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Five Methods to Mitigate Rayleigh Fading

Amit Kumar Dutta

Calcutta Institute of Technology, West Bengal, India

ABSTRACT

In this paper, five methods to mitigate Rayleigh fading for different modulation schemes are explained and theoretical calculation is achieved to find the capacity of WLAN under fading. We consider Rayleigh fading as well as multipath dispersion. Schematic diagram for their circuits are also given.

INTRODUCTION

Consumer market is driving the high speed data communication according to advancement in device technology. LAN has achieved a speed of 100 Mbps and wireless LAN is needed at the last stage. Hence we need a WLAN speed of 100 Mbps, but the question is whether we can achieve it theoretically in presence of fading. Also we find the possible solutions for wireless handsets. Here we give the theoretical bound over the capacity and the circuits for best SNR/BER, assuming the network protocol remained hardwired controlled.

The organization of the paper is as follows. Section I introduces the subject and Section II introduces the Rayleigh fading. Section III , section IV and Section V introduce two different methods for cancelling the effect of Rayleigh fading in Analog AM demodulation and a method for digital PAM demodulation. In Section VI and VII we discuss about the FM and FSK demodulation. We conclude the paper in the next Section.

1.0 Model of Fading

Clarke developed a model for flat fading and found that the amplitude of the received signal in in-phase and quadrature phase are Gaussian distributed with a Doppler spread [1][2].

If a vehicle is travelling with a speed v at x direction and the plane Electromagnetic Field waves are incident on the antenna placed on top of the vehicle. The Doppler shift is given by

$$f_n = \frac{v_n}{\lambda}$$

where □ is the wavelength of the radio wave.

The E field is given by,

$$E = E_0 \sum_{n=1}^{N} C_n cos(2\pi f_c t + \theta_n)$$

Where,

$$\theta_n = 2\pi f_n t + \phi_n$$

Where □$_n$ is also uniformly distributed [0, 2□]. The H fields have similar equations.

We find for E_z that

$$E_z = T_c(t)\cos(2\pi f_c t) - T_s(t)\sin(2\pi f_c t)$$

Where,

$$T_c(t) = E_0 \sum_{n=1}^{N} C_n cos(2\pi f_n t + \phi_n)$$

And

$$T_s(t) = E_0 \sum_{n=1}^{N} C_n sin(2\pi f_n t + \phi_n)$$

Similarly we can find H field. For large N, $T_c(t)$ and $T_s(t)$ are of Gaussian distribution but the magnitude is of Rayleigh. The noise in magnitude will be Rayleigh distributed.

2.0 SOLUTION TO RAYLEIGH FADING : Method 1:AM

For single ray, the Doppler frequency is dominant over the in-phase and quadrature-phase amplitudes. It will be,

$$X_r(t) = A(t)C_1 cos(2\pi f_1 t + \varphi)\cos(2\pi f_c t) + B(t)C_1 sin(2\pi f_1 t + \varphi)\sin(2\pi f_c t)$$

Here we consider the case of cell phone where A(t) or B(t) and f_1 have similar frequency.
We demodulate $X_r(t)$ using a PLL, Low pass filter and a VCO in direct down conversion and get the I / Q components as I= $A(t)C_1\cos(2\pi f_1t+\varphi)$ and Q=$B(t)C_1\sin(2\pi f_1t+\varphi)$. Now we put A(t)=B(t) and get $I^2+Q^2=A^2(t)$. We transmit A(t) (actually it is [1+ A(t)])which is positive only like in Amplitude Modulation and get square root to get A(t). Instead in Rayleigh fading it will be much worse.

For multipath Rayleigh fading

$$E_z = A(t)\sum C_n cos(2\pi f_1 t + \varphi_n)\cos(2\pi f_c t) + B(t)\sum C_n sin(2\pi f_1 t + \varphi_n))\sin(2\pi f_c t) + Ng$$

With single Doppler frequency we demodulate the signal and get the I/Q component and the noise will be Gaussian in I and Q. We track the phase and frequency component $\sum C_n cos(2\pi f_n t + \varphi_n)$ and$\sum C_n sin(2\pi f_n t + \varphi_n)$.

