DESDE 2013
https://repository.uaeh.edu.mx/revistas/index.php/icbi/issue/archive
Pädi Boletín Científico de Ciencias Básicas e Ingenierías del ICBI

ISSN: 2007-6363

Publicación Semestral Pädi Vol. 11 No. Especial 2 (2023) 161-166

Evaluation of Telemedicine systems for ECG analysis: Advances in the design of RF schemes
Evaluación de sistemas de Telemedicina para ECG análisis: Avances en el diseño de esquemas de RF

M. J. García-Ortega [a], J. R. Cárdenas-Valdez [a], A. H. Corral-Domínguez [a]
F. Ramírez-Arzate [a], A. Calvillo-Téllez [b]

[a] IT de Tijuana, Tecnológico Nacional de México, Tijuana 22435, México.
[b] Instituto Politécnico Nacional, CITEDI, 22435, Tijuana, Baja California, México.

Abstract

The monitoring and transmission of biomedical signals, particularly ECG is essential in the post-pandemic era. In this research, an RF transmission with a carrier frequency of 2.45 GHz for ECG is used. A testbed for variable n-QAM schemes is developed with a low noise amplifier characterized in its linear region based on its P1dB, to guarantee a low level of induced non-linearities. The system includes an acquisition stage using the Olimex module and electrodes with an Ag/AgCl type sensor, and an algorithm is developed for detecting peaks in heart signals, heart rate and calculation of sample-based heart rate. The transceiver has total control of the transmitted tones, and a signal demodulation process is carried out in the receiver, one of the main challenges in Telemedicine is to ensure the fidelity of a signal, an EVM_{RMS} of 8.36 is obtained for fifteen OFDM symbol frames. The developed system as a Telemedicine proposal provides versatility for signal acquisition, digitalization, data storage and a multivariable n-QAM scheme, which makes it viable for Telemedicine and classification processes.

Keywords: n-QAM, Post-pandemic, P1dB, RF, Transceiver.

Resumen

El monitoreo y transmisión de señales biomédicas, particularmente ECG, es fundamental en la era pospandemia. En esta investigación se utiliza una transmisión de RF con una frecuencia portadora de 2.45 GHz para ECG. Se desarrolla un banco de pruebas para esquemas n-QAM variables con un amplificador de bajo ruido caracterizado en su región lineal en base a su P1dB, para garantizar un bajo nivel de no linealidades inducidas. El sistema incluye una etapa de adquisición mediante el módulo Olimex y electrodos con sensor tipo Ag/AgCl, y se desarrolla un algoritmo para la detección de picos en señales cardíacas, frecuencia cardíaca y cálculo de frecuencia cardíaca en base a muestra. El transceptor tiene el control total de los tonos transmitidos, y en el receptor se realiza un proceso de demodulación de la señal, uno de los principales retos en Telemedicina es asegurar la fidelidad de una señal, se obtiene un EVM_{RMS} de 8.36 para quince tramas de símbolos OFDM. El sistema desarrollado como propuesta de Telemedicina brinda versatilidad para la adquisición de señales, digitalización, almacenamiento de datos y un esquema n-QAM multivariable, lo que lo hace viable para procesos de Telemedicina y clasificación.

Palabras Clave: n-QAM, Pospandemia, P1dB, RF, Transceptor.

1. Introduction

Cardiovascular disease (CVD) is one of the most common causes of death in the world, which include heart failure, heart disease, cardiomyopathy, and congenital heart disease, to name a few; it is expected that over 17 million deaths per year worldwide, and an increase of around 23 million is expected by 2030 (Mendis, 2011). This is more prevalent in low and middle-income countries with critical infrastructure and lack of funding for healthcare support services (Faruk,

*Autor para la correspondencia: jose.cardenas@tectijuana.edu.mx
Correo electrónico: manuel.garciao@tectijuana.edu.mx (Manuel de Jesús García-Ortega), jose.cardenas@tectijuana.edu.mx (José Ricardo Cárdenas-Valdez), angel.corral@tectijuana.edu.mx (Ángel Humberto Corral-Domínguez), fortunato.ramirez@tectijuana.edu.mx (Fortunato Ramírez Arzate), acalvillo@ipn.mx (Andrés Calvillo-Téllez).

