Topographic Monitoring over Land Surface using Radar Altimeter

Yong-Hoon Kim

Kwangju Institute of Science and Technology (K-JIST)

572 Sangam-dong, Kwangsan-ku, Kwangju, 506-712, Korea

Tel:+82-62-970-2387 Fax: +82-62-970-2384 E-mail: yhkim@kjist.ac.kr

ABSTRACT

In this paper, the radar altimeter for topographic mapping over land is introduced and the characteristics of the return signals are analyzed. The radar system is described briefly and the requirements to get the fine resolution of the terrain surface height are considered. The designed radar altimeter was tested on the landscape in the near of Stuttgart. The measured data shows very fine profile of the test landscape and the height errors induced from different geometrical structure of the land surface are acquired in the measurement. In the test area, most characteristics of radar return signals over land could be tested and the results of the topographic mapping using our radar altimeter can be used for future radar altimeter development for land applications.

1. INTRODUCTION

Spaceborne radar altimeter is one of the new promising microwave instruments to observe the earth environment. SEASAT, ERS-1 radar altimeters provided us new understanding of the ocean circulation, sea surface dynamics, and process of climate exchange between ocean and land. But this type of altimeters could provide only a limited capability to the application on ocean. They can not be extended to the land topography mapping [1][2]. Based on the initial requirements worked out in altimeter user working group [3][4], the new system concept of high performance radar altimeter for land application has been studied and implemented at Ku-Band.

This paper is primarily concerned with system design and demonstration of proposed design concept of radar altimeter for high resolution topographic mapping over land. The system concept and characteristics of the prototype are described and geometrical structure land surface is modeled to interpret the echo signal properties. Using this echo signal model relating land structure, one can analyze the effects of terrain profile from return signal of complex land surface height. In order to demonstrate the mapping capability, the instrument is tested on the landscape underneath a bridge 'Neckatalviadukt' in the near Stuttgart, Germany. The measured topography profile of the landscape shows a very good representation of the topography and it enables first order interpretation of the observed surface. The land experiment justified the demonstration version of this kind system for the application of land topographic mapping.

The obtained precision of this radar altimeter was in the order of 2cm.

2. SYSTEM CONCEPT OF RADAR ALTIMETER

In contrast to altimeter for ocean application [1] [2], land altimeter system has to the tracking possibility of terrain height over different land surface roughness. For the exact measurement of terrain height, the antenna beamwidth, range resolution, dynamic range of the receiver, and antenna incident angle, and detection algorithm of return signal should be optimized in the altimeter design. The major parameters of the designed land altimeter are listed in Table1 and the system block diagram is shown in Fig.1[5]. The proposed altimeter has been designed at the same frequency band of ERS-1 and 2 altimeter to compare the characteristics of the return echo signal and earth surface profile.

Table 1. System parameters of radar altimeter

Frequency	13.74GHz	Antenna:	
Bandwidth	80MHz	Antenna gain	25dB
Pulse length	4,8,16μs	Antenna size	56 ×40cm
Max. integration time	16μs	No of element	24 × 132
Compression ratio	1280	Beamwidth	0.35°× 0.4°
System noise figure	3.5dB	Polarization	Linear

