Transnational News

Microwaves in Ukraine

■ A.I. Nosich, Y.M. Poplavko, D.M. Vavriv, and F.J. Yanovsky

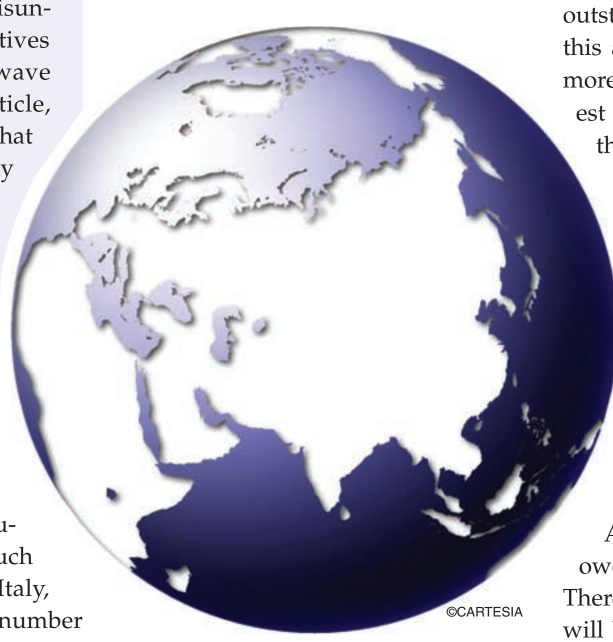
The Jubilee Issue of *MTT Transactions* (March 2002) contains no information on microwaves in Ukraine. This was a great misunderstanding. The representatives of the Ukrainian microwave community prepared an article, "Microwaves in Ukraine," that will fill this gap here. I kindly encourage you to get acquainted with this interesting and important material.

Jozef Modelski

There are several milestones in Ukrainian microwave research. The Ukrainian microwave community is comparable to that in such nations as France, Germany, Italy, and the United Kingdom in number and potential, although today it is scarcely funded. This article sheds light on the history and present state of microwave research, industry, and education in Ukraine.

Background

In 2000, Yevgeny M. Kuleshov, a Ukrainian scientist, was awarded the IEEE MTT-S Microwave Pioneer Award for the development (in 1964-1972) of hollow dielectric beamguide (HDB) technology and measuring circuits of the near- and sub-millimeter wavelength ranges [1]. He is the only European to be awarded this prestigious international prize, after 11 Americans and three Japanese, since 1990. This recognized the outstanding contribution of his team to this area of engineering science, made more than 30 years before today's interest in the terahertz range. This is but the tip of the iceberg of dozens of years of microwave R&D in dozens of laboratories in Ukraine.



However, the invited paper on microwaves in Europe, in the Jubilee Issue of the *IEEE Transactions on Microwave Theory and Techniques* [2], did not mention Ukraine at all. In part, this may be explained by the fact that the history of Ukraine as an independent nation only started on 24 August 1991. It is still overshadowed by its greater eastern neighbor. Therefore, we believe that our article will be of interest for the international microwave community.

R&D in Ukraine is concentrated in three traditional branches inherited from the Soviet Union Originally, fundamental sciences were studied in the National Academy of Sciences of Ukraine (NASU). Applications were developed in the laboratories of the ministries. Universities combined science and education. Although today the pattern

A.I. Nosich is with the National Academy of Sciences of Ukraine (NASU), Kharkov, Ukraine. Y.M. Poplavko is with the National Technical University—Kiev Polytechnic Institute, Kiev, Ukraine. D.M. Vavriv is at the Institute of Radio Astronomy NASU, Kharkov, Ukraine. F.J. Yanovsky is at the National Aviation University, Kiev, Ukraine.

is less fixed, we shall follow this traditional classification.

