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Development of a Cheap Helicopter Assisted Landing System Method

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Abstract **– This paper presents a relatively cheap helicopter assisted landing system concept. A frequency modulated continuous radar (FMCWR) is used to check an unprepared landing area for the presence of interfering objects. The spectrum processing of the converted signal is used to provide multi target resolution. The experimental research is done by using a 4.3 GHz FMCWR radar. The converted signal spectra are provided for mirror and rough surfaces, as well for multiple targets in a case of interfering object existence.**

Keywords **– Diffusive reflection, frequency modulated continuous wave radar (FMCWR), mirror reflection, multiple target resolution, rough reflective surface, smooth reflective surface, spectral processing.**

I. INTRODUCTION

Helicopter approach and landing are the most critical phases of the flight. Usually, they are performed visually. The safety of these phases depends on the pilots' skills and visual contact with the landing area. Landing a helicopter on unprepared terrain causes a massive dust cloud generated by helicopter rotors which reduce the pilots' visual contact with the landing area. In addition to that, rescue operations by means of helicopters are usually performed in bad weather conditions when snow, rain and mist can completely obstruct the pilots' view of the landing area. Sometimes rescue operations can be delayed for up to several days due to the low visibility of the landing area.

Airplane landing safety is generally affected by human errors. The number of human errors made by airplane pilots can be reduced with the help of an automatic landing system, which requires additional ground equipment. In contrast to an airplane runway, a helicopter landing area is not equipped with ground radio beacons. The absence of landing beacons prohibits helicopter dependent landing procedures. For automatic helicopter landing, most researchers use vision based approaches with further image processing techniques. For example, [1] describes a system which uses 3 cameras to process 3D vision information in order to determine the distance to the ground during helicopter landing. The system described in [2] can also detect and avoid hazardous objects such as steep slopes and large rocks. This system uses single rotating camera and is based on visual image processing techniques. In [3], there is described a real-time stereo vision system that can be used for the landing of an unmanned helicopter. In [4], there is presented a vision processing technique which allows an unmanned helicopter to land on a ship. All of the previously described systems and ideas are based on visual image processing and cannot be used if the visibility is low. In [5], the author has described how a tether can be used for a more secure landing in bad weather conditions. This method can be used only for prepared platforms or areas and is not suitable for rescue operations. The use of GPS also cannot guarantee safe landing on an unprepared surface and cannot be used in rescue operations because any interfering objects cannot be located by means of GPS signals [6].

A millimetre-wave (MMW) three-dimensional imaging pulse radar system can be used to help the pilot to check the landing area for any hazards of unprepared landing area also in zero visibility conditions [7]. The use of 95 GHz frequency upper millimetre waves helps to increase range resolution and reduce the size of scanning antennas [7]. To provide good range resolution radiated pulses should be very short: close to one nanosecond [8]. High frequencies and short pulses increase

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the cost and complexity of the equipment. In this case, the processing of the time delay of reflected pulses requires more complex and costly solutions.

The processing of frequency-modulated continuous wave radar (FMCWR) converted signals is carried out in low frequency band [8]. The processing of signals at low frequencies decreases the cost and complexity of the radar processing section. The integral method of converted signal processing is mainly used in aviation radio altimeters and was first applied for an aircraft altimeter in the 1930s [9]. The distance to the flat landing area is extracted from the beat frequency of the low frequency converted signal by means of integral method. In a case of multiple reflecting surfaces, an integral method will provide an average distance value which is weighed by the reflected signal strength from all reflective surfaces. This method of converted signal processing does not allow multi-target resolution [10].

The delay of the reflected signal is a linear function of the distance. As the transmitted signal is frequency modulated by the modulating frequency, its spectrum is discrete and similar to the frequency modulated signal spectrum. A mirror reflection occurs if the mean value of surface roughness is less than $\lambda_0/16$, where λ_0 is a wavelength of the central frequency. In a case of mirror reflection, the received signal spectrum is also discrete. In this case, the converted signal processing will provide a discrete spectrum [11], where the central frequency is defined by the distance transformation coefficient expressed in Hz/m. An explanation of the Doppler impact onto the spectrum can be found in [10] and is not discussed here.

The converted signal is a sum of many discrete spectra in a case of multiple mirror surface reflections. The spectral method of converted signal processing allows to provide multi-target resolution [10]. A 4.3 GHz FMCWR is used in the experiments to compare the real spectra with the theoretically calculated ones. The experimental results are used to validate the idea of FMCWR as an effective interference object detector during helicopter landing.

II. EXPERIMENTAL PART

A. The Testbed

As the experimental setup FMCWR 4.3 GHz radar with two directional antennas is used. The receiving and transmitting antennas are located in the same plane. Both antennas and the FMCWR module are grounded. The emitted radar signal is modulated in frequency by the symmetrical sawtooth function. The signal from the receiving antenna is fed to the mixer, where it mixes with the signal of the high-frequency (UHF) reference oscillator and decreases in frequency. The output signal from the mixer contains the difference frequency between the radiated and reflected signals. Further, the converted signal (signal from the mixer) is fed to a spectrum analyser using fast Fourier transform (FFT). More detailed description of the experimental setup can be found in [11]. General characteristics of the experimental setup are shown in Table I.

