FM THRESHOLD AND METHODS OF LIMITING ITS EFFECT ON PERFORMANCE

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ABSTRACT

This paper presents the outcome of the investigative study carried out on threshold effect in FM systems. The study gave a proper insight on how the threshold effect affects the performance of FM systems by giving detailed report on the occurrence. Performance evaluation shows that the threshold is the existence of large noise in the output of the system, which makes signal detection impossible. The effect, as was discovered through analysis, is more serious at very high frequencies as can be seen from the deviational effect noticed on the graph which depicts the presence of noise in the system and it is in-fact a confirmation that noise at that level is frequency dependent.

Pre- emphasis and de – emphasis networks were discussed to show how the effect could be controlled in FM systems.

1. INTRODUCTION

The study of FM threshold is quite important, and a lot of studies have been carried out on how to lower it using special circuits. The threshold effect in FM system affects the performance of FM system [1]. In this work, efforts are being made to find out in what manner this occurs and how actually does it affect the performance of FM system and then assess the ways and means of reducing this effect on performance.

The threshold level may be defined as the level of observation referenced to the ratio of signal - to - noise level. And in this context, threshold is said to be the value of signal - to - noise ratio below which the output signal - to - noise ratio degrades more quickly than the input signal to – noise ratio [2]. The threshold effect is first noticed when the input signal - to - noise ratio reaches the vicinity of unity [2]. Where this exists, the amplitude of the signal is smaller than that of the noise to the point that it becomes difficult if not impossible to detect the presence of signal (in this case, information signal). Hence, we see that the threshold effect is due to the existence of large noise in a signal received after transmission. This point is usually identified between 10 dB to 12 dB [4]. If the input Signal-to-Noise Ratio (SNR) falls below this threshold point, then the Demodulation Gain (D.G) becomes smaller, where D.G is given by: (So / No) / (Si / Ni) [2].

2. FM THRESHOLD EFFECT

FM threshold is usually defined as a Carrier-to-Noise ratio at which demodulated Signal-to-Noise ratio falls 1dB below the linear relationship [4]. This is the effect produced in an FM receiver when noise limits the desired information signal. It occurs at about 10 dB, as earlier stated in the introduction, which is at a point where the FM signal-to-Noise improvement is measured. Below the FM threshold point, the noise signal (whose amplitude and phase are randomly varying) may instantaneously have amplitude greater than that of the wanted signal. When this happens, the noise will produce a sudden change in the phase of the FM demodulator output. In an audio system, this sudden phase change makes a "click". In video applications the term "click noise" is used to describe short horizontal black and white lines that appear randomly over a picture [6].

3. NOISE PERFORMANCE MODEL

The receiver may be modeled as shown in Figure 1. The receiver front-end combination (RF / Mixer / IF stages) is modeled as an ideal band-pass filter, with frequency function H_R (f), and the bandwidth B_T. The bandwidth, B_T is assumed to be equal to the bandwidth of the information bearing signal V_C (t), where

$$V_c(t) = A \cos [\omega_c t + \varphi(t)] \qquad (1)$$

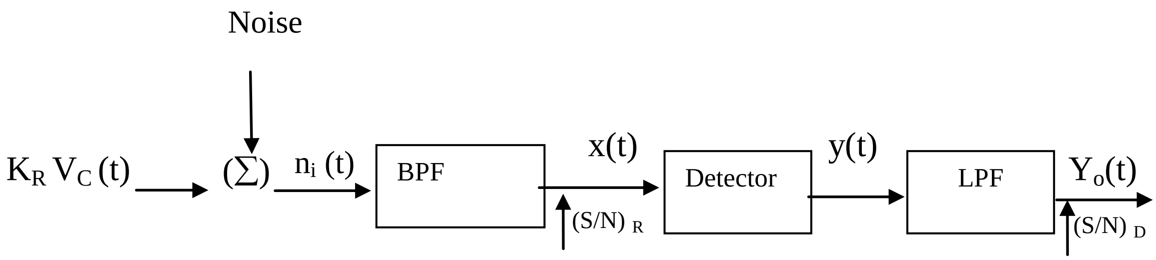

Fig.1: Receiver Block

The additive noise accompanying the signal is modeled as zero-mean, stationary, gaussian, random process, with two-sided power spectral density given by

$$Gni (f) = \eta/ 2 \qquad (2)$$

The system front-end band pass filter passes V_C (t) completely but band-limits n_i (t). The input to the detector may therefore be expressed as

$$X (t) = K_R V_C (t) + n (t) \qquad (3)$$

Where n(t) is the band-pass filter version of n_i (t) and K_R is a constant.

