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Design of A Novel Vessel Monitoring System Using Satellites

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ABSTRACT

In this paper, a novel status data communications system is proposed and designed for monitoring vessels. The idea of the system is to build an information transceiver system for maritime vehicles similar to the Automatic Identification System but more active. The transmitter is automatically able to switch the suitable power level and the operating frequency from VHF/UHF band when at short distance to the shore to S band when at long distance to the shore to communicate with satellites. The receiver uses a low noise amplifier that based on a balanced configuration with some advantages. The calculated ship-to-satellite link budget when using S-band shows that the received power at satellite better than the one of the conventional system. The status data of the vessels are gathered at a ground station and displayed on a map to track their signs. The fundamental characteristic of the implemented system has been measured and vertified.

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1. INTRODUCTION

The Automatic Identification System (AIS) is a maritime navigation safety communications system standardized by the International Telecommunications Union (ITU) and adopted by the International Maritime Organization (IMO). The main purpose of AIS is to exchange messages among ships, and between ships and shore stations. Each massage provides vessel information including identity, position, type, speed, navigational status and other safety related information. The AIS receivers on ships or shore stations detect this information and show a comprehensive picture of the local environment, complementary to the radar information. The operational frequency of AIS is 161.975 MHz and 162.025 MHz. However, due to the curvature of the Earth, the communications range is limited to approximately 20 to 30 nautical miles (37 to 55 km) under atmospheric conditions [1], [2]. According to [2], requirements of the long-range applications such as better handling of hazardous cargo, improved security, and countering illegal operations suggest a need to detect approaching ships at distances of 200 nautical miles (370 km) from shore and beyond. And this reference also introduces satellite detection of AIS as one means of accomplishing long range ship detection. AIS signals can now be detected by satellites in low earth orbit and provide a global capability for monitoring all AIS-equipped vessels using a satellite constellation and an extensive network of ground stations. Satellite AIS is relatively new technology that has changed the landscape for monitoring the maritime domain. Improving upon existing technology has already deployed aboard most of large vessels across the globe, Satellite AIS is truly revolutionary in providing a complete and global picture of the world's shipping [3]. Although satellite technology has advantages in signal receiving in global scale, AIS system has the main mission of exchanging messages among ships and between ships and earth stations. Thus receiving AIS signal on satellites is still dealing with many difficulties. Firstly, most ships use some kind of monopole antennas, hence their zenith radiation is already quite limited [4]. Therefore, the strength of signal at nadir is typically insuficient to be received by satellite. Secondly, the maximum transmitting power of AIS devices on ships is set at a mere 12.5 W [4]. Thirdly, operating frequencies of AIS devices are 161.975 MHz or 162.025 MHz, which could be absorbed by the ionosphere. Reference [4] also presents several methods to enhance AIS signal receiving efficiency of satellites.

