SPREAD SPECTRUM CONCEPT APPLIED IN NEW ACCURATE MEDIUM-LONG RANGE RADIOPOSITIONING SYSTEM

by Georges NARD [*]

---

1. — ABSTRACT

Principles of Spread Spectrum Systems (SSS) have already found several radiolocation applications well known in the field, such as SYLEDIS, JTIDS or GPS NAVSTAR. All these existing systems operate UHF or SHF with relative spectral widths which do not exceed 1 or 2 per cent of the frequency carrier.

In the new application, subject of this paper, a far larger extension of the spectrum spread associated with a drastic narrowing of the base band useful for the radiopositioning information leads to a very high B/b_0 bandwidth expansion ratio of 10^8 or so.

This opens to the conception of a new precise (5 to 20 metres) land-based radiopositioning system which is lightweight, of high discretion, and capable of any weather long range operation (up to 1 200 kilometres).

This system, named GEOLOC, fully eliminates drawbacks often undergone by other existing systems such as ionospheric and multipath interferences, position or phase ambiguity and frequency allocation.

Two years of prototype field experiments validate the overall concept of the system, the full compatibility with other radio services, the safety and reliability of position information offered.

Either standing alone or integrated with other location means, GEOLOC is a modern, precise, easy to set and move system. Its all-time, all-weather long range allows the easy coverage of extended continental shelves when the most precise and reliable positioning is required.

(*) SERCEL, B.P. 64, 44471 Carquefou Cedex, France.

For tomorrow this kind of system will offer either an important alternative to Global Positioning Systems or a useful complement to compensate the effects of a momentary precision shade-off or degrading, or some restriction in the use of these systems.

2. — SPREAD SPECTRUM TECHNIQUES CONCEPT REMINDER

Any information transmission through electric signals requires a useful or necessary bandwidth proportional to the information rate flow, often called base band b_0. The conventional methods make use of a transmission occupying a spectral bandwidth as close as possible to this b_0 value. Then the overall radiated energy is concentrated within this b_0 bandwidth, leading usually to a high-power spectral density. Conventional receivers use a bandwidth matched to b_0 and high side selectivity.

When the spread spectrum technique is used in a transmitter, the normal baseband signal goes through an additional coded modulation, precise, easy to reproduce, the rate of which is far higher than the base band flow. Then the energy is spread over a wide spectral band B leading to a strong decrease of the power spectral density down to a B/b_0 ratio often called Bandwidth Expansion Ratio. The spread spectrum receivers use a wide bandwidth front end before a decoder or "correlator" which correlates the incoming signals with a local coded generated signal identical to that of the transmitter, and accurately time synchronised with it. The multiplier of this correlator is followed by a base band filter b_0 and the other regular elements of a receiver.

An advantageous feature of this technique is such a potentially significant decrease of the power spectral density, even quite close to the transmitter, that the spectral level could be lower than radio noises given normal reception constraints. Moreover, if powerful enough coding is used, only authorised listeners are able to proceed to the transmitted information.

This leads to the two basic features of SSS : discretion and multiple simultaneous uses of the same frequency band for several transmissions.

Three other important associated benefits arise :

— The accurate time resolution capability leading to the possible undesired multipath signals rejection.

— The spectral spread by the receiver decoder of the undesired narrow bandwidth "jammers" and their attenuation by a b_0/B ratio.

— The liberation from most frequency allocation constraints.

The SSS efficiency is directly proportionally related to B/b_0. For radiocommunication purposes this ratio is often in the order of 1000. On the other hand, SSS needs minimal safe-guard distances between transmitters and receivers of different systems. This is not a constraint when an inevitable natural minimum distance exists, i.e. :

— Satellite-borne transmitters and land based receivers.

— Inland transmitters and shipborne receivers, etc.

SSS involve also a noticeable increase in equipment complexity.

3. — APPLICATION OF SPREAD SPECTRUM TO RADIOLOCATION

As communication systems do, radiolocation ones can use SS techniques. Most often those systems are coded with Pseudo Random Noise (PRN) maximal length sequences, which may be obtained through the use of Linear Feedback Shift Registers (LFSRG) composed of n stages. One may shift the logic state through the n stages of the register by means of a logic frequency clock Fc. Using a proper combination of logic feedback, such an LFSRG outputs a recurring bits sequence, each bit having a nearly equal state probability to be 0 or 1. Moreover, the occurrence probability of p successive unchanged state bits approaches $1/p$. This looks like random noise. The overall duration T of a sequence is $T = 1/Fc \times (2^n - 1)$, as the total number of bits within the sequence is $2^n - 1$.

One may understand this number becoming rapidly very large when the number of stages n is increased, and this number in any case remains odd. The sequence recurs identically and permanently.

It is very easy to have two or several identical LFSRGs, each driven by a clock of the same frequency Fc, and which will all deliver the same sequences. However, these sequences will be simultaneously identical only if the LFSRGs are "phased on", this yields the analysis of what is the correlation function of two identical PRN sequences generated by two independent LFSRGs. This could be obtained through the modulo 2 product of the bit-flow coming from each register and the integration of this product over T. One could obtain a well-known correlation function, the features of which are shown in Figure 1 A; it presents a sharp maximum which reaches the value $2^n - 1$ when the perfect synchronism of the two sequences exists, and an identical symmetrical trend to $- 1$ for all other relative time shifts exceeding $\pm 1/Fc$.

Most often, in these systems, the useful signals (either the carrier or the carrier already modulated by the base band signal) are simply phase-inverted according to the state of the bits of the LFSRG. This is equivalent to a BPSK modulation. In the receivers, it is possible to correlate the signals having in mind only the envelope of signals, paying no attention to the carrier frequency Fo, and then one obtains a correlation function identical to that of Figure 1 A. It is the simplest process and the most often used : for instance in SYLEDIS, NAVSTAR P or C/A receivers.