The received noise power N_R may be assumed to be equal to

$$N_R = \eta/2 \int_{-\infty}^{\infty} |H_R| dF \; [3] \qquad (4)$$

In assessing the noise performance of receiver systems (FM), we are interested not just on $(S/N)_R$, but also, on the destination signal-to-noise power ratio $(S/N)_D$. This helps to determine how the various demodulation processes affect signal-to-noise ratio.

The analysis of this work is carried out based on two conditions:

(1) High-signal-to noise ratio, when
$$[A_c + V_m (t)] >> R_n (t)$$

(2) Low – signal-to-noise ratio, when
$$R_n (t) >> [A_c + V_m(t)]$$

Where R_n (t) = Received noise signal
$[A_C + V_m (t)]$ = Received signal power.

It should be noted that in condition (1), the noise and the signal are additive at the output whereas they are multiplicative when the signal-to-noise ratio is low which is equivalent to condition (2). There is therefore, a transition between these states known as the threshold level. Non-coherent detection schemes are characterized by this threshold effect. Below the threshold the message is lost as the system performance deteriorates rapidly. Below $(S/N)_R$ = 10dB, the output is generally dominated by noise, coherent detection does not exhibit threshold effect [3].

3.1 Noise in frequency modulation systems

Based on the model for the FM detector (3)

If $$Y(t) = G\left[\frac{d\phi_x(t)}{dt}\right] \quad (5)$$

We may express $\phi_x(t)$ as

$$\phi_x(t) = \underbrace{\phi(t)}_{signalterm} + \underbrace{\frac{Rn(t)}{K_R A_C} Sin\left[\phi_n(t) - \phi(t)\right]}_{noiseterm} \quad (6)$$

Similarly, for Rn (t) >>$K_R A_C$,

$$\phi_x(t) = \underbrace{\phi_n(t)}_{noise\ term} - \underbrace{\frac{K_R A_C}{R_n(t)} Sin\left[\phi_n(t) - \phi(t)\right]}_{signal+noise\ term} \quad (7)$$

This indicates complete loss of message signal.

Therefore,

$$Y(t) = 2\pi G_4 K_f V_m(t) + G_4 \frac{d}{dt}\left[\frac{R_n(t)}{K_R A_C}\sin(\phi_n(t) - \phi(t))\right] \quad (8)$$

And setting $\phi(t)$ = 0, we get

$$Y(t) = 2\pi G_4 K_f V_m(t) + \frac{G_4}{K_R A_C}\frac{d}{dt}[n_s(t)] \quad (9)$$

or $$Y(t) = 2\pi G_4 K_f V_m(t) + n_i(t) \quad (10)$$

The power spectral density for $n_1(t)$ is

$$G_{ni}(f) = \frac{G_4^2}{K_R^2 A_C^2} W^2 G_{ns}(f) \quad (11)$$

$$= \frac{G_4^2}{K_R^2 A_C^2}(2\pi f)^2_\eta \ for\left|f\right| < \frac{B_T}{2} \quad (12)$$

or else where

Note that for PM system, Gnv (f) is constant in the transmission bandwidth whereas in FM system, Gni (f) is frequency dependent. Hence the degrading effect increases with increased frequency in FM systems and this is the more reason why FM systems use pre-emphasis and de-emphasis networks to check this ugly effect. In such a situation, the post detection filter has a cut-off frequency say, W. Therefore, the output noise power spectral density may be expressed as:

$$Gno(f) = \frac{G_4^2}{K_R^2 A_C^2}(2\pi f)^2_\eta \ for\left|f\right| < W$$

or else where

A plot of Gno (f) is given in Fig 2 as a result of the differentiation action. The diagram clearly shows that low-frequency signal components are less influenced by noise than the higher- frequency components. The output signal is same as before and maybe expressed as

$$(2\pi k_f G_4)^2 E\left\{V_m^2(t)\right\} = (2\pi k_f G_4)^2 S_v m \quad (14)$$

The corresponding output noise power is

$$E\left\{n_0^2(t)\right\} = \int_{-W}^{W} Gno(f)df = \frac{2G_4^2(2\pi)^2}{K_R^2 A_C^2 3}\eta W^3 \quad (15)$$

Therefore

$$(S/N)_D = \frac{3K_R^2 A_C^2 S_{vm}(2\pi K_f G_4)^2}{2G_4^2(2\pi)^2 \eta W^3} \quad (16)$$

where $(S/N)_D$ is the signal-to noise ratio at the Destination.

