A MODIFIED COSTAS LOOP FOR FREQUENCY TRACKING IN HF COMMUNICATION SYSTEM

THAY ĐỔI CẢI TIẾN VÒNG KHÓA PHA COSTAS ỨNG DỤNG CHO KHÂU DÒ TẦN SỐ TRONG HỆ THỐNG THÔNG TIN HF

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Abstract - The Costas loop is a special type of Phase locked loop widely used in wireless communication systems. HF band always plays an important role in wireless communication systems with several applications in many areas. In this paper, the modified Costas loop for frequency tracking in HF communication system is proposed. The improved performance in phase and frequency tracking is very important for Automatic Link Establishment (ALE) mechanism in HF communication system in order to ensure the quality of wireless channels. The simulation results using Matlab for Frequency estimation of HF signals with the proposed architecture will be shown and analyzed to verify its performance.

Key words - Phase Locked Loop (PLL); Costas Loop; High Frequency (HF); Automatic Link Establishment (ALE); Double Side Band Suppressed Carrier (DSBSC); Single Side Band Suppressed Carrier (SSBSC).

Tóm tắt - Vòng khóa pha Costas là một loại vòng khóa pha đặc biệt được sử dụng rất rộng rãi trong các hệ thống thông tin vô tuyến. Trong bài báo này, các tác giả đề xuất chỉnh sửa vòng khóa pha Costas nhằm ứng dụng cho khâu dò tìm tần số trong các hệ thống thông tin HF. Việc cải thiện hiệu năng làm việc của khâu dò tìm tần số là rất quan trọng đối với cơ chế tự động thiết lập kênh truyền trong các hệ thống thông tin HF nhằm cải thiện chất lượng và hiệu quả của đường truyền. Các kết quả mô phỏng đối với việc dò tìm tần số sử dụng vòng khóa pha Costas đã chỉnh sửa sẽ được trình bày phân tích và đánh giá bằng công cụ mô phỏng Matlab nhằm chứng minh hiệu quả của vấn đề mà bài báo đã đề xuất.

Từ khóa - vòng khóa pha (PLL); vòng Costas; tần số cao (HF); tự động thiết lập kênh truyền (ALE); điều chế hai biên (DSBSC); điều chế đơn biên (SSBSC).

1. Introduction

HF band always plays an important role in wireless communication systems with several applications in many areas. HF band is very popular in practice with a lot of advantages such as long distance, flexibility and economy. HF communication systems usually have a simple infrastructure with a low cost and is easy to deploy.

However, HF band has some drawbacks such as strong interference and high sensitivity to change in the ionosphere. Ionosphere is a region of the Earth's atmosphere. It is ionized by sonar and cosmic radiation. The ionized plasma of the ionosphere changes the propagation property of electromagnetic waves in the HF band. The HF signal could be passed or absorbed in the ionosphere. This phenomenon happens to the specific frequency of transmitted signal and depends on the time of day, weather conditions, season and the Earth's geomagnetic field, etc. In other words, the usable frequencies will be continuously changed due to the factors mentioned above. And the key requirement of HF receiver is that it can exactly find the frequency of transmitted signal to set up a desired link.

In HF communication, in order to make a contact between two HF radio stations, the Automatic Link Establishment (ALE) [1-6] mechanism is used. This is a feature that scans the available frequencies called channels and selects one of them to establish a link. This process is carried out by microprocessor, and the frequency measurement is the most important duty. In general, the frequency is estimated by many methods such as counting or using measurement circuits. In RF communication, the second method is mostly used in which the Phase locked loop (PLL) and Delay locked loop are above all others.

Costas loop is a special PLL invented in 1950s by John P. Costas [7, 8]. It is used to recover the carrier frequency, acquire, synchronize and demodulate suppressed-carrier modulation signals such as AM [7]. The Costas loop makes good some defects of original PLL especially with the suppressed-carrier modulation signals which PLL cannot track, acquire and synchronize to the received signal. With the advantages mentioned above, Costas loop is not only used to track and demodulate double side band AM but also is very useful for other suppressed-carrier modulations such as single side band AM (SSB) or Binary Phase Shift Keying (BPSK).