When the ratio Fo/Fc is not very high, it is possible to process also the carrier components in the correlation operation : for that purpose one elaborates a local pseudo carrier BPSK modulated by the local LFSRG to create a copy of the transmitted signal. Then, one can multiply it with the incoming signals and integrate the result within the base bandwidth. The result is a correlation function identical to Figure 1 B which displays a central maximum and several attenuated side ones.
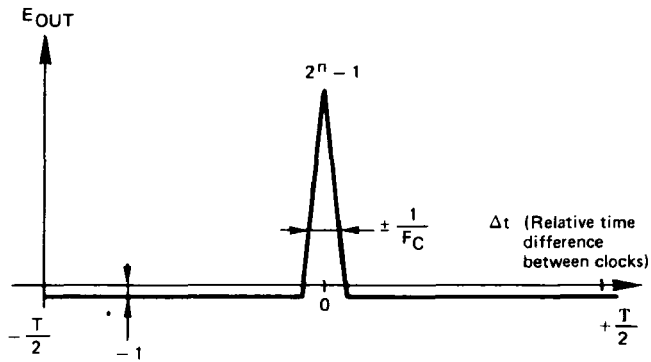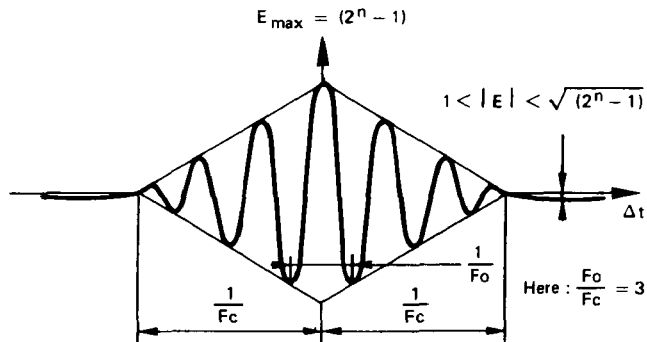
FIG. 1 A

FIG. 1 B

The spread level of this function for any time shift larger than $\pm\ 1/Fc$ is : $1\ <\ |E|\ <\ \sqrt{(2^n - 1)}$, according to its frequency domain analysis. It is clear that the choice of a low Fo/Fc ratio (2 or 3 for instance) makes it possible to identify accurately the central maximum by the module — analysis of the correlation function, even if the signal-to-noise ratio is quite low. Further to the regular signal envelope time of arrival measurement, a major refinement can be obtained by the phase measurement of the carrier with practically no risk of phase ambiguity.

It is a similar operation which is done in GEOLOC : it is more complex than the standard methods, but far more efficient. SS techniques application to radiolocation systems is particularly beneficial for the following reasons :

— It offers a high degree of time discrimination capability, of prime importance for precision and multipath rejection.

— It allows the operation of very-low-power continuous transmission, the performances of which are equivalent to the use of short pulses of tremendous peak powers.

— It provides a very efficient protection against the effects of all kinds of interference coming from either continuous or pulse-type jammers.

— It is easy to operate simultaneously several transmitters in the same coverage area without any interference problems and with identification capability.

— A sufficiently powerful encoding may allow a selective access only to authorized users and eliminates most of the constraints concerning frequency allocation difficulties.

For all these features, the higher the B/b_0 ratio the better the performance.

4. — FEATURES COMPARISON OF SEVERAL SSS

The tables of Figures 2 and 3 display a comparison between the characteristics of the SYLEDIS, NAVSTAR "C/A" and "P", and GEOLOC systems.

We must emphasize the value of B/b_0 of about 10^4 for SYLEDIS and NAVSTAR C/A (taking into account the additional coherent integration processed in those systems). It commonly exceeds 10^5 in NAVSTAR "P" and reaches nearly 10^8 for GEOLOC. Figure 3 particularly shows the energy equivalence of short high peak power pulses applicable to those systems. They can reach several hundreds of megawatts for GEOLOC.

GEOLOC uses a 0.6 MHz B bandwidth of the same magnitude or a bit narrower than the other systems ($1 < B < 10$ MHz). To obtain such a high B/b_0 ratio, the base band b_0 had to be drastically reduced.

In the field of phase comparison radionavigation systems, the base band is mainly determined by the dynamics of the mobiles carrying the receivers, and it is in direct relationship with Doppler effect and its first derivative : at frequencies of GEOLOC, a ship capable of a 30-knot speed induces a $\pm$ 0.1 Hz shift which requires a few tenths of hertz bandwidth. The introduction of processing of heading and speedlog information into the correlation operator allows reduction of the ultimate b_0 value down to 0.01 hertz.

5. — GEOLOC SYSTEM — FEATURES

GEOLOC operates both PN sequence group delay measurements and frequency carrier phase ones from the incoming continuous signals permanently transmitted by the system inland based stations.

— The carrier frequency is chosen in the 2 MHz band. This frequency band offers the best well-known compromise between practicable size of lightweight antennae on one hand, and long-range low diffraction losses on the other. This leads to both long ranges and high precision.

— The transmitted energy is spread on a wide relative bandwidth. The 0.666 MHz value of B represents 33 per cent of the frequency carrier; this allows for a reliable full cycle ambiguity solution.

— Compulsory use of heading and speed log data in the correlation process leads to the very narrow baseband b_0 value of 0.01 Hz.

