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Design of an S-Band Vessel Monitoring System Using Satellites

The Anh Nguyen Dinh*, Minh Ngo Duc*, Duong Bach Gia**

**Vietnam National Space Center – Vietnam Academy of Science and Technology,*
*** University of Engineering and Technology - Vietnam National University*

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 able to automatically switch to the suitable power level and the operating frequency from VHF/UHF bands for ship-to-shore communication to S-band for ship-shore satellite broadband connection. The receiver integrates a low noise amplifier that is designed based on a balanced configuration with several advantages such as high gain, high flatness, and low noise figure. The calculated ship-to-satellite link budget when using S-band shows that the received power at satellite is 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 location. The technical parameters of the system have been measured and verified.

Keywords: Marine communications, RF Amplifier, Satellites, VCO-PLL

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 purposes of AIS are to exchange messages among ships, and between ships and shore stations. Each message 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 frequencies of AIS are 161.975 MHz and 162.025 MHz. However, due to the curvature of the Earth, the communication range is limited within 20 to 30 nautical miles (37 to 56 km) range under atmospheric conditions [1], [2]. According to [2], the 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 distance of 200 nautical miles (370 km) from shore and beyond. 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 Improving upon existing technology has already deployed aboard most of the 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 at global scale, receiving AIS signal on satellite 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 insufficient 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 frequency of AIS devices is 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.

The idea of the proposed system is to build an information transceiver system for maritime vehicles similar to AIS system but more active. The transmitter is able to automatically switch to the suitable power level and the operating frequency from VHF/UHF bands for ship-to-shore communication at short distance to S-band for ship-shore satellite broadband connection at long distance as illustrated in Fig. 2. The conventional Ship-to-Satellite link budget was presented in [2]. Ref [5] introduces the method to calculate a link budget. The S-band Ship-to-Satellite link budget is also estimated in this paper. The comparison of the Ship-to-Satellite link budget in VHF band and S-band is proposed in Table 1. In this table, when the system operates in S-band, the free space propagation loss is higher than one that in 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. The receiver inside S-band communication system is designed and fabricated with -113 dBm sensitivity. 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 communication 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 is designed based on a balanced configuration.

Table I. Comparison of the Ship-to-Satellite Link Budget in VHF Band and S-Band

Parameter	**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 losss at maximum range (dB)	147.8	196.6
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

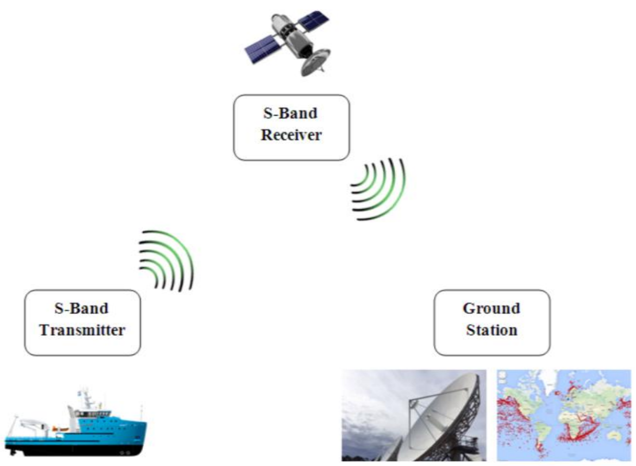


Figure 1. The proposed vessel status data communication system

The paper is organized as follows. Section 2 introduces the architectures of 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.

DESIGN OF THE STATUS DATA TRANSMITTER ON VESSELS

The status information of ships including identification, longitude, latitude, and state of vessel is packed into data frames as follows (<GPS>, <ID>, <LAT>, <LONG>, <SOS>). In the status module, Analog device ADF7021 is used for the transceiver to process data. Based on its design, ADF7021 transceiver has many advantages including high performance, low power consumption, highly integrated 2FSK, 3FSK, 4FSK, MSK, GMSK. Moreover, it can operate efficiently in narrow band, license-free ISM bands,

