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A NEW MULTIMODE FM/CW IONOSONDE

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Abstract: A low power FM/CW ionosonde was constructed to investigate the vertical motion of the polar ionosphere. The most suitable pulse length is selected automatically according to the ionospheric layer height. Microcomputer control and data acquisition make it possible to select observation mode easily by changing software. A good deal of effort was made to eliminate interference with other observations and short wave telecommunications and by other emissions on neighboring spots.

1. Introduction

Rapid progress in the electronics and advanced techniques in the remote probing of the ionosphere have enabled ionosondes to measure many ionospheric parameters (WRITE, 1975; BIBL and REINISCH, 1978; POOLE, 1985; POOLE and EVANS, 1985). REINISCH distinguished modern ionosondes from classical ones by observables (REINISCH, 1986).

Ionospheric routine observation by ionosondes has supplied basic data for short wave telecommunications and for studying the polar ionosphere from the early years of Japanese Antarctic Research Expedition (JARE). In spite of several renovations and reconstructions, starting with PIR-1 used for JARE-1, the ionosondes have always employed swept-frequency mono-pulse radar system and only have been used to get virtual height *vs.* frequency records (ionograms). Ionograms recorded on 35 m/m films are developed at Syowa Station and parameters are manually scaled according to the international standards (PIGGOTT and RAWER, 1972; PIGGOTT, 1975) after they have been brought back to Japan.

The ionosonde in current use (type 9B), the prototype of which was developed in 1973, also adopts swept-frequency mono-pulse radar method of 10 kW peak transmitting power with vaccum tubes in the final stage of the transmitter (KOSEKI *et al.*, 1980). Since a pulse burst emitted every 15 min with duration of 20 s disturbs other observations and telecommunications around the ionosonde, the continuous operation becomes unfeasible. Moreover, having no data processing function, manual data processing is required to extract ionospheric information from ionograms. Details of phenomena cannot be detected because of a rough height resolution of 5 km in manual scaling.

The polar ionosphere is forced to modify its electron density profiles owing to substorms and it is a source region of large scale traveling ionospheric disturbances. Observation of Doppler frequency shift of standard wave is one of excellent ways to observe a vertical motion of the ionosphere continuously; however, there is no suitable standard frequency station around Syowa Station. The fixed frequency short wave radar is needed for observing the ionospheric motion like a standard frequency Doppler shift observation.

At the time of substorms an increased electron density of the polar ionosphere causes unusual radio absorption, then the ionosonde in current use often loses echoes from the ionosphere (Aurora black-out).

The FM/CW (chirp) technique requires a lower peak power of radar as compared with the conventional pulse method, so that it contributes to a reduction of disturbances to the neighboring telecommunications and observations. Furtheremore the FM/CW radar is also subjected to reduced interferences from other stations because of narrow bandwidth. Therefore, the FM/CW radar is suitable for continuous observation of the ionosphere. The FM/CW transmitting power of several tens of watt corresponds roughly to the mono-pulse 10 kW power. If the FM/CW signal is supplied to appropriate antennas, even echoes partially reflected from the lower ionosphere can be detected with 100 W transmitting power (RINNERT *et al.*, 1976). The first model of FM/CW ionosonde was designed for an oblique sounding (BARRY and FENWICK, 1965). Afterwords vertical incidence FM/CW ionosonde was developed by alternating transmission and reception in 50% duty cycle (BARRY, 1971). With additional hardware and appropriate software, FM/CW ionosondes as well as pulse type ionosondes are able to acquire additional function of Doppler measurement and direction finding (POOLE, 1985; POOLE and EVANS, 1985).

In order to study the vertical motion of the polar ionosphere on a continuous basis a low-power pulsed chirp (pulsed FM/CW) ionosonde (PCS1) was newly designed and constructed. The main purpose of PCS1 is

1) continuous observation of the ionospheric height and absorption with fixed frequency (h'-t mode),

besides, the following examinations are planned;

2) to compare ionograms with those of the current ionosonde with sweeping frequency in full range (ionosonde mode),

3) to detect partially reflected echoes from the lower ionosphere (partial reflection mode).

