EVALUATION OF A RANDOM ACCESS SYSTEM WITH HARDWARE SIMULATION

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Summary. The purpose of this study is to solve the problem of the determination of the exact capacity and performances of a satellite location and data collection system using random access. Here is described the method we apply in the particular case of the ARGOS system; the TIROS-N and NOAA-A to G satellites will be equiped with the ARGOS on-board experiment and will ensure an operational service from 1978 to 1985 at least. The results we obtained are significantly better than the first estimations and should allow us to increase the number of the platforms.

Introduction. In the case of the first location and data collection systems including non geostationary satellites, such as IRLS and EOLE CAS-A, the beacons were equiped with both receiver and transmitter subsystems. When the beacons were in visibility of the satellite, they received its call message and they transmitted back their answer message to it. This double link between the satellite and the beacons allowed to do range and Doppler effect measurements owing to which the beacons are localized. With such a system, not only the programming of the beacons to be localized is complex, but also the transponder of the beacons is elaborate and, consequently, expensive. In order to avoid these disadvantages, in the ARGOS random access system the one-way link "beacons to satellite" is used, the beacons transmitting their messages at periodic intervals, independantly of the satellite. Per contra, the probalistic aspect of the method appears ; several beacons can simultaneously transmit their own message to the satellite, and possibly cause interference phenomenas. So, several processing channels are necessary. Moreover, the location can only be done from doppler effect measures with oscillators the frequency of which is not well known. Here we will not treat of this location problem, except when it has consequences on the random access evaluation. Previous studies demonstrated that the location is possible in these conditions.

When we examine the problem of beacons mutual interferences, we have to consider the characteristics of on-board experiment, which includes non-linear elements, the working manner of which is generally not known when they are in presence of two or several signals. Through this way of study, the evaluation of the system is approximate, so the only solution is to simulate by hardware the messages received by the onboard receiver of the satellite. In this purpose, we have realized a model of the ARGOS receiving system. Although the results we obtained be specific to the ARGOS equipment, we think that they can be used as a general rule.

General. Here we consider the ARGOS program, which includes users beacons, an equipment to be put on-board a satellite and acquisition and processing facilities. As also others on-board experiments, the ARGOS receiving system will equip the TIROS-N and NOAA-A to G satellites. An operational service will be ensured from 1978 to 1985. The orbit of these TIROS-N and NOAA satellites is circular, sun synchronous and quasi-polar ; they will be placed at about 830 km altitude. Two satellites with almost orthogonal orbit planes will simultaneously operate. A world coverage can be ensured by such a system.

The working manner of the whole ARGOS system is as follows - the beacons transmit periodically coded messages independently of the satellite. Every time a beacon is in visibility of the satellite, the latter receives the transmitted message, operates the acquisition, decommutates the data, measures the signal frequency, operates the time referencing of the message and elaborates a new message which is stored by the S/C memory. When the satellite comes in visibility of one of the two network ground-stations, all the data collected by the satellite are transmitted to ground, the ARGOS data are extracted and they are sent to the French Processing Center, which operates the location and the decommutation of the data. Then, the users are supplied with the results of ARGOS system.

Aims - Location. The initial purpose of such a system was to locate a float of 2000 beacons uniformly distributed around the world surface, with an accuracy of about 5 km. So the problem was to determine if it was possible to obtain this accuracy rate with the only doppler effect measures, in the case of a random access system. Here we don't go further back into the matter (Ref. 1 and 2); only some general results, necessary to establish the performances of the random access, are given every doppler effect measuring done for one beacon determines a geometric locus : it is a cone the axis of which is the satellite velocity vector and the half apex angle of which is called θ, such as :

$$\cos \theta = \frac{C}{V} \quad \frac{fd}{fo}$$

fd : doppler frequency
fo : carrier frequency
V : velocity of the satellite

In case fo is known, the accurate determination of the beacon position can be computed at the second pass of the satellite it is located at the intersection of such two cones and of the altitude sphere of the beacon. But, in ARGOS configuration, we have to take in consideration that the carrier frequency is not know and that the beacons are moving, so it is necessary to do more measurements. The required location accuracy rate necessitates that (Ref. 1) :

(Ref. 1) : Note interne CNES. Etudes sur la localisation de plates-formes par mesures doppler “one-way” système TIROS-N par A. CARIOU, C. FARJOT.
(Ref. 2) : Un système de localisation et de collecte de données par accès aléatoire. XXIVème Congras d’Astronautique de Bakou par G. DELMAS.