TABLE I

GENERAL CHARACTERISTICS OF THE EXPERIMENTAL SETUP

Characteristics of the Experimental Setup	Value
Transmitter oscillating mode	Continuous
Transmitter modulation	Frequency
Modulation voltage	Symmetrical sawtooth
Modulation frequency	150 Hz
Radiated frequency deviation	100 MHz
Radiated signal power	≥0.4 W
Transmitting antenna feeder length	3 m
Receiving antenna feeder length	2 m

Distance between antennas	1 m
Antenna beam angles in *E* and *H* planes at –3 dB level	≥40°
Spectrum analyser selected performance data	*is specified under experimental results

B. Reflection From a Rough Surface

In the case of reflection from a mirror surface, the width of the main and side lobes of the spectrum of the converted signal is determined by the F_M modulation frequency. When using a symmetric sawtooth modulation function, the width of the main lobe of the converted signal is equal to $4F_M = 4 \cdot 150 = 600$ Hz. The width of the side lobes is $2F_M = 2 \cdot 150 = 300$ Hz. The spectrum itself has a discrete character, where the discrete components are located at a distance F_M from each other [10]. In the experiment this F_M distance is 150 Hz. The envelope of the spectrum of the main and two side lobes is shown in Fig. 1.

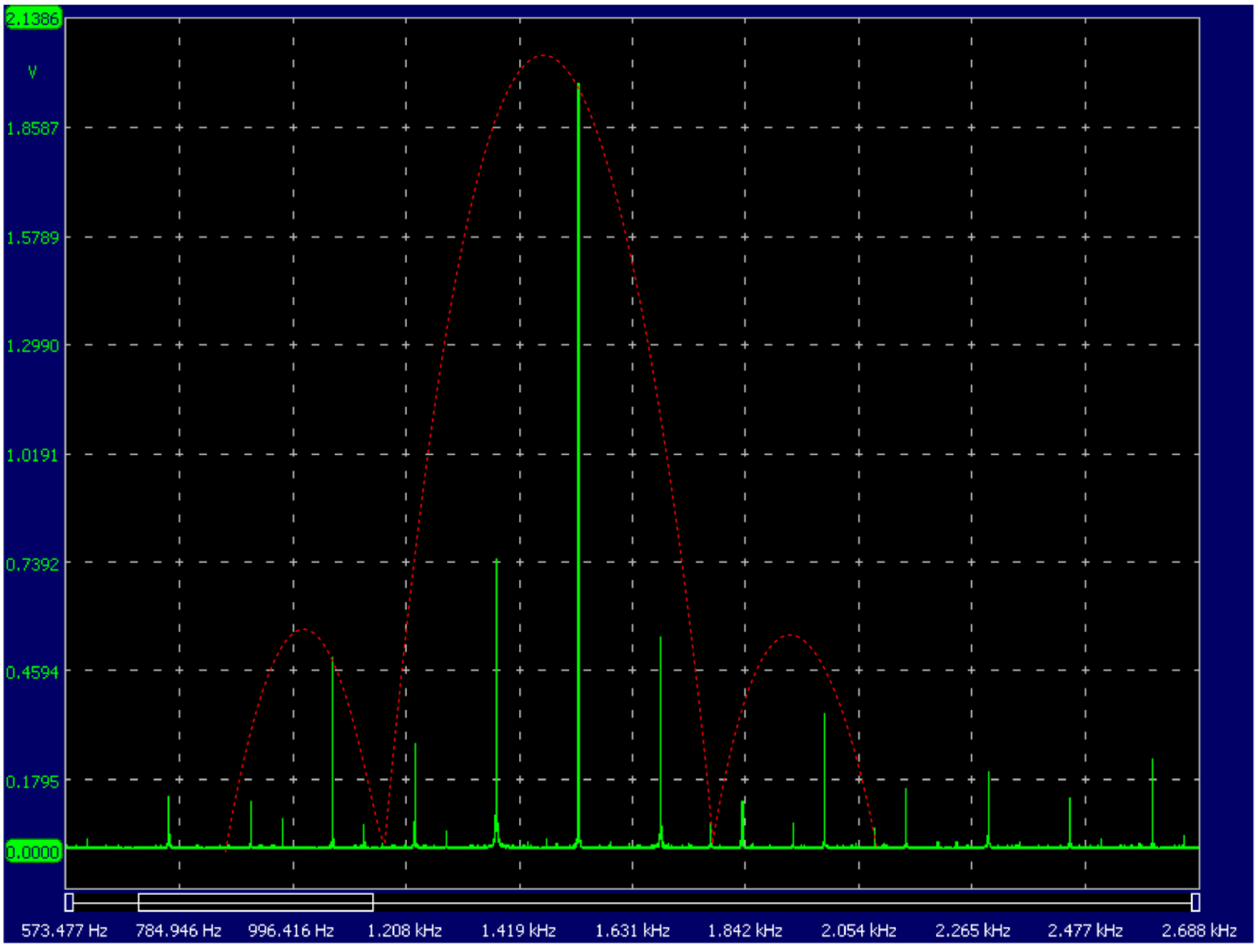

Fig. 1. Main spectrum lobe and two side lobes of the converted signal.

