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Discriminator and Energy Based Demodulators: Revisited

A Mukherjee, D Muchahary, B Basumatary, P Brahma, B Brahma, M Mushahary

Department of Electronics & Communication Engineering
Central Institute of Technology, BTAD, Kokrajhar, Assam

Abstract

This paper audits FM detectors using non-conventional energy based demodulators. The conventional FM demodulators using diode-detector and square-law are also presented. Simulation results give encouraging results regarding demodulation capabilities of the system. A new method of implementation of a diode detector circuit is proposed using MATLAB SIMULINK. Interesting results are obtained by comparing the single and double Teager Energy Operator. This novel concept of detecting an angle modulated signal has been verified through MATLAB simulation results.

Keywords: Discriminator, Square-law detector, Teager Energy Operator.

I. INTRODUCTION

In recent days, the most inspiring quest is to establish connectivity anywhere, anyone and at anytime. These demand for higher and higher band of frequencies for transmission and reception of frequencies. This paper focuses the implementation of better synchronization techniques for reception.

In this paper we look into the aspect of reception of an FM signal. Prior investigations [1] indicated that the frequency modulated receiver would always respond to the signal having the largest amplitude. Thus, selective circuits would be required to pick out a desired signal existing simultaneously with a number of other signals. The first item considered in this paper is that the signal carrier is tuned to the steep side of the resonance curve. It is found that in this case conversion from frequency modulation into amplitude modulation can be effected. It is required that the amplitude and phase characteristic of the circuit be linear with respect to frequency over the whole frequency interval occupied by the modulated signal. In order to derive a faithful audio signal reproduction from the complete detection process, a phase modulated signal must be transformed into frequency modulation first. Next, the case is considered in which the signal carrier is tuned to the linear-portion of the resonance curve by a single-tuned circuit. A square-law demodulator circuit is also investigated for the demodulation capability of angle-modulated signal under consideration. A novel method of square law based demodulator is proposed which shows excellent result. Finally, an energy based demodulator (Teager Energy Operator) is considered [2]-[5]. The demodulation capability of TEO is studied and considerable amount of distortion is observed. A dual TEO based demodulator is proposed which reduces this distortion.

II. SINGLE TUNED CIRCUIT

A single-tuned parallel circuit injected by a time varying current source '$I(t)$' is considered. The output voltage from the tuned circuit is given by

$$\frac{dv_0}{dt} = \frac{I}{C} - \frac{1}{RC}v_0 - \frac{1}{LC}\int \frac{dv_0}{dt} \quad \text{.................(1).}$$

The above equation is simulated using MATLAB SIMULINK, and the frequency response of the parallel-tuned circuit is obtained.

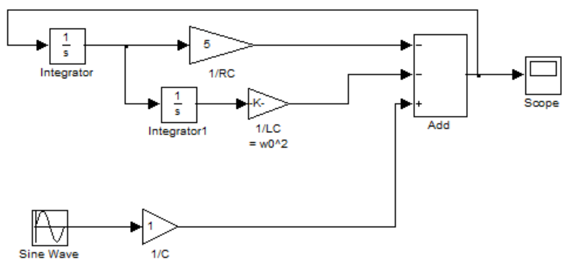

Fig. 1 Parallel tuned circuit (RLC) simulation

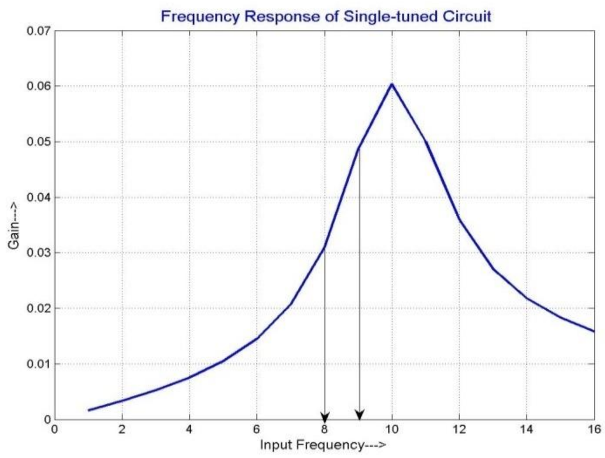

Fig. 2 Frequency response of single tuned circuit

The frequency-selective network has a transfer characteristic of slope 'α' over an adequate frequency range in the neighborhood of the carrier frequency 'f_0', such that $\alpha = \frac{d}{df}\left(\frac{A_0}{A_i}\right) \Rightarrow A_0 = \alpha f A_i + C$; where 'C' is a constant. Now at the linear portion of the curve, we get $A_0 = R_0 A_i\big|_{f=f_0}$ and thus $A_0 = R_0 A_i + \alpha A_i\left(f - f_0\right)$.

