Packet Transceiver on 2.4GHz for Whooper Swan

Kaoru Nakada[1*], Isao Nakajima[1], Jun-ichi Hata[2], Masuhisa Ta[3]

Abstract

We devised a bird-borne transceiver unit for S-band packet radio communications based on the CC2500 transceiver, a device manufactured by Texas Instruments (TI). Our assessments determined the optimal parameters needed to achieve successful bird-to-center communication over a distance of 18 km and bird-to-bird communication over a distance of 200 m. These parameters included optimal modulation methods, transmission rates, and antennas. We equipped the transceiver unit with a modified dipole antenna (collinear antenna), which we tested in a 10 m anechoic chamber. Our experimental assessments and circuit design review identified the following parameters: 2FSK modulation method; 14.28 kHz frequency shift; 101.56 kHz IF reception bandwidth; and Manchester encoding (+). Our assessments showed bird-to-bird communications could be achieved over a distance of 200 m assuming MSK, FEC (+), and 500 kbps. Following tests by an official body, we obtained 28 sets of a type approval license for 2.4 GHz. In cooperation with the Yamashina Institute for Ornithology, we attempted to tag and release six or more swans. This unit gives us the ability to obtain vital data on swans. We expect this data to provide significant benefits, including clues on improving screening for infected individuals.

Key Words: Avian Influenza, Bird-borne , CC2500, Vital Data

I. INTRODUCTION

Avian influenza

Influenza has been a human affliction since antiquity. Although the development of oseltamivir phosphate makes it possible to suppress the proliferation of influenza viruses, the efficacy of influenza vaccines remains suboptimal. The emergence of a particularly virulent strain of avian influenza poses the risk of pandemics like the Spanish influenza pandemic of 90 years ago. Some 7% of waterfowl are said to be carriers of the avian influenza virus. New virus strains continue to emerge and present ongoing threats to public health. We believe developing methods or systems for monitoring links between migratory birds and virus mutations will help make the status of communicable diseases more transparent and strengthen the planning of epidemiological preventive measures.

Internet of Things

Recently, communication among things not previously connected to the Internet is collectively called Internet of Thinks(IoT) [1,2,3]. Managing vital data for migratory birds via digital communication would be an application of IoT in a broad sense, not limited to cases involving the use of the Internet and smartphones. Multicast video distribution and other modes of communication suggest intraflock broadcasting could be used to merge or integrate data gathered from individual birds within a flock[4,5,6]. Other key technologies supporting IoT are so-called green energy sources (solar power and conversion of kinetic energy from the flapping of wings), which power the transceivers carried by the birds [7,8,9,10]. The International Telecommunication Union (ITU) has confirmed the need to monitor migratory birds across national borders using ICT [11,12]. With data collection and wide-ranging coverage capabilities, the Argos system aboard NOAA polar orbiting satellites has been used to track migratory birds [13,14]. However, this system presents several drawbacks, including low position fix accuracy and little ability to gather other data. In response, we launched a research project based on ground wave packet communication transceivers designed to be attached to migratory birds—swans, for our purposes—and obtained biological data and positional information on these birds using bird-to-bird and bird-to-center communications.

Texas Instruments has publicly disclosed all information and data pertaining to the IC used in its CC2500 transceiver product. Disclosed on the Internet, these 3,000-odd pages of technical documents gave us the

information needed to set the IF frequency bandwidth for analog circuits, modulation methods, and output levels. The availability of this information was the primary reason for choosing the CC2500. The disclosure of such extensive information—common in the United States—is rare among Japanese or Korean companies [15,16].

II. DEVELOPMENTS

We installed the TI CC2500 transceiver for packet radio communications on a bird-borne transceiver unit (circuit board = 20 g). The CC2500 accommodates transmission rates from 1,200 bps to 500 kbps, and the modulation method can be set to 2FSK, GFSK, or MSK. This report describes how we determined projected maximum communication distances after selecting the optimal modulation method, antenna gain, and circuit design.