The more detailed explanation of the spectrum when reflected from the mirror surface can be found in [11].

FMCWR (frequency modulated continuous wave radar) resolution depends mainly on the width of the main and side lobes of the spectrum of the converted signal Narrow lobes make it possible to improve the range resolution [10].

The mean value of the surface roughness should be less than $\lambda_0/16$ to meet the mirror surface criteria. It means that for a frequency 4.3 GHz the average surface roughness value should be less than 2 mm. Under real-life conditions no surfaces these conditions. Therefore, practically all real reflecting surfaces (in real-life) are considered to be rough (not mirror). The spectrum of the converted signal in diffuse reflection (when reflected from a rough surface) differs from the spectrum when reflected from the mirror surface.

In the following experiment a building wall is used as a roughened reflecting surface. The antennas layout is shown in Fig. 2 and Fig. 3.

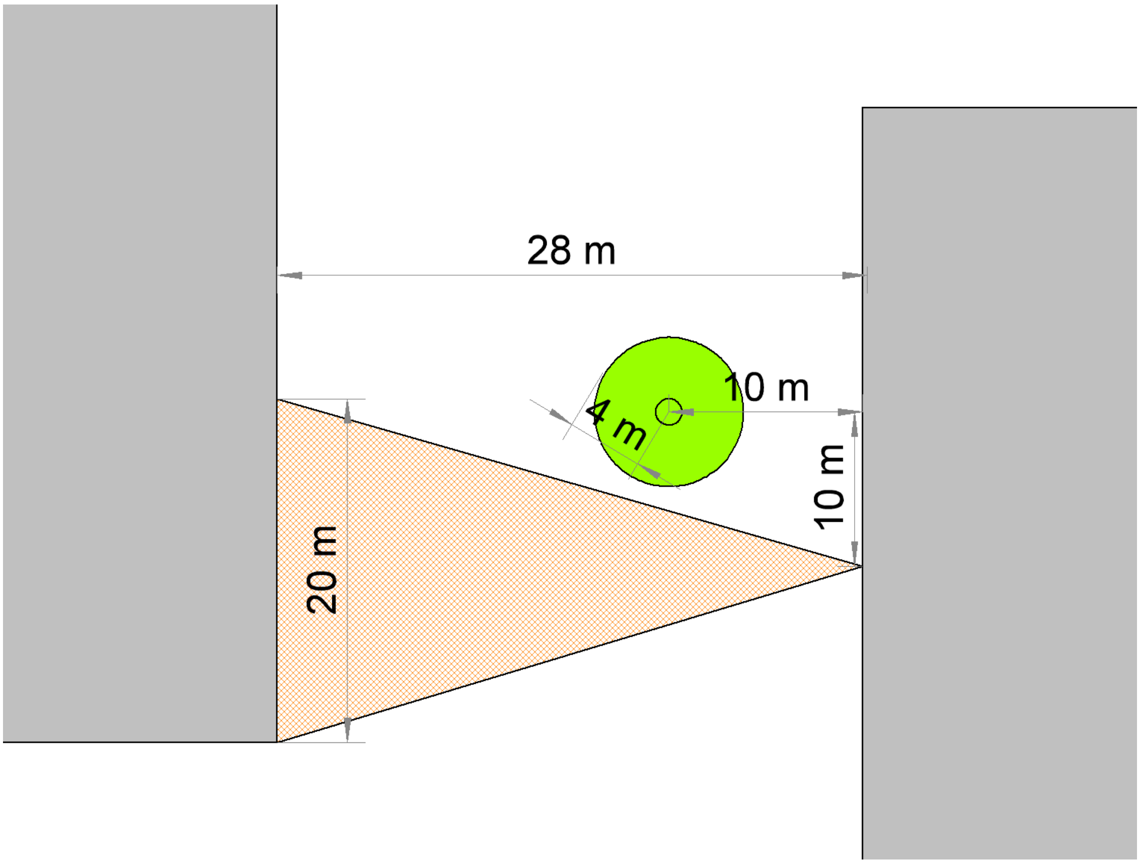

Fig. 2. Schematic of antennas layout.

