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THIRTY YEARS OF MICROWAVES IN CHINA

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Summary

This report is a brief survey of the evolution of microwave art in China through its several stages in the past thirty years. After a historical account of the Chinese microwaves, the author has endeavored to provide a cross-sectional view of the current state of the microwave art in this country. Emphasis is laid on some typical microwave systems, on microwave solid-state devices and integrated circuits, on the efforts made by the Chinese microwave people in pushing the frequency to the short millimeter or submillimeter wavelength range with a view to covering the entire electromagnetic spectrum, and on exploring novel microwave applications which appear potentially attractive and very promising. A survey of the past and the present shows that remarkable progress in microwave R&D has been made in China, despite long periods of hard times. However, it is expected that more years of assiduous effort will be required in many areas of the microwave art before the advanced standards in other parts of the world can be attained.

History of Microwaves in China

The 30-year history of the microwave art in China is, in fact, one that covers the entire course of development of this discipline in China. While conventional microwaves had come to maturity in some other countries during the post World War II years, China did not have any microwave technology to speak of until the 50's, for the simple reason that China was so seriously afflicted during the war years of 1937-1945 that the building of a domestic microwave industry was not possible. Nor was it possible to import microwave technology from the West, since China was then virtually isolated from the outside world, the only outlet being the one known as Yunnan-Burma route for war use.

The three decades since early 50's when China began to build its own microwave technology can be roughly divided into four periods: 1952-60, 1961-65, 1966-76 and 1977-82. The present report attempts to outline the main features of each period as well as some typical microwave events in China during this time.

First Period (1952-60) — Early Years of Microwaves in China.

The first period spans almost a whole decade, in which the Chinese microwave people endeavored to establish their own microwave technology and to catch up with Western countries. Progress during this decade was much influenced by the Russian system, not only in R&D, but also in education.

China set up its first radar factory in the mid-50's, which began to manufacture air-defense radars at meter-wavelength band, and then sea-shore surveillance radars. In the last few years of the decade, a number of factories were capable of manufacturing them in quantity with a considerable extension of frequency range.[1] Towards the end of the 50's, China began to build microwave relay links for peacetime communication uses. Efforts in this direction have continued to the present day.

Large-scale work on dielectric-coated and helix waveguides transmitting circular electric mode started in 1958. For field trial, an underground circular waveguide of 1 km was laid in Peking near the Institute of Electronics. At millimeter wavelengths, the average overall attenuation was found to be several dB/km, and transmission of television and picture fascimile was satisfactory.

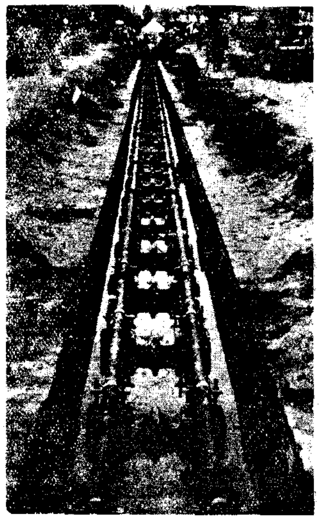

Fig. 1
Lay-out of an underground circular waveguide in Peking, 1959.

Second Period (1961-65) — Microwave R&D Continued

The year of 1961 marks the beginning of the second period of Chinese microwave history. That is the year the Russians left China. China then awoke to the importance of a self-contained microwave industry of its own, ranging from materials growth to system assembly.

This period witnessed a broad-based R&D effort by the Chinese microwave people, with some emphasis on basic theoretical studies.[2] Meantime, the advent of laser in the USA in 1960 had a strong impact on microwave study in China, with the result that many microwave people turned to the field of laser research. Interest in circular-electric wave began to wane.

An important event in this period was the founding of the Chinese Institute of Electronics (CIE) in 1963. The Society of Microwaves was formed as soon as the founding of CIE, being the counterpart of the MTT-S in the USA.

Third Period (1966-76)— Hard Years

The third period covers a whole decade when there was an interruption of scientific inquiry in China. Some intermittant efforts were made at a few microwave engineering projects during this period. Nevertheless, the loss which China suffered through the years was heavy. Most severe was loss in basic research and in education. It is all the more significant to see what great efforts have been made subsequently to catch up with progress made elsewhere.

