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A New AM Demodulation Scheme with a Blind Carrier Recovery Method

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***Abstract*—In this paper, the proposed large carrier AM demodulation scheme implemented based on the proposed sinusoidal automatic gain control scheme (SAGC) is presented. A Multiplier, a LPF and 2 sets of SAGC are combined to accomplish the new AM demodulation scheme. The prominent benefit of the proposed AM demodulation scheme is having the blind carrier recovery method. For any ranges of the carrier frequencies and wide range of the modulation indexes, the proposed AM demodulation scheme has the ability to recover the baseband signal. With a very simple mathematical analysis, the proposed SAGC provides unity magnitude and 90-shifted phase output for all input's frequency components. By using the computer simulation, the proposed SAGC and AM demodulation schemes provide the convenience, advantages and acceptable results compared to their traditional techniques.**

***Index Terms*—AM demodulation, carrier recovery, Hilbert transform, sinusoidal automatic gain control**

I. Introduction

When free space is the communication channel, antennae, operating effectively only when their dimensions are of the order of magnitude of the signal wavelength, radiate and receive the signal. Therefore, the required-antenna length may be reduced to the practicability point by shifting the audio tone to a high frequency. Amplitude modulation method [1] has been used as tools for this objective. However, the problem may occur in signal recovery process when the local frequency generated differs in phase or frequency from the transmitting site. The recovered baseband signal strength will, thus, be proportional to these phase differences [1-2], unless it is possible to maintain the phase difference to be zero. If the frequency difference occurs, the quality of the information signal recovered will also be decreased. Since the carrier synchronization [3-4] has been an important problem for the communication systems, envelope detection is an alternative recovery method which does not need the carrier to obtain the information signal. But envelope detection still requires some conditions such as the transmitting massage must not be a negative value and the time constant (RC) must be in between the period of the carrier wave and the shortest period of a baseband signal $(1/f_c << RC << 1/f_m)$. In addition, the Costas loop [1] is one of the powerful demodulation techniques because of its ability to demodulate AM, FM and PSK signals without the need for mode switching. Still its carrier recovery method relies on the knowledge of the modulated frequency and a false the lock phenomenon [6-7] relies on accumulated delay in the long loop. According to these conditions, the large carrier AM demodulation scheme with a non-data aided carrier recovery method is proposed. It is based on a new sinusoidal automatic gain control scheme (SAGC) which is also proposed in this paper.

The organization of this paper is as follows. Principle of the Hilbert transform and a new sinusoidal automatic gain control scheme are mentioned in section II. In section III, new AM demodulation scheme using a new SAGC will be discussed in great detail. Section IV illustrates the results of Matlab computer simulation. Finally, conclusions are given in section V.

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II. Principles

A. Hilbert Transform

The Hilbert transform is the convolution of an input signal $(x(t))$ with the signal $-1/\pi t$, which is the impulse response of the Hilbert system. The Hilbert transform of $x(t)$ by $\mathrm{H}[x(t)]$ is defined as

$$\hat{x}(t) = x(t) * \frac{-1}{\pi t} \quad (1)$$

when $\hat{x}(t)$ is the Hilbert transform of $x(t)$. Let us consider the Fourier transform of the Hilbert impulse response, which is

$$H(j\omega) = F\left\{\frac{-1}{\pi t}\right\} = j\,\mathrm{sgn}(\omega) \quad (2)$$

where the function $j\,\mathrm{sgn}(\omega)$ can be defined as

$$H(j\omega) = j\,\mathrm{sgn}(\omega) = \begin{cases} 1; & \omega > 0 \\ 0; & \omega = 0 \\ -1; & \omega < 0 \end{cases} \quad (3)$$

Similarly, the Hilbert system can be expressed in terms of magnitude and phase as follows.

$$|H(j\omega)| = 1 \quad (4)$$

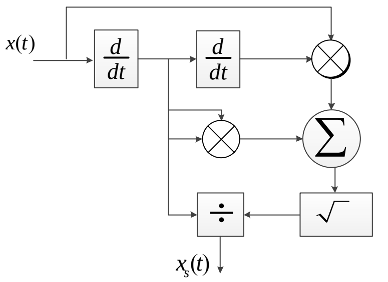

Fig. 1. The proposed SAGC block diagram based on the Hilbert transform

$$\angle H(j\omega)=\begin{cases}\frac{\pi}{2}; & \omega>0\\ -\frac{\pi}{2}; & \omega<0\end{cases} \quad (5)$$

Eq.(4) and (5) indicate that the system of the Hilbert transform has no impact on the input's magnitude but phase of the input is shifted by $\pi/2$ radians for all frequency components. For example, $x(t)=A\cos(\omega t)$ is the input signal then the output of the Hilbert transform is $\hat{x}(t)=-A\sin(\omega t)$.

