



(57) **Abrégé(suite)/Abstract(continued):**

environment of the signals, each channel comprising a code generator, a carrier phase generator, integrators, phase and code discriminators, a code phase numerically- controlled oscillator (NCOC), a carrier phase numerically-controlled oscillator (NCOP), carrier phase loop matched filtering means, and code phase loop matched filtering means, comprising, furthermore:

- means for determining the respective phase errors in the said main and secondary channels comprising means of interspectral correlation (INT3, M3) of the signals of the main and secondary channels (L1, L2) already correlated by the local code, after frequency compensation of the relative Doppler shifts of the said signals; and
- respective feedback loops (B1, B2) for the said code and carrier phase errors in the said main and secondary channels.

**ABSTRACT****Dual-frequency receiver for satellite-based positioning and  
associated method of reception**

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Dual-frequency (L1, L2) receiver for satellite-based positioning, comprising a main measurement channel (L1) and a secondary channel (L2) for a calculation for correction of ionospheric propagation robust to differential errors linked to the local reception environment of the signals, each channel comprising a code generator, a carrier phase generator, integrators, phase and code discriminators, a code phase numerically-controlled oscillator (NCOC), a carrier phase numerically-controlled oscillator (NCOP), carrier phase loop matched filtering means, and code phase loop matched filtering means, comprising, furthermore:

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- means for determining the respective phase errors in the said main and secondary channels comprising means of interspectral correlation (INT3, M3) of the signals of the main and secondary channels (L1, L2) already correlated by the local code, after frequency compensation of the relative Doppler shifts of the said signals; and
- respective feedback loops (B1, B2) for the said code and carrier phase errors in the said main and secondary channels.

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25 Reference: Figure 1

## **Dual-frequency receiver for satellite-based positioning and associated method of reception**

5           The present invention pertains to the improvement of robustness in relation to multipaths of a dual-frequency receiver for satellite-based positioning.

          The measurements of pseudo-distances and of signal phases of a global navigation satellite system, or GNSS for "Global Navigation Satellite System" in English, for location and attitude measurement purposes, may be  
10           marred by large errors, if the propagation environment modifies the assumption of direct rectilinear trajectory between the satellites and the receiver.

          This may, for example, be the case upon multiple reflections of the  
15           signals (multipaths) or upon maskings or obscurations (blade modulation in the case of installation on a helicopter).

          Modern receivers generally integrate specific processing procedures, also called discriminators, for a correlation function so as to decrease the impact of the effects of the multipaths on the measurement of  
20           time received (by improving the code discriminator of the code tracking loops or DLL for "Delay Lock Loop" in English), but these processing procedures have a restricted domain of effectiveness (for example according to the delay of the paths) and entail only a small improvement in the carrier phase errors. Moreover, the extensions of the GPS system and the new GNSS systems  
25           base the monitoring of the integrity of the signals essentially on the coherence of the measurements of pseudo-distances and not on the measurements of the carrier phases.

          Now, the phase of GNSS signals is increasingly becoming used for high-precision location (RTK for "Real Time Kinematic" in English) and  
30           attitude measurement applications with multiple antennas.

          Known advanced schemes for reducing multipath errors in pseudo-distances, make use of the shape of the correlation function, such as the Double-Delta, MEDLL, or narrow-correlator schemes.

          However, these schemes remain linked to propagation models  
35           (specular reflection, triangular correlation function, etc).

An aim of the invention is to improve at one and the same time the measurements of pseudo-distances and of phases, as well as to help to increase the coherence of the measurements of code and carrier phases thus obtained.

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There is proposed, according to one aspect of the invention, a dual-frequency receiver for satellite-based positioning, comprising a main measurement channel and a secondary channel for a calculation for correction of ionospheric propagation robust to differential phase errors linked to the local reception environment of the signals. Each channel comprises a code phase generator, a carrier phase generator, integrators, phase and code discriminators, a code phase numerically-controlled oscillator, a carrier phase numerically-controlled oscillator, carrier phase loop matched filtering means, and code phase loop matched filtering means. The receiver comprises, furthermore:

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means for determining the respective code and carrier phase errors in the said main and secondary channels comprising means of interspectral correlation of the signals of the main and secondary channels already correlated by the local code, after frequency compensation of the relative Doppler shifts of the said signals; and

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respective feedback loops for the said code and carrier phase errors in the said main and secondary channels.