The Costas Loop was firstly designed for phase detection purpose. However, it can be used to estimate the frequency of incoming signal which is considered to be the most important factor of synchronous procedure. Therefore, in this paper, a modified Costas loop operating as a frequency detector of SSB signals in HF band is proposed. The frequency of received signals will be estimated and stored in order to help the receiver determine the in use channels which is the important information for ALE mechanism as shown in Figure 1. The performance of this architecture will be assessed in many cases that depend on the modulation types of incoming signals as well as signal properties.

The paper is organized as follows. Section II presents the proposed architecture and its mathematic model. The simulation results are shown in section III. The conclusion is given in section IV.

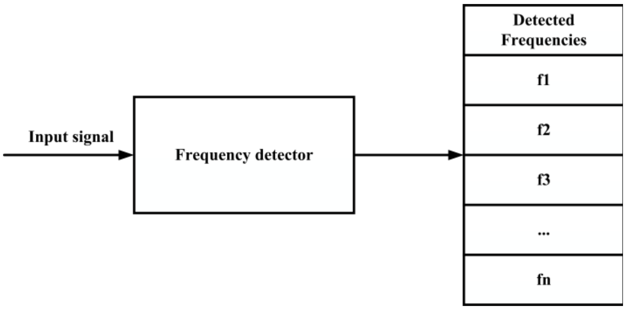

Figure 1. *Role of frequency detector in ALE*

2. Modified Architecture And Mathematic Model

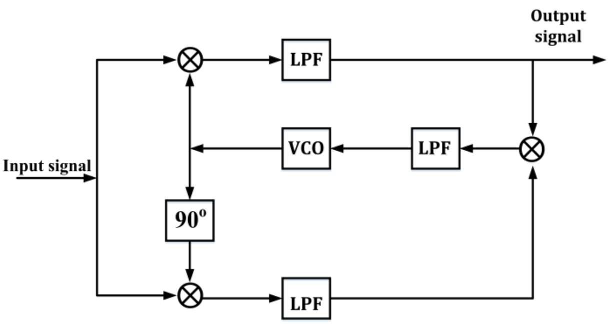

Figure 2. *Block diagram of original Costas loop*

The block diagram of original Costas loop is shown in Figure 2 [7]. It contains 3 Phase Detectors (PD) or Product Detectors, 2 Low pass Filters (LPF), Loop Filter (LF) and Voltage Controlled Oscillator (VCO). The input signal is divided into 2 branches as I channel and Q channel. Signal in I channel is multiplied by VCO's output while in Q channel, signal is multiplied by 90 degree phase shift of VCO's output. The multiplier outputs are passed through LPFs and then fed into the third PD in order to get the error signal. The error signal is filtered by the loop filter which is another LPF in general. The output of LF is used to control phase and frequency of VCO. When the VCO frequency and the incoming carrier frequency become the same, Costas loop is in locked state and the output signal can be extracted in I channel.

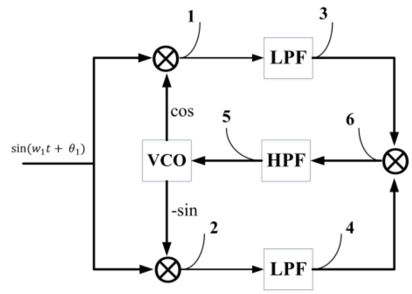

Figure 3. *Modified diagram of Costas Loop*

The modified architecture of Costas loop is plotted in Figure 3. In this model, the LPF is replaced by High Pass Filter (HPF) at LF position. By using HPF, it can be seen that the performance of Costas loop is improved. This point of view can be demonstrated by using the spectrum analysis shown in Figure 4.

