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Letter to the Editor

SCIPION, a new flexible ionospheric sounder in Senegal

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Abstract. SCIPION is a new state of the art digital sounder that has been developed by France Telecom-CNET for ionospheric monitoring and research. Extensive data processing using DSP technology has resulted in a low power, low cost and full featured system for both vertical and oblique soundings. A SCIPION system is in the process of being installed in Dakar, Senegal, to study HF propagation in the sub-equatorial ionosphere. However, preliminary results have still been obtained during experiments wit a prototype system. In this paper, the system is described and some illustrative examples of its capabilities are shown.

Key words. Ionosphere (Equatorial ionosphere, Instruments and Techniques) · Radio science (ionospheric propagation).

1 Introduction

Vertical and oblique HF sounders have proved to be particularly relevant for ionospheric studies. In the past, until the 1970s, most of sounding techniques were based on the transmission of high power pulses as it was the case for the US C-4 sounder, the Australian IPS-sounders and the Cossor system in Canada. Coded signals and frequency modulated waveforms were later introduced in order to save power while keeping acceptable range resolution (Wright and Pitteway, 1982; Bibl and Reinisch, 1978; Barry, 1971).

The ionospheric oblique/vertical sounder described in the paper use M-PSK coded waveforms, associated with specific digital signal processing techniques, which permits accurate measurements of the HF channel to be performed while using low transmitted power levels. It is the most recent version of systems that have been operated since the beginning of the 1980s, over various links (Le Roux *et al*., 1984; Le Roux *et al*. 1987),

Depending on options, the SCIPION sounder can perform the following measurements:

– Vertical sounding.
– Oblique sounding with time synchronization.
– Scattering function measurements.
– Polarization filtering.
– Angle of arrival measurements.
– Coherence analysis between spaced antenna while using only one receiver.
– Noise level or spectrum measurements.
– Impulse response sequences acquisition.

Furthermore, the impulse response sequences of the ionospheric channel measured by the system can be stored and later used in a channel reproducer for simulation purposes (Le Roux *et al*., 1990).

2 The SCIPION ionospheric sounder

Figure 1 summarizes the salient features and main performances of SCIPION.

2.1 System components

Tx/Rx units. The transmitter and the receiver are integrated either into one single Tx/Rx unit (monostatic option) or into two separate units (bistatic option). In the Tx unit, a synthesizer using direct digital synthesis (DDS) provides frequency generation. The HF transmitted signals are subsequently generated by modulation and frequency conversion. The RX unit comprises two HF heads with computer-controlled gains and phases. In normal operations, these two heads are associated with cross-polarized antennas to allow for O and X mode separation.

By means of a switching device, up to 8 receiving antennas can be used as an option. In this case, the antennas are sequentially scanned so that only one receiver is needed. This reduces cost and calibration problems. The minimum duration of analysis per antenna is 10 ms.

A 25 W Max amplifier is found in a separate unit so as to be located in the vicinity of the antenna if needed.

HF SIGNAL	
Duty cycle	10% to 100%
Modulation	2-4 PSK
Instantaneous bandwidth	programmable (±6.25 kHz
Frequency range	from 1 to 30 MHz
Frequency hopping	sequential, interleaved, random
Duration of frequency scan	from 30 sec to 3 min
Frequency stability	0.005 PPM
TRANSMITTER	
Fully programmable	manually or remotely (modem)
Output power maximum	25 W average
Output impedance	50 Ω
RECEIVER	
Switching device	up to 16 antennas
Input impedance	50 Ω
2 HF input channels	phase and gain programmable
Noise factor	< 15 dB
Input range	> 100dB
Image frequency rejection	> 90 dB
IF output	< 20 kHz

DIGITAL SIGNAL PROCESSING	
A/D conversion	16 bits
DSP	60 MFlops
Signal processing gain	20 to 42 dB
Group delay range	0 to 50 ms
Group delay spread/resolution	up to 8 ms / 0.5 ms
Max number of range bins	256
Range resolution	> 3 km
Doppler range/resolution	±1 Hz to ±30 Hz / 10mHz typical
Noise	Spectrum *vs.* sounding frequency
Polarization filtering	gain and phase adjustable
ADD ON SOFTWARES AND FACILITIES	
Windows application	
On line help	
Vertical to oblique conversion	
Regional predictions	
Real- heights	
Angles of arrival : skymap	
Spatial coherency	

Fig. 1. Performance specifications

Control unit. A Pentium PC provides control of the sounder operations, display of the results and data storage. Plug-in cards are added to the PC to permit control and synchronization of the sounder units and to provide the necessary signal processing capabilities.