B. The Proposed SAGC Scheme

From Fig. 1, let $x(t)$ be the sinusoidal input, which is

$$x(t) = A\sin(\omega_0 t) \quad (6)$$

where A and ω_0 are amplitude and angle frequency of the input signal. By taking first and second derivative to $x(t)$, it respectively yields

$$x'(t)=\frac{dx(t)}{dt}=A\omega_0\cos(\omega_0 t) \quad (7)$$

$$x''(t)=\frac{d^2x(t)}{dt^2}=-A\omega_0^2\sin(\omega_0 t) \quad (8)$$

Squaring both sides of (7)

$$\left(x'(t)\right)^2=\left(A\omega_0\right)^2\cos^2(\omega_0 t) \quad (9)$$

By multiplying both sides of (8) by $x(t)$, it yields

$$x(t)x''(t)=-\left(A\omega_0\right)^2\sin^2(\omega_0 t) \quad (10)$$

Subtraction (10) from (9) yields

$$\left(x'(t)\right)^2-x(t)x''(t)=\left(A\omega_0\right)^2 \quad (11)$$

Then taking square root of (11) results in

$$\sqrt{\left(x'(t)\right)^2-x(t)x''(t)}=\sqrt{\left(A\omega_0\right)^2}=\left|A\omega_0\right| \quad (12)$$

After dividing (7) by (12), it yields

$$x_s(t)=\frac{x'(t)}{\omega_0 A} \quad (13)$$

Then substituting (7) for (13), the system's output finally is

$$x_s(t)=\cos(\omega_0 t)=\sin(\omega_0 t+\frac{\pi}{2}) \quad (14)$$

By taking Laplace transform to both sides of (13), then the AGC's transfer function can be expressed

$$H(s)=\frac{X_s(s)}{X(s)}=\left(\frac{1}{\omega_0 A}\right)\cdot s=jA^{-1} \quad (15)$$

Hence from Eq.(15), the transfer function of the proposed system can be expressed in terms of magnitude and phase as followings.

$$\left|H(j\omega)\right|=A^{-1} \quad (16)$$

$$\angle H(j\omega)=\begin{cases}\frac{\pi}{2}; & \omega>0\\ -\frac{\pi}{2}; & \omega<0\end{cases} \quad (17)$$

In comparison with the single sinusoidal input signal as given in (6), the unity magnitude and 90-degree-shifted phase characteristics corresponding to the magnitude and phase responses of the system are applied to obtain the output as given by (14).

III. LARGE CARRIER AM DEMODULATION SCHEME

From Fig. 2, let $m(t)$ be the information signal and the input $x(t)$ applied into the proposed sinusoidal AGC is the amplitude-modulated signal by multiplying the input $m(t)$ with the carrier $\cos(\omega_c t+\theta)$. Thus,

$$x(t)=m(t)\cos(\omega_c t+\theta) \quad (18)$$

The output signal obtained by applying $x(t)$ to the first new sinusoidal AGC is

$$x_{s1}(t)=-\sin(\omega_c t+\theta) \quad (19)$$

By feeding (19) into the second AGC, then its output can be expressed as

$$x_{s2}(t)=-\cos(\omega_c t+\theta) \quad (20)$$

The multiplication between (18) and (20) yields

$$x_m(t)=-\frac{m(t)}{2}\cos(2\omega_c t+2\theta)-\frac{m(t)}{2} \quad (21)$$

As can be seen in (21), the low frequency component obtaining by using a low pass filter can be expressed as

$$y(t)=-\frac{m(t)}{2} \quad (22)$$

IV. SIMULATION RESULTS

In this section, two parts of SAGC scheme simulation results are illustrated. The first part presents the essential characteristics of SAGC scheme such as amplitude and phase characteristics. The second group is to describe the proposed large carrier AM demodulation behaviors.

A. SAGC Characteristic Results

From Fig. 3(a), this result is obtained by applying 10 kHz sinusoidal input signal with peak amplitude of 10 mV. In this case, the proposed SAGC performs as amplifier with 20 dB gain in order to provide the unit output amplitude depicted by the dash line. The spectrum plots shown in Fig. 3 (b) and (c) confirm that the frequencies of input and output signals are not different.