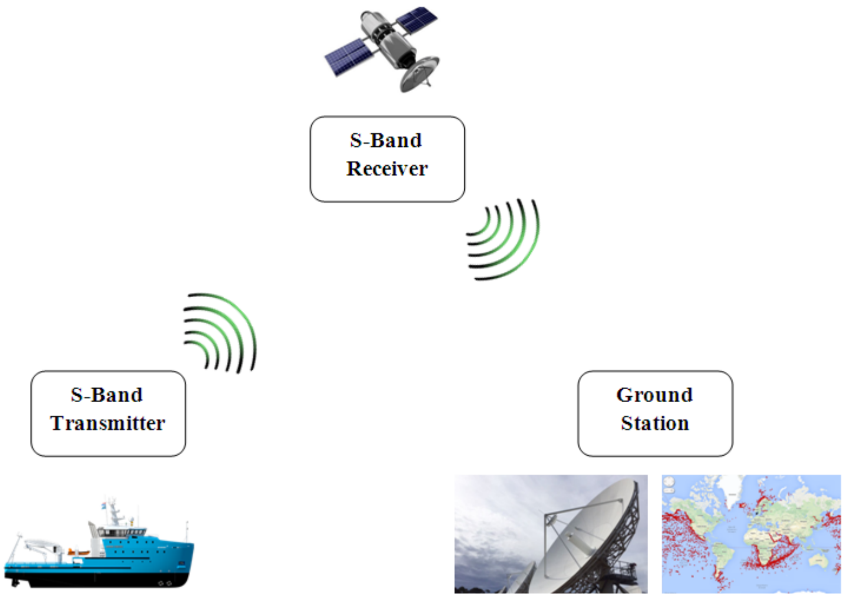

Figure 1. The proposed vessel status data communications system

Table 1. Comparison of the Ship-to-satellite link budget at VHF band and S band

Parameters	Conventional	proposed
Satellite altitude	950	*950*
Frequency (MHz)	161.975 or 162.025	*2000*
Satellite antenna off-axis angle (degrees)	60.5	*60.5*
Maximum slant range (Km)	3606	*3606*
Maximum surface range (Km)	3281	*3281*
Transmit power (dBm)	41 (12.5 W)	*49.54 (90 W)*
Transmit antenna gain (dBi)	2.0	*17 [6]*
Effective Isotropic Radiated Power (EIRP:dBm)	40.47	*64.04*
Transmit cable and miscellaneous losses (dB)	3.0	*3.0*
Free space propagation loss at maximum range (dB)	147.8	*169.6*
Polarization mismatch loss (dB)	3.0	*3.0*
Satellite antenna gain at the horizon (dBi)	1.6	*8.3 [7]*
Satellite RF line/filter losses (dB)	2.5	*2.5*
Received power at satellite (dBm)	-111.7	*-103.26*

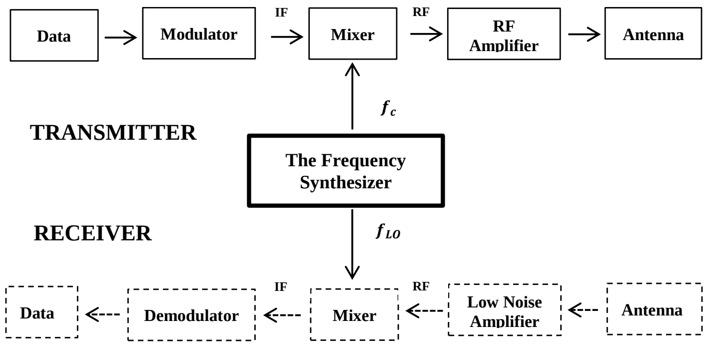

Figure 2. The status data transmitting system

The idea of the proposed system is to build an information transceiver system for maritime vehicles similar to AIS system but more active. The transmitting part can automatically switch the suitable power level and the operating frequency from VHF/UHF band when at short distance to the shore to S band when at long distance to the shore to communicate with satellites as illustrated in Fig. 2. The conventional Ship-to-Satellite link budget was presented in [2]. Ref [5] shows how to calculate a link budget. The S-band Ship-to-Satellite link budget is also estimated in this paper. The comparision of the Ship-to-Satellite link budget at VHF band and S band is proposed in Table 1. In this table, when the system operates at S-band, the free space propagation loss is more than that at VHF-band. However, there are some advantages such as better gain antenna and higher power level. These make the received power at satellite better (-103.26 dBm instead of -111.7 dBm) . On the other hand, the dimensions are minimized because of the wavelength. In this paper, a S-band communications system is designed and fabricated with -113 dBm sensitivity of the receiver. In case of using the system, the net margin of the system will be about 10 . This is a good margin to ensure the system's operational reliability.