Universities

Today, some 10,000 Ukrainian students study microwave science and engineering in a network of state universities. Kharkov National University [(KhNU), www.univer.kharkov.ua] was established in 1804. It was a leader in the early work on *L*-band magnetrons and pulsed radars in the 1920s and 1930s. In 1952, a full-scale department of radio physics was established there. It has played an important role in developing millimeter-wave quasioptics, vacuum tubes, semiconductor devices, HCN sub-millimeter wave lasers, and spectroscopy. In 1964, Kharkov National University of Radio Electronics [(KhNURE), www.kture.kharkov.ua] was established. Today, this is the only technical university in Ukraine that specializes entirely on electronics and computers. More recently, it has been involved in R&D on lasers, optoelectronics, and wireless power transmission. The bulk of its teachers were originally with the radio-engineering department of National Technical University—Kharkov Polytechnic Institute [(NTU-KhPI), www.kpi.kharkov.ua], established in 1885. Between 1955 and 1992, the Kharkov Military University (KhMU) was better known as the USSR Military Academy of Radio Engineering. This used to be the most reputable military school for microwaves, radar, and communications. Many first-class researchers of microwave sources, antenna arrays, radar, and signal processing worked there, although their achievements were not well known, even in the Soviet Union. The department of radio physics of Kiev National University (www.univ.kiev.ua), founded in 1834, is active in semiconductor and quantum electron devices and polarimetry. The National Technical University—Kiev Polytechnic Institute [(NTU-KPI), www. ntu-kpi.kiev.ua] was established in 1898 and today is the largest Ukrainian technical university. It has had a radio-engineering department since 1952 and now also has departments of electronics and telecommunications. In the 1950s, it was famous for pioneering research on microwave klystrons, power combining, and wireless power transmission. By the 1990s, its main focus was on developing multibeam high-power vacuum sources, dielectric resonators, and phased-array antennas.

Another remarkable technical university in Kiev is the National Aviation University [(NAU), www.nau.edu.ua], founded in 1933 as a spin-off from NTU-KPI. It has a radio-electronics department, which has been involved in research on microwave avionics and remote sensing of atmospheric phenomena. The Black Sea Navy University in Sebastopol and Odessa Ecological University have been studying microwave propagation in evaporation ducts and over the sea surface. Dnepropetrovsk National University, Kharkov National Aerospace University, Vinnitsa National Polytechnic University, and Sebastopol Technical University have strong radio physics and engineering departments active in electromagnetics, solid-state electronics, and microwave applications. In the West Ukraine, the National Technical University—Lvivska Politekhnika [(NTU-LP), www.polynet.lviv.ua], which dates from 1844, has a radio-engineering department (which, since 1952, has become an institute of telecommunications and radio electronics) and long-lasting traditions of research into microwave antennas, electromagnetic compatibility, and medical engineerin g. Smaller units of radio physics, microwaves, and telecommunications exist in all the other national and technical universities, whose number is around 50, in Kiev, Lviv, Ternopil, Chernivtsy, Zhytomir, Zaporozhye, Kharkov, Odessa, Kherson, Donetsk, Simferopol, etc.

Academy of Sciences

NASU (www.nas.gov.ua) is a network of government R&D institutes employing over 40,000 staff, including 13,000 scientists, 9,800 of whom hold a Ph.D. or higher degree. There are a number of institutes that have played a key role in advancing microwaves in the Soviet Union and Ukraine. Most of them are located in Kharkov. The oldest is the Institute of Radio-Physics and Electronics [(IRE), www.ire.kharkov.ua], established in 1955 as a spin-off from KhIPT (see below). Through the 1960s to the present time, it has been active in millimeter-wave and sub-millimeter wave research and engineering, especially in vacuum electronics, quasioptical circuits, remote sensing, radar design, and numerical modeling. Millimeter-wave klystrons, magnetrons, clinotrons, and orotrons were developed here, as well as the systems for hot-plasma diagnostics, masers for radio astronomy, Doppler, noise and other radars, polarimeters, HTSC sensors, RCS testing ranges, and others. The Institute of Radio Astronomy [(IRA), www.ira.kharkov.ua] was established in 1985 as a spin-off from the IRE and has now developed millimeter-wave magnetrons and radars for meteorology and remote sensing. The Institute of Low-Temperature Physics and Engineering [(ILTPE), www. ilt.kharkov.ua] has developed a series of multipurpose microwave devices based on superconductivity and Joseffson's effect. The Institute of Ionosphere (II) is a smaller laboratory, developed in 1994 as an offshoot from NTU-KhPI. It has a unique field facility for microwave sensing. The Donetsk Institute of Physics and Technology (DIPT) has been involved in research of microwave ferrites and other magnetic effects and applications. The new Institute of Applied Physics in Sumy and the Institute of Electron Physics in Uzhgorod are involved in beam physics research, including the de-

