Microwave radiometric and antenna systems for mapping of atmosphere and underlying surface

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Abstract – Application of microwave imaging systems significantly raises their efficiency in comparison with one-dimensional remote sensing systems. Microwave imaging systems can be used for the following applications: detection of forest fires and effective fire-fighting, monitoring of soil moisture especially during sawing periods, determining of moisture characteristics of an atmosphere in the process of weather modification, determining of optimum traffic of ships in Arctic regions due to reception of an ice distribution and state map and many other. For radical reduction of system cost in some cases it is possible to use commercially available satellite TV LNB and communication down-converters of C, S, K_u and K_a bands. Variants of imaging systems with the use of Luneberg lens and long focus reflector are presented. Simulated characteristics of multibeam antennas are given in the report as well as receiver array prototypes.

Keywords: atmosphere and underlying surface mapping, multibeam antenna, focal plane array, Luneberg lens, radiometer, remote sensing.

1. INTRODUCTION

It is generally known, that the application of the VHF-systems for mapping significantly increases their efficiency as compared to the application of systems which use traced or elevation cuts. As an example it is possible to present the well known complex of Nimbus 5 [1] or more modern MICCY system for microwave cloudy mapping [2].

Figure 1. Scanning antenna system installed at airplane-laboratory ILT-18

NIC DZA and SPbSPU developed a similar scanning antenna system installed at airplane-laboratory ILT-18 (Fig.1) [3] and a scanning system of L-range for helicopters (Fig. 2). Such systems being installed on the satellites are able to produce small scale mapping of the underlying surface including ice situation in the Arctic, humidity of soil etc. Large scale mapping with the same systems is done from airplanes for regional needs.

Figure 2. Scanning system of L-range for a helicopter

All above mentioned systems are scanning systems with the unique antenna and receiver that determine high cost and limit their application in spite of their efficiency and usefulness.

Last years VHF electronics made an enormous technological step ahead due to wide spreading of the direct TV satellite of Ku, C and S bands, mobile satellite communication and mobile telephony (L-range). As a result high-quality components and whole blocks appeared which can be used to manufacture inexpensive radiometers in the same bands. This progress may be successfully used to build multibeam antennas with receiver arrays. It is possible to use spherically symmetric Luneberg lens as a multibeam antenna [4].

2. MODERN STATE OF PROBLEM

2.1 Luneberg lens

The refraction coefficient of a spherical Luneberg lens is permanently varied along the lens radius. Due to central symmetry we can form a few independent beams with several feeds (Fig.3) or scan a beam in a wide angle sector with a single light feed which moves along the spherical surface.

In recent years we have seen progress in technology of Luneberg lenses due to appearance of inexpensive low loss dielectric materials [5]. Parameters of Luneberg lenses produced by

Konkur Co. are given in table 1. Most of lenses presented in table 1 are suitable for airborne applications.

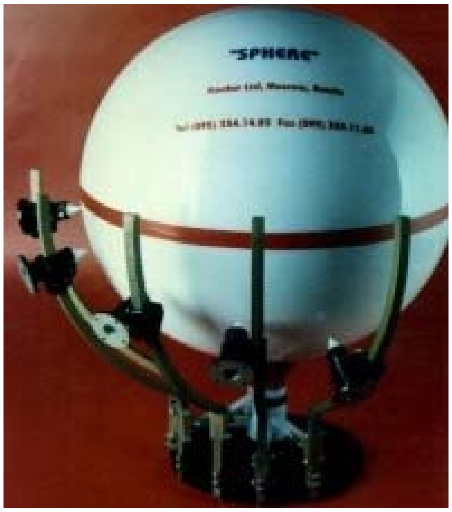

Figure.3. Luneberg Lens of Konkur Co. (Moscow)

Table 1. Parameters of Luneberg lenses produced by Konkur Co.

f, ГГц Parameter	10.7-12.7	10.7-12.7	10.7-12.7	38 ± 1 28 ± 1	38 ± 1 28 ± 1
Diameter, mm	460	660	900	230	290
Weight, kg	25	50	150	12	13
Beamwidth (–3 dB)	3.7	2.8	1.9	2.6 3.4	1.9 2.5

A radiation pattern of Luneberg lens with standard off-axis feed for satellite TV LNB at 10.7-12.7 is given in Fig.4.