Such a receiver makes it possible to eliminate errors linked to the existence of multipaths on the two frequency channels, thus providing an improvement at one and the same time of the measurements of pseudo-distance and of phase, and helps to increase the integrity of the measurements of carrier and code phases thus obtained.

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This interspectral product of the frequency channels makes it possible to identify within each the signals obtained in baseband (resulting from the correlation by the local codes), the correlated errors, linked to the modes of propagation (multipaths), that are common to the two reception frequencies. In particular, it makes it possible to identify errors which are not necessarily linked to simple specular reflections, which are manifested by a complex composition of the amplitude and phase terms of the various signals

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received. This complex error term, also called the transfer function of the propagation channel, is then used to recompose a local code matched to the propagation channel, coherent with this complex propagation error.

5 The present receiver discloses new "open", i.e. unencrypted, multi-frequency signals such as L1C, L2C, L5 for GPS or Galileo (L1BC, E6BC, E5a and E5b), which make it possible to carry out the intercorrelation between frequency channels on the demodulated signals, obtained after matched filtering, doing so without loss of signal-to-noise ratio (zero need for prior processing of the P code).

10 The main aim of this intercorrelation or interspectral correlation is the identification of the characteristics of the specular multipaths and the correction of the errors which stem therefrom in the code discriminator, under the assumption that they are common to the two frequency channels. The processing assumption presumes that the propagation multipaths are  
15 identical on the two frequencies, and that they are identifiable after matched filtering in the form of a summation of attenuated paths, delayed and affected by different Dopplers.

In an embodiment adapted to the case of fixed or slowly moving receivers exhibiting slowly variable multipath errors, the observation of the  
20 response of the channel is carried out each second in the medium term (over a sliding horizon of about 10 to 20 seconds) in a 50Hz band on each frequency channel by spectral analysis (by FFT of from 512 to 1024 points) of the signal obtained on output from matched filtering after coherent integration of a duration of 20 ms. In another embodiment adapted to the  
25 case of mobile receivers exhibiting rapidly variable (typically from 1 Hz to 1000 Hz) multipath errors, the observation of the response of the channel is carried out each second in the short term (over a horizon of about 1 second) on each frequency channel by spectral analysis (by FFT of 1024) of the signal obtained on output from matched filtering after short coherent  
30 integration of a duration of 1 ms.

The correction of the propagation channel consists in carrying out, prior to the correlation with the signal received, the temporal multiplication of the local code with the complex conjugate response of the propagation channel.

The implementation of this correction of the channel is carried out in the domain as follows:

5 spectral analysis (by Fourier transformation or FFT) with sliding window by intervals of 1 second, carried out on the demodulated signals obtained after matched filtering and pre-integration, for each of the two frequency pathways,

identification by interspectral product (of the outputs of the Fourier transformations) of the propagation characteristics (spectrum of the propagation channel) common to the two frequency channels,

10 inverse Fourier transformation of this product by  $DFT^{-1}$  for estimation in the temporal domain of the complex response of the propagation channel, at the rate of a second,

multiplication at the rate of the calculation of the  $DFT^{-1}$ , between the complex conjugate temporal response of the propagation channel and the local code,

15 multiplication of the signal received by the conjugate local code (P and E-L) thus obtained.

Thus, the improvement of the estimation of the ionospheric propagation delay is a consequence derived from the claim of the correction of the errors of the propagation channel; the ionospheric propagation delay is estimated in the short term (of the order of each second) on the basis of the instantaneous measurements of pseudo-distance carried out on the two frequencies, after correction of the propagation channel (of the order of a few tens of seconds).

In an embodiment, the said determination means comprise means of Doppler-effect compensation of the said signals.

