12.5 kHz to 6.25 kHz channelization.

QPSK-c:

For use in 6.25 kHz channels, Motorola commercialized QPSK-c. It possesses greater bandwidth efficiency than C4FM and operates at a gross information rate of 9.6 kb/s and is transmitted at a symbol rate of 4.8 Ks/s. This is a linear modulation technique.

Table Motorola-2
QPSK-c Nomenclature

Access Methodology	FDMA
Channel Rate	9.6 kb/s
Symbol Rate	4.6 Ks/s
Channel Spacing	6.25 kHz
Vocoder Line Rate	4.8 kb/s IMBE
Vocoder EDAC (FEC)	2.4 kb/s
Modulation	QPSK-c
Premodulation Filter	Raised Cosine 0.2 alpha
C/N Static	9 dB
C/N dynamic @ 5% BER	17 dB
Peak/Mean Ratio	4.0 dB
Bandwidth Efficiency	1.655 b/s/Hz @ 5.8 kHz occupied bandwidth 1.536 b/s/Hz @ 6.25 kHz channel bandwidth
Occupied Bandwidth	5.8 kHz (-20 dB point)

QQAM:

In the area of TDMA, Motorola commercialized quad-quadrature amplitude modulation (QQAM) consisting of four multitone QAM carriers employing pilot symbol insertion for linearization and synchronization. In this technique, a 64 kb/s gross channel rate is supported in a 25 kHz channel. Four (4) slot TDMA provides four subbands. This technique is a linear modulation.

Table Motorola-3
Q-QAM Nomenclature

Access Methodology	4 Slot TDMA
Channel Rate	64 kb/s
Symbol Rate	4.0 Ks/s
Channel Spacing	25 kHz
Vocoder Line Rate	7.4 kb/s VSELP
Vocoder EDAC (FEC)	included in Vocoder Line Rate
Modulation	Multi-Tone four 16-QAM carriers
Premodulation Filter	Root Raised Cosine 0.2 alpha
C/N Static	*
C/N dynamic @ 5% BER	*
Peak/Mean Ratio	5.0 dB
Bandwidth Efficiency	3.0 b/s/Hz @ 20 kHz occupied bandwidth 2.56 b/s/Hz @ 25 kHz channel bandwidth
Occupied Bandwidth	20 kHz (-20 dB point)
Other	Employs pilot symbol for linearization

* Indicates information not available.

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Bandwidth & Spectral Efficiency for the Millennium

Technology Evolution: 1994-2004 Predictions

Linear System Architectures

Highly scaleable linear system architectures will universally proliferate during the next 10 years, permitting the deployment of wireless communications systems employing FDMA, TDMA, code division multiple access (CDMA) bandwidth and spectrally efficient technologies.

In land mobile radio (LMR), in particular public safety and law enforcement, private systems will predominate that have very large service contours and operational areas spanning distances ranging from 10 km to 100 km or more. Rural areas of the country will continue to be served by such systems where the infrastructure costs prohibit the use of lower power system architectures. Such systems will support party-line communications as is common in the LMR industry today and will support integrated packetized and switched data and provide hooks into the public switched telephone network in a ubiquitous fashion.

Private and public wireless subscriber set architectures will be linear based upon multimode operation. High-power subscriber modes will be applicable in the rural and transitional suburban areas, while low-power broadband systems likely will predominate in urban areas.

Mobile and portable telephone and multimedia service provided by public carriers will employ linear system architectures based upon cellular/microcell and picocell configurations. Effective cell radii will range from .01 km to 10 km and will be very physical plant investment intensive.

Both private and public linear system architectures will support adaptive and dynamic information transfer rate on demand supporting the needs of traditional voice and text and emerging multimedia digital services.

Linear techniques may permit the ultimate sharing and combing of resources, thus permitting an ever-increasing quantity of wireless stations to use a given site location and antenna configuration based upon diplexerless duplex and combinerless multichannel systems employing master linear amplifier subsystems.

Linear architectures will require the deployment of robust broadband adaptive phase and amplitude channel equalization techniques that are efficacious not only in single site systems but in multisite quasi and fully synchronous systems.

Digital Signal Processing & Signal-to-Noise Ratio Improvements

In the area of digital signal processing, by 2004, we will see the proliferation of specialized DSP at a very high level of integration employing .05 to .1 uM technology. These devices will be very low power and operate at a performance level in excess of 5,000 MIPS.

It is obvious that one means of improving signal-to-noise is by increasing power. However, in many instances such as with handheld/portable radio equipment, severe limitations on radio frequency power generation are imposed by limited battery energy densities and capacities. Therefore, future innovations are needed in reducing the noise component. Adaptive interference cancellation, very low-noise high-dynamic range detection systems, and radical improvements in noise reduction technology are candidate solutions that may be implemented in very high-performance m-ary data communications systems.

DSP advancements will facilitate the deployment of very computationally intensive signal processing algorithms that are able to adaptively and dynamically improve recovered signal-to-noise and signal-to-interference ratios by as much as 50 dB to 60 dB.

These advanced signal processing algorithms will make use of *a priori* knowledge of the desired signal(s) and dynamically assess and evaluate the transmission channel to determine the characteristics of all other information present, i.e., other signals and/or noise sources. Thus, real-time spectral analysis will be performed with the processing algorithms adaptively eliminating undesired signal and/or noise sources.

Very advanced linearization and detection systems will be fielded. These systems likely will employ correlation and autocorrelation detection techniques approaching theoretical limits. Narrowband and broadband channel linearization will be accomplished by such techniques as using pseudorandom (PR) pilot symbol insertion that will adaptively eliminate system phase and amplitude perturbations and ambiguities. With PR-pilot symbol techniques, known symbols are inserted periodically into the data sequence prior to pulse shaping to form some given data frame length. The composite signal is transmitted over a channel characterized by a multiplicity of factors, including Rayleigh and log normal variability and noise from multiple sources. The detection system, based upon its a prior knowledge of the transmitted pilot symbol values, extracts the samples corresponding to the pilot symbols and interpolates them to form an estimate of the channel state at the data symbol to be detected.

These improvements in detection system base sensitivity in conjunction with novel noise and interference suppression will be able to compensate for the increased energy per bit needed by bandwidth efficient technologies.

Source Coding and Compression

Radical advancements in the area of information source coding and compression will occur. Current vocoder technologies permit the transmission of communications quality digital voice at around 4,000 b/s, with toll quality voice at around 7,200 b/s. Advancements in both DSP capacity and vocoder algorithms will permit toll quality digital voice based upon vector quantizing vocoder techniques at rates of between 1,200 b/s and 2,400 b/s. This will be implementable at a level of computational complexity supportable in multimode subscriber transceivers of the era.

More substantive compression gains will be realized in the area of multimedia data compression. For real-time interactive video that now requires 10 MB/s information transfer rate, a 1,000-1 improvement is projected.

Channel Coding, EDAC and Modulation

The advent of extremely high-resolution, high-speed powerful A/D and DSPs will permit the full realization of very high-level linear coherent m-ary linear digital coding to be employed. While today commercial land mobile products support 16-level modulation, with 128-level imminent, the 1994-2004 time frame will see the commercialization of 1024 level modulation greatly improving information transfer and bandwidth efficiency. Of particular interest are advancements in trellis coding and in other techniques that maximize performance in a AWGN perturbed channel.

These very high-level techniques will approach the Shannon limit in terms of bandwidth efficiency, achieving efficiency values in excess of 10 b/s/Hz in typical mobile environments.

It is likely that considerable interaction between the advancements in source coding/compression and channel coding and error detection and correction will occur. As compression gains continue to be realized, increased pressure will be placed on phase and amplitude perturbation correction techniques and on EDAC development due to the sensitivity of compressed information to phase and amplitude ambiguity and their resultant bit errors.

Should compression improvements become asymptotic, emphasis logically will shift to channel coding and signal-to-noise enhancement techniques to achieve higher levels of information transfer and bandwidth efficiency.

Radio Frequency Power Amplification

Advanced linear modulation techniques mandate the use of highly linear power amplification. For all modalities (FDMA, TDMA and CDMA), linear amplification will predominate. The emerging power of next-generation DSPs and gains in MMIC technology will permit low-cost, feed-forward and feedback techniques to be implemented that are suitable for miniaturization in handheld subscriber sets.

Likewise, both very broadband (100 MHz to 2,500 MHz) and high-power (10 kW+ PEP) linear amplifiers will be developed. These devices will facilitate near loss-less, low-power combining of multiple sources into a multifrequency adaptive linear antenna array minimizing infrastructure costs.

A revisitation of linearization techniques from the 1940s and 1950s, such as envelop elimination and restoration (EER) utilizing modern practices and technology, may hold promise for low-cost, high-power systems.

Technologies of 1994 allow for the suppression of out-of-band intermodulation products by at least 75 dB through the use of linearized amplifiers employing DSP-based feed-forward control. However, in portable subscriber sets in particular, the variation in load phase angle complicates most current implementations due primarily to DSP processing limitations. Very narrowband systems of the future will need to maintain very low IM across a wide frequency band of interest under all typical loads.

Detection Systems

Direct conversion linear detection systems with very high-dynamic range (in excess of 150 dB) will become common by 2004. In addition, a proliferation of low-cost, very low-noise radio frequency front ends will be necessary to accrue the advantages needed to overcome the bandwidth efficient modulation C/N requirements especially with subscriber equipment. Noise figures of .1 dB with bandwidths in the order of 100 MHz to 200 MHz will be needed, especially in very broadband CDMA systems intended to overlay existing and future services.

In order to effect linear direct conversion detection systems, advancements are required in analog-to-digital (A/D) converter resolution, speed and in minimizing stray capacitance and propagation delays in the ASIC. We envision linear direct conversion systems operating at frequencies as high as 2,500 MHz by 2004.

Likewise, with the anticipated availability in DSP power, near perfect theoretical Nyquist linear phase x/2 Hz filters will be "realizable."

Synchronization

Advanced technologies discussed so far have one element in common: the need for robust synchronization to provide the required "frequency" stability and timing needed to make these aggressive technologies function in the real world.

Future networks and systems will be based upon derivative master synchronization, likely from GPS or another disseminatable atomic frequency, phase and time references. Networks and systems will be "pre-synchronized," thus factoring out clocking ambiguities and, more importantly, permitting very rapid acquisition.

As future system swill likely employ cryptographic protection, the ability to have networks in synchronism will provide a more stable environment for both encrypted and highly compressed information transport.

Additionally, continuous network frequency and phase synchronization will result in economically viable frequency control and stability requirements being imposed on subscriber equipment obviating the need for "guard band" allocations.

Information Transfer Capacity and Information Transfer Rate

In terms of information transfer capacity, advancements in coding algorithms will result in the ability to approach within 1 dB of the Shannon limit Eb/No and in bandwidth efficiencies of 10 b/s/Hz at very low-error rates (10 exp-9).

Concomitant breakthroughs in information theory will result in the deployment of a new generation of cryptographic protection that will be robust and sustain attacks from quantum based optical processors that will emerge during this period.

Philosophically, wireless vs. cable transmission often is compared with a garden hose attached to a water main, with the wireless leg being the garden hose. In the future, this analogy will not hold true.

For a given unit bandwidth (in Hz), wireless systems will have information transfer rate parity with cable systems.

In a faded mobile environment, information transfer rates of 1 MB/s at frequencies to 2,500 MHz are envisioned. And, in fixed station point-to-point and multipoint wireless links where more bandwidth (in Hz) is available, data rates now in the MB/s range will increase into the GB/s range.

Antenna Technology

Broadband (100 MHz to 2,500 MHz) high-efficiency, linear adaptive phase and amplitude multibeam forming with dynamic tracking and acquisition and adaptive nulling interference cancellation will be common first in fixed station applications and eventually in mobile applications.

Spectrum Use Efficiency

Contrary to the assertions of the cellular industry and infrastructure manufacturers, spectrum efficiency does not mandate microcell architectures either in private or public carrier systems. In future systems, a balance between infrastructure cost and technology cost must be found. Certainly we can expect to see manufacturers of infrastructure pushing microcell infrastructure as a solution due to the economic benefits to be reaped by proliferating microcell solutions.

Rather, user requirements must drive technology. Multiple solutions ranging from very high-power, large service radii that employ very narrowband FDMA will exist, as well as microcell CDMA techniques. The challenges will be in developing forward-looking standardized protocols that facilitate information transfer between and amongst these various system architectures to and from the various end-users. Spectrally efficient solutions will be found in a variety of architectures: broadband covert waveform overlay, narrowband FDMA and in multislot TDMA.

Broadband covert waveform techniques such as CDMA using PN-DSSS, frequency hopping (FH) and hybrids there of will permit universal overlay of existing and future narrowband and broadband signals.

Depending upon the application and the signal statistics of the band to be overlaid, dynamically allocated PN-CDMA spread bandwidths ranging from 20 MHz to 500 MHz will be deployed as will FH systems operating over a 100 MHz bandwidth at hop rates of 100,000 hops/second. Information transfer rates supported by these covert broadband systems will range from the low 100 kb/s to low MB/s.

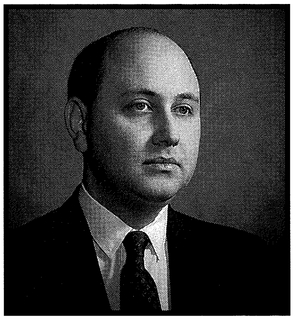
Unique developments in hybrid linear architectures will facilitate deployment of systems that make use of frequency division multiplexing, frequency hopping, time division multiplexing and CDMA.