Historial del manuscrito: recibido el 21/03/2023, última versión-revisada recibida el 27/06/2023, aceptado el 27/06/2023, publicado el 11/09/2023. **DOI:** https://doi.org/10.29057/icbi.v11iEspecial2.10779

2021). The acquisition of cardiac electrical signals is a fundamental point in the process of interpretation of anomalies in the human body; the systems based on the acquisition of signals through electrodes provide a wide range of helpful information related to the essential functions of the heart without requiring invasive methods (Kligfield, 2018), one of the most essential medical signals for a transmission and analysis process is the electrocardiogram (ECG) (Affanni, 2020).

One of the main challenges is related to using different technologies in commercial devices, as well as aligning the measurements and pre-, and post-processing stages for different sensors (Algarni, 2021). Telemedicine is widely used in the vast majority of countries to increase access to health care by eliminating proximity; however, technological resources and applications have a lack for proper implementation and interpretation of results (Kruse, 2018). In (Pineda-Lopez, 2018), a proposal is developed based on cardiac monitoring through 12-leads and the possibility of incorporating additional signal pre-conditioning processes. ECG data storage is one of the most valuable and standard methods of medical procedures. ECG is used for diagnosis and response to therapies; despite its frequent use, it requires systems for analysis and diagnosis, as well as for signal transmission (Breen, 2022). Sensing in the time domain has been a fundamental part of the investigation of the acquisition of ECG signals; in (Chen, 2021), a reconstruction approach for compressed ECG signals and detection of QRS waves is presented.

Additionally, the design of a digital-to-analog converter (DAC) for the selection of cardiac activity has been carried out through various classification techniques, a potential candidate for a diagnosis of CVD (Qaisar, 2018). In (Affanni, 2020), a wearable sensors system for simultaneously measuring two channels ECG where the data are sent via WiFi is designed as a Telemedicine application. The development of precise ECG acquisition systems has an essential boom concerning the design of sensing systems. In (Marisa, 2017), an asynchronous analog to digital converter (ADC) is developed for ECG data acquisition.

In this research review of relevant Telemedicine works is made, in addition to the implementation of a proposal, which develops a multivariable n-QAM modulation system, time-domain digitization algorithm, data storage, and an RF signal transmission stage in the 2 GHz band. This work is developed as follows: Section II depicts a review of signal extraction and measurement techniques; Section III details the proposal for ECG acquisition data and RF transmission stages. Finally, Section IV describes perspective of Telemedicine in ECG applications and future work.

2. Signal Extraction and Measurement

The electrical impulses of an ECG signal come from the sinoatrial node and travel to the atrioventricular node to contract as the potential electrical moves, exciting the cells along its path; the analysis of ECG signals is essential for the diagnosis of pathologies in the analysis of the time domain. ECG signal is divided into complex P, QRS, and T waves; the atrium consists of two parts divided into the left and right atrium, ECG biomedical sign is used in medicine for CVD diagnosis. Figure 1 shows the essential parts of the ECG signal in the time domain (Tsai, 2018).

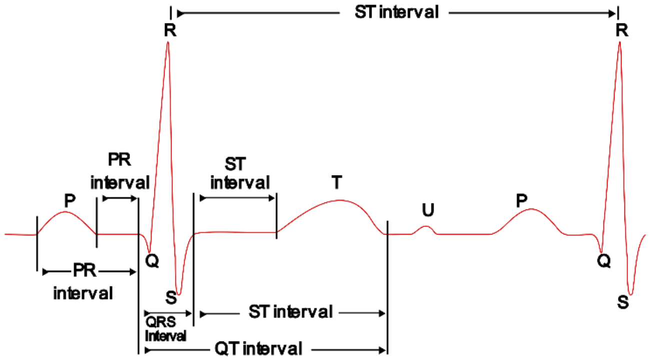

Figure 1: Fundamental parts of the ECG signal in the time domain.

During the last few years, the scientific interest related to measurements and data transmission of ECG signals has increased exponentially. Above all, addressing problems of prevention and diagnosis of cardiovascular pathologies. There are various works in the literature related to Telemedicine systems for monitoring and diagnosis, especially systems related to ECG; in (Bhalerao, 2019) in developed an artificial neural network (ANN) along with prediction error expansion for data prediction, the algorithm proposed requires a single loop execution process, the system is based on an arrhythmia database. Figure 2 depicts the ANN architecture, the number described by stages in each of the boxes shows the main configuration for three hidden layers with 20 neurons in it, and the middle hidden layer has 30 neurons.

