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Budapest University of Technology and Economics
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Radar and Satellite Applications of Radio and Antenna Systems

Summary of PhD Theses

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Contents

1 Calibration Process Optimization of Transmitter Antenna Systems

1.1 Research Background

It is well known, that the far field radiation pattern of an antenna is the two dimensional Fourier transform of the amplitude and phase distribution on the antenna aperture. In case of conventional antennas, this amplitude and phase distribution is determined by the mechanical construction, and it is very difficult or impossible to change electronically. If an antenna system is used, where several (2, 4, 8...) elementary antennas are placed close to each other (e.g. at half wavelength distance) and driven by their own transmitter channels, the overall radiation pattern of the antenna system can be changed or formed electronically.

1.2 Research Objectives

The aim was to realize such an antenna system, whose radiation pattern can be controlled electronically without a mechanical antenna rotator. Thanks to electronic control (the amplitude and the phase transmission of each transmitter channel can be adjusted electronically), the main radiation direction, the null-point direction and distribution, the side-lobe level and its distribution can be changed and formed in milliseconds.

1.3 New Scientific Results - Thesis 1.

Based on the transfer characteristics of transmitter channels of microwave transmitter antenna systems, I have introduced a new automated measurement method: applying a complex calibration matrix extrapolation, I have decreased the measuring time of the calibration by several orders of magnitude. Beside this, I have ascertained that concerning control (linear control in amplitude and Spline interpolation control in phase), my method provides better results of calibration-matrix extrapolation than known methods.

Explanation

Based on the transfer characteristics of transmitter channels of microwave transmitter antenna systems, I have determined a minimum number of control points necessary to make the radiation pattern of the controlled antenna system to approximate best the ideal computed radiation pattern. The difference was less than 1 dB in amplitude and less than 1 degrees in direction for the cases of the main lobe, the side lobes and the null directions as well.

With these minimum number of control points, I have developed an automated measurement method to calibrate the transmitter channels of transmitter antenna systems.

Applying a 2-dimensional complex matrix extrapolation method, I have decreased the calibration measuring time of transmitter channels by several orders of magnitude.

I have demonstrated that the optimal solution for extrapolating the calibration matrices is to apply together a linear interpolation in amplitude control and Spline interpolation in phase control.

I have demonstrated both by laboratory and in-situ measurements, that by applying the results of extrapolated calibration measurements, microwave transmitter antenna systems work correctly in practice.

Publications related to Thesis 1:

LIKF: [1],[2], RINK: [4],[5],[6],[7],[8],[9],[10],[11],[12], RIHK: [23],[24],[25], NRK: [29],[30].

2 Radartester

2.1 Research background

To monitor an ATC (Air Traffic Control) radar in operation, usually special connectors (so-called service connectors) are placed inside the radar instrument. Connecting certain measurement instruments, the different radar parameters (not all) can be monitored. Though, literature can be found about similar radar testers, but the adjustable parameters of their imitated target, so the quantity and quality of the testable radar features are limited.

2.2 Research Objectives

The target was to develop a radar tester which can monitor the functions of air traffic control radars. It is very important to be able to monitor the radar during normal operation, i.e. there is no need to remove it from the air traffic control system during the testing and measurement time. As the radar tester is installed at a certain distance from the radar itself, the imitated target has not only relative but absolute calibration concerning the RCS (radar cross section). In practice, this means that during the calibration process, absolute RCS values can be generated with the radar tester, in other words, the radar cross section of the imitated target can be adjusted from the size of a bird to the size of a fighter-bomber.

2.3 New Scientific Results - Thesis 2.

Based on a digital intermediate frequency (IF) unit, I have introduced a novel radar testing method for air traffic control far-field primer radars, which is capable of testing and carrying out qualifying measurements during the radar operation. I have demonstrated both by laboratory and in-situ measurements that the introduced radar testing method is applicable for testing both magnetron-based impulse and semiconductor-based pulse-compression (spread-spectrum) Air Traffic Control radars.

Explanation

The radar tester equipment is installed at a certain distance from the ATC radar itself; after installation, only one calibration and measurement procedure is needed to match to the radar by adjusting the signal levels, carrier frequencies and bandwidth. The only thing we must know about the testable radar is its nominal carrier frequency.

The tested loop contains the whole radar transmitter and receiver chain including antennas, transmission-lines, radio frequency-, intermediate frequency-, base band analogue and digital units; and the signal processing unit which generates hits, plots and tracks. The radar tester receives the RF (radio frequency) signal transmitted by the radar, and after modifying the signal parameters, retransmits it back to the direction of the radar. This means that there is no need to have any wired connections - no analogue nor digital - so the radar can be tested during normal operation, it is not necessary to detach it from the air traffic control system to carry out the measurements.

