$3.00

XXXII CONGRESS
INTERNATIONAL ASTRONAUTICAL FEDERATION

IAF'81

ROME, ITALY, SEPTEMBER 6-12, 1981

PREPRINT

IAF-81-94

Radar Altimeter for Ocean Remote Sensing

S. Pardini, G. Picardi, R. Ronconi and R. Somma, *Italy*

This Preprint is for distribution at the Congress only

Published for the

International Astronautical Federation

by

Pergamon Press

Oxford · New York · Toronto · Sydney · Paris · Frankfurt

RADAR ALTIMETER FOR OCEAN REMOTE SENSING[1]

S. Pardini*, G. Picardi**, R. Ronconi*, R. Somma*

*Selenia S.p.A.
Rome - Italy
**Dept. of Electrical Communications
University of
Rome - Italy

ABSTRACT

Radar Altimeter described herein is a radar based instrument where a suitable processing of the return echo from ocean surface allows the determination of the following meaningful characteristics: satellite altitude over sea surface, H, significant wave height (SWH), and wind speed. Key performance of the instrument is the high required accuracy in the measurement of the above characteristics. This implies high precisions in radar measurements of the pertinent return echo parameters, well above the conventional radar performances. Then suitable concepts and techniques have to be applied both at system and implementation level. This paper focushes on problem areas and reviews the adopted solutions.

KEYWORDS

Remote Sensing, Radar Altimetry, Signal Processing, High Resolution Radar.

INTRODUCTION AND BASIC CONCEPTS

The ocean radar altimetry is based on the electromagnetic backscattering of the ocean surface in response to a narrow pulse (few ns) waveform under near normal incidence.
In fact the average return echo (average return power vs. time) carries out information on the sea surface as the mean sea level and the sea state (significant wave height and wind speed). It has been shown, (Miller, Hayne, 1971; Brown, 1977) that the above average power response can be modelized by the convolution of the following three time functions:

- the average flat surface impulse response (decreasing exponential with time constant related to antenna beamwidth);

[1] The Radar Altimeter feasibility study has been performed in the frame of the European Remote Sensing Preparatory Program (RSPP) under ESA contract 4428/80.

- the height (converted in delay time) pdf of the sea surface scatterers (gaussian with standard deviation proportional to the rms waveheight);
- the altimeter system point target response (gaussian with standard deviation proportional to the pulsewidth).

The resulting function is a shaped pulse, see fig. 1, whose leading edge has a slope proportional to the significant wave height, and whose mean power carries out information about sea reflectivity, which in turns depends on the wind speed.
The third ocean information, mean sea level, is conceptually a classical measurement of radar systems, as it is related to the time delay between transmitted pulse and the half power point of the received echo.
All the above qualifies the Radar Altimeter as a radar system having a signal processing suitable to the estimation of the above parameters of the return echo.
Peculiar to Radar Altimeter system is the high required accuracy in the measurement of the ocean characteristics of interest. This implies high precisions in radar measurements on the related echo characteristics, which result well above the conventional radar performances, this mainly for the classical radar measurement of the range.
Next section describes the system concept adopted to face the above problems, while sect.s 3 and 4 are devoted to RF/IF section and signal processor respectively.

SYSTEM DESCRIPTION

The high required accuracy in range measurement, in the order of few cm, implies to start with an high radar resolution, i.e. pulselenght in the order of few ns. The resulting very high RF bandwidth, in the order of some hundreds of MHz, entails difficulties both in receiver matched filter implementation and , even if such a filter were available, in video signal handling.
The solution to both the above problems has been suggested by the Seasat-A Altimeter system concept. It consists of a tracking radar in which the full-deramp concept has been implemented. This concept requires the use of a linear FM pulse (chirp) in trasmission. It is graphically shown in fig. 2 and consists in mixing the echo RF signal with a replica of the transmitted signal suitably time delayed in order to aligne it with the chirped echo from the mean sea level, with reference to which the tracking is performed.
Due to the linear behaviour of the frequency vs. time, time delays map into frequency offsets at the output of the mixer.
Of course the IF bandwidth has to be dimensioned according to the maximum expected wave height. That is :

$$B_{IF} = \frac{B}{T} \Delta t \qquad (1)$$

were :
B = RF signal instantaneous bandwidth
T = pulse duration
Δt = time delay corresponding to maximum expected waveheight.