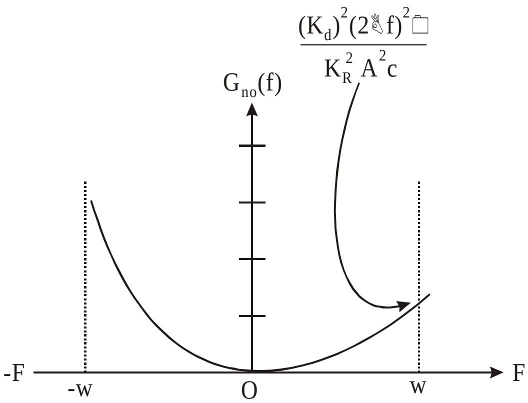

Fig .2 shows Noise Power Spectrum in FM Systems.

6. GRAPHICAL ANALYSIS OF FM THRESHOLD EFFECT

To be able to present a reasonable account of the effect of FM threshold on the received signal, we considered it wise to take a sample signal and relate it to equations (14) and (15) already stated in the last section and we may recall them at this stage in order to have a critical look on the analysis:

$$Signal = (2\pi K_f G_4)^2 S_{vm} \qquad (14)$$

$$Noise = \frac{2G_4^2(2\pi)^2 \eta W^3}{3K_R^2 A_C} \qquad (15)$$

Where W is the angular frequency in radians / seconds. Or W = 2πf and S_{vm} is the so called intelligence signal or the information signal while others not mentioned here are constants.

It is pertinent to observe here that the noise signal is frequency dependent whereas the intelligence signal is not although both contain frequency components. By implication therefore, any frequency increase in the course of signal transmission will definitely affect the noise signal, however, the effect will depend much on the relationship existing between them. In FM systems, the detected noise or interference power increases with frequency according to the relation $N \propto F^2$. The result is that signal components at higher frequencies suffer the most degradation [3].

As the frequency increases beyond the VHF band (30 MHz – 300 MHz) or level, noise becomes more apparent and this can be seen from the graph given in figure 3.

Table 1: Signal/Noise Variations with Frequency.

Frequency (MHz)	Signal (mV) rms	Noise Signal (mV) rms	(S/N) dB
20	70	1.65	35.55
30	70	5.57	24.98
40	70	13.0	17.62
50	70	25	11.94
60	70	44	7.03
70	70	70	3.00
80	70	105	-0.52
90	70	150	-3.62
100	70	206	-6.37

Table 1 shows the sample values used; based on equations (14) and (15) earlier stated. The assumed constants are;

$\pi = 3.14$, $K_f = 1$, $G_4 = 5$, $S_{vm} = 70$ mV,

$K_R = 0.95$, $A_C = 70$ mV,

$\eta = 8 \times 10^{-14}$ Vm²/Hz.

The mutilation or loss of message at low pre-detection signal-to-noise ratio is called threshold effect. The name comes about because there is some value of (S/N)R above which mutilation is negligible and below which the system performance rapidly deteriorates [8].

The intelligence signal and noise signal are in root mean square values but were converted to decibel (dB) using appropriate conversion factor. The graph (S/N)/ dB; versus frequency (MHz) is given in figure 3. The behaviour of the graph depicts the presents of large noise as the frequency increases. At about 55MHz, the threshold value is 10dB as can be seen from the graph of Figure 3. This is the determined threshold on performance.

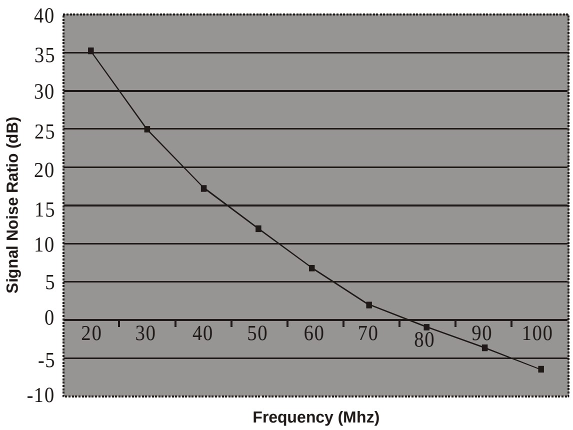

Figure 3 Showing the graph of Signal-To-Noise Ratio against Frequency.

