# 50 Years of Microwave Communications Systems Development in the San Francisco Bay Area

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Abstract -- This historical overview summarizes the rich industrial heritage in terrestrial microwave communications systems in the Bay Area over the past 50 years. Local companies have established themselves among the world's technologically most advanced and most competitive suppliers of systems for use in telecommunications infrastructures, cellular infrastructures, and broadband wireless access. What particularly sets the Bay Area companies apart from the rest of the major global players in the same markets is the spirit and successful practice of entrepreneurship that greatly facilitates effective adaptations to changing market conditions.

*Index Terms* -- Microwave communication, technological innovation, history.

#### I. INTRODUCTION

This is a great story of technological advances, shifting market requirements and entrepreneurship, which deserves telling in more detail than can be done in this paper. It all started in the 1950s when microwave communications systems development in the Bay Area reached critical mass due to three synergistic developments: (1) the 1951 completion of AT&T's 107-station 4 GHz New York - San Francisco microwave system, (2) the post-WWII expansion of local microwave tube manufacturing into commercial products, (3) the rapid growth of the local electronics industry in a favorable entrepreneurial climate. The following decades saw rapid industrial growth and technological advances in terrestrial and satellite microwave communications systems development in the Bay Area, but the great majority of these industrial activities concentrated on terrestrial applications on which this paper focuses .

## II. BASIC TRENDS

The milestone technological advances in this market segment were "transistorization" in the 1960s, digital systems in the 1970s, synthesized frequency tuning in the 1980s, and digital signal processing with programmable digital modulation in the 1990s, accompanied by a continuing trend toward higher spectral efficiencies, more robust architectures, and the use of ever higher frequency bands. The local industry successfully adapted to the competitive large scale introduction of fiber optic transmission systems in the 1980s, by introducing new generations of digital radio systems for local access applications and mobile infrastructures. There was a mix of in-house manufacturing of key active microwave integrated circuit components and of procurement from specialized suppliers including local ones. Outsourcing and off-shoring started early and increased over time. The thrust of ongoing new systems development was consistently toward greater versatility, user friendliness, and cost competitiveness. These were of crucial importance for successful participation in the worldwide market for point-to-point microwave systems that currently amounts to approximately \$4B per year.

Systems development and manufacturing in this market segment emerged in different ways. While multiplex systems manufacturers intent on increasing their market with new products took the early lead, specialized microwave systems manufacturers soon followed and predominated. But some of the subsequent market entrants came from the government market sector or started as microwave Accelerating semiconductor device manufacturers. technological progress and the growing and shifting telecommunications market demanded corresponding changes in the existing microwave systems industry and continually attracted new entrants. As a result, a complex picture emerges that defies neat categorization and simple description. The approach chosen in this paper is therefore to follow the historical trail by highlighting key developments to the extent possible within the limited page budget.

#### III. THE HISTORICAL TRAIL

## A. The Trunk of the Corporate Tree

The historical beginning of microwave radio manufacturing in the Bay Area was in 1953 at Lenkurt Electric that was established in 1944 in San Francisco as a wireline telephone multiplex manufacturer and relocated to San Carlos by 1947. Its first radio product was a 48-channel analog 900 MHz system used by independent telephone companies, Bell System companies and pipelines. The radio product line eventually expanded to 2400 channel capacities in frequency bands through 11-13 GHz. In 1959 Lenkurt became a subsidiary of General Telephone & Electronics. GTE Lenkurt's employment in San Carlos peaked to over 4000 employees by the mid 1960s, but GTE closed this Bay Area radio manufacturing operation in 1982 while retaining for a time its Arizona, New Mexico and Texas facilities.

Significantly, Lenkurt (called "Lenkurt U" by appreciative former employees) turned out to be a fertile breeding ground for new local ventures stimulated by ever brighter prospects in microwave communications. Foremost among these was Farinon Electric, established in 1958 in San Carlos to address an unfilled niche market for narrow-band, multichannel radios. The first product line used vacuum tubes and operated in frequency bands between 72 MHz and 2700 MHz with capacities up to 36 analog channels. Farinon delivered its first all solid-state 2 GHz radio in 1965. By 1980, when the company became the Farinon Division of Harris Corporation, it had expanded the analog product line to 11 GHz and a variety of video microwave systems in the bands between 2 and 13 GHz, and introduced a first generation of digital radios in the same bands and in the 18 GHz band. New generations of point-to-point and multipoint digital radios followed in frequency bands up to 38 GHz. The current most advanced product families offer 4 to 180 Mb/s capacity and multiples thereof in frequency bands ranging from 4 GHz to 38 GHz, thus capable of satisfying a great variety of needs in the different segments of the worldwide point-to-point microwave market. In 1998 the Harris Farinon Division was renamed Harris Microwave Communications Division (MCD). By 1999 most manufacturing had migrated to Texas, and in 2002 the division's headquarters and engineering operations were moved to North Carolina, but proprietary microwave integrated circuits (MIC) engineering and manufacturing as well as MCD sales management remain in the Bay Area.

