GENERATORS, ANTENNAS AND REGISTRATOR FOR UWB RADAR APPLICATION

Alexandr Andriianov, Life Sensor Co., Ltd. E-mail: andriianov@lifesensor.co.jp

AIOS Gotanda Annex Bldg.#704, 1-7-11 Higashi Gotanda, Shinagawa-ku, Tokyo, 141-0022, Japan

Tel: 81-3-5449-2337 www.lifesensor.co.jp

Abstract

This paper describes the basic elements developed for realization of the UWB radar: generators, antennas and registrator. Generators produce UWB signals of nano- and picosecond duration, having the form of step-like function, a monopulse, a pulse in the form of sine wave single period (monocycle). Fulfillment of FCC requirements to radiation require using of filtration UWB signals spectrum, which results in distortions of the waveform. It is shown, that a filtration of a sine wave single period pulses of 0.2ns duration provides the slight distortions. Description of TEM broadband shielded horn antenna with low side and back pattern lobes is given. Registrator for reception of UWB signals and software for secondary signal processing are described.

Keywords: UWB signal, radar, generator, antenna, registrator, subsurface, emission, spectral density.

1. INTRODUCTION

The devices for object sensing by ultra wideband (UWB) signals have got a widely spread application since 1978 [1,2]. The following devices such as time domain reflectometers (TDR), subsurface radars, radars for thru-walls imaging, antenna measurement systems in time domain are used in different applications.

TDR are used for investigation of the transmission lines and are applied not only to locate of discontinuity places and quality estimate of their character (capacity, inductance), but also for broadband measurement of the amplitude and phase-frequency characteristics (VSWR, attenuation), dielectric permittivity [3] and humidity.

Radars with UWB signals have the high spatial resolution, small power consumption and allow getting images of objects [1,4]. The restriction to spectral power density for emitting UWB signals, introduced by Federal Communication Commission (FCC) of the United States, however limited UWB device possibilities, but still allowed to solve the wide area of problems: search of alive people, location of people movement behind walls, search of mines, etc.

Time domain systems for antennas measuring become more and more attractive for wide area of application [5] due to low cost, faster measurement time especially for research of broadband and super broadband antennas in contrast to direct frequency measuring. The merit of a time domain method is the opportunity of simultaneous measurement of antenna parameters in a wide range of frequencies and to carry out time selection of the signals, allowing eliminating the expensive anechoic chambers.

In the present report the description of UWB signals generators, antennas, and subsurface radar allowing solving the wide area of technical problems is described.

As waveforms of UWB signals differ in these systems the description of three generator options is given in section 2. The TEM shielded horn antennas for radiating and receiving UWB signals are described in section 3. The universal registrator and the radar on its basis with the characteristics close to potential ones are described in section 4.

2. GENERATORS OF UWB SIGNALS

Field of application of generators depends from its spectral density. Three groups of generators can be specified. The first group is generators with the most uniform spectrum. They are used in measurements of antennas and super broadband characteristics of objects. Second group includes generators with the waveform of step like function. This type of waveforms is usually used in TDR. Third group is the monocycle generators. The monocycle signals with slow distortion are radiated by broadband antennas and are used in the UWB radar. The output circuits of the generators are mostly carried out on step recovery diodes. Specifications of generators with the various output waveforms are summarized in Table 1. Waveforms of generators signals and their spectrums are shown on Fig.1.

Generators PF-1-PF-4 with the output signals in a form of Gaussian function with additional small negative wave (monopulse) have the most uniform frequency spectrum and are intended for use as measuring for goals of objects frequency characteristics determination in time domain. Additional negative wave after a main impulse flattens out a signal spectrum. For example, at pulse duration of 30ps a drop in spectrum by 10dB is revealed just on the frequencies 25-30GHz. They are also used in systems for measuring of broadband antennas (high to low frequency ratio more than 10).

Generators PG-1 – PG-4 with the output signals in the form of step like function are used in TDR systems, for measurement of a characteristic impedance, a dielectric permittivity. This form signals show an increased spectral density on low frequencies. Model PG-4 is distinguished by small non-uniformity of the pulse top (0,3%) and can be used in systems that require high accuracy.

Generators PF1.1-PF5.1 with the output signals in a form of sine wave single period (monocycle) have got a spectral density concentrated near by some central frequency and are used in video pulse location systems as well as in UWB communications when the system bandwidth is limited.