2.1. Technical requirements for communication

We designed a database and implemented an RBBS (Radio Bulletin Board System). We entered biological and position information and data for each device as files into a database, with each filename based on a unique identification number and date. For bird-to-bird communications, the autonomous decentralized RBBS first exchanged data between files, then picked up files possessed by one bird, but not others. First installed in the PAX-88B packet radio communication modem by Escuela Inc. (Yokohama) in 1988, this RBBS function has been successfully applied to radio communication systems. (Nakajima Lab is the current software copyright holder.)

Communication requires establishing synchronization (for macro time and micro time) of two communicating devices. In our test unit, the synchronizing circuit of the packet communication device handled micro time synchronization, while the CPU mounted on the circuit board performed macro time synchronization based on GPS data. In cases in which GPS failed to function properly, the CPU determined the scheduled macro time based on hours of sunlight, time of sunrise, and time of sunset obtained from ambient light sensor data.

The CPU on the circuit board determines whether to rely on bird-to-bird or bird-to-center communication. For example, if the bird is located north of Hokkaido and other birds are located nearby, the transceiver selects bird-to-bird communication. The transceiver also broadcasts positional data and IDs at set intervals to provide location information. Mutual communication begins if a transceiver on another bird receives the data broadcast. In previous research on autonomous decentralized data management, we approximated their distances between each terminal based on the strength of received signal and

calculated network topology such as mathematical models of ant formation. Since the CPU mounted on the circuit board performs network topology management and RBBS file management in parallel, our design called for two communication rates and two communication ranges.

The Table 1 specifies the requirements. It is thought that avian influenza requires close proximity to pass from bird to bird. Infection occurs when the virus in the intestines of a single bird is excreted and ingested by other feeding birds. Observations of swans near Lake Kutcharo and Lake Tofutsu in Hokkaido suggest a flock may span some 100–200 m in diameter. Thus, we assumed the required range of bird-to-bird radio communication to be 200 m. The range required for communication between swans and the mobile center station was assumed to be 18 km. This is two-thirds the projected line of sight from a hilltop 25 m above sea level at Cape Soya to flocks of swans observed with the unaided eye in their fall migrations from the southern tip of Sakhalin Island (Figure 1).
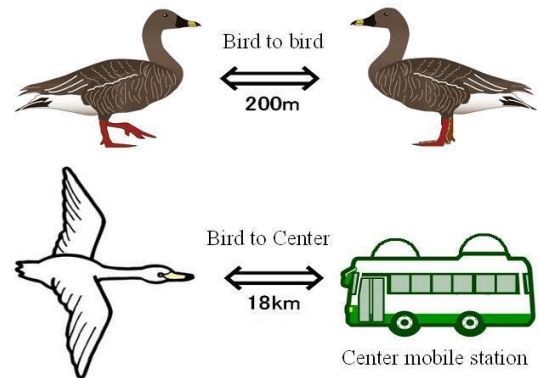

Fig. 1. Two communication methods

Table1. Requirements for radio communication circuit

Demand specifications	Distance[km]	Data speed[kbps]	Communication contents
bird to center	18	2.4	ID confirmation
bird to bird	0.2	250-500	file transfer

2.2. Overview of packet communication device

The Figure 2 gives the internal specifications of the CC2500. The functions are described in A–D below.

A: Internal structure

The low-power S-band (2.4 GHz) packet transceiver is capable of transmitting data at rates from 1.2 kbps to 500 kbps. The FIFO serving as memory for the packets was extremely small (64-byte capacity) but nevertheless capable of handling larger packets when used in combination with the interrupt function. The modulation methods available were 2FSK, GFSK, and MSK. For structural reasons, the error correction options—FEC (Forward Error Correction) or Manchester encoding—

could not be used in combination. The independent automatic repeat request (ARQ) function was disabled during the Forward Error Correction measurements. The Figure 3 is a schematic block diagram of the device.
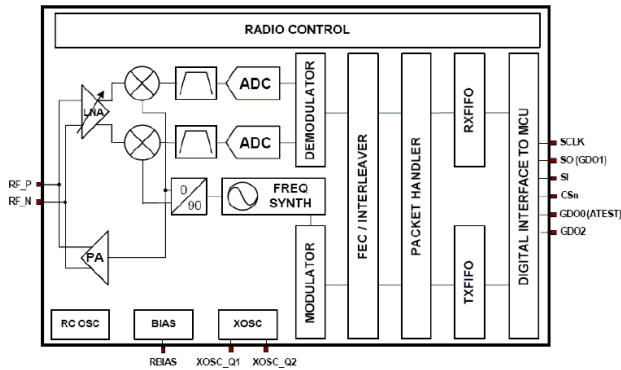