SYSTEM	S.S. WIDTH OR P/N CLOCK FREQUENCY	P/N SEQUENCE DURATION	CORRELATION BANDWIDTH	ULTIMATE COHERENT BANDWIDTH	CORRELATION AND ANTIJAMMING GAIN	OVERALL ENERGY INTEGRATION	DISTANCE DISCRIMINATION
	B		b	bo	B/b	B/bo	
SYLEDIS	2 MHz	66 2/3 MICROSECONDS	15 KHz	200 Hz	21 dB	40 dB	± 150 m
NAVSTAR C/A	1,23 MHz	832 MICROSECONDS	1200 Hz	50 Hz	30 dB	44 dB	± 300 m
NAVSTAR P	10,23 MHz	SEVERAL WEEKS	50 Hz	50 Hz	53 dB	53 dB	± 30 m
GEOLOC	0,666 MHz	25 SECONDS	0,01 Hz	0,01 Hz	75 dB	78 dB	± 450 m

FIG. 2. — Comparative correlation properties of several systems.

SYSTEM	CARRIER FREQUENCY	S.S. BANDWIDTH	MODULATION TYPE	TYPE OF EMISSION	ENERGY PROCESS EFFICIENCY	ACTUAL RADIATED POWER	EQUIVALENT SHORT PULSE DURATION	EQUIVALENT PEAK POWER	EQUIVALENT REPETITION RATE
	F_o	B			B / B_o	P_r	$\tau = \dfrac{1}{B}$	$P_p = P_r \times \dfrac{B}{b_o}$	T
SYLEDIS	408 / 450 MHz	2 MHz	Bi-phase B.P.S.K.	PULSED 5333 µs FR=5 to 50 Hz	10^4 / 40 dB	13 W	0,5 µs	130 KW	20 / 200 ms
						220 W	0,5 µs	2,2 MW	20 / 200 ms
NAVSTAR C/A	1500 MHz	1,2 MHz	Bi-phase B.P.S.K.	Continuous	$2,5.10^4$ / 44 dB	10 W	0,8 µs	250 KW	20 ms
NAVSTAR P	1500 MHz	10,2 MHz	Bi-phase B.P.S.K.	Continuous	2.10^5 / 53 dB	10 W	0,1 µs	2 MW	20 ms
GEOLOC	2 MHz	0,6 MHz	Quadri-phase C.P.S.M. ≈ M.P.S.K.	Continuous	6.10^7 / 78 dB	10 milliwatts to 10 Watts	1,5 µs	630 KW to 630 Megawatts	50 sec.

FIG. 3. — Equivalent short pulses and energy comparison.

— The bandwidth expansion ratio, as per CCIR report No. 328 definition, reaches an exceptional value of : $B/b_0 = 0.666 \, MHz/0.01 \, Hz = 6.6 \, 10^7$, which corresponds to an energy processing ratio and a rejection capability of unwanted signals of 78 decibels.

This very high B/b_0 value results in the following performances :

● Multipath and ionospheric reflections rejection. The very sharp correlation shape provides a 75 dB attenuation of any front components time shifted more than a few microseconds.

● The vectorial addition of ionospheric components usually observed by conventional systems does not occur with the GEOLOC processing of signals; all those components remain scattered and attenuated. Any ionospheric component, even 50 decibels stronger than the desired surface wave, is unable to disturb the useful phase measurement.

● All the other multipath signals which could result from diffraction or reflection coming from large natural obstacles are also rejected.

● Interference rejection : the correlation operator of the receiver spreads the energy of unwanted jammers over the 0.666 MHz wide band B, and then attenuates them through the narrow 0.01 Hz baseband filter. 75 to 90 decibels' natural protection is obtained. An additional 20 to 40 dB protection provided by internal microprocessor-controlled notch filters could be used if needed.

— The powerful encoding performed allows the permanent simultaneous operation of 20 or more GEOLOC transmitters in the same geographical area without any interference. It makes possible selective access, if needed, to unauthorized users.

— Together with the high bandwidth expansion ratio B/b_0, a permanent automatic radiated power adjustment related to the atmospheric noise level changes leads to a full discrete system. As a matter of fact, the spectral power density of the noise like GEOLOC signals is permanently kept at a level under the normal atmospheric noise, in the whole maritime area concerned. Then, none of the radiomaritime users in that area can detect the existence of GEOLOC signals, and obviously cannot suffer from any interference. This automatic permanent adjustment of the radiated power provides the following two important features :

● It eliminates the need for a frequency allocation : only administrative authorization concerning the transmission of information and local rules must be considered.

● It "standardizes" the possible operational range, as the signal to noise ratio is kept nearly constant.

— The initial search of the signals follows the simplest known methods. However, each component of the system, either shore based or mobile stations, must use a compulsory reliable means of accurate time knowledge through the use of so-called "time-keepers".

— GEOLOC may be operated according to different modes. Although some of them may be filed in the circular geometry line of position class, a GEOLOC transmission is never performed from a mobile. This allows a large number of users to be able to work in the same area.

— Any no-time-discrimination system is subject to a time group or a phase delay jitter induced by multipath or various reflections : this usually bounds the precision and availability of those systems operating in this frequency band. Thanks to its high time-discrimination performances, GEOLOC is fully insensitive to this kind of interference and, as a matter of fact, the use of an accurate correction propagation model becomes significant and efficient.

Such a model is used. It encompasses an accurate determination of the refractive index computed on board, thanks to a permanent local gathering of meteorological parameters. This model compensates also for local time group and phase delay distortions which arise from the electric properties of the ground all along the radio paths. This leads to a high precision of distance measurements even at long ranges. The error for every line of position is about 2 metres + $(1.5 + 10^{-5} \times$ distance) and, hence, of the order of 20 metres at more than 1000 kilometres.

6. — EQUIPMENT DESCRIPTION AND FUNCTIONING

Transmitter

Figure 4 shows a block diagram of a GEOLOC transmitter. It includes the following units :

— One main time keeper driven by either a caesium or rubidium oscillator (option) packed into a protected and temperature-controlled oven, and equipped with an internal standby battery.