Thus, the error phase of the complex propagation signals, obtained after demodulation by the local code on each of the frequency channels dependent on the frequency of the reception carrier, may be compensated as a function of the frequency discrepancy between the two pathways so as to manifest solely the delay errors, presumed to be identical for the propagation multipaths received on the two frequency pathways.

According to one embodiment, the said determination means comprise means for compensating for the output signal of the said dedicated

means of intercorrelation by the respective carrier phase errors of the said signals, specific to the local reception environment on the one hand and to the propagation of the signal on the other hand, so as to transmit the resulting signals in the said loops.

5           Thus, the compensation of the output error signal of the carrier phase tracking loops by the estimations of the carrier phase errors ( $\varphi_1$  and  $\varphi_2$ ), obtained after correlation by each of the local codes averaged in the pre-detection band on the frequencies L1 and L2, makes it possible to compensate, after multiplication of the resulting error signal, representing the  
10           estimate of the transfer function of the propagation channel, with the locally generated code, for the spurious errors introduced by the signal propagation channel (multipaths). The signals thus obtained represent the phase errors, observed for example in a band of 50Hz (corresponding to the coherent integration of 20 ms), linked solely to the propagation disturbances.

15           According to another aspect of the invention, there is also proposed a method of dual-frequency reception for satellite-based positioning, by a main measurement channel and a secondary channel for calculating a correction of the ionospheric propagation, in which:

20           respective code and carrier phase errors in the said main and secondary channels are determined by interspectral correlation of the signals of the main and secondary channels already correlated by the local code, after frequency compensation of the relative Doppler shifts of the said signals; and

25           respective feedback loops for the said code and carrier phase errors in the said main and secondary channels are effected.

30           The invention will be better understood on studying a few embodiments described by way of wholly non-limiting examples and illustrated by the appended drawings in which:

          Figure 1 schematically illustrates a receiver according to one aspect of the invention; and

          Figure 3 illustrates an embodiment of the interspectral correlation module comprising the third multiplier M3 and the third integrator INT3.

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In Figure 1 is schematically illustrated the processing of a tracking pathway limited to a satellite of a dual-frequency L1, L2 receiver for satellite-based positioning.

The receiver comprises a main measurement channel L1 and a secondary channel L2 for a calculation for correction of ionospheric propagation.

The main L1 and secondary L2 channels comprise respectively first multipliers M1\_1 and M1\_2 for multiplying the respective signals at the input of the main L1 and secondary L2 channels, by the signals of the respective carrier phase tracking loops or PLL for "Phase Lock Loop" in English.

The main L1 and secondary L2 channels comprise respectively second multipliers M2\_1 and M2\_2 for multiplying the respective output signals of the first multipliers M1\_1 and M1\_2, by the signals of the respective code tracking loops or DLL for "Delay Lock Loop" in English.

First integrators INT1\_1, INT1\_2, are respectively disposed at the output of the second multipliers M2\_1 and M2\_2 for carrying out the correlation with the signal received over the length of the local code, over a duration of the order of 1 ms.

Second integrators INT2\_1, INT2\_2, integrating over a duration of the order of 20 ms, are respectively disposed at the output of the first integrators INT1\_1, INT1\_2.

The output signals of the second integrators INT2\_1, INT2\_2, are respectively transmitted in the code tracking loops, which each comprise respectively a code discriminator DISC\_C\_1, DISC\_C\_2, followed by a filter F\_D\_1, F\_D\_2, followed by a numerically-controlled oscillator NCO\_C\_1, NCO\_C\_2, whose output is transmitted to the second multiplier M2\_1, M2\_2.

The output signals of the second integrators INT2\_1 and INT2\_2 are also respectively transmitted in the phase tracking loops, which each comprise respectively an arctangent discriminator ARTG\_1, ARTG\_2, delivering as output an estimation of the carrier phase error  $\varphi_1$ ,  $\varphi_2$ , followed by a filter F\_P\_1, F\_P\_2, followed by a numerically-controlled oscillator NCO\_P\_1, NCO\_P\_2, whose output is transmitted to the first multiplier M1\_1, M1\_2.