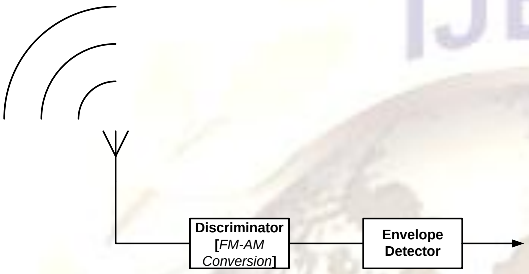

Fig. 3 Discriminator Circuit

III SIMULATION OF DIODE DETECTOR CIRCUIT

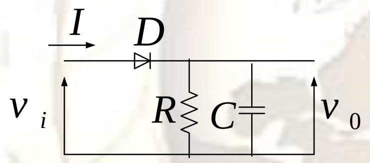

Fig. 4 Diode detector circuit

Application of nodal analysis yields,

$$\frac{dv_0}{dt} = \frac{I_S}{C}\left[e^{\alpha(V_i - V_0)} - 1\right] - \frac{1}{RC}v_0 = K_1 e^{\alpha(V_i - V_0)} - K_2 - \frac{1}{RC}v_0$$

...(2)

Equation (2) forms the basis for the simulation of a diode-detector circuit, where we have assumed $\alpha = \frac{1}{\eta V_T}$ and $V_T = \frac{kT}{q} \approx 26$ mV at room temperature, $\eta = 2$ for small current.

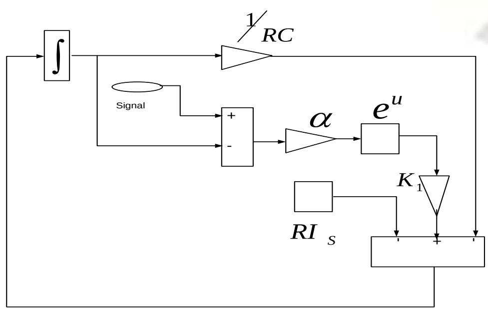

Fig. 5 Simulation of diode detector circuit

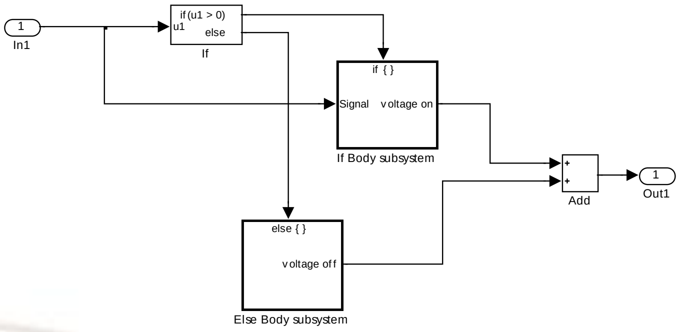

Fig. 6 Simulation of diode detector circuit using if-else subsystem

A novel method of the implementation of diode-detector circuit is proposed. When the input is greater than zero, the 'if Body Subsystem' will be enabled, and the output will be obtained from fig. (5). Hence FM to AM conversion is done using the parallel-tuned circuit shown in fig. (1). This amplitude modulated signal is demodulated by the diode-detector circuit shown in figs. (5) and (6). Excellent results are obtained for the demodulation capabilities of the system using MATLAB SIMULINK.

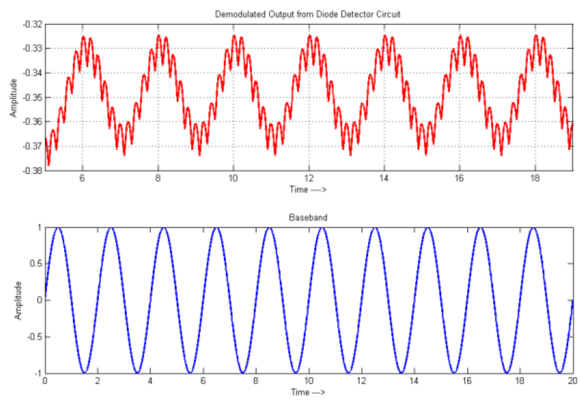

Fig. 7 Demodulated output from diode-detector circuit.