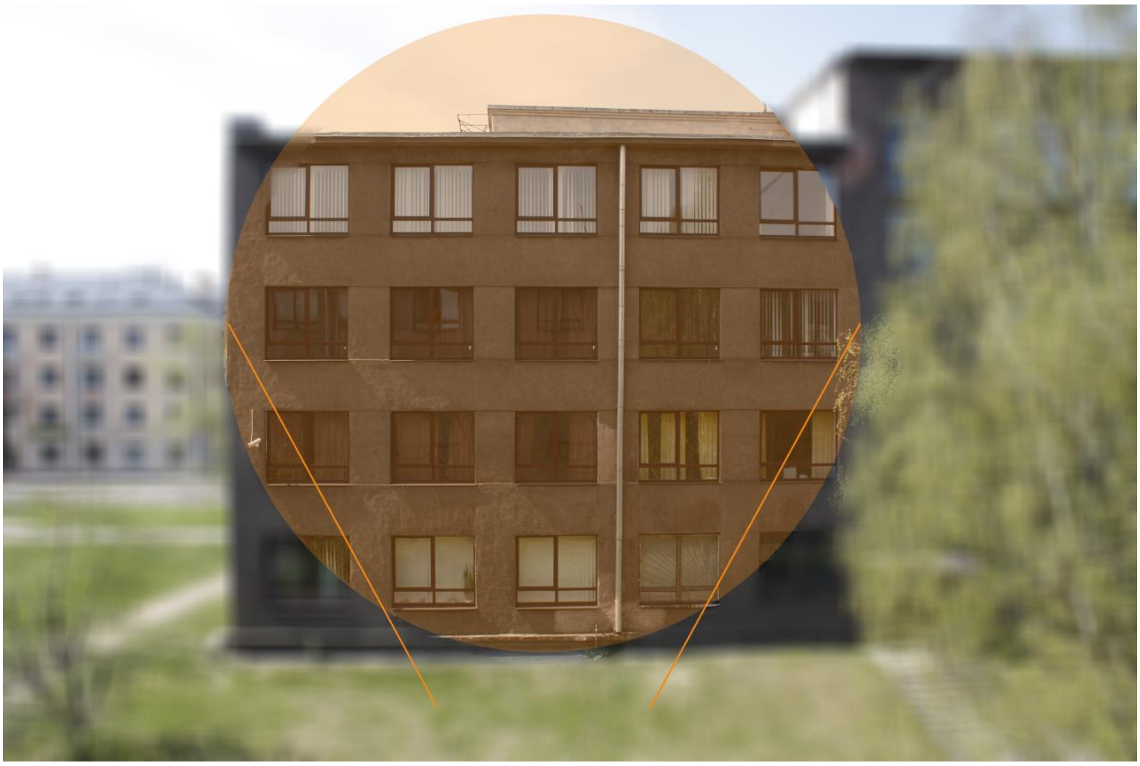

Fig. 3. Antennas beam overlap view.

Sampling frequency of the spectrum analyser is f_s = 50 kHz, number of samples is $N = 100 \cdot 10^6$, resolution is 12 bits. A number of measurements were performed to confirm the repeatable occurrence. However, only one snapshot of the spectrum of the converted signal is represented in Fig. 4 and is analysed below.