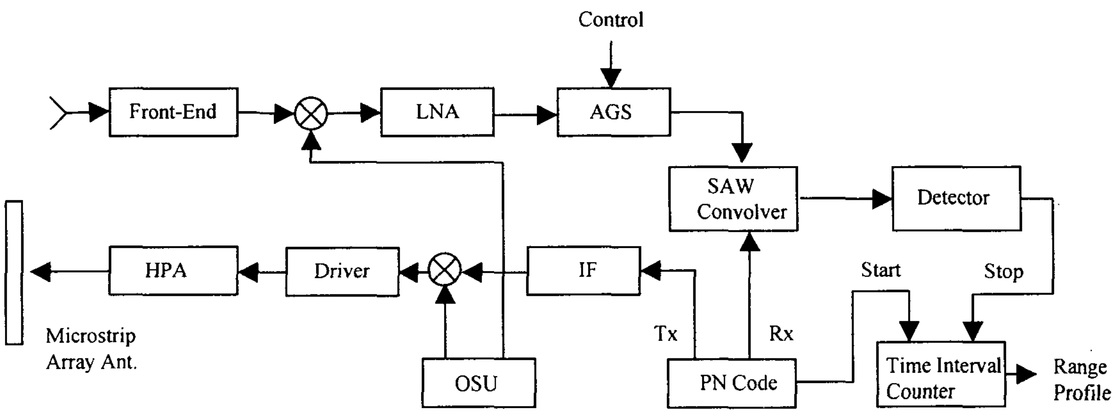

Fig.1 Block diagram of radar altimeter at 13.5GHz

A. Antenna

Radar altimeter on ERS-1 and 2 measure the slope of the echo signal from ocean surface and integrate the signal over 1KHz to discriminate the surface significant wave height. The return signal from land surface is quite different signal waveform because the terrain surface roughness is not evenly distributed in antenna illumination area. Therefore the detection method in ERS-1 altimeter can not use to monitor the terrain height over land. Generally the radar echo signal from terrain is strong disturbed by land surface roughness, then it is very difficult to track the terrain height accurately. Using very narrow beam antenna –beamlimited operation-, this effect can be reduced significantly. Considering different trade-off on the antenna type, array antenna with microstripline technology has been selected and designed at Ku-band. The antenna design was focused to realize very narrow beamwidth, high gain and mounting possibility on airplane for airplane experiment in the future. A microstrip array antenna is fabricated on Teflon microstrip substrate with permeability of ε_r=2.2 and has an aperture size of 56 ×40cm and gain of 25dB. The measured beamwidth of array antenna is 0.35°× 0.4° on horizontal and vertical axis.

B. Range Resolution

The stability and resolution in range measurement are critical parameters to track the fine variation of the terrain surface height. High range resolution is accomplished by digital pulse compression technique using SAW convolver that can enable to get high accuracy range measurement in real time. The PN code having 4,8,16μs length was used for the pulse compressor and the time bandwidth production was 1280. The measured standard deviation of traveling time in two-way range measurement is better than 350ps over the average of 100 return signals in 10 minutes integration time which correspond to 10cm accuracy.

C. System Dynamic Range

The receiver having high dynamic range can detect more accurate return signal level that can represents the power profile of the echo signal. The return signal strength depends on the area size of antenna foot print and scattering properties of the land surface materials. Generally more than 60dB dynamic range is required for land altimeter. In the measurement of land profile having the height of 50m in section III, the return powers have been changed about 30dB.

D. Detection of Echo Signal

The method of exact detection of the echo signal is one of the major critical technologies that decide the performance of the altimeter. For high resolution radar, digital correlator, convolver or SAW convolver are used at base band or at IF bands. Compared with digital correlator, SAW convolver gives a possibility of real time signal processing for the pulse compression and also it enables the very fine detection of the echo signal to get high range resolution. . In our instrument, a digital pulse compression method using SAW convolver was used at 300MHz.

3. LAND PROFILE MAPPING

A. Test Site

To acquire topographic mapping data, the altimeter has been tested on the long bridge "Neckartalviadukt" in the near of Stuttgart as shown in Fig.2. The bridge is connected over two valleys. The length of the landscape under bridge is 745m and the maximum distance from bridge to ground is 47m. The left site in small valley is divided by narrow wood (forest) way. Left of it, long fir trees of at least 15m to 30m long are stand and foliate tree without leaves are sited in right side. The right valley contain different types of landscape elements like asphalt road of B297, wood land, lake of Baggersee, meadow, land slope, tree, small canal, house with roof as shown in Fig.2. The landscape underneath of the bridge "Neckartalviadukt is an ideal test area. Practically, one can find most kind of objects that can be existing for the topographic mapping. In this test site, range variation effect, return signal properties of radar altimeter corresponding geometrical structure of landscape, surface roughness and compound, and land slope in terrain can be simulated by measurement with designed altimeter in test area.

B. Topographic Measurement

The radar was mounted at the end of a horizontally aligned boom carried by a truck and passed along a bridge whilst measuring the terrain height of the landscape underneath of bridge. The measurement range from bridge to ground is 1m to 45m that change the antenna foot print diameter from 0.61m to 2.75m with the antenna beamwidth of 3.5 degree on the ground. The range that represents the terrain height is acquired by the traveling time measurement using HP Time Interval Counter and the power of return echo signal is detected by AGC and converted to the power in dBm. The measured topographic mapping of test site in Fig.3 shows the very fine representation of topography as shown in Fig.2. The range accuracy of the profile has been accomplished better than 2.5cm in the measurement.

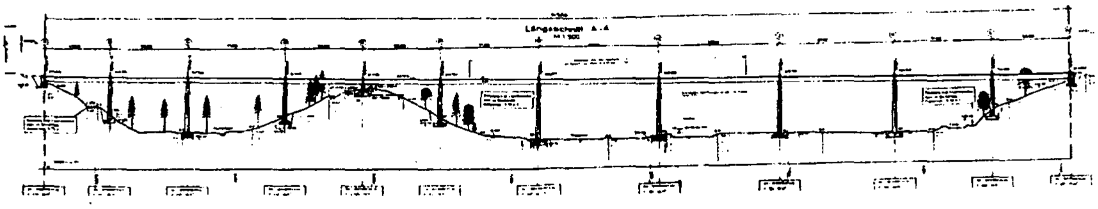

Fig. 2 Landscape and bridge construction plan of test area "Neckartalviadukt" in the near of Stuttgart

