Underwater acoustic comunication for the marine enviroment

MARÍA CAMPO VALERA*, IVAN FELIS ENGUIX

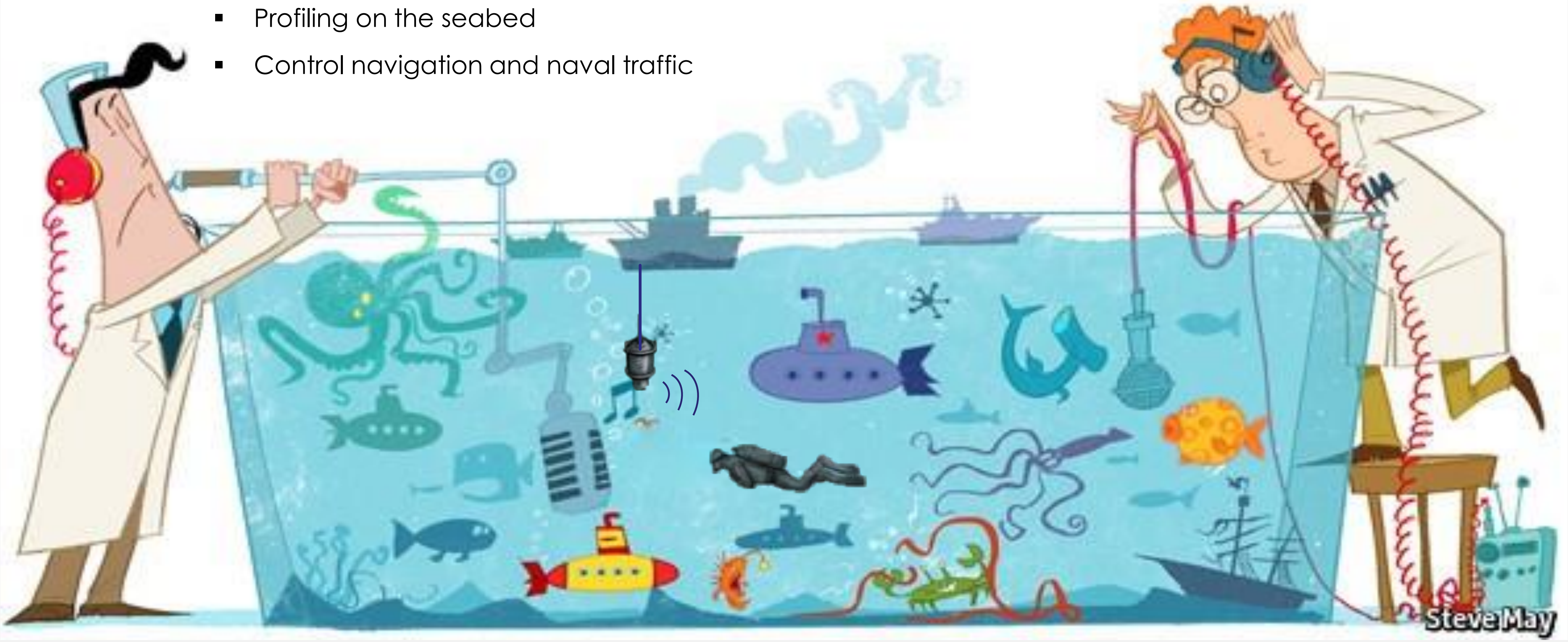
CONTENIDO

I. INTRODUCTION

ACOUSTIC COMMUNICATION IN UNDERWATER ENVIRONMENTS THROUGH PARAMETRIC EFFECT:

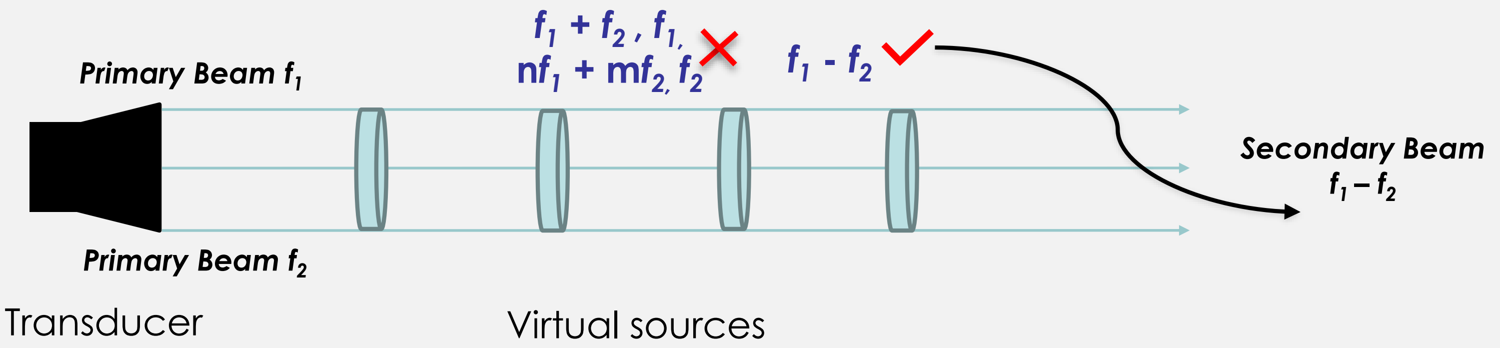
allowing the transmission of information in a directivity controlled and efficient manner.

- Environmental monitoring
- Profiling on the seabed
- Control navigation and naval traffic



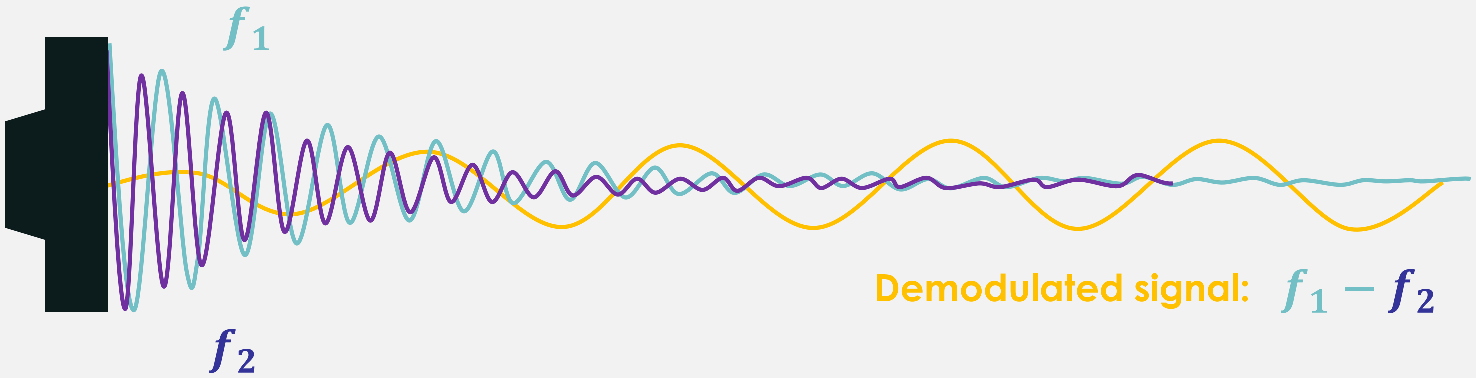
II. Theoretical foundations of the parametric effect

- Non-linear acoustic: Scattering of Sound by Sound



When a wave with a carrier frequency is modulated in amplitude by another low frequency, the medium is responsible for demodulating the wave resulting in another type of frequencies not present in the emission but that bear some relation with the modulating frequency.