Fig. 2. CC2500 internal configuration

B: FEC and interleaving hardware

An FEC function corrected errors generated in the transmission channel on the receiving side. Interleaving hardware on the transmitting side reordered the codes. The deinterleaver on the receiving side reversed this operation, thereby dispersing concentrated burst errors in the transmission channel.

C: Manchester encoding

In principle, when a code string including continuous repetitions of 000 or 11 (NRZ: Non Return to Zero) undergoes modulation, an error occurs in the determination of the number of the same codes transmitted. To eliminate this error, we implemented Manchester encoding to insert a clock component to split each bit into two to distinguish between the rising edge and trailing edge of a signal, an approach also known as biphase encoding. Generally speaking, since a failure to demodulate the clock component generates errors, Manchester encoding is suitable for data streams communicated close to the noise floor.

D: Automatic repeat request (ARQ)

For codes not correctable by either FEC or CRC, the ARQ function requests a retransmission. The FEC and ARQ are mutually independent inside the CC2500 and capable of operating in hybrid mode.

E: Antenna design and assessment

The output from the packet communication device (TI's CC2500) attached to a bird is weak: -30 dBW(0 dBm). For the transceiver unit including the antenna, we

submitted an application for certification of compliance with technical standards imposed by the Japanese Ministry of Internal Affairs and Communications. Migratory birds seldom fly squarely toward the center station and often choose to fly, where possible, in the same direction as the wind. Ideally, then, beams would be emitted to the left and right of the bird. The bird-borne circuit board is extremely narrow and cannot assure sufficient gain. Nevertheless, we sought to achieve a 3 dBi gain to the right and left sides. The Figure 3 shows the balanced feed collinear antenna we designed and fabricated. For the center antenna, we used a 1 m dish antenna and measured the antenna pattern in a 10 m anechoic chamber.
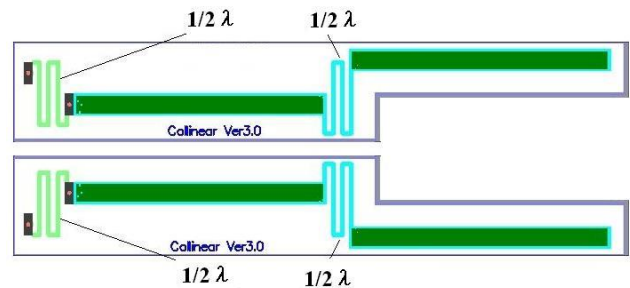

Fig. 3. Balanced feed collinear antenna

III. TESTS AND RESULTS

3.1. Modulation

Due to the distance between any given bird and the center and the proximity of the signal to the noise floor, slower transmission rates and Manchester encoding offer advantages over FEC. For our assessment, we connected two CC2500 boards (Figure 4), configured an attenuator between them, reduced the received power, and varied the relative C/N (signal-to-noise ratio) to determine the ideal settings for modulation method, transmission rate, and intermediate frequency (IF). FEC and ARQ were disabled for this experiment.

For the CC2500 communication control program, we used the EW430 KickStart version (JAJA173.zip) obtained at no cost from IAR Systems. This program allows the transmission of commands to the CC2500 on the target board via the PC serial port for continuous modulated wave transmission, non-modulated output, continuous receiving, and parameter setting. To confirm signal levels after the attenuator, we used a spectrum analyzer to measure error rates between the two boards, as shown in Figure 5.