In this paper, we are going to present the designs and measurement results of a status data communications system for monitoring vessels. The system is able to flexibly change the transmitting parameters such as frequency, power level, mode of modulation, and state of a vehicle. The receiver uses a low noise amplifier that based on a balanced configuration. The paper is organized as follow. Section 2 introduces the architectures of the proposed status data transmitter including detailed descriptions of each building block. Section 3 introduces the architectures of the proposed status data receiver. Conclusions are given in the last section.

2. DESIGN OF THE STATUS DATA TRANSMITTER ON VESSELS

The information is packed into data frames including the identification, longitude, latitude, and state of a vessel (<GPS>, <ID>, <LAT>, <LONG>,<SOS>). The proposed status module uses ADF7021 transceiver from Analog Device to process the data. The ADF7021 transceiver is a high performance, low power, highly integrated 2FSK, 3FSK, 4FSK, MSK, GMSK transceiver. It is designed to operate in the narrow-band, license-free ISM bands, and in the licensed bands with frequency ranges from 80 MHz to 650 MHz and 862 MHz to 950 MHz. This device has both Gaussian and raised cosine transmitting data filtering options to improve spectral efficiency for narrow-band applications. A LC bandpass filter was designed to have 50 dB out-of-band attenuation for the suppression of harmonics. In this design, the status data module is integrated with a LTC5510 mixer from Linear Technology. The LTC5510 is a high linearity mixer optimized for applications requiring very wide input bandwidth, low distortion, and low LO leakage. The mixer includes a double-balanced active mixer with an input buffer and a high speed LO amplifier. The input is optimized to use with 1:1 transmission line baluns, allowing very wideband impedance matching. Measurement results of the status module were presented in [8]. The frequency synthesizer based on the ADF4350's integrated PLL and the STM32F103C8 microcontroller are designed and implemented [9],[10]. The 80 W and 130 W power amplifiers were presented in [11] and [12], respectively. The simulation results were obtained using a well-known professional design software for microwave engineering, Advanced Design System 2009. The performance of the power amplifier modules were verified experimentally using a vector network analyzer. We use a horn antenna and have applied the beveling technique to control the impedance bandwidth and increase the bandwidth with good control of the edge frequency. The structure of transmitter was shown as in Fig. 2 and presented in as in [6].

Diem manh cua phan phat la kha nang chuyen tan linh hoat trong dai tan so bang S nho bo chuyen doi tan so bang rong. Ben canh do mot bo tien khuech dai bang rong duoc tinh toan va thiet ke nhu trong hinh Fig. 3. Bo tien

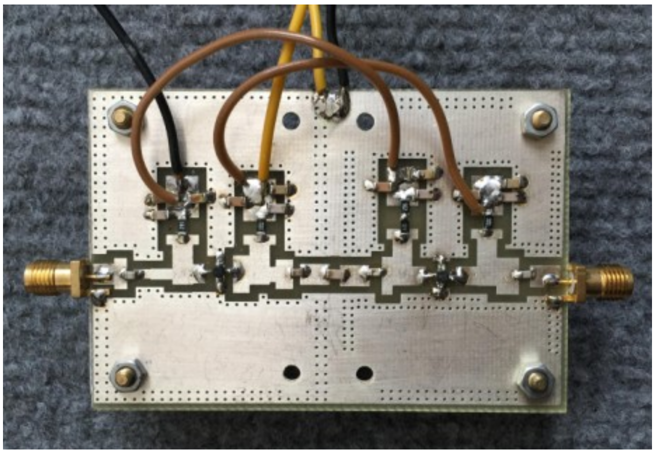

Figure 3. The proposed vessel status data communications system

khuech dai hoat dong full dai tan bang S voi he so khuech dai lon hon 10 dB, cong suat toi da 20 dBm.