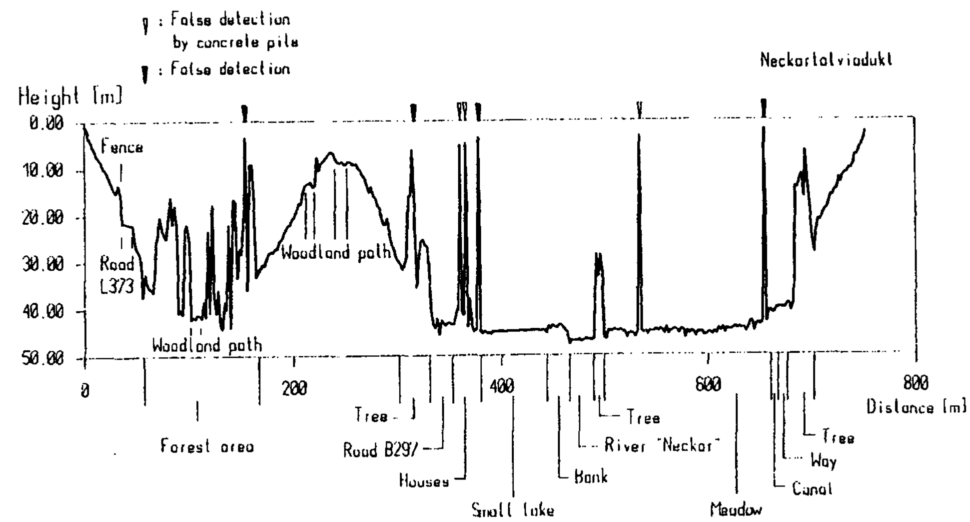

Fig.3 Topography profile of the test area

4. INTERPRETATION OF MEASURED LAND SURFACE HEIGHT

A. Water Surface: Range variation from ground line monitoring

The horizon of a small lake “Baggersee” surface in the middle of right valley is an ideal reference to justify the range measurement accuracy of the designed radar altimeter. The lake is 75m wide and a few hundred meters long. At measured day, there is no wind in this area; therefore the surface of the lake was very calm like mirror surface. The height measurement over small lake surface is shown in Fig. 3. In the measured data, one can find a slope of the surface horizon line. This means that it is not the slope the lake horizon line but also bridge slope that can be showed in the bridge construction plan. As compared with the construction plan of the bridge and the measurement results, the slope difference of the bridge is only 2.5cm. The result represents the range accuracy of the proposed radar altimeter system. The accuracy obtained along the bridge was in the order of 3cm. Beside of Baggersee, small canal “Neckar” is sited and it is divided by bank of 3m width covering bush. Compared with Baggersee, the surface line of Neckar canal is showed very fluctuate line because of the fast flowing of the water. The surface fluctuation of canal makes non-specular reflection like in Baggersee.

B. Road: Range variation induced mutipath effect

The road of L373 on the middle of slope in left side valley is an asphalt road of two lanes. The land road on the middle of hill and the asphalt road L373 are showed very different profile in Fig.2. While the ground line of asphalt road is flat, the land road shows very fluctuate in Fig.3. The difference of the two types of road is a roughness of land surface. More interested result was monitored in the measurement of road B297. The road B297 is a state road, therefore there are many traffics. Normally, the ground line of the road B297 should be flat like road L373, but the profile is fluctuate in profile. By the measurement also trucks and cars are passed in measured footprint of antenna. At this measured point, the return signals can be reflected from the asphalt flat or from the roof of a car or backside. These signals can be delayed to the receiver. These mutipath effects induced by the geometrical structure of the measured object cause the range errors that can change the profile line of surface height and make a false detection in some case. The mutipath effect in range can move the location or the position of the object in topographic profile and show double image of Golden Gate Bridge in radar image [7]. However the return signals from complex surface structure are very complex and it is required to analysis the scattering properties in detail.

C. Single Tree and Forest: Range variation induced volume scattering

The scattering characteristics of the tree are very complex and dependent on the figure of the leaf and density of the trees in antenna footprint. The reflection signals from firtree in left valley have been detected very clearly and it measured the range from top of the tree. But in right side of forest area, long trees having little leaf are stand. In this area, the radar signals are reflected from top of trees or from land ground. Beside the river Neckar, two trees are stand very closely, but the profile can be distinguished these two trees.

D. Land Slope and Grassland

At right valley, grassland is sited between small river Neckar and a canal. The length of the grassland is more than 150m long and the land surface is covered by grass, but some parts are barren ground. The over structure of grassland is not flat and the grasses have different length. Because of the different surface condition, the reflection signal from grass is changed and the range profile is fluctuated very strong.

In the distance of 530m, there is a large hole in barren ground. The echo signal at this measurement point is reflected to the concrete pile of bridge, therefore a false detection was measured.

5. CONCLUSIONS

A very accurate radar altimeter has been designed and tested to monitor the land surface height. The measured data are showed the system performances and justified the possibility of the land topography mapping. The variations of terrain height are analyzed by the measurement. The different height errors induce by surface geometrical structure, surface roughness, mutipath effects, land slope are observed and studied in detail. The interpretations of topographic data that are acquired in this measurement can be used very valuable for the future radar altimeter study especially for land applications.

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