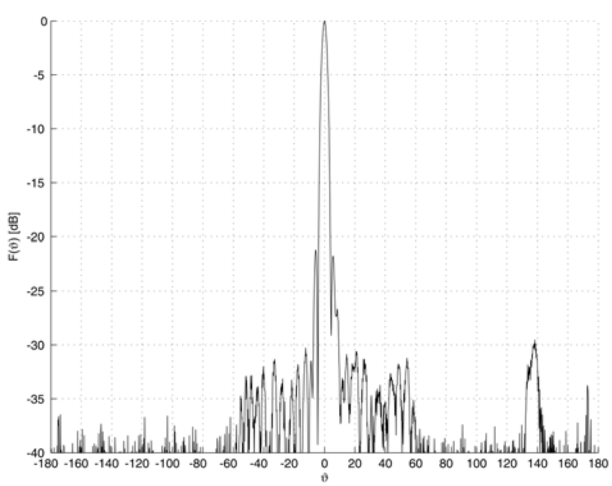

Fig.4. Radiation pattern of spherical Luneberg lens by Konkur Co. at f=10.79 GHz in E-plane

Characteristics of Luneberg lens can be improved by accurate modeling. The program for calculation of lens characteristics and antenna optimization has been developed in the SPbSPU. Some useful results were obtained in [6].

2.2 Multibeam reflector antenna

A mapping system may incorporate a low aberration reflector antenna with a Focal Plane Array (FPA). For simulation of the multibeam radiation pattern, calculation of some other antenna characteristics (illumination, aperture, spillover, sidelobe efficiencies, beam overlapping level etc.) FOcal Plane Array Simulation (FOPAS) program was written in Mathcad first and then at C++. FOPAS takes into account geometry of a single or dual reflector antenna, expected aperture distribution or beam pattern of ideal broadband feed, the feed removal from the focus and off-axis aberrations. FOPAS allows us to optimize an array geometry with beam spacing and overlapping level which are optimal for the given mapping task [7]. Multibeam radiation pattern of 2 m Cassegrain reflector antenna in 3 mm band is given in Fig.5.

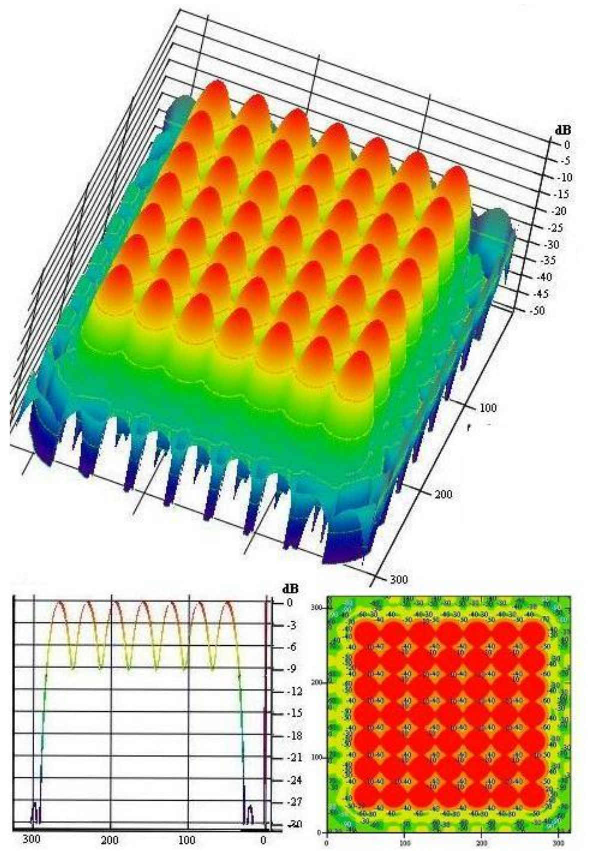

Figure 5. Three dimensional 7x7 beam pattern of 2 m Cassegrain antenna in 3 mm band (top), one dimensional cut (left bottom), isoclines (right bottom), the feed taper is –10 dB

2.3 Radiometric systems

On the basis of the modern converters "total power" radiometers were developed and manufactured for ground based fire-detecting systems [8]. 8 similar feeds placed on the arc with $R=1.5\,R_L$ (Luneberg lens radius) form us 8 beams which cover ±45°sector (Fig.6). Maps are produced due to airplane moving. Such system is most effective for detection of forest fires and fire-fighting. It may be also used for determining of ice state and optimum traffic of ships in Arctic regions.