As an option to the bistatic version, modems can be used for remote maintenance and/or control through telephone lines. In this case, the whole operating modes are controlled from one site (e.g. the Rx site).

The synchronization of the Tx and Rx units is provided by a plug-in card associated with a Global Positioning System (GPS) receiver. This permits the system to be operated everywhere in the world.

A signal-processing card provides digitization and processing of the analog signals from the Rx unit.

An MS-WINDOWS based graphical interface with mouse and on-line help in provided to visualize the data. Capabilities exist to visualize measurements either in real-time or in the form of animations for stored data.

Virtually any mass storage unit compatible with the PC can be used to store the data. Presently, an external 1 GByte disk unit permits the recording of several months of data in routine operations (4 ionograms per hour).

Antennas. Aerials must be broad bandwidth (1.5 to 30 MHz) and have a radiation pattern appropriate to the current option (oblique or vertical). For vertical or quasi-vertical systems, DELTA type antennas are appropriate for both transmission and reception. Two cross-polarized antennas can be used at reception to perform O/X mode separation. For oblique systems, inverted-V are appropriate at both the transmitter and receiver sites. Loop antennas can also be particularly convenient as receiver antennas.

2.2 Operating modes and data display

The operating modes are the following:

– Sweep or fixed frequency.
– Frequency scanning according to a selected program.
– Vertical incidence soundings (monostatic option).
– Quasi-vertical or oblique soundings (bistatic option)

All operating modes are computer controlled and can be activated according to any user-defined schedule. Depending on the SCIPION version and by means of the MS-WINDOWS graphic interface, the following data displays are provided:

– Amplitude ionogram (virtual heights vs. sounding frequency with color-coded echo amplitudes).
– Doppler ionogram (virtual heights vs. sounding frequency with color-coded Doppler shifts).
– Scattering function (virtual heights vs. Doppler shift with color-coded echo amplitudes).
– Noise spectrum vs. sounding frequency.
– Angles of arrival and their time evolutions (skymap).
– Coherence functions of received signals using several antennas.

3 Examples of experimental results

3.1 Vertical ionograms and oblique extrapolations

Figures 2 shows an ionogram measured with a prototype of the SCIPION sounder, in Dakar. For this ionogram, the frequency sweep duration was 100 s, whereas the frequency step was 100 kHz. The relative amplitudes of the echoes are indicated by colors. It can be noticed that significant spread-F appears on the ionogram. This is a typical feature of the equatorial ionosphere which is known to severely affect HF transmissions in these areas. On the