II. THEORETICAL FOUNDATIONS OF THE PARAMETRIC EFFECT



$$p_{param} = \left(1 + \frac{B}{2A}\right)\frac{p^2 S}{16\pi\rho c^4 \alpha x}\frac{\delta^2}{\delta t^2}\left[E\left(t - \frac{x}{c}\right)\right]^2 \sim \frac{\delta^2}{\delta t^2} E^2$$

Where:

B/A	Nonlinearity parameter of the medium
P	Primary beam pressure amplitude [V]
S	Area of the vibrating surface of the transducer [m^2]
ρ	Density [kg/m^3]
c	Velocity of sound [m/s]
α	Absorption coefficient in the medium [Np/m]
x	Distance to the source [m]
t	Time[s]
$E(t-x/c)^2$	Envelope of modulation

The resulting wave p_{param} will be proportional to the second derivative of the square envelope of the emitted signal

II. THEORETICAL FOUNDATIONS OF THE PARAMETRIC EFFECT

In this non-linear communication approach, the technique consists of causing a change in the modulation signal according to the change in the data transmitted (1 or 0) and this change can be detected through the resulting parametrical signal.

Three modulations are studied:

- CPFSK: Continuous-Phase Frequency-ShitKeying
- LFM: Linear Frequency Modulation
- AM: Amplitude Modulation

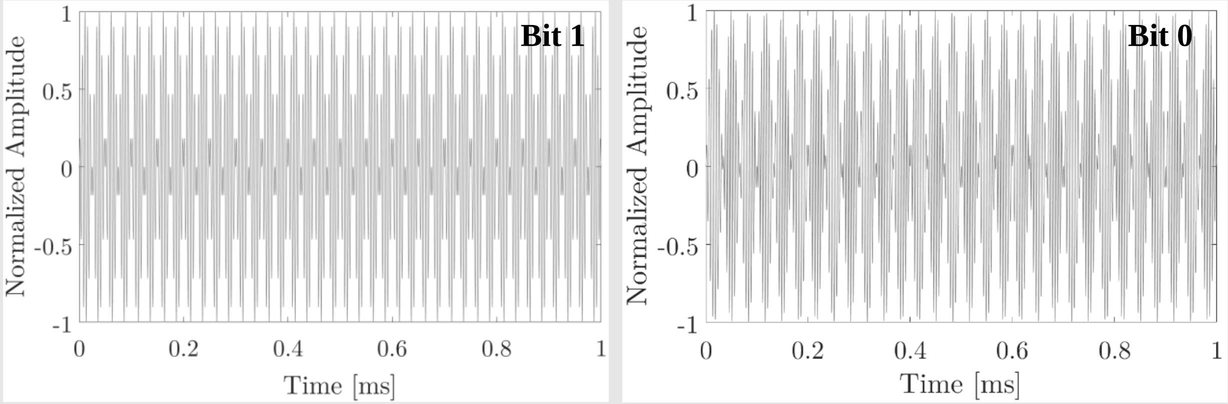
To obtaining the suitable modulated signal $z(t)$ and its envelope $E(t)$, a double integration is carried out, which does not always make it possible to use all the modulations that are used in underwater acoustic communications in the linear range. The modulations CPFSK, LFM and AM present no problems in this development and can be used without any inconvenience.

The modulations are analyzed by the cross-correlation method to detect bits 1 and 0, when a message (bit string) is sent to the communication channel.

II.1 CPFSK Modulation

This modulation uses a signal with two frequencies (that represent bits 1 and 0) those alternation, maintaining the continuous phase, represents the corresponding bit change linked until reproducing the desired binary code.

- Modulating signal that is used parametrically to the carrier signal: $\boldsymbol{p_{CPFSK}(t)} = \begin{cases} \boldsymbol{sin(2\pi f_{bit1} t + \varphi_{bit1}), t = t_{bit1}} \\ \boldsymbol{sin(2\pi f_{bit0} t + \varphi_{bit0}), t = t_{bit0}} \end{cases}$



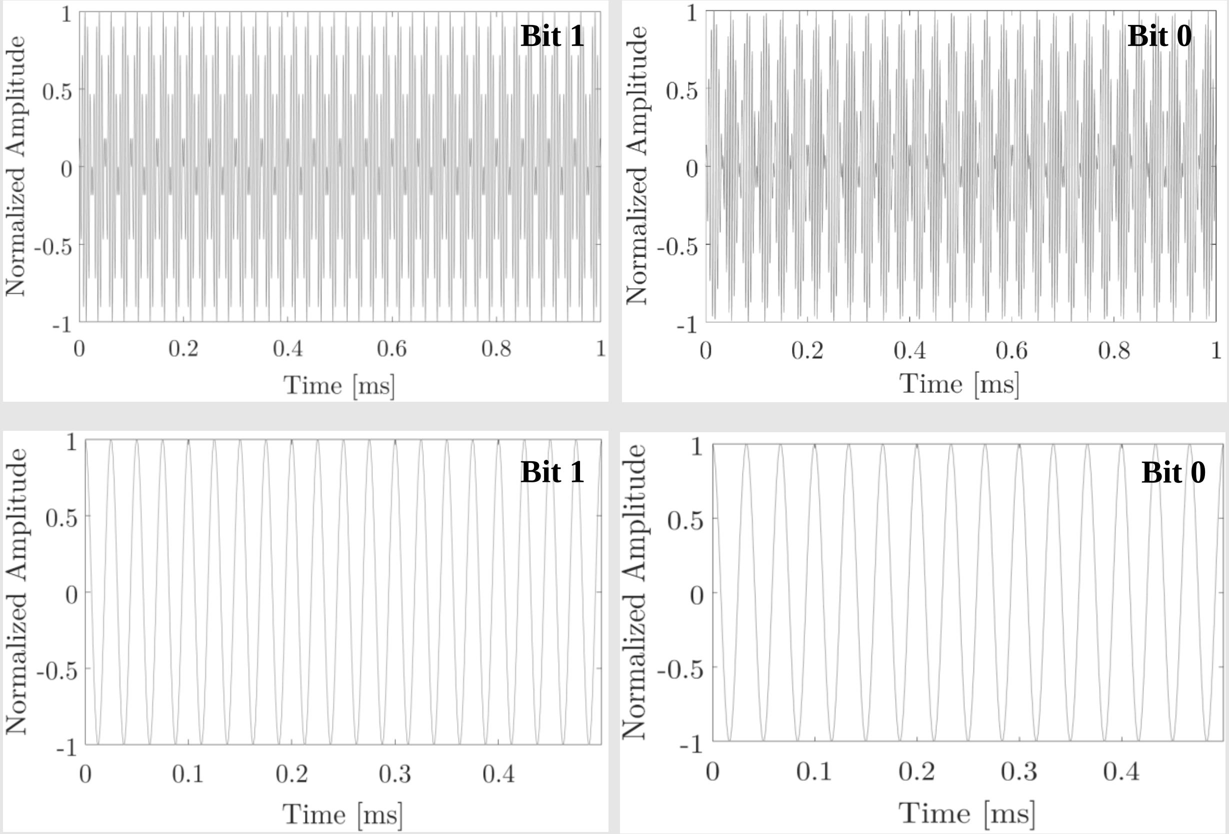
Sent CPFSK signals obtained from modulating a tone with a f_p of 200 kHz to 20 kHz and 15 kHz respectively.