1. - the orbitography of the satellite be ensured with specific beacons ;
2. - the frequency of the beacon equipment abide by precise specifications :
   - stability during the counting (100 Ms) : 10^{-9}
   - deviation during a pass of the satellite (20 mn) : 10^{-8}
3. - 6 measurements at least be done during each of two successive passes of the satellite.

The problem of the random access. The messages transmitted by the beacons include :
- a pure carrier part in order to allow the on-board receiving system to do the acquisition;
- a frequency modulated part including the synchronization words, the identification of the beacon and the data furnished by the sensors. Table I shows some specifications required by the transmitted messages.

unmodulated carrier 160 ms	Bit synch (15 bits)	Frame synch (8 bits)	1 bit	iden- tifi- cat. (24 bits)	1 2 3 4 (32 bits)	other sensors lot added by lot of 4 sensors

Table 1 .- Specifications of the platforms messages.

digital rate : $395 < f_b < 405$ b/s
phase modulation : biphase L
message structure :
- bit synchro : 15 bits “1”
- frame synchro 8 bits 00010111
- initialization : 1 bit “1”
- identification : 24 bits
- sensors : 4 n eight bits word $1 \leq n \leq 8$

repetition period :
- for location : T = 40 s or more following accuracy excepted
- d.c. only : T 200 s

transmission :
- frequency : 401,65 MHz

- osc. stability :
  short term (20 mn) : $0{,}5.10^{-9}$ /mn
  jitter,(100 ms) : 10^{-9}
- transmitted power : 3 watts

When several messages are received at the same time, the random access sets two problems : the mutual interferences between the present messages and the simultaneous processing of several messages. This second problem can be resolved easily, it is a problem of “queue”. On the other hand, the first one is very much more complex : the mutual interferences require the consequent study of the receiving system principle and of its working manner in the presence of signals having different levels and some frequency shift.

In order to minimize these interferences, it is necessary that the signal be as short as possible and, consequently, that the processing be done as fast as possible by the on-board receiving system. Of course, during the study, the evaluation of the performances and the principle of the receiving system will be continually reconsidered the one dependent on the other (Ref. 3). The block diagram is shown in fig. 1. The characteristics of the beacons are themselves consequent from this optimization.

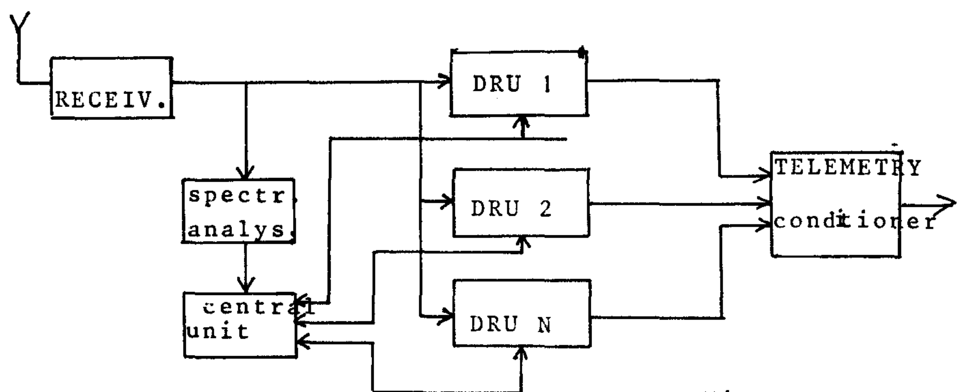


Fig. 1

The receiving system is composed with

- linear receiver ;
- a fast spectral analysis device called Search Unit, which measures approximatively the frequency ;
- 4 processing units which ensure the definitive acquisition of the message when the frequency is established, the decommutation and the doppler counting ,
- a control device, which assigns the input signals to the available processing units and determines a rough frequency position of these processing units phase-lock loop.