The output signal of the first integrator INT1\_2 of the secondary channel L2 is also transmitted to a module for compensation C\_D of the relative frequencies of the main L1 and secondary L2 channels for adjusting the Doppler shift of the error signals at the output of the first integrator  
5 INT1\_2 of the secondary channel L2.

Its aim is to refer the phase errors obtained after correlation of the local code on each frequency pathway (which depend on the carrier frequency) to one and the same phase scale representative of the delays and Doppler shifts of the multipaths.

10 The output signal of the compensation module C\_D and the output signal of the first integrator INT1\_1 of the main channel L1 are transmitted to a third multiplier M3 whose output signal is transmitted to a third integrator INT3, integrating over a duration of the order of from 1 second (mobile receivers) to 20 seconds (fixed receivers). Thus, the correlated common  
15 errors, for example identical propagation defects such as multipaths, which appear are isolated from noise.

The third multiplier M3 and the third integrator INT3 form an intercorrelation module or interspectral correlation module MI for the signals of the main and secondary channels L1, L2 correlated by the local code, after  
20 compensation of the relative frequencies of the said signals.

In fact, the operations of Doppler shift compensation and correlation of the two frequency pathways are performed, according to the proposed embodiment, by passage to the spectral domain by Fourier  
25 transformation or FFT, thereby making it possible to compensate for the frequency scales by simple spectral interpolation and to perform the correlation, by multiplication in the spectral domain and inverse Fourier transform or  $FFT^{-1}$  back to temporal.

As illustrated in Figure 2, the complex FFT Fourier  
30 transformations are applied to each of the input signals sampled either at 1 kHz (directly arising from the correlation with the local code of length 1 ms) adapted to the case of a mobile receiver, or at 50 Hz (after pre-integration of a duration of 20 ms of the correlation outputs with the local code) adapted to the case of a fixed receiver.

An amplitude interpolation of the spectrum is carried out along the frequency axis on the spectrum obtained so as to reduce the frequency samples to identical samples of Doppler speed (thus making it possible to match up at one and the same Doppler speed the samples  $k_i$  of the scale of the spectrum of the secondary channel L2 with the values interpolated at the values  $k_i \cdot F1/F2$  of the scale of the spectrum of the main channel L1).

The complex values of the two spectra can then be multiplied after complex conjugation of the spectrum of the channel L2 and the output of the correlation with zero delay is obtained by inverse discrete Fourier transform or  $DFT^{-1}$  of the resulting spectrum on the frequency domain.

Figure 2 schematically illustrates an embodiment of the interspectral correlation module MI. It specifies the manner of carrying out the correlation between the outputs at 1 kHz or at 50 Hz of the two correlation operations by the local codes (matched filtering by the local codes).

The interspectral correlation is carried out by passage to the spectral domain by FFT Fourier transformation on a length of N points, i.e. about 10 to 20 s in the case of a fixed receiver or 1 s in the case of a mobile receiver.

In the case of GPS signals, it is important that the signal slice obtained at the output of the integrator of the matched filtering, retained on the FFT Fourier transformation, be synchronized with the data (typically, at the rate of 20 ms in the GPS case corresponding to the duration of a data bit), that the data be previously demodulated and that the two FFT Fourier transformations be themselves carried out in a synchronous manner on the two frequency pathways.

The synchronization of the FFT Fourier transformation slices is determined in the data synchronization phase during the acquisition phase.

On the other hand, in the case of the signals of future systems, which comprise a pilot pathway (without data), it is no longer necessary to carry out such a demodulation of the data bits, it being possible for the tap-off rate at the output of the matched filtering and the number of FFT points to be arbitrary.

The interpolation consists in realigning the Doppler shift resulting from the FFT Fourier transformations of the two frequency pathways so as to compensate for the discrepancy due to the differences in carrier

frequencies, in such a way that one and the same reflected path arriving with the same delay and the same relative speed with respect to the direct signal can be summed coherently in the frequency domain.

