

Development of a receiver circuit for medium frequency shift keying signals.

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Abstract: Frequency shift keying (fsk) mode of digital signal information transfer switches between two predetermined frequencies of the carrier wave, either by modulating one sine wave oscillator or by switching between two oscillators. The need for a receiver to decode an fsk signal along the transmitting medium from a digital source code within about 5 kilometer radius for security monitoring of environment informed this work. The design of a receiver circuit at a frequency of 500 kHz for an input frequency shift keying (fsk) signal from a transmitter is presented. The receiver is to receive an RF signal, amplify it, filter it to remove unwanted signals, and recover the desired base band information. It consists of an amplifier, tuned circuits and mixers which filters the base-band information. A comparator circuit is incorporated, to detect the digital signal received. The output from the comparators is the digital equivalent of the coded signals sent by the transmitter circuit, and transferred to a microcontroller circuit, to act as a coded signal representing information from the transmitting end. The bode-plot response of the receiver to the incoming signals using a FET tuned circuit, shows that only frequencies above 470kHz, and below 495kHz are allowed to pass through the network with a resonant frequency of 483.553 kHz and a gain of 27.734dB, while others are totally attenuated. The reliability of the designed receiver circuit was evaluated for a 1 year continuous operating period and was found to be 74.7%. Area of application of this work include electronic policing of a defined environment with good success.

Keywords: Band-pass network, Comparator, Detector, FET amplifier, FSK signals, Resonant circuit, Quality factor.

I. Introduction

A receiver is the destination end of any communication system, having the capability of recovering the original information sent. The first three blocks of a generic receiver are the RF amplifier, mixer and oscillator [1,2]. They form what is known as the “front end” of the receiver as shown in Figure 1. The front end is very important in setting the noise figure of the receiver. In particular, the RF amplifier should be a low noise design because it amplifies all the low-level signals from the antenna – including noise – with a significant amount of gain. The better the low-noise design of the RF amplifier, and the mixer, the better the receiver sensitivity [1,3,4]. The RF amplifier designed to amplify the low level signal from the antenna. At the input terminal of the amplifier, a rhombic antenna was connected which receives the signals and other surrounding signals which needed to be separated. A FET amplifier was selected to amplify the received signals from the antenna end. The choice was based on its advantages over bipolar transistors which include (i) extremely high input impedance (ii) less noise and better thermal stability [3, 5].

The receiver circuit consists of an AM receiver and a comparator circuit. The basic purpose of a receiver is to receive an RF signal, amplify it, filter it to remove unwanted signals, and recover the desired base band information. Since the RF signal usually comes from an antenna, its amplitude is very small, often in the order of a few micro-volts [4, 6, 7]. The receiver is to amplify the signal from a very small level up to usable levels of several volts or more. The basic digital modulation techniques used in wireless communications include the frequency shift keying (fsk) among others [6,8], and fsk is a form of frequency modulation in which the modulating wave shifts the output between two pre-determined frequencies, usually termed the mark and space frequencies. Because of the narrow bandwidths in fsk, it offers only slightly improved noise performance over the AM two-tone modulation scheme, however, the greater number of sidebands transmitted in fsk allow better ionospheric fading characteristics than do a two-tone AM modulator schemes. With fsk, there is a change in the output frequency each time the logic condition of the binary input signal changes. Consequently, the output rate of change is equal to the input rate of change. In digital modulation, the rate of change at the input to the modulator is called the bit rate and has the units of bits per second (bps). The rate of change at the output of the modulator is called baud rate or band and is equal to the reciprocal of the time of one output signaling element [6, 7]. In fsk, the input and output rates of change are equal and thus, the bit rate and baud rate are equal. Recall that we modulate a sine wave carrier with the baseband binary stream of necessity to shift the resultant modulated signal to an appropriate frequency for transmission [8, 9]. At the receiver we must undo this process or demodulate the signal to recover the original binary stream. This process of demodulation is often called detection. There are essentially two common methods of demodulation [10]. One, called

synchronous or coherent detection, simply consists of multiplying the incoming signal by the carrier frequency that is locally generated at the receiver and then low-pass filtering the resultant multiplied signal. The other method is called envelope detection. The synchronous detection procedure in which fsk signals require two sine waves, one for each frequency transmitted is used for this work.

II. Materials and Method

2.1. Materials Used: An op-amp in summing mode and a FET transistor 2N4416A as the amplifier circuit with frequency tuning were used in the design with calculations made to select the circuit parameters. A diode 1N914 was used as a detector and an fsk mode of frequency modulation was developed using two separate band pass filters with an op-amp LF411CN. A comparator TLC 372D was used to generate the digital circuit. Multism -12 was used for the design schematics and analysis of the circuit with measurements using Oscilloscopes and Bode plotter.