Fourth Period (1977-82) — Recovery & Advance

The present or fourth period spans another half decade. The lesson learned from the previous decade has taught us the need to affiliate our R&D ever more closely with the world scientific community. Efforts made during the past several years have begun to bear

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fruit.

In addition to continued interest in conventional microwave art, emphasis has shifted in recent years to some modern technological areas. A general description of the microwave R&D during this period will be the subject matter under the following headline.

Present State of Microwave Art in China

For a rapidly expanding field like microwaves, it is probably impossible to enumerate all details of the state-of-the-art of the entire discipline. We shall therefore only attempt to give a description of some typical topics of the current microwaves in China. It will be seen that microwave R&D in this country follows the general pattern of the advancement of the microwave science characterized by a number of features: higher level of sophistication of the conventional microwave technology, coverage of a wider wavelength range, particularly the short millimeter and submillimeter microwaves, interdisciplinary fields formed by the union of microwaves and other branches of science, among others.

Microwave Communication

Relay Link. Conventional point-to-point microwave relay remains to be the work horse of domestic long-distance communications in China, despite the admirable realization of satelitte communication on the one hand, and of optical fiber on the other. A nation-wide relay-link system has been established which transmits information from Peking to almost all provinces across the great distances of this country. The total distance of relay communication amounts to 7500 km.

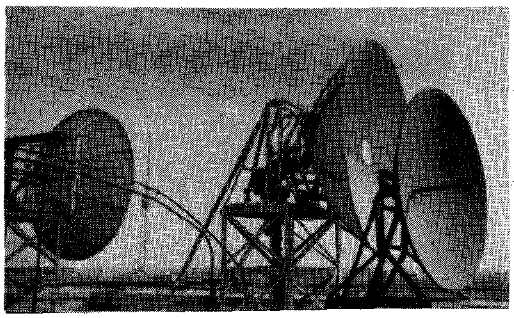

Fig.2 On top of the relay station in Shanghai

Mobile communication systems at L-band using MIC are under study in some university laboratories.

Satellite Communication. China was late in developing the satellite communication system. Research work in this field began since the early years of 70's.

Fig.3 China-made ground station in Nanking

In addition to importing some ground stations from the West, China constructed in 1975 a home-made ground station in Nanking for satellite communication, which has worked satisfactorily during these years.[3]

Satellite TV direct broadcasting is under study in Nanking, Shanghai and many other cities. Current research work is directed to the construction of miniaturized receivers. In a typical setup, the antenna aperture is 1.2 m, power consumption is 60 W and the over-all weight is 23 Kg. Received pictures and sound are clear and stable.

Radio Telescope

Three well-known observatories of long tradition are located in Nanking, Peking and Shanghai. A more recent one is in Kunmin. The Nanking observatory is featured by its R&D in mm wavelength radio telescope, useful for observing solar radiation and for measuring atmospheric absorption. The Peking observatory has constructed a compound interferometer for observing radiation from beyond the Milky Way. In Shanghai, very long base-line interferometer is used for the study of geokinetics.

A 8 mm wavelength solar radio telescope has been installed on the beautiful Purple Mountain in Nanking.[4] A newer 3.2 mm radio telescope has been completed, with sensitivity smaller than $1^{o}K$ and noise coefficient around 13 dB.

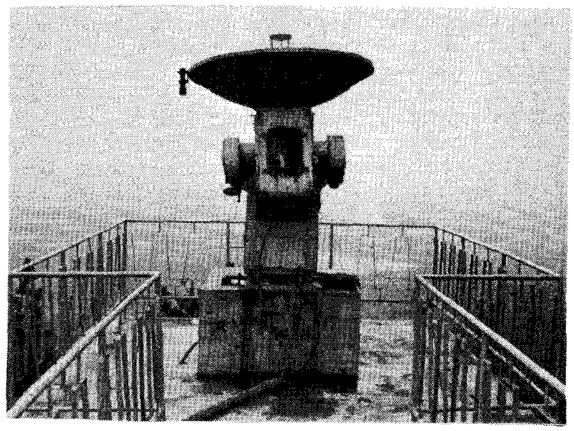

Fig.4 Radio telescope at 3.2 mm, installed on Purple Mountain

Microwave Remote Sensing

The art of remote sensing did not start in China until the middle of 70's. In recent years, a long-term research project is being carried out in the field of remote sensing at microwaves, along with remote-sensing at other wavelength bands.