The imitated target has the following adjustable parameters: radar cross section of the imitated target - by adjusting the amplitude transmission (0.1 ... 100 m^2) of the digital IQ baseband signal channel; the velocity of the imitated target (relative to the radar) - by adjusting the frequency difference (0 ... 1000 m/s) of the local oscillators of the down- and upconverter of the digital IF unit; the distance of the imitated target from the radar - by adjusting the delay time of the digital IF unit (I-Q baseband FIFO length: 300 ... 380 000 m, with 150 m resolution); the fluctuation statistics of the imitated target - by the amplitude- and angle modulation of the I-Q baseband signal of the digital IF unit according to the Swerling 0-4 models (30 dB, 0 ... 360 degrees, 20 kHz bandwidth).
Thanks to the digital IF unit, the parameters of the imitated target and their fluctuation in time can be controlled digitally, which enables such target motion dynamics, that real flying objects does not have at present time. However, in the future, the presented radar tester will be able to measure radars for sensitivity concerning more advanced types of real target objects.

Publications related to Thesis 2:

LIKF: [3], RINK: [13],[14],[15],[16].

3 Soil Reflection-based Motion Estimator Radar

3.1 Research Objectives

The long-term aim of this research was to indicate and to detect (earlier than conventional sensors could) the drifting and the driving direction slip of a motor-vehicle, a truck or its tow during maneuvering, e.g. turning. The presented measurement system is capable of detecting and - in case of certain conditions - measuring the relative displacement of the soil to the vehicle.

Using the soil reflexion-based radar, the soil is irradiated by an X-band microwave Continuous Wave (CW) signal with its patch antennas, which are fixed to the bottom side of the vehicle (onto the chassis). The signals reflected back from the soil are received by a 2 + 2 coherent I-Q receiver. The received signals are loaded with additional amplitude and phase modulation caused by the surface irregularities depending on the soil type: pavement, dirt road, wet pavement, lawn etc. Creating a complex cross-correlation between the received signals, the relative motion (displacement) of the vehicle to the soil can be measured.

3.2 New Scientific Results - Thesis 3.

I have demonstrated both by laboratory and in-situ measurements that an active microwave CW Doppler radar with multiple coherent receiver channels is capable of measuring the relative displacement of a motor-vehicle or its tow; with the following assumptions: the measurable displacement should be minimum the half of the physical distance between the receiver antennas and in case of finite memory size, at least the time-domain holder of a displacement equal to the half-distance between receiver antennas must be smaller than the time-domain length of I-Q baseband signal pattern vectors (per channel) - the vectors which are used for the correlation calculating.

Explanation

The realized radar can measure two displacement vectors perpendicular to each other (2D displacement and the velocity vector) and the velocity calculated from them.

The resolution of the displacement- and velocity measurement is depending on the baseband sampling frequency and on the number of the correlated samples. The accuracy of the measurement is highly influenced by the microwave reflexion properties of the soil in issue (i.e. the more random the correlated signal, the more precise the measurement regarding both the displacement and the velocity calculated from it).

Publications Related to Thesis 3:

RINK: [17], NRK: [31].

4 The Communication Subsystem of Masat-1

4.1 Research Objectives

The development of Masat-1 picosatellite started in 2007 at the Faculty of Electrical Engineering and Informatics of Budapest University of Technology and Economics. This student initiative was taken up by the Department of Broadband Infocommunication and Electromagnetic Theory and the Department of Electron Devices. The whole design work was made by Hungarian engineers and engineering students, therefore Masat-1 is the first separate satellite of Hungary.

4.2 Research Obejctives

Masat-1 picosatellite is a 1U (1 unit) class cubesat: a 10x10x 10 cm cube, with the -that time- maximum allowed mass of 1 kg. The Masat-1 satellite itself, its communication system and the modulation and coded modulation processes of the communication subsystem is unique among cubesats. It means that among the 1-2-3 U size cubesats (10x10x10, 10x10x20 and 10x10x30 cm) there is no such a satellite which contained similar redundant subsystems for single-point failure, designed in order to produce a stable and reliable functioning.

4.3 New Scientific Results - Thesis 4.

I have introduced a novel application of spread spectrum modulation which was not, until now, applied on-board of LEO (Low Earth Orbit) satellites yet. The modulation was implemented in the redundant, single-point failure tolerant, single-chip transceiver-based communication subsystem of Masat-1, the first Hungarian satellite. The aims are to make the satellite detectable in case of a probable failure of the on-board antenna; and to synchronize the asynchronous Earth-satellite communication subsystem in time-domain - which is necessary to operate and control the satellite automatedly from the ground stations. Such application of the modulation process is unique at present time; the effectiveness of this process is proven by 1061 days of the Masat-1 in operation. As opposed to conventional usage, the use of this new modulation in practice did not resulted in an increasing bandwidth, but decreased the effective transmission data rate (the usable bandwidth was 2400 Hz so the 1250 bit/s was transformed into a 1 bit/s on the output of the correlator). For that reason, we have achieved that the satellite signals *can be detected having several orders of magnitude lower signal power level compared to the thermal noise power level existing on the given bandwidth.*

Explanation

The communication system of Masat-1 included a GMSK (Gaussian Minimal Shift Keying) data package containing a binary code which enabled the detection of the satellite even 30 dB below the thermal noise power level - presuming a given, limited bandwidth. The GMSK data package was also used for the synchronization with the ground stations. The detection below the noise limit would have been used if the satellite antenna have not been opened and consequently its transmitted power would have decreased by at least 20 dBs.