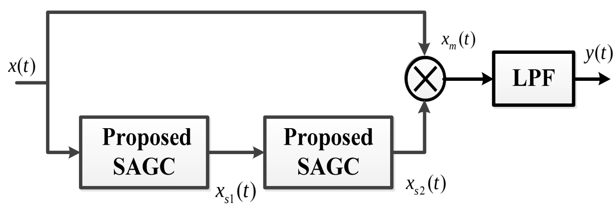

Fig. 2. Large carrier AM demodulation block diagram based SAGC scheme

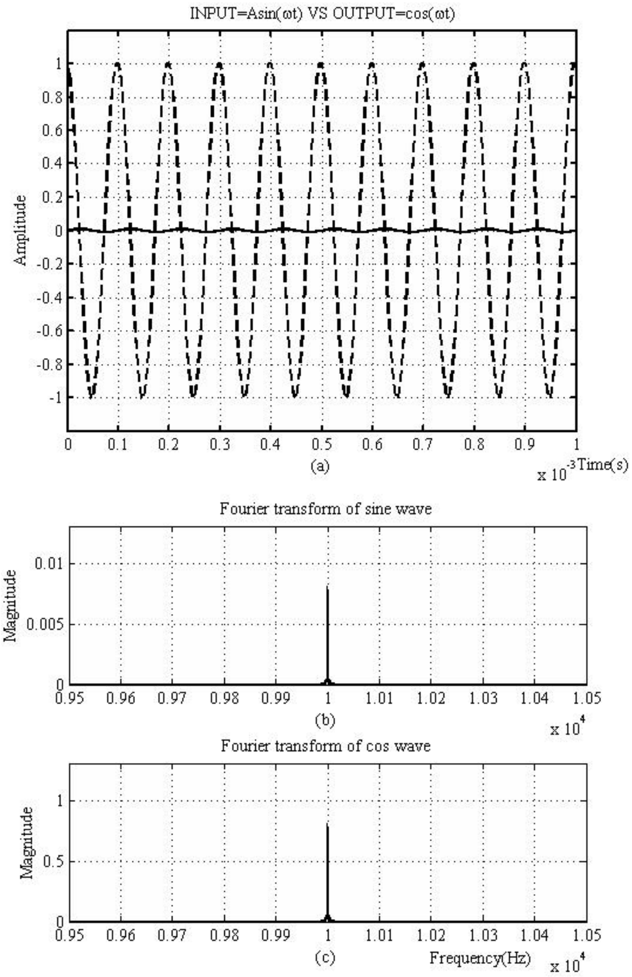

Fig. 3. The unit amplitude characteristic of the SAGC's output for a sinusoidal input (10mV and 10 kHz).

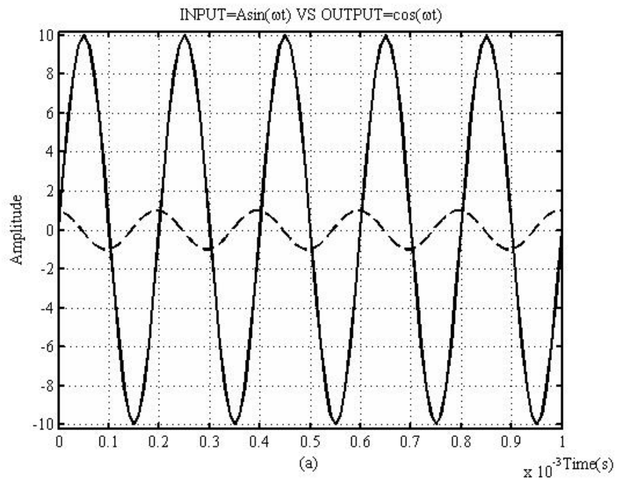

Fig. 4. The 90-shifted phase characteristic of the SAGC's output for a sinusoidal input (10 V and 5 kHz).

In order to acquire the 1-Volt output amplitude shown in the dash-line signal in Fig. 4 (a), the SAGC scheme fed with the sinusoidal input signal at 5 kHz and with peak amplitude of 10 V performs as an attenuator with attenuated gain -10 dB. Besides the unit amplitude behavior, the proposed scheme also delivers the output signal with 90-shifted phase as illustrated in the dash line.

From results in both figures, this scheme can perform as a unit amplitude stabilizer for all input's frequency components because of its characteristics. It is either an attenuator for the input greater than 1V or an amplifier with an input lower than 1V.