A group of Farinon executives left the company and in 1984 formed Digital Microwave Corporation (DMC), located in San Jose. It was intended to serve the domestic bypass market which appeared promising in view of the Bell System divestiture. However, Mercury Communications of the U.K. became the first major bypass customer for the first DMC product line operating in the 23 GHz band. This foreshadowed the company's future market position which is strongest in international sales. However, the major future market turned out to be in mobile infrastructures which DMC addressed with expanded product offerings in bands between 2 GHz and 38 GHz with capacities ranging up to 155 Mb/s and multiples thereof. The company started offshoring production of subassemblies from the beginning and is currently off-shoring all manufacturing except proprietary MICs, as well as substantial part of engineering. In 2002 DMC was renamed Stratex Networks.

Besides of course Lenkurt Electric, Harris MCD and Stratex Networks stand out as the two largest microwave systems suppliers in the Bay Area during the past 50 years and, coincidentally, the only survivors in the long run. Both have global presence in their markets and are among the world's technologically most advanced and most competitive companies in their business. Thus they represent the trunk of the microwave communications systems tree in the Bay Area. A number of technologically advanced Bay Area off-shoots participated in niches of the same market with apparent success for various lengths of time, but eventually exited in one way or another. While Farinon / Harris MCD and DMC / Stratex Networks had their share of ups and downs, the critical common contributor to their survival in the fierce global competition seems to be their variety of products that found a great variety of customers in a large number of countries.

## B. Branching Out

Different patterns emerged in subsequent spin-offs and start-ups, depending on the founders' different backgrounds and objectives, and on how they adapted to technological advances and changing market conditions in their pursuit of sustainable business.

The earliest amongst other spin-offs were Karkar Electronics and Western Multiplex. Both started as multiplex equipment suppliers and expanded to microwave systems, but in entirely different ways. Karkar, the second largest Lenkurt spin-off, started manufacturing carrier multiplex systems in 1960 in San Francisco, but became a niche microwave system supplier in 1980, launching a 6 GHz high-capacity 6000 channel single-sideband analog system product line and delivering it to MCI in substantial quantities until 1985 when the company was sold to General Signal and this product line was terminated. A 256 QAM modem was added to this product line for modular conversion to digital traffic.

Western Multiplex, a 1979 spin-off from Farinon, started with digital modems and analog baseband equipment for microwave radio, and in 1990 started offering a variety of point-to-point microwave systems in the 2 GHz to 6 GHz frequency range. This included the industry's first spreadspectrum radios for the license exempt 2.4 GHz and 5.8 GHz bands, and a Gigabit Ethernet bridge. The product lines expanded to point-to-multipoint and mesh networks based on the IEEE 802.11 standards (Wi-Fi). In 2002 the company merged with Proxim and adopted its name. In 2005 it was acquired by Terabeam and as Proxim Wireless its current product development includes applications based on the 802.16 standard (WiMAX). This corporate IEEE transformation exemplifies the emergence and growth of the new breed of "wireless" microwave communications systems suppliers growing in numbers in a dynamic process involving numerous start-ups and subsequent mergers, acquisitions and restructuring. More about these in Section IV.A.

P-Com, a 1992 spin-off from DMC, developed first a 38 GHz radio based on a conventional 10-14 GHz radio design, and started shipping in 1993, mostly to European mobile service providers. Additional products of the same family were introduced in the 23 GHz and 50 GHz bands. Manufacturing was outsourced. The company's international presence broadened and shipments peaked in 2000, but subsequent declining sales resulted in restructuring, downsizing and refocusing on wireless mesh routers for the license exempt bands 2.4 GHz, 4.9 GHz and 5.8 GHz. In 2005 P-Com was renamed Wave Wireless. This transformation is also in line with the predominant "wireless" orientation of microwave systems start-ups in the last decade or so.

The 1995 P-Com spin-off Netro developed along a similar path. The company's first family of digital radio operating in the 10 GHz, the 26-28 GHz local multipoint distribution service (LMDS) bands and the 39 GHz band generated substantial interest in some international markets but suffered severe demand decline in 2001, which brought about downsizing and refocusing. In 2002 Netro acquired AT&T Wireless' product line of 1.9 GHz and 2.3 GHz broadband wireless access (BWA) systems and the following year the Canadian company SR Telecom acquired Netro.