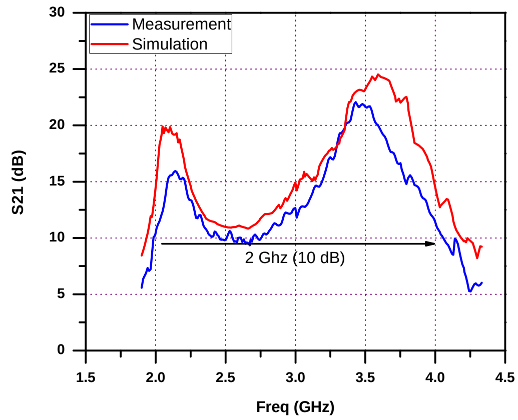

Figure 4. Comparision of gain factor (S21) between simulation and measurement

Ket qua so sanh he so khuech dai giua mo phong va ly thuyet duoc trinh bay nhu trong hinh Fig. 2

3. DESIGN OF THE STATUS DATA RECEIVER ON SATELLITES AND GROUND STATION

In this paper, the proposed LNA is composed of two stages as illustrated in Fig. 5. The first stage uses the balanced configuration to solve the return loss problem. The second stage is a single-stage amplifier to increase the total gain of the proposed module. The balanced amplifier circuit uses 90° couplers to cancel input and output reflections from two identical amplifiers. The first 90° hibrid coupler divides the input signal into two equal-amplitude components with a 90° phase difference. The second coupler recombines the amplifier outputs. Because of the phasing properties of the hybrid coupler, reflections from the amplifier inputs are canceled at the input of the hybrid, resulting in an improved impedance match; a similar effect occurs at the output of the balanced amplifier [13]. This type of circuit is more complex than a signle-stage amplifier since it requires two hybrid couplers and two separate amplifier sections. However, it has a number of interesting advantages such as improving input/output matching as well as the stability of the individual amplifiers, providing a redundancy and increasing the bandwidth.

Using the ADS software to calculate and simulate the proposed LNA at 2 GHz. The fabricated LNA is given in Fig. 6. Results are plotted in Fig. 7 and Fig. 8.

The simulated gain factor has been compared to that of measurement as depicted in Fig. 7. It is clear that the fabricated LNA has the maximum gain of 30 dB that is the same with the simulated result. The fabricated LNA uses two 1.7 - 2.3 GHz hybrid couplers. As a result, frequencies excluding the coupler's the frequency is suppressed. If the gain fatness is 0.2 dB, the bandwith will be 30 MHz and 130 MHz in case of 0.5 dB. The measured noise figure of