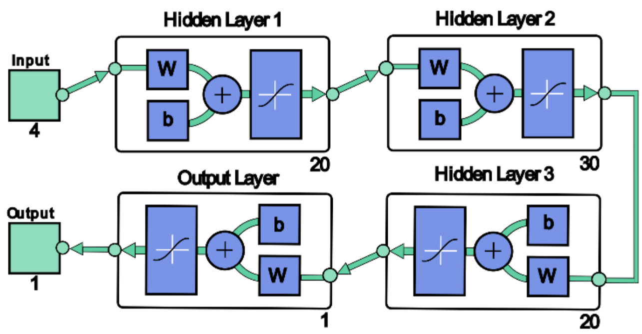

Figure 2: Overview of the developed artificial neural network architecture (Bhalerao, 2019).

In (Algarni, 2021), the two-channel design of the electrodermal activity sensor and two channels ECG sensor is described. ECG signals are sent via WIFI, and they are graphed and stored in real-time. In the proposed design, the wearable sensor system is applicable for two channels of ECG acquired on the chest and, as further work is planned, support vector machine (SVM) classification. Figure 3 describes the scheme of sensors and electrode positioning acquired on the chest and the block diagram of ECG box.

Additionally, an on-body wireless sensor network is used to monitor ECG signals from wireless electrodes located on the human body for home healthcare of patients. The main contribution is that the electrodes are connected to a base station (Aboalseoud, 2019). In Figure 4, a top-level block diagram of the general system is demonstrated; it consists of electrodes interconnected via wireless, and a wireless biomedical monitoring device is developed; the patient's information under test is transmitted to a central base through a transceiver.

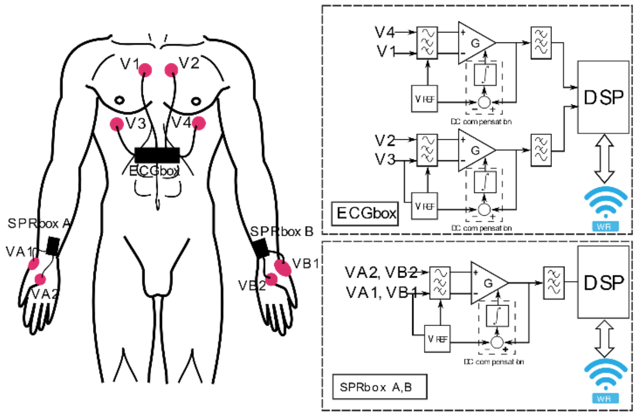

Figure 3: Fundamental parts of the ECG signal in the time domain.

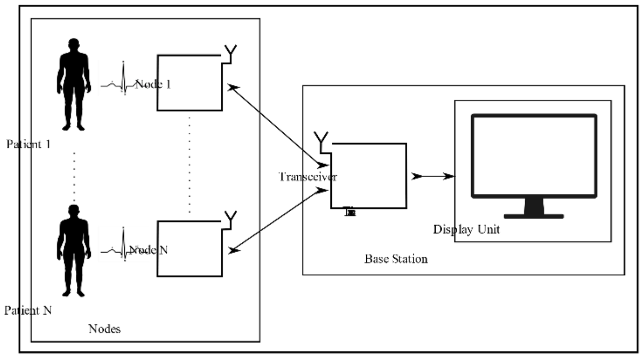

Figure 4: Communication scheme of the wireless electrodes and base station.

3. Proposed ECG acquisition data and RF transmission stages

The block diagram of the experimental setup is depicted in Figure 5 and Figure 6, initially describes the process of acquiring a precordial signal, establishing an aVr, aVl and aVF type lead placement to form the Einthoven triangle for acquiring P, QRS, and T waves (Abi-Saleh, 2010). In this case, the used electrodes include polyethylene, they are biocompatible, coated with acrylic copolymer, with an Ag/AgCl type sensor; conductive gel was placed on the terminal to improve the acquisition of the ECG signal. In the acquisition stage, an Olimex module is used coupled to the digital I/O port with the Arduino Uno embedded system; the design was built in C language in a Java environment. The storage between boards allows heart peak detection, calculation of sample based heart rate, and adequate accuracy of the extracted biomedical signals. As an intermediate stage, the ECG signal segmentation process is carried out based on the flowchart of the Figure 7 showing the acquisition, segmentation and storage stages, later in the processing of the data to operate the FMCOMMS3 RF transceiver, a variable n-QAM stage is designed; the characteristics of bandwidth (BW), gain mode sampling frequency are adjusted in the AD9361 transceiver toolkit, the transmitter stage comprises an n-QAM modulator, coupled with a raise cosine filter coupled prior to transmission. A spectral evaluation of error vector magnitude (EVM) is performed for the validation of the transmitted OFDM symbols.