The 1998 Netro spin-off BridgeWave started in the LMDS bands but focused in 2002 on the license exempt 60 GHz band. The current point-to-point systems product line provides 100 Mb/s and 1 Gb/s capacities.

Adding to the variety of spin-offs at an early stage are California Microwave and Avantek, both emerging from Applied Technology (ATI) which served the government market. Avantek started in 1965 with a line of solid-state RF components, expanded it into the microwave range, started in-house manufacture of Si transistors and GaAs FETs, and in 1972 introduced a 2 GHz digital radio product line using these devices. It was manufactured until 1988 when this product line was sold to Telesciences, and in 1993 to California Microwave. Avantek's RF devices division was acquired by Hewlett-Packard in 1991.

California Microwave, founded in 1968, started with a product line in competition with microwave sources that originated in 1963 at the Fairchild Microwave Division which was subsequently acquired by the East Coast company Frequency Sources. The main users were Bell System companies retrofitting their 4 GHz, 6 GHz and 11 GHz electron tube systems with solid-state subassemblies, and upgrading to higher capacities. California Microwave later expanded into a variety of microwave system product lines for a variety of customers, mainly through acquisitions. After a change of management in 1997 the company started selling off business entities, changed name to Adaptive Broadband in 1999, sold its remaining microwave systems product line in 2000 and was acquired by Moseley Associates in 2001.

There were a number of additional manufacturers of point-to-point microwave systems that participated in this market in various ways and exited some years ago under various circumstances. Among these are (years indicate actual system deliveries): Kebby Microwave (1964-1968) which became Farinon Microwave, Granger Associates (!970-1992) and Granger/Telettra (1986-1991), Culbertson Industries (1971-1974), and Aydin Microwave (1990-1999).

While not a manufacturer of complete communications systems, Endwave, founded in 1992, evolved as a supplier of microwave and millimeterwave subsystems to systems manufacturers in different bands ranging from about 3 GHz to 65 GHz. Outdoor units represent the highest level of integration among the company's current products.

The above historical summaries reveal a notable outcome. Attempted competition with Farinon/Harris MCD and/or DMC/Stratex in their main markets turned out to be unsustainable. Subsequent pursuits of alternative sustainable business opportunities proceeded in two main directions: into the "wireless" market below 6 GHz, and into the millimeterwave market.

### IV. ENABLING TECHNOLOGY

Starting the development and manufacture of commercial microwave communications systems in the Bay Area was facilitated by the rapid post-WWII growth of the local electronics industry, in particular the specialized RF and microwave companies serving the military market, and the microwave tube manufacturers. Planar microwave triodes from Eimac (founded as Eitel-McCullough in 1934) and klystrons from Varian Associates (founded in 1948) were used in the vacuum tube microwave radio generations, and Varian traveling wave tube amplifiers even in some later systems using solid state components in all other active microwave functions. Varian acquired Eimac in 1964. At a later stage, when solid-state microwave devices became available, Varian and Litton Industries developed their own in-house capabilities to replace their vacuum tube products with solid-state oscillators and amplifiers, serving OEMs.

Fairchild Semiconductor started developing Si RF transistors in the late 1950s, and delivering "microwave sources" using transistors oscillators and varactor multipliers in 1965. Varian started GaAs device development in the early 1960s, and Gunn diode deliveries in 1969. Beginning in 1970, Farinon introduced Gunn diode local oscillators and 1W transmitter oscillators and amplifiers into analog and digital radios for the 6 GHz, 7 GHz and 11 GHz bands.

The first GaAs MESFET was demonstrated at Fairchild in 1967, and the company began delivering Ga As FETs in 1970. Hewlett-Packard started work on GaAs MESFETs in 1969. A succession of Bay Area spin-offs from Fairchild and Hewlett Packard ended up with three existing Bay Area manufacturers serving the commercial microwave systems market with products ranging from discrete devices to hybrid microwave integrated Circuits (MICs) to monolithic MICs (MMICs): Microwave Technology, MIMIX and Excelics. A much larger number of intermediate local spin-offs and start-ups from the 1970s and 1980s are no longer in business.

Farinon started building and using low-noise GaAs FET amplifiers in 1975 in the 2 GHz band, and power amplifiers in 1977. An in-house MIC facility was built in 1972. Farinon spin-off DMC also built an in-house MIC facility.

The ultimate example of this in-house trend is Intel's Centrino with a Wi-Fi card incorporating the transmitter and receiver functions for IEEE 802.11a, b and g operation in the 2.4 GHz and 5.8 GHz bands!

The subject of enabling technology deserves much more detailed coverage which, unfortunately, is not feasible within the limited scope of this paper.