— An ancillary and portable time keeper driven by a high-quality crystal oscillator, and fed through a several-hour-capacity internal standby battery. This unit could be used, when needed, to "carry the time references" from one component of a chain to another.

A transmitter cabinet containing most of the electronic circuitry :

● LSFRG phase modulator, amplifier and output filter.

● A built-in noise spectrum analyser and duplexer.

● A microprocessor unit which analyses the noise frequency and amplitude distributions, and drives accordingly the power amplifier output. This unit controls and monitors all the functions of the transmitter, and elaborates alarms whenever some failure or malfunctioning occurs. The transmitter output power can be automatically adjusted by nearly 1 dB steps from 10 milliwatts to 10 watts according to the measured external noise level. The maximum and minimum could possibly be bounded on preset values.

● A control and display unit connected to the transmitter allows any control and local monitoring.

— A wide bandwidth transmitting antenna (and a receiving one as well during very short time slots dedicated to noise measurement). This antenna is 24 metres high and is connected to a coaxial cable and the transmitter through a matching and discharge protective box.
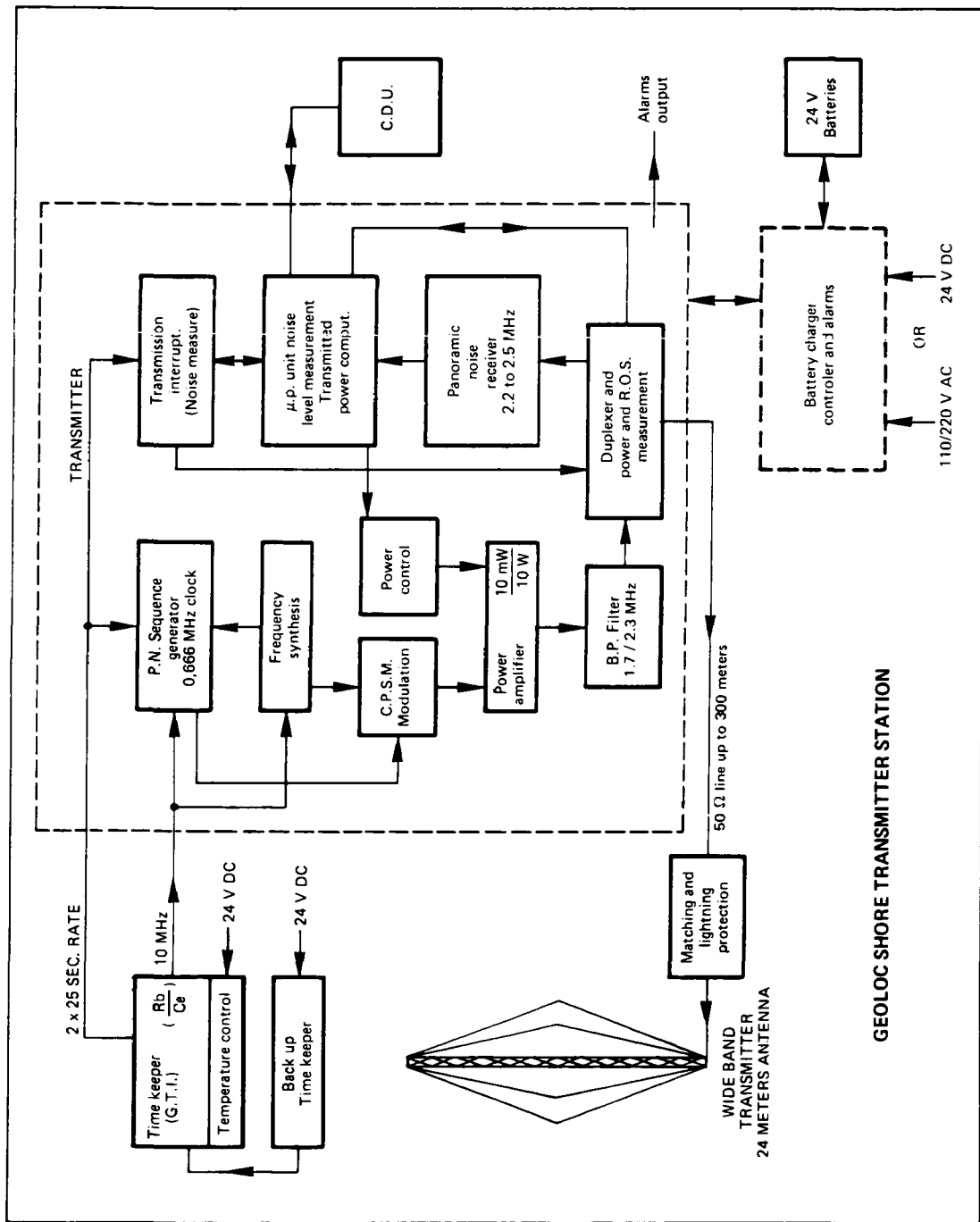
Fig. 4. — GEOLOC shore transmitter station block diagram.

As Figure 5 depicts, the code used includes two successive symmetrical sequences of about 10 megabits each. The carrier modulation is not a simple BPSK phase inversion, but a Continuous Phase Shift Modulation (CPSM) very similar to MPSK (Minimum Phase Shift Keying). The phase integral over these two sequences is zero and the shift phase speed equal to $\pm 1/\pi$ Fc.
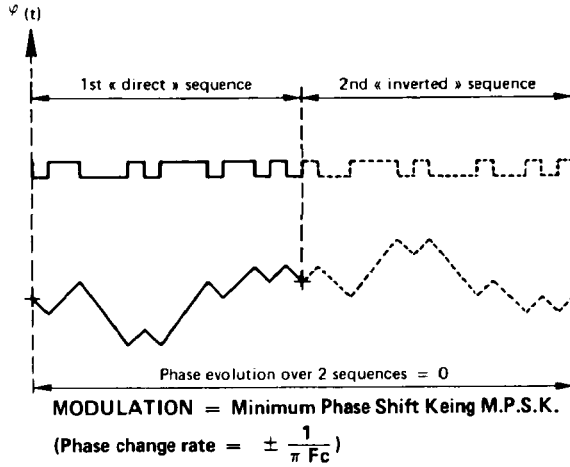
FIG. 5. — Minimum phase shift keying (MPSK) characteristics.