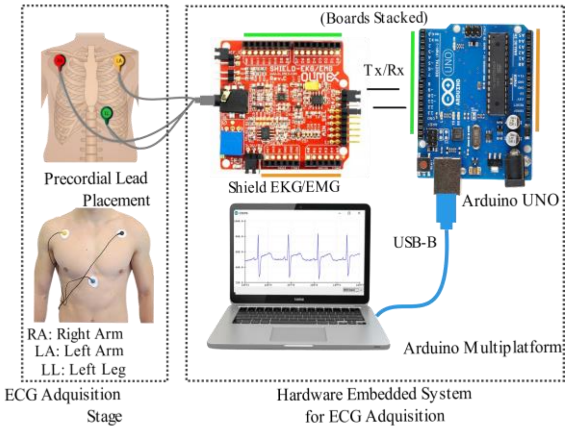

Figure 5: Communication scheme of the wireless electrodes and base station.

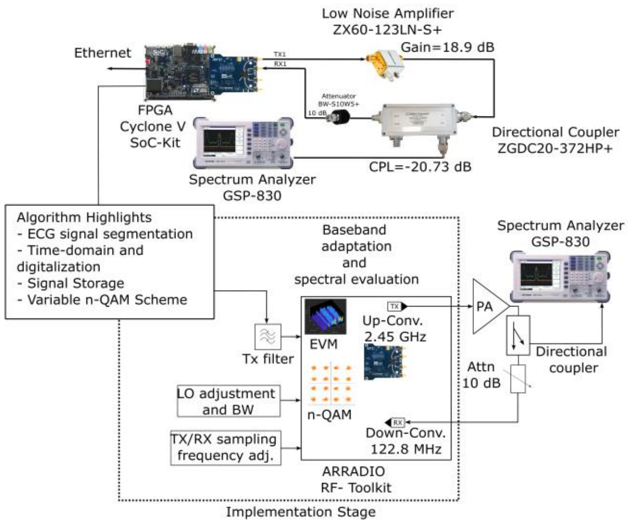

Figure 6: Segmentation, RF transmission stage and ECG validation.

The core part of this developed work comprises a system adaptable to various n-QAM schemes, equation (1) represents a signal with the combination of variations in the amplitude and phase time domain, which by means of the trigonometric identity of COS(A+B) generates the depicted by (2) where both transmission channels are shown, in the first instance channel I and channel Q.

From equation 1it is shown that $A_m \cos(\emptyset_m)$, is the projection of the modulation on X axis, while $-A_m \sin(\emptyset_m)$. is the projection on the Y axis, that modulation is shown by the set of two carriers $\cos(2\pi\mathrm{Ft})$ and $-sin(2\pi\mathrm{Ft})$, which together form the RF signal (Rouphael, 2009).

$$s(t) = A_m \cos(2\pi\mathrm{Ft} + \emptyset_m), \tag{1}$$

$$s(t) = A_m \cos(2\pi\mathrm{Ft}) \cos(\emptyset_m) - A_m \cos(2\pi\mathrm{Ft}) \sin(\emptyset_m). \tag{2}$$

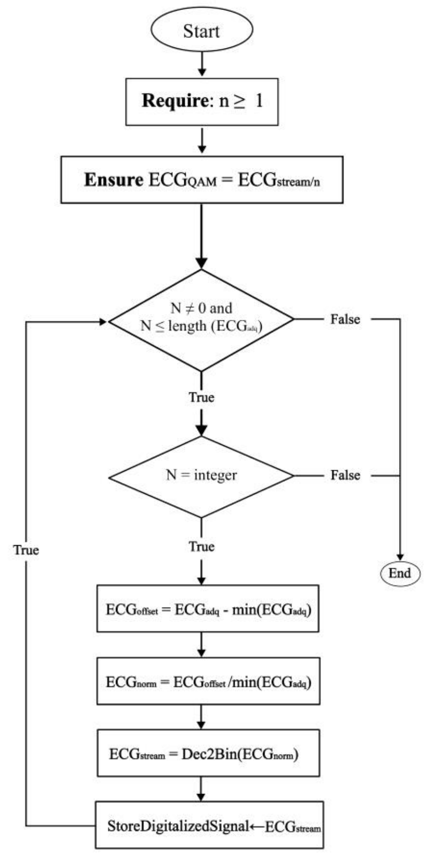

Figure 7: Flow chart of the acquisition, segmentation and storage stages.