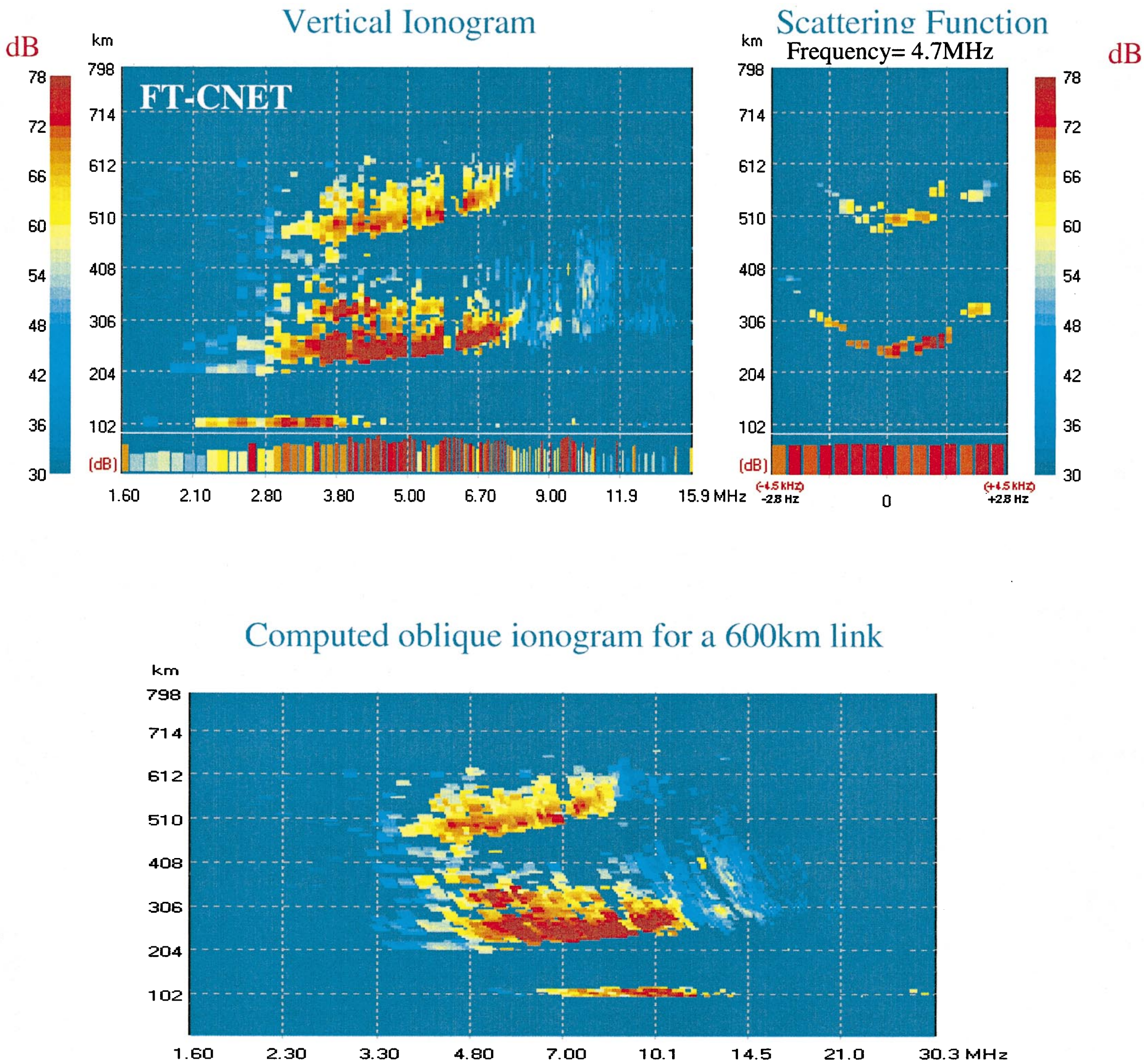

Fig. 2. Experimental results obtained in Dakar on the 18/01/1997 at 23h02UT

upper part of figure 2, the vertical ionogram which is shown presents both frequency and range spreading. The interpretation of these features is still a matter of discussion (Wright *et al*., 1996, Lauer *et al*., 1996). In our example, echoes resulting from total reflection are still visible with a characteristic curvature of the range versus frequency pattern in the vicinity of the critical frequency at 8.4 MHz. Examination of the scattering function (upper part of figure 2) may cast some light on the origin of the phenomena. This scattering function, shown here for 4.7 MHz, is clearly winglike shaped in the delay-Doppler frame. This indicates a quasi-uniformly horizontal moving structured plasma as described by Nickisch, 1992 by means of a phase screen diffraction method. In our example, the observed range spreading is clearly the result of echoes from multiple scatterers located within the antenna lobe. The impact of such phenomena on digital communication systems needs to be further studied and carefully modeled.

Figures 2 also shows an oblique ionogram synthesized from vertical incidence data by using the shell-like assumption (Davies, 1965). Such results can be used to monitor ionospheric conditions for radio paths in the vicinity of the sounder.

Noise level measurements at each sounding frequency are displayed at the bottom of the ionograms. The noise spectrum in the frequency band ±4.5 kHz with a 600 Hz resolution is visible at the bottom of the scattering function display.

3.2 Oblique HF channel analysis

Figure 3a shows the time evolutions of the group delays measured at a fixed frequency over a sub-equatorial path between Abidjan and Dakar. Figure 3b shows a set of consecutive scattering functions corresponding to the same experiment. Each scattering function is integrated over an 11 s time period, resulting in a frequency resolution of about 0.09 Hz. A very typical spread of the group delays can be seen on this figure. The fine range-Doppler structure is visible on the sequence of scattering func-