Thanks to the thorough designing and testing, the on-board antenna successfully opened after 30 minutes from putting it to orbit out of the nosecone, so there was no need to apply the detection from below noise power level in practice. I have done only testing measurements concerning the radio detection below noise power level. A monopole antenna made of a space-qualified steel measuring-tape - tied rolled up in its box with a space-qualified fishing line - was opened by a thermal knife which has melted the fishing line during 8.3 seconds).

The Masat-1 is unique in the cubesat category also concerning the amount of downloaded data, thus we have downloaded multiple times more data from Masat-1 than all other Low Earth Orbiting satellites - which were functioning at least during some time - until this day.

Publications related to Thesis 4:

RINK: [18], [19], [20], RMHK: [26], [27].

5 The Communication and the Spectrum Monitoring Systems of the Smog-1 Satellite

5.1 Antecendent of the Research

Following the Masat-1 on the educational domain, we have started a new project in 2014 with creating Smog-1, a PocketQube-class satellite having eight times smaller volume, 5x5x5 cm size and a maximum of 250 g mass.

5.2 Research Objectives

1. The primary aim of the mission of Smog-1 is to measure the electromagnetic pollution near the Earth in the Digital Video Broadcasting Terrestrial (460-860 MHz) frequency band, generated by mankind as digital television transmission.

2. The secondary target is to confirm the effectiveness of a total ionizing dose measurement unit belonging to the electrical power system of the Smog-1. It means that by monitoring the high energy ionizing radiation coming from the Sun, the operation lifetime of the redundant on-board electronics can be estimated.

3. The tertiary target of Smog-1 mission is to demonstrate the orbit lifetime reducer effect of special magnetic materials built between the solar cells and side covering plates. This solution is made to minimize the duration of the satellite being space debris (the time from the overall failure of the redundant on-board electronics until the satellite is destroyed in the atmosphere).

5.3 New Scientific Results - Thesis 5.

Fulfilling national and international environmental requirements I have worked out the redundant, single-point of failure tolerant, intelligent communication and spectrum monitoring system of Smog-1 PocketQube, I have executed qualifying measurements on the whole system, and I calibrated its broadband on-board antenna with a measurement system.
For the relevance of the primary mission target of Smog-1, I have demonstrated by results of in-situ balloon measurements, that there is a high extent human-made radio frequency pollution in the higher atmosphere - and supposedly in space as well - in the digital video broadcasting terrestrial band.

Explanation
Smog-1 is a 5 cm cubic PocketQube class satellite, which is a special, unique and cost-effective solution with regard to both its existence and mission, and as a forerunner of a global spectrum monitoring system, measuring - with Gaussian-monostatic arrangement - the electromagnetic fields with fast-varying polarization in the near future. The primary aim of the satellite is to draw a map about human-originated radio frequency pollution around the Earth while on low earth orbit.

Both by laboratory and in-situ measurements, I have demonstrated the proper functioning of redundant systems:

- I have demonstrated that the communication system is capable of keeping contact with the automated and remote-controlled ground stations according to the parameters defined in the frequency licence.

- As the preliminary balloon experiment of Smog-1, with the measurement results of the spectrum monitoring system I have demonstrated that human-made radio frequency pollution really present in the higher atmosphere, and can be detected globally during orbiting on LEO, thus the DVB-T signals, as they are in the 460-860 MHz frequency range, are also radiated freely to space. These signals make LEO satellites harder to control, in addition, it is a waste of power - therefore can be called an RF smog. The mission of Smog-1 is to execute spectrum monitoring measurements in the DVB-T band in the area around the Earth.

Until now, a functioning satellite of 1P size (5 x 5 x 5 cm) does not exist in space, i.e. Smog-1 is (will be) unique both in its existence and mission. Even a redundant and single-point failure tolerant design is not typical in the cubesat class (10 x 10 x 10 cm) either (Masat-1 is an exception), but the application of distributed intelligence (every subsystem has its own micro controller) is not common as well.

Publications related to Thesis 5:

RINK: [21], [22], RMHK: [28].

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The list of publications not stricty related to the Theses can be found in the full Ph.D. dissertation.

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