Table 1 Characteristics of pulse generators

Model	A (V)	τ (ns)	A_V	Δ_A
PF-1	500	3-5		
PF-2	50	0,2-0,5		
PF-3	30	0,03		
PF-4	6	0,025		
PG-1	30	0,05	0,15A	0,05A
PG-2	10	0.035	0,05A	0,03A
PG-3	5	0,02	0,05A	0,03A
PG-4	0,2	0,02	0,03A	0,003A
PF-1.1	300	8		
PF-2.1	200	4		
PF-3.1	40	1		
PF-4.1	25	0,5		
PF-5.1	10	0,2		

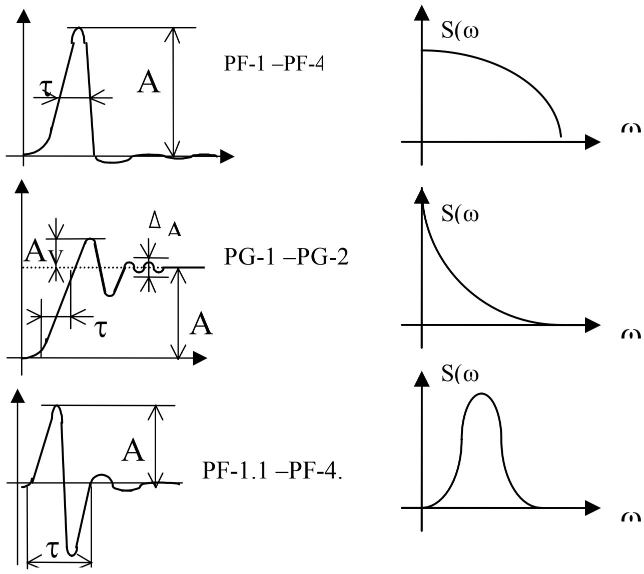

Fig.1 UWB signals in time and frequency domain

In connection with the emission limits on UWB signals for thru-wall imaging and surveillance systems introduced by FCC 02-48 we have investigated changes in signal waveform of a sine wave single period at it transition through band pass filter. As result optimal filter (Fig.2) was designed that provide the output spectrum met requirements of the above-mentioned restriction. On illustration below result of passing through the filter of ideal monocycle signal weighted by a window in the form of cosine is presented and experimentally achieved waveform with a spectrum, corresponding the emission requirements. Restriction of low frequencies band results in some lengthening a pulse, but does not effect essentially to distortion of the form.

3. ANTENNAS FOR UWB SIGNALS

The most popular antennas used to receive and transmit UWB signals include dipoles, biconicals, ridget horns and TEM horns. For radiation and reception of UWB signals it is convenient to use TEM horn antennas that don't have the low cut off frequency and have the wide bandwidth, high gain and a linear phase characteristic. The main disadvantage of TEM antenna is a significant level of side and back lobes in a radiation pattern.

For overcoming this problem the shielded TEM antennas of 0,5-6GHz and 1-18GHz bandwidth having considerably better radiation patterns have been developed. Antennas have a dielectric filling (permittivity ≈ 2) and can be used both for airborne and ground operation. The voltage standing-wave ratio (VSWR) and gain (G) plots in a frequency range of from 1 to 18GHz as well as the E plane pattern of this antenna are shown on the Fig.3.

Specification of the 1-18 GHz antenna:

1. Frequency range: 1- 18 GHz.
2. Gain: 5 – 15 dB.
3. VSWR: no more 2.
4. Polarization: linear.
5. Weight: 2.5 kg.
6. Dimensions: 130*160*260 mm.

The large back lobe exists only on frequencies below 2 GHz. The 0.5–6 GHz frequency range antenna has similar characteristics, but the larger size (300*255*465mm).

Despite of some increase in weight the dielectric filling of antenna allows to reduce the sizes and to improve quality of the signals waveform.

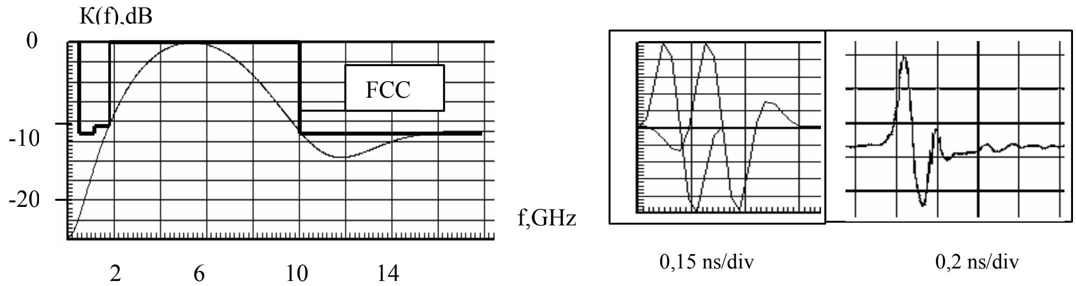

Fig.2. Frequency characteristic of the additional filter and its effect on distortion of a pulse signal. At the left oscillogram of the experimentally obtained pulse of 0,2 ns duration is shown