Of 2FSK, GFSK, and MSK, 2FSK provided the best C/N ratios. With 2FSK selected, the frequency shift was smallest at 14.28 kHz and with Manchester encoding(+),

as shown in Figure 7, while error rates were lowest at a receiving bandwidth of 101.56 kHz (Figure 6).
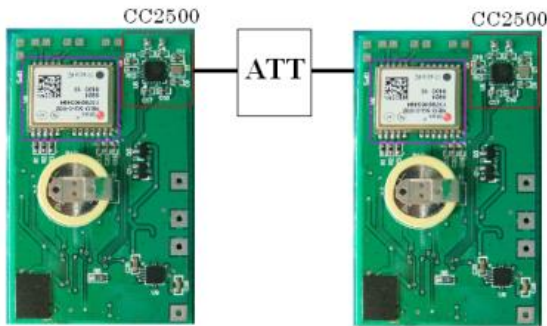

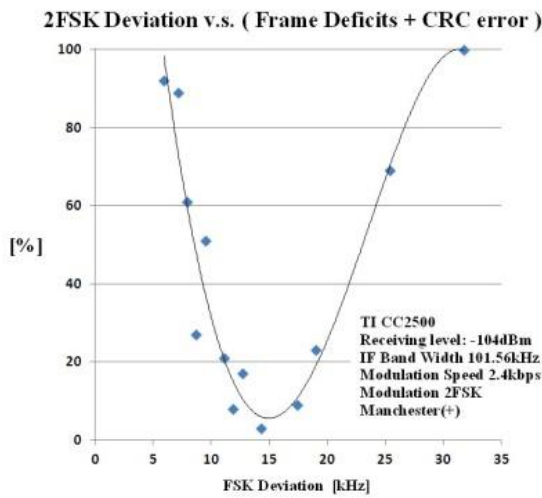Fig. 4. Overview of assessment test equipment
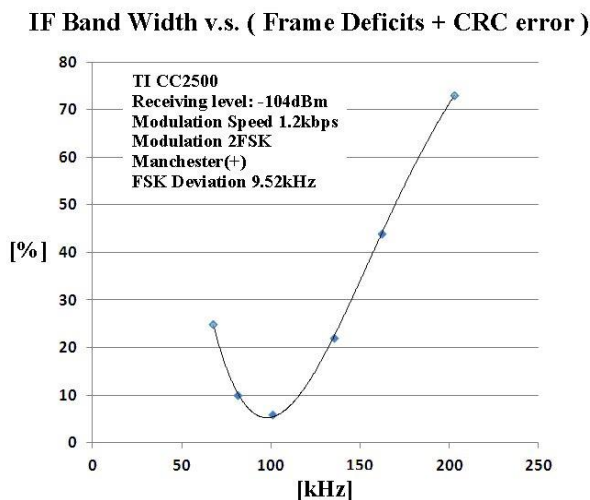

Fig. 5. Frequency shift and error rate

Fig. 6. IF bandwidth and error rate

3.2. Error rate

We measured the error rate for the Texas Instrument CC2500 with the modulation method set to 2FSK, frequency shift at 14.28 kHz, a transmission rate of 2.4

kbps, Manchester encoding(+), and receiving IF bandwidth of 101.56 kHz (Fig. 7). The error rate was 5% or less at -135 dBW. Changing these settings to MSK modulation method, 500 kbps transmission rate, and 812.5 kHz receiving IF bandwidth resulted in an error rate of 5% or less at -116 dBW. Since this data was communicated in packets, issuing a resend request would allow successful communication even with error rates around 20%, but at slower speed. We opted for an error rate of 5%.
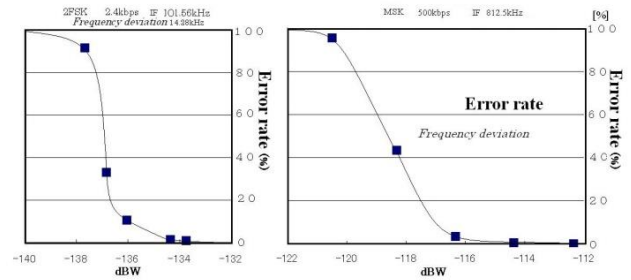

Fig. 7. Receiving power and error rate characteristics
(left: 2.4 kbps; right: 500 kbps)