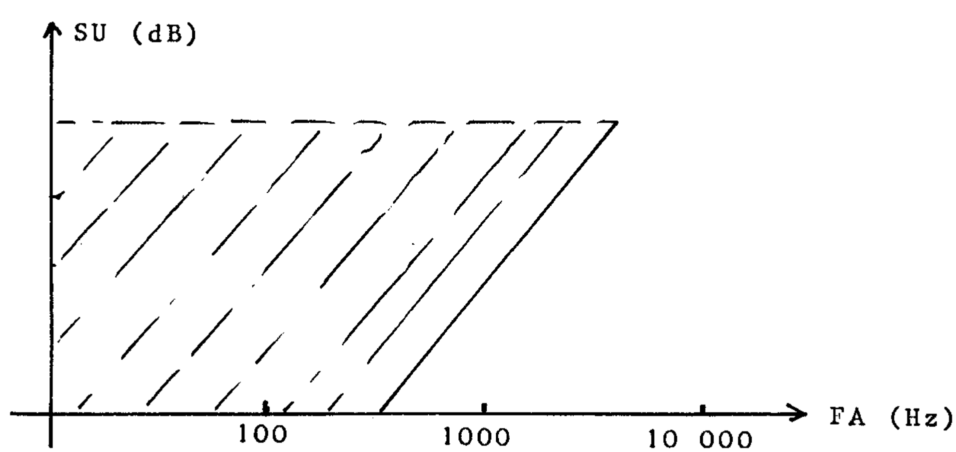
First evaluation of the random access problem. An estimation induces us to consider, on the one hand, the different mod of a message and the filled spectral bandwidth : pure carrier frequency, modulated carrier ; on the other hand, the different traversed equipment or functions and their bandwidth : receiver, search unit, phase-lock loop during acquisition and during tracking, doppler counting, bit synchronization, demodulation. For each of these phases, that leads to determine disturbance ranges defined into the frequencies amplitude field. Inside a disturbance range no other signal has to be present in order to avoid the considered signal be disturbed. These disturbance ranges, elementary at the begining, have been gradually studied thoroughly as we acquired a better knowledge of the equipment owing to various tests. But if it is easy, from well defined signals, to determine the disturbance range of an equipment, the input of a nth equipment of the system is badly defined.

(Ref. 3) : Conception d'un satellite à accès aléatoire par D. LUDWIG. Texte présenté au Colloque National sur le traitement du signal et ses applications - Nice 16-21 juin 1975.

So, we conclude that the only significant estimation necessitates a real simulation : a set of messages would be injected in a model of the receiving system in order to exactly reproduce the working conditions of receiving and processing.

The principle is as follows :
under the control of a minicomputer, an emission simulator, composed of 5 subsystems, generate signals toward the input of the receiver model. These signals are identical to those which will be received by the on-board receiver during orbital flight. The processing of these signals is done by the receiving system and the telemetry is recovered owing to the minicomputer through an interface bay simulating, among other things, the functionning of the on-board processor.

Fig. 2 - Example of disturbance range



By comparison of this telemetry and of the characteristics of the generated emissions, an evaluation of the system performances is deduced.

Emission simulation. The emission simulator consists of 5 simulating subsystems and of a mixing unit. Every simulating subsystem is composed of a programmable synthetizer and of a command block charged with checking the synthetizer and with generating the video-message, according to informations furnished by the computer. So, a simulation subsystem allows to generate a UHF signal which has the encoding characteristics indicated in table 1, as well as the frequency and the level that such a signal could have at the input of the receiver. So, the 5 simulation subsystems allow to simulate 5 simultaneous messages. In the case of the 2000 beacons, the loss of messages due to the fact that there are only 5 subsystems is lower than 1%, which is the required precision.