As Δt is in the order of some hundreds of ns, while T is in the order of some μs, there is a significant reduction of B_{IF} with respect to B.
B_{IF} assumes values in the order of some MHz, so it is suitable for video signal processing.
Fig. 3 shows a schematic diagram of the radar altimeter.

Tx and Rx trigger enable chirp generation for transmission and L0 respectively, this last is driven by the coarse altitude estimate. The received signal, after the full-deramping (mixer M) is IF amplified and coherent detected. The resulting in-phase and quadrature components enter the signal processor where, based on errors between the received echo and a suitable reference signal (recursively updated), the position and slope of the echo signal are evaluated. An AGC loop, necessary for the correct operation of the receiving chain, is used to extract the information on the echo average power.
The dimensioning of the radar system has to account for the S/N needed by the signal processor to achieve the required measurement accuracies. Of course some constraints affect the selection of the various parameters of the radar equation. This apply for example for the antenna gain (there is a maximum size not to be exceeded), for the wavelength (frequency has to consider WARC' 79 allocations, and propagation losses), and so on.
If a conservative S/N of 10 dB is assumed, the main parameters have been assumed as follows :

- P_T = transmitted peak power ≃ 400 W
- f = transmitted frequency = 13.5 GHz
- G = antenna gain (1 m dish) = 40 dB
- T = pulse duration = 5 μs
- τ = equivalent compressed pulse duration = 2.5 ns
- PRF= 1000 Hz

The tracking operation of the system is preceeded by an acquisition phase, during which a first estimation is performed of the satellite - ocean dinstance. The estimate is used to initialize the tracking mode.
Other operating mode have been foreseen for system monitoring and energy saving during not operative phases.

RF/IF UNIT

The functions of RF/IF unit are :

- the generation and amplification of chirp pulse;
- the amplification, filtering and detection of return echo;
- the generation of Local Oscillator signals and of system timing
- the configuration switching according to the operation mode (acquisition, tracking, etc.).

The main problem areas are as follows :

- distorsion of chirp signals : the effect of distorsions introduced by chirp generation and amplification circuitry (both linear and not linear) is the generation of spurious chirp signals together with the useful one (paired echoes). The spurious chirps enter the receiving chain and can appear as usefull echoes leading to errors in estimation of usefull information. Then spurious echoes have to be reduced at a level consistent with the required accuracy performances;

- short and long term sources stability: the required high accuracy in height estimation entails a consistent high accuracy in time delay measurement, then timing circuits and LO sources have to be very stable in long (aging) and short term (statistical fluctuations in few msec);
- signal propagation time in the instrument: in fact the signal propagation time in the instrument is very high with respect to required resolution and accuracy in time measurement, then fluctuations of propagation time due to circuitry aging and operation environment have a not negligible effect. To account for that the propagation time has to be periodically measured;
- level of transmitted power and RF/IF gains: as the sea reflectivity is extracted by the received mean power, variations in transmitted power and in amplifiers gain affect the accuracy of the measurement. This entails that the above parameters have to be periodically monitored.

The techniques adopted to solve the above problems ar both at system and circuit level. The main among them are :

- Double conversion receiver;
- High stability coherent sources;
- On board time and amplitude autocalibration.

The main system differences with respect to Seasat solution refer to the use of double conversion and in the presence of the on board time calibration .