$$\left.\begin{array}{l} f_{m1} = f_{bit1}/2 = 20 \text{ kHz} \\ f_{m0} = f_{bit0}/2 = 15\ kHz \end{array}\right\}$$ Frecuncies at half the parametric frequency.

II.1 CPFSK Modulation

This modulation uses a signal with two frequencies (that represent bits 1 and 0) those alternation, maintaining the continuous phase, represents the corresponding bit change linked until reproducing the desired binary code.

- Modulating signal that is used parametrically to the carrier signal: $\boldsymbol{p_{CPFSK}(t)} = \begin{cases} \boldsymbol{sin(2\pi f_{bit1} t + \varphi_{bit1})\,, t = t_{bit1}} \\ \boldsymbol{sin(2\pi f_{bit0} t + \varphi_{bit0})\,, t = t_{bit0}} \end{cases}$



Sent CPFSK signals obtained from modulating a tone with a f_p of 200 kHz to 20 kHz and 15 kHz respectively.

$$\left.\begin{array}{l} f_{m1} = f_{bit1}/2 = 20 \text{ kHz} \\ f_{m0} = f_{bit0}/2 = 15\ kHz \end{array}\right\}$$ Frecuncies at half the parametric frequency.

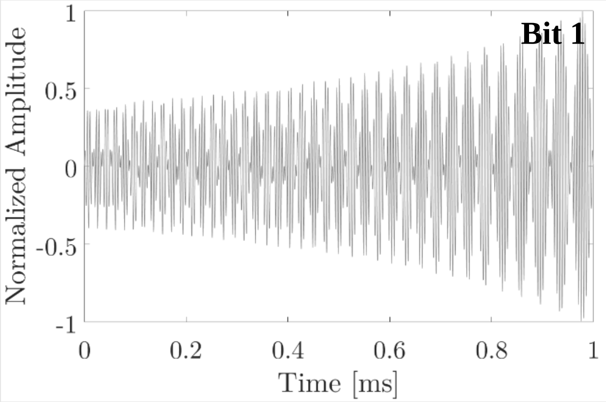
A double frequency CPFSK is obtained, that is, 40 and 30 kHz, respectively.

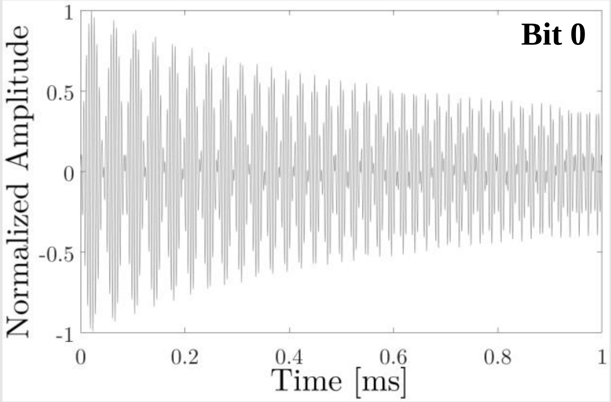
II.1 LFM Modulation

This modulation is a technique in which the frequency of the emitted signal varies quadratically with time for a given duration τ.

- Using a central difference frequency equivalent to the modulating frequency, $f_{dc} = f_m$ and a bandwidth Δf. It represented as:

$\boldsymbol{P_{LFM}(t) = sin\left(2\pi f_m t + 0.5\mu t^2\right)}$ where $\mu = 2\pi\Delta f/\Delta\tau$ frequency coefficient, the time of a bit in betwen$-\tau/2 \leq$ t $\leq \tau/2$





Sent signals obtained from modulating a 200 kHz tone with the previous expression and values:

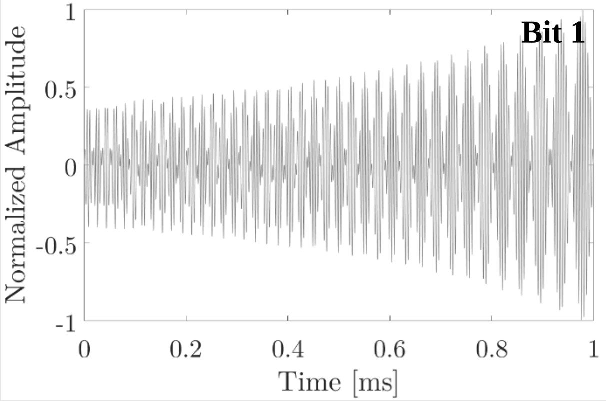
f_m = (2+20 kHz)/2 =**11 kHz**
Δf = 20 kHz – 2 kHz =**18 kHz**

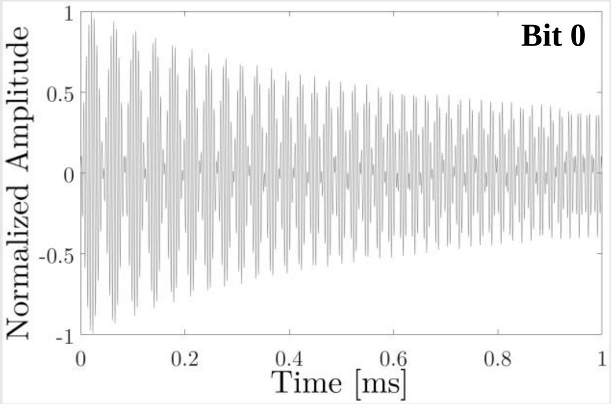
II.1 LFM MODULATION

This modulation is a technique in which the frequency of the emitted signal varies quadratically with time for a given duration τ.