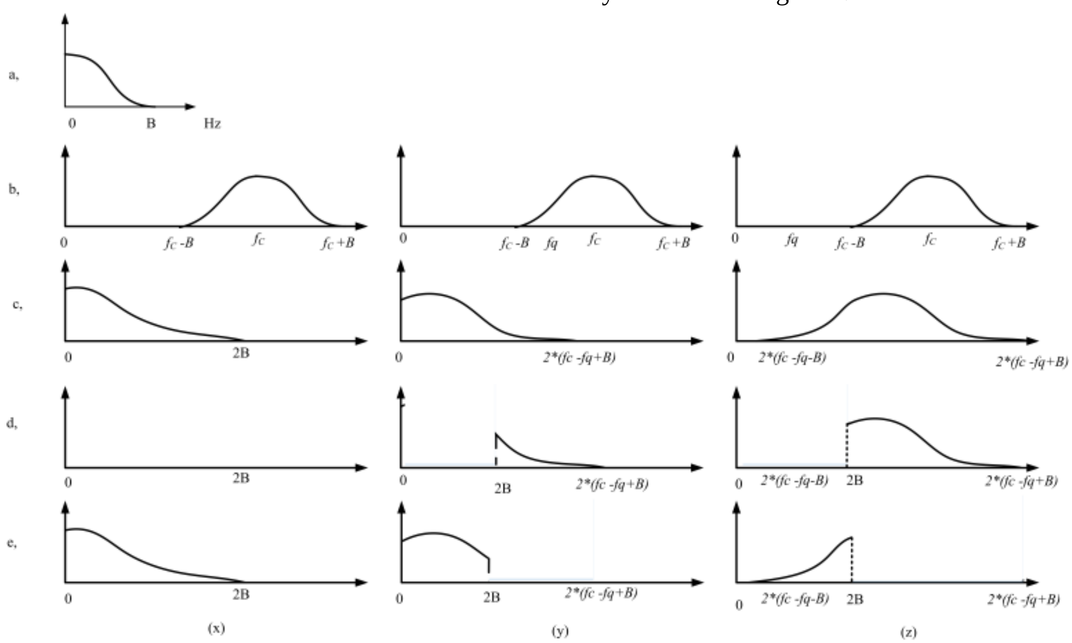

Figure 4. *LPF and HPF Spectrum analysis*

This figure illustrates spectrum of input signal which is experimented with LPF and HPF, respectively in three cases: (x) $f_c = f_q$; (y) $f_q \in [f_c - B, f_c + B]$; (z) $f_q < f_c - f_q - B$ or $f_q > f_c + f_q + B$, where f_c is input frequency, f_q is the output frequency of VCO, B is bandwidth of input signal. This figure includes five graphs:

- (a) is spectrum of baseband signal
- (b) is spectrum of band-pass signal.
- (c) is spectrum of signal which is the input of LF block.
- (d) is spectrum of signal passed through HPF
- (e) is spectrum of signal passed through LPF

According to (d) graph, it can be seen that the power of signal after passing through HPF will be approximately zero when $f_q = f_c$. Meanwhile, by using LPF, the unknown frequency f_c could not be extracted by basing on the power of output signal.

The input signal $u(t)$ has a frequency ω_1 and phase θ_1.

$$u(t) = Asin(\omega_1 t + \theta_1) \tag{1}$$

where A is the amplitude of input signal.

Assuming that the initial output signals of VCO at I and Q branches are

$$u_{0I}(t) = Acos(\omega_2 t + \theta_2) \tag{2}$$

$$u_{0Q}(t) = -Asin(\omega_2 t + \theta_2) \tag{3}$$

where ω_2, θ_2 are initial frequency and phase which is set to 0 in general.

Using trigonometry operations, the outputs of PD1 and PD2 are

$$u_{PD1}(t) = \frac{1}{2}[\sin((\omega_1 + \omega_2)t + \theta_1 + \theta_2) + \sin((\omega_1 - \omega_2)t + \theta_1 - \theta_2)] \tag{4}$$

$$u_{PD2}(t) = \frac{1}{2}[cos((\omega_1 + \omega_2)t + \theta_1 + \theta_2) - cos((\omega_1 - \omega_2)t + \theta_1 - \theta_2)] \tag{5}$$

After passing LPF1 and LPF2, the received signals are

$$u_{LPF1}(t) = \frac{1}{2}\sin((\omega_1 - \omega_2)t + \theta_1 - \theta_2) \tag{6}$$

$$u_{LPF2}(t) =. -\frac{1}{2}\cos((\omega_1 - \omega_2)t + \theta_1 - \theta_2) \tag{7}$$

The outputs signal of these filters will be fed into the PD3 to obtain u_{PD3}

$$u_{PD3}(t) = -\frac{1}{8}\left[\sin\left(2(\omega_1 - \omega_2) + 2(\theta_1 - \theta_2)\right)\right] \tag{8}$$

u_{PD3} is then passed through the High Pass Filter (HPF) to produce the control signal of VCO - u_{con}. By using HPF, there are two possible cases:

$$(\omega_1 - \omega_2) < 4\pi f_c \text{ then } u_{con} = 0 \tag{9}$$

$$(\omega_1 - \omega_2) > 4\pi f_c \text{ then } u_{con} = u_{PD3} \tag{10}$$

Based on Eq.9 and Eq.10, if $u_{con} = 0$ then the output frequency – f_2 of VCO is approximate unknown frequency – f_1. In other words, f_1 belongs to $[f_2 - f_{bnf}/2 \div f2 + f_{bnf}/2]$, where f_{bnf} is the cutoff frequency of HPF.