If we consider two paths with same Doppler frequency but with different phases and A(t)=B(t), then we get

$$E_z = A(t)\big(C_1 cos(2\pi f_1 t + \varphi_1) + C_2 cos(2\pi f_1 t + \varphi_2)\big)\cos(2\pi f_c t) + A(t)(C_1 sin(2\pi f_1 t + \varphi_1) + C_2 sin(2\pi f_1 t + \varphi_2))\sin(2\pi f_c t)$$

If we demodulate by PLL with cos (wct) and sin(wct), then in I and Q we get,

$$I = A(t)\big(C_1 cos(2\pi f_1 t + \varphi_1) + C_2 cos(2\pi f_1 t + \varphi_2)\big) + Ng1$$

$$Q = A(t)\big(C_1 sin(2\pi f_1 t + \varphi_1) + C_2 sin(2\pi f_1 t + \varphi_2)\big) + Ng1$$

Now we get I^2+Q^2which is equal to

$$A^2(t)\big({C_1}^2 + {C_2}^2 + 2C_1C_2\cos(\varphi_2 - \varphi_1)\big)$$

with Rayleigh distributed noise with nonzero mean and variance. We get the square root of the signal which is positive only to get A(t).

3.0 SOLUTION TO RAYLEIGH FADING: Method 2:AM

For single ray, the Doppler frequency is dominant over the in-phase and quadrature-phase amplitudes. It will be,

$$X_r(t) = A(t)C_1 cos(2\pi f_1 t + \varphi)\cos(2\pi f_c t) + B(t)C_1 sin(2\pi f_1 t + \varphi)\sin(2\pi f_c t)$$

We demodulate $X_r(t)$ using a PLL, Low pass filter and a VCO in direct down conversion and get the I / Q components as I= $A(t)C_1\cos(2\pi f_1t+\varphi)$ and Q=$B(t)C_1\sin(2\pi f_1t+\varphi)$. Now we put phase frequency tracker as PLL in in-phase and quadrature-phase. The low pass filter will give a zero value if we extract $\cos(2\pi f_1t+\varphi)$ and $\sin(2\pi f_1t+\varphi)$ terms correctly. The VCO input has a capacitor thus the integrating constant will maintain the correct phase and frequency. Now we first form the equation $I\cos(2\pi f_1t+\varphi_1)+Q\sin(2\pi f_1t+\varphi_1)$, assuming A(t)=B(t). We demodulate the signal A(t) for half the capacity. Instead in Rayleigh it will be much worse. Here the noise is Gaussian distributed.

For multipath Rayleigh fading

$$E_z = A(t)\sum C_n cos(2\pi f_1 t + \varphi_n)\cos(2\pi f_c t) + B(t)\sum C_n sin(2\pi f_1 t + \varphi_n))\sin(2\pi f_c t)$$

With single Doppler frequency we demodulate the signal and get the I/Q component. We track the phase and frequency component $\sum C_n cos(2\pi f_n t + \varphi_n)$ and $\sum C_n sin(2\pi f_n t + \varphi_n)$.

If we consider two paths with same Doppler frequency but with different phases and A(t)=B(t), then we get

$$E_z = A(t)\big(C_1 cos(2\pi f_1 t + \varphi_1) + C_2 cos(2\pi f_1 t + \varphi_2)\big)\cos(2\pi f_c t) + A(t)(C_1 sin(2\pi f_1 t + \varphi_1) + C_2 sin(2\pi f_1 t + \varphi_2))\sin(2\pi f_c t)$$

This can be simplified to

$$E_z = A(t)(C_1 cos(2\pi f_1 t + \varphi_1) + C_2 cos(2\pi f_1 t + \varphi_1)\cos(\varphi_2 - \varphi_1) - C_2 sin(2\pi f_1 t + \varphi_1)\sin(\varphi_2 - \varphi_1))\cos(2\pi f_c t) + A(t)(C_1 sin(2\pi f_1 t + \varphi_1) + C_2 sin(2\pi f_1 t + \varphi_1)\cos(\varphi_2 - \varphi_1) + C_2 cos(2\pi f_1 t + \varphi_1)\sin(\varphi_2 - \varphi_1))\sin(2\pi f_c t)$$