- Using a central difference frequency equivalent to the modulating frequency, $f_{dc} = f_m$ and a bandwidth Δf. It represented as:

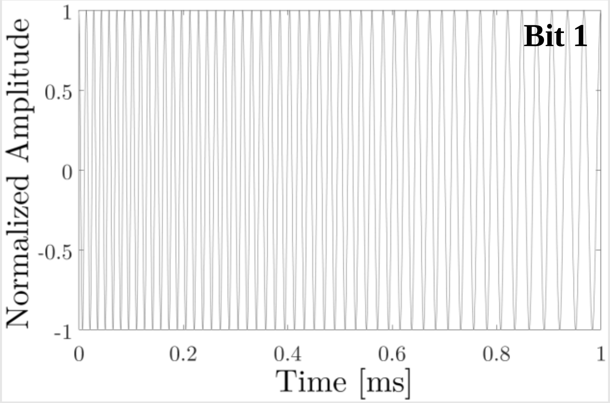
$\boldsymbol{P_{LFM}(t) = sin\left(2\pi f_m t + 0.5\mu t^2\right)}$ where $\mu = 2\pi\Delta f/\Delta\tau$ frequency coefficient, the time of a bit in betwen$-\tau/2 \leq$ t $\leq\ \tau/2$

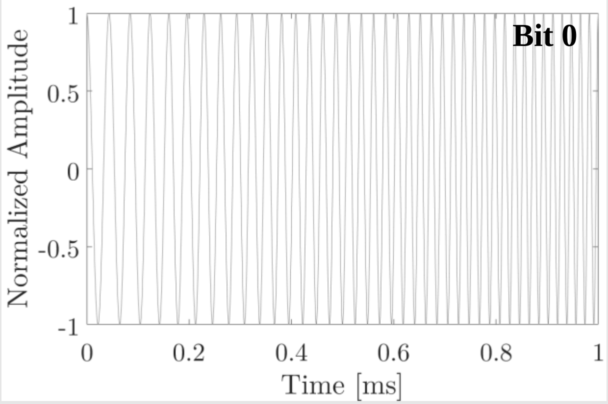




Sent signals obtained from modulating a 200 kHz tone with the previous expression and values:

f_m = (2+20 kHz)/2 =**11 kHz**
Δf = 20 kHz – 2 kHz =**18 kHz**





This type of signal can be obtained parametrically by using a modulated signal whose modulation $P_{LFM}(t)$ corresponds to the spectrum of the modulator components that is twice that of the signal to be obtained.

The expected modulating frequency is f_m = 22 kHz and Δf = 36 kHz.

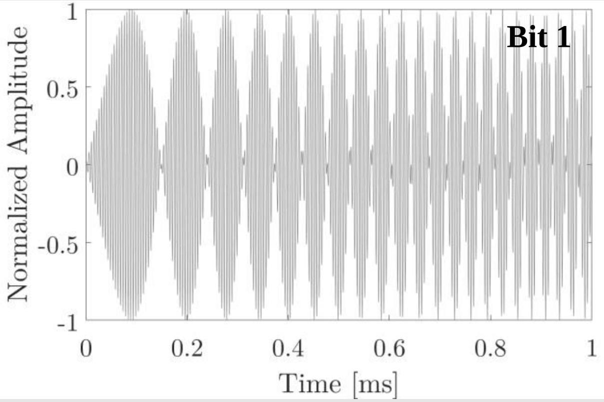
II.1 AM Modulation

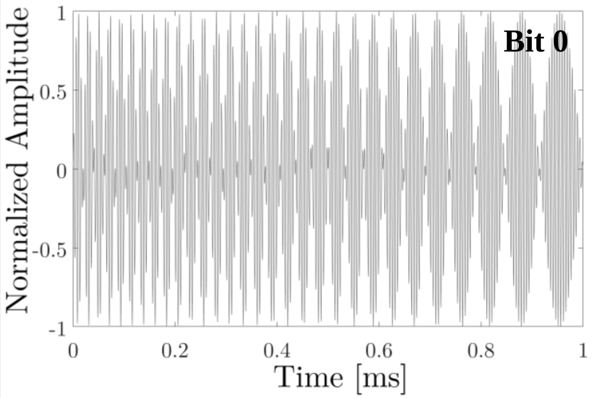
This modulation consist of changing the amplitude of the carrier signals as a function of the modulation signal (information).

- In this work, to improve the behavior of the previous modulations, two sine sweeps are used as a modulating signal, one ascending (bit 1) and other descending (bit 0). The expression that defines the modulating signal is:

$$z_{AM}(t) = sin\left[2\pi\left(\frac{|f_{m2} - f_{m1}|}{T} \cdot t + f_1\right)t\right]$$

where f_{m1} and f_{m2} are the initial and final frequency of the sweep, and T is the total sine sweep duration.





Sent AM signals obtained from modulating a 200 kHz tone:

- Upward sweep from 2 to 20 kHz (bit 1)
- Sweep descending from 20 to 2 kHz (bit 0)

Expected at twice the frequency.

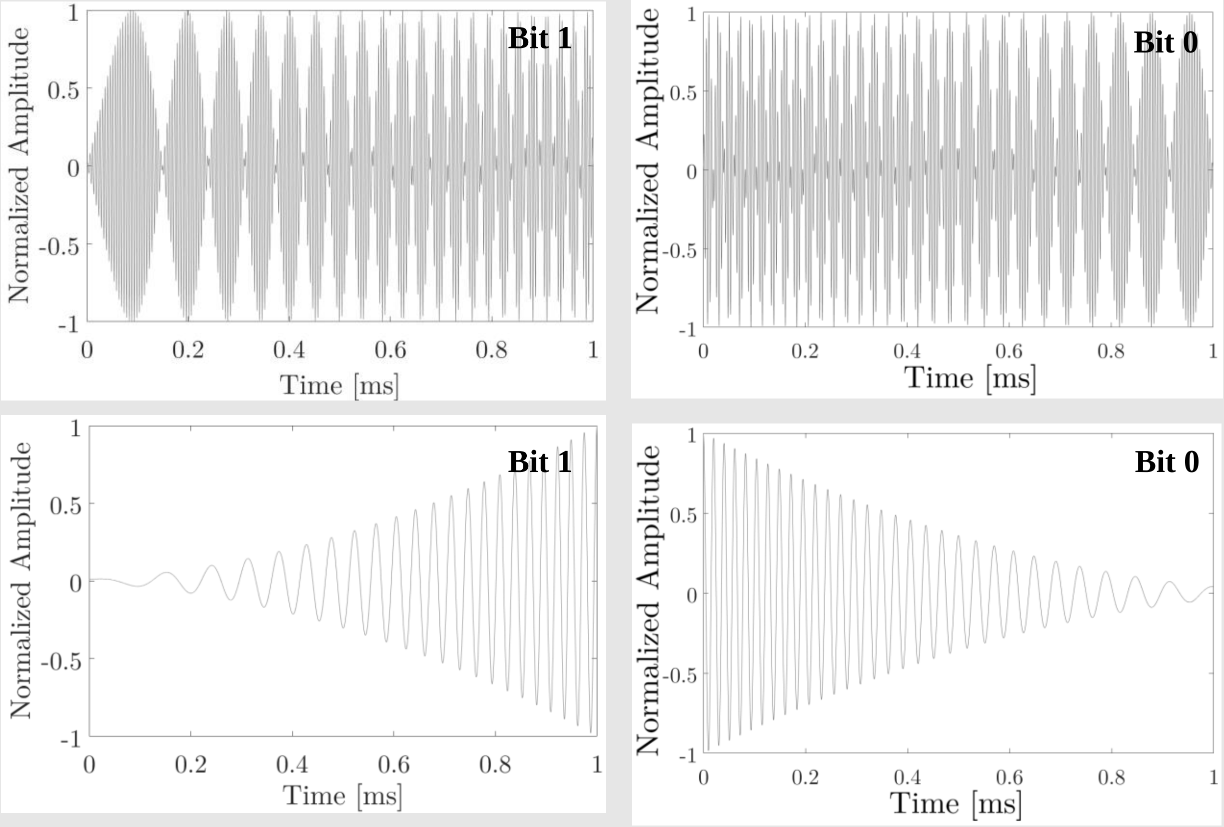
II.1 AM Modulation

This modulation consist of changing the amplitude of the carrier signals as a function of the modulation signal (information).