Once the interpolation has been carried out, the operations of  
5 (complex) product between the complex spectrum of the pathway L1 and the complex conjugate spectrum of the pathway L2 and of summation (in the frequency domain) of the samples make it possible to carry out the equivalent of a temporal correlation (for the value with zero delay).

The adjustment in the spectral domain of the Doppler scales thus  
10 makes it possible to enhance all the phase distortions linked to the signal propagation (assumed to be common on the two frequency channels), and to reduce solely the noise contributions (incoherent between frequency).

The resulting phase error is then representative solely of the signal propagation defects, with a view to the best matching of the local code to  
15 these defects of the received signal.

The signals estimating the errors of carrier phases  $\varphi_1$ ,  $\varphi_2$  output by the arctangent discriminators ARTG\_1, ARTG\_2, of the main L1 and secondary L2 channels, are also respectively transmitted to correction signal generators GEN\_CORR\_1 and GEN\_CORR\_2. The generators  
20 GEN\_CORR\_1 and GEN\_CORR\_2 allow the generation, for each frequency pathway, of a complex signal of correction of the evolution of the carrier phase representing solely the contribution of the dynamics of the carrier (estimated after integration over 20 ms of the phase). This signal is applied, at the rate of 50 Hz, in phase opposition (complex conjugate signal) so as to  
25 eliminate the contribution of the dynamics of the carrier to the instantaneous phase error in order to preserve only the errors linked to multipaths. The resulting signal calculated at the rate of 50 Hz then depends solely on the contributions to the output error of the arrival signal propagation disturbances.

The output signal of the third integrator INT3 is transmitted at the  
30 rate of a second to two fourth multipliers M4\_1 and M4\_2. The fourth multiplier M4\_1 also receives, at the rate of 50 Hz, the generator GEN\_CORR\_1 output correction signal, and the fourth multiplier M4\_2 also receives the generator GEN\_CORR\_2 output correction signal.

The output signal of the fourth multiplier M4\_1 is transmitted, at the rate of 50 Hz, by a feedback loop B1, to a fifth multiplier M5\_1 disposed between the output of the numerically-controlled oscillator NCO\_C\_1 and the second multiplier M2\_1. The fifth multiplier M5\_1 therefore receives as input  
5 the output signal of the fourth multiplier M4\_1 and the output signal of the numerically-controlled oscillator NCO\_C\_1, and transmits their product as output to the second multiplier M2\_1.

The output signals of the fourth multipliers M4\_1 and M4\_2 thus obtained then represent the phase errors, which are observed in a band of  
10 50 Hz in the case of a fixed receiver, or of 1000 Hz in the case of a mobile receiver, and which are related solely to the propagation disturbances (no compensation of the useful signal's carrier phase, compensated moreover by the "conventional" phase loop, via the output signals of the arctangent discriminators ARTG\_1 and ARTG\_2.

The output signal of the fourth multiplier M4\_2 is transmitted by a feedback loop B2, to a fifth multiplier M5\_2 disposed between the output of the numerically-controlled oscillator NCO\_C\_2 and the second multiplier M2\_2. The fifth multiplier M5\_2 therefore receives as input the output signal  
15 of the fourth multiplier M4\_2 and the output signal of the numerically-controlled oscillator NCO\_C\_2, and transmits their product as output to the  
20 second multiplier M2\_2.

The output signals of the fourth multipliers M4\_1 and M4\_2 thereafter make it possible to compensate for the local code signals of the disturbance errors by simple complex multiplication (after complex  
25 conjugation of the compensation signal) by the fifth multipliers M5\_1, M5\_2.

The present invention makes it possible to improve at one and the same time the measurements of pseudo-distances and of phases, as well as to help to increase the integrity of the phase measurements thus obtained.