2. Observation Modes

We neglect Doppler shift by assuming the reflecting layer to be stable. Transmissions and receptions are alternated in every pulse repetition time T while the carrier frequency is swept at the rate of $\dot{f}$ (Fig. 1a). Transmitted signal P_T in one pulse cycle is described as

$$\begin{aligned} P_T &= A_0 \cos 2\pi(f_0 t + \dot{f} t^2/2) \qquad \text{for } 0 \leqq t < T/2 \\ &= 0 \qquad \text{for } T/2 \leqq t < T, \end{aligned} \tag{1}$$

where A_0 is a constant signal amplitude and f_0 is the initial frequency at $t=0$. The deviation of instantaneous transmitting frequency from that of received signal reflected from the ionosphere results the signal which is called the base band. The frequency of

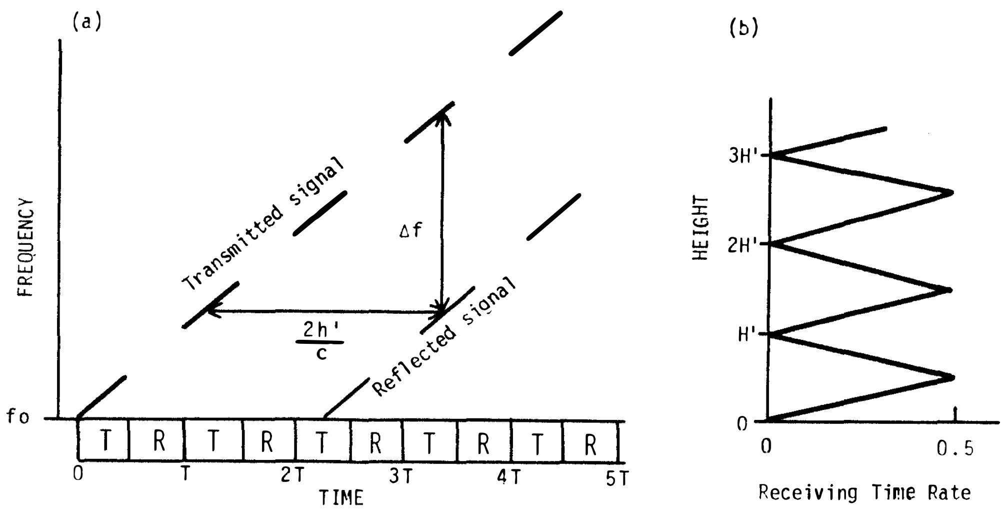

Fig. 1. Concept of pulsed FM/CW (pulsed chirp) method.
a. Frequency-time representation of signals. Frequency swept signal is transmitted with the period of T and reflected signal is taken in by the received only in receiving windows (time interval indicated by R).
b. The reception time rate with layer height h′ for the fixed pulse period of T=2H′/c.

the base band (Δf) is proportional to the distance from the ionosphere. The frequency analysis of the base band directly gives the virtual height of the ionosphere h' by

$$h'=\frac{c\cdot\Delta f}{2\dot{f}}\,, \tag{2}$$

where c is the velocity of light in vacuum.

If the radio signal reflected from the layer at the height of h' reaches the receiver in the n-th pulse cycle, it is taken in the period of

$$\begin{aligned} &\frac{2h'}{c}-nT && \text{for } 0<\frac{2h'}{c}-nT\leqq\frac{T}{2} \\ &(n+1)T-\frac{2h'}{c} && \text{for } \frac{T}{2}<\frac{2h'}{c}-nT\leqq T \end{aligned} \qquad (n=0,1,2,\cdots)\,, \tag{3}$$

effectively by the receiver in each pulse cycle. When the pulse length is fixed, the reception time rate moves periodically between 0 and 0.5 as a function of the layer height (Fig. 1b).

When the repetition time of transmitting and receiving alternation is selected as

$$T=\frac{2h'}{m\cdot c} \qquad (m=1,2,3,\cdots)\,, \tag{4}$$

the reflected radio waves from the layer of height h' cannot be taken in the receiving window. Weak echo signals, which are reflected by faint layers around height h' and are masked by strong echo signals from the layer in height h' in ordinary observation, can be obtained by a sensitive receiver.

On the other hand, when the pulse repetition time is selected as

$$T=\frac{2h'}{(m+1/2)\cdot c} \qquad (m=0, 1, 2, \cdots), \tag{5}$$

the whole echo pulse can be taken in the receiving window and the reflected echo from the layer at h' can be detected in the highest sensitivity as expressed in eq. (3).