- In this work, to improve the behavior of the previous modulations, two sine sweeps are used as a modulating signal, one ascending (bit 1) and other descending (bit 0). The expression that defines the modulating signal is:

$$\boldsymbol{z_{AM}(t) = sin\left[2\pi\left(\frac{|f_{m2} - f_{m1}|}{T} \cdot t + f_1\right)t\right]}$$

where f_{m1} and f_{m2} are the initial and final frequency of the sweep, and T is the total sine sweep duration.



Sent AM signals obtained from modulating a 200 kHz tone:

- Upward sweep from 2 to 20 kHz (bit 1)
- Sweep descending from 20 to 2 kHz (bit 0)

Expected at twice the frequency.

The expected parametric signal is the double of the modulated signal, corresponding to:

- Bit 1: from 4 kHz to 40 kHz.
- Bit 0: from 40 to 4 kHz.

III. Experimental Set-Up

- The experimental set-up was carried out at the Centro Tecnológico Naval y del Mar in agreement with the Universidad Politécnica de Cartagena in Murcia, Spain in a lake of tapered shape with a 10 m depth and a diameter of 20 m.

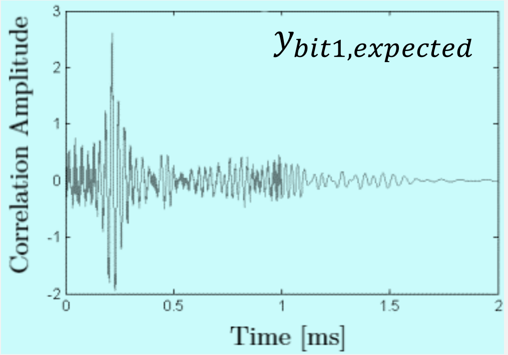
Transducer Airmar P19
- Transmitting Voltage Response (TVR): 167 dB re μPa/V @ 1 m
- Resonance frequency: 200 kHz

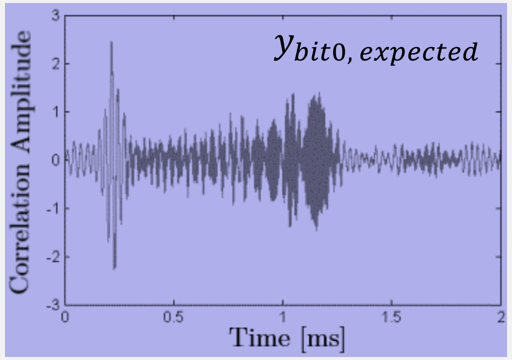
Hydrophone ITC 1032
- Receiving Voltaje Response (RVR): -194 dB @ 1 V/μPa
- Resonance frequency: 33 kHz

IV. Results: Bit detection

Cross correlation

$$r_{xy}[l] = \sum_{n=1}^{N} x[n]\, y[n+l]$$

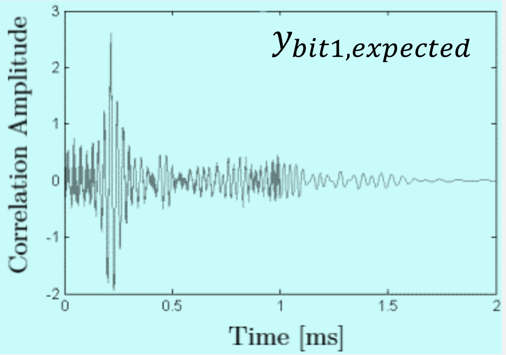


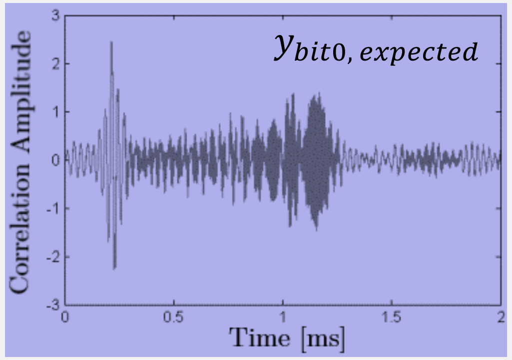


IV. Results: Bit detection

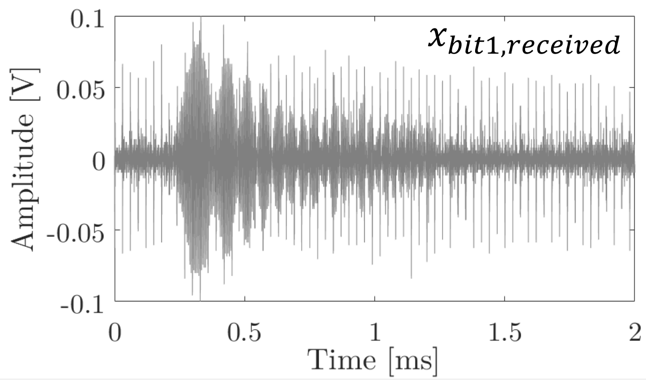
Cross correlation

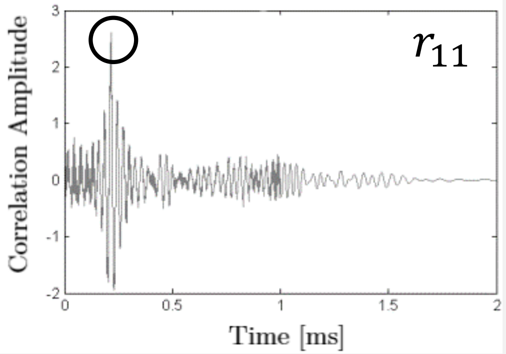
$$r_{xy}[l] = \sum_{n=1}^{N} x[n]\, y[n+l]$$

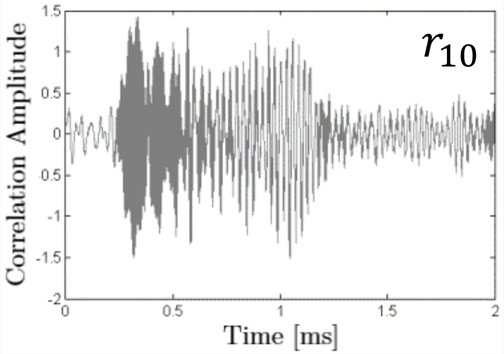




Knowing the speed of sound propagation where the signal is transmitted, the distance $d = c/t$ between the emission and the reception is determined.