Figure 6 shows the interest of this type of modulation against regular BPSK : the side lobes amplitude of the spectrum of the original modulation decreases following a $\sin^2 \Phi/\Phi^2$ law for MPSK, instead of a $\sin \Phi/\Phi$ one for BPSK (where $\Phi = \pi (f - fo)/Fc$. Then a simple low-distortion filter attenuates easily the lateral out-of-band spectrum components to a very low level. The spectral power density of these out-of-band components reaches a level under that of the external noise at only 300 metres from the transmitter.

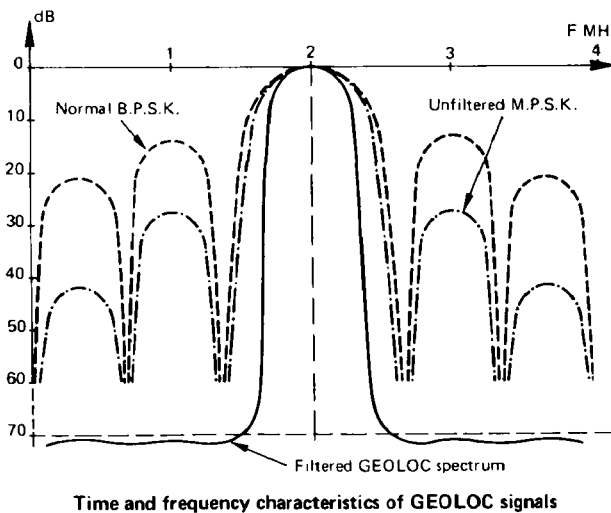Time and frequency characteristics of GEOLOC signals

FIG. 6. — Spectrum characteristics of : normal BPSK; unfiltered MPSK; filtered MPSK GEOLOC signal.

Figure 7 displays the watertight cabinets housing the equipment and Figure 8 shows the transmitting antenna.
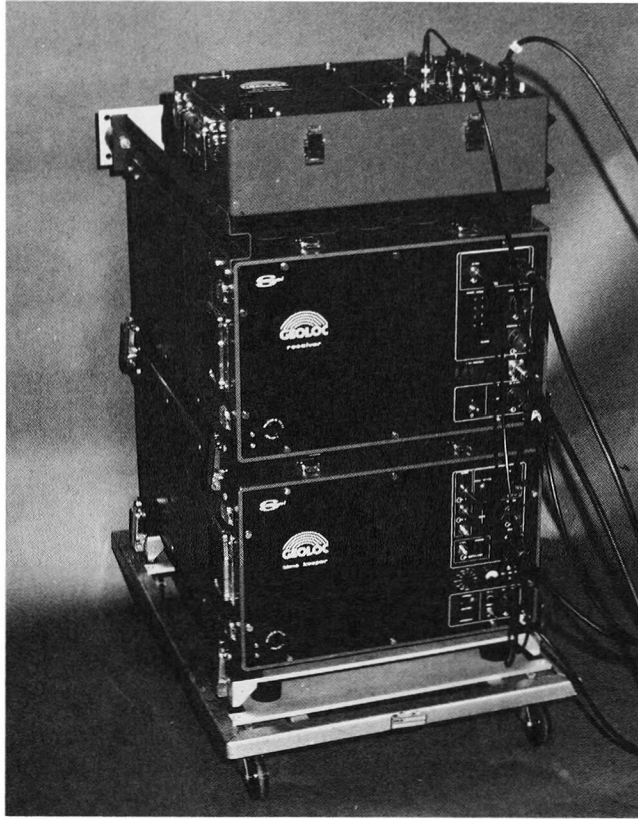

FIG. 7. — GEOLOC transmitter. From top to bottom : backup time keeper; transmitter; main time keeper.

Receiver

The GEOLOC mobile receiver is composed of elements described by the block diagram of Figure 10.

— Main and ancillary time-keepers identical to transmitter ones.

— One "reception unit" comprising the following :

• Front-end wide-band amplification equipped with notch filters driven by a central microprocessor according to a permanent built-in frequency analysis of the jamming situation of the band.

• Four independent and identical "correlation channels", each one processing the incoming signals received from a designated shore station. Every channel operates with its own microprocessor.

• One central microprocessor unit for the general control of the receiver and for all data input/output handling : mainly speed and heading and PTU
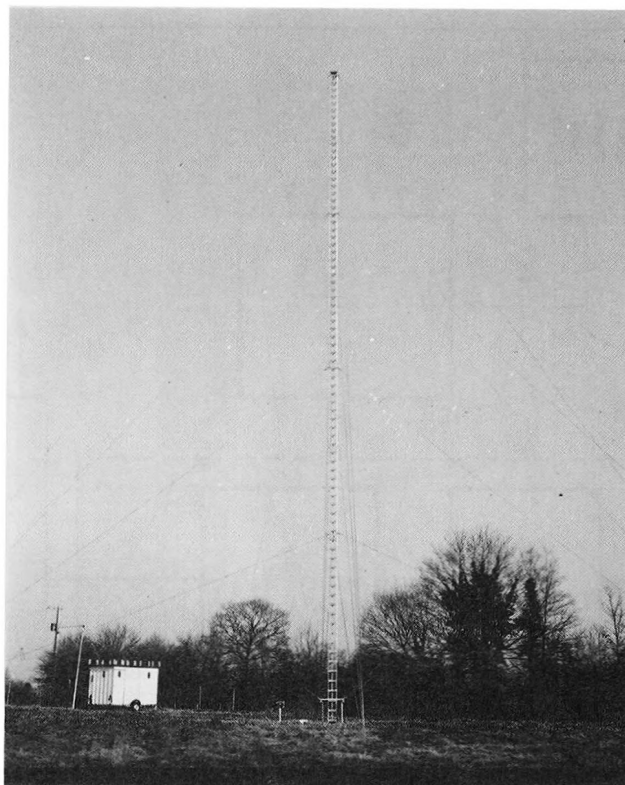
FIG. 8. — GEOLOC 24 metre high antenna.