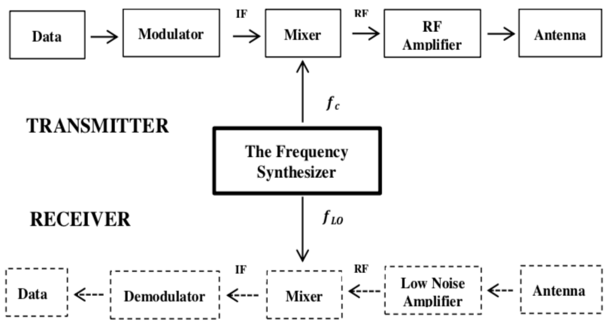


Figure 2. The structure of the status data monitoring system

and especially in the licensed band with corresponding frequency from 80 MHz to 650 MHz and from 862 MHz to 950 MHz. To have a better performance in narrow-band, both Gaussian and raised cosine transmitting data filter are integrated into this device. The harmonics are suppressed by using a 50 dB out-of-band attenuation LC bandpass filter. Besides, a high linearity mixer LTC5510 is also integrated into the status data module [8]. The design of this mixer is optimized by using a double-balanced active mixer, an input buffer, and a high-speed LO amplifier. Therefore, it has many advantages such as wide input bandwidth, low distortion, and low LO leakage. On the input of mixer, 1:1 balun transmission line transformers are used for wideband applications. Experiment results of status module are shown in [9]. The frequency synthesizer is designed and manufactured by using ADF4350 integrated PLL and STM32F103C8 microcontroller. Reference [10], [11], [12], [13] present 80 W and 130 W power amplifiers, respectively. We used Advanced Design System for simulation, and vector network analyzer to verify the performance of the power amplifier modules. We controlled the impedance bandwidth and increased the bandwidth with good control of the edge frequency by using a horn antenna and beveling technique. The design of transmitter was shown in Fig. 2 and in [6].

The transmitter is capable of switching frequency flexibly in S-band by using a broadband frequency converter. In addition, a broadband amplifier is designed and integrated inside the transmitter as illustrated in Fig. 3. The 2-stage pre-amplifier is matched at two different frequencies. Thus, it can operate across spectrum of S-band.

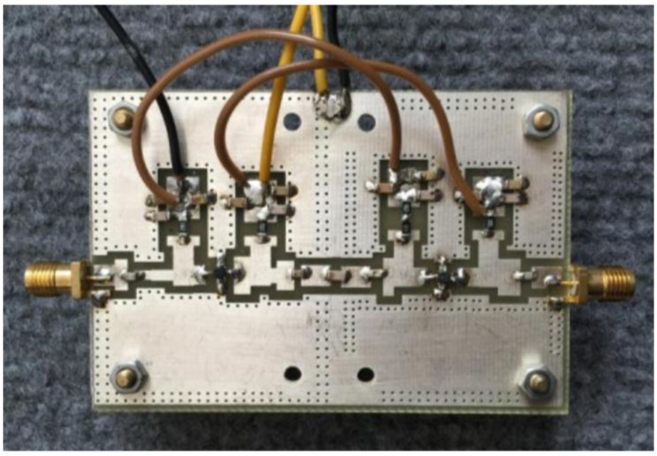
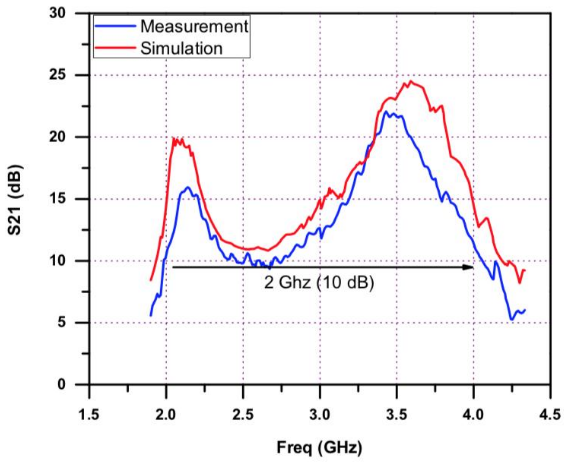


Figure 3. Photo of the fabricated 2-stage pre-amplifier.



Figuire 4. Comparison between the simulation and measurement results of pre-amplifier gain factor (S21).

The comparison between simulation and measurement results is plotted in Fig. 4. The pre-amplifier can operate in S-band with a gain greater than 10 dB, and the maximum power of 20 dBm. Moreover, the pre-amplifier is able to operate well at 2.15 GHz and 3.4 GHz. At 2.15 GHz, the pre-amplifier has a gain of 16 dB and bandwidth of 19 MHz. At 3.4 GHz, it can achieve 22 dB of gain and 310 MHz of bandwidth.