The signals of these 5 subsystems are mixed and appropriately attenuated before their introduction into the receiving system.

Preparation of a "float". The messages presented to the receiver have to be representative of a "float". In order to furnish a file of the emissions present at the input of the satellite at every moment to the minicomputer of the testing bench, a simulation of the orbital path of the satellite above a beacons float is done owing to a computer.

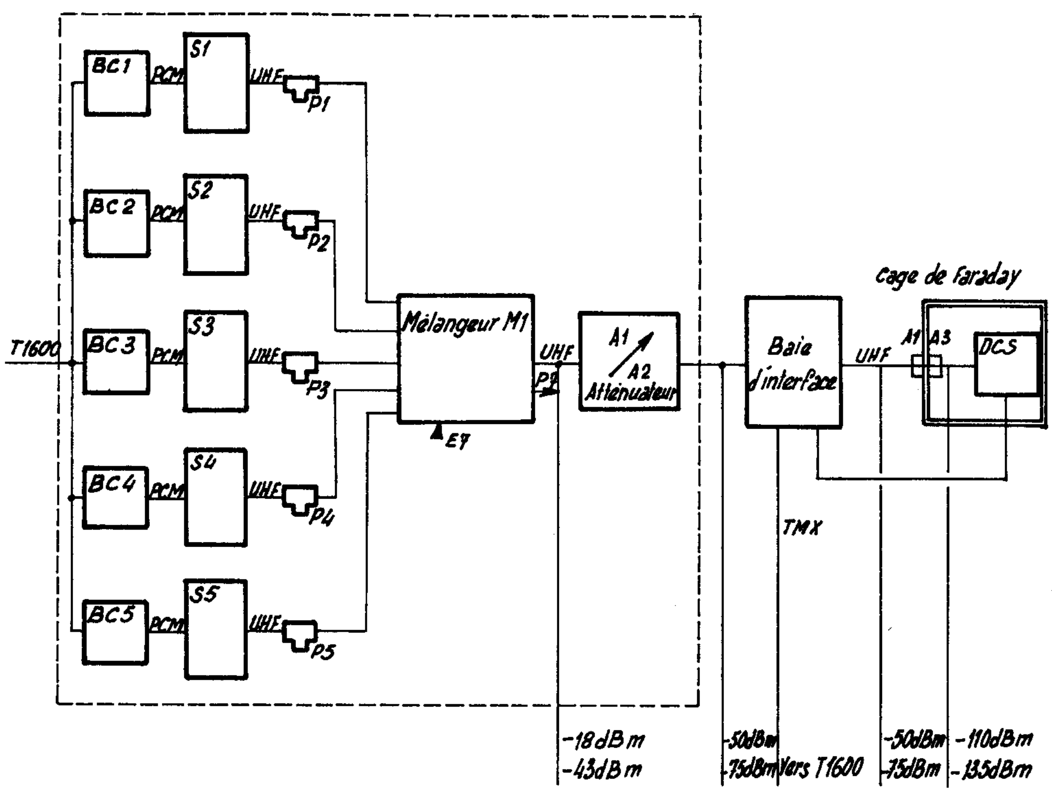


Fig. 3 - EMISSION SIMULATION

The principle of this simulation is as follows

– on a Larth likened to an ellipsoid with an oblateness of 1/298,25 and an equatorial radius of 6378,155 K M, N beacons are geographically dispatched as it is required by the mission. The geographical dispatching can be wether statistical (result of a drawing according to a specific constant density) or deterministic.

Every beacon is characterized by its own parameters :

– identification number, number of sensors
– position and eventually movement ; latitude, longitude and velocity
– emission frequency and drift level of this frequency
– repetition period drawn at random according to an uniform law
– the time reference of the first emission of every beacon is also drawn according to an uniform law between 0 and medium repetition period.

The position of the satellite is characterized by a file (identical to the one which will be used for the processing) in the same coordinates system as the beacons. This allows to calculate at every moment the relative satellite-beacons positions.