2.2 Receiver circuit design for frequency shift keying signals.

A tuned circuit amplifier offers a way to achieve gain and a particular response at high frequencies. The amplifier circuit pass-band can be controlled by the design of a resonant circuit as long as the transistor has the necessary gain. The tuned circuit for the FET amplifier was designed using equations 1 and 2, it is a narrow band filter that passes frequencies in the range of 475- 495kHz, noting that the transmitted frequency lies between 480kHz and 490kHz. To determine the parameters of the parallel resonant circuit, the quality factor [7,11,12, 18].

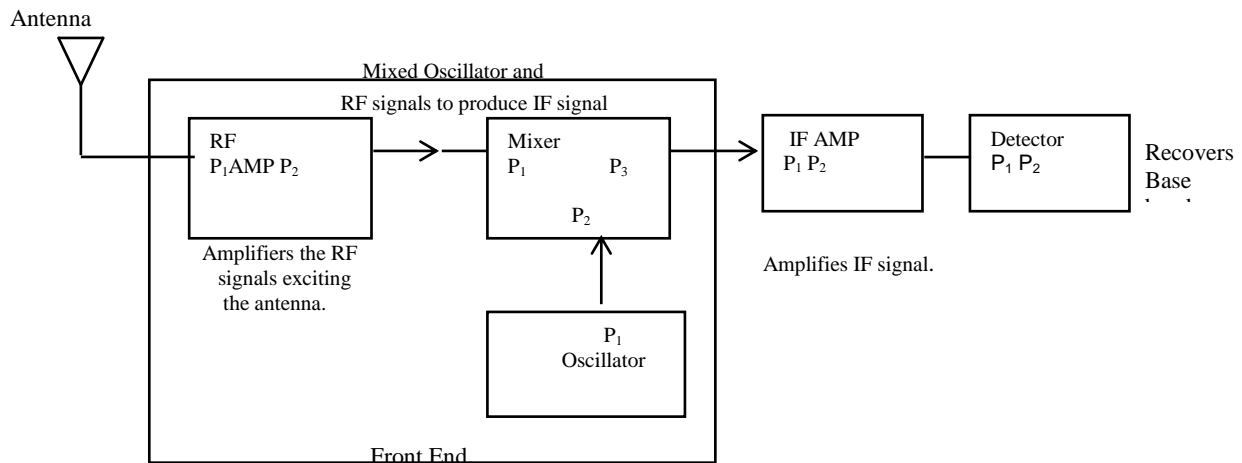


Figure 1: Receiver circuit block diagram.

$$Q, \text{ is } = f_R / BW \quad (1)$$

where the bandwidth ; $B = f_{L1} - f_{L2} = 495 - 475 \text{ kHz} = 20 \text{ kHz}$

and, the resonant frequency ; $f_R = \sqrt{f_{L1} f_{L2}} = 485 \text{ kHz}$

Thus, Q is $485/20 = 24.3$ which is a narrow band pass filter design specification.

For a parallel resonant circuit,

$$Q = R_p / X_L \text{ or } R_p / X_C \quad (2)$$

where $X_L = 2\pi f_R L$ and $X_C = 1/2\pi f_R C$, and $R_p = Q X_L$.

If L is taken as $10 \mu\text{H}$, then $X_L = 2\pi \times 485 \times 10^3 \times 10 \times 10^{-6} = 30.473$. Therefore $R_p = 24.3 \times 30.473 = 741 \Omega$ or 750Ω .

At resonance, $X_L = X_C = 2\pi f_R L$; thus, $X_C = 30.473 = 1/2\pi f_R C$ and $C = (1/2\pi f_R) \times 30.473 = 10.76 \text{ nF}$

For a tuned amplifier circuit, the gain,

$$A_v = -g_m \cdot Z_L \quad (3)$$

where Z_L is the net impedance seen by the drain circuit i.e. $r_L // Q X_L$, thus,

$Z_L = 1.5 // 1.5 \text{ k}\Omega = 0.75 \text{ k}\Omega$; and $A_v = -g_m \cdot Z_L = -3.33 \times 10^{-3} \times 0.75 \times 10^3 = -2.50$ (the -ve sign indicates a 180° phase shift).

The tuned circuit amplifier calculated values is as shown in Figure 2, with an inductance value of $10 \mu\text{H}$ and a capacitance value of 10 nF . This is required to pass a frequency of 480 kHz and 490 kHz freely, and reject any other frequencies surrounding it. A circuit that extracts the original baseband signal from the modulated carrier is called a demodulator or detector. The AM demodulator is the key circuit used for the demodulation of the