SIGNAL PROCESSOR

The signal processor operation is based on the estimation of the position and the slope of the return echo with respect to a reference signal internally generated.
The reference signal is generated on the basis of previous estimations and is a linearized model of the return echo shown in fig. 1.
The signal processor implementation relies mainly on the use of two loops:

- the Height Tracking Loop (HTL), to estimate the position of the return echo, hence the satellite altitude over the ocean;
- the Slope Tracking Loop (STL), to estimate the slope of the return echo leading edge, hence the significant waveheight (SWH.

The principle of operation can be summarized in the following two steps, see fig. 4 :

- the return echo (input waveform to the processor) is compared with a suitable reference (or estimated) waveform. Area C of fig. 4a, evaluated over a number N_E of samples, gives information on position error, then it is used to operate HTL which acts to superimpose central points of the two waveforms; this way the position of the return echo is estimated ;
- the estimated (or reference) signal is rotated according to information given by (A + B) area of fig. 4b. This way its slope is corrected and the input waveform slope is estimated.

In the above description, the signal amplitude, D, is assumed normalized. Indeed the ampli-

tude normalization is accomplished by using an Automatic Gain Control (AGC) loop, which acts on the IF amplifier.
The main problems pertinent to processor operation rely on :

- the initial pull-in phase (after a search and external acquisition): this problem mainly refer suitable choice of the initializing reference waveforms and of loops bandwidth;

- the tracking phase: loops parameters have to be dimensioned in order to obtain the best estimation compatible with the ocean dynamic characteristics and with the need of storaging to react to transmission fading (due to rain, etc.).

The problem of the pull-in phase initialization has lead to the decision of using two separated loops for position and slope. In fact it has resulted that to react to high errors in pull-in phase HTL and STL have to be initialized with reference waveforms having a high slope and a low slope respectively.
The correct operation of the processor requires a further loop, Height Slope Adjustment (HSA), to connect HTL and STL. It acts by copying the slope from STL to HTL, in fact in steady state the two slopes have to be identical.
Fig. 5 gives a schematic view of HTL, STL and HSA connection.
Fig. 6 has resulted by a preliminary deterministic simulation and shows the convergence of the three loops connected together during pull-in phase.
Key performance of the proposed signal processor rely to the discriminators concept. They use continuously generated reference waveforms, the resulting processor is close to the matched one, then obtainable results are close to those from a MLE estimator.

CONCLUSION

The obvious starting point for the Radar Altimeter feasibility study has been the previous system for Seasat A (Macarthur J.L., 1976). The resulting system architecture reflects this fact.
On the other hand the analysis of the problems pertaining to the various system areas has lead to some solutions, both at system and implementation level, which differ from the Seasat altimeter.
The main differences are :

- the discriminators concept;

- the presence of time autocalibration.

The resulting system seems to be intrinsecally able to give better results in terms of accuracy than the quoted one.
The authors wish to express their thanks to Mess.rs M. Canevari, P. Lombardi, G. Di Gesaro, P. Porzio, T. Bucciarelli and G. Pozzolini, who partecipated to the Selenia team who carried out the work.

REFERENCES

Brown, G.S. (1977). The Average Impulse Response of a Rough Surface and its Applicat -

ions. IEEE Trans. on Antennas and Propagation, vol. AP-25, n. 1, 64-77.

Macarthur, J.L. (1976). Design of Seasat-A Radar Altimeter. Oceans '76, 10B1-10B8.

Miller, L.S., G.S. Hayne (1971). System study of the Geodetic Altimeter Concept - Final Report NASA Contract n. NAS6-1829, Research Triangle Institute.