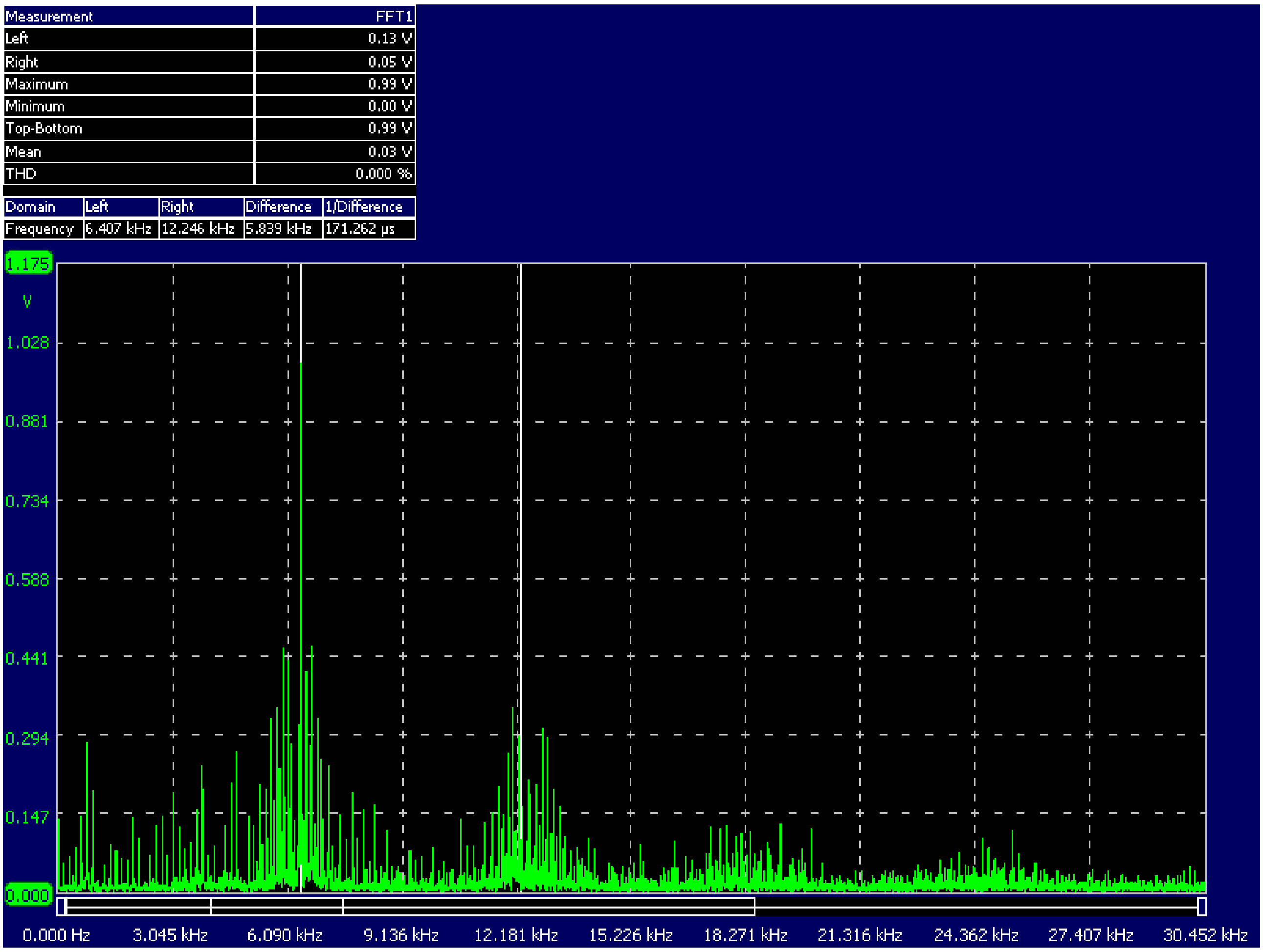

Fig. 4. Converted signal spectrum.

The maximum of the spectrum of the converted signal from the main reflection (from the opposite wall) is at a frequency of 6.407 kHz, which is equivalent to a distance of 28.23 m. The second maximum of the spectrum of the converted signal is 12.246 kHz, which is equivalent to a distance of 57.43 m. The third and fourth maximums are at 18.125 kHz and 24.694 kHz, which is equivalent to 86.83 m and 119.7 m, respectively. The first maximum of the spectrum of the converted signal is caused by reflection from the irradiated wall of the building. The second, third and fourth maxima are caused by re-reflected signals between two buildings.

An enlarged section of the converted signal spectrum from the primary (first) reflection is shown in Fig. 5.