FIG. 9. — Typical mobile station. From left to right : Transit receiver, central processor, receiver and time keepers.
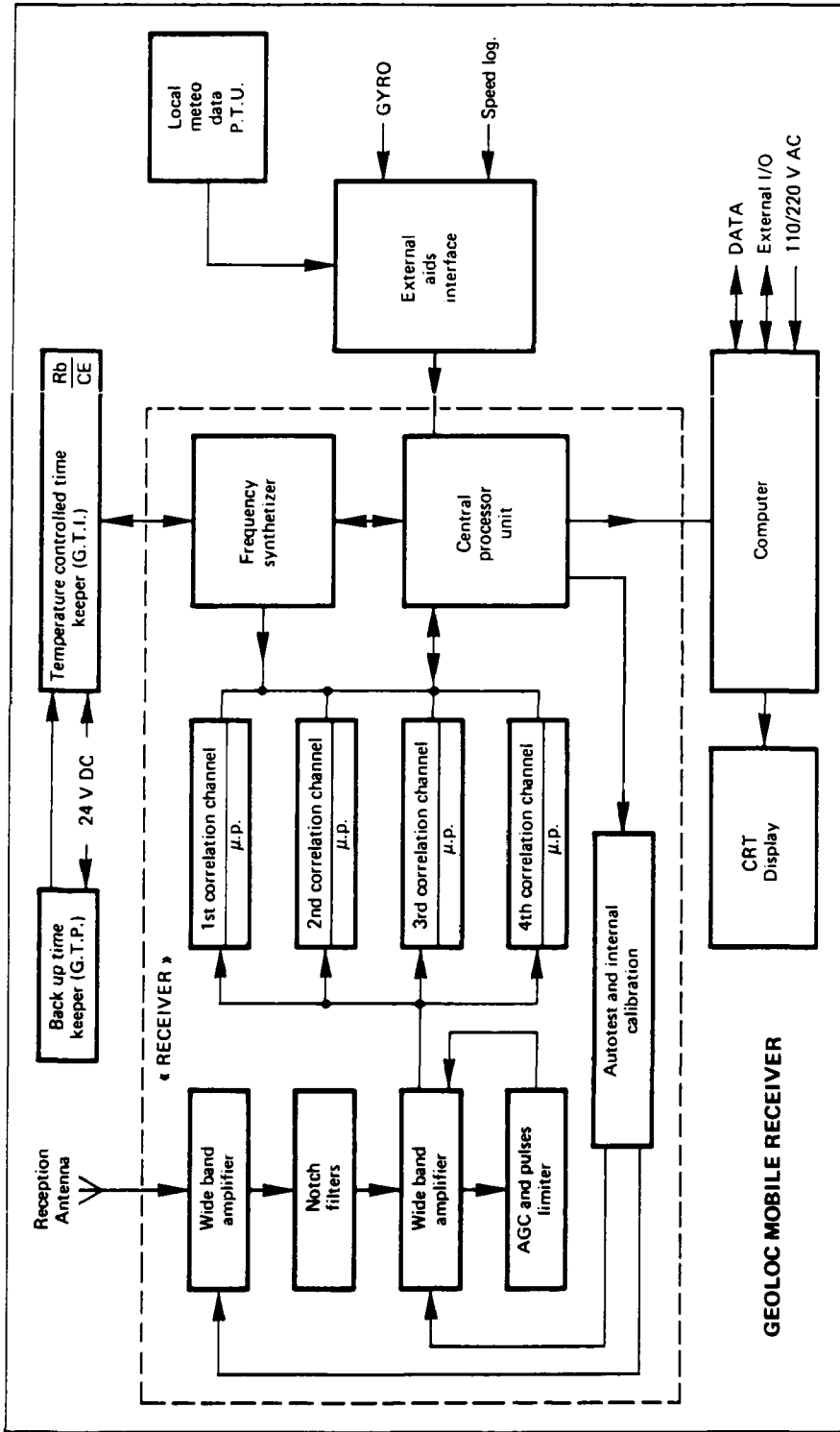
FIG. 10. — GEOLOC mobile receiver diagram.

(meteorological) data gathering, and for the connection to the mobile station central computer.

● Some built-in autotest and autocalibration means.

Figure 11 depicts details of hard and software organization of a correlation channel.

— One central computer unit, the tasks of which are :

● Operator-system interface, CRT display and keyboard.

● External data gathering : dead reckoning input or satellite position (TRANSIT or NAVSTAR), and external various time reference data.

● Data input/output from the GEOLOC receiver : measured phases, phase rates, variances, validity flags, speed and heading, meteo data.

● General GEOLOC network data handling, and state and drift of each time keeper of the system.

● Graphic displays of reception quality, interference situation, and notch filter handling.

● Correction propagation computation from PTU meteo data, and memorised ground characteristics (σ_i, Σ_i).

● Best estimate and Kalman filtering of position, speed and course made good, ship set and drift.

● Input/output handling from/to satellite receivers, printers or recorders, other computers, etc.