When the ionograms are required (ionosonde mode), the frequency of the carrier signal is swept continuously and linearly, while randomized pulse length makes constant sensitivity over all height range (POOLE, 1979). In the case of the h'-t mode, the frequency of the carrier is repeated to sweep around some fixed frequency as will be explained in the next section, and T is controlled to track the layer. And for the partial reflection mode, the frequency of the carrier is also repeated to sweep, but T is controlled to erase the fully reflected echo from the E layer and relatively intensify the echo from the D region.

The received signals are switched on and off by the period of $T/2$, then the base band signal is modulated with the Fourier series of pulse duration. If we put $F=1/T$, the base band contains F and $F\pm\Delta f$ components besides Δf as shown in Fig. 2. To distinguish ionospheric echoes from the unexpected components, the condition

$$2\Delta f_{\max}<F, \tag{6}$$

must be held, where $\Delta f_{\max}$ is the maximum base band frequency corresponding to the maximum height range $h'_{\max}$. Then the intermediate frequency bandwidth of $\Delta f_{\max}$ eliminates the unexpected components.

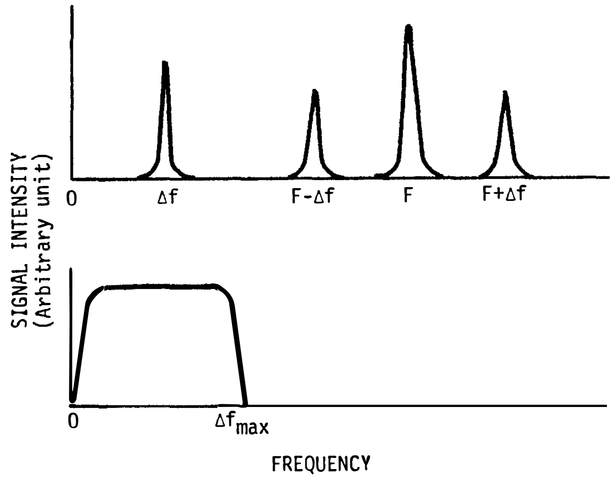

Fig. 2. Frequency spectrum of base band signal (top) and receiver bandwidth (bottom). Signals except from the target (Δf) are eliminated by the receiver IF filter.

The height resolution is defined by the frequency resolution of the base band spectrum analysis as follows,

$$\Delta h'=\frac{2h'_{\max}}{n}, \tag{7}$$

for the sampling number n.

The time resolution is also defined by the sampling time of n data and spectrum analyzing time. The data sampling time T_s is given by

$$T_s=\frac{n\cdot c}{4h'_{\max}\cdot \dot{f}}. \tag{8}$$

3. Equipments

The principal specifications of the FM/CW ionosonde (PCS1) are listed on Table 1 with those of the current ionosonde (9B) and the block diagram of PCS1 is shown in Fig. 3. The greatest advantage of FM/CW technique as compared with the conventional mono-pulse technique is the capability eliminating interference by using narrow bandwidth filter of the receiver (BARRY and FENWICK, 1965). However, since the sweep rate is in proportion to the receiver bandwidth as indicated in eqs. (2), (7) and (8), the more reduced interference needs a longer observation time. The polar ionosphere may change its electron density profile within one sweep period. PCS1 has three sweep rates and it is planned to examine which the most adequate sweep rate is.

Table 1. Specification of the multimode FM/CW ionosonde (PCS1) and the ionosonde in current use at Syowa Station (9B).

Item	PCS1	9B
Frequency range (MHz)	2–16 (programmable)	0.5–15
Height range (km)	450	800
Height resolution (km)	1.76	5
Type	Pulsed chirp	Mono-pulse
Pulse width (μs)	225–4095 (variable)	80
Duty cycle (%)	50	0.4
Transmitting power (W)		
Peak	20	10 k
Average	10	40
Receiver bandwidth (Hz)	20, 75, 300, 1500	15 k
Sweep rate (kHz/s)	25, 100, 500	Log sweep
Observation mode	h'-f (ionosonde)	h'-f (ionosonde)
	h'-t	
	Partial reflection	
Control	Microcomputer	Timer
	MPU=i8086 (8 MHz)	
	RAM=384 k Bytes	
	5″ floppy disk ×2	
Recording	Dot impact recorder	35 m/m film
	h'-t mode	Ionofax
	Printer copy	
	ionogram mode	
	partial reflection mode	

As the echo signal is integrated in one FFT sampling time (Table 2) in case of the FM/CW method, total echo energy of PCS1 is comparable to the current ionosonde of pulse type.