If we demodulate by PLL with cos (wct) and sin(wct), then in I and Q we get,

$$I = A(t)(C_1 cos(2\pi f_1 t + \varphi_1) + C_2 cos(2\pi f_1 t + \varphi_1)\cos(\varphi_2 - \varphi_1) - C_2 sin(2\pi f_1 t + \varphi_1)\sin(\varphi_2 - \varphi_1))$$

$$Q = A(t)(C_1 sin(2\pi f_1 t + \varphi_1) + C_2 sin(2\pi f_1 t + \varphi_1)\cos(\varphi_2 - \varphi_1) + C_2 cos(2\pi f_1 t + \varphi_1)\sin(\varphi_2 - \varphi_1))$$

Now we can track the phases, so we know $\cos(2\pi f_1 t+\varphi_1)$ and $\sin(2\pi f_1 t+\varphi_1)$. Then we get $I\cos(2\pi f_1 t+\varphi_1)+Q\sin(2\pi f_1 t+\varphi_1)$ which is equal to

$$A(t)(C_1 + C_2\cos(\varphi_2 - \varphi_1))$$

with same noise variance. For n paths with same Doppler frequency but different phases, it will be

$$A(t)(C_1 + C_2\cos(\varphi_2 - \varphi_1) +..+ C_n\cos(\varphi_n - \varphi_1))$$

with same Gaussian noise variance. We have here half the capacity or less.

4.0 SOLUTION TO RAYLEIGH FADING : Method 3:PAM

The transmitted signal is

$$X(t) = A(n)\cos(wct) + B(n)\sin(wct)$$

The received signal for two multipaths is

$$X_r(t) = \big(A(n)C_1 cos(2\pi f_1 t + \varphi_1) + A(n-1)C_2 cos(2\pi f_1 t + \varphi_2)\big)\cos(w_c t) + \big(B(n)C_1 sin(2\pi f_1 t + \varphi_1) + B(n-1)C_2 sin(2\pi f_1 t + \varphi_2)\big)\sin(w_c t)$$

$$X_r(t) = (A(n)C_1 cos(2\pi f_1 t + \varphi_1) + A(n-1)C_2(cos(2\pi f_1 t + \varphi_1)\cos(\varphi_2 - \varphi_1) - sin(2\pi f_1 t + \varphi_1)\sin(\varphi_2 - \varphi_1))\cos(w_c t) + (B(n)C_1 sin(2\pi f_1 t + \varphi_1) + B(n-1)C_2(sin(2\pi f_1 t + \varphi_1)\cos(\varphi_2 - \varphi_1) + cos(2\pi f_1 t + \varphi_1)\sin(\varphi_2 - \varphi_1)))\sin(w_c t)$$

Here f_1 is single Doppler frequency. We demodulate it in I and Q phase,

$$X_I(t) = (A(n)C_1 cos(2\pi f_1 t + \varphi_1) + A(n-1)C_2(cos(2\pi f_1 t + \varphi_1)\cos(\varphi_2 - \varphi_1) - sin(2\pi f_1 t + \varphi_1)\sin(\varphi_2 - \varphi_1))$$

$$X_Q(t) = (B(n)C_1 sin(2\pi f_1 t + \varphi_1) + B(n-1)C_2(sin(2\pi f_1 t + \varphi_1)\cos(\varphi_2 - \varphi_1) + cos(2\pi f_1 t + \varphi_1)\sin(\varphi_2 - \varphi_1)))$$

We do addition of

$$X_I(t)\cos(2\pi f t + \varphi_1) + X_Q(t)\sin(2\pi f t + \varphi_1) = A(n)C_1 + A(n-1)C_2\cos(\varphi_2 - \varphi_1)$$

As, we use Phase locked loop to track cos(□ □$_1$t+□ 1), sin((□ □$_1$t+□ 1). Noise will increase to 2/(1+k) where k=C2/C1 (instead of bpsk we transmit PAM of level 4) signal power increased to 5 to get the same throughput.

We send differential signal so in the receiver at the last stage we integrate it lowering noise variance. If we code A(n), we can decode it by correlator. So if we use a code (6,3) then get gain of 30 dB using a highpass filter with corner at 5 Hz in the signal path.

5.0 SOLUTION TO RAYLEIGH FADING : Method 4:FM & FSK

Here we use Frequency Modulation (FM) and demodulation scheme. We use a Phase Locked Loop to demodulate FM carrier [3]. We put a discriminator followed by a series capacitor to block the dc voltage induced by the Doppler frequency. Similar principle can be used to demodulate FSK by PLL.