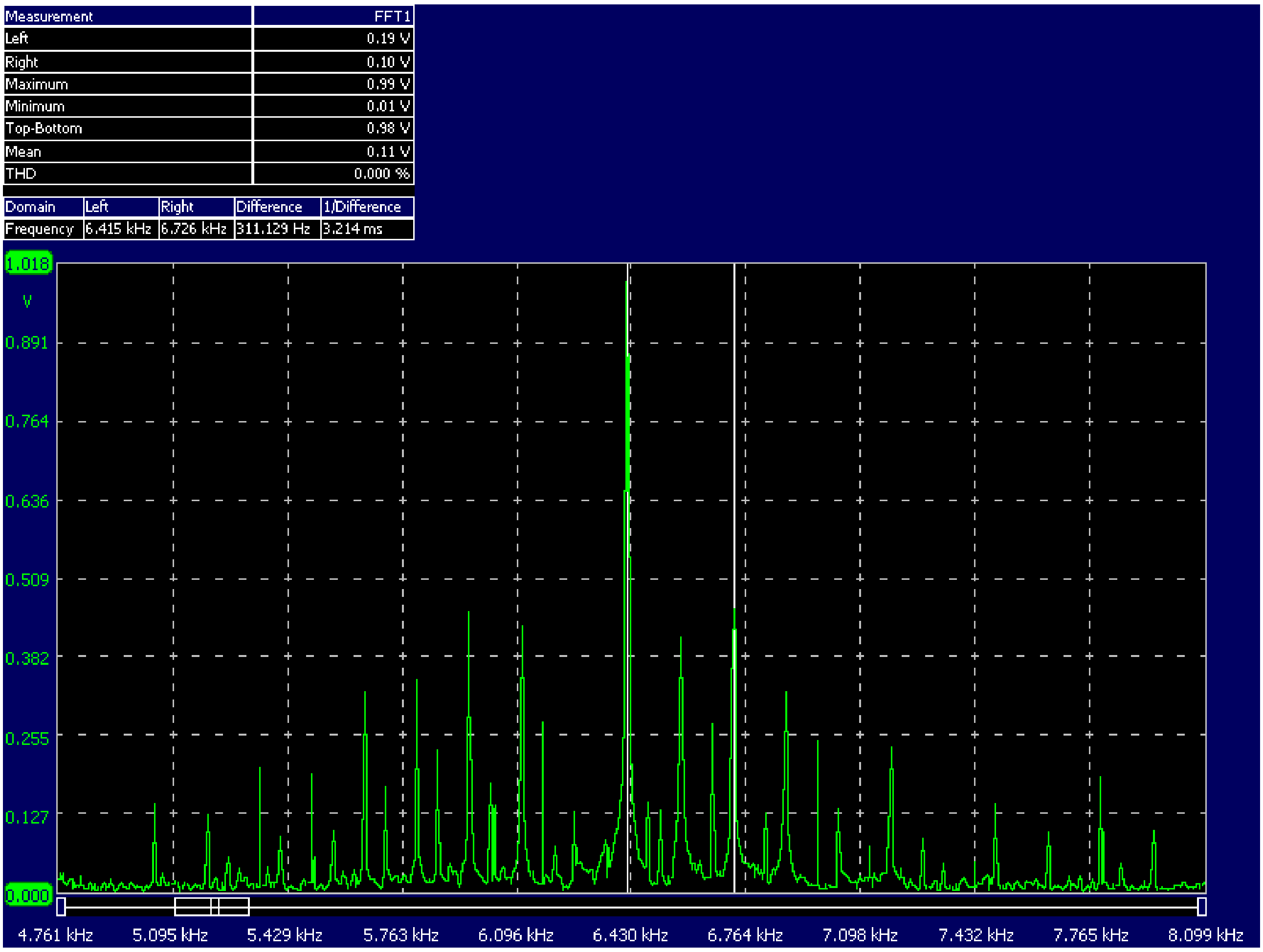

Fig. 5. First diffuse reflection converted signal spectrum.

The spectrum of the converted signal in the case of diffuse reflection also has a discrete character. However, the spectrum with diffuse reflection has a different structure than it had with mirror reflection. In this case, additional discrete spectral components appear, which are arranged between already existing components. The width of the spectrum, in comparison with the spectrum in the case of reflection from the mirror surface, is also greater due to diffuse reflection. In general, this causes a deterioration in the resolution of the FMCWR range capability [10]. A more detailed description of the nature of diffuse reflection can be found in [12].

C. Reflection From the Multiple Rough Surfaces

The main task of the helicopter assisted landing system when landing is to alert the pilot about the presence of any foreign (obstructive) objects in the landing area. This problem can be solved using the spectral processing of the converted FMCWR signal. The transmitting and receiving antennas should be directed vertically towards the landing zone (s). Any reflective surface (object) in the antenna overlap area will cause a certain amount of reflected energy/power. The power of all signals (energies) reflected from all surfaces are summed up in the converted signal. As mentioned above, in real-life conditions, virtually all surfaces are rough (carrier frequencies at 1 GHz and below are not considered because its use significantly reduces the resolution of the radar) [10]. Therefore, the spectrum of the transformed signal will consist of the sum of the spectra of all reflections, which, moreover, will have a diffuse character.

In this experiment, the wall of the building is used as the surface of the landing zone. The birch simulates the foreign object in the landing zone. Both antennas are located in the same plane at a distance of 1 m from each other. The angle of antenna installation is 110° with respect to the wall of the building. The lengths of the feeders of the transmitting and receiving antennas are 3 m and 2 m, respectively. The frequency conversion coefficient at a distance of 200 Hz/m, and the velocity of propagation of the electromagnetic wave in the feeders is 0.76 from the velocity in vacuum. The antennas layout is shown in Fig. 6 and Fig. 7.