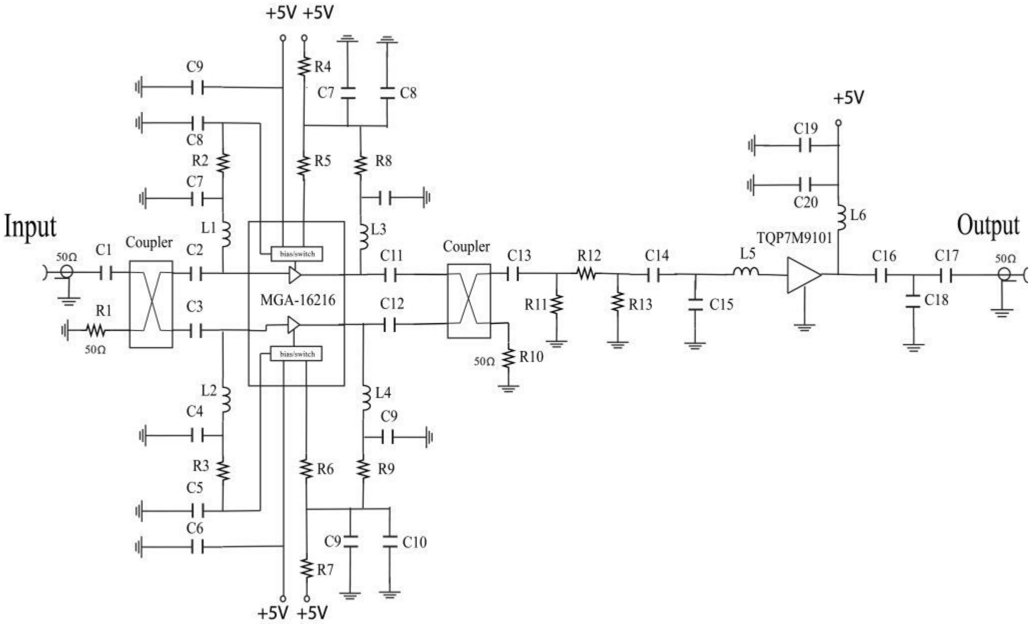

Figure 5. Structure of the proposed LNA

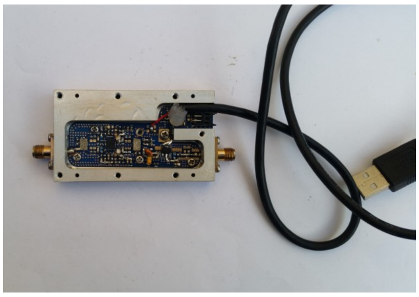

Figure 6. The fabricated LNA (7x4x1.2 cm)

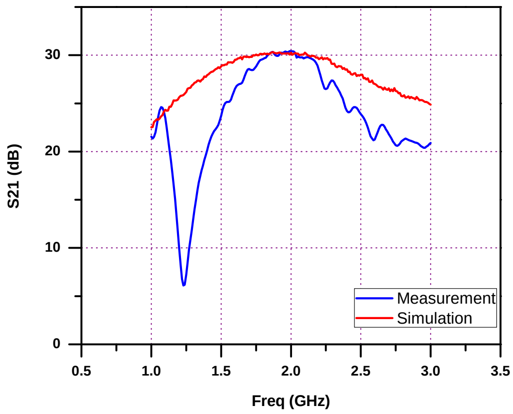

Figure 7. Comparision of gain factor (S21) between simulation and measurement

the LNA is shown in Fig. 8. The noise figure factor and P1dB at frequency from 1.9 GHz to 2.1 GHz are alternately about 1.5 and 23 dBm. Table 2 summaries the performance of the proposed low noise amplifier and compares it to

Table 2. Comparison with the recent published works

Ref	Freq(GHz)	Struc	Gain(dB)	Gain flatness(dB)	NF(dB)	P1dB(dBm)
Ref. [14]	2.15-2.65	Not balanced	28.1	0.57	Less than1 (meas)	18
Ref. [15]	2.9-3.1	Not balanced	30.87	0.5	1.18-1.37 (simu)	-
Ref. [16]	2.4	Not balanced	10.84	-	Less than 1 (simu)	-
Ref. [17]	3	Not balanced	23.71	-	6.17(meas)	-
Ref. [18]	1.85-1.95	Balanced	31	Less than 1	Less than 0.9 (simu)	-
This work	1.9-2.03	Balanced	30	0.5	1 (simu) and 1.5 (meas)	23

other published designs operating in a similar frequency range.

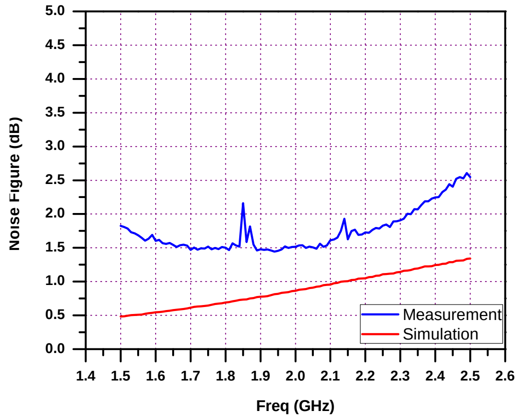

Figure 8. The measured noise figure of the proposed LNA

In this paper, the mixer is designed and fabricated at 300 MHz by using LTC5510. The LTC5510 is a high linearity active mixer optimized for applications requiring very wide input bandwidth, low distortion and low LO leakage. The IC includes a double-balanced active mixer with an input buffer and a high speed LO amplifier. LTC5510 can be used for both up and down coversion. It requires only 0 dBm of LO power to achieve excellent distortion and noise performance [23]. Fig. 9 investigates harmonics of the fabricated mixer. It is clear to see that there are no harmonics from 100 MHz to 1.49 GHz.