2.5 kHz FDMA channelization will become practicable with the goal of digital channelization comparable to analog VF becoming a reality. With bandwidth efficiencies of 10 b/s/Hz, a very narrowband 2.5 kHz channel could support information transfer rates as high as 25 kb/s.

In the area of linear TDMA architectures, systems that employ master synchronization will be able to provide economical multislot TDMA systems (10 slots in a 25 kHz channel), affording bandwidth efficiencies comparable to 2.5 kHz channelized FDMA.

Conclusions

The 1994-2004 time frame will be a period of significant technological breakthrough in the area of wireless communications. The single, most important development will be wireless systems achieving information transfer rate parity with cable systems per Hz bandwidth.



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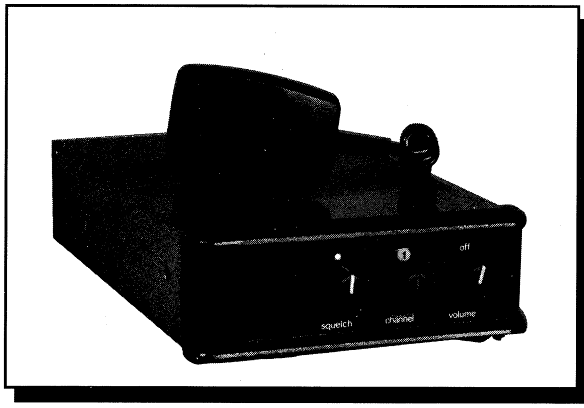

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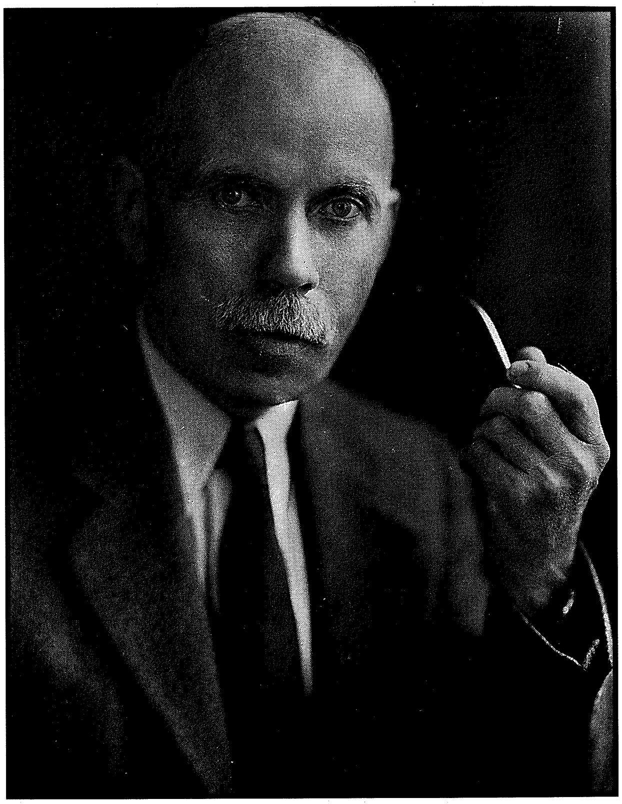
Commander Albert Hoyt Taylor: The Navy's Radio Pioneer

By Robert H. Welsh



Neither the U.S. Navy nor any other modern Navy can operate effectively around the world without radio communications between their far-flung fleets and their command centers. Before the days of radio communications, ships at sea were totally out-of-touch with civilization until they arrived at their next ports. The introduction of radio communications allowed Naval surface ships, submarines and aircraft to be in constant touch with each other and with their shore commands anywhere in the world.

The major world powers' Navies began to consider wireless for fleet communications almost from the birth of practical radio. As early as November 1899, the U.S. Navy experimented with Marconi communications equipment between the cruiser *New York* and the battleship *Massachusetts*. The system, built by Marconi Co., was successful in communicating to distances as far as 36 miles. Unfortunately for Marconi, the Navy was not pleased with the terms demanded by Marconi, and Admiral Bradford, Equipment Bureau chief, decided the Navy should develop its own wireless system.[1]

Several years of investigation of different wireless systems led to the purchase in 1902 of the Navy's first wireless stations. Two shore stations were installed; one at the Washington Navy Yard and the other at the U.S. Naval Academy. In addition to the shore stations, the Navy made available two ships for sea trials—the *USS Prairie* and the *USS Topeka*. After another year's worth of testing, the Navy chose the Slaby-Arco system manufactured by General Electric Co. of Berlin. The spark-type transmitter operated at a power of 1,000 watts on wavelengths between 200 meters and 400 meters. The operational tests between Annapolis, Md., and the *Prairie* confirmed a maximum usable range of about 100 miles. By 1904, 58 different ships and stations were linked by wireless. The Navy entered the electronics age.

In May 1900, Russia announced plans to equip the Black Sea Fleet with wireless. During 1902, the Imperial Japanese Navy began equipping its ships with Marconi equipment, and France installed wireless sets on its Mediterranean Fleet. The British seriously had been engaged in wireless experiments as well. It is interesting to note that the Navies of Great Britain, France, Japan, Russia and the United States began equipping their naval forces with wireless at almost the same time.

The U.S. Navy was fortunate in having Commander Albert Hoyt Taylor as one of its members during a time when wireless communications was in its infancy. Commander Taylor began his professional career as a physicist, earning a B.S. degree from Northwestern University in 1902. He began teaching physics and electrical engineering at Michigan State (1900 to 1903), moving subsequently to the University of Wisconsin, where he published five papers on electrical measurements. Taylor left Wisconsin in 1908 to attend Imperial University at Goettingen, Germany, where he studied physics with an emphasis on electricity and wireless. Returning to the United States, he served as a physics professor at the University of North Dakota from 1909 to 1917.

Even before he began his formal education, Taylor was interested in the development of electricity and then wireless. With his boyhood friends, he constructed a wire telegraph connecting their homes. The first several experiments failed until the boys recognized the necessity of a good earth ground to complete the path for their telegraph circuit. Taylor closely followed the activities of the European experimenters such as Lodge, Righi and Marconi, eventually duplicating some of their experiments during his undergraduate years.

"...the Navies of Great Britain, France, Japan, Russia and the United States began equipping their naval forces with wireless at almost the same time."

He was so keen on their work that he published a paper, using his best mathematical skills, showing that trans-Atlantic wireless communication could not happen. The paper was delivered several years before Marconi's record-breaking trans-Atlantic experiment on Dec. 12, 1901. Taylor commented after the fact, "From then on to this day, I have been very wary of making predictions of what radio cannot do."[2]

The eight years that Taylor spent at North Dakota were important both for his future and for the future of radio. Two of his former students went on to make significant contributions to communications theory and practice. They were R.A. Heising (modulation) and H. Nyguist (information transmission theory). In addition to teaching courses in alternating current and electromagnetic theory, Taylor began serious wireless experiments at North Dakota.

Wireless Experiments

First, a receiving station and antenna system were constructed; then a transmitting station was added. Much of the two-way wireless activity in the early 1900s was between amateur stations, with a few universities constructing experimental stations. Licensing and regulation, as performed by the Federal Communications Commission today, were non-existent until the London Convention of 1912 forced the organization of operating wavelengths. It was quite common for the few Naval wireless stations, university experimental stations and amateur stations to regularly communicate with each other. Today, the tradition of amateur-to-military radio communications is carried on during the yearly Armed Forces Day in May.

The University of North Dakota amateur radio station, call sign 9YN, was both powerful and active. Under Taylor's direction, 9YN communicated regularly with the Navy wireless stations at Arlington, Va., and Key West, Fla. Taylor was interested in how diurnal and seasonal weather changes affected the strength of received signals.

Taylor obtained his own experimental license—call sign 9XN—for propagation experiments on frequencies between 100 kHz and 600 kHz. Using a 4,000 watt transmitter and an 800-foot-long antenna, elevated 125 feet between the Science Building and a chimney, he communicated primarily with amateurs for the purpose of studying diurnal, seasonal and weather effects on propagation. The conclusions drawn from the amateur experiments were published in the *Physical Review* during 1914. The article was titled "Radio Transmission and Weather."

The University of North Dakota-Navy wireless experiments led to a paper published in the *Physical Review,* May 1913, and it was delivered before a meeting of the Institute of Radio Engineers in New York City. Taylor's professional relationship with the Navy at the university led him to meet Admiral Bullard, the first director of naval communications. Bullard suggested that Taylor's experiments might aid in improving the wireless station at the Great Lakes Naval Station near Lake Bluff, Ill. Those experiments continued until 1916 when the Navy found that war preparations were interfering with the experiments.

Taylor's relationship with Navy wireless continued by way of his setting up amateur relay stations for passing messages from Great Lakes to various part of the country. Of the 50 amateurs operating in the relay, 45 enlisted in the Navy during World War I.

Navy Experience

In February 1917, Taylor gave a lecture in Chicago on his experimental work, stopping off at Great Lakes on his return to North Dakota. While meeting with Lieutenant McCauley, a Navy acquaintance, Taylor was persuaded to apply for a commission in the Naval Reserve. After passing the medical exam, he was commissioned a Lieutenant in what then was called the Coast Defense Reserve. On March 28, 1917, Lieutenant Taylor was ordered to active duty, reporting to Great Lakes just a few days before the U.S. declared war on Germany.

His experiments with wireless at Great Lakes were cut shore, when in November 1917, Assistant Director of Naval Communications Commander Fawall ordered him to assist in setting up the Naval Radio Station at Belmar, N.J. Belmar originally had been a trans-Atlantic receiving station operated by American Marconi Co. With the advent of war, the Navy took control of the station. Taylor became commanding officer of the Belmar station with the title TCO (Trans-Atlantic Communications Officer), quite possibly the only Naval officer to have ever had that title. Considering the importance of this station to Naval communications, he was allowed a wide latitude in staffing the site.

Needless to say, he had the choice of the best of the Navy's operators, technicians and engineers.[3]

The transmitting sites that supported the Belmar receiving station were at Tuckerton, N.J., and Sayville. Both sites were German transmitting stations that were taken over by the Navy just prior to the outbreak of hostilities. It was the transmitter at Tuckerton, originally operated by the Gesellshaft fur Drahtlose Telegraphie (Telefunken), that was suspected of transmitting the "Get Lucy" message to submarine U-39 for the purpose of sinking the Cunarder *Lusitania*, which was hit by a German U-boat off the Irish coast on May 7, 1915.[4]

Taylor worked closely with the transmitting stations at Tuckerton and New Brunswick, N.J., and Sayville. Locating a receiving system adjacent to a transmitter site was technically difficult during the days of very-low-frequency (VLF) (33 kHz) rotary spark transmitters.[5] The Navy transmitter site at New Brunswick (call letter WII, then NFF) was taken over from American Marconi Co. It used a 50,000 watt Alexanderson alternator that generated such an intense electric field under the antenna that blue sparks were seen leaping off the bayonets of the sentries on night duty.

The Tuckerton (call letter WGG, later NWW) and Sayville (call letters SLI, later NDD) transmitters operated at powers of 100,000 watts. These three shore stations used operating wavelengths that were in the VLF portion of the electromagnetic spectrum (frequencies from 3 kHz to 30 kHz).

Connecting Washington to Europe

For the duration of the war, Taylor actively was engaged in providing the Navy with reliable communications between Washington and the European stations at Paris and Crois D'Hins, France. When not receiving scheduled traffic from France, Taylor ordered his operators to perform radio intercepts of the German station at Nauen operating at a frequency of 24 kHz. The Nauen station usually transmitted propaganda, in English, to North America, but the Navy operators reported that the Nauen station occasionally would stop transmitting for periods of 20 minutes then resume their propaganda broadcasts.

Taylor suspected that the Germans might be transmitting military traffic from the Nauen station, so he ordered his operators to look for the transmitter at multiples of their usual operating frequency. Taylor's understanding of how radio transmitters could be tuned allowed the New Brunswick operators to find the Germans transmitting at 48 kHz, sending four-letter code groups during the 20 minute interval. The messages were sent to Washington for decoding along with Taylor's suggestion that these coded messages could be directing the German submarine fleet.

Formula Emerges for Radio Wave Propagation

Dr. Louis Winslow Austin, a physicist and authority on wireless, became director of the newly established U.S. Naval Radio Telegraphic Laboratory in 1908. The Radio Telegraphic Laboratory performed quantitative experiments on the propagation of radio waves over long distances. As a result of the experimental data collected by Dr. Austin's laboratory, the first scientific formula for the propagation of radio waves was written. The formula's solution showed an attenuation in the field intensity amplitude of radio waves as the distance between transmitter and receiver increased. In addition, the attenuation of the received signal decreases at longer wavelengths.[6] As a result of Dr. Austin's hypothesis, the shorter wavelengths were left to the use of amateur radio operators in the belief that they would be useless for the long-distance communications necessary to the Navy.

Taylor's experimental curiosity, his early association with amateurs while teaching at the University of North Dakota and his wariness at making predictions about what radio "cannot do" led him to direct his research toward shorter radio wavelengths.