B. *AM Demodulation Results*

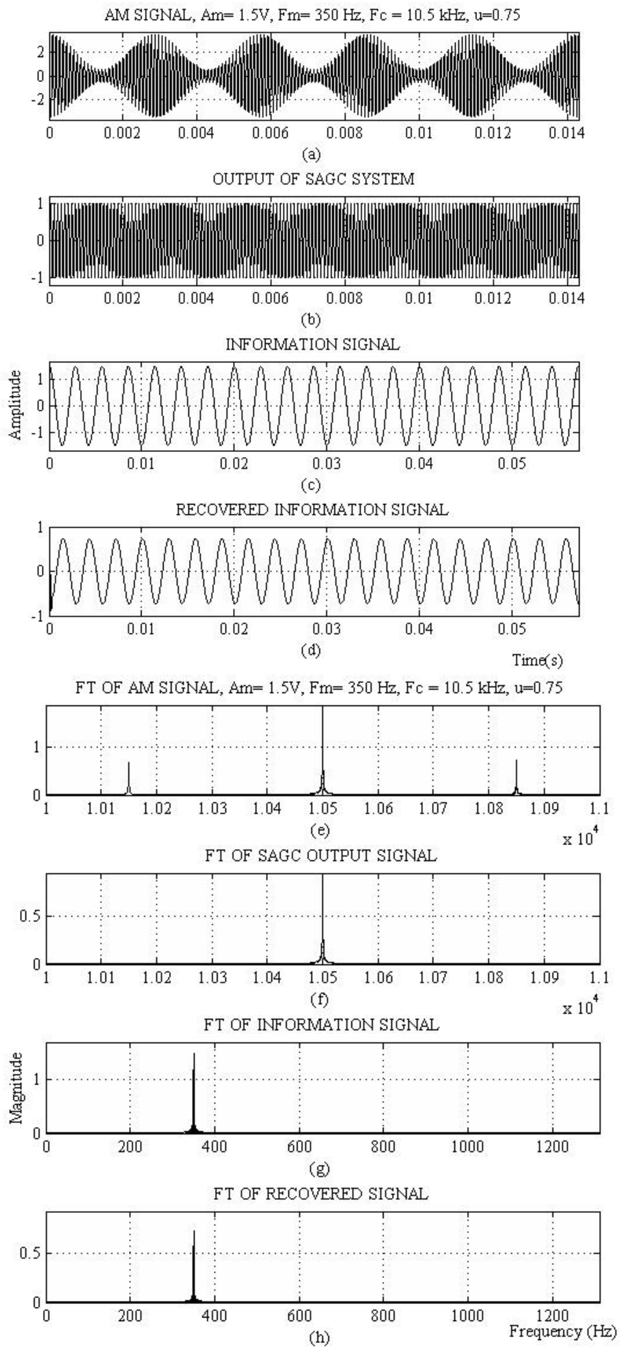

Fig. 5. The result of AM demodulation system using the proposed sinusoidal automatic gain control scheme based the Hilbert transform where (a) and (b) are the AM signal and the output of the proposed AGC scheme, respectively, (c) and (d) are the information signals at the transmitter and receiver, respectively, and (e)-(h) are the frequency component of the signals (a)-(d).

The simulation result of the proposed AM demodulation technique [Fig. 2] has been illustrated in this sub-section. In Fig. 5 (a), the AM signal has been generated from 10.5 kHz carrier and 350 Hz information signal. In Fig. 5 (b), the signal can be obtained by feeding the AM signal into the proposed SAGC scheme twice. The spectrum in (f) shows that the carrier frequency is equal to the transmitted carrier frequency in (e).The spectra shown in (g) and (h) indicate that the information signals at the receiver can be recovered. Moreover, in Fig. 6 (b), white noise (-28.62 dB) has been added into the AM demodulation system so as to estimate the signal to noise ratio output which is 23.47 dB.