DESIGN OF THE STATUS DATA RECEIVER ON SATELLITES AND GROUND STATION

The design of LNA shown in Fig. 5 includes 2 stages. In the first stage, the balanced configuration is used to resolve the return loss problem. The next stage uses a single-stage amplifier to increase the total gain of LNA module. The input and output reflections are canceled from two identical amplifiers by using 90^o couplers in the balanced amplifier circuit. The input signal was separated into two equivalent amplitude components with a 90^o phase shift. On the other hand, the amplifier outputs are recombined by the second coupler. The phasing properties of hybrid coupler cancel the reflection from the input of amplifier, as a consequence, the impedance match is improved. The similar effect also happened at the output of the balanced amplifier [14]. This design is much more complicated than the single-stage amplifier because two hybrid couplers and two separate amplifiers are needed inside. However, it provides many benefits such as higher stability of individual amplifiers, wider bandwidth, and better input/output matching.

The LNA is designed and simulated at 2 Ghz by using ADS software. The manufactured LNA is illustrated in Fig. 6. The experimental and simulation results are demonstrated in Fig. 7 and Fig. 8.

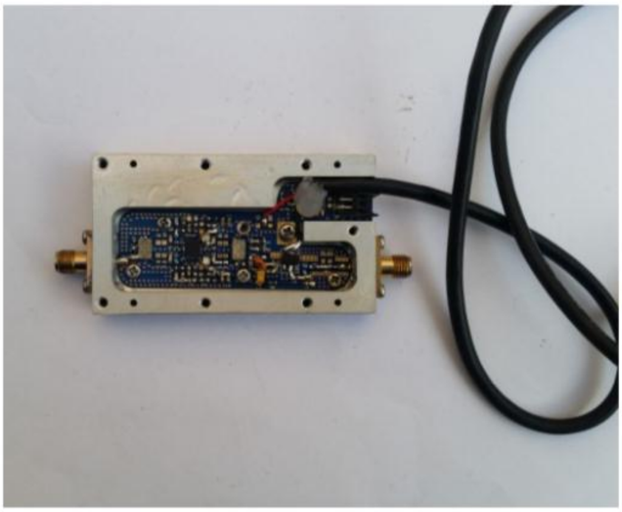


Figure 6. The fabricated LNA (7x4x1.2 cm).

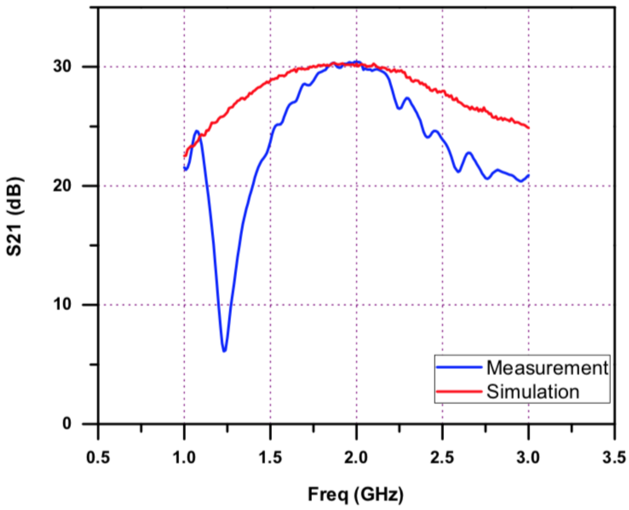


Figure 7. Comparison between simulation and measurement results of LNA gain factor (S21).