The complicated circuit of linear sweep frequency synthesizer has prevented the FM/CW ionosonde spread; however, the synthesizer is commercially available these days and PCS1 employed also a ready-made frequency synthesizer. Since the sweep frequency synthesizer cannot cover 70 MHz band which is 1st IF of the receiver, it is controlled to oscillate at a half the frequency and a frequency doubler makes the local sweep signals for the receiver and the transmitter.

The real time spectrum analysis of the base band signal is carried out by software

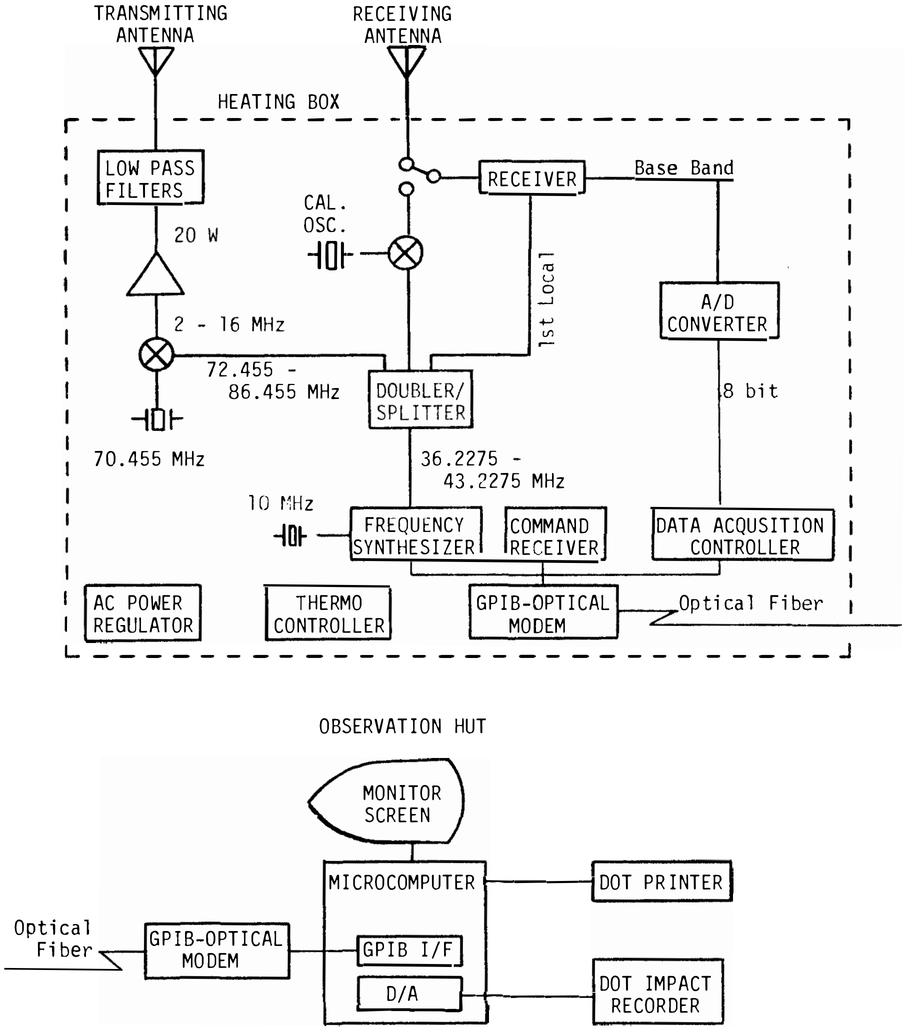

Fig. 3. Block diagram of the system.

FFT of the microcomputer which also controls transmitter, receiver and data acquisition controller. Observation modes are easily changed by replacing the floppy disk. Although main portion of the software is coded with BASIC, some repeating parts are expressed in machine code to save processing time.

The height resolution is defined by pulse length in the pulse radar, but in FM/CW, eq. (7) gives the height resolution. The height range of 450 km is divided by 256. Then the height resolution comes up to 1.76 km in the case of PCS1.