Figure 1. *Single-antenna L-band pulsed radar "Zenit," developed in UIPT (1938-1943).*

velopment of microwave sources and sensors. In Sebastopol, the Institute of Marine Geophysics studies wave propagation over the sea surface. There is a remarkable cluster of NASU institutes in Kiev, although they are more related to other engineering sciences and physics. Among them, the Institute of Semiconductor Physics (www.isp.kiev.ua), founded in 1960, is very active in semiconductor devices for microwaves and optoelectronics. The Institute of Physics (founded in 1929, www.iop.kiev.ua) has been involved in tunable lasers and solid-state microwave sources and receivers. The largest NASU institution in the West Ukraine is the Institute of Physics and Mechanics [(IPM), www.ipm.lviv.ua], founded in 1951 in Lviv. It is active in microwave theory, optoelectronics, nondestructive testing, and radio astronomy. The Scientific Council of NASU on Radio Physics and Microwave Electronics, currently headed by the director of the IRE, is coordinating NASU policy in the broad area of microwaves.

Other Government and Public R&D Organizations

The National Scientific Center— Kharkov Institute of Physics and Technology [(NSC-KhIPT), www.kipt.kharkov.ua] was founded in 1929 as UIPT. Before 1992, it belonged to the U.S.S.R. nuclear industry and used to enjoy generous funding. Its main profile was connected to charged particle accelerators and plasma science and technology. Today, it is the national center of nuclear science and technology and consists of several semi-independent units. One of them is the Institute of Plasma and New Methods of Acceleration, a key laboratory for developing plasma-filled high-power microwave sources.

Another application of microwaves is in compact accelerators of electrons, ions, and protons based on various principles. The National Space Agency was created in 1992 to manage the heritage of the U.S.S.R. space industry, and capacities remained in Ukraine. It operates a Center of Remote Sensing jointly with the IRE and a Center of Space Facilities Control and Testing in the Crimea, jointly with the IRA and other organizations. The Molniya Institute was established in Kharkov as the first U.S.S.R. center of research in electromagnetic durability and compatibility of electronic systems. It has a huge countryside testing range equipped with various EMP simulators. In Kharkov, there is also the Institute of Radio Measurements, which originally related to the U.S.S.R. ministry of space industry and is now a joint-stock company. It works on microwave antennas, space-borne radars, remote sensing, and biomedical applications. The Institute of Metrology is responsible for national standardization in the area of microwaves. There is a cluster of R&D centers in Kiev that formerly belonged to the U.S.S.R. ministries of radio industry, electronic industry, and communications. Here, a major national center in GaAs technologies is the Saturn Institute (www. jssaturn.kiev.ua), which was founded in 1968, has been a joint stock company since 1994, and is a huge complex of research laboratories and clean production lines involved in the development and production of communication systems, microwave ICs, and microwave and millimeter-wave transmitter-receiver modules. The Orion Institute is well known for the development of advanced microwave and millimeter- wave solid-state devices and systems, vacuum sources, and radars. The Buran Institute is famous for a family of microwave airborne weather radars developed in the 1980s and 1990s in collaboration with experts of the NAU. The Kvant Institute was involved in maritime radar developments and applications. In Lviv, a remarkable laboratory is the Institute of Radio Engineering, formerly with the U.S.S.R. ministry of radio industry (founded in 1956). Since the 1970s, it has been active in R&D for millimeter-wave and sub-millimeter wave radars and imaging systems.