Being known these relative positions (beacons / satellite), it is possible to calculate the emission characteristics at the satellite level :

– its frequency, bearing the doppler deviation
– its level, which depends on the propagation attenuation and on antenna diagrams of the beacons and of the satellite. So for an orbital or an half orbital path of the satellite, a file will characterize all the messages transmitted by the beacons which are in optical visibility with their significant parameters as above.

These files are established for different geographical configurations. Various numbers of beacons and different repetition periods will allow the minicomputer to get to generate the messages mixtures which could be received by the on-board receiving system.

Then, we have to compare the processed telemetry with the transmitted file and to determine the system performances :

– accuracy of the doppler counting
– bits errors
– general performances with regard to random access
– capacity.

Results. The tests are far from being ended and others missions will be studied later. The missions we have studied at the present time are :

N = number of beacons evenly dispatched on Earth = 2000 and 4000

TR = Repetition period = 40, 30, 20 seconds message duration = non modulated part : 160 ms
= modulated part : 200 ms(4 sensors)

Number of processing units : 4 or extraction flow towards the spacecraft processor : 720 B/S which makes us sure that there is no blocking at this level, and 480 B/S.

The measured values are :

Po : Probability for a message to be satisfactorily received with an error of the frequency measuring inferior to 2Hz

σo : Standard deviation of frequency errors in Hz

Ps : Probability for a message to be received without errors on sensors bits.

L : Loss of messages because insufficient flow towards the spacecraft.

The table 2 shows some results :

ARGOS DCS PERFORMANCE

Number of Platforms N	Repetition Period TR (s)	Number of DRU	TIP data rate (Bits/s)	Po % ($\Delta f < 2$ Hz)	σ_o (Hz)	Ps % (0 false bits)	L % (Loss when 480 B/S)
2000	20	4	720	83	0.195	81	
	20	4	480	60	0.195	58	28 %
	20	3	720	77	0.195	75.5	
	20	3	480	59	0.195	58	23 %
2000	30	4	720	87.6	0.183	86.5	
	30	4	480	82	0.183	81	6 %
	30	3	720	84	0.185	83	
	30	3	480	83	0.185	82	1 %
2000	40	4	480	91	0.180	90	0
	40	3	480	89	0.180	88	0
4000	40	4	720	84	0.190	82.6	
	40	4	480	59.6	0.190	58.6	29 %

TABLE - 2

From these results the general performances given in table 3 are obtained ; we take into account the fact that 6 messages must be received at each one of two successive orbital pathes of the satellite and that, moreover, there are at least 420 s between the first and the last measuring.

The results due to the only random access are shown in the column 1 and 2 : Po previously defined and P, probability of location for a beacon which is geometrically localizable ; in the 4 next columns, the results are given with regard to the geometry of the pathes in the -40° + 40° latitude aeras, inside of which some beacons are not in visibility of the satellite during two successive pathes.

Table 3

Mission	Po	P	P1.12	P1.24	MIN P2.24	MAX P2.24
2000 Platforms 20 s	0.83	0.99	71,3	89.6	90	100
2000 Platforms 40 s	0.91	0.92	66.2	88	90	100
4000 Platforms 40 s	0.84	0.88	63.4	86	90	99

P : Location probability if geometrecally locatable
P (1.12) : Percentage of located platforms by a S/C each 12 h
P (1.24) : Percentage of located platforms by a S/C each 24 h
P (2.24) MIN : Percentage of located platforms by a S/C each 24 h
P (2.24) MAX : Percentage of located platforms by a S/C each 24 h

By way of comparison, the first approximate value of Po was 0.7 for a 2000 beacons mission.

Conclusion :

So the tests of real simulation allowed us to demonstrate that the capacity of this system is almost twice what was expected previously. Of course, in order to be really realist, it would be necessary to take into account the electrical interferences. such tests will be carried out, but the only experience will be significant.

On the other hand, the tests allowed to do precise measures on the disturbance ranges previously indicated and consequently, to perfect a numerical model of the on-board equipment which will ensure the management of the float-and consequently to ensure a judicious “so wing”-during the operational phase.