The mathematical expression representing the n-QAM signal is considered to be the transmission of two independent bit strings α_I and α_Q respectively is shown by (3) and (4).

$$v_I(nT_S) = \sum_m \alpha_I[m]p(nT_S - mT_M), \quad (3)$$

$$v_Q(nT_S) = \sum_m \alpha_Q[m]p(nT_S - mT_M). \quad (4)$$

The QAM signal can be reconstructed by multiplying v_I with $\sqrt{2}\,cos\left(2\pi\frac{F_C}{F_S}n\right)$ and v_Q with its corresponding $-\,sin\left(2\pi\frac{F_C}{F_S}n\right)$ and it can be represented by (5),

$$s(nT_S) = v_I(nT_S)\sqrt{2}\,cos\left(2\pi\frac{F_C}{F_S}n\right) - v_Q(nT_S)\sqrt{2}\,sin\left(2\pi\frac{F_C}{F_S}n\right). \quad (5)$$

In this implementation was applied a quadrature phase shift keying (QPSK) modulator called traditionally as 4-QAM. The modulated signal output can be expressed by (6)

$$x(t) = \frac{A}{\sqrt{2}}I(t)cos(w_c t) - Q\left\{t - \frac{T_S}{2}\right\}sin(w_c t), \quad (6)$$

where w_c is the angular frequency of the carrier, and I(t) and Q(t) are the transmitted I and Q channels and T_S the delay of 90^o between channels.

Figure 7 depicts the acquired ECG signal prior to QPSK modulation under test; Figure 8 shows the signal received under QPSK demodulation. The low noise amplifier (LNA) used was operated in its linear region, and the developed Algorithm 1 guarantees to operate below the P1dB. The developed system allows variable levels of n-QAM to be used for high data rate signals.

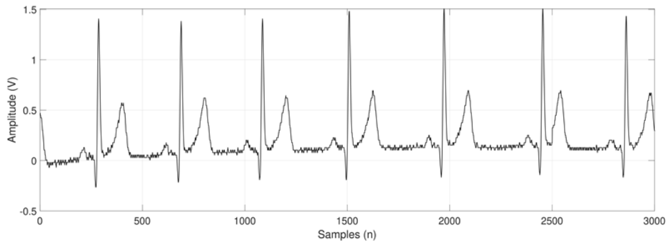

Figure 7: ECG signal transmitted in the transceiver platform.

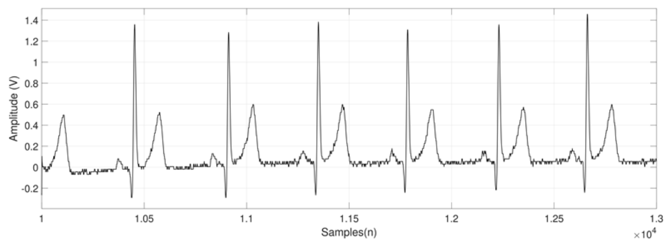

Figure 8: Received ECG signal after QPSK demodulation.

Figure 9 shows the results of the EVM validation as a figure of merit compared with the frames of OFDM symbols. In this case, an EVM_{RMS} of 8.3 was obtained on average in the fifteen frames transmitted through QPSK. Figure 10 shows the ratio of input power against output power normalized. It should be noted that the LNA is used in its linear region for purposes of transmission applications in Telemedicine with the best power efficiency; in this case, at the central point of the BW there is a power of -32.52 dBm, see Figure 11, as can be seen in Figure 12 the output power of -16.37 dBm give a 16.15 dB gain during the LNA operation. One of the challenges to be addressed in Telemedicine applications is to guarantee that biomedical signals operate in power regions below P1dB in order to reduce the intrinsic non-linearities. The ZX60-123LN-S+ LNA operates close to the P1dB of 16.5 dBm, which guarantees high linearity without sacrificing power during the RF transmission. The combination of low noise and high IP3 of 28 dBm makes the DUT ideal for low noise in the receiver stage. In the spectrum of Figure 11 and 12, power peaks are observed that represent the transmission of ECG signal blocks in the assigned BW, in this implementation fifteen OFDM symbols frames were sent.