Industry

One of the major microwave application establishments is the Design Bureau Yuzhnoye. Associated with Yuzhmash Industry in Dnepropetrovsk, it is one of the three largest rocket and missile manufacturing sites in the former Soviet Union (along with Energiya and Khrunichev, near Moscow). It supervised the design of microwave sensors and radars for the Ukrainian Earth-observation satellite Sich, launched in 1996 in Russia by a Ukrainian booster. Today it participates in the international project “Sea Launch,” together with Russia, Norway, and the United States, which has already placed several satellites in orbit. The Generator Industry in Kiev produces a variety of high-power vacuum tubes for industrial and other applications. The Topaz Industry in Donetsk has recently entered international markets with a brand-new broadband Kolchuga electronic intelligence station and Pogonya countermeasure station. Design Bureau Nezhinskoye, in Nezhin, has developed optoelectronic sensors and now offers Kvitnyk self-guided artillery shells for sale. The Radar Industry in Kiev is known for the production of wideband airborne weather and navigation radars. The Znamya Industry in Poltava manufactures microwave and millimeter-wave TWTs with very attractive characteristics, including low-noise amplifiers.

Microwave Chapters and Conferences

There are four joint chapters of the IEEE MTT-S in Ukraine: AP/ED/MTT/CPMT SSC West Ukraine in Lviv (since 1995); AP/NPS/AES/ED/ MTT/GRS/EMB East Ukraine in Kharkov (since 1995, www.rocket.kharkov.ua/~eua chapter); ED/MTT/ CPMT/ COM/SSC Central Ukraine in Kiev (since 1998); and CAS/IM/C/MTT Vinnitsa in Vinnitsa (since 1999). The largest are East Ukraine, which has 50 members and dozens of students, and West Ukraine, which has 32 members and 22 students. It became the 2001 Chapter of the Year in Region 8 in the category of “small and middle size chapters.” Two other chapters have around 15 members each. Each year, chapters hold a number of workshops and conferences. The main meetings are as follows.

The Kharkov International Symposium on Microwaves, Millimeter and Sub-millimeter Waves (MSMW) has been held once every three years since the 1980s in Kharkov by the Scientific Council of NASU on Radio Physics and Microwave Electronics and the IEEE East Ukraine Chapter. The main organizations behind it are the IRE, IRA, and

KhNU. Since 1998, it has been conducted in English and enjoys permanent technical cosponsorship of the IEEE MTT and ED Societies, URSI, INTAS, and STCU. There are usually around 300 people in attendance, including some 20-30 invited speakers and participants from the West. The next symposium will be held 20-25 June 2004.

The International Conference on Mathematical Methods in Electromagnetic Theory (MMET) is held biennially by the IEEE East Ukraine Joint Chapter in collaboration with IRE and Ukrainian URSI Commission B. Since 1990, it has been conducted in English. It is technically cosponsored by the IEEE AP, MTT, ED and NPS Societies, and URSI. There are usually 200 people in attendance, including some 30-40 invited speakers and participants from the West. The next conference was held 10-13 September 2002 at the NTU-KPI in Kiev.

The International Workshop on Direct and Inverse Problems in Electromagnetic and Acoustic Wave Theory (DIPED) is organized every fall in Lviv or Tbilisi by the IEEE West Ukraine and Georgia Joint Chapters. The working languages are Russian, Ukrainian, and English. It enjoys technical cosponsorship of the IEEE ED-S. The most recent one was held in Tbilisi 10-13 October 2002.

The Crimean Microwave Conference (CriMiCo) was first held in the mid-1990s by the joint efforts of the Sebastopol and Moscow communities. It is now co-organized by the IEEE Central Ukraine Joint Chapter and the APS Moscow Chapter. It is held every September at the Sebastopol Technical University. Its language is basically Russian, although Western speakers present papers in English.

Historical Sketch

Early Magnetrons and Radars

Research into microwaves was initiated in Ukraine in the 1920s by Abram Slutskin (1881-1950) at KhNU. In 1924, he succeeded in generating magnetron oscillations with 7.3-cm wavelength. By the end of the decade, his studies led the world in this area. After 1929, this work was greatly expanded and intensified when the the Ukrainian Institute of Physics and Technology (UIPT, now NSC-KhIPT) was established in Kharkov, then the capital city of Ukraine (till 1934). There, Slutskin obtained his second job, as a head of the Laboratory of Electromagnetic Oscillations (LEMO). His team designed and studied both CW and pulsed magnetrons: water-cooled, not cooled, packaged, in glass and metal cases, tunable, etc. Their success attracted the attention of the military, which was quite timely not only because of the pre-war circumstances but also because defense projects could save the team from the Orwellian political purges of the late 1930s. Based on the successful source development, in 1935 Slutskin started an ambitious project, developing the first-ever three-coordinate *L*-band pulsed radar with a working wavelength of 60 cm. At that time, existing systems were able to determine only two coordinates of targets, and it was far from clear that *L*-band and the pulse method would be more promising. A two-antenna radar was designed, fabricated, and tested. However, at first the purges that smashed UIPT after 1937 slowed down the work. Then WWII and the defeat of the Red Army in Ukraine disrupted the plans, and no radar was put into serial production. Before Kharkov was lost, the LEMO team had been evacuated to Central Asia, where it managed to design a sample single-antenna pulsed radar with advanced characteristics (Figure 1) that was used for sea and air surveillance in the Arctic region. This history has been published in [3].