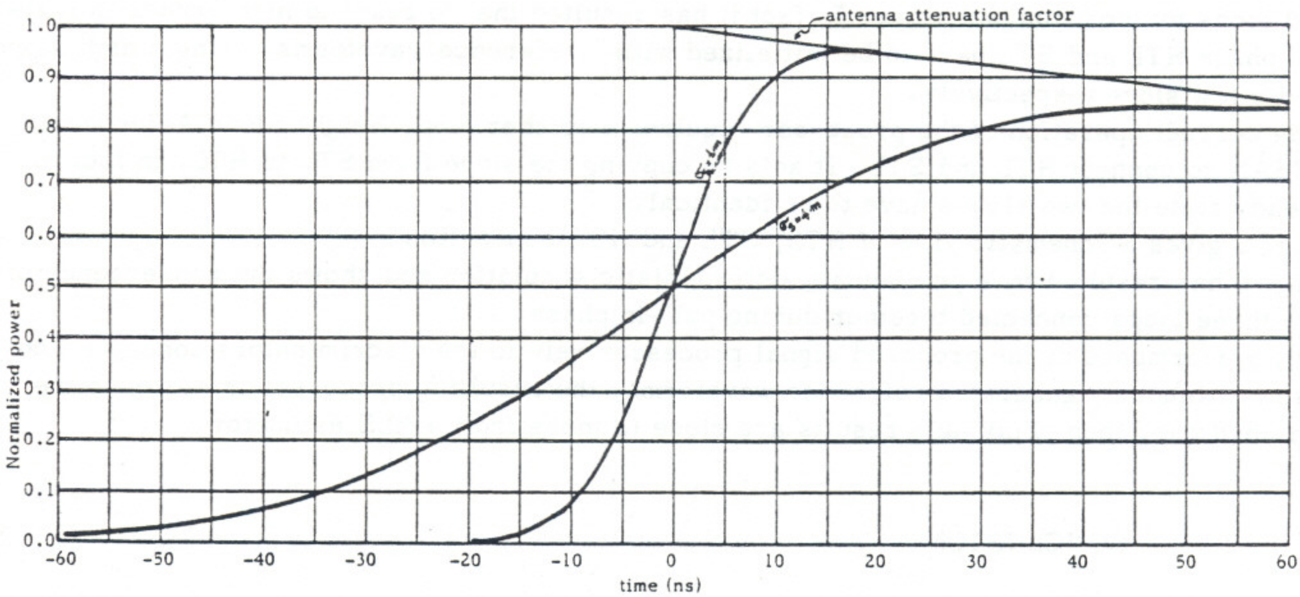

Fig. 1. Average return power waveforms for two rms waveheight.

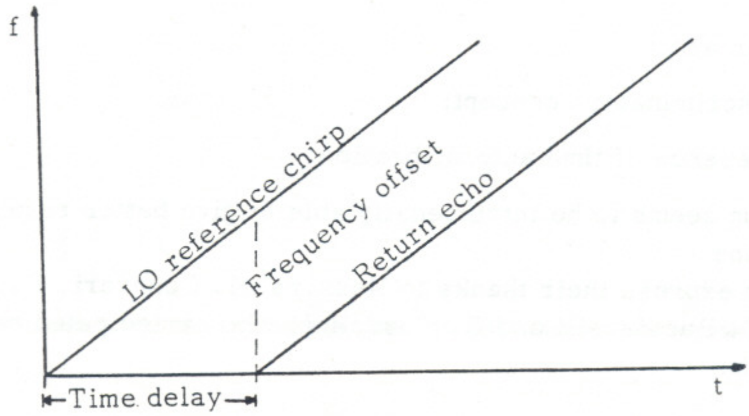

Fig. 2. The full-deramp concept.