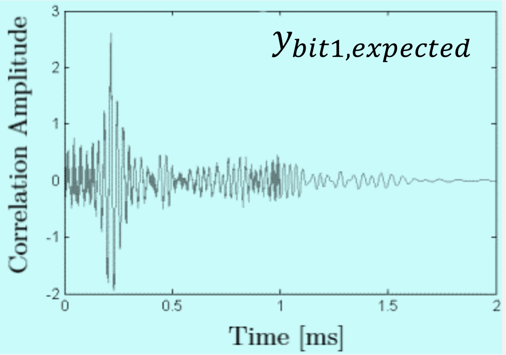


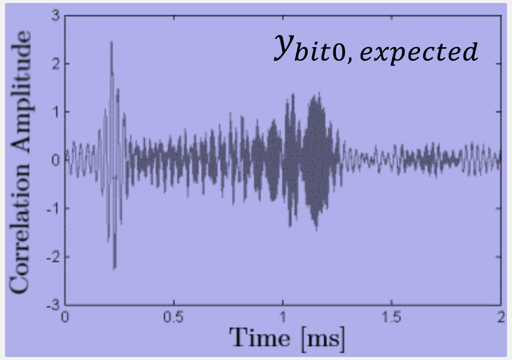
Example of sine sweep parametric signal received in 0.2 ms with the resulting correlation with expected bit 1 and bit 0 signal.

IV. Results: Bit detection

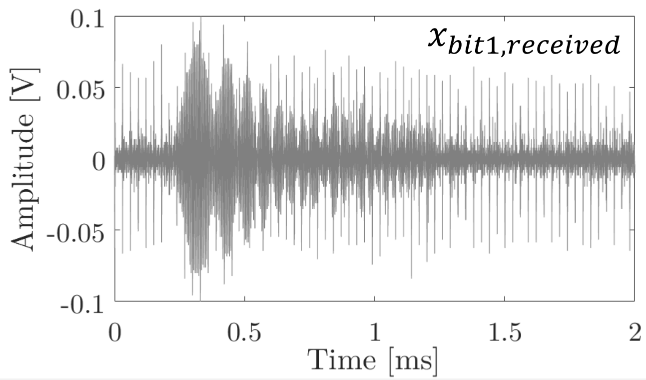
Cross correlation

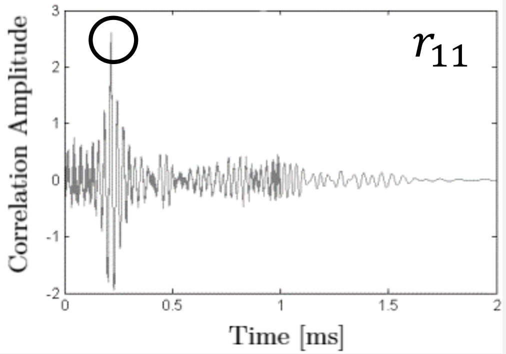
$$r_{xy}[l] = \sum_{n=1}^{N} x[n]\, y[n+l]$$

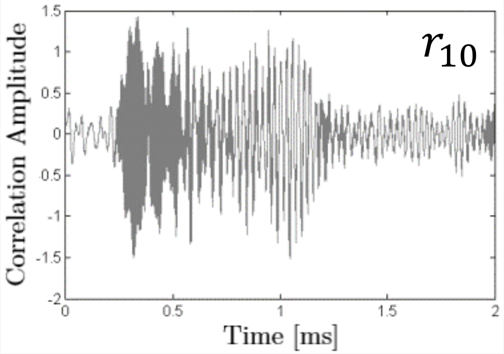




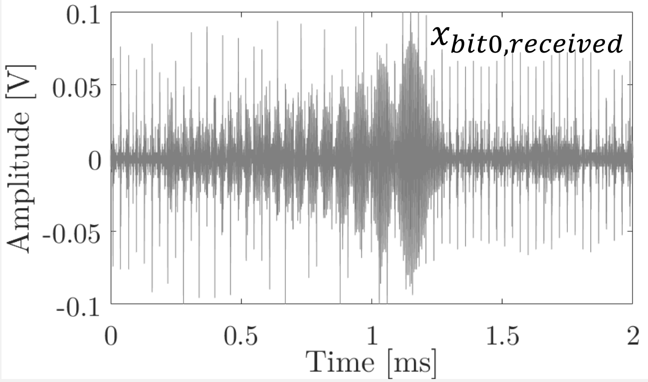
Knowing the speed of sound propagation where the signal is transmitted, the distance $d = c/t$ between the emission and the reception is determined.

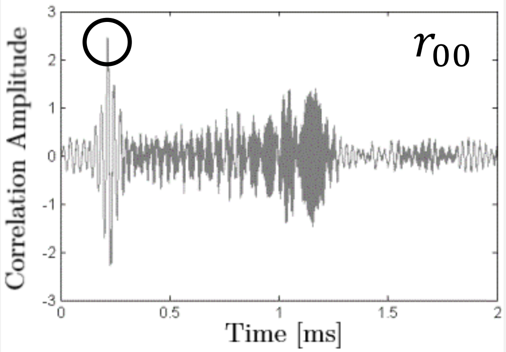


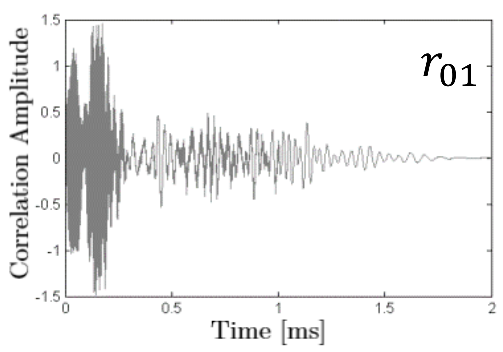




Example of sine sweep parametric signal received in 0.2 ms with the resulting correlation with expected bit 1 and bit 0 signal.

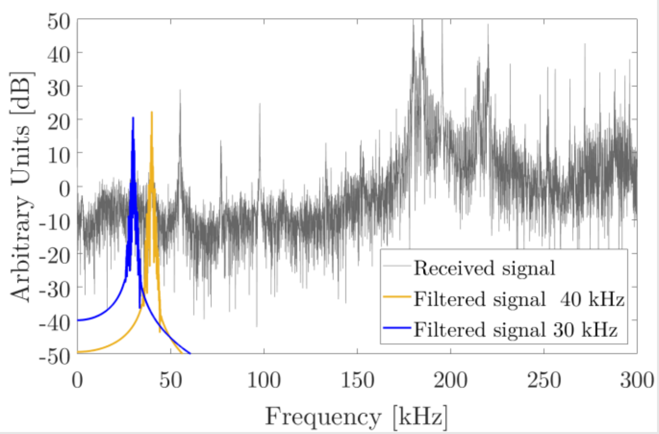






IV.1 Results: CPFSK Modulation Detection

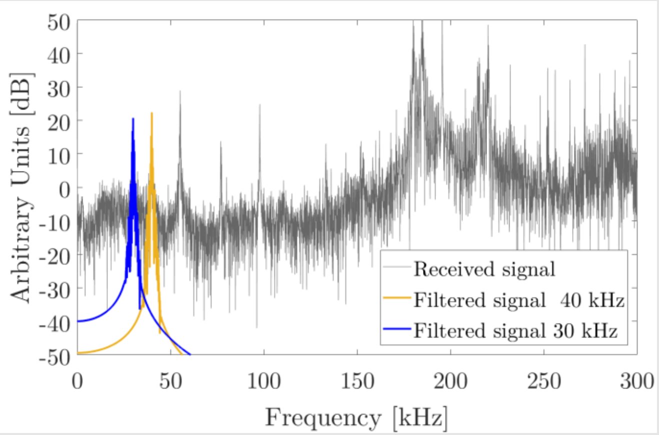
- An organized bit string is studied as follows: [**1 0 1 0 0 1 0 1 1 0 0 1 0 1 1 0**]