Millimeter-Wave Vacuum Tubes

After WWII, magnetron research continued, with the emphasis on developing more powerful sources of shorter waves. These works concentrated in the IRE after its branching off from UIPT in 1955. They resulted in a series of millimeter-wave magnetrons designed in the mid-1960s by Ivan Truten (1909-1990). In particular, his research of higher-frequency sources led to the discovery, in 1945, of the spatial-harmonic magnetron (SHM), which does not use the conventional π-mode for operation. The operation mode of SHM was later called "the Kharkov-type mode" in U.S.S.R. literature. The innovations introduced in the SHM enabled one to considerably reduce the permanent magnetic field magnitude and the dimensions of the magnetron cavity. As a result, millimeter-wave magnetrons were designed having champion power (e.g., pulse power of 100 kW at the wavelength of 4 mm) [4]. By the 1990s, this technology had been lost in the IRE. However, millimeter-wave magnetrons had been reborn in the IRA, where marketable SHMs with cold-cathode are now produced for the frequencies of 36, 94, and 140 GHz [5].

In the early 1950s, Semion Tetelbaum (1905-1958) at the NTU-KPI proposed a high-power vacuum tube that can be considered as a prototype of today's gyrotron. It was based on the interaction of an electron beam with a nondelayed microwave field.

Other tubes that had been actively developed in the 1950s through the 1970s were klystrons and BWOs. This work was concentrated in the IRE, Orion, and the NTU-KPI. Grigory Levin (1910-1997) of the IRE proposed an original version of BWO called "clinotron" [4], [6], where an electron beam was scattered on a diffraction grating. The clinotron is characterized by a high CW power level (say, 2 W at frequencies around 140 GHz) while retaining other advantages of BWO [7]. The klystron activities in IRE were directed by Alexander Usikov (1904-1995) and resulted in the development of millimeter-wave and sub-millimeter wave tubes [4] superior to those produced in other labs around the word.

In the 1960s, rapid development of millimeter-wave technologies and lasers brought to life a completely new vacuum electron tube: the orotron, known also as the diffraction radiation oscillator (DRO), which was famous for extremely high stability of oscillations. This was achieved due to the use of a very high-Q open resonator as an oscillation contour. One of its reflectors is periodically grooved, either completely or in part, which causes electron beam radiating. Petr Kapitsa (Nobel Prize winner) was the first to propose the idea of the orotron in 1963; however, this was triggered by a theoretical study, done in KhNU, on the Smith-Purcell radiation of

Figure 2. *Quasi-optical LEGO-like kit for a sub-mm wave engineer (1971). HDB-based components developed in IRE NASU for building wideband (λ = 0.5-1.7 mm) measuring circuits. Left to right from top to bottom: polarization attenuator, polarization phase shifter, tunable attenuator/power divider, polarization plane rotator, wave meter, polarization transformer, tunable phase shifter, matching unit, beam splitter, a cassette of polarization discriminator, linear polarizer, right-angled bend, movable two-facet reflector, rotary joint, termination load, movable reflector, two waveguide-to-beamguide transformers, telescopic section, straight section.*

a modulated electron beam moving over a periodic grating. Therefore, later on, intensive theoretical and experimental research on the orotron was conducted in Kharkov and Moscow in parallel. In the IRE, this work was directed by Viktor Shestopalov (1923-1999) and resulted in a series of small power tubes of the whole millimeter-wave band [8].