#### V. NEW DIRECTIONS

## A. "Wireless" Systems

Substantial industrial activities in this systems category started in the Bay Area in the 1990s, stimulated by apparently attractive potential business opportunities in the 2.5 GHz multichannel multipoint distribution service (MMDS) band and in the 2.4 GHz and 5.8GHz license exempt bands. In the following years, the number of "wireless" spin-offs and start-ups exceeded by far the number of all past microwave systems suppliers in the Bay Area, but most of the entrants over the past decade or so have in the meantime exited in one way or another. Covering them in the same way as those covered in Sections III and IV would therefore greatly exceed the scope of this historical overview. It is also not necessary because this is well known recent history of a new industry segment transitioning from proprietary to standardized systems based on the IEEE 802.11 ("Wi-Fi") and IEEE 802.16 ("WiMAX") standards.

The following listing of existing "wireless" systems suppliers headquartered in the Bay Area or with local engineering and/or manufacturing activities is the result of a "best effort" search. Listed in chronological order (start-up year in parentheses): Arraycom (1992), Alvarion (1992), Gigabit Wireless (1998, changed name to Iospan in 2000, and acquired by Intel in 2002), Aperto Networks (1999), TeleCIS (2000), Tropos Networks (2000), Airespace (2001, acquired by Cisco in 2005), Aruba Networks (2002), Meru Networks (2002), Trapeze Networks (2002), Beceem Communications (2003), Firetide (2003), and PacketHop (2003). The companies in this group already covered in Section III are Proxim/Terabeam, P-Com/Wave Wireless, and Netro/SR Telecom. Apologies for any inadvertent omissions!

Significantly, 11 of the 16 listed companies were founded or acquired after the year 2000, which best exemplifies the accelerating technological progress and market dynamics. The notable acquisitions are by Intel and Cisco, industry leaders with strong leverage in the wireless systems market. Intel's Centrino is apparently the best known favorable example of such leverage in the Wi-Fi market. The company shows intent to add a WiMAX version, which can be expected to have a similarly favorable market impact. And the list of big-name companies expanding the wireless market for their own purposes is much longer, recently including Google, for example. Nevertheless, big-name wireless initiatives are not necessarily successful – remember Cometa?

The greatest challenge to independent wireless systems suppliers in the Bay Area is therefore in their pursuits of business by incorporating competitive sustainable proprietary features into standardized systems and developing advantageous applications. A major trend in progress is toward mobility in Wi-Fi and WiMAX networks. If, and when, mobility in such networks lives up to its apparent promise, market requirements could greatly exceed what the currently available frequency bands can accommodate, because plans for Beyond 3G systems aim at 100 Mb/s mobile subscriber throughput and 1 Gb/s nomadic throughput. This issue is already being addressed in the ITU-R, and requires timely attention among competing Bay Area wireless systems suppliers using the IEEE 802.16 standard. IMS 2006 Focused Session WE3G "4 GHz for 4G?" addresses one particular aspect of the issue.

## B. Millimeterwave Systems

The emergence of multi-Gigabit fiber optic systems and their inroads into the broadband access market provided attractive new opportunities for complementary or competitive millimeterwave systems that are particularly well suited for multi-Gigabit access. The first Bay Area entrant into this market was BridgeWave with a 60 GHz product line mentioned in Section III.b. In 2003 the FCC substantially enhanced the mm-wave systems prospects by approving use of the bands 71-76 GHz, 81-86 GHz and 92-95 GHz. GigaBeam, founded in 2004, entered this market in 2005 with a 1 Gb/s product in the 70/80 GHz bands and announced a 10 Gb/s product for 2006. BridgeWave is also planning products for these bands.

## VI. CONCLUSION

The highlighted 50-year history portrays the emergence of an industry sector in the Bay Area that thrives on entrepreneurship and technological innovation. Two early start-ups successfully established themselves among the world's major suppliers of point-to-point systems in the 4 GHz to 38 GHz range for use in telecom and cellular infrastructures, and private networks.

The broadband wireless access (BWA) market that started growing substantially in the 1990s stimulated an increasing number of Bay Area start-ups that successfully advance new systems development and greatly contribute to IEEE 802.11 and IEEE 802.16 standardization and to FCC initiatives for opening new frequency bands for BWA applications.

The two apparently most promising BWA pursuits in the Bay Area are toward complementarity and competition with 3G and Beyond 3G cellular systems through mobile extensions of Wi-Fi and WiMAX applications in frequency bands below 6 GHz, and toward complementarity and competition with fiber optic access systems through the use of millimeterwave systems above 50 GHz.

These activities are intensifying in an increasingly dynamic entrepreneurial environment that continuously challenges all parties involved. Fortunately, however, the overall most favorable environment of this kind is in the San Francisco Bay Area.

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