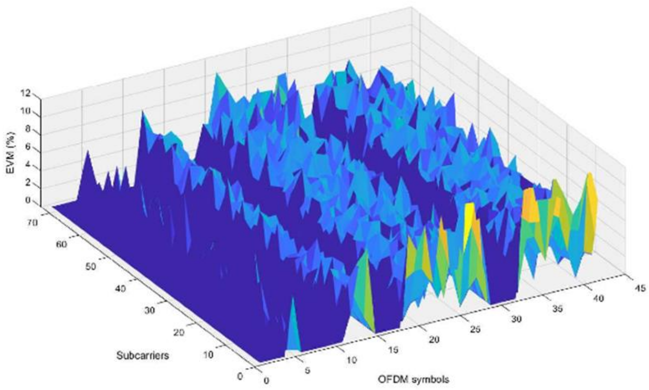

Figure 9: OFDM symbols and EVM spectral validation.

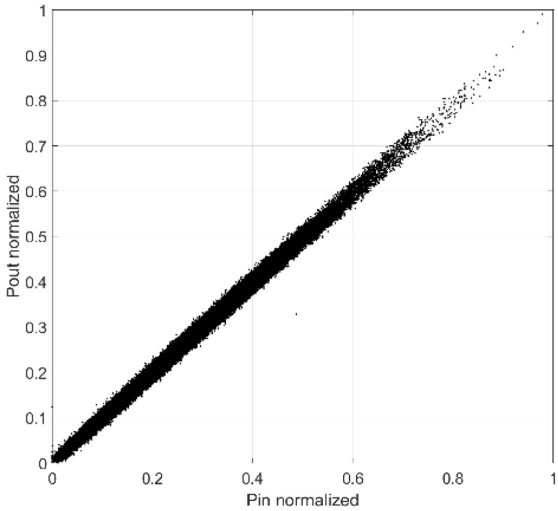

Figure 10: AM-AM Conversion curve of the RF-PA under n-QAM stimulus.

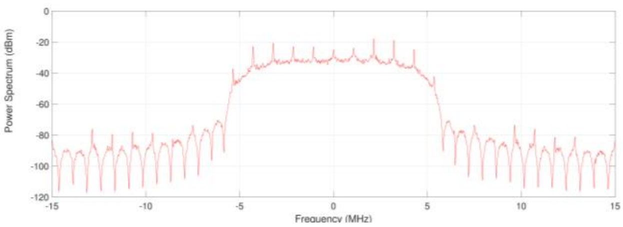

Figure 11: QPSK transmitted ECG signal with BW=12 MHz.

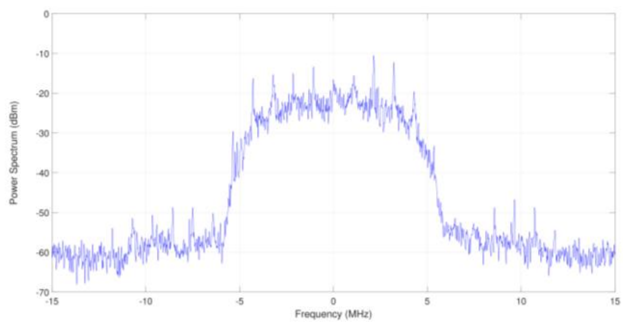

Figure 12: QPSK demodulated ECG signal with BW=12 MHz.

4. Discussion and perspective of telemedicine in ECG applications

In this work, a contribution to Telemedicine is proposed, the main stages comprise a signal acquisition stage using an Olimex module and electrodes with an Ag/AgCl type sensor. Additionally, an algorithm used for biomedical signal segmentation and data storage is developed in C language. The digitalized ECG signal is modulated under a variable n-QAM scheme, and through an ARRadio-Sockit transceiver, the LNA ZX60-123LN-S+ used as device under test (DUT) is characterized and operates in its linear region. One of the challenges in Telemedicine transmissions is to guarantee the fidelity of a signal in the receiver for subsequent signal classification and diagnosis processes, mainly; in this sense, an EVM_{RMS} is obtained that averages between fifteen packets sent, an average of 8.36. The testbed uses a high-power directional coupler to eliminate signal feedback. The developed algorithm allows heart peak detection, calculation of sample-based heart rate, and adequate accuracy of the extracted waveforms. The DUT is operated below the P1dB to induce high intrinsic non-linearities to ensure adequate gain and low noise in the receiver stage. The developed system is multivariable at the command of n-QAM; further work is the data classification for the diagnosis of pathologies derived from heart problems.