Wireless Power Transmission

This challenging research was initiated by S. Tetelbaum at NTU-KPI in Kiev. In the early 1950s, he worked on power combining of several klystrons, with application to a microwave city trolley bus for public transportation. His impact as a talented teacher was tremendous. One of his students was Yevgeny Kuleshov, a future IEEE microwave pioneer. A new stage of R&D came in the 1980s, when several types of rectennas were proposed in NTU-KPI and KhNURE for possible use in solar power satellite technology.

Sub-Millimeter Wave Quasi-Optics

A very important and well-funded direction of R&D in the Soviet Union was in the areas of thermonuclear and plasma science. Here, one of the major technologies was the Tokamak principle. To learn how to stabilize this fusion machine, some sort of hot plasma diagnostics was needed. This could be done by using millimeter and sub-millimeter waves for probing the plasma and measuring the characteristics of the reflected signal. Therefore, starting from the late-1950s, a special laboratory was engaged in the IRE for developing sub-millimeter wave technologies. Very soon it was realized that quasi-optical principles should be used. Based on them, Yevgeny Kuleshov (born in 1922) designed, in the mid-1960s, so-called ribbed hollow-dielectric beamguide (HDB) technology (Figure 2) [1], [9]. The latter happened to be very promising and enabled him to develop complete sub-millimeter systems, such as multichannel interferometers, for Tokamaks. This was well before all modern trends in terahertz technologies. It was no surprise that Kuleshov was awarded a very prestigious IEEE MTT-S Microwave Pioneer Award in 2000. From the 1970s through the 1990s, HDB technology was also used in the design of quasi-optical antenna-feeding circuits for 2-mm band battlefield radars and miniature RCS testing ranges [10]. In such a system, a downscaled model of a studied target is placed inside HDB, and the polarization scattering matrix of the mode HE11 is measured to simulate the free-space scattering.

Meteorological Radars

In the 1960s and 1970s, important research into clouds and precipitation was conducted in the radar laboratory of the Ukrainian R&D Institute of Hydro-Meteorology in Kiev. This research was spearheaded by Volf Muchnik (1912-1986), who designed an *X*-band weather radar Meteorolog for accurate measuring of rainfall [11]. Then, an NAU radar laboratory developed various methods for detection of dangerous atmospheric phenomena with conventional, Doppler, and Doppler-polarimetric radars [12]. In the 1980s, NAU experts supervised the development of weather radars Groza-M, Buran, and MNRLS-85 that became standard airborne equipment of the Tupolev, Ilyushin, Antonov, and Yakovlev airliners. These radars were designed in the Buran Institute and were put into serial production at The Radar Industry in Kiev. Today, the Antonov-140 medium-range, medium-capacity jetliner is assembled in Iran, equipped with *X*-band weather radar Buran A-140 (Figure 3). This monoblock (antenna-transmitter-receiver) digital radar is remarkable for scanning in both horizontal and vertical planes and provides automated navigation mapping [13].

In the 1990s, activities were initiated at IRA to meet the demand for high-resolution, high-sensitivity cloud radars. Both 36- and 95-GHz Doppler polari-

Figure 3. *Outdoors photo of the 36-GHz cloud radar developed in IRA NASU in collaboration with METEK, Germany (2000).*

metric radars have been developed [14]. These systems provide long-term, unattended operation at remote locations and can be accessed via the Internet. It is remarkable that the 95-GHz system is the first ever coherent-on-receiver Doppler radar with a magnetron source. Here, a smart digital signal processing technique is the key to successful performance. So far, no other comparable instruments have been designed in Europe.