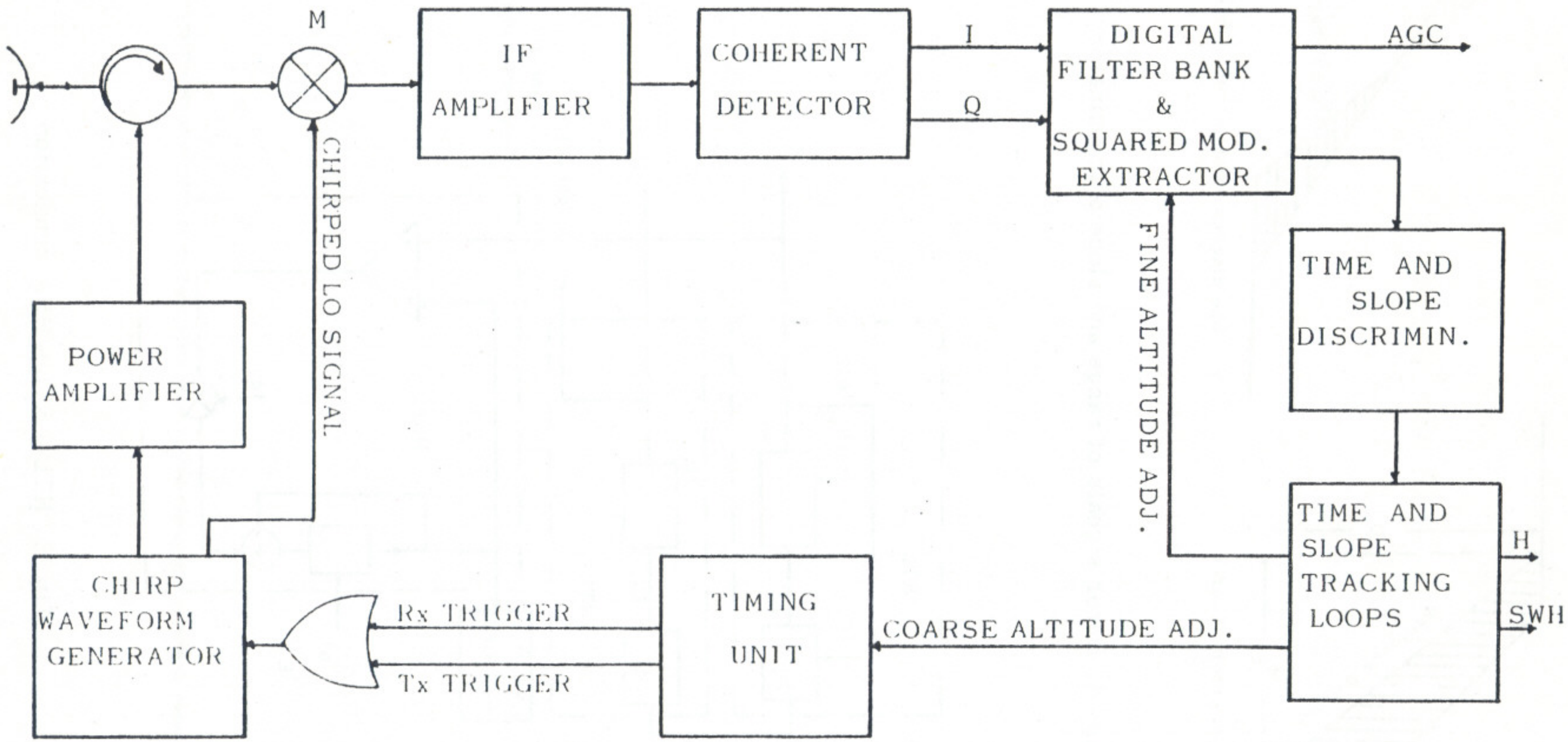

Fig. 3. Radar altimeter functional block diagram.