Acknowledgment

Los autores deseamos expresar nuestro agradecimiento al TECNM, en especial al programa de investigación: Científica, Tecnológica o Educativa bajo la modalidad: A1. Proyecto de Investigación Científica: “Aplicaciones de Radio Frecuencia bajo el estándar LTE”. Con Autorización, No. SS-1-135/2023.

References

Abi-Saleh, B., and Omar, B. (2010). Einthoven's triangle transparency: a practical method to explain limb lead configuration following single lead misplacements. *Reviews in cardiovascular medicine*, 11(1): 33-38.

Aboalseoud, A. et al. (2019). Wireless ECG Monitoring System for Telemedicine Application. *Ninth International Conference on Intelligent Computing and Information Systems (ICICIS)*, Cairo, Egypt, 2019: 300-305.

Affanni, A. (2020). Wireless sensors system for stress detection by means of ECG and EDA acquisition. *Sensors*, 20(7): 2026.

Algarni, A. D., Soliman, N. F., Abdallah, A. H., and Abd El-Samie, F. E. (2021). Encryption of ECG signals for telemedicine applications. *Multimedia Tools and Applications*, 80: 10679-10703.

Bhalerao, S., Ansari, I. A., Kumar, A., and Jain, D. K. (2019). A reversible and multipurpose ECG data hiding technique for telemedicine applications. *Pattern Recognition Letters*, 125: 463-473.

Breen, C. J., Kelly, G. P., and Kernohan, W. G. (2022). ECG interpretation skill acquisition: A review of learning, teaching and assessment. *Journal of electrocardiology*, 73: 125-128.

Chen, J., Sun, S., Bao, N., Zhu, Z., and Zhang, L. B. (2021). Improved Reconstruction for CS-Based ECG Acquisition in Internet of Medical Things. *IEEE Sensors Journal*, 21(22): 25222-25233.

Faruk, N., Abdulkarim, A., Emmanuel, I., Folawiyo, Y. Y., Adewole, K. S., Mojeed, H. A., and Katibi, I. A. (2021). A comprehensive survey on low-cost ECG acquisition systems: Advances on design specifications, challenges and future direction. *Biocybernetics and Biomedical Engineering*, 41(2): 474-502.

Kligfield, P. (2002). The centennial of the Einthoven electrocardiogram. *Journal of electrocardiology*, 35: 123-129.

Scott Kruse, C., Karem, P., Shifflett, K., Vegi, L., Ravi, K., and Brooks, M. (2018). Evaluating barriers to adopting telemedicine worldwide: a systematic review. *Journal of telemedicine and telecare*, 24(1): 4-12.

Marisa, T., Niederhauser, T., Haeberlin, A., Wildhaber, R. A., Vogel, R., Goette, J., and Jacomet, M. (2017). Pseudo asynchronous level crossing ADC for ECG signal acquisition. *IEEE transactions on biomedical circuits and systems*, 11(2): 267-278.

Mendis, S., Thygesen, K., Kuulasmaa, K., Giampaoli, S., Mähönen, M., Ngu Blackett, K., and Writing group on behalf of the participating experts of the WHO consultation for revision of WHO definition of myocardial infarction. (2011). World Health Organization definition of myocardial infarction: 2008–09 revision. *International journal of epidemiology*, 40(1): 139-146.

Pineda-López, F., Martínez-Fernández, A., Rojo-Álvarez, J. L., García-Alberola, A., and Blanco-Velasco, M. (2018). A flexible 12-Lead/Holter device with compression capabilities for low-bandwidth mobile-ECG telemedicine applications. *Sensors*, 18(11): 1-22.

Qaisar, S. M., and Subasi, A. (2018). An Adaptive Rate ECG Acquisition and Analysis for Efficient Diagnosis of the Cardiovascular Diseases. *IEEE 3rd International Conference on Signal and Image Processing (ICSIP)*, 21(22): 177-181, Shenzhen, China.

Rouphael, T. (2009). Common digital modulation methods. In *RF and Digital Signal Processing for Software-Defined Radio*, volume 11, chapter 3, pp. 25-85.

Tsai, T. H., and Kuo, W. T. (2018). An efficient ECG lossless compression system for embedded platforms with telemedicine applications. *IEEE Access*, 6: 42207-42215.