FSK signal used. A simple demodulator circuit for the design is as shown in Figure 3. The diode detector used is basically a half-wave rectifier circuit with a low-pass filter [4,13]. The diode conducts during the positive half cycle of the amplitude-modulated carrier. During the negative half cycle, the diode is reverse biased and no current flows through it or resistor R1. This causes the voltage across resistor R1 to be a series of positive pulses whose amplitude follows the amplitude of the modulated carrier. Capacitor C1 forms an R-C filter with resistor R1. The operation of the R-C filter can be analyzed in the time domain or the frequency domain [8,13]. If we examine the operation of the R-C filter in the frequency domain, it can be considered to be a low-pass filter. This low-pass filter should pass the modulating signal frequencies and reject the carrier frequency and all other harmonic frequencies generated by the nonlinear diode. If the correct value of C₁ is selected for a cutoff frequency that is above the modulating frequencies and below the carrier frequency, the waveform across capacitor C₁ will be a close approximation to the original modulating signal. If the cutoff frequency is too close to the carrier frequency, the output ripple will be too large. If the cutoff frequency is lower than the modulating frequency, diagonal distortion will result. The purpose of coupling capacitor C₂ in the AM diode detector is to remove the dc component from the recovered signal. The coupling capacitor will eliminate this dc component because a capacitor can pass an ac signal, but does not pass a dc voltage. The coupling capacitor (C₂) and load resistor (R₂) combination acts like a high-pass filter [6,8,14].

With the use of the tuned circuit design of Figure 2 and the demodulator circuit of Figure 3, the receiver circuit for the medium frequency fsk circuit was developed, which consist of the oscillator circuit, FET amplifier circuit with a tuned circuit, operational amplifiers amplifier circuits, and a comparator as shown in Figure 4. The output from the detector, which is the FSK signal generated at the transmitting end, is fed into two separate band-pass filters; one for mark at 20kHz and the other for space at 10kHz. To extract the 10 kHz space frequency from the base-band information received after the amplification of the detected signals [8, 12, 13, 14] a band-pass filter network was designed to pass a frequency of 10 kHz. To determine the parameters of the parallel resonant band-pass circuit and the quality factor, we use equation 1, 2 and 3 to arrive at $Q = f_R / BW = 100$ for a bandwidth of 100Hz . If L is taken as 10uH, we get by calculation, $C = 25.36\mu F$ with $R_p = 63 \Omega$.

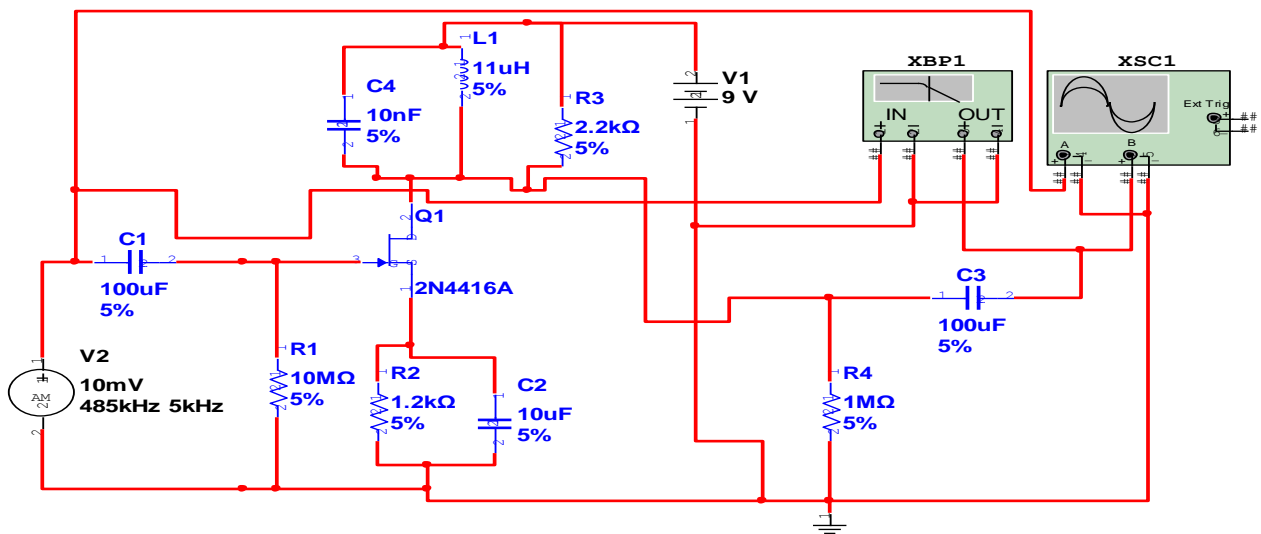


Figure 2: Tuned circuit receiving circuit design.

To extract the 20kHz mark frequency, a band-pass filter network was designed with the same equations as applied to the extract of 10kHz information , but here, using a bandwidth of 200Hz, to get $Q = 100$, $R_p = 126\Omega$ and $C = 25.36\mu F$. The output from the parallel filters are fed to a comparator circuit. A comparator is a circuit which compares an input signal $V_i(t)$ with reference voltage V_r . When the input exceeds V_r , the comparator output voltage (V_o) takes on a value which is very different from the magnitude when V_i is smaller than V_r . If the input to an op-amp comparator is a sine wave, the output is a square wave. If a zero crossing detector is used, (i.e. when V_r is set to zero), a symmetrical waveform results. The output from the comparators is the digital equivalent of the coded signals sent by the transmitter circuit, and this can be transferred to a microcontroller circuit, to act as a coded signal representing an information from the transmitting end.