NARL staff members began radio propagation experiments at shorter wavelengths in 1919. The laboratory established both transmitting and receiving stations in the medium wave band (frequencies on the order of 700 kHz to 900 kHz). This band later became popular as the "AM broadcast band." It is interesting to note that during the early 1920s, the NARL stations (call signs NSF and NOF) were broadcasting music, songs by popular singers of the day, talks by famous persons and lectures from government officials. During 1922, this included a series of lectures by the U.S. Public Health Service and the first radio transmissions by a U.S. Senator (Henry Cabot Lodge), a Supreme Court Justice (Chief Justice White) and President Warren G. Harding. The rise in public interest in broadcast radio led to many reception reports being sent to NARL by amateur and non-amateur enthusiasts alike. This data provided Taylor and his staff with information on the range and signal strengths of the NARL transmitters at various times of the day and the year.[7]

Radio Propagation Studies

During the summer of 1920, Taylor and the NARL staff participated in one of the most important radio propagation studies conducted during that time. The objective of this experiment was the investigation of fading of radio signals propagated over long distances.

The Kennelly-Heaviside hypothesis stated that long-range radio propagation is the result of the reflection of radio signals from a layer of ionized particles about 100 miles above the Earth. The upper atmosphere propagation hypothesis offered by Kennelly and Heaviside shed doubt on the Austin-Cohen theory. Since the amateur radio operators of the 1920s were experimenting with shorter wavelengths and observing improved reception over long distances, there seemed to be some basis to the Kennelly-Heaviside hypothesis.

The Radio Laboratory of the U.S. Bureau of Standards and the American Radio Relay League met April 7, 1920 and proposed a series of summer radio propagation experiments with the purpose of collecting quantitative data on the shorter wavelengths. Commander Taylor was invited to attend and promptly offered the use of the station at Anacostia (in Washington, D.C., NSF) to assist in the experiment. The tests were made at a wavelength of 250 meters (1.2 MHz) using, in addition to the Anacostia station, the station of the Bureau of Standards (WWV) and about 45 amateur stations, including two universities, Dartmouth and Cornell. The summer experiments results added confirmation to the hypothesis that long-distance radio propagation was the result of reflections of the signal from a layer about 100 miles in altitude. Additionally, there appeared to be evidence that stations geographically close to each other could communicate by ground wave propagation, and that local weather conditions had little effect upon the propagation of radio signals.[8]

From the data collected, Taylor, thinking like a physicist, reasoned that fading at shorter wavelengths was a result of a phenomenon in geometric optics known as superposition of waves.[9] The Bureau of Standards published his results as a scientific paper, No. 353, "Variation in Direction of Propagation of Long Electromagnetic Waves."

This experiment added another piece to the solution of the puzzle of how shorter waves were propagated around the Earth. A firm understanding of this type of propagation was imperative if these frequency bands were to be used routinely by Naval aircraft and ships.

Additionally, the success of the 1920 experiment led Taylor to request the assistance of amateur operators during the flight of the Navy airship *Shenandoah* in October 1924.

The *Shenandoah* was scheduled for a flight to the North Pole, and Taylor had a 100-meter (3

MHz) transmitter installed in order to study the propagation of these signals from the Polar regions.[10]

In retrospect, the years 1919 to 1923 that Taylor spent at NARL were a prelude to the next six years in which the U.S. Navy, through Taylor's tireless efforts, led the scientific community in opening up high frequency radio. In 1923, the Naval Aircraft Radio Laboratory and the Naval Radio Telegraphic Laboratory were consolidated into the Radio Division of the Naval Research Laboratory (NRL) with Dr. Taylor as superintendent. The consolidation of these two laboratories was significant, considering how many new discoveries in radio science were made during that six-year period.

Development of Intrafleet Radio System

One of the first tasks of NRL's Radio Division was the development of an intrafleet radio system that operated on wavelengths of 200 meters to 100 meters (1.5 MHz to 3 MHz). Just prior to the end of 1923, two amateur operators, Fred Snell (later captain USNR) and John Reinartz (later Commander USNR), succeeded in trans-Atlantic communications on a wavelength of 1,200 meters. The Radio Division followed this work in detail, putting their station (call sign NKF) on the air for trans-Atlantic communications with European amateurs. It was becoming evident to Taylor and the NRL staff that the shorter wavelengths were proving to be outstanding parts of the spectrum for communications, particularly for nighttime operations.

Even though radio signals were being propagated over distances, the signals transmitted by the amateurs were often difficult to copy. The amateurs were using "raw alternating current" applied to the anodes of their transmitting tubes. This resulted in a transmitted signal that wandered in frequency, making the transmission difficult for the receiving operator to copy Morse characters. This would never do for fleet communications where traffic had to have a high probability of perfect copy.

In response, Taylor and his assistant, Leo C. Young, designed a "master oscillator-power amplifier" (MOPA) transmitter with direct current applied to the anodes of the transmitting tubes, an operating design that became a standard for future radio transmitters. Using an operating wavelength of 52 meters (5.7 MHz), Taylor and Young were able to communicate reliably during the daytime over ranges of 500 miles and at night over ranges in excess of 5,000 miles. Taylor and Young were pleased with the system but, typical of good experimenters, they continued to pursue a more stable transmitting system.

The MOPA transmitter design previously was used in one of the most important radio experiments ever conducted. In December 1921, members of the Radio Club of America—Ernest V. Amy, Edwin H. Armstrong, George E. Burghard, Minton Cronkhite, John F. Grinan, Walter P. Inman—transmitted the first radio message across the Atlantic. The transmitting station, 1BCG, was set up at Cronkhite's estate in Greenwich, Conn., and transmitted to Paul Godley, who set up a receiving station at Androssan, Scotland.

The original 1BCG transmitter was a self-excited, self-rectifying Colpitts oscillator using a pair of 250 watt UV-204 Radiotrons. The plates were connected to the secondary of an 8,000 volt center-tapped transformer. Just as in Taylor's earlier experiments, this circuit produced a 120 Hz modulation on the keypad signal. Armstrong suggested rebuilding the transmitter into an MOPA system in order to produce a pure, steady CW signal for heterodyne reception. Four UV-204s were used with one as the master oscillator and three as parallel amplifiers. At 1250 hours, Greenwich Mean Time, Dec. 9, 1921, Godley copied a complete message transmitted by 1BCG on the "commercially useless short waves." Both the amateur community and the Navy were quick to recognize the importance of this experiment.[11]

Crystal-Controlled Transmitter Surfaces

For improved frequency stability, Taylor and Young chose to control transmitter frequency using quartz crystals specifically ground for that purpose. In 1924, Louis Gebhard of the Radio Division constructed the world's first crystal-controlled high-power transmitter. [12] This transmitter spent many years operating on a frequency of 4015 kHz for communications between the Navy in Washington, D.C., and the U.S. Embassy in London. During this same period, the Radio Division designed and built several receivers to complement the new transmitters.

The experiments during 1924 produced not only improvements in radio equipment but also a new understanding of the phenomenon of radio propagation. The Kennelly-Heaviside hypothesis was put on a firmer foundation by the success of radio communications at increasingly higher operating frequencies. Data collected on the Washington to London circuit confirmed that nighttime communications were much improved over that of daytime on the 4 MHz to 5 MHz frequency bands. On the other hand, frequencies between 5 MHz to 12 MHz showed a marked improvement over the lower frequencies during daytime. These differences intrigued Taylor and Young enough that they began investigating the reliability of higher frequency communications.

As had been done so many times in the past, Taylor turned to radio amateurs for assistance. John Reinartz, who lived near Hartford, Conn., and maintained a powerful amateur station, was asked to assist in a new series of propagation experiments. Reinartz, who was stationed at NRL during World War I, was only too happy to comply. Taylor and Young at NRL, with Reinartz at Hartford, maintained a number of radio schedules in which the operating frequency of Reinartz's transmitter would be increased in steps while the NRL receiver would be tuned to follow. The first observation made was that there would be a limiting frequency above which no signals would be heard. Current ionospheric theory explains this phenomenon as the maximum usable frequency (MUF) above which there is insufficient ionization of the Kennelly-Heaviside layer to support reflection of HF radio signals.[13]

Skip Effect Discovered

During the experiments, Taylor and Young obtained the assistance of another amateur, William Justice Lee (Captain Lee USNR) of Orlando, Fla., who monitored the experiments from geographically south of NRL. Lee reported to Taylor that when Reinartz's signal at the higher frequencies was not being received in Washington, Reinartz's signal still was coming in strong in Orlando. Taylor, Young, Reinartz and Lee discovered the "skip" effect: Radio signals were capable of skipping over large distances by way of reflection from the Kennelly-Heaviside layer—now referred to as the ionosphere. With this new information, Taylor and Dr. E.O. Hulbert of the NRL's Division of Physical Optics were able to rewrite the previously existing theories of radio propagation via the ionosphere. Enough data was being collected by NRL to permit the publication of communications charts for the fleet that would aid in more reliable radio communications. Rather than have ships assigned to one given frequency, a number of different frequencies could be chosen based on the time of day, the ship's range to a shore station or a specific location.[14]

The scientific results of the "skip" experiments were published in the *Proceedings of the Institute of Radio Engineers*, August 1926.[15] In this classic paper, Taylor summarizes the experiments as follows:

1. Skip distance is explained in terms of the optics of total internal reflection;
2. Ray path analysis of waves is used to support the equations relating wave angle, Heaviside layer height and geographic breadth of the zone of reception of the received signal;
3. Signal reports between NRL and Radio Corp. of America stations; and
4. Experimental evidence is presented to show how skip distance and layer height are related to frequency.

During the summer of 1925, Drs. Merle Tuve and Gregory Breit approached NRL with the novel idea of testing the height of the reflections from the ionosphere by transmitting short pulses of radio energy and measuring the time delay between the transmission of a given pulse and the return of its echo from the reflecting layer. Gebhard of NRL constructed the first high-power pulse transmitter operating at the frequency of 4 MHz. This system worked so well that the Patent Section of the Judge Advocate's office of the Navy Department urged NRL to file patents with the understanding that this system would be given a "secret" status in terms of confidentiality.

Radio Reflections Discoveries

In 1922, Taylor and Young observed reflections from a wooden ship using the wave-interference method. The system used in the experiment operated at a wavelength of 5 meters; the receiver and transmitter were separated physically. The procedure of physically separating the transmitter and receiver is known as a bistatic radar. Its most recent use has been by the United States and the Soviet Union during the Cold War. It has been referred to as over-the-horizon radar.

Although Taylor and Young hit upon a totally new technology for radio waves, their studies were not pursued at that time. In June 1930, L.A. Hyland of NRL was the first American to detect flying aircraft using the wave-interference method.

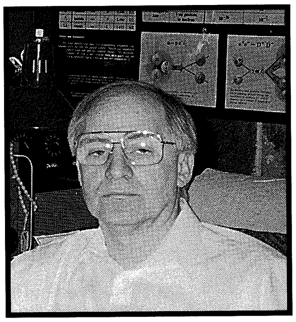
Again, just as in the 1922 radio reflection discoveries, little further investigation was made into this phenomenon. Taylor, Young and Hyland did file a patent in 1933 entitled "System for Detecting Objects by Radio" (U.S. patent 1,981,884, Nov. 27, 1934).[16] So much has been written about the importance of radar in winning the Second World War that it is easy to forget radar's humble beginnings as an anomaly of early radio research.

I began this piece by asking the reader to consider the importance of radio communications to the modern Navy. An observer looking at that marvel of modern sea power, an AEGIS-class cruiser, sees a ship covered with a wide assortment of antennas: HF, VHF and UHF radio communications, microwave satellite communications and radar. This ship could not perform its mission without the systems that were developed by Taylor and his scientific partners. In just more than a decade, Taylor provided the Navy with the theory and practice of high frequency radio, with the operating systems to support the theory and with the foundations of radar. In closing, I would like to quote from Taylor's fascinating autobiography, "If I could shuffle off 50 years and begin over again, I would ask nothing better than to start another 50 years of radio."[17]

For his gracious assistance during the preparation of this article, I extend my sincere thanks to Dr. David van Keuren, historian, U.S. Naval Research Laboratories, Washington, D.C.

NOTES:

1. Louis A. Gebhard, "Evolution of Naval Radio-Electronics and Contributions of Naval Research Laboratory," Naval Research Laboratory, 1979, p. 2.
2. A. Hoyt Taylor, "Radio Reminiscences: A Half Century," Naval Research Laboratory, 1960, p. 3.
3. Naval Communications at the outbreak of World War I were under the control of the Bureau of Steam Engineering. The advent of steam propulsion brought engineering to the Navy and the transitional title "Steam Engineering" remain din use. The Naval Officers who did engineering work were known simply as "Line Officers, EDO (Engineering Duty Only."
4. Walter J. Schulz, *Wireless Antenna History*, Herbst Verlag, Cologne, 1988, p. 10.
5. Gebhard.
6. Robert H. Welsh, "The Discovery of the Ionosphere: 1900-1930," *Proceeding of the Radio Club of America*, November 1994.
7. Gebhard.
8. S. Kruse, "The Bureau of Standards—ARRL Tests of Short Wave Radio Fading," *Proceedings of the Radio Club of America*, September 1920.
9. Superposition is a phenomenon occurring when a single frequency source of waves travels over two or more paths to reach a fixed point in space (the observer). At the fixed point of the observer, the amplitudes of the new waves combine vectorially such that in-phase waves create larger amplitudes and out-of-phase waves create smaller amplitudes or cancellation.
10. A.H. Taylor, "The Navy's Work on Short Waves," *QST*, May 1924, pp 9-14.
11. "The Story of the First Trans-Atlantic Short Wave Message," 1BCG Commerative Issue, *Proceedings of the Radio Club of America*, October 1950.
12. Taylor, "Radio Reminiscences...," p. 108.
13. Kenneth Davies, *Ionospheric Radio Propagation*, National Bureau of Standards, Washington, D.C., November 1965, p. 167.
14. Taylor, "Radio Reminiscences...," pp. 109-112.
15. A. Hoyt Taylor, "Relation Between the Height of the Kennelly-Heaviside Layer and High Frequency Radio Transmission Phenomena," *Proceedings of the Institute of Radio Engineers*, August 1926, pp. 521-540.
16. Merrill I. Skolnik, *Introduction to Radar Systems*, McGraw-Hill, New York, 1962, p. 10.
17. Taylor, "Radio Reminiscences...," p. 248.