Expected frequencies of each bit 1 and 0 are 40 and 30 kHz, respectively, before correlating a filter centered on each of these frequencies is made to the received signal.

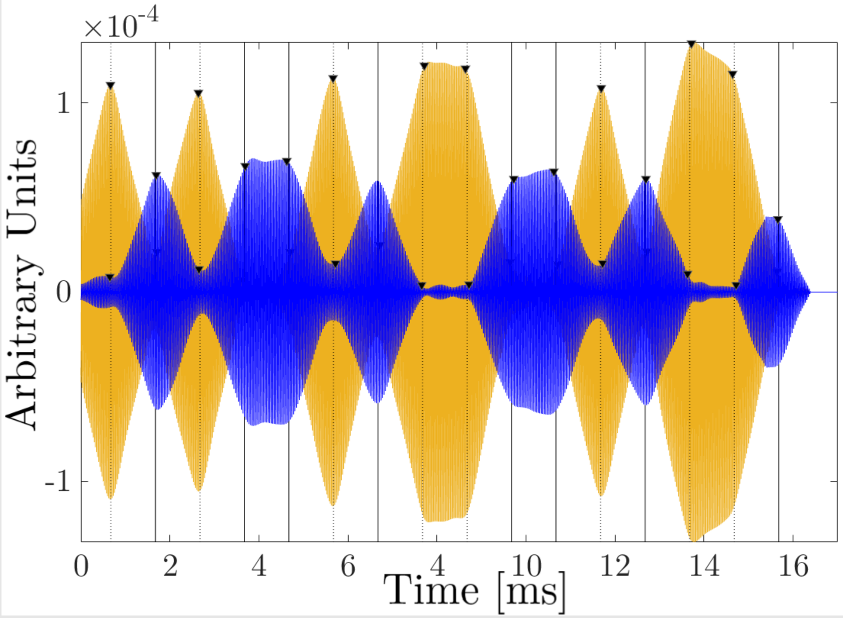
IV.1 Results: CPFSK Modulation Detection

- An organized bit string is studied as follows: [**1 0 1 0 0 1 0 1 1 0 0 1 0 1 1 0**]



Expected frequencies of each bit 1 and 0 are 40 and 30 kHz, respectively, before correlating a filter centered on each of these frequencies is made to the received signal.

Cross Correlations: bit 1 expected (yellow), and bit 0 expected (blue)

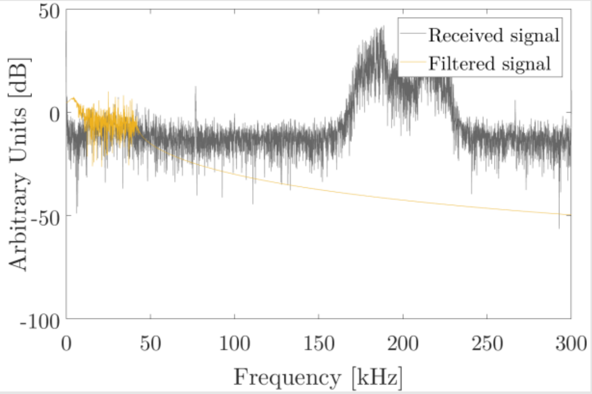


- Correlation peaks quite wide (inefficient in their detection and temporary discrimination).
- Average amplitudes of bits 1 and 0 detected correctly is $1.15 \cdot 10^{-4}$ y $0.60 \cdot 10^{-4}$ respectively.
- Average amplitudes of false bits 1 and 0 $0.16 \cdot 10^{-4}$ and $0.09 \cdot 10^{-4}$.

Is obtained

IV.2 Results: LFM Modulation Detection

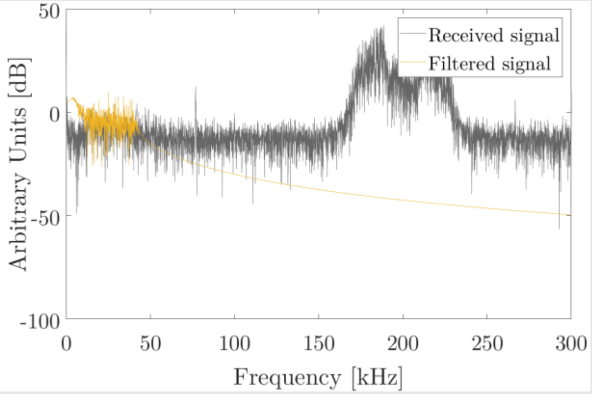
- An organized bit string is studied as follows: [**1 0 1 0 0 1 0 1 1 0 0 1 0 1 1 0**]



Before correlating, a unique filter passes to the received signal was applied because the expected parametric frequencies of both bits oscillate between 22 and 38 kHz.

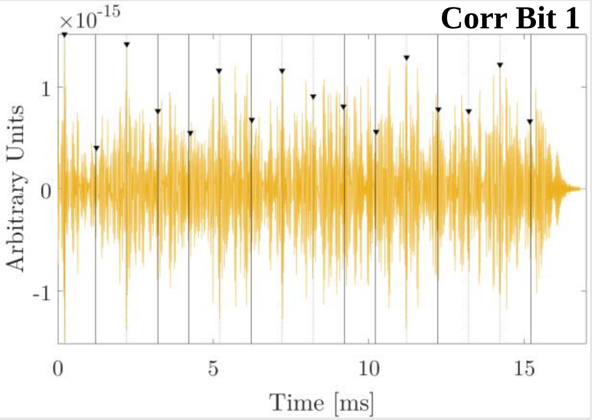
IV.2 RESULTS: LFM MODULATION DETECTION

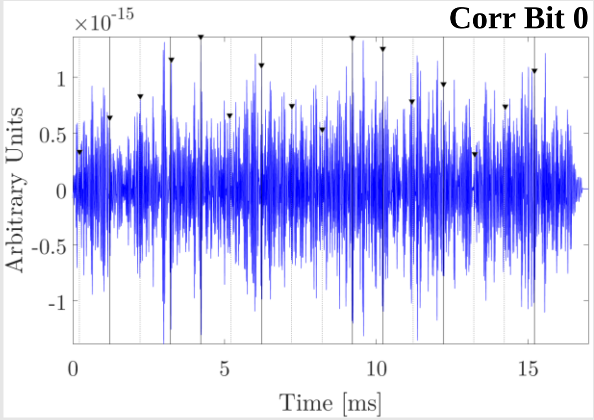
- An organized bit string is studied as follows: [**1 0 1 0 0 1 0 1 1 0 0 1 0 1 1 0**]



Before correlating, a unique filter passes to the received signal was applied because the expected parametric frequencies of both bits oscillate between 22 and 38 kHz.