In case of suppressed – carrier modulation signals with bandwidth $= f_{max} - f_{min}$, the output of HPF includes sine waves which have frequencies in the range from $2(f_2 - f_{min})$ *to* $2(f_2 + f_{max})$. In this case, the bandwidth of control signal is $2B$. However, if f_2 is equal to $f_{mean} = \frac{f_{max} - f_{min}}{2}$, the bandwidth of control signal is only B. For this reason, the cutoff frequency of HPF should be chosen as $f_{cutoff} = B + 2bnf$ in order to get the minimum power of HPF's output signal when $f_2 \in [(f_{mean} - bnf) \div (f_{mean} + bnf)]$. Then value of unknown frequency is $f_c = f_2$ in case of DSB and $f_c = f_2 + B/2$ in case of SSB.

According to the above analysis, the operation of modified Costas Loop can be summarized as a diagram shown in Figure 5 and the procedure of frequency detector is plotted in Figure 6.

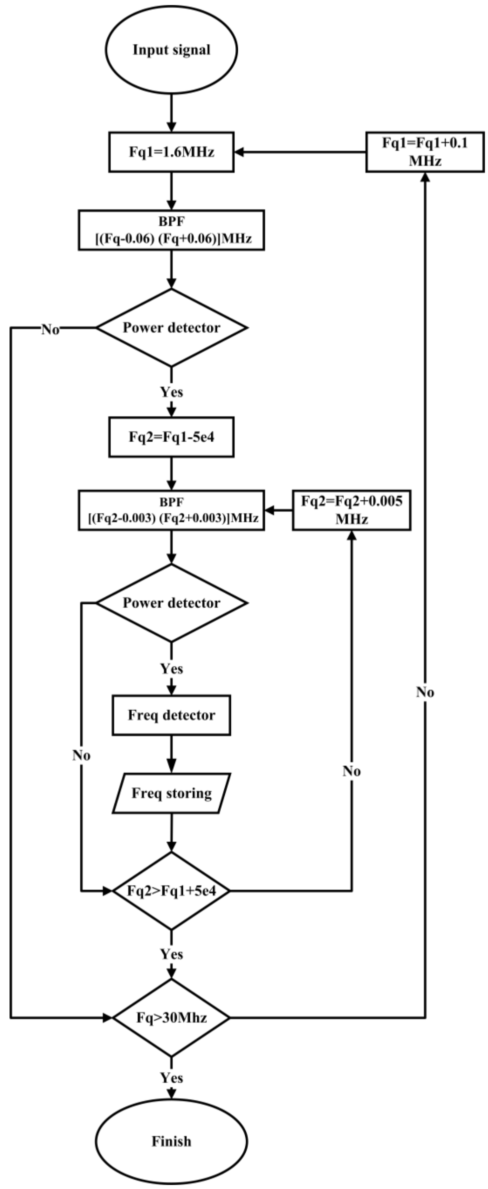

Figure 5. *Operation diagram of modified Costas Loop*

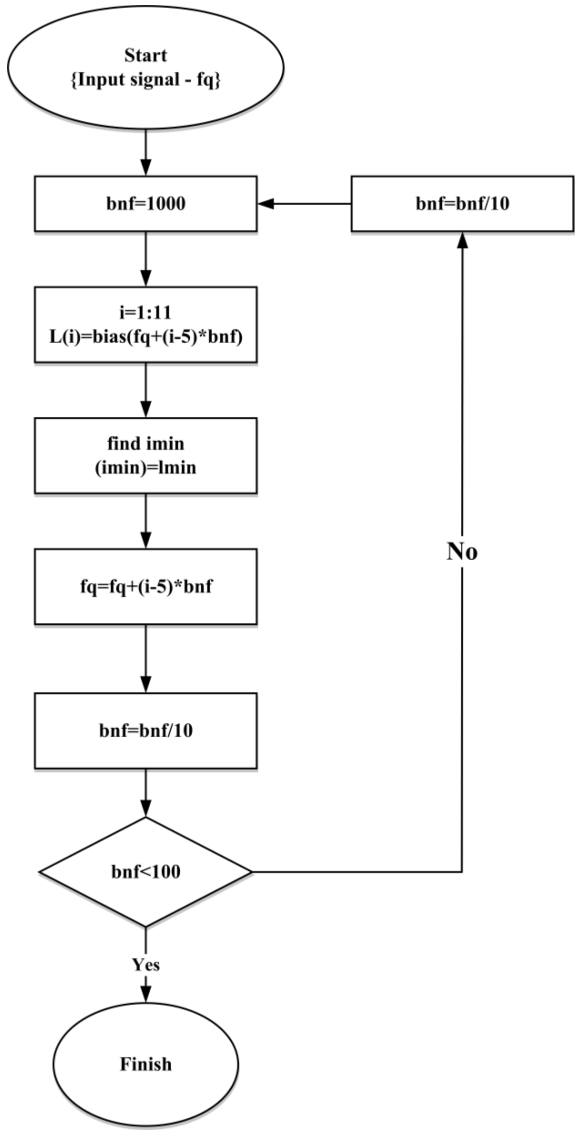

Figure 6. *Algorithm diagram of Phase Detector block*

3. Simulation results and discussion