3.3. Antennas

The dorsally mounted antenna has lateral directionality and is powered from the left and right, with phases of the half-wavelength elements matched. This configuration is ideal for communication with adjacent birds. The antenna pattern was measured in an anechoic chamber in Toyama Prefecture measuring 10 m × 10 m × 10 m (Figure 8). The mobile center antenna is equipped with a gimbal tracking system for elevation and azimuth angle measurements to enable communication with swans in flight. The Figure 9 shows the antenna pattern of an antenna attached to a swan. The Figure 10 shows the antenna pattern of the dish antenna positioned at the center. These antenna patterns indicate maximum gains of 3 dBi and 23 dBi, respectively.
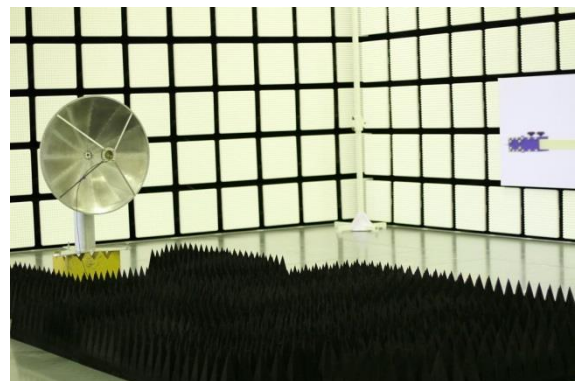

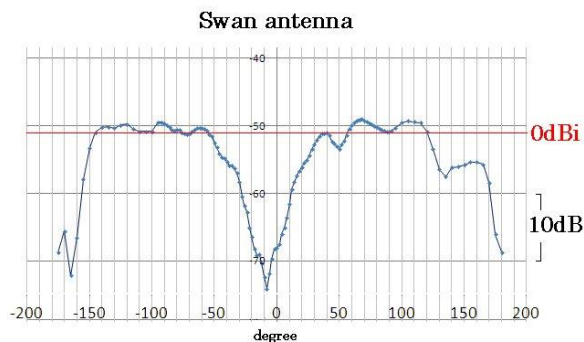Fig. 8. Measurement in anechoic chamber (performed at Toyama Industrial Technology Center)
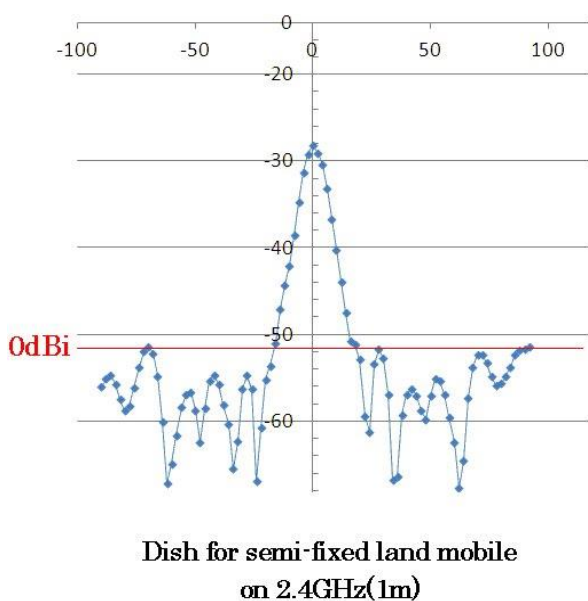
Fig. 9. Antenna pattern of bird-borne antenna

Fig. 10. Antenna pattern of 1-m dish antenna positioned at the center station

IV. CONSIDERATIONS

4.1. Modulation method

Based on our assessments, we determined that the ideal modulation method for bird-to-center communication over relatively long distances was 2FSK with a frequency shift at 14.28 kHz and receiving IF bandwidth of 101.56 kHz. Our assessment disregarded the effects of radio waves reflected from lake surfaces, mountains, and so forth (the propagation environment). Thus, we needed to examine signal interference using a phasing simulator and to take the results into account.

Admittedly, suggesting that MSK and GFSK are inferior to 2FSK contradicts the received wisdom. The results of our study suggest that the CC2500's analog circuit was initially designed for use with 2FSK at the development stage, after which MSK and GFSK were later added to make the product more marketable. This underscores the benefits of thoroughly analyzing the manufacturers'

design intentions when, as in this case, designing transceivers using existing devices.