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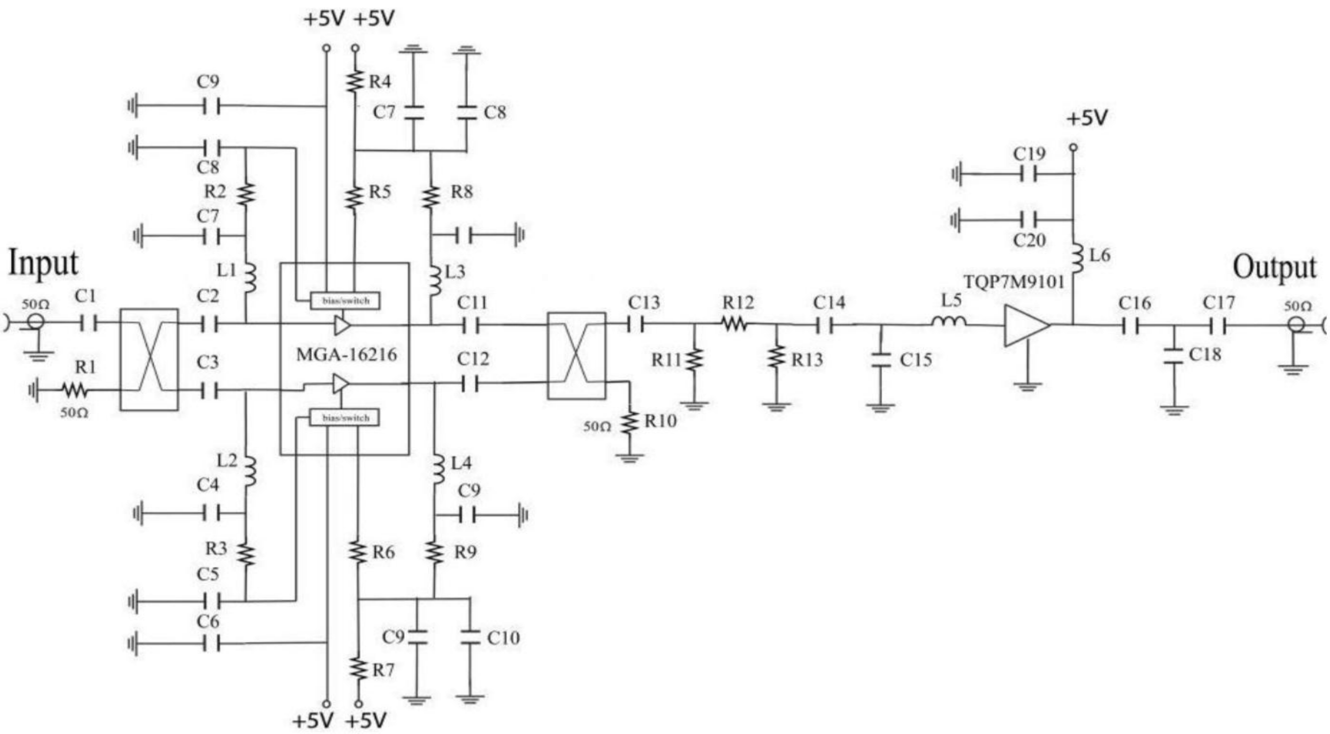

Figure 5. The design of 2-stage Low Noise Amplifier (LNA).

Table II. Comparison with the Recent Published Works

Ref	**Freq(GHz)**	**Struc**	**Gain (dB)**	**Gain flatness (dB)**	**NF(dB)**	**P1dB(dBm)**
Ref. [15]	2.15 - 2.65	Not balanced	28.1	0.57	Less than 1 (meas)	18
Ref. [16]	2.9 - 3.1	Not balanced	30.87	0.5	1.18 - 1.37 (simu)	-
Ref. [17]	2.4	Not balanced	10.84	-	Less than 1 (simu)	-
Ref. [18]	3	Not balanced	23.71	-	6.17 (meas)	-
Ref. [19]	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

It can be seen that our LNA has the maximum gain of 30 dB that is the same as the simulation result. Two 1.7-2.3 GHz hybrid couplers were used in this LNA. As a consequence, they suppressed all frequencies other than the frequencies of coupler. When the gain flatness is 0.2 dB and 0.5 dB, the bandwidth of 30 MHz and 130 MHz will be achieved, respectively. The Fig. 8 depicts noise figure of this LNA. For the range of frequency between 1.9 GHz and 2.1 GHz, the noise figure factor and P1dB are approximately 1.5 and 23 dBm, respectively. The performance of LNA is compared to the other published designs operating at the same frequencies in Table II.

The mixers in receiver systems on satellite and ground station are also designed and manufactured at 300 MHz by using LTC5510. The only requirement of this mixer is 0 dBm of LO power to accomplish an excellent distortion and noise performance. Fig. 9 shows the harmonic of our mixer. It can be seen that there is no harmonics for frequency range from 100 MHz to 1.49 GHz.

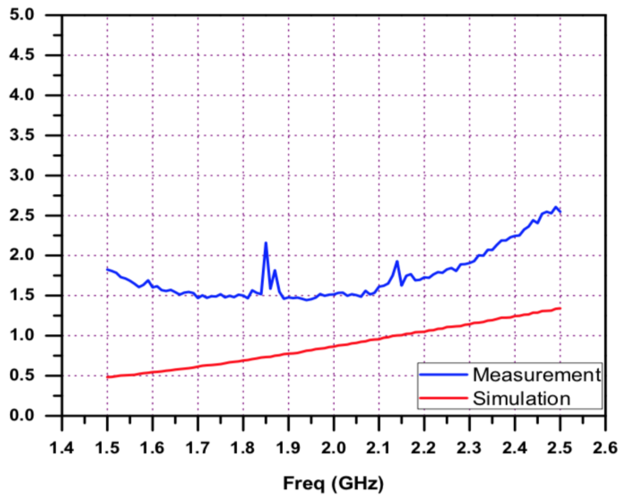

Figure 8. The measured noise figure of the proposed LNA.