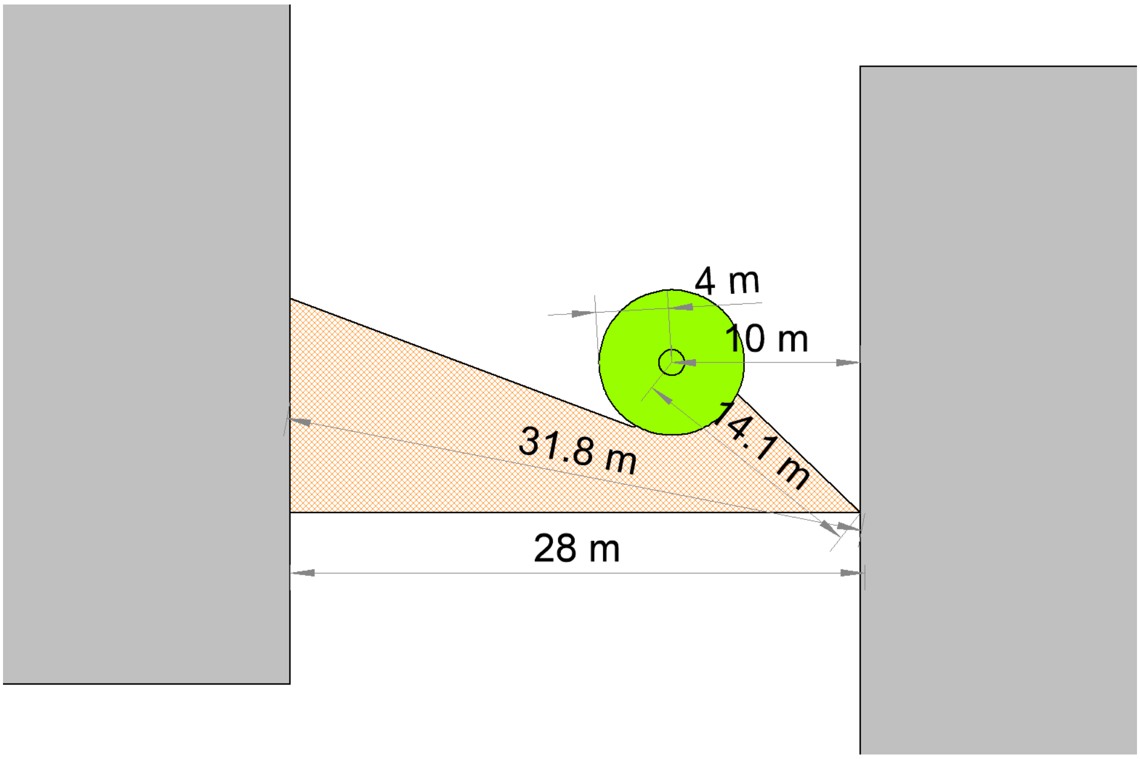

Fig. 6. Schematic of antennas layout in the multi target resolution experiment.

Fig. 7. Antennas overlap beam view in the multi target resolution experiment.

The spectrum of the converted signal can be calculated, using the distances, feeder lengths and the coefficient of the distance transformation in the frequency. In this case, the spectral maximum from the reflection from the wall should be in the range of 6.261 kHz and 7.121 kHz. The birch trunk should give a converted signal spectrum at a frequency of 3.562 kHz. The birch crown should give a converted signal spectrum at approximately 2.762 kHz.

Fig. 8 shows the experimental converted signal spectrum data.