The proposed architecture of Costas Loop is simulated using Matlab to examine its performance. In this paper, both of modified and original architecture will be executed in three cases of received signal: no – modulation, DSBSC and SSBSC. All simulations are in the AWGN channel.

In the first case, it is assumed that there are 29 in use channels in HF band and the signals are sin wave without modulation with the parameters as follows.

- Range of frequency: 1.6 MHz ÷ 30MHz
- Frequency detection step: 100 KHz.
- Sampling frequency: 90MHz
- SNR = 3dB
- Frequency bias: 100Hz.

The simulation results plotted in Figure 7 and Figure 8 show the ability to detect the in – used channels of modified and original architecture, respectively.

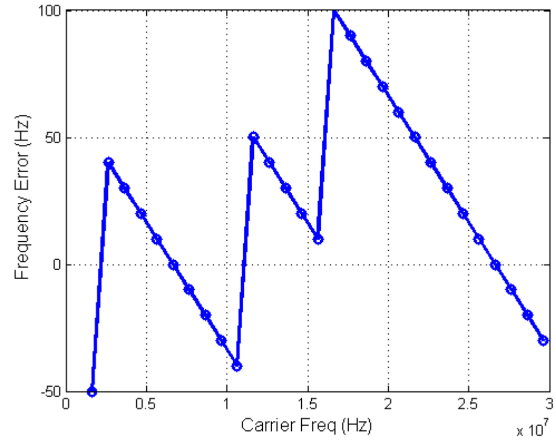

Figure 7. *Frequency detection accuracy of original architecture with no-modulation signal*

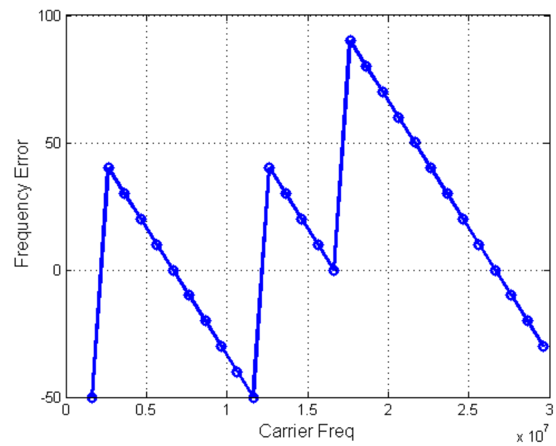

Figure 8. *Frequency detection accuracy of modified architecture with no-modulation signal*

It can be seen that in this case both architectures have worked well on all HF bands with the deviations of detected frequencies less than 100Hz. Their accuracy is similar. So in order to see the advantages of modified architecture, the other simulation will be executed with modulation signals.