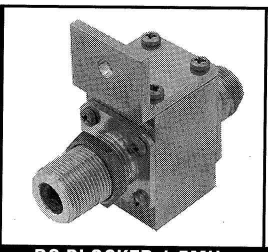


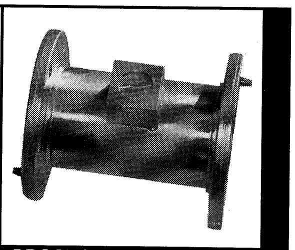
Robert H. Welsh (M) has a diploma in radio engineering from Philadelphia Wireless Technical Institute (1961). He is a graduate of the U.S. Army Signal School (Radar and Electronic Warfare). He received a B.A. in history and electronic physics from LaSalle College (1972) and an M.S. in science education from Temple University (1977), both in Philadelphia. He completed additional graduate work in radio astronomy at the National Radio Astronomy Observatory in West Virginia.

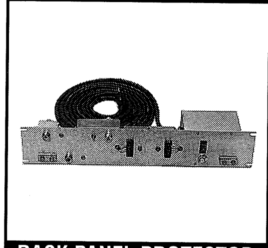
Welsh formerly worked as an electronics technician and laboratory engineer for such employers as the Radio Corporation of America, American Electronics Laboratories and the University of Pennsylvania for 12 years. He has taught electronics technology, and he currently teaches physics for the School District of Pennsylvania. He is a lecturer in the Department of Physics at LaSalle.

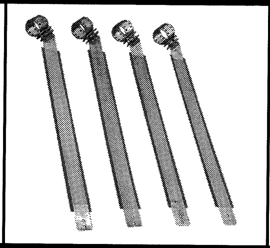
Welsh has been a licensed radio amateur since 1959. His original station call sign was K3JHE. Since 1977, his station call sign has been N3RW. Using vacuum tube equipment, he operates CW more than any other mode.

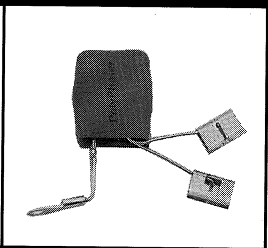
Grounding & Lightning Protection Solutions

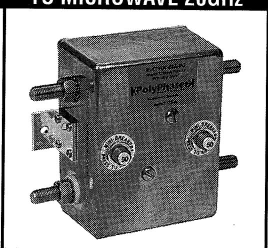

DC BLOCKED 1.5MHz TO MICROWAVE 20GHz

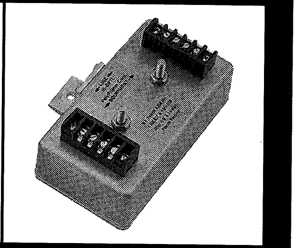

BROADCAST & MILITARY TO 80 kW

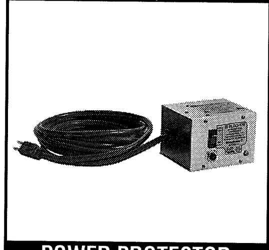

RACK PANEL PROTECTOR 120/240Vac, 15-20A

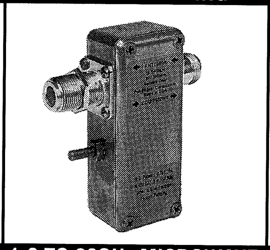

UNI-KIT COAX CABLE GROUNDING

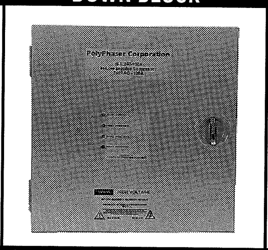

DATA/PHONE PUNCH DOWN BLOCK


SOLAR/BATTERY

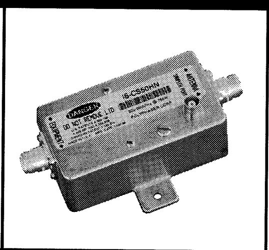

PHONE LINE/LAN/T-1


POWER PROTECTOR 120/240Vac,15-20A

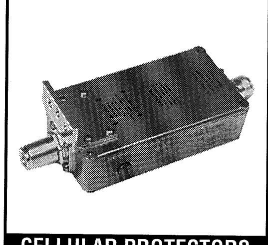

1.2 TO 20GHz MICROWAVE & DOWNCONVERTERS



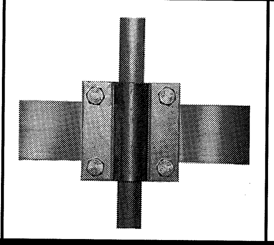
IN-LINE POWER MAINS


COAX PROTECTOR WITH SAMPLER PORT


SHUNT-TYPE POWER MAINS


CELLULAR PROTECTORS TO 980MHz


STRIKE COUNTERS TOWER/POWER/PHONE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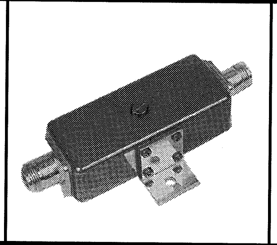
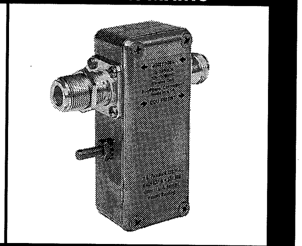

LAN/VIDEO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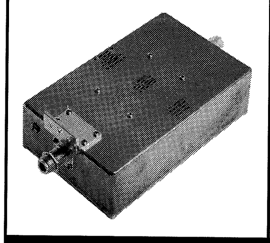
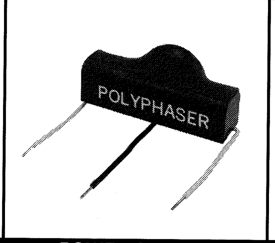
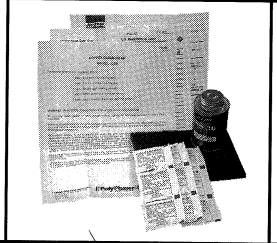
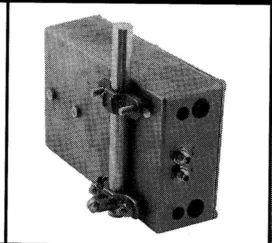
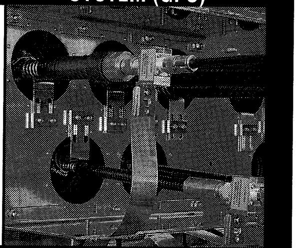

UHF COMBINERS

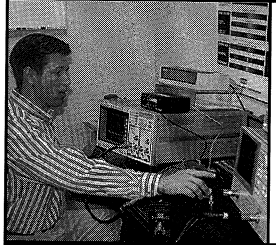


POWER SUPPLY PROTECTOR


COPPER CLEANING KIT (CCK)


TVRO PROTECTOR LNB & MOTOR CONTROL


COAX ENTRANCE PANELS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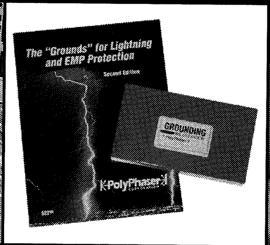

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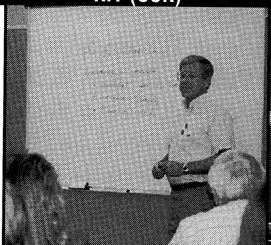
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A Tutorial on Global System for Mobile Communications (GSM)

By Theodore S. Rappaport, Rias Muhamed
and Kevin J. Saldanha

Abstract: GSM quickly is emerging as the leading cellular radio standard throughout the world. With the advent of new personal communications frequencies in the 1.8 - 2 GHz band, GSM and its PCS offshoot, DCS, may be implemented in North America within the next 12 months to 18 months. This tutorial is part of an independent learning program prepared by the authors for the IEEE. This material is taught as part of an introductory course on wireless communications at Virginia Tech and will be included in the textbook Wireless Communications: Principles and Practice published by Prentice-Hall.

Global System for Mobile Communications

Global system for mobile communications (GSM) is a second-generation cellular system standard that was developed to solve the fragmentation problems of the first cellular systems in Europe [Mou92]. Unlike the U.S. cellular carriers which implemented the first-generation analog mobile phone system (AMPS) throughout the country, the first-generation cellular service providers in Europe took a provincial view of cellular.

Before GSM, European countries used different cellular standards throughout the continent, and it was not possible for a customer to use a single mobile phone throughout Europe.

After five years and hundreds of person-years of engineering, the European community developed an amazingly robust and complex cellular standard that was first to specify digital modulation and network level architectures and service.

GSM originally was developed to serve just the pan-European cellular market and promised a wide range of network services through the use of integrated services digital network (ISDN). However, during the past two years, GSM's success has exceeded the expectations of virtually everyone, and it is now the world's most popular standard for new cellular radio and personal communications equipment throughout the world.

It is predicted that by the year 2000, there will be between 20 million and 50 million GSM subscribers worldwide [Mou92], [Dec93]. The task of specifying a common mobile communication system for Europe in the 900 MHz band was taken up by the GSM (Groupe special mobile) committee, which was a working group of the Conference of Europeóene Postes des et Teóleócommunication (CEPT). The setting of standards for GSM is currently under the aegis of the European Technical Standards Institute (ETSI).

GSM first was introduced into the European market in 1991. By the end of 1993, several non-European countries in South America, Asia and Australia had adopted GSM and the technically equivalent offshoot, DCS 1800, which supports personal communication services (PCS) in the 1.8-2.0 GHz radio bands recently created by governments throughout the world.

GSM Services, Features

GSM services follow ISDN guidelines and are classified as either teleservices or data services. Teleservices include standard mobile telephony and mobile-originated or base-originated traffic. Data services include computer-to-computer communication and packet-switched traffic. User services may be divided into three major categories:

Telephone services, including emergency calling and facsimile. GSM also supports Videotex and Teletex, though they are not integral parts of the GSM standard.

Bearer services or data services, which are limited to layers 1, 2 and 3 of the open system interconnection (OSI) reference model. Supported services include packet-switched protocols and data rates from 300 bps to 9.6 kbps. Data may be transmitted using either a transparent mode (where GSM provides standard channel coding for the user data) or non-transparent mode (where GSM offers special coding efficiencies based on the particular data interface).

Supplementary ISDN services, including call diversion, closed user groups and caller identification. These services are not available in analog mobile networks. Supplementary services also include the short messaging service (SMS), which allows GSM subscribers and base stations to transmit alphanumeric pages of limited length (160 7-bit ASCII characters) while simultaneously carrying normal voice traffic. SMS provides cell broadcast, which allows GSM base stations to repetitively transmit ASCII messages with as many as fifteen 93-character strings in concatenated fashion. SMS may be used for safety and advisory applications, such as the broadcast of highway or weather information to all GSM subscribers within reception range.

From the user's point of view, one of the most remarkable features of GSM is the subscriber identity module (SIM), which is a memory device that stores information such as the subscriber's identification number, the networks and countries where the subscriber is entitled to service, privacy keys and other user-specific information. A subscriber uses the SIM with a four-digit personal ID number to activate service from any GSM phone.

SIMs are available as smart cards (credit-card-sized cards that may be inserted into any GSM phone) or plug-in modules, which are less convenient than the SIM cards but are nonetheless removable and portable. Without a SIM installed, all GSM mobiles are identical and non-operational. It is the SIM that gives GSM subscriber units their identities. Subscribers may plug their SIM into any suitable terminal—such as a hotel phone, public phone, or any portable or mobile phone—and then are able to have all incoming GSM calls routed to that terminal and have all outgoing calls billed to their home phone, no matter where they are in the world.

A second remarkable feature of GSM incorporates the on-the-air privacy, which is provided by the system. Unlike analog FM cellular phone systems which can be readily monitored, it is virtually impossible to eavesdrop on a GSM radio transmission.

The privacy is made possible by encrypting the digital bit stream sent by a GSM transmitter, according to a specific secret cryptographic key that is known only to the cellular carrier. This key changes with time for each user. Every carrier and GSM equipment manufacturer must sign the memorandum of understanding (MoU) before developing GSM equipment or deploying a GSM system. The MoU is an international agreement that allows the sharing of cryptographic algorithms and other proprietary information between countries and carriers.

GSM System Architecture

The GSM system architecture consists of three major interconnected subsystems that interact between themselves and with the users through certain network interfaces. The subsystems are the base station subsystem (BSS), network and switching subsystem (NSS) and the operation support subsystem (OSS). The mobile station (MS) is also a subsystem, but it is usually considered to be part of the BSS for architecture purposes.

Equipment and services are designed within GSM to support one or more of these specific subsystems.. The BSS, also known as the radio subsystem, provides and manages radio transmission paths between the mobile stations and the mobile switching center (MSC). The BSS also manages the radio interface between the mobile stations and all other GSM subsystems.