4.2. Propagation

We calculated the maximum propagation distance in each communication case based on the premise of the error rate above. The results of calculations using the formula for propagation loss in free space showed 400 m at 500 kbps for bird-to-bird communication and 35 km at 2.4 kbps and in 2FSK mode for bird-to-center communication. These values met the required specifications of 200 m and 18 km.

4.3. Actual use

The research consortium applied to the organization affiliated with the Japan Ministry of Internal Affairs and Communications for wireless-form authorization. After the tests performed by the official body, we obtained 28 sets of a type approval license for 2.4 GHz. In cooperation with the Yamashina Institute for Ornithology, we attempted to tag and release six or more swans (Figure 11 and 12). The transceivers attached to the back of these birds record data on respiration and cardiac beats with an angular velocity meters. They also perform store and forward data transmission to other transceivers and to the center terminal in Japan. For use in preventing avian flu, we intend to collect and analyze vital data on wild swans. Although various communication apparatus have been attached to wild birds to date[17,18,19,20,21], our system should prove remarkably capable in collecting vital data.
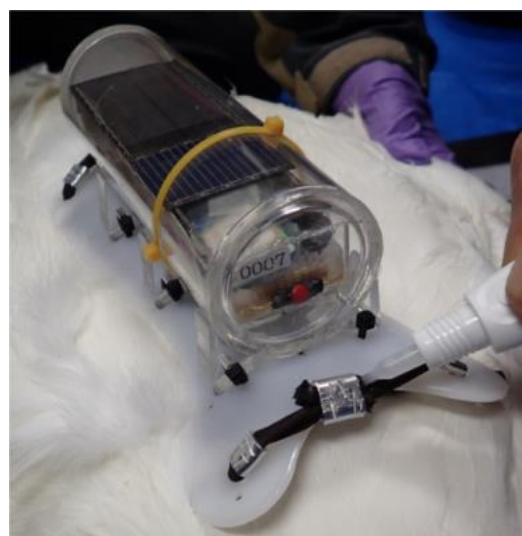

Fig. 11. Packet transceiver on the back of a swan (courtesy of Yamashina Institute for Ornithology)

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Fig. 12. Photograph of whooper swan

V. CONCLUSION

We designed and produced an S-band packet communication terminal to achieve bird-to-bird communication over distances of up to 200 m at 500 kbps and bird-to-center communication over distances of up to 18 km at 2.4 kbps, assuming 2FSK, 0 dBm output. We also verified the performance of this system.

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Authors

Kaoru Nakada graduated Tokai University School of Medicine in 1980. He had finished his clinical resident course at Toshima Hospital in Tokyo and opened his clinic in Shudama Town, Yamanashi Japan 1985. He got the board member of the International Chinese Medicine in 1995. Since 2009, he has been investigated on influence of the sympathetic nervous system of Chinese medicine as a researcher at Nakajima Laboratory of Tokai University Isehara campus. For years, he has studied on screening of avian flu with ICTs.

Isao Nakajima He works now for Tokai University School of Medicine as Professor of Nakajima Laboratory, Department of Emergency and Critical Care Medicine. The Doctor of Applied Informatics (Ph.D.) from Graduate School of Applied Informatics University of Hyogo 2009. The Doctor of Medicine (Ph.D.) from Post Graduate School of Medical Science Tokai University 1988. Medical Doctor (M.D.) from Tokai University School of Medicine 1980. For years, he has researched and developed the advanced telemetory and eHealth system.

Jun-ichi Hata has received his MD degree from Keio University School of Medicine, Tokyo, in 1966. In 1971, he received a PhD degree in Keio University Post Graduate School of Medicine. Since then, he has been mainly involved in molecular pathology for pediatric tumors and embryonal pathology. He was appointed to a professor of pathology, Keio University School of Medicine in 1990. In 2013, he has been appointed as research director of Central Institute for Experimental Animals.

Masuhisa Ta graduated the College of Engineering, Ibaraki University in 1975. He has developed the ETS-V satellite mobile earth stations for Asia Pacific Medical Network in 1990 and the quadrant detector on Ku-band to track GEO (N-star) satellite from moving ambulance in urban area. He also handed the wireless license related these transceiver units. He is the CEO of Tasada Works Inc., and interesting in general machinery and equipment manufacturing industry.