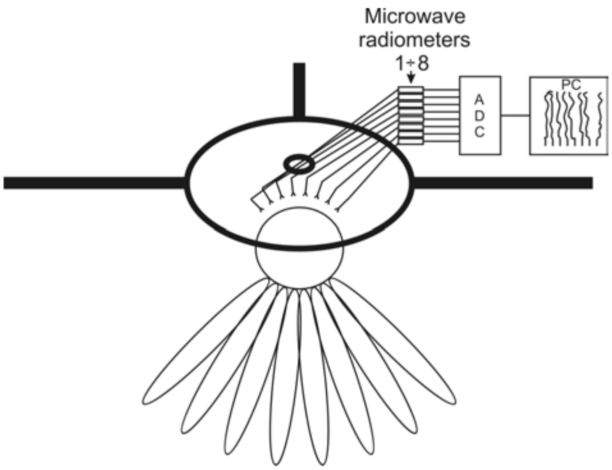

Figure.6. Luneberg lens and 8 radiometers

In the process of weather modification we must chose a cloud with maximum water content for reagents dispersion. For remote sensing of water content in clouds it is preferable to use radiometers of mm band where noise temperature grows. Cloud mapping process allows us to choose a proper cloud or its part. A Luneberg lens or reflector antennas with low off-axis aberrations and wide field of view may be used for this goal as well (Fig. 7).

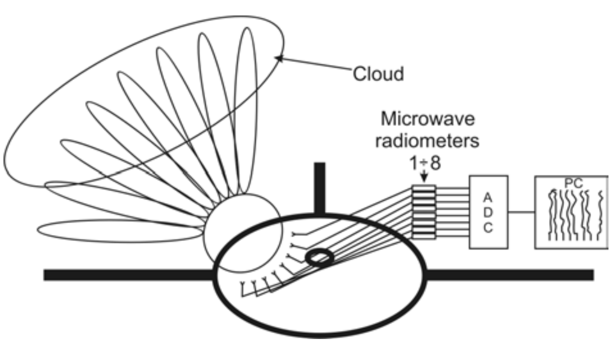

Figure 7. Cloud mapping with Luneberg lens and 8 radiometers

2.4 MMIC array receiver modules

Several types of MMIC array receiver modules of 10 mm band were developed for monitoring of Solar flares and atmospheric research [9]. A prototype of FPA with "total power" MMIC receiver modules at 26-30 GHz is presented in Fig.8. In array receiver modules MMIC LNAs (LMA-422 of FSSD Co., US) with NF=2.5 dB are used for direct RF amplification with a total gain of 65-70 dB. Zero bias Schottki chip-detector is installed after the 3-d order microstrip BP filter. A volume spiral is applied in compact array modules as a feed of circular polarization. Noise receiver temperature of array modules is 300 K. Mm-wave imaging systems with FPA may be successfully used for atmosphere mapping.

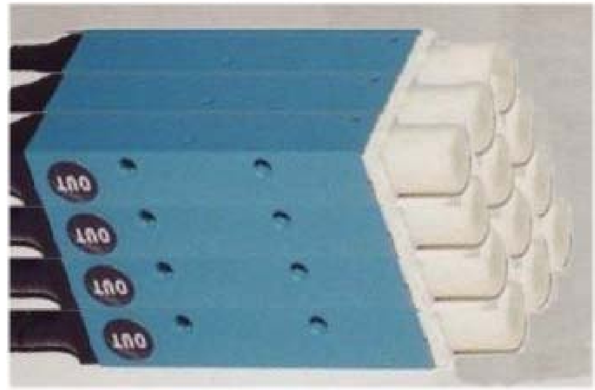

Figure 8. A prototype of FPA with MMIC receiver modules at 26-30 GHz.

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