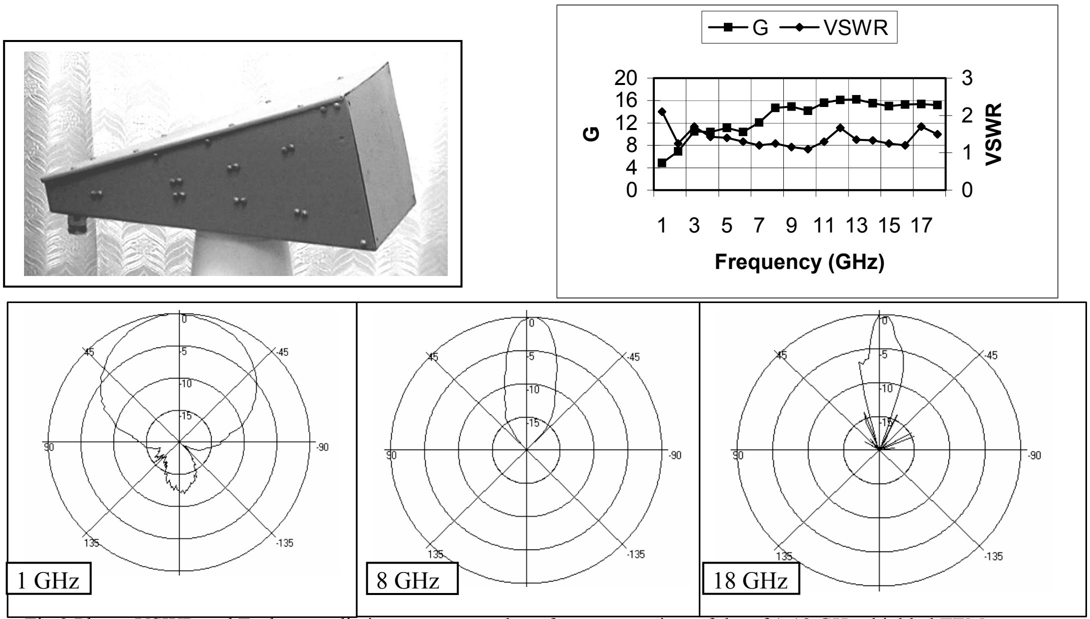

Fig.3 Photo, VSWR and E-planes radiation patterns on three frequency points of the of 1-18 GHz shielded TEM antenna

4. HIGH RESOLUTION RADAR GPHR-02

Universal radar for objects remote probing was developed (Fig.4). When the radar is moving over a surface to provide reflected signal discretization there is used a sampling conversion of HF signal in to LF with subsequent analog to digital converter (ADC). One point on depth is written in registrator memory for one period of a signal repetition. In comparison with direct ADC application it provides a decrease in power consumption and increase in signal-to-noise ratio. Special pseudo-random time modulation is used for channelization and reduction of influence by other radio devices. Pseudo-random time modulation makes UWB signal appear indistinguishable from white noise. Knowledge time-hopping code allows to form the same pulse sequence in the receiver and to detect a reflected signal.

Radar can work with one, two and several (up to 12) antennas. Antennas could be for airborne or ground use. Radar consists of the antenna system, the registrator and portable PC. Specification of the registrator is shown in Table 2. For multichannel radar realization (with many spatial separated antennas) the special high-speed switch on 12 channels is used. A frequency range of the switch - 0,5-5GHz, time of channels switching - no more than 300ns. Let us estimate the radar energy potential for various applications.

Energy potential of radar D is equal to ratio of probing signal spectral density to noise spectral density. For determined by FCC emission level S and sine wave single period pulse with a duration τ average power can be estimated from equation $Pav = S/\tau$. Energy of periodic pulse sequence accumulated in integrator at correlation receiver (correlator). Time of integration depends on speed of information change and is proportional to interval T of discretization. Spectral density of signal in a bandwidth F=1/2T, is equal $Pavs=S2T/\tau$. Ratio $2T/\tau$ represents gain of correlation receiver. Spectral density of thermal noise is equal to kTo where To–absolute temperature, k-is the Boltzman's constant. Energy potential equals to ratio of signal to noise spectral densities, so far bandwidth of 1Hz is equal

$$D = S + 10\lg 2T/\tau - 10\lg kTo - R_T - I$$

where R_T-noise figure of receiver, I–implementation loss including phase noise, filter distortion etc.