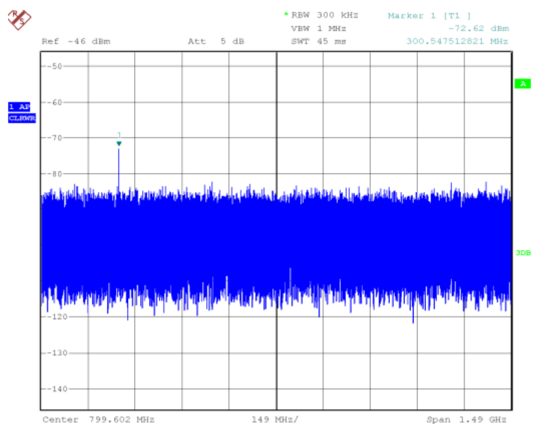

Figure 9. Measuring the hamornic of the mixer

We use ADF4350 IC to design a LO. The ADF4350 has an integrated VCO with a fundamental output frequency ranging from 2200 MHz to 4400 MHz. In addition, divide-by-1/2/4/8 or 16 circuits allow users to generate RF output frequencies as low as 137.5 MHz. Control of all the on-chip registers is through a simple 3-wire interface. The device operates with a power supply ranging from 3.0 V to 3.6 V and can be powered down when not in use [9].