6.0 SOLUTION TO RAYLEIGH FADING : Method 5: FSK

In this method we use FSK modulation and demodulation. The received signal is

$$X(t) = \sum C_n cos(\alpha_n) \cos(w_c t + w_n t \pm 2\pi f_1 t + \phi_n)$$

where, w_c is the carrier frequency, w_n is the Doppler frequency here we assume that it is same for different n and f_1 is the binary FSK modulated signal. Here we neglect the ϕ_n phase.

We recover the carrier using a phase locked loop with integrator as filter. This recovered carrier is used in demodulation which reduces the phase noise. The output is $\sum C_n cos(\alpha_n)\sin(w_n t/2 \pm 2\pi f_1 t)$ and $\sum C_n cos(\alpha_n)\cos(w_n t/2 \pm 2\pi f_1 t)$. Then we derive cos (2□ f_1t) and sin(2□ f_1t) from w_c and get the envelop of $\pm \sum C_n cos(\alpha_n)\sin(w_n t)$ and $\pm \sum C_n cos(\alpha_n)\cos(w_n t)$. We multiply them by their phase component and addition gives the equation $\pm(\sum C_n cos(\alpha_n))^2$. We demodulate this signal. We may use differential encoding of data to get benefit over noise.

CONCLUSION

In this paper, we addressed the problem of WLAN capacity and found that it is half of LAN [4] if the signal is strong in a sense that direct line of sight with good SNR exist for same device technology**.** We also proposed a schematic diagram of receivers and proposed method of improving SNR by 30 dB for PAM and similar result for FSK**.**

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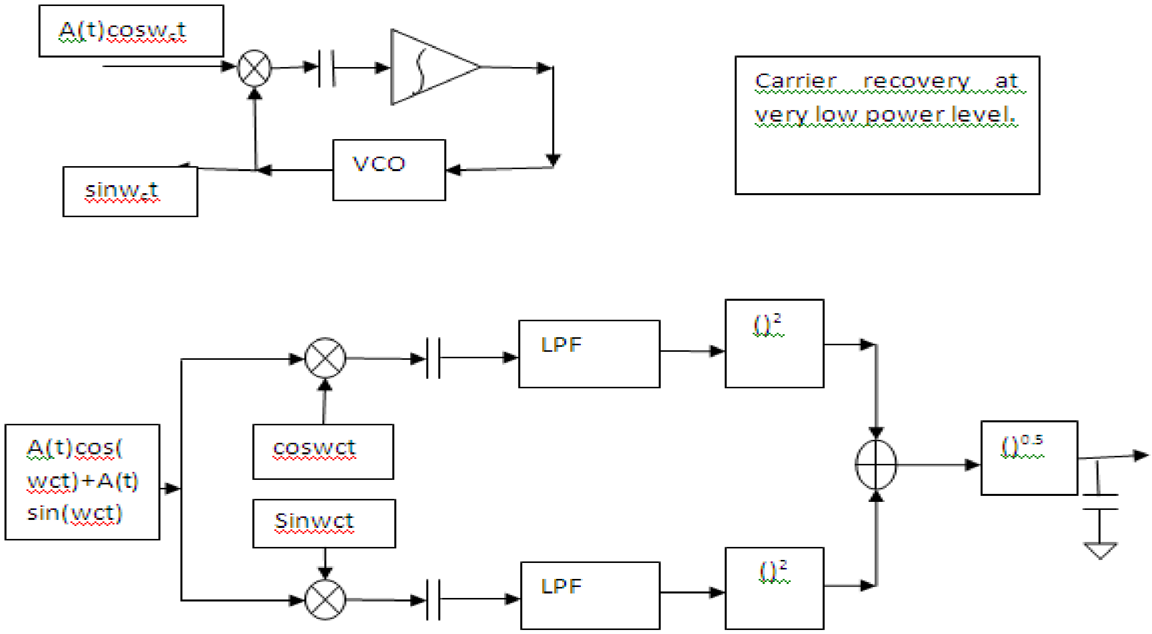

Figure 1: Rayleigh Fading Cancellation with noise as Rayleigh Distributed. Here A(t) frequency could be same as the phase frequency.