Figure 9 shows a whole typical mobile station with the GEOLOC receiver rack, its central computer and a Transit precise positioning receiver.

7. — FIELD TEST RESULTS

The main aim of the first field tests was to verify with numerous measurements made under realistic field conditions, the validity of the newly introduced concepts. For that purpose, measurements of level, SNR and distances were observed using one transmitter and one receiver located on known geodetic positions. During those tests, absolute distance measurements were possible thanks to accurate external means of time transfer allowing availability of the same time reference at each end of the link. The permanent estimates of the initial set and drift between the time keepers of the GEOLOC transmitter and receiver was established with a second order least mean squares fitting on all time transfer measurements performed over a period of several hours. This was made possible with the SYLEDIS equipment used in time transfer mode. Basically, this concept is fully insensitive to path alteration, topographic errors or propagation velocity of wave changes. It allows time to calibrate the two distance time keepers to within 3.10^{-9} seconds for distances up to 200 kilometres (direct link) or about 10^{-8} seconds in using relay-stations for distances of 500 kilometres or more. This yields a distance calibration accuracy of 1 and 3 metres respectively.
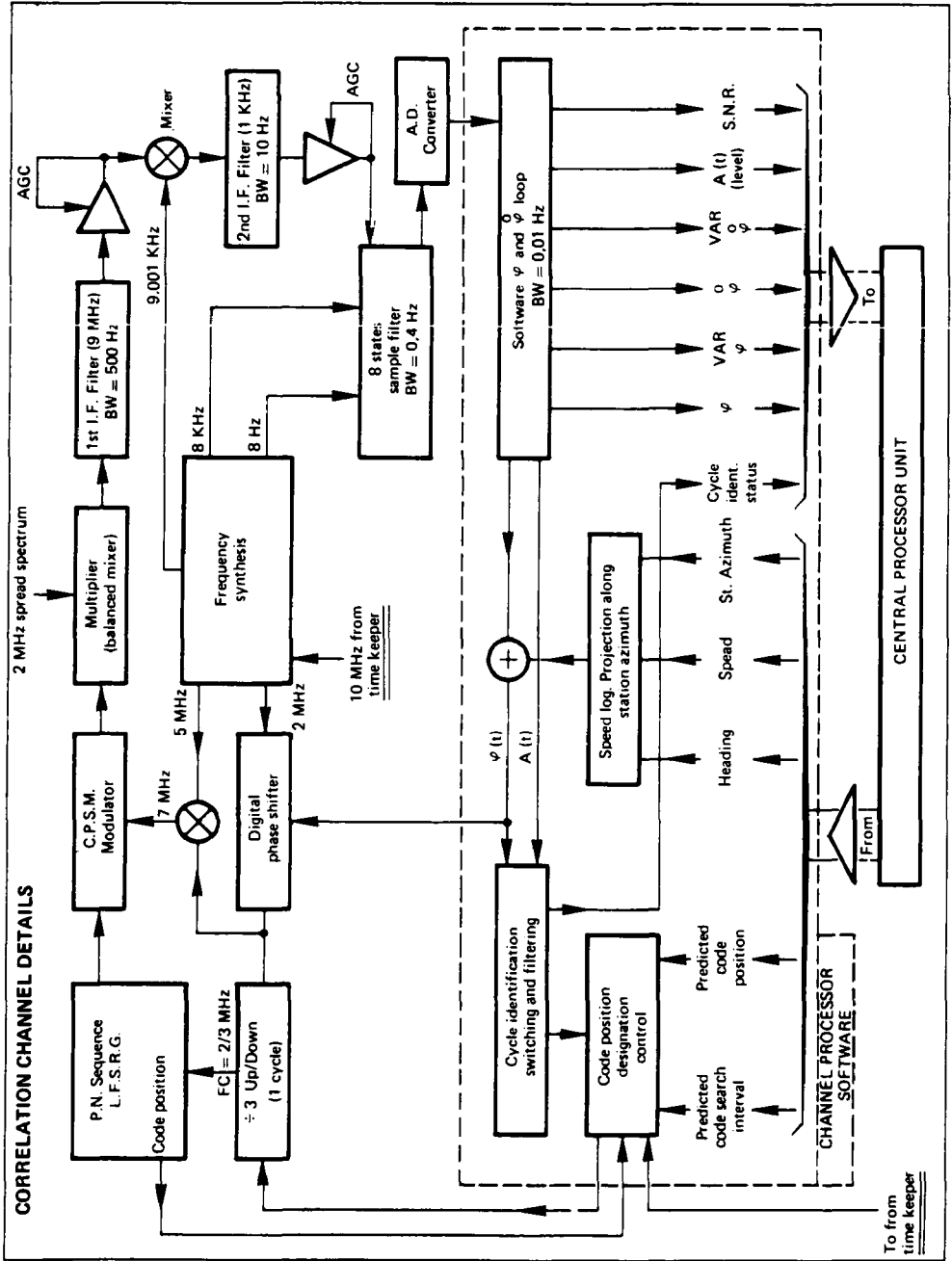
FIG. 11. — Correlation channel diagram.

Long-term tests

A first group of experiments has taken place using a permanent link of 60 kilometres distance over a ground of average characteristics ($\sigma = 3.10^{-3}$, $\Sigma = 15\%$) and for a long time period of nearly one year. Distance data were collected every 6 minutes day and night, and averages and standard deviations computed over 12-hour time slices. Tens of thousands of data gathered led to the following conclusions :

— There is no average difference between day and night.

— The short-term standard deviation is less than 1 metre for day time, and 2 metres at night.

— There is no long-term drift or change noticeable, even between most extreme seasonal conditions and the standard deviation of the 24 hour average values over 200 days is 1.5 metres.