Each BSS consists of many base station controllers (BSCs), which connect the MS to the NSS via the MSCs. The NSS manages the switching functions of the system and allows the MSCs to communicate with other networks such as the public switched telephone network (PSTN) and ISDN.

The OSS supports the operation and maintenance of GSM and allows system engineers to monitor, diagnose and troubleshoot all aspects of the GSM system. This subsystem interacts with the other GSM subsystems and is provided solely for the staff of the GSM operating company, which provides service facilities for the network.

Figure 1 shows the block diagram of the GSM system architecture. The mobile stations communicate with the BSS over the radio air interface. The BSS consists of many BSCs that connect to a single MSC, and each BSC typically controls as many as several hundred base transceiver stations (BTSs).

Some BTSs may be co-located at the BSC, and others may be remotely distributed and physically connected to the BSC by microwave link or dedicated leased lines.

Mobile handoffs (called handovers, or HO, in the GSM specification) between two BTSs under the control of the same BSC are handled by the BSC, and not the MSC. This greatly reduces the MSC's switching burden.

As shown in Figure 2, the interface that connects a BTS to a BSC is called the Abis interface. The Abis interface carries traffic and maintenance data and is specified by GSM to be standardized for all manufacturers. In practice, however, theAbis for each GSM base station manufacturer has subtle differences, thereby forcing service providers to use the same manufacturer for the BTS and BSC equipment.

The BSCs are connected physically via dedicated/leased lines or microwave link to the MSC. The interface between a BSC and a MSC is called the A interface, which is standardized within GSM. The A interface uses an SS7 protocol called the signaling correction control part (SCCP), which supports communication between the MSC and the BSS, as well as network messages between the individual subscribers and the MSC. The A interface allows a service provider to use base stations and switching equipment made by different manufacturers.

The NSS handles the switching of GSM calls between external networks and the BSCs in the radio subsystem and is also responsible for managing and providing external access to several customer databases. The MSC is the central unit in the NSS and controls the traffic among all of the BSCs.

In the NSS, there are three different databases called the home location register (HLR), visitor location register (VLR) and the authentication center (AUC).

The HLR is a database that contains subscriber information and location information for each user who resides in the same city as the MSC. Each subscriber in a particular GSM market is assigned a unique international mobile subscriber identity (IMSI), and this number is used to identify each home user.

The VLR is a database that temporarily stores the IMSI and customer information for each roaming subscriber who is visiting the coverage area of a particular MSC. The VLR is linked between several adjoining MSCs in a particular market or geographic region and contains subscription information of every visiting user in the area. Once a roaming mobile is logged in the VLR, the MSC sends the necessary information to the visiting subscriber's HLR so that calls to the roaming mobile can be appropriately routed over the PSTN by the roaming user's HLR.

The authentication center is a strongly protected database that handles the authentication and encryption keys for every single subscriber in the HLR and VLR. The center contains a register called the equipment identity register (EIR), which identifies stolen or fraudulently altered phones that transmit identity data that does not match with information contained in either the HLR or VLR.

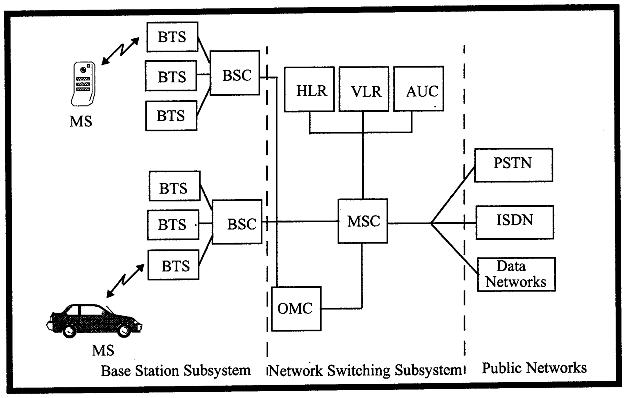

Figure 1. GSM System Architecture

The OSS supports one or several operation maintenance centers (OMC), which are used to monitor and maintain the performance of each MS, BS, BSC and MSC within a GSM system. The OSS has three main functions, which are to maintain all telecommunications hardware and network operations with a particular market, manage all charging and billing procedures and manage all mobile equipment in the system.

Within each GSM system, an OMC is dedicated to each of these tasks and has provisions for adjusting all base station parameters and billing procedures, as well as for providing system operators with the ability to determine the performance and integrity of each piece of subscriber equipment in the system.

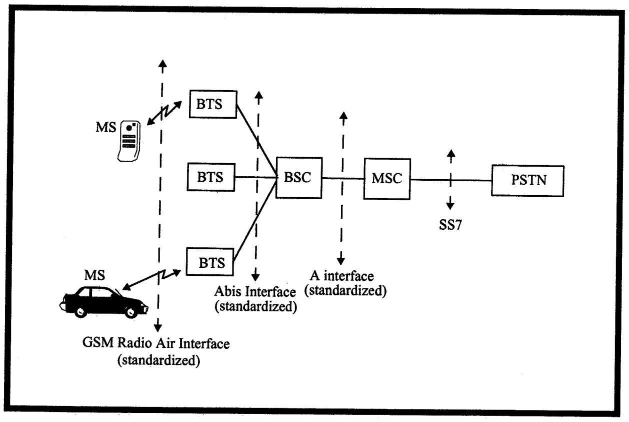

Figure 2. The various interfaces used in GSM

GSM Radio Subsystem

GSM uses two bands of 25 MHz that have been set aside for system use in all member countries. The 890-915 MHz band is used for subscriber-to-base transmissions (reverse link), and the 935-960 MHz band is used for base-to-subscriber transmissions (forward link).

For mobile applications in the 1.8-2.0 GHz band, DCS provides the same interface as GSM. Both GSM and DCS use FDD and a combination of TDMA and FHMA schemes to provide base stations with simultaneous access to multiple users. The available forward and reverse frequency bands are divided into 200 kHz wide channels called ARFCNs (absolute radio frequency channel numbers).

The ARFCN denotes a forward and reverse channel pair that is separated in frequency by 45 MHz (90 MHz for DCS), and each channel is time shared between as many as eight subscribers using TDMA.

Each of the eight subscribers uses the same ARFCN and occupies a unique time slot (TS) per frame. Radio transmissions on both the forward and reverse link are made at a channel data rate of 270.833 kilobits per second (1625.0/6.0 kbps) using binary 0.3 GMSK modulation. Thus, the signaling bit duration is 3.692 microseconds, and the effective channel transmission rate per user is 33.854 kilobits per second (270.833 kpbs/8 users).

With GSM overhead (described subsequently), user data actually is sent at a maximum rate of 24.7 kilobits per second. Each TS has a time allocation of 156.25 channel bits, but 8.25 bits of guard time and 6 total start and stop bits are provided to prevent overlap from adjacent time slots. Each TS has a time duration of 576.92 microseconds, and as shown in Figure 3, a GSM TDMA frame spans 4.615 milliseconds. The total number of available channels within a 25 MHz bandwidth is 125 (assuming no guard band).

Since each radio channel consists of eight time slots, there are thus a total of 1,000 traffic channels within GSM. In practical implementations, a guard band of 100 kHz is provided at the upper and lower end of the GSM spectrum, and only 124 channels are implemented.

The combination of a TS number and an ARFCN constitutes a physical channel for both the forward and reverse link. Each physical channel in a GSM system can be mapped into different logical channels at different times. That is, each specific time slot or frame may be dedicated to either handling traffic data (user data such as speech, facsimile or teletext data), signaling data (required by the internal workings of the GSM system) or control channel data (from the MSC, base station or mobile user). The GSM specification defines a wide variety of logical channels that can be used to link the physical layer with the data link layer of the GSM network. These logical channels efficiently transmit user data while simultaneously providing control of the network on each ARFCN. GSM provides explicit assignments of time slots and frames for specific logical channels, as described below.

GSM Channel Types

Channel Types: There are two types of GSM logical channels, called traffic channels (TCH) and control channels (CCH) [Hod90]. Traffic channels carry digitally encoded user speech or user data and have identical functions and formats on both the forward and reverse link. Control channels carry signaling and synchronizing commands between the base station and the mobile station.

Certain types of control channels are defined for just the forward or reverse link. There are six different types of TCHs provided for in GSM, and an even larger number of CCHs, which are described next.

GSM Traffic Channels (TCH)

GSM traffic channels may be either full rate or half rate and may carry either digitized speech or user data. When transmitted as full rate, user data is contained within one TS per frame. When transmitted as half rate, user data is mapped onto the same time slot but is sent in alternate frames. That is, two half-rate channel users would share the same time slot but would alternately transmit during every other frame.

In the GSM standard, TCH data may not be sent in TS 0 within a TDMA frame on certain ARFCNs that serve as the broadcast station for each cell (since this time slot is reserved for control channel bursts in most every frame, as described subsequently). Furthermore, TCH data frames are broken up every 13th frame by either slow associated control channel data (SACCH) or idle frames.

Figure 3 illustrates how the TCH data is transmitted in consecutive frames. Each group of 26 consecutive TDMA frames is called a multiframe (or speech multiframe, to distinguish it from the control channel multiframe described below). For every 26 frames, the 13th and 26th frames consist of slow associated control channel (SACCH) data, or the idle frame, respectively. The 26th frame contains idle bits for the case when full-rate TCHs are used and contains SACCH data when half-rate TCHs are used. In GSM, fast associated control channel (FACCH) data may be sent in place of user data at any time.

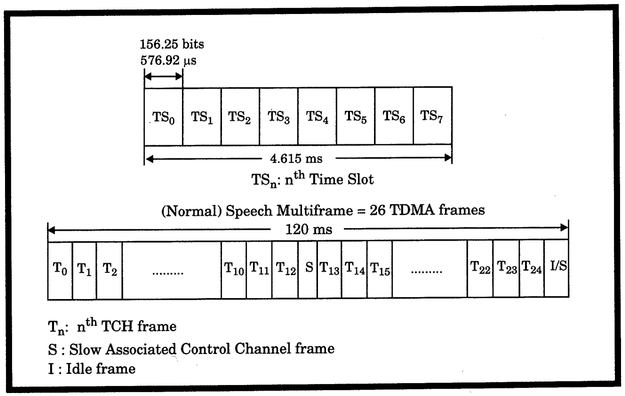

Figure 3. The Speech Dedicated Control Channel Frame and Multiframe structure

GSM Control Channels (CCH)

There are three main control channels in the GSM system. These are the broadcast channel (BCH), the common control channel (CCCH) and the dedicated control channel (DCCH). Each control channel consists of several logical channels that are distributed in time to provide the necessary GSM control functions.

The BCH and CCCH forward control channels in GSM are implemented only on certain ARFCN channels and are allocated time slots in a very specific manner. Specifically, the BCH and CCCH forward control channels are allocated only TS 0 and are broadcast only during certain frames within a repetitive 51 frame sequence (called the control channel multiframe) on those ARFCNs that are designated as broadcast channels. TS1 through TS7 carry regular TCH traffic, so that ARFCNs that are designated as control channels still are able to carry full-rate users on seven of the eight time slots.

The GSM specification defines 34 ARFCNs as standard broadcast channels. For each broadcast channel, frame 51 does not contain any BCH/CCCH forward-channel data and is considered to be an idle frame. However, the reverse channel CCCH is able to receive subscriber transmissions during TS 0 of any frame (even the idle frame). On the other hand, DCCH data may be sent during any time slot and any frame, and entire frames are dedicated specifically to certain DCCH transmissions.

On the BCH channel, synchronization and frequency correction data are sent to each mobile on the forward link using broadcast control channel (BCCH), frequency correction channel (FCCH) and synchronization channel (SCH).

The CCCH provides common control channels on both forward and reverse links. On the reverse link, the mobile responds to a call or requests service via a random access control channel (RACH). The base station broadcasts paging messages to all mobiles on the paging channel (PCH).

The DCCH provides dedicated slow and fast control signaling to calls as they are initiated. In particular, the slow dedicated control channel (SDCCH) is used to carry data following the connection of the mobile with the base station, and just before a TCH assignment is issued by the base station. The SDCCH ensures that the mobile station and the base station remain connected while the MSC verifies the subscriber unit and allocates resources for the call.

How a GSM Call Is Made

To understand how the various traffic and control channels are used, consider the case of a mobile call origination in GSM. First, the subscriber unit must be synchronized to a nearby base station as it monitors the BCH. By receiving the FCCH, SCH and BCCH messages, the subscriber would be locked on to the system and the appropriate BCH.

To originate a call, the user first dials the desired digits and presses the "send" button on the GSM phone. The mobile transmits a burst of RACH data, using the same ARFCN as the base station to which it is locked. The base station then responds with an AGCH message on the CCCH, which assigns the mobile unit to a new channel for SDDCH connection.

The subscriber unit, which is monitoring TS 0 of the BCH, would receive its ARFCN and TS assignment from the AGCH and would tune immediately to the new ARFCN and TS. This new ARFCN and TS assignment is physically the SDCCH (not the TCH).

Once tuned to the SDCCH, the subscriber unit first waits for the SAACH frame to be transmitted (the wait would last, at most, 26 frames or 120 ms, as shown in Figure 3), which informs the mobile of any required timing advance and transmitter power command. The base station is able to determine the proper timing advance and signal level from the mobile's earlier RACH transmission and sends the proper value over the SAACH for the mobile to process.

Upon receiving and processing the timing advance information in the SAACH, the subscriber now is able to transmit normal burst messages as required for speech traffic. The SDCCH sends messages between the mobile unit and the base station, taking care of authentication and user validation, while the PSTN connects the dialed party to the MSC, and the MSC switches the speech path to the serving base station.