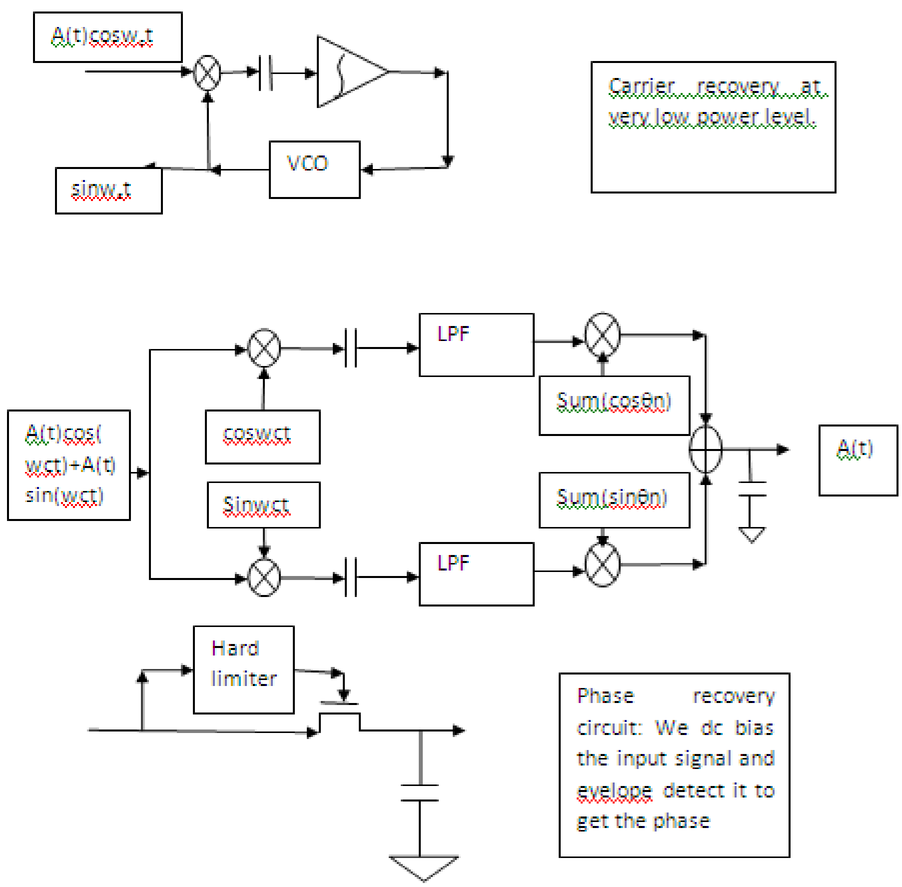

Figure 2. Cancellation of Rayleigh Fading, noise will be Gaussian. Here the A(t) frequency is more than phase frequency.

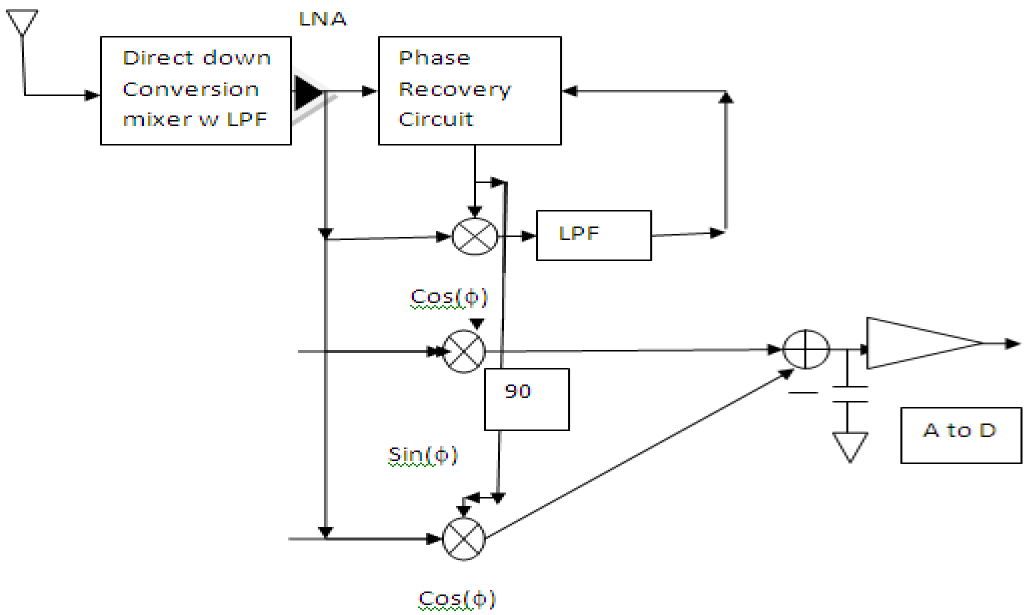

Figure 3. This is similar to method 1, but for PAM modulation.