For $T=290^o$, kTo =-174 dBm, S=-101dBm/Hz, R_T=6dB, I=4dB, $D \approx 63+10\lg T/\tau$, dB

Table 2 Registrator specification

Parameter	Value
Pulse width	0.2-5 ns
Bandwidth	0.1-10 GHz
Sweep number points	128-1024
Measuring time interval	200 ns
Pulse repetition frequency	1 MHz
Interface	LPT port
Supply	12V, 1 A
Dimensions	26*210*80 mm
Mass	2 kg

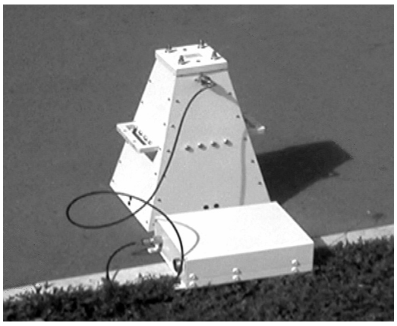

Fig.4 Photograph of GPHR -02 radar with 0.5-6 GHz TEM antenna

Thus the energy potential of radar with a sensing signal corresponding in spectral density to requirements FCC-02-48, 0,2ns duration and 1MHz digitization frequency is equal to 103dB. At digitization frequency of 10Hz potential is equal to 153dB. These estimations take into account only thermal component of noise. Actually the potential is limited additionally by presence of jitter, pulsations, and external noise. It can be taken into account by factor I. Radar GPHR-02 at frequency of digitization of 1 MHz forms a probing signal as pseudo-random sequence and has potential around of 100dB. Depending on quantity and the position of antennas it is possible to build monostatic, bistatic, ground and airborne version of radar.

The bistatic version of radar has two antennas. The advantages of this option are in a fact that the receiving and transmitting antennas are separated and realization of a high energy potential (ratio of the power generator to noise of the receiving device) is possible. Other positive property of bistatic option is the ability to measure permittivity and speed of signals propagation in ground layers using a method of a Wide Angle Refraction and Reflection (WARR).

The monostatic version of realization has a single antenna. This antenna is more compact, and the delay of the signals reflected from objects is proportional to their depth. A drawback of this version is complexity of isolation of the generator from the receiver. As a rule, energy potential of the given circuit is worse by 10-20dB.

The location of antennas on the ground provides the best matching with medium. Practically all the energy, radiated by antennas is absorbed by subsurface medium. However, the antenna movement over a surface limits a speed of a movement and in some cases does not allow to carry out measurements (rough ground, bush, high grass).

When the antennas are lifted above a surface (the operation from air) it is possible to move them with higher speed in a car automobile or in a helicopter. Additional reflection from transition the air - medium is characterized by reflection factor $K = Uo/Us = (1-\sqrt{\varepsilon}) / (1 +\sqrt{\varepsilon})$, where ε - permittivity of the medium, Uo and Us are amplitudes of the reflected and sounding wave. K = 0,38 for dry medium with ε =5 and K = 0,8 for a water surface with ε = 81. Besides, the useful signal is attenuated due to finite directivity of antennas. The realization of antennas with narrow pattern (up to ten degrees) and amplification more than 30dB requires creation of the apertures in several wavelengths that is very difficult at frequency range below 200MHz.

The software providing primary and secondary data processing is developed. Primary processing of the information is the data processing that is carried out in rate of reception of signals.

Primary processing of the information allows to change number of points of signal registration, to average signals, to transform a time scale to a scale of distances, to carry out time amplification of signals with the purpose of compensation losses in the media, to transform a peak scale to color scale, to display the information as one or several realizations or as the two-dimensional color image.

The secondary processing is performed on a data of a file written into a computer memory and requires a significant time. The program package GDW (Geo Data for Windows) for secondary processing allows performing many operations. The basic GDW algorithms for improvement of the radar characteristics include Hilbert transform, aperture synthesis and inverse filtration. Hilbert transform is used for extracting the positive envelope of signals.

To achieve high characteristics of radar on a depth resolution it is necessary to have hardware function (HF) of radar close to ideal, described by Dirac function. On practice real HF equals to convolution of generator signal and impulse characteristic of receiver including antennas is usually far from ideal. Therefore we use inverse filter (IF) to achieve the required results. IF is performed with FFT algorithm. Spectrum of reflected signals is calculated and is divided by spectrum of HF. Since realization of IF belongs to incorrect problems of mathematical physics to limits dispersion of noise after filtering special windows is used.