Cross correlations between the received signal filtered between 20 and 38 kHz and the LFM signal expected parametrically for each bit.



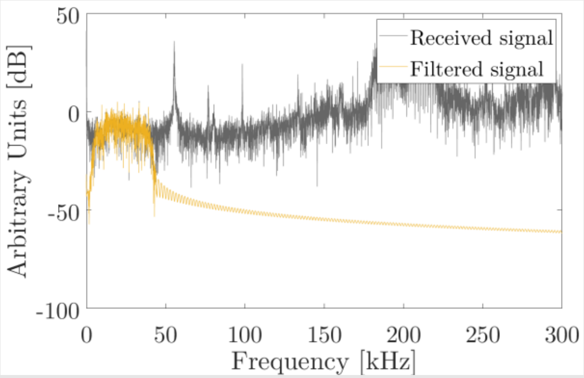


Is obtained

- Correlation peaks, even being much narrower than those obtained with CPFSK modulations, but, do not allow clear discrimination between correct and false bits.
- The average of the amplitudes of bits 1 and 0 detected at the correct time is $1.17 \cdot 10^{-15}$ and $1 \cdot 10^{-4}$, respectively.
- The average of the amplitudes of the false bits 1 and 0 is $0.64 \cdot 10^{-4}$ and $0.61 \cdot 10^{-4}$.

IV.3 Results: AM Modulation Detection

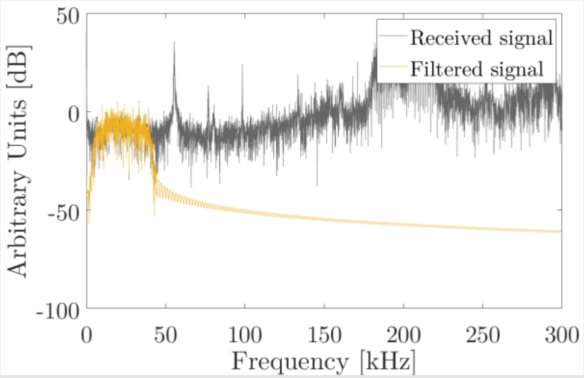
- An organized bit string is studied as follows: [**1 0 1 0 0 1 0 1 1 0 0 1 0 1 1 0**]



Before correlating, a single filter passes between 4 and 40 kHz was applied.

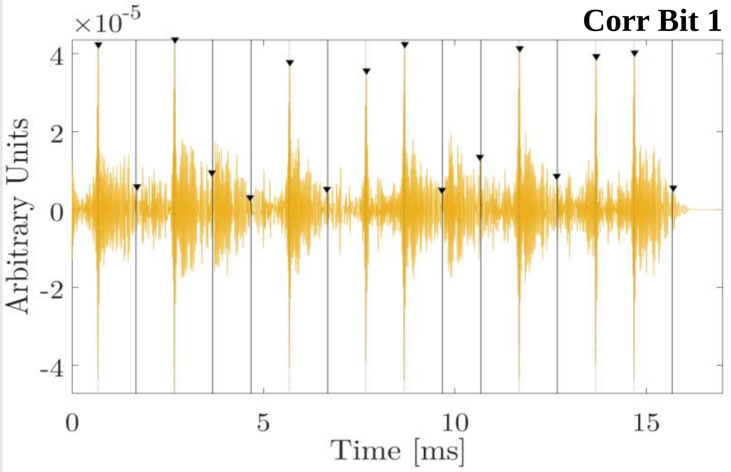
IV.3 Results: AM Modulation Detection

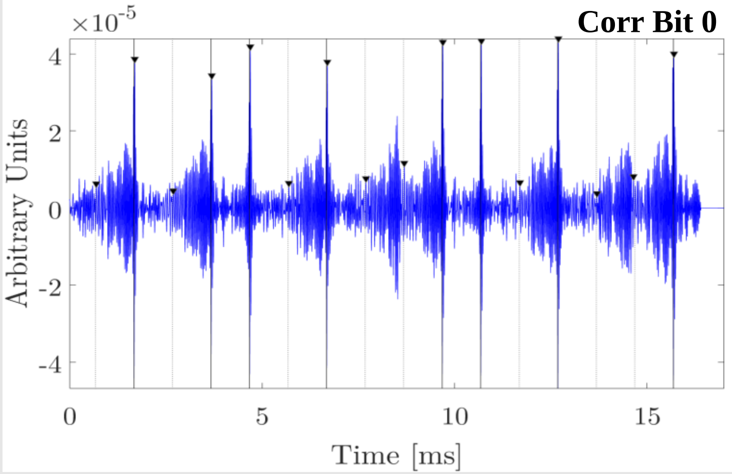
- An organized bit string is studied as follows: [**1 0 1 0 0 1 0 1 1 0 0 1 0 1 1 0**]



Before correlating, a single filter passes between 4 and 40 kHz was applied.

Cross Correlations between the received signal filtered from 4 to 40 kHz and the envelope (parametric).





Is obtained

- Correlations peaks, much narrower than those of the CPFSK.
- Correct bits regarding the false ones are much clearer to discern regarding the LFM.
- Average amplitudes of bits 1 and 0 detected at the correct time is $0.41 \cdot 10^{-5}$ and $0.40 \cdot 10^{-5}$.
- Average amplitudes of false bits 1 and 0 is $0.07 \cdot 10^{-5}$.

V. Conclusions

- CPFSK → Quite wide correlation peaks because this type of modulation is a pure tone that changes with the frequency.

- LFM → Narrow correlation peaks more than the CPFSK, however, the correlation amplitudes do not allow clear discrimination between the correct and false bits.

- AM → The maximum correlation behaves more narrowly, the signal is amortized much faster, therefore, there is a correlation amplitude and a much more defined width of it.

  The amplitude averages of the bits 1 and 0 detected at the correct moment is $0.41 \cdot 10^{-5}$ and $0.40 \cdot 10^{-5}$ u.a., respectively; while the amplitude average of the false bits 1 and 0 is $0.07 \cdot 10^{-5}$ u.a. We can conclude a correct detected bit rate is obtained correctly with respect to the false ones of around 5.8 for bit 1 and 0.

With all this, it is concluded that AM modulation with parametric sine sweeps is a suitable alternative for use in nonlinear underwater acoustic communications for the marine environment's monitoring it provides a very high maximum correlation of the true bits with respect to the false ones with very narrow peak amplitudes. to the broad frequency bandwidth used.

THANK YOU