Among the initial work done by various research groups in this area, design and manufacture of different kinds of radiometer are most common. Radiometers for different uses have been constructed, working from 21 cm to 4 mm.

One type of scattermeter has been manufactured at 3 cm wavelength. Another home-made device is the altimeter at 3.5 wavelength. In addition, a synthetic aperture radar has been completed recently in Peking, whose resolution for terrain objects is about 20 meters.

The remote-sensing devices have been used in measuring the atmospheric temperature and humidity, as well as in measuring the rain. Among its various applications, remote sensing for agricultural use is of particular interest in this country.

The art of remote-sensing is one of the areas in which China lags more years behind many Western countries. A major topic in this research area is advancement of the technique of image recognition relevant to remote-sensing at microwaves.

Microwave Devices

Conventional Microwave Tubes. Tubes like klystron, magnetron, TWT and BWO have reached a sophisticated level required for industrial production. This approximately equals the Western level in the early 70's.

Solid-State Devices. Major work is centered at two places: the Nanking Solid-State Research Institute and the Hebei Semiconductor Institute. A comprehensive report about their work appeared in the literature.[5] Here, it is necessary only to add some supplementary material.

For Gunn oscillators, avalanche diodes, VCO transistor oscillators, etc, the operating frequencies have been pushed to the millimeter wavelength range with advanced qualifications.

Fin-line devices have attracted the interest of many research groups in China. As a typical example, a fin-line balanced mixer at Q-band has been constructed in the University of Science and Technology of China.

Low-temperature superconductor has been under study in a few places in China. For example, in Nanking University a Josephson junction mixer without matching devices has been made at 8 mm band. Measurements at 4.2^{o}K on a Nb-Nb point contact junction yield a value of 100^{o}K for the single side-band noise temperature, and 0.8 for the efficiency.[6] At the Institute of Physics in Peking, an x-band superconducting niobium cavity has been developed recently.[7]

Microwave Integrated Circuit (MIC). The art of MIC has captured the ingenuity of a good number of Chinese microwave people. Surprisingly enough, hybrid MIC's of different forms have become rather common in many research laboratories, with different levels of sophistication.

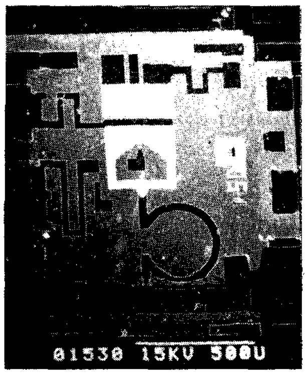

Fig. 5
GaAs Monolithic IC FET Oscillator made in Nanking Solid-State Institute

Monolithic MIC research has just started in China. Initial success has been achieved by the Nanking Solid-State Institute in making a GaAs monolithic IC FET oscillator, with an output power of 40 mW at 8 GHz, and an efficiency of 15%.

An interesting work made in Nanking Institute of Technology is a millimeter wave integrated antenna, which consists of a quasi-optic grating with an inverted strip-waveguide as the substrate.

Ferrites. Work on conventional microwave ferrite devices has come near to maturity in China during the last decade. Polycrystal ferrite devices, including circulators, isolators, phase shifters and switches, are available as commercial products, with an extended operating frequency range from 30 MHz up to 75 GHz.

Single-crystal YIG has been utilized in making tunable oscillators, gyromagnetic filters, etc. Wide-band operation remains a problem to be solved by the Chinese investigators for achieving improved device performances.

Experimental work on magnetostatic surface wave devices has been explored in Huazhong University of Science and Technology.[8]

Microwave Acoustics

SAW. This is an area which began late in China. However, during the last decade, it has become one of the most active areas in the broad field of microwave science. Many research groups have joined the work, notably the Institute of Acoustics in Peking and the Institute of Acoustics of the Nanking University.[9]

Among the early success in SAW devices, one was the pulse-compression filter. Another SAW device of practical importance, which has been handed over to factories for mass production, is the IF band-pass filter used in TV set.