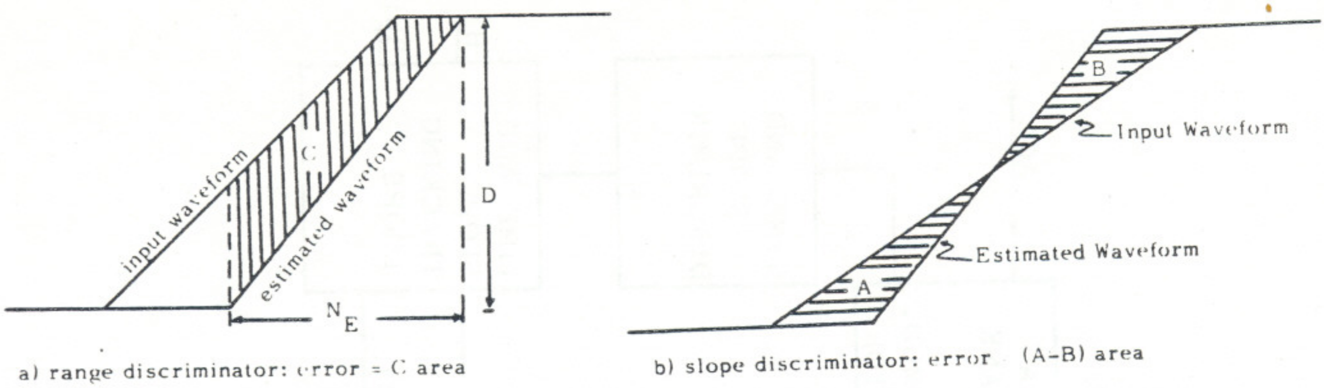

Fig. 4. Error signals of range and slope discriminators

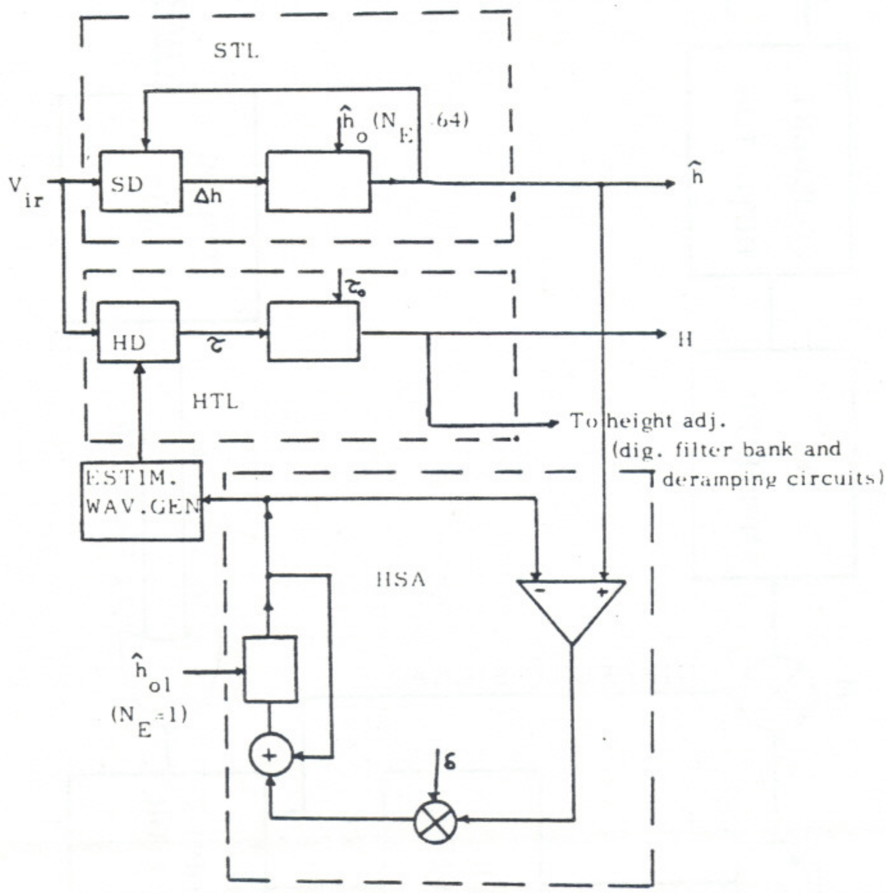