Remote Sensing with Side-Looking Radars

By the 1980s, remote sensing from Earth observation satellites became the cutting edge of microwave science and technology. The Soviet Union tried to cope with the needs of its economy by transferring some innovations to the civil sector. One such application was the detection of cracks and channels in Arctic Sea ice for safe cargo navigation. In the IRE, the department of remote sensing, headed by Anatoly Kalmykov (1936-1996), developed the first space-borne *X*-band side-looking radar (SLR). Equipped with an original deployable 12-m slotted-waveguide antenna, it was placed in orbit onboard the Kosmos-1500 satellite in the fall of 1985. Immediately after launch, it proved to be invaluable when a caravan of freighters was blocked in the East Siberian sector of the Arctic Ocean. Orbital SLR was the only instrument available to rescue the caravan because it could operate in the nighttime polar conditions. The following year, the story almost repeated itself in the opposite hemisphere. The science ship *Somov* was sent to change a team of scientists at one of the U.S.S.R. Antarctic stations but became trapped by the ice. Again, it was the orbital SLR of Kosmos-1500 that saved the ship by providing microwave images of the ice fields necessary to guide a rescue icebreaker. Later, this technology was released to the industry and used in a series of Earth observation satellites, Okean. Today, Ukraine is proud to have its own satellite, Sich (launched in 1996 and still operational), equipped with a variety of sensors, including microwave SLR and millimeter-wave radiometers. A copy of the first SLR is on display at the IRE.

In the 1990s, research in this area was extended due to activities in the IRA, where onboard dual-frequency (36 and 95 GHz) SLR with an SHM source was developed and put into operation [14]. This work continues now toward the development of sophisticated SAR systems.

Radio Telescopes

The Ukrainian microwave community is proud of several remarkable radio telescopes. They include the Ukrainian T-shape radio telescope (UTR-2), the largest in the world, operated at decameter wavelength and located near Kharkov. The collective area of the UTR-2 is 150,000 m^2, and the resolution is about 40 × 40-ft at the middle frequency 16.7 MHz. In the 1970s, wide-scale research was started in the broad area of radio astronomy, headed by Semion Braude (born in 1911) [15]. Among the objects studied was Jupiter radiation, solar storms, quasars, galaxies, and other objects. Today it is managed by the IRA and has the status of the "National Scientific Instrument" of Ukraine. Since 1973, a radio-interferometer URAN, based on five radio telescopes in the east, west, and south of Ukraine, is operational. The telescope, located in the west Ukraine, is managed by IPM NASU. It has a variable arm and can be additionally used as an ionosphere-sensing facility. In the 1980s and 1990s, IRA designed and built several microwave and millimeter-wave reflector-type radio telescopes.

The RT-22 telescope in Simeiz, belonging to NASU, is another famous instrument built in the 1970s and capable of performing astronomical observations in a wide frequency band up to about 140 GHz. This capability is provided by a unique 22-m dish antenna with high-precision steering mechanics and sensitive receivers.

The Center of Space Facilities Control and Testing was used since the early 1970s as the U.S.S.R. deep space communication center. It possesses a cluster of telescopes and radars near Yevpatoriya, including radar with a 70-m antenna dish, a multireflector array of smaller dishes, and others. Originally, they were used to control the spacecraft traveling to Mars and Venus and also for planet probing and microwave mapping. Today, the opportunities provided by this complex are in little use as Russia relies on its own instruments for space communications.

Conclusion

This review is probably not complete and may be extended. Additional references and other information can be found on the Internet. We also invite our colleagues to send their comments.

However, even this quick glance of the history and state of microwaves in Ukraine shows that this area is well developed and has great potential. One should keep in mind that Ukrainian science is a part of the former U.S.S.R. system of state science. It is quite clear that research into microwaves was mainly oriented to defense applications. In the new conditions of a transfer-to-market economy and the demilitarization of R&D, Ukrainian science still has to find a proper way of reforming itself. Today, the balanced part of the Ukrainian state budget is only US$12 billion and R&D is scarcely funded, at a 0.2% level. To attract investments, several technoparks opened after 2000 in NTU-KPI, and some NASU institutes offer a relaxed taxation regime for innovative business activity; however, their impact is still small. Therefore, the international community plays a significant role through several foundations and collaboration programs, such as Soros-ISF (now closed), EU-Copernicus, INTAS, NATO Science for Peace, USA-CRDF, and through university interlaboratory programs. Since 1993, the Science and Technology Center in Ukraine (www.stcu.kiev.ua)—a foundation funded by the EU, USA, Canada, and Japan—provides moderate research grants in physical and engineering sciences allocated on a competitive basis. The main objective of STCU is to prevent the spread of weapons of mass destruction by providing scientists and engineers from Ukraine (and, since 1998, Georgia and Uzbekistan) opportunities for employment on peaceful scientific projects. For example, in June 2002 its Board granted almost US$6 million for several dozens of research teams. Other sizable sources of support are the projects funded by the third-world countries that try to develop modern sciences and sensitive technologies at minimum cost and who turn to Ukraine as a place of available prototypes. All this shows that Ukrainian science, as well as Ukraine itself, underwent painful but necessary transformations. The Ukrainians hope to eventually join Europe both economically and politically. In the case of positive development, Ukraine's contribution to microwave technologies may quickly obtain a much greater impact.