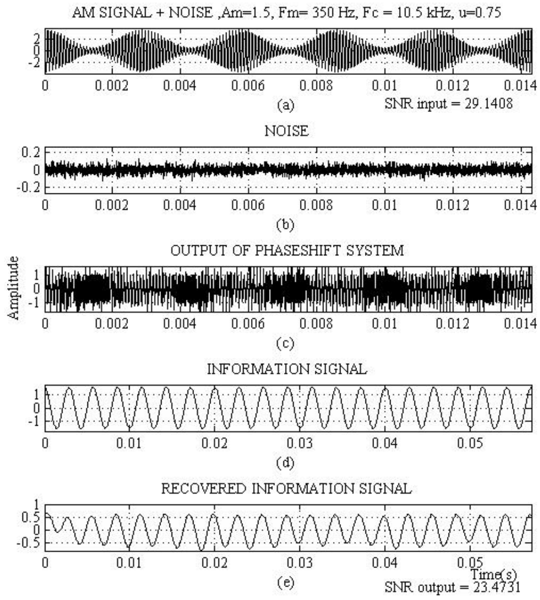

Fig. 6. The result of AM demodulation system using the proposed sinusoidal automatic gain control scheme based the Hilbert transform for white noise environment where (a), (b), and (c) are the AM signal, noise and the output of the proposed AGC scheme, respectively, (d) and (e) are the information signals at the transmitter and receiver, respectively.

In Fig.7 (a) and (c), the modulation indexes of AM signals generated by 1.05 MHz carrier frequency are 0.1 and 1 respectively. By using the proposed AM demodulation scheme, baseband signals depicted in Fig. 7 (b) and (d) are recovered from (a) and (c) respectively. By changing the carrier frequency for generating AM signals (in Fig.7 (e) and (g)) from 1.05 MHz to 10.5 MHz, the baseband signals in Fig. 7 (f) and (h) are obtained. In short, the proposed AM demodulation model has ability to recover the information signal with wide range of carrier frequencies and modulation indexes.

V. Conclusion

With a simple mathematical analysis, a new sinusoidal automatic gain control scheme is presented. Based on Hilbert transform, the proposed SAGC provides unity magnitude and 90-shifted phase output for all input's frequency components. Without the feedback structure, this proposed SAGC's properties are quite similar to the feed-forward AGC's one. Hence, this proposed scheme does not take much time to provide the unit output signal and can process more information comparing to the feedback structure. Based on the proposed SAGC, it can be applied for a large carrier AM demodulation scheme that can avoid the problem of matching recovery carrier. In addition, a priori known frequency for the VCO does not require as in the conventional AM demodulator. For wide ranges of the carrier frequencies and modulation indexes, the proposed AM demodulation has the ability to recover the baseband signal back. Because of the unit amplitude characteristic of the proposed SAGC, the local carrier frequency can be generated with unit constant amplitude for the modulation procedure. However, it should be noted that the baseband signal output of the proposed AM demodulation will be phase shifted by 180 degree compared to its original version.

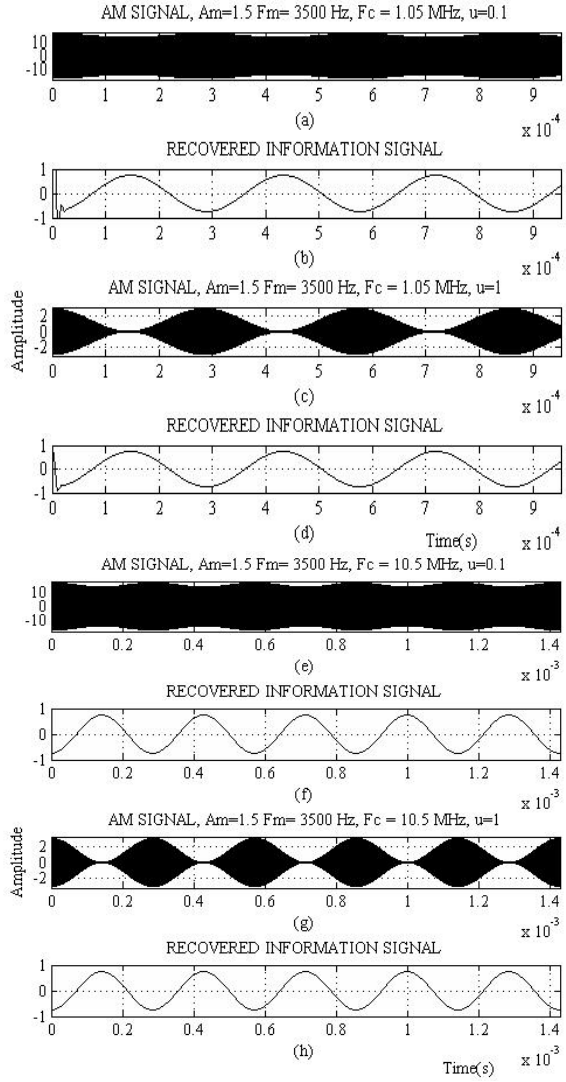

Fig. 7. The result of AM demodulation system using the proposed SAGC scheme based on the Hilbert transform in order to evaluate the effect of modulation index and carrier frequency.

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