Fig. 5. HTL - STL - HSA connection

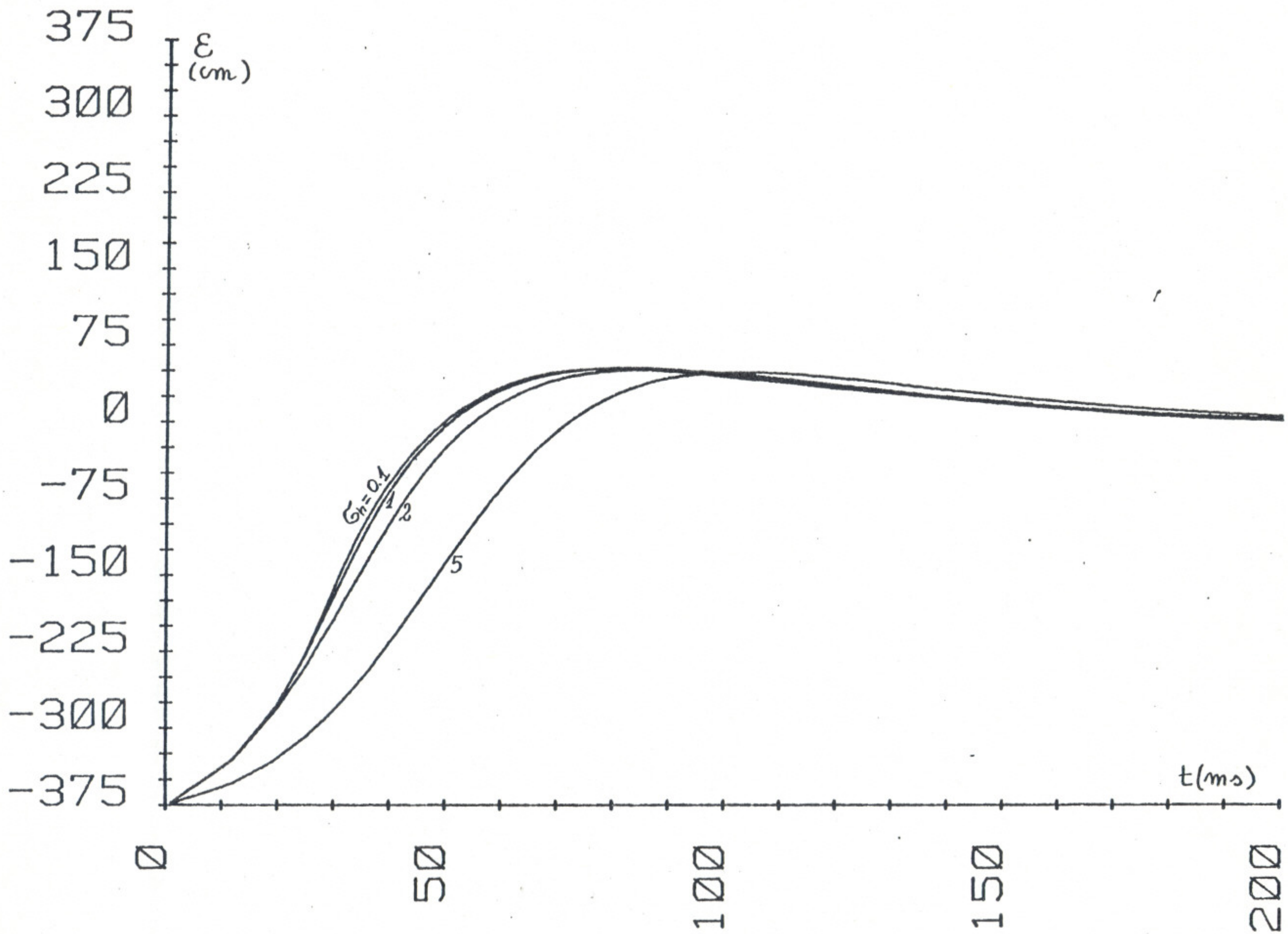

Fig. 6. Deterministic simulation of loops operation.