IV. SQUARE LAW DETECTOR

The received frequency-modulated signal shining on the antenna of the receiver for tone modulation is given by $v_r(t) = A_1 \cos\left(\omega_c t + k_f \sin\left(\omega_m t\right)\right)$ ……………………………………………….…...……(3),

where 'k_f' is the frequency deviation constant in rad/sec-volt. It is not difficult to show that the output of the squarer circuit (non-linear device) is

$$v_r^2(t) = K + \frac{A}{2}\left[\cos\left(2\omega_c t\right)\cos\left(2k_f \sin\left(\omega_m t\right)\right)\right] - \frac{A}{2}\left[\sin\left(2\omega_c t\right)\sin\left(2k_f \sin\left(\omega_m t\right)\right)\right]$$

…………………………………………………….(4)

where 'A' is the signal amplitude and 'K' is a d.c. term. Using Jacobi-Anger expansion [6],

$$\cos\left(z\sin(\theta)\right)=J_0(z)+2\sum_{n=1}^{\infty}J_{2n}(z)\cos(2n\theta)$$

and

$$\sin\left(z\sin(\theta)\right)=2\sum_{n=1}^{\infty}J_{2n-1}(z)\sin\left[(2n-1)\theta\right],$$

eqn.(4) can be simplified as

$$v_r^2(t)=K+\frac{A}{2}\left\{\cos(2\omega_c t)\left[J_0(2k_f)+2J_2(2k_f)\cos(2\omega_m t)+.......\right]\right\}$$
$$-\frac{A}{2}\left\{\sin(2\omega_c t)\left[2J_1(2k_f)\sin(\omega_m t)+2J_3(2k_f)\sin(3\omega_m t)........\right]\right\} \quad ..(5)$$

where '$J_n(z)$' is the nth Bessel function. After low-pass filtering eqn.(5) with a cut-off of 'ω_m' rad/sec, the final output is

$$v_r^2(t)=K+\frac{A}{2}\left\{\left[J_m(2k_f)\cos(m\omega_m-2\omega_c)t\right]\right.$$
$$\left.+\sum_{g=1}^{r}J_g(2k_f)\cos(g\omega_m-2\omega_c)t-\sum_{p=1}^{q}J_p(2k_f)\sin(p\omega_m-2\omega_c)t\right\}$$

…………………………………………………………….(6)

Now, the terms given in eqn.(5) within the bandwidth of the low-pass filter generates the distortion terms in the output of the demodulator. Hence, considering the term containing the baseband frequency, the output of the squarer circuit will be

$$v_r^2(t)\cong K-A\left[J_1(2k_f)\sin(2\omega_c t)\sin(\omega_m t)\right]$$

………………………………………………………….(7)

Further squaring eqn.(6), simplifying ad neglecting high-order frequency terms results

$$v_r^4(t)\cong K^2-2AKJ_1(2k_f)\sin(2\omega_c t)\sin(\omega_m t)$$

………………………………………………………….(8)

Multiplying eqn.(8) by $\sin(2\omega_c t)$ and further low-pass filtering, will give us the

$$output\cong 2AK_1J_1(2k_f)\sin(\omega_m t)\ldots\ldots\ldots\ldots.(9)$$

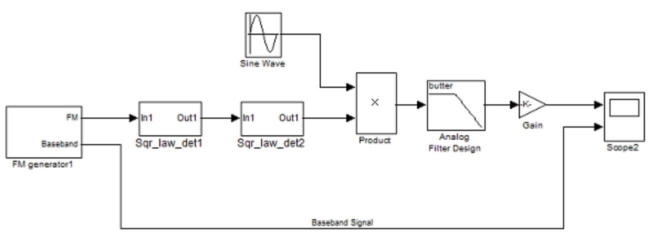

Fig.8 Square law based FM demodulator

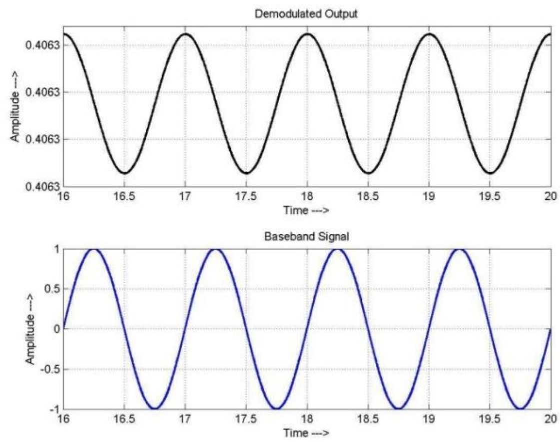

Fig.9 Output response from square law demodulator

V. TEAGER ENERGY OPERATOR (TEO)

The simple and elegant non-linear energy operator [3]-[5], developed by Teager, is of the form $\psi\left[v_r(t)\right]=\left(\frac{dv_r}{dt}\right)^2-v_r\frac{d^2v_r}{dt^2}$, where '$v_r$' is the signal input to the energy operator. Applying TEO to the angle-modulated signal in eqn. (3) one can show that [5],

$$\psi\left[A\cos(\varphi(t))\right]=A^2\dot{\varphi}^2(t)+A^2\ddot{\varphi}^2(t)\frac{\sin(2\varphi(t))}{2}$$