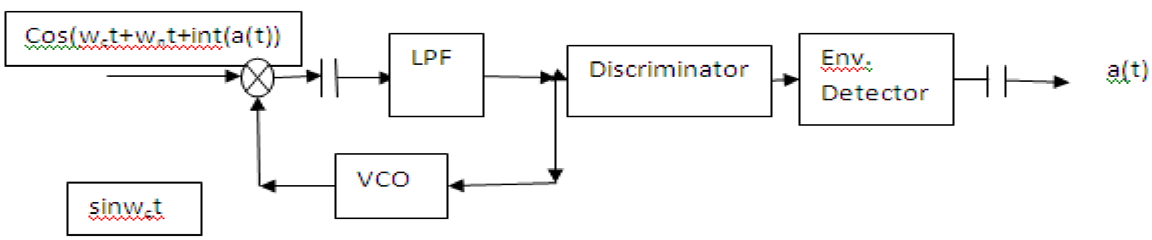

Figure 4. FM detector under Rayleigh Fading.

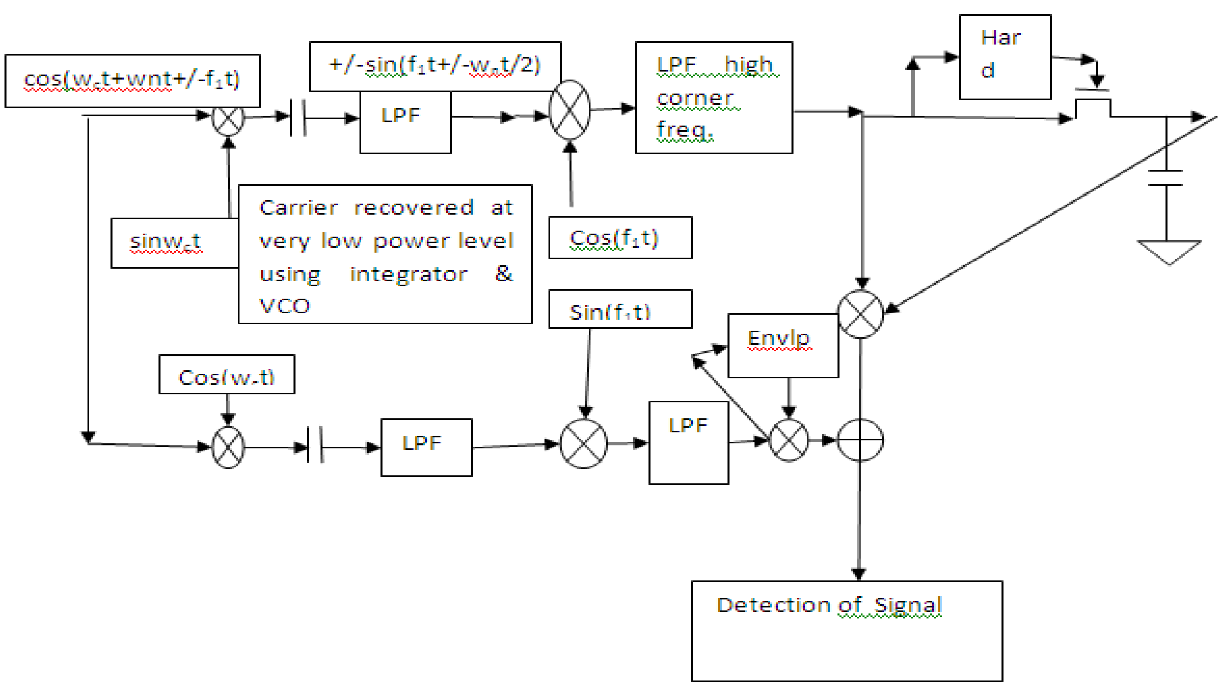

Figure 5: FSK detection. We can do demodulation like method 2!! We recover f_1 from w_c.