**CLAIMS**

- 5 1. Dual-frequency (L1, L2) receiver for satellite-based positioning, comprising a main measurement channel (L1) and a secondary channel (L2) for a calculation for correction of ionospheric propagation robust to differential phase errors linked to the local reception environment of the signals, each channel comprising a code phase generator, a carrier phase generator, integrators, phase and code discriminators, a code phase  
10 numerically-controlled oscillator (NCOC), a carrier phase numerically-controlled oscillator (NCOP), carrier phase loop matched filtering means, and code phase loop matched filtering means, characterized in that it comprises:
- 15 - means for determining the respective code and carrier phase errors in the said main and secondary channels comprising means of interspectral correlation (INT3, M3) of the signals of the main and secondary channels (L1, L2) already correlated by the local code, after frequency compensation of the relative Doppler shifts of the said signals; and
  - 20 - respective feedback loops (B1, B2) for the said code and carrier phase errors in the said main and secondary channels.
- 25 2. Receiver according to Claim 1, in which the said determination means comprise means of Doppler-effect compensation (C\_D) of the said signals.
- 30 3. Receiver according to one of the preceding claims, in which the said determination means comprise means for compensating for the output signal of the said dedicated means of interspectral correlation (INT3, M3) by the respective carrier phase errors of the said signals, specific to the local reception environment on the one hand and to the propagation of the signal on the other hand, so as to transmit the resulting signals in the said loops (B1, B2).

4. Method of dual-frequency (L1, L2) reception for satellite-based positioning, by a main measurement channel (L1) and a secondary channel (L2) for calculating a correction of the ionospheric propagation, in which:

- 5       - respective code and carrier phase errors in the said main and secondary channels are determined by interspectral correlation (INT3, M3) of the signals of the main and secondary channels (L1, L2) already correlated by the local code, after frequency compensation of the relative Doppler shifts of the said signals; and
- 10      - respective feedback loops (B1, B2) for the said code and carrier phase errors in the said main and secondary channels are effected.