Acknowledgments

The authors acknowledge helpful information provided by M.I. Andriychuk, V.V. Belkin, F.V. Kivva, A.A. Kostenko, V.I. Naidenko, and Z.T. Nazarchuk.

References

[1] "Awards," *IEEE Microwave*, vol. 1, p. 75, Mar. 2001.

[2] R. Sorrentino, T. Oxley, G. Salmer, A.V. Vorst, L.P. Ligthart, P. Russer, G. Gerosa, G. Pelosi, J.B. Andersen, A.V. Raisanen, E. Kolberg, J. Modelski, O.G. Vendik, I.B. Vendik, T. Bercelli, M. Salazar-Palma, J. Costa Freire, and N. Uzunoglu, "Microwaves in Europe," *IEEE Trans. Microwave Theory Tech.*, vol. 50, pp. 1056-1072, Mar. 2002.

[3] A.A. Kostenko, A.I. Nosich, and I.A. Tishchenko, "Development of the first Soviet 3-coordinate L-band pulsed radar in Kharkov before WW II," *IEEE Antennas Propagat. Mag.*, vol. 43, pp. 28-49, Jun. 2001.

[4] A.Y. Usikov, "Works in radio engineering, radio physics, electronics and communications in Ukraine for the past 60 years" (in Russian), *Radiotekhnika* no. 12, pp. 5-14, 1982.

[5] V.D. Naumenko, K. Schünemann, and D.M. Vavriv, "Miniature 1 kW, 95 GHz magnetrons," *Electron. Lett.*, vol. 35, pp. 1960-1961, 1999.

[6] A.Y. Usikov, Ed., *Electronics and Radio Physics of Millimeter and Sub-Millimeter Waves* (in Russian). Kiev, Ukraine: Naukova Dumka, 1986.

[7] G.Y. Levin, et al., *The Clinotron* (in Russian). Kiev, Ukraine: Naukova Dumka, 1992.

[8] V.P. Shestopalov, Ed., *Diffraction Radiation Oscillators* (in Russian). Kiev, Ukraine: Naukova Dumka, 1991.

[9] A.A. Kostenko, A.I. Nosich, and I.A. Tishchenko, "Quasi-optics of near-mm and sub-mm waves in IRE-Kharkov in the 1960-70s," in *Proc. European Microwave Conf. (EuMC-02)*, Milan, 2002.

[10] V.K. Kiseliov, T.M. Kushta, and P.K. Nesterov, "Quasioptical waveguide modeling method and microcompact RCS range for the mm and sub-mm wave bands," *IEEE Trans. Antennas Propagat.*, vol. 49, pp. 784-792, May 2001.

[11] V.M. Muchnik, *Physics of Thunderstorm* (in Russian). Leningrad, Russia: Gidrometeoizdat, 1974.

[12] F.J. Yanovsky and L.P. Ligthart, "Microwave remote sensing of dangerous meteorological phenomena," in *Proc. Int. Conf. Microwaves (MIKON-2000)*, Wroclaw, Poland, 2000, vol. 3, pp. 70-82.

[13] V.V. Belkin, V.P. Dzubenko, and F.J. Yanovsky, "Automatic forming of the earth surface map with airborne weather radars," in *Proc. Int. Conf. Land Use and Cover Change Dynamics (LUCCD-2001)*, Beijing, China, 2001, pp. 105-116.

[14] D.M. Vavriv, et al., "95 GHz Doppler polarimetric cloud radar based on a magnetron transmitter," in *Proc. Euro. Microwave Conf. (EuMC-02)*, Milan, Italy, 2002.

[15] S.Y. Braude, "Decametric survey of discrete sources in the northern sky. The UTR-2 radio telescope," *Astrophys. Space Sci.*, vol. 54, pp. 3-36, 1978.