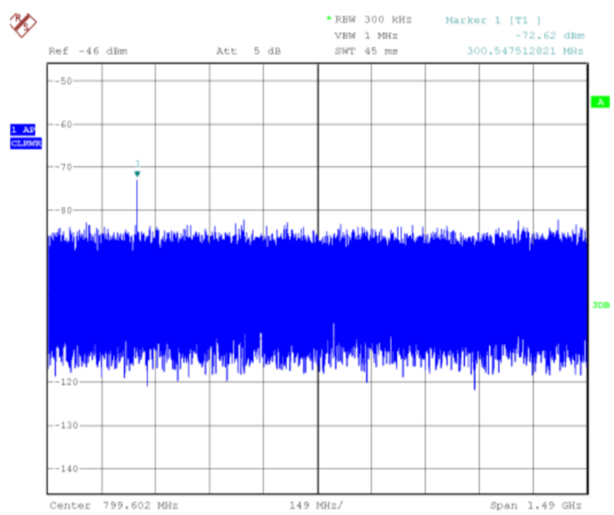

Figure 9. Measuring the hamornic of the mixer.

LO device is designed by using an ADF4350 IC. A VCO with fundamental output frequency range from 2200 MHz to 4400 MHz is integrated inside ADF4350. In addition, RF output frequency as low as 137.5 Mhz can be generated by using divide-by-1/2/4/8 or 16 circuits. The on-chip registers can be controlled through a simple 3-wire interface. The device requires a power supply range from 3.0 V to 3.6 V to operate and can be shut down when it is not in use [10].

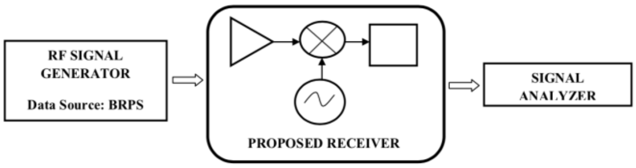

Figure 10. The sensitive measurement of the proposed receiver.

Received messages are demodulated and unpacked by the data processor. The vessel status information can be achieved after processing by using ADF7021 transceiver. The receiving parameter can be configured by using the touch screen on the control board.

The S-band receiver sensitivity measurement is set up as illustrated in Fig. 10. When the sensitivity of receiver is -113 dBm, and the net margin is approximately 10, the operational reliability can be confirmed.

The Fig. 11 shows the simulation result of this system when it is integrated in a small satellite at altitude of 950 Km. Obviously, the use of S-band communication system to communicate with satellite can extend (or increase) the radius of tracking area from 25 Km to 250 Km.

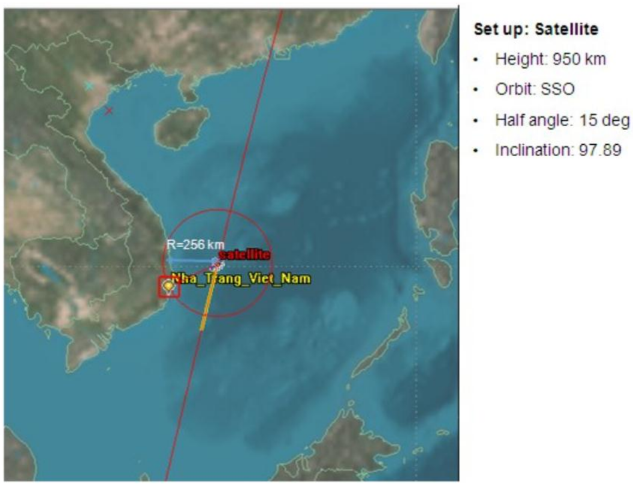

Figure 11. Communication range simulation of the proposed vessel status data communication system.

CONCLUSION

In this paper, the 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 shore stations, solving the communication distance issue. The transmitter can flexibly operate by using a broadband local oscillator (from 600 MHz to 4.2 GHz) and a wideband pre-amplifier (from 2 GHz to 4 GHz). The local oscillator's stability over temperature and tolerance are comparable to TCXO that is about +/- 3 ppm by 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 ships including 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 is designed based on a balanced configuration with several advantages such as high gain flatness, low NF, and high P1dB. With the sensitivity of -113 dBm, the system's operational reliability has been confirmed. The status data of the vessels are gathered at a ground station and displayed on a map to track their location. The technical parameters of the system have been measured and verified.

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