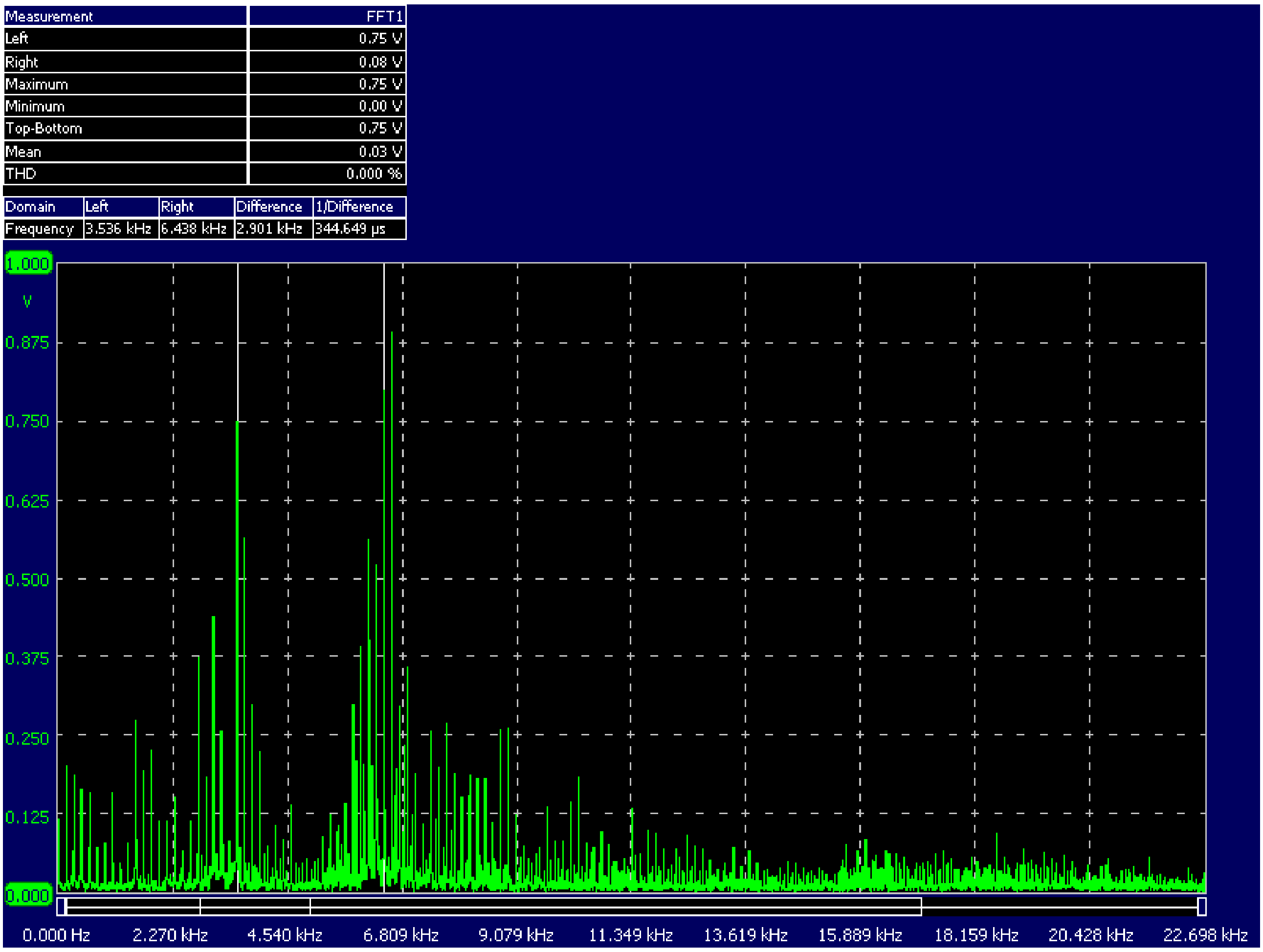

Fig. 8. Converted signal spectrum in the multi target resolution experiment.

The spectrum of the reflected signal from the first surface is in the range 2.50 kHz to 3.80 kHz. Its maximum is at 3.53 kHz, which corresponds to a distance of 13.85 m. This distance is almost equal to the distance between the antenna and the centre of the birch. Since the reflection is diffuse, the frequency of 2.50 kHz does not mean the presence of a rotating octet at a distance of 8.7 m (there is an expansion of the spectrum due to diffuse reflection). The real crown of birch begins a few meters further.

The spectrum from the next reflection is located at 5.60 kHz to 8.00 kHz (here the side lobes from the expanding spectrum are no longer taken into account (approximately) which is equivalent to distances of 27 m and 32 m, respectively. These distances are practically equal to the distances between the antenna plane and the wall of the building. The reflection from the wall of the building gives more than one brightly-expressed maximum and some maximums of frequency range are because the antennas are at 110° angle with respect to this wall. The maximum reflection spectrum from the wall is at a frequency of 6.44 kHz, which is equivalent to the distance of 28.4 m. This distance is equal to the average value of the distance between the plane of the antennas and the wall of the building (since the angle is not 90°).

Spectra from reflections in this case do not exist because the antennas are arranged at an angle to a reflecting surface other than 90° with respect to both building walls.

III. Conclusion

The display of multiple targets of FMCWR is possible using the spectral processing of the converted signal. The last spectral maximum of the FMCWR converted signal (at higher frequencies) is caused by reflection from the surface of the landing area. Any interference between the helicopter and the landing area will be displayed as a spectral maximum positioned at frequencies between 0 and the last maximum (from the landing area).

The range resolution of the FMCWR is defined by frequency deviation value and reflected signals strength ratio of both reflecting surfaces. Generally, if the reflection occurs from mirror surfaces and both reflected signal strengths are equal in value, the maximum range resolution is equal to speed of light divided by frequency deviation. However, it is better to place at least one discrete spectrum component between two spectrum maximums [10]. In this case the maximum range resolution of two reflected signals will be $1.5C/\Delta f$. In our experimental setup this value is 2.25 m. Please note than this value does not depend on modulation function, modulation frequency and type of the reflected surfaces. However, if the reflected signals strengths are not equal in value, the range resolution will be affected to. In this case it is desirable to use modulation function which produce less side lobes in the converted signal spectrum. A ramp function can be a good choice [10], however the use of ramp instead of symmetrical sawtooth modulation function increase the cost and complexity of the FMCWR equipment. In real-life almost all reflective surfaces give a diffuse reflection. In this case, the spectrum of the reflected signal becomes wider (spreads out) in comparison with the spectrum in the case of mirror reflection. This leads to a deterioration of the FMCWR resolution over the range if the reflected signal strengths are not equal. An also wider spectrum complicates the operation of the operator (pilot).

Can conclude that 4.3 GHz FMCWR with 100 MHz frequency deviation confidently recognizes tree crowns or separate branches with leaves. If higher resolution is required, than higher frequency deviation and probably higher carrier frequency should be used. However, this will increase the cost and complexity of the FMCWR but can help to reduce antennas size. We suggest to use up to 10 GHz carrier frequencies to build a cheap FMCWR for vertical assisted landing system development which operation will not be affected by sand and dust clouds, show or rain.

Mapping the raw spectrum of the transformed signal can disorientate the operator, so it is advisable to perform additional signal processing in order to improve its perception by the pilot (operator) [13], [14].

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