Other SAW devices like multi-terminal delay lines, fixed delay lines, oscillators, etc, are being under study in several laboratories.

Bulk Wave. Research in this area has covered an extended frequency range from 100 MHz to 1 THz. A transmission-type acoustic microscope working at 100 MHz has been constructed at the Institute of Acoustics in Peking, with a resolution about 30 μm,[10] a figure lagging considerably behind that achieved by some other countries. Study of the phonon (acoustic wave at 1 THz and higher) is only at the exploratory or preparatory stage.

Optical Fiber

Optical fiber has become a common research area of the opticians and the microwave people. Large-scale work in this area has been centered in Wuhan, which is strongly supported by the Ministry of Post and Telecommunication, and also in Peking and Shanghai. Until very recently, major work has been done on short-wavelength multimode fibers. In April 1979, an 1.8 kM experimental line with a 0.85-0.9μm LED or LD source was installed in Shanghai, which transmits 120 PCM channels at 8.448 Mbit/s, with an error rate no worse than 10^{-9}. Several experimental lines of similar characteristics were installed in other places in China: Wuhan (5.7 kM, June 1979), Peking (3.1 kM, Sept. 1979; 10 kM, July 1980), etc. Generally speaking, short-wavelength multimode-fiber cable have reached a level near to commercial production, with attenuation less than 4.5 dB/km, reproducibility equal or better than 50% and bit rate about 8 Mbit/s.

Laboratory experiments on long-wavelength multimode optical fiber carried on in Wuhan Research Institute of Telecommunication, with the long-wavelength LED and LD supplied by the Chang-jiang Laser Electronics Inc., achieved low attenuation of about 0.3 dB/km in 1981. Installation of a 14.8 km field trial cable working at 34 Mbit/s has been planned to finish before the middle of 1982. The cable consists of six fibers, two of which are intended to work at long wavelengths with an average attenuation for the line (including bends, joints, etc) below 1dB/km. With a view to testing the line under a variety of severe environments, some sections of the line are laid in conduit while other sections are suspended. One section is intentionally installed to go along with the Wuhan railway bridge over the Yangtzi River for vibration test.

Single-mode optical fiber achieved initial success in Shanghai in 1980.[11] Measurements of the single-mode fiber characteristics have been carried on in the Wave Sciences Laboratory of the Shanghai University of Science and technology. A tunable Raman source for long-wavelength dispersion measurement is about to finish.

Gyrotron

China began a few years ago to build laboratories for the research of gyrotron and other related areas. This was apparently stimulated by the significant Russian breakthrough in gyrotron and the great advances made in the USA in the study of coherent scattering of electromagnetic wave by relativistic electron beam. There are now at least two gyrotron laboratories in Peking, one in Nanking and one in Chengdu. The wavelengths so far used are 8 mm, 2 cm and 3 cm.

One Peking laboratory affiliated to the Ministry of Electronics Industry has produced a gyrotron pulsed power of 100 kW at 8 mm wavelength, which is the highest power yet achieved at this wavelength in China. Another Peking laboratory affliated to the Institute of Electronics also worked on 8 mm wavelength gyrotron, which is featured by the use of H_{02} mode with a corresponding reduction of the magnetic field required.

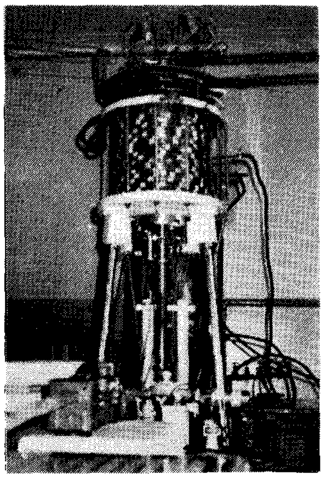

Fig. 6
An experimental 15 GHz gyrotron setup at Nanking Institute of Technology

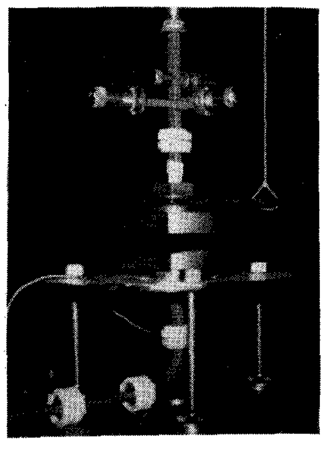

Fig. 7
An orotron under cold test at Chengdu Institute of Radio Eng.