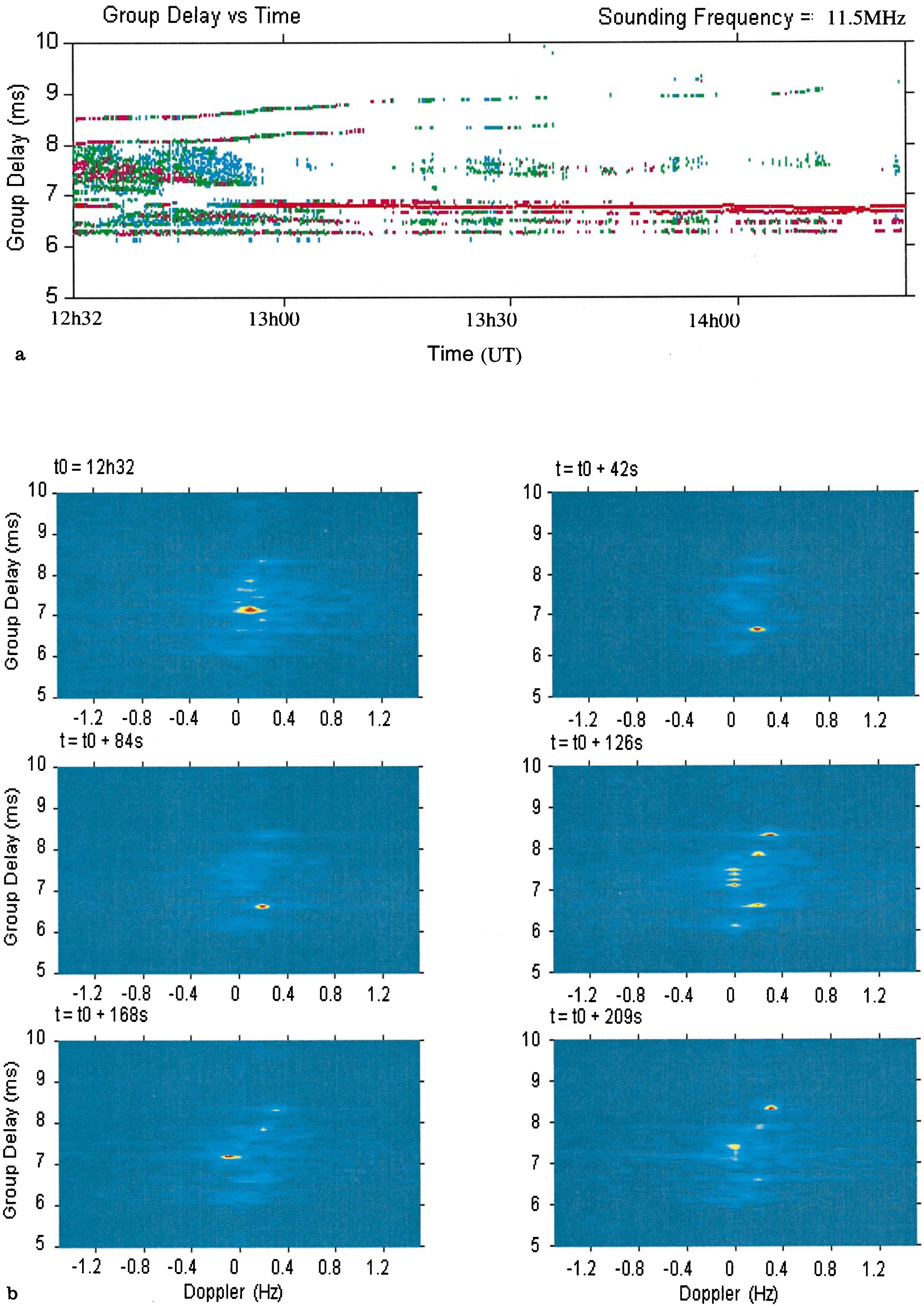

Fig. 3 a, b. Experimental analysis of the HF channel working at fixed frequency over a 2000 km length link between the Ivory-Coast and Senegal on the 21/06/1993. **a** Group delay evolutions for about 2 h. **b** A sequence of scattering functions over a short period from the same experimentation

tions. The results from figure 3 have been obtained at the middle of the day and consequently the Doppler shifts are not very significant. However, Doppler shifts may often be much greater, as at sunrise and sunset for instance.

4 Conclusion

We have briefly described in this paper the new CNET SCIPION sounder. It is a new state of the art digital sounder that has been developed for ionospheric monitoring and research at both vertical and oblique incidences. A SCIPION system is in the process of being installed in Dakar, Senegal, to study HF propagation in the sub-equatorial ionosphere. However, a prototype version of the sounder has yet been operated there on November 96 and January 97. Some results from these experiments have been shown here. These results indicate clearly that SCIPION permits accurate measurements of the HF channel to be performed while using low transmitted power. It therefore appears that SCIPION is a very well suited tool for studying the HF channel, in particular at sub-equatorial latitudes where severe propagation conditions are to be found.

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