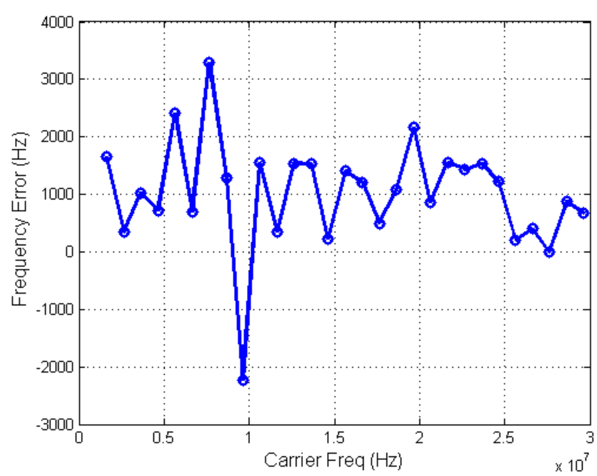

Figure 9. *Frequency detection accuracy of original architecture with DSBSC signal*

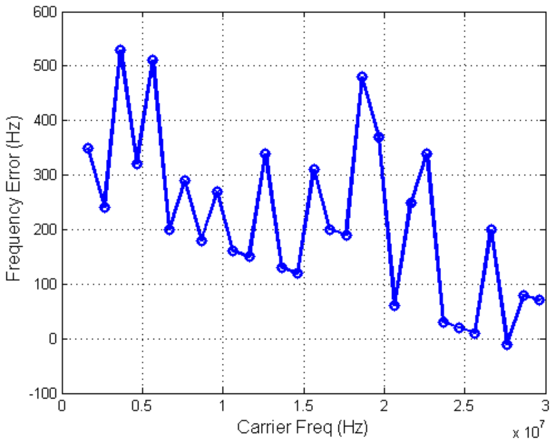

Figure 10. *Frequency detection accuracy of modified architecture with DSBSC signal*

In the second case, the HF signal is modulated using double side band AM technique. This signal also has the same parameters as in the first case. The simulation results using original and modified architectures are shown in Figure 9 and Figure 10.

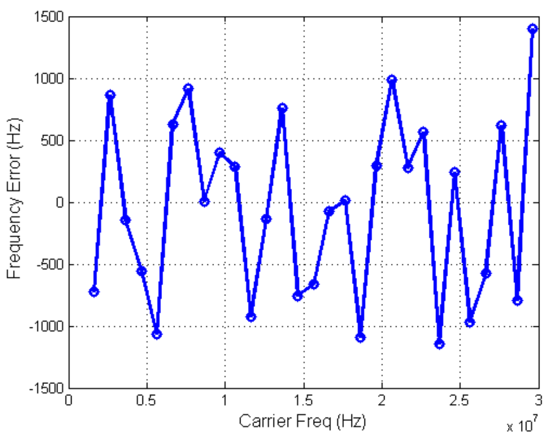

Figure 11. *Frequency detection accuracy of original architecture with SSBSC signal*

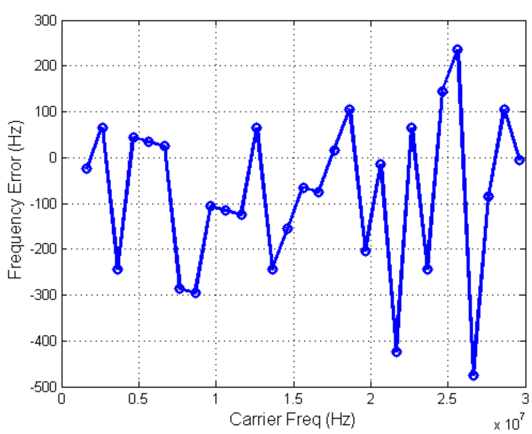

Figure 12. *Frequency detection accuracy of modified architecture with SSBSC signal*

Figure 11 and Figure12 present the simulation results in case the received signal is the SSBSC signal.

Obviously, the error of frequency estimation in the second and the third cases significantly increases in comparison with no – modulation case. This fact is due to the influence of information signal on carrier wave in the modulation procedure. According to the simulation results in two last cases, it is easy to see that both original and modified architectures work well on all HF bands. However, with the modified architecture, the signal frequencies are estimated more accurately.

4. Conclusions

In this paper, a modified Costas loop used for frequency tracking in HF communication is proposed. With the small change in architecture, the modified Costas Loop can detect and estimate all the in use frequency channels in HF band more accurately in comparison with original Costas Loop. This fact is very good for wireless system in general as well as for ALE mechanism of HF communication in particular and the proposed architecture can be implemented for all real time digital radio systems.

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