After a few seconds, the mobile unit is commanded by the base station via the SDCCH to retune to a new ARFCN and new TS for the TCH assignment. Once retuned to the TCH, speech data is transferred on both the forward and reverse links, the call is successfully under way, and the SDCCH is vacated.

When calls are originated from the PSTN, the process is quite similar. The base station broadcasts a PCH message during TS 0 within an appropriate frame on the BCH. The mobile station, locked on to that same ARFCN, detects its page and replies with an RACH message acknowledging receipt of the page. The base station then uses the AGCH on the CCCH to assign the mobile unit to a new physical channel for connection to the SDCCH and SAACH while the network and the serving base station are connected.

Once the subscriber establishes timing advance and authentication on the SDCCH, the base station issues a new physical channel assignment over the SDCCH, and the TCH assignment is made.

Frame Structure for GSM

Figure 4 illustrates the data structure within a normal burst. It consists of 148 bits, which are transmitted at a rate of 270.833333 kbps (an unused guard time of 8.25 bits is provided at the end of each burst). Out of the total 148 bits per TS, 114 are information-bearing bits that are transmitted as two 57-bit sequences close to the beginning and end of the burst.

The midamble consists of a 26-bit training sequence that allows the adaptive equalizer in the mobile or base station receiver to analyze the radio channel characteristics before decoding the user data. On either side of the midamble, there are control bits called stealing flags. These two flags are used to distinguish whether the TS contains voice (TCH) or control (FAACH) data, both which share the same physical channel.

During a frame, a GSM subscriber unit uses one TS to transmit, one TS to receive, and may use the six spare time slots to measure signal strength on five adjacent base stations as well as its own base station.

As shown in Figure 4, there are eight time slots per TDMA frame, and the frame period is 4.615 ms. A frame contains 8X 156.25=1,250 bits, although some bit periods are not used. The frame rate is 270.833 kbps/1,250 bits/frame, or 216.66 frames per second. The 13th or 26th frame are not used for traffic, but for control purposes. Each of the normal speech frames are grouped into larger structures called multiframes, which in turn are grouped into superframes and hyperframes (hyperframes are not shown in Figure 4).

One multiframe contains 26 TDMA frames, and one superframe contains 51 multiframes, or 1,326 TDMA frames. A hyperframe contains 2,048 superframes, or 2,715,648 TDMA frames. A complete hyperframe is sent about every three hours, 28 minutes and 54 seconds and is important to GSM since the encryption algorithms rely on the particular frame number, and sufficient security only can be obtained by using a large number of frames as provided by the hyperframe.

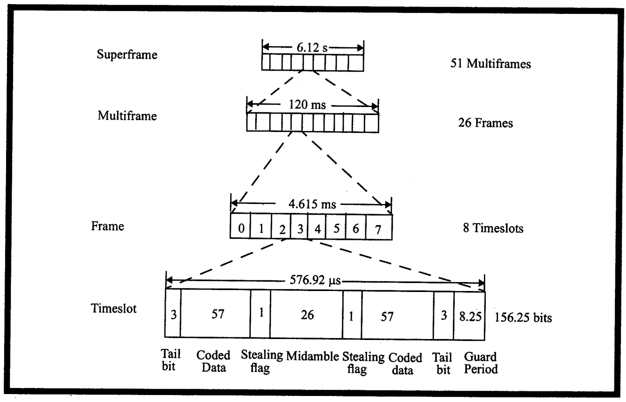

Figure 4. GSM Frame Structure

Signal processing in GSM

Figure 5 illustrates all of the GSM operations from transmitter to receiver.

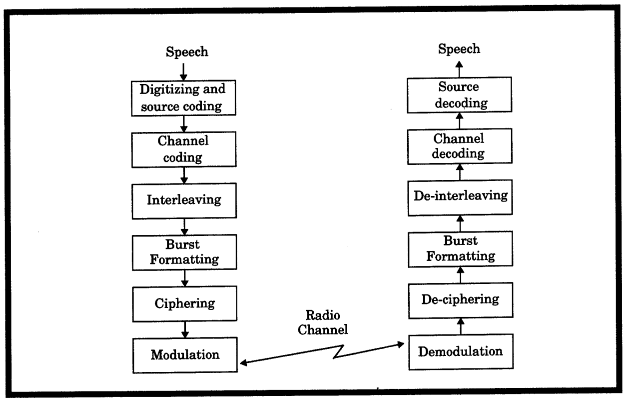

Figure 5. GSM Operations from Speech Input to Speech Output

Speech Coding: The GSM speech coder is based on the residually excited linear predictive coder (RELP), which is enhanced by including a long-term predictor (LTP) [Hel89]. The coder provides 260 bits for each 20 ms blocks of speech, which yields a bit rate of 13 kbps. This speech coder was selected after extensive subjective evaluation of various candidate coders available in the late 1980s. Provisions for incorporating half-rate coders are included in the specifications.

The GSM speech coder takes advantage of the fact that in a normal conversation, each person speaks on average for less than 40 percent of the time. By incorporating a voice activity detector (VAD) in the speech coder, GSM systems operate in a discontinuous transmission mode (DTX), which provides a longer subscriber battery life and reduces instantaneous radio interference since the GSM transmitter is not active during silent periods. A comfort noise subsystem (CNS) at the receiving end introduces a background acoustic noise to compensate for the annoying switched muting, which occurs due to DTX.

TCH/FS, SACCH and FACCH Channel Coding: The output bits of the speech coder are ordered into groups for error protection, based upon their significance in contributing to speech quality. Out of the total 260 bits in a frame, the most important 50 bits called type Ia bits have 3 parity check (CRC) bits added to them. This facilitates the detection of uncorrectable errors at the receiver. The next 132 bits along with the first 53 (50 type Ia bits + 3 parity bits) are reordered and appended by 4 trailing zero bits, thus providing a data block of 189 bits. This block then is encoded for error protection using a rate 1/2 convolutional encoder with constraint length $K = 5$, thus providing a sequence of 378 bits.

The least important 78 bits do not have any error protection and are concatenated to the existing sequence to form a block of 456 bits in a 20 ms frame. The error protection coding scheme increases the gross data rate of the GSM speech signal, with channel coding, to 22.8 kbps.

Channel Coding for Data Channels: The coding provided for GSM full-rate data channels (TCH/F9.6) is based on handling 60 bits of user data at 5ms intervals, in accordance with the modified CCITT V.110 modem standard. As described in Chapter 8 of Ste92, 240 bits of user data are applied with 4 tailing bits to a half-rate punctured convolutional coder with constraint length $K = 5$.

The resulting 488 coded bits are reduced to 456 encoded data bits through puncturing (32 bits are not transmitted), and the data is separated into four 114-bit data bursts that are applied in an interleaved fashion to consecutive time slots.

Channel Coding for Control Channels: GSM control channel messages are defined to be 184-bits long and are encoded using a shortened binary cyclic fire code, followed by a half-rate convolutional coder.

The fire code uses the generator polynomial,

$$G_5(x) = (x^{23}+1)(x^{17}+x^3+1) = x^{40}+x^{26}+x^{23}+x^{17}+x^3+1$$

which produces 184-message bits, followed by 40 parity bits. Four tail bits are added to clear the convolutional coder that follows, yielding a 228 bit data block. This block is applied to a half-rate $K = 5$ convolutional code (CC(2,1,5) using the generator polynomials $G_0(x) = 1+x^3+x^4$ and $G_1(x) = 1+x+x^3+x^4$ (which are the same polynomials used to code TCH type I_a data bits). The resulting 456 encoded bits are interleaved onto eight consecutive frames in the same manner as TCH speech data.

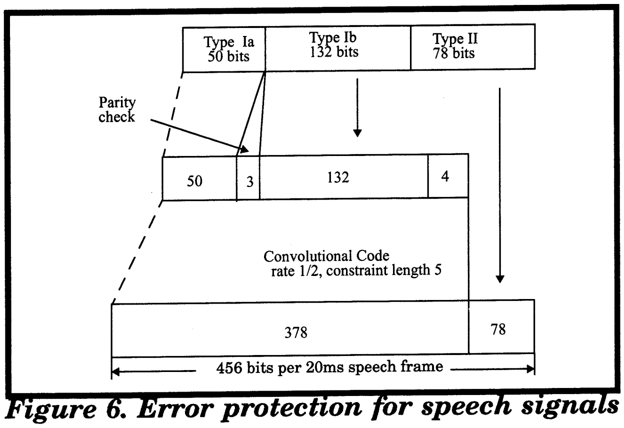

Figure 6. Error protection for speech signals in GSM

Interleaving: In order to minimize the effect of sudden fades on the received data, the total of 456 encoded bits within each 20ms speech frame or control message frame are broken into eight 57 bit sub-blocks. These eight sub-blocks, which make up a single speech frame, are spread over eight consecutive TCH time slots. (i.e. eight consecutive frames for a specific TS).

If a burst is lost due to interference or fading, channel coding ensures that enough bits still will be received correctly to allow the error correction to work. Each TCH time slot carries two 57-bit blocks of data from two different 20 ms (456 bit) speech (or control) segments.

Figure 7 illustrates exactly how the speech frames are diagonally interleaved within the time slots. Note that TS 0 contains 57 bits of data from the 0th sub-block of the nth speech coder frame (denoted as "a" in the figure) and 57 bits of data from the 4th sub-block of the (n-1) st speech coder frame (denoted as"b" in the figure).

Ciphering: Ciphering modifies the contents of the eight interleaved blocks through the use of encryption techniques known only to the particular mobile station and base transceiver station. Security is further enhanced by the fact that the encryption algorithm is changed from call to call.

Two types of ciphering algorithms, called A3 and A5, are used in GSM to prevent unauthorized network access, and privacy for the radio transmission, respectively. The A3 algorithm is used to authenticate each mobile by verifying the user's passcode within the SIM with the cryptographic key at the MSC. The A5 algorithm provides the scrambling for the 114 coded data bits sent in each TS.

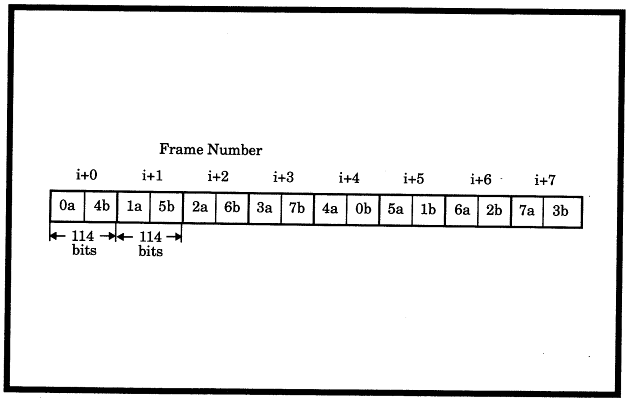

Figure 7. Diagonal Interleaving used for TCH/ SAACH/FAACH data. 8 speech sub-blocks are spread over 8 successive TCH time slots for a specific time slot number.

Burst Formatting: Burst formatting adds binary data to the ciphered blocks, in order to help synchronization and equalization of the received signal.

Modulation: The modulation scheme used by GSM is 0.3 GMSK, where 0.3 describes the 3dB bandwidth of the Gaussian pulse shaping filter with relation to the bit rate (e.g. BT = 0.3). GMSK is a special type of digital FM modulation. Binary ones and zeros are represented in GSM by shifting the RF carrier by +/-67.708 kHz.

The channel data rate of GSM is 270.833333 kbps, which is exactly four times the RF frequency shift. This minimizes the bandwidth occupied by the modulation spectrum and hence improves channel capacity. The MSK modulated signal is passed through a Gaussian filter to smooth the rapid frequency transitions that would otherwise spread energy into adjacent channels.

Frequency Hopping: Under normal conditions, each data burst belonging to a particular physical channel is transmitted using the same carrier frequency. However, if users in a particular cell have severe multipath problems, the cell may be defined as a hopping cell by the network operator, in which case slow frequency hopping may be implemented to combat the multipath or interference effects in that cell.

Frequency hopping is carried out on a frame by frame basis, thus hopping occurs at a maximum rate of 217.6 hops per second. As many as 64 different channels may be used before a hopping sequence is repeated. Frequency hopping is completely specified by the service provider.

Equalization: Equalization is performed at the receiver with the help of the training sequences transmitted in the midamble of every time slot. The type of equalizer for GSM is not specified and is left up to the manufacturer.

Demodulation: The portion of the transmitted forward channel signal, which is of interest to a particular user, is determined by the assigned TS and ARFCN. The appropriate TS is demodulated with the aid of synchronization data provided by the burst formatting. After demodulation, the binary information is deciphered, de-interleaved, channel decoded and speech decoded.

Parameter	Specifications
Reverse Channel Frequency	890 - 915 MHz
Forward Channel Frequency	935 - 960 MHz
ARFCN Number	0 to 124 and 975 to 1023
Tx/Rx Frequency Spacing Tx/Rx Timeslot Spacing	45 MHz 3 Timeslots
Modulation Data Rate	270.833333 kbps
Frame Period	4.615 ms
Users per Frame (Full Rate)	8
Timeslot Period	576.9 μs
Bit Period	3.692 μs
Modulation	0.3 GMSK
ARFCN Channel Spacing	200 kHz
Interleaving (max. delay)	40 ms
Voice Coder Bit Rate	13 kbps

Table 1. GSM Air Interface Specifications

Summary

The GSM standard is the world's first digital cellular communications standard and offers unprecedented network services for its users. Already with a four-year track record in Europe, GSM is poised for leadership in new personal communications systems being built throughout the world.