The substantial increase of resolution on longitudinal surface coordinate can be obtained with the algorithm of the aperture synthesis of the hypothetical antenna with a large effective area. The essence of algorithm consists in summing reflected signals with delays appropriate to signal propagation time in each point of surface.

The 3D viewer program allows looking through the data at two-dimensional measurements on a surface. Localization of objects in the set layer is carried out by means of markers. As illustration of this method for information displaying on Fig 5 is shown the result of experimental research of a sandy ground (sizes of 2*1m) with dielectric mines TS-2.5, TS-6.1, on depth 70 and 120 mm. On crossing of markers one could see mine TS-6.1

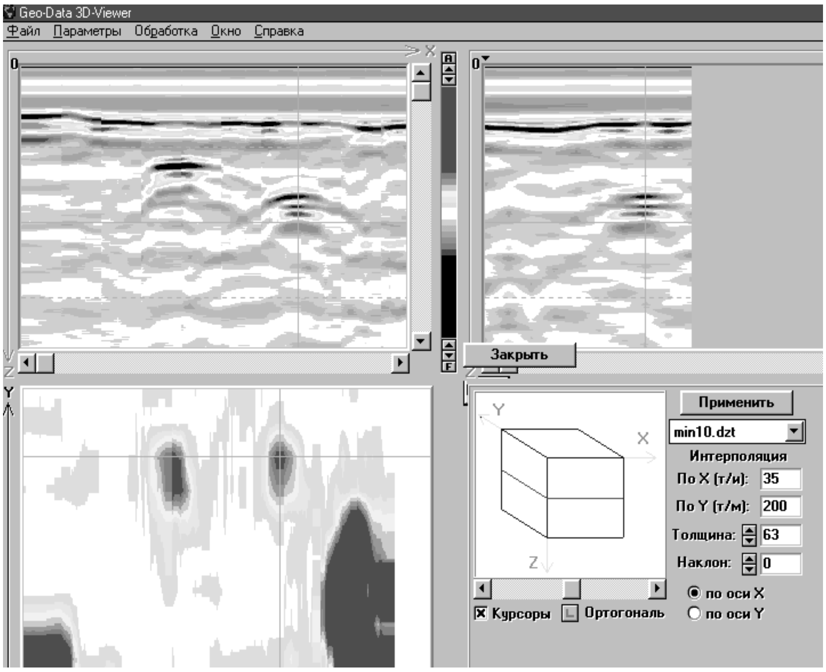

Fig. 5. Displaying of the information with subsurface objects as three projections. Cube below on the right shows a position of central plane of the layer displayed in coordinates X-Y

5. Conclusion

The description of basic elements for realization of devices for sensing of objects by UWB signals is presented. The estimation of UWB signal distortions and energy potential with emission limits corresponding to requirements FCC 02-48 for radar imaging system is carried out.

Radar GPHR-02 described in article has high spatial resolution, close to potential characteristics and can be used for thickness definition of dielectric media: asphalt, concrete, brick walls, thru-wall object imaging and so on.

Using in radar an optimal receiving technique such as correlator with time gating multiplier and output integrator provide huge dynamic range of radar.

The software package Geo-Data for Windows for secondary data processing essentially expanding functionality of the device and allows: filtration on spatial coordinates, inverse filtration, allocation of layers, synthesis of antenna aperture etc. The program of three-dimensional processing 3-D viewer is convenient for objects research at scanning on area, allowing to objects analyzes in various layers.

6. References

1. C.L.Bennett, G.F.Ross, Time-domain electromagnetics and it’s applications. Proc.IEEE, v.66, no.3, p.299-318, March 1978.
2. T.W.Barrett. History of ultra wide band communications and radar. Microwave J., v.44, Part 1 no 1, p.22, January, Part 2 no 2, p.22 February, 2001.
3. A.V. Andriianov. Time-domain reflectometers for dielectric material investigations. 1 st International conference on dielectric Spectroscopy. Books of abstracts. Jerusalem, 2001, p.23.
4. A.V. Andriianov, A.Y. Grinev, A.I. Giboko. Radar image forming via spectral method. Proc. 12 International conference on Microwave Technique and Communications. Sevastopol, p. 581-582, Sept. 2002.
5. A.V. Andriianov. Antenna measurement time-domain system. Proc. 13 International conference on Microwave Technique and Communications. Sevastopol, p.652-654. Sept. 2003