7. LIMITING THE EFFECT OF FM THRESHOLD

In the section just discussed, we were able to show that conventional FM reception is characterized by a threshold level, above which the output signal-to-noise ratio **(S / N)**o increases linearly with the received carrier level, and below this level there is a very rapid deterioration of the $\mathbf{(S/N)_O}$ as the received carrier level falls. This threshold level therefore determines the maximum operation range of the FM communication system[5].The determined threshold value or level is 10 dB at about 55 MHz.

It follows then that any technique which will lower the threshold will enhance the system reliability, or any given reliability specification, will either reduce the transmitter power requirements or extend the operation range. Since the threshold point depends on the carrier –to-noise ratio at the input $\mathbf{(C / N)}_i$ within the IF amplifier, reduction of noise at this point will lower the threshold. It then implies that a reduction in the Intermediate Frequency (IF) bandwidth will result in an improvement of threshold level. However, such a reduction cannot be achieved without proper reduction in the frequency deviation at the transmitter; this follows the fact that in a conventional FM system, the bandwidth required depends on both the peak deviation and the highest modulation frequency, that is, ΔF and fm respectively. Hence,

$$B = 2 (\Delta f + fm) [5].$$

7.1 Pre – Emphasis and De-Emphasis in FM Systems

Earlier, we noted that in FM systems, the detected noise or interference power, N, increases with frequency according to the relation $N \propto F^2$ and this is clearly shown in Fig 3. The result is that signal component at the higher frequencies suffer the most degradation. The overall system performance may be improved by using a pre-emphasis network to emphasize the higher frequency components of the message signal before modulation, since noise at this point is at a minimum then a complementary de – emphasis network is used at the receiver, after demodulation, to restore the original signal. AM and PM systems have nothing to gain from this scheme since the noise or interference in such a system is independent of frequency [3]. Hence, threshold effect is usually not a serious limitation for AM broadcasting and where AM is used for digital transmission, Synchronous detection may be necessary to avoid threshold effects [8].

7.2 CONCEPT OF THRESHOLD EXTENSION

The concept of lowering the threshold or as it is commonly called, threshold extension, usually means to extend the region relative to a conventional FM demodulator in which the output signal-to-noise ratio $(S/N)_O$ is linearly related to the input carrier-to-noise (C/N) without affecting the high $(S/N)_0$ performance. There exist some techniques or methods for extending threshold.

Threshold extension techniques fall essentially into two major categories. One category follows the basic idea of frequency following or **frequency compressive feedback** originated by Chaffee [6] and the other centers around what is known as a **phase-locked detector**. In this second one, the instantaneous phase of the received FM signal is compared with the phase of the locally generated FM signal in a phase detector. The output of the phase detector is used to modulate the local oscillator and close the feedback loop.

All threshold extension devices are essentially tracking filters, which can track only the slowly varying frequency of the modulated carrier and consequently respond to only a narrow band of noise centered about the instantaneous carrier frequency. [7]

We should note that the threshold of improvement is extended without affecting the efficiency with which bandwidth is exchanged for signal-to-noise in conventional FM demodulators. A conventional receiver with a phase – lock loop demodulator also provides threshold extension and has the advantage of simpler implementation [8]. A more detailed treatment is given references 7 and 8.

CONCLUSION

From all observation and representation so far, we have noticed that FM has a low signal-to-noise ratio because of its inherent noise reduction characteristic. But when affected by noise the signal is highly distorted and this distortion occurs when the ratio of the signal-to-noise at the input and the signal-to- noise ratio at the output are approaching unity, this is the threshold point. This distortion leads to a reduction in the output signal strength and this affects the end of the day-transmitted signal as a consequence. The study of how the interference regarded as noise affects an FM transmitted signal is of utmost importance in the design of FM transmitters and receivers. The threshold effects in FM system as we have seen affect the throughput or the performance of an FM system. Hence, to improve FM system performance, the threshold point has to be moved and this has been well elucidated in this work through the use of special circuits. It is however recommended that designers of FM system should adopt some measures that can help to limit the effect of FM threshold in their systems. Such measures may include the use of pre-emphasis and de-emphasis networks in the transmission and reception of base band signals. Also, transmission of signals at very high frequencies must be guided by the provision of adequate techniques or circuits that may contend with any noise introduction at such range of frequencies.

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