— A comparison of phase stabilities observed on the same path, but without the GEOLOC phase encoding, shows clearly what are the compared possible stabilities of normal phase measurements in continuous wave systems : and evident proof of deterioration under conditions reaching a ratio of 3 in daytime, and far larger at night, was observed. (Most of the time, the phase measurement of ground waves at night for such a 60 km distance is impossible without the GEOLOC encoding, the ionospheric reflected waves having a higher level). This proves also that, even for such short distances and in day time, normal continuous wave uncoded phase measurement systems could suffer from various phase changes due to multipath effect residues; GEOLOC avoids most of them.

Tests over various paths

Another group of tests has consisted in moving either the transmitter or most often the receiver, successively to different places and for 24 hour or longer periods. The chosen paths correspond to increased distances up to 600 kilometres and to a good selection of ground characteristics (mixed land-sea paths, grazing angle of the path over coastline and where tidal effects could be suspected), this in view of the propagation correction model validation.

All these distance measurements are calibrated through the time transfer method and compared to geodetic distances.

Numerous paths have been checked from 100 up to 500 kilometres, the results being the following :

— The observed short-term standard deviations are not dependent on the range. It is commonly of 1 to 3 metres, day or night, and is related to the signal-to-noise (or signal-to-interference) ratio. A full insensibility to any ionospheric reflected wave at any distance has been demonstrated.

— The average residual distance errors observed are mainly due to the inaccuracies of the propagation correction model, and show a maximum spread of a 5-metre standard deviation even for the longest distances, and practically no standard error. These residues must be compared to the magnitude of the

corrections computed through the model, which could be from 30 to 50 metres or more, and that well illustrates its efficiency.

— At long distances of 500 kilometres or more, one can observe ionospheric reflections between 100 to 150 microseconds after the arrival of the surface wave component (this agrees with reflections on 90 to 110-kilometre altitude layers). Their level is about 10 to 15 decibels higher than that of the ground wave. As the correlation function of GEOLOC reaches 60 dB or more for a shift of only 3 microseconds, or so, one may understand GEOLOC's insensitiveness to the so-called "sky waves".

— No false phase cycle indication has ever been observed.

— Last but not least, permanent day and night transmission for nearly one year of GEOLOC signals, within an area where maritime radio service traffic is very high, demonstrated no interference.

Technical tests at sea using three stations and real time positioning aboard a vessel are currently under way.

8. — OPERATING MODES OF GEOLOC

GEOLOC may be operated according to several different modes, the choice of which must be related to the kind of mission and to available logistics. One must distinguish between available integrated or assisted modes which require help of external means (the main ones being TRANSIT or NAVSTAR satellite data) and other so-called "autonomous" modes, which allow GEOLOC equipment, along with local synchronisation means, to perform positioning itself without any help.

Assisted modes

Those modes require satellite data either for time synchronisation and/or periodic updating of the position.

— Mode "H" :

With this mode, both transmitters and receivers are equipped with ultra-stable time-reference sources, which are free running caesium or rubidium sources. A permanent updating of the position is obtained due to the very slow drifting pseudo ranges measured from 2 or 3 shore transmitters. A periodic absolute updating of the position occurs when the information coming from satellites TRANSIT or NAVSTAR is available. It must be noted that the quality of time sources used allows for the long time intervals between either the TRANSIT fixes occurrence or the quite long duration of GDOP degradation of NAVSTAR constellation : 1 or 2 absolute updates per day is allowable. In any case, the stability of GEOLOC timekeepers is good enough to afford a valid time integration of the external absolute data over several hours.

This mode displays a circular pattern of lines of position geometry (LOPs). The absolute precision could remain within 20 to 40 metres permanently.

— *Mode TSS (Time synchronised with satellite data)* :

For this mode all transmitters are equipped with stable time sources and simplified NAVSTAR receivers, used only to collect the accurate time data and the synchronisation of inland transmitting stations.

On board ships, two sub-modes may be operated :

- TSSA mode : the GEOLOC mobile receiver is fitted only with an ancillary simplified time keeper and it alone processes the position fix with at least 3 pseudoranges coming from shore transmitters, leading to a "hyperbolic" pattern of the LOPs. The receiver is then in its simplest configuration and could be convenient for numerous users in the same area.

- TSSI mode : if the ship could be equipped with a simplified NAVSTAR receiver, it could receive time data not very sensitive to ship position errors using high elevation satellite passes. In that case, with good timekeeper stability, the pattern of LOPs tends to be "circular". Moreover, if the on-board NAVSTAR allows this, its position data could be also integrated.

Autonomous modes

These modes involve only independent land-based equipment.

— *Mode AS (autonomous synchronised)* :

The inland base transmitting stations are relatively time-synchronised by a shore-based monitoring station, and a two-way digital HF radio link. The mobile receivers could be the same as for TSSA mode. They also process the position from hyperbolic LOPs.

— *Mode "GEOSYL" (Time synchronisation by SYLEDIS time transfer mode)* :

The shore GEOLOC stations are linked together with a two-way time-transfer SYLEDIS chain which allows for precise time synchronisation of all the stations without any disturbances which could be induced by propagation velocity or wave-path changes.

According to the ship equipment, two submodes exist :

- Passive GEOSYL :
  The mobile receiver could be identical to TSSA mode ones. The geometry of positioning is "hyperbolic".

- Active GEOSYL :
  If the ship can be equipped with an on-board time-transfer SYLEDIS equipment, this may be linked to *only one* of the shore GEOLOC synchroni-

sed stations. This allows for an accurate recovery of relative time information between general shore time reference and the on-board time reference. In that case a "circular" LOP crossing is possible leading to good long-range GDOP.

A high flexibility of equipment allows for possible combinations of these several modes making possible the optimum solution for the most difficult location of shore stations.