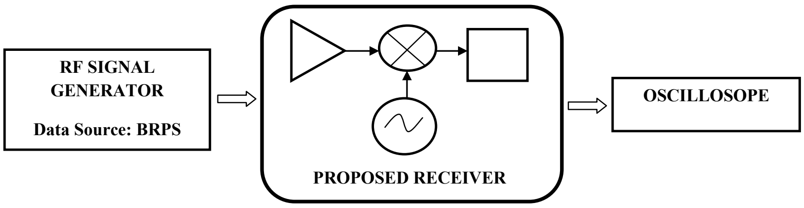

Figure 10. The sensitive measurement of the proposed receiver

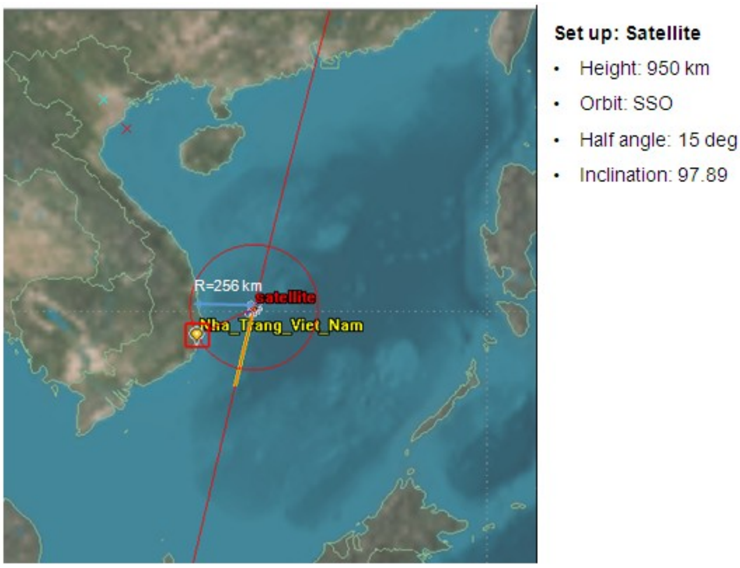

Figure 11. The proposed vessel status data communications system

The data processor demodulates and unpacks information from received messages. After processing, the detected information includes the identification, longitude, latitude and state of a vessel (<GPS>, <ID>, <LAT>, <LONG>,<SOS>). The proposed module uses ADF7021 transceiver to process the data. The ADF7021 transceiver from Analog Device is a high performance, low power, highly intergrated 2FSK, 3FSK, 4FSK, MSK, GMSK transceiver. It is designed to operate in the narrow-band, license-free ISM bands, and in the licensed bands with frequency ranged from 80 MHz to 650 MHz and from 862 MHz to 950 MHz. This device has both Gaussian and raised cosine transmitting data filtering options to improve spectral efficiency for narrow-band applications. The receiving parameters can be set up by using the touch screen of the control board.

The proposed S-band receiver and its sensitive measurement are given in Fig. 10. With the sensitivity of -113 dBm, the net margin of about 10, the system's operational reliability is possibly confirmed.

Hinh 11 mieu ta ket qua mo phong he thong neu tren khi su dung ve tinh nho voi quy dao 950 Km. Co the thay rang, voi viec su dung he thong bang S ket noi voi ve tinh co the mo rong vung kiem soat tu ban kinh 25 Km (he AIS thong thuong) den ban kinh 250 Km.

4. CONCLUSION

In this paper, a design of a novel vessel monitoring system using satellites has been presented. By changing the parameters automatically, the status data transmitting system is able to communicate with both satellites and stations, solving the communication distance issue. The transmitter on vessels can flexibly change the frequency in a wide range (from 600 MHz to 4.2 GHz) and the output power (up to 90 W). The local oscillator's stability over temperature and tolerance are comparable to TCXO that is about +/- 3 ppm by using using the phase-locked loop. Moreover, phase noise performance of the synthesizer is less than -90 dBc/Hz at 1 KHz and -100 dBc/Hz at 100 KHz. The impedance bandwidth of the horn antenna can be controlled by using the beveling technique. The status data module packs information of the identification, longitude, latitude, and state of the vessel into data frames. FSK/MSK/GMSK schemes were used to modulate the data. The receiver uses a low noise amplifier that based on a balanced configuration with some advantages such as gain flatness, NF and P1dB. With the sensitivity of -113 dBm, the net margin of about 10, the system's operational reliability is possibly confirmed. The status data of the vessels are gathered at a ground station and displayed on a map to track their signs. The fundamental characteristics of the system have been measured and vertified.

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Tuan Anh Vu received the B.S Degree and M.Sc Degree in Electronics and Telecommunications Technology from University of Engineering and Technology, Vietnam National University in 2006 and 2009, respectively. In 2013, he received Ph.D Degree in the field of analog/mixed-signal RF nano electronics from University of Oslo, Norway. Since 2014, he has been a lecturer at Faculty of Electronics and Telecommunications, VNU University of Engineering and Technology. Dr. Tuan Anh Vu was with Department of Semiconductor Electronics and Integration Science, Hiroshima University as a postdoctoral researcher for one year. He is now doing postdoc at Department of Electrical and Computer Engineering, University of California, Davis. His research interests are analog RF integrated circuit designs, energy harvesting, microwave engineering, etc.

Duong Bach Gia was born in Ha Dong Dist, Ha Noi Province, Viet Nam in 1950. He received the B.S degree in radio physics in 1972 and the Ph.D degree in wireless physics from University of HaNoi in 1988. From 1988 to 1990, he was a researcher assisstant in Leningrad University, Russia. From 1991 to 2005, he was a researcher in academy of air force. He has been a lecturer and head of electronics and telecommunications center, University of Engineering and Technology, Vietnam National University since 2006. He was promoted to Associate Professor in 2009 and to Professor in 2016. His research forcuses on RF analog singal processing, RF chip design, radar engineering and technology, automatic control. Email: duongbg@vnu.edu.vn