This paper has attempted to boil down the GSM standard from 15 large volumes into a tutorial that is less intimidating. As service providers strive to offer new wireless services with minimal risk and quickest time to market, we are likely to see GSM deployed in some of the new U.S. PCS systems that were licensed earlier this year.

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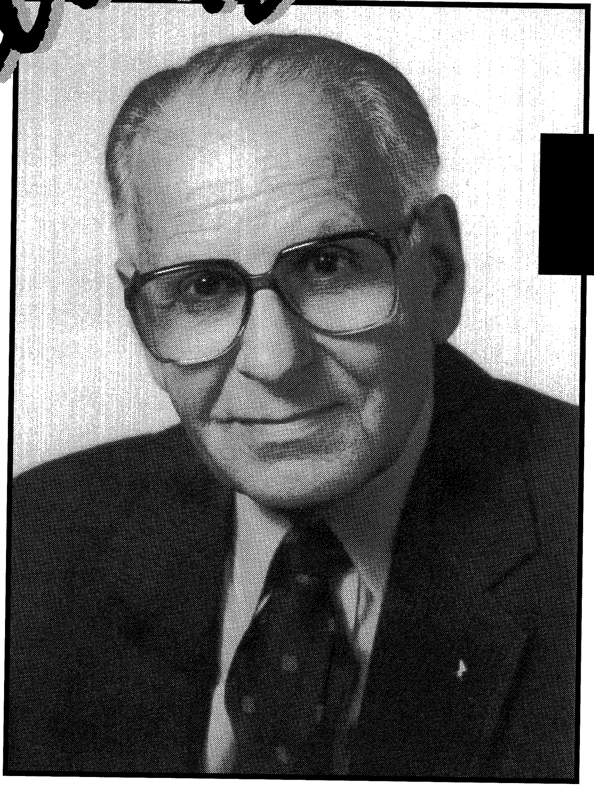
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the Radio Club
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The Global Positioning System

By Dr. Albert Helfrick, Ph.D., P.E.

One of the first radio applications, other than for communications, was for navigation. The straight line propagation and constant velocity along with the ability to penetrate clouds made radio waves the obvious choice for bad weather navigation for ships and aircraft. Since the 1920s, a wide variety of radio-based navigation aids were invented, developed and fine-tuned.

For aircraft, systems were developed that included homing beacons, low frequency range stations, VHF navigation aids for en route and landing guidance, distance measuring and a variety of radars. For ships at sea and for trans-oceanic aircraft flight, there was Loran, Shoran, Omega and Decca.

All of the radio-based navigation systems mentioned operated with terrestrial transmitting stations and relied on either ground wave or direct line-of-sight propagation. Ionospheric propagation would ruin the accuracy of the navigation as the path through the ionosphere is very predictable.

The Need For Global Navigation

Of the pre-satellite systems for long-distance navigation, about the best for accuracy is the most advanced Loran, Loran-C, which can provide about 500 feet accuracy and about 50 feet repeatability. These accuracies are obtained only with strong signals that are not available everywhere in the Loran-C coverage area. It is also necessary that the Loran-C signals not be corrupted with noise and static. In the summer in areas with high thunderstorm activity, Loran-C accuracy is compromised. Finally, there are many locations throughout the world that have no Loran-C coverage. This is particularly true over land as the Loran-C system originally was developed for ships.

The VHF and UHF navigation systems do not suffer from unpredictable ionospheric propagation and are significantly less susceptible to static due to thunderstorms. VHF and UHF propagation are primarily line-of-sight, which avoids the problems of ionospheric propagation but also prevents the navigation systems from providing long-distance coverage.

VHF and UHF are the frequency ranges used by the instrument landing system (ILS) that has been the mainstay of all-weather commercial air travel for 50 years. Because the ILS provides only one radio beam for landing guidance, one instrument landing system is required for each runway. This and the high cost of installation and maintenance makes the ILS an expensive landing aid. In the developed countries, all the available frequencies are used, and installing a new ILS is virtually impossible.

Satellite Navigation

The U.S. military needed navigation systems that could be used by any type of conveyance as well as man-pack portable that would have full global all-weather operation. It was clear that a satellite-based system would have the characteristics required for providing this navigation system. Radio transmitters in space would transmit a direct, line-of-sight signal that would be predictable. Although the signals pass through the ionosphere and troposphere, they travel a straight line from satellite to user and thus are quite predictable.

Because the propagation is direct, not requiring any interaction with the ionosphere, troposphere or ground wave propagation, the UHF part of the spectrum could be used, which would place the required signals away from the low frequency noise generated by thunderstorms.

In order to provide full global coverage, several orbits would be used for the satellites, and a number of satellites would be provided so that sufficient signals would be available around the clock.

These requirements were met by a satellite navigation system originally call Navstar and eventually expanded and renamed Global Positioning System (GPS).

GPS can be divided into three basic parts. First is the spaceborne part, which consists of 24 satellites, 21 operational and three spares, orbiting in six orbital planes inclined at 55 degrees to the equator. The second part is the user segment, which includes the GPS navigation equipment. The third segment is the control segment, which includes monitor stations that observe the satellites and control stations that transmit information to the satellites. Thus, the satellites actually are radio repeaters under control from the ground.

GPS is an example of a range-navigation system, indicating that position is determined by measuring the range to various reference points, typically the transmitter. These systems also are called rho-rho for the Greek letter rho that is used to indicate range. The Loran and Omega systems are examples of rho-rho navigation.[1.]

To be effective, a rho-rho navigation system must make an accurate measurement of range to a radio transmitter and know the precise location of the transmitter. Knowing the range to a specific location places the receiver on a sphere with a radius equal to the measured range—with the transmitter at the center of the sphere. If the transmitter and receiver were on the surface of the Earth such as a Loran transmitter and a ship at sea, knowing the range to the transmitter places the receiver on a circle because the navigation is in two dimensions. Measuring the range to a second transmitter, or in the case of GPS, a second satellite, places the user on a second sphere with the second satellite at the center. Of course, the user's position is now known to lie on a circle that is the intersection of the two spheres. This circle is called a line of position (LOP).

The use of a third satellite introduces a third sphere that produces three LOPs. Each pair of intersecting spheres produces a LOP and thus three satellites taken two at a time produce three LOPs. Where the three LOPs intersect is the receiver's location or fix in three dimensions.

Each satellite transmits a navigation message that includes the time of day along with other pertinent data. The range is measured by the receiver by simply determining the elapsed time from the transmission of the navigation message and the time of day as determined by the GPS receiver's time-of-day clock. Because the speed of radio waves is a constant, the elapsed time can be used to calculate range to the satellite.

Implementing Concepts into Hardware

Like so many engineering accomplishments, what appears so simple in theory is another matter in practice. First, the accuracy of this type of navigation system depends on the accuracy of several factors. One parameter is the position of the satellites. The system's accuracy is no better that the ability to predict the location of the satellites.

> ***"Like so many engineering accomplishments, what appears so simple in theory is another matter in practice."***

Theoretically, satellites orbiting the Earth follow a well-defined orbit. This would be true if the Earth were a perfect, homogeneous sphere, of which the Earth is neither. The satellites are placed into an orbit such that the satellites orbit the Earth exactly twice for each rotation of the Earth. Because the Earth is not a perfect sphere, the uneven pull of gravity of the Earth rotating below the satellites causes the satellites not to have exact circular orbits but to have slightly distorted orbits.

The distortions are not great when considering the satellites are almost 12,550 miles above the Earth. However, the accuracy of the satellites' positions will have a direct bearing on the accuracy of the navigation 12,550 miles away.

This is where the control segment comes into play. The monitor station can determine the amount of distortion of the orbits, parameters called ephemerides, and transmit these correction factors to the satellites, which include them in the navigation message. The user receivers now can calculate the precise satellites' positions.

When the orbit deviations become excessive, the control segment can fire retro-rockets in the satellites and restore the orbit to a more nearly circular orbit.

A second practical matter that must be addressed to make the GPS system function is the accuracy of the time-of-day clock. Radio energy travel about 1 foot in one nanosecond. If GPS is to provide navigation accuracy of a few hundred feet, a time-of-day clock with an accuracy of a few hundred nanoseconds is required for both the user receiver and the satellite.

The satellites have extremely accurate atomic clocks that can provide the necessary precision. However, providing the GPS receiver with an atomic clock is out of the question as these devices are large and extremely expensive.

An effective means is used to provide an accurate time-of-day clock for the GPS receiver. The method requires the use of a fourth satellite. Since three satellites are sufficient to provide a fix, four satellites provide four combinations of three or four independently derived fixes.

If the system had no errors due to any cause, the four points would coincide. However, the points do not coincide, and the spread is due to the contribution of all error sources. The greatest error source is the on-board clock as the typical quartz clock falls far short of the accuracy necessary to calculate the range to the satellite. The time of the on-board clock is adjusted, while the spread of points is observed. As the clock is adjusted to the exact time, the spread of points is minimized.

Before the clock adjusting is performed, the ranges calculated from the elapsed time data is called pseudo-range, meaning the range measured is not sufficiently accurate to perform any serious navigation.

To further increase the accuracy of the measured fix, corrections other than the on-board clock and ephemerides are used. The navigation message includes correction factors for a satellite's clock; information that was relayed to the satellite from the ground control segment. The GPS receiver also makes radio energy in the atmosphere. Corrections are made for the relativistic effects of the gravity field surrounding the Earth. The receiver analyzes the visible satellites and removes from the position calculation those satellites that have weak signals of which geometry does not add precision to the calculation. Finally, the receiver averages, analyzes and filters the data to arrive at the most precise position fix.

GPS calculates a fix relative to the satellites that are orbiting the center of the mass of the Earth. Because the Earth's shape is not an exact sphere, a model of the Earth is required that considers the actual the Earth's actual shape. This Earth model is based on the WGS-84 model, which was created by the World Geodetic Survey of 1984. This allows the GPS receiver to display latitude, longitude and altitude.

GPS incorporates two accuracy capabilities. The less accurate to the two is the standard position service (SPS). There is a more accurate mode called the precision position service (PPS), which only is available to military users of GPS.

The Signals in Space

The GPS satellites transmit on two frequencies by direct sequence spread spectrum. Two data streams are transmitted; one code is called the C/A code, and a second code is called the precision, or P-code. The C in the C/A code refers to coarse, or coarse range, and the A refers to acquisition.

The C/A code is clocked at a 1.023 MHz rate and has a length of 1023 clocks. Therefore, the code repeats every 1 ms. The P-code is clocked at 10 times the C/A code rate, which is a reason the P-code provides greater accuracy. The P-code is a long code, and even at 10 times the clock rate of the C/A code, the P-code would repeat every 266 days. In the GPS system, the code is reset every seven days, and each satellite uses a different part of the entire code. To frustrate unauthorized P-code use, the code is encrypted using a secret code, a technique called anti-spoofing.

The P-code is difficult to lock on because of its long repeat time. With the C/A code being much shorter, it is synchronized easily and is used as an aid to synchronizing the P-code for the PPS mode. A part of the navigation message is a "hand-off word" that tells the military GPS receiver where the P-code is in its 266-day cycle. The use of the C-code alone provides the lower-precision SPS mode of operation. One of the two operating frequencies, 1575.42 MHz, is modulated by both codes while the second frequency, 1277.6 MHz, is modulated by only the P-code.

The use of two carrier frequencies permits the GPS receiver to measure the difference in propagation time for the two frequencies. Unlike the troposphere, the velocity of radio waves in the ionosphere depends on frequency. The use of two frequencies allows the actual amount of slowing the radio wave from day to night, and as a function of sunspot activity, while the radio propagation characteristics of the remainder of the atmosphere remain relatively constant.

The use of spread spectrum allows all the satellites to use the same transmitting frequencies, while the receiver is capable of separating the satellites. The spread spectrum allows for security from unauthorized reception in the case of the P-code and provides jam resistance. The direct sequence spread spectrum also provides a precise time reference.

GPS is first and foremost a military system. The PPS is encrypted to prevent unauthorized use, but even the SPS in the hands of hostile forces concerns the U.S. military.

To prevent GPS from being used for hostile actions, a method of deliberately degrading the SPS accuracy is used called selective availability (SA). The degradation of the GPS accuracy by SA is achieved by deliberately providing false time-of-day information in the navigation message. The errors of the reported time-of-day are totally random and cannot be predicted. Therefore, the fixes tend to wander and continually show random errors.

The PPS is not affected by SA as the hand-off word and the P-code's navigation message are not affected by SA. Like all facets of GPS, the SPS accuracy due to SA is under complete control from the ground segment by setting the magnitude of the random errors. As an interesting note, during the Gulf War, SA was turned off because civilian GPS receivers were being used by American forces to make up for a shortage of military receivers.

There is a method of undoing SA's effects called differential GPS. A GPS receiver, called a reference locator, is placed at a known location. The receiver, knowing where it is, knows the correct ranges to the satellites. Using this knowledge, the receiver determines the clock error and transmits this information to the GPS user receiver. The differential GPS receiver corrects the bogus clock information and determines the fix without the error. Using this technique, accuracies of better than a few meters are possible.

This technique works best when the reference locator is relatively close to the GPS user. Even when reference locators are several hundred miles distant, the correction information is useful in reducing SA's effects. Generally, when high precision is required, such as an instrument landing, local correction information will be available. When a nearby reference locator is not available, such as in the middle of an ocean, the accuracy usually is not needed.