The sweep rate and the corresponding pulse length range, the receiver IF bandwidth and the sampling time T_s are given in Table 2. In the case of the partial reflection mode, the only echoes below 95 km are needed, so the narrow band IF filters are selected.

In the case of the h'-t and the partial reflection modes the microcomputer repeats ① determining pulse length T and commanding the system to sweep frequency, ② sampling the base band and ③ carrying out FFT and sending results to a recorder as shown in Fig. 4. It takes 0.6 s to carry out FFT and at the sweep rate of 100 kHz/s for example, one sequence time of processes ①, ② and ③ is about 1.5 s.

Table 2. Transmitting and receiving alternation period range, receiver IF bandwidth and the base band data sampling time for each sweep rate.

Sweep rate (kHz/s)	Pulse length (μs)	Receiver IF bandwidth (Hz)	Sampling time (s)
25	225–4095	75, 20*	3.41
100	225–1667	300, 75*	0.85
500	225– 315	1500	0.17

* is for partial reflection mode.

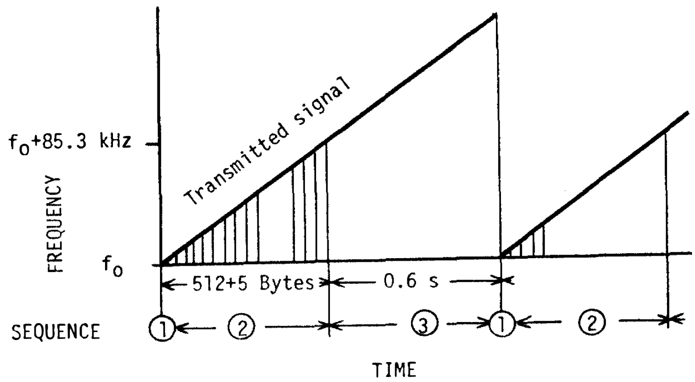

Fig. 4. Time sequence of h′-t and partial reflection mode. The microcomputer repeats to, ① set pulse repetition period T and command the synthesizer to start frequency sweeping, ② sample 512 byte base band signal and 5 byte house-keeping data of the heating box and ③ carry out FFT and control recorders.

The frequency of carrier is always increased by

$$T_s \cdot \dot{f} = 85.3 \text{ kHz}, \tag{9}$$

while a series of data is sampled.

In the case of the ionosonde mode, the microcomputer commands the synthesizer to start sweeping at first, and then repeats to ① determine T, ② sample the base band and ③ carry out FFT and make an ionogram.

The ionospheric absorption of radio waves is inversely proportional to the square of the operating frequency. The observation frequency of the ionosonde is much lower than riometer frequencies, so the signal intensity reflected by the ionosphere responds to the particle precipitation more sensitively than that observed by the riometer.

Since Syowa Station is constructed on the rock, the ground condition of electric signal is bad and the earth resistance comes to be more than 1 kΩ in winter. Therefore, observation instruments tend to interfere with each other. The heating box containing the transmitter, the receiver and the data acquisition controller is settled outside just beneath the antenna. Because of the minimum length of the antenna feeder, spurious signals to and from the feeder line is expected to be eliminated.

The microcomputer in the observation hut remote-controls the heating box equipments and receives signals *via* GPIB interface with the optical fibers of 200–600 m length. Then the electric noise can be rejected from the control/telemetry line.

In the case of the h'-t mode, the virtual height of the ionosphere is recorded together with the signal intensity and the environment data in the heating box. Ionograms are drawn on the microcomputer screen and then copied by a dot printer.

A delta shaped antenna of 20 m high is used for the ionosonde mode and a cross dipole is used for the h'-t and the partial reflection mode.

4. Concluding Remarks

Only the ionosonde carries out the operation during 20 s in every fifteen minutes at Syowa Station and other instruments operate continuously. The recent advancement of electronics and microcomputers enables us to construct a complicated but not so expensive ionosonde. The multimode FM/CW ionosonde is able to minimize the intervals of successive observation in comparison with the current ionosonde, and the data recorded by different observation equipments come to be easily compared with each other.

The software of the microcomputer deals with all the data handling procedures including FFT. If hardware processors are incorporated into PCS1 to save processing time, observation by the ionosonde will approach more continuous observation.

PCS1 was transported to Syowa Station and constructed by JARE-27 wintering party.

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