…………………………………………..………(10),

where $\varphi(t)=\omega_c t+k_f\sin(\omega_m t)$. Now, the second term of eqn. (10) contains the distortion term. This distortion can be removed if the TEO is operated on '$A\sin(\varphi(t))$' and the two output are added to give

$$\psi\left[A\sin(\varphi(t))\right]=A^2\dot{\varphi}^2(t)-A^2\ddot{\varphi}^2(t)\frac{\sin(2\varphi(t))}{2}$$

……………………………………………………..(11)

Hence, the output from the system is

$$\sqrt{\psi\left[A\cos(\varphi(t))+A\sin(\varphi(t))\right]}=\sqrt{2}A\dot{\varphi}$$
$$=\sqrt{2}A\left(\omega_c+k_f\omega_m\cos(\omega_m t)\right)$$

…………………………………………………….(12)

which is the required baseband signal. Subtracting eqn.(9) from eqn.(8) gives the distortion term.

Total Harmonic Distortion Results

Single TEO	Dual TEO
0.7329	0.4451

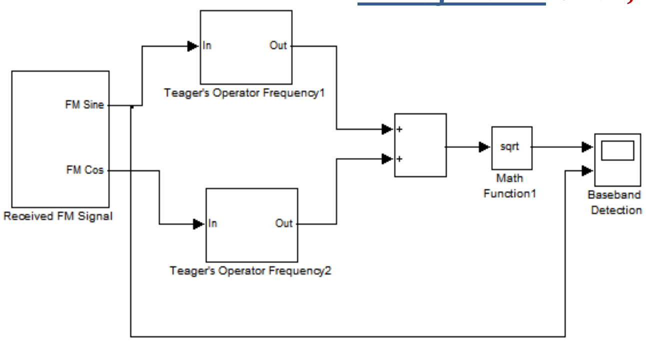

Fig.10 Dual Teager Energy Operator based demodulator

The output from the single TEO is distorted because of the second term in eqn. (10). A comparative result of THD (Total Harmonic Distortion) is calculated which shows that the dual TEO contains less distortion than a single TEO. Outputs from the two TEO are also shown in fig. (11) showing the improvement in harmonic distortion.

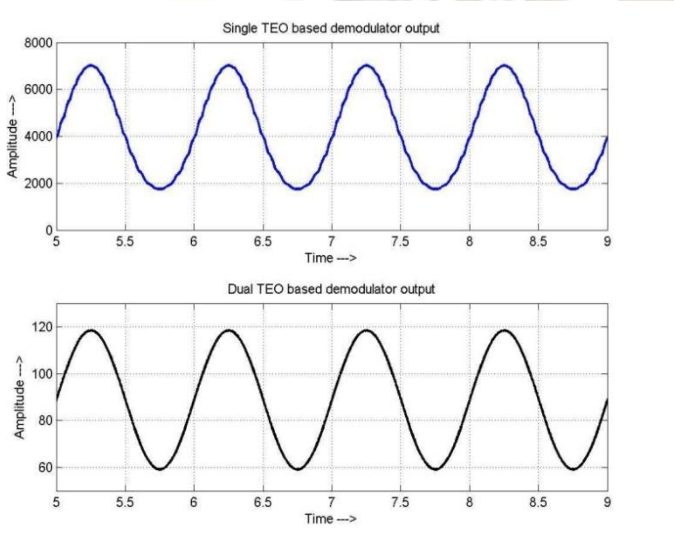

Fig.11 Comparative output response from the two energy operators

VI. CONCLUSION

In this paper, a novel method of implementing a diode-detector circuit is proposed using the using if-else subsystem in MATLAB. Excellent results are obtained for the demodulation capabilities of the system. A square-law demodulator circuit for the reception of angle modulated signals is considered. A simple and elegant non-linear energy operator (TEO) is studied and its demodulation capabilities to angle modulated signals are observed. Considerable distortion is present in the output of the single Teager Energy Operator. This distortion can be eliminated by the proposed double TEO.

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