There have been reports of using GPS for centimeter precision, and, indeed, this is possible. Centimeter accuracy would be useful for surveying, and this is an important GPS application. To achieve this accuracy, some specific techniques are used. First is the technique of carrier phase tracking where the actual number of 30 cm carrier wavelengths between two receivers is counted. Second, measurements are made over a long period of time to allow considerable data filtering. Third, most high-precision measurements involve post-measurement processing. This involves using GPS receivers to simply record data and the actual position is calculated using a large computer after the fact. This allows the computer to include correction factors that are obtained after the fact.

> ***"Although the military had a definite need for inventing GPS, in the civilian sector, it emerged as a system looking for an application, and the applications flowed like water from an open faucet."***

There are a number of factors that prevent high accuracy GPS in aircraft. First, the aircraft is a moving platform. The presence of velocity, and particularly acceleration, makes it difficult to obtain an accurate fix. Second, an aircraft requires a three-dimensional fix, and altitude is the weakest of the three dimensions. Third, the aircraft cannot employ any post processing; aircraft must know position now. Because of the acceleration capability of aircraft, old position data is worthless. In a moving aircraft using non-differential GPS and after all the range corrections are made by the receiver and the accuracy of the Earth model are accounted for, the result is a position fix with an accuracy of 100 meters latitude and longitude and about 200 meters altitude for the SPS. In other slower platforms, improved accuracies are available. Of course, because of SA, the accuracy is under control of the Pentagon.

Using differential GPS, an appropriate tenfold improvement in accuracy is possible, and the Pentagon is removed from the equation.

GPS Applications

Although the military had a definite need for inventing GPS, in the civilian sector, it emerged as a system looking for an application, and the applications flowed like water from an open faucet.

The first applications were the obvious—essentially specialized navigation tasks. GPS receivers are used in automobiles along with moving map displays. GPS is used to track city buses, emergency vehicles, delivery trucks and other fleets. Today when a consumer calls a parcel delivery service, because of GPS and data radio, the locations of a customer's package can be stated, even in the middle of frozen Arctic tundra where the nearest benchmark may be hundreds of miles away. GPS is used to monitor the positions of marine buoys and alerts the Coast Guard when a buoy has broken free of its mooring.

After the obvious applications came the more clever applications. First, the GPS receiver provided an extremely accurate time-of-day. GPS receivers can provide an accurate frequency standard and a clock that is far superior than WWV or WWVL. With super precise time available worldwide, astronomers could coordinate observations, and other physical science experiments requiring accurate time measurements would benefit, as well.

GPS is being proposed as the basis for an airborne collision-avoidance system where every aircraft will broadcast its position on a common frequency. Aircraft simply monitor all broadcasts, and when a position is too close, the aircraft can make an evasive maneuver. GPS has been used to monitor the movement of the Earth's surface as a tool in predicting earthquakes. GPS is used to monitor the accuracy of conventional radio-based navigation systems.

What is absolutely incredible is GPS provides a level of performance that would have required upward of $50,000 of navigation equipment a decade ago and is available in a handheld receiver costing less than $500 today.

Controversies

The GPS system has a number of controversial areas. First, the Federal Aviation Administration (FAA) has shown great interest in the use of GPS for replacing the older VHF navigation systems in use today. If all aircraft navigated using GPS, the FAA could decommission all of the VHF navigation aids and realize a huge cost-savings. Using differential GPS, the GPS system's accuracy is sufficient to permit instrument landings. This would allow the existing ILS systems to be turned off and the cessation of new installations. Effectively, every airport in the world could become an instrument airport.

> ***"What is absolutely incredible is GPS provides a level of performance that would have required upward of $50,000 of navigation equipment a decade ago and is available in a handheld receiver costing less than $500 today."***

In addition, the next generation instrument landing system, which is meant to replace and improve on the ILS, the microwave landing system (MLS), has not been installed yet in any significant numbers in the United States and could be dispensed with before any additional investment is made.

These goals have brought considerable controversy. First, the GPS is owned and operated by the U.S. Department of Defense. Many countries' civil aviation authorities are not in favor of relying on another country's military for civilian air travel, particularly when that military deliberately has degraded the navigation system by SA.

The use of GPS for both en route and landing requires that differential GPS be used because of SA. The FAA is working on a wide-area augmentation system that is a differential GPS in order to make the GPS suitable for aircraft. If the FAA makes corrections available for differential GPS, there will be a situation where one government agency is deliberately degrading the GPS accuracy while another agency is undoing the degradations. This kind of government activity does not sit well with many taxpayers.

As far as using GPS for instrument landings, although there are virtually no U.S. MLS installations, there are quite a few installations in Europe. The MLS was invented in the United States and was accepted by the International Civil Aviation Organization as the international standard for future landing systems. Now, before any MLS installations are built in the United States, the system is declared obsolete and will be replaced, leaving Europe with a significant number of obsolete MLS installations. On the other hand, there are some European manufacturers that recognize the tremendous opportunity available for GPS-based systems and have jumped on the GPS bandwagon, causing frictions within Europe.

> ***"If the controversies can be resolved, GPS is capable of becoming the backbone of all navigation, instrument landings, collision avoidance, ground movement and more."***

Even in the United States, there are controversies involving GPS. A collision-avoidance system, TCAS III, has been scrapped in favor of a GPS-based system that has not been accepted internationally yet. Manufacturers which own the patents and have the technology for TACS now find they have no market for their technology, and those in the GPS industry that are recent newcomers in the aviation electronics field now are reaping the benefits.

What Is in Store for the Future?

One thing is for certain; the GPS systems is a fantastic position determination system that can be used for navigation on both sea and air, vehicle location, moving map displays and other technologies. If the controversies can be resolved, GPS is capable of becoming the backbone of all navigation, instrument landings, collision avoidance, ground movement and more. What is envisioned for the future in aviation is a fully automated system that controls aircraft from gate to gate.

Another concept that will use GPS is called free flight—where rather than using specific airways that are based on the 50-year-old VOR system, aircraft can choose practically any path that provides the quickest or most fuel-efficient path. Unless aircraft automatically are controlled, this type of flying would be an air traffic controller's nightmare. GPS would allow for continuous and accurate updating of an aircraft's position. This information in conjunction with ground-based computers and global communications can provide effective collision avoidance and air traffic control. The extremely low cost of GPS receivers would permit even the smallest aircraft to have coverage.

NOTES

1. Some navigation systems provide an angle such as VOR. When a VOR is used with distance measuring equipment (DME), the navigation is rho-theta, indicating the use of range and bearing. Even without DME, two VORs can be used to find a position by the intersection of two LOPs obtained from two angles. This method of navigation is an example of theta-theta.

Albert Helfrick, Ph.D., P.E. (LF), is an associate professor at Embry-Riddle Aeronautical University.

Book Review: "Modern Aviation Electronics" by Albert D. Helfrick

Reviewed by Jerry Minter

This is an updated revision of an earlier book published in 1984 also by Prentice-Hall. This 1994 edition has been re-arranged to include recent additions such as the GPS and EFIS systems. A brief section has been added on encoding altimeters. Also a new section on "Flight Control Systems" includes some information on autopilot basic design principles.

It is worth noting that the 1994 first edition mentioned the microwave landing system (MLS) was being installed to replace the instrument landing system (ILS). Now in 1994, it is repeated that the MLS still is being installed; however most MLSs are installed in Alaska where unfavorable terrain conditions justify the improved MLS over the ILS. In the continental United States, many improvements during the years to the existing ILS have reduced the original problems with it greatly. Furthermore the promising approach and future landing via GPS is being given weight when planning funding at this time. A good section on GPS describes in detail how the accuracy can be improved by various means. On page 185, the typical accuracy is stated as being "10 to 20 mi"—this is a typo, since the accuracy is the order of a few meters and much better when maximum correction is available.

The Russian GLONASS satellite system does not provide as complete a worldwide coverage, but mention is made of its existence.

Both satellite systems do require regular adjustment and correction of position over a period of time in order to assure maximum accuracy. The upkeep of these systems should be shared by all the actual users.

In the historical background introduction, no mention is made of dual doppler inertial navigation as used for international trans-polar flights, etc. Also no mention is made of the recent improvements offered by optical gyroscopes for navigation systems. Although every aircraft is required to have one, no mention is made of the emergency locator beacon upgrade requirements.

The introduction of Mode S transponders and the TCAS system of collision warning are described in detail. The prediction is made that all aircraft will instal TCAS as the price of the equipment comes down. At the present time, each TCAS installation in air transport aircraft costs more than the entire cost of the most smaller private aircraft.

In summary, this edition provides a useful source of aviation electronic system design and operation.

"Modern Aviation Electronics" by Albert D. Helfrick, Prentice-Hall, ISBN 0-13-097692x, 370 pages.

The Radio Club of America, Inc.

Founded 1909, New York, U.S.A.

WORLD'S OLDEST RADIO COMMUNICATION SOCIETY

APPLICATION FOR MEMBERSHIP

Date:____________________

TO: THE EXECUTIVE COMMITTEE

I hereby apply for membership in THE RADIO CLUB OF AMERICA, INC. and agree, if elected, that I will be governed by the Club's Constitution and By-Laws as long as I continue to be a Member.

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Signature

Full Name:____

(FAMILY NAME) (GIVEN NAME) (INITIAL) (CURRENT AMATEUR CALL)

Home Address: ____

(STREET) (CITY) (STATE) (ZIP CODE)

Business Address:____

(ORGANIZATION) (DIVISION)

____

(STREET) (CITY) (STATE) (ZIP CODE)

Telephones: Home (____)________________, Business (____)________________ Ext. ____________

Birthplace ________________________Date of Birth: ____________________

Education and memberships in other clubs and societies: ____________________

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In what particular branch of the Communications Art are you most interested? ____________________

Present occupation: ____

In what year did you become interested in electronic communications?____________________

Previous experience (indicate approximate dates): ________________________________

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Please list the names of two or more members to whom you are personally known and who will sponsor you. A letter of recommendation must be submitted by one of the sponsors, and entered on the reverse side, before submission to the membership chairman.

Sponsors

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Mail this application to the Membership Chairman, Mrs. Vivian Carr, at 645 Hoey Avenue, Long Branch, NJ 07740, with $25.00 entrance fee, plus $40 for three year's dues, in U.S. funds. made payable to The Radio Club of America, Inc.

(OVER)

The Radio Club of America was founded in 1909 by a group of the industry's pioneers, and is the oldest active electronics organization in the world. Its roster of members is a world-wide Who's Who that include many who founded and built the radio industry.

The Club's objectives include promoting cooperation amongst individuals interested in electronic communications and in preserving its history. The Club administers its own Grants-in-Aid Fund to provide educational scholarships from tax free contributions of the Club's members and business organizations.

The Club publishes and distributes its PROCEEDINGS twice a year.

EXTRACTS FROM BY-LAWS

ARTICLE II — ENTRANCE FEE AND DUES

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FOR OFFICIAL USE

Date Application received: ______________________________

Admitted to Membership: ______________________________

Date and Amount
of Dues Received: ______________________________

Membership Certificate
and Card issued on: ______________________________

TREASURER'S REPORT FOR FISCAL YEAR 1994

(October 1, 1993 — September 30, 1994)

REVENUES

Dues Collected & Applied	$14,243
Other Member Fees	1,136
Sections Operations - net	(840)
Banquet - net	3,878
Advertising Sales	5,758
Pins & Plaques Sales	488
Interest on General Funds	3,085
Publications Sales & Misc.	380
TOTAL Revenues	$28,128

EXPENSES

Publications	
Printing & Supplies	$4,526
Mailing Expenses	1,479
Meeting Expenses	3,124
Office Expenses	
Printing & Stationery	643
Postage	1,184
Office & Computer Expenses	556
Executive Secy & Other Admin Fees	7,500
Legal & Accounting	1,100
Pins & Plaques - net	1,622
Miscellaneous	196
TOTAL Expenses	$21,930
NET Revenues less Expenses	$6,198
Other Adjustments (net) (see note -->)	($5,980)
Net Increase in Fund Balance	$218

BALANCE SHEET

ASSETS

Inventory & Receivables	$3,351
Section & Banquet Funds	20,490
Cash in Bank - Operating	46,982
Investments - Securities	60,525
GNMA Certificates	47,680
Fed Home Loan Mtge	26,963
Putnam Fund	36,403
Fed Natl Mtge Assn	27,978
TOTAL Assets	$270,372

LIABILITIES

Prepaid Dues	$10,870
Prepaid Banquet Tix-94 Banquet	0
Prepaid Advertising	0
Fund Balances:	
Scholarship Funds - Principal	152,905
For Distribution	12,306
General Funds - Oprt'g Balance	34,355
Reserve for Oprt'g Deficits	17,511
Life Member Fund	21,780
Legacy Fund	7,457
Other Assets & Liab-Net	13,188
TOTAL Liabilities	$270,372

N.B. Other adjustments include contributions to funds, scholarships and grants awarded, earnings on funds and changes in values of investments.

SCHOLARSHIP & GRANTS FUNDS

	Capital	Available for Distribution	Totals
Opening Balance Oct. 1, 1993	$138,519	$14,081	$152,600
Contributions	14,386		
Interest Earned		9,625	
Scholarships & Grants Awarded		(11,400)	
Ending Balance Sept. 30, 1994	$152,905	$12,306	$165,211

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