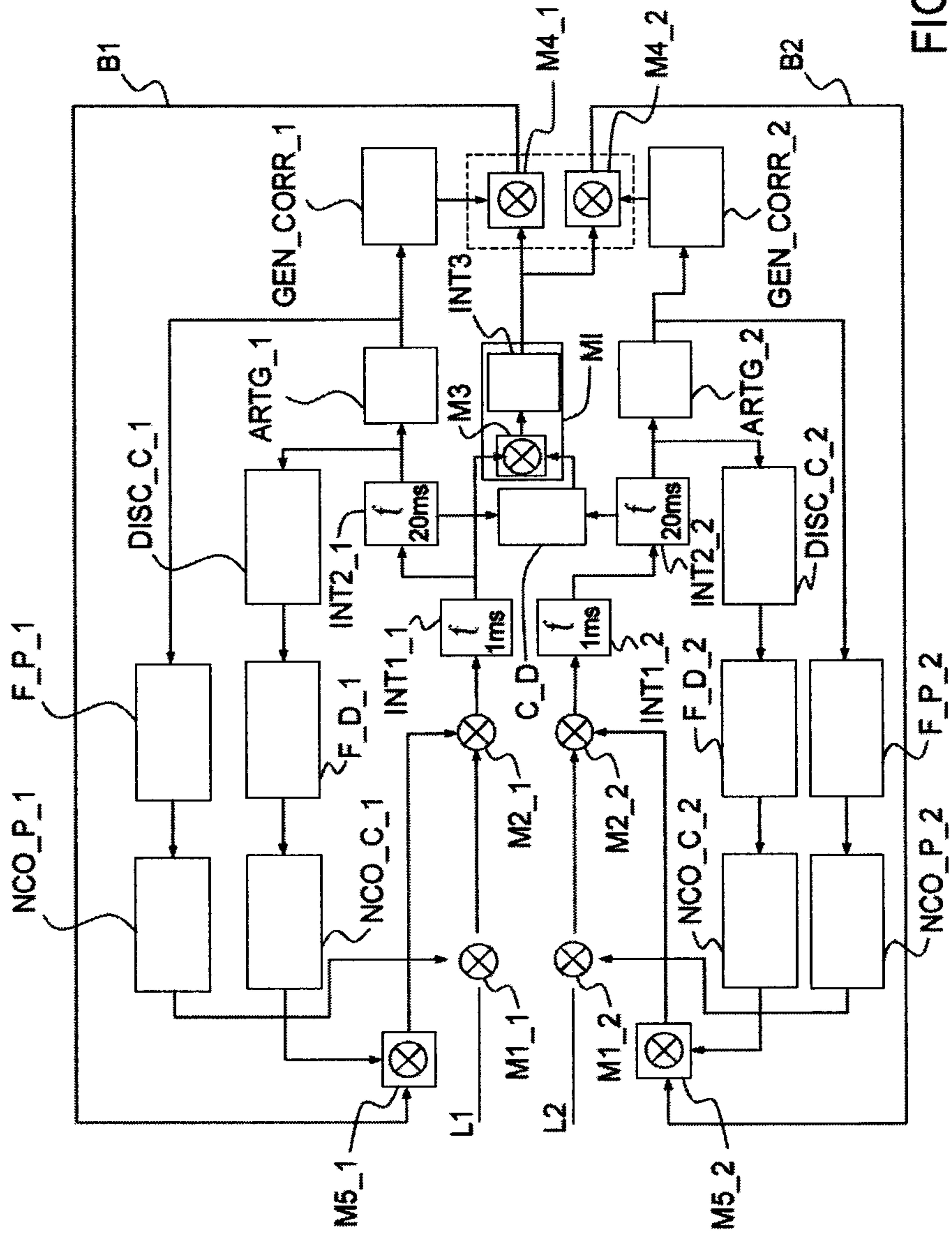


FIG. 1

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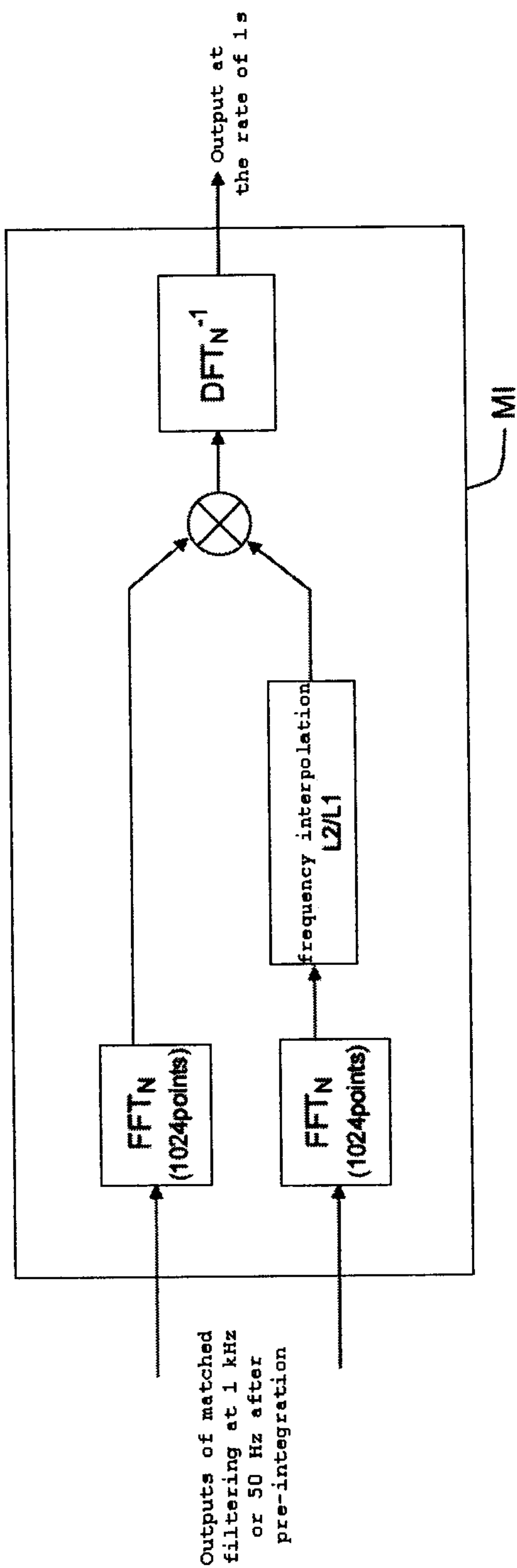


FIG.2