The Chengdu Institute of Radio Engineering has built a 2 cm wavelength gyrotron, which yields pulsed power greater than 50 kW, with an efficiency around 30%. Another gyrotron working at 4 mm wavelength with superconductor magnetic field is under construction.

The Chengdu laboratory has also done research work on orotron at 8 mm and 4 mm wavelengths. Cold-test of the orotron cavity yields a Q factor higher than 10^5. Along with experiments on gyrotron and orotron, extensive work has been done in this laboratory on quasi-optics as well as on the theoretical study of the high-energy electronics.[12]

While devices like gyrotron going to higher and higher frequencies, the electromagnetic spectrum of millimeter and submillimeter waves has also been explored by quantum-mechanical means. In China, several optically pumped lasers have been constructed, since 1978, in the Shanghai Institute of Optics,[13] the Shanghai Institute of Technical Physics, the Sun Yat-sen University at Canton,[14] among others. Typical examples include methylfluoride laser yielding 3.8 mW at 496 μm, methanol laser yielding 12.6 mW at 118.8 μm and 3.5 mW at 570 μm, and HCN laser yielding 4 mW at 337 μm.

Microwave Biological and Medical Applications

This is an interzonal field which requires the combined efforts of microwave technicians, physicians and biologists. A large-scale work in this field has been done in China during the last decade.[15] CW magnetrons operating at different wavelengths, which China has been capable of manufacturing in quantity, serve as power sources required for research, and for different applications.

Microwave Biological Effects. As is known to many, birth control has been a serious problem in China. Microwave therapy, mostly applied to the male, has been used clinically in a number of hospitals in Szechwan Province and in Shanghai. According to a preliminary estimate from about 300 cases, the effectiveness of this method is well over 90%.

Microwave breeding of the seeds of wheat, rape, mulbery, etc, has been under investigation in Szechwan and Hei Longjiang. Preliminary results are found encouraging. Problems remain, however, as regards whether biological effects will happen in the later generations of the agricultural products.

Microwave Medical Applications. Physical therapy by the use of microwave radiation has been found effective for certain cases of inflammation, injury, piles, etc.

Microwave treatment of cancer has been studied in China since 1979. Microwave radiations have been applied to cancers of the breast, of the esophagus, of the bladder, of the skin, etc. The number of cases treated already amounts to 1000 in this populated country. The method has been proven useful for cancers at their early stages. For the late-stage cancers, the effectiveness is not quite for certain. Attempt has been made to combine the microwave therapy with other conventional methods to achieve better results. Linear accelerators have been in use in a number of hospitals in China.

The Chinese traditional acupuncture has been modified by the use of microwave radiation, which is directed to the acupuncture points on a patient's body via a shaped inner conductor of a coaxial cable.[16] Laser needleless acupuncture instrument has also been devised for clinical use.

The area of microwave biological research and medical application is still at its early stage in China. No breakthroughs have yet been made. Real advances in this area need more sophistication in microwave electronics art. For example, accurate determination of the temperature in the human body remains an unsolved problem. So far, most of the work has only been done experimentally. A workable microwave-biological theory is still lacking. Many investigators believe that the microwave-biological effects are essentially thermal in nature, while some others have also observed non-thermal phenomena. Indeed, the modern union of microwaves and biology presents a hard challenge to the microwave technicians, and to the physicians and biologists as well.

Conclusion

In this report, no attempt has been made to give an exhaustive account of the microwave R&D in China in the past 30 years and at the present time. Purely military applications of this science have been omitted. Moreover, limitation of space has not permitted inclusion of many interesting items which are being studied or are about to be investigated in this country, such as microwave holography, microwave industrial applications, microwave measurements, microwave material research, etc. Although the author is chiefly involved in theoretical study,[17] he has found it difficult to cover in this report the large amount of theoretical work done by his Chinese colleagues.[18]

In conclusion, it can be stated that remarkable progress in microwave R&D has been made in China during the last 30 years, despite long periods of hard times. Admittedly, however, many more painstaking years may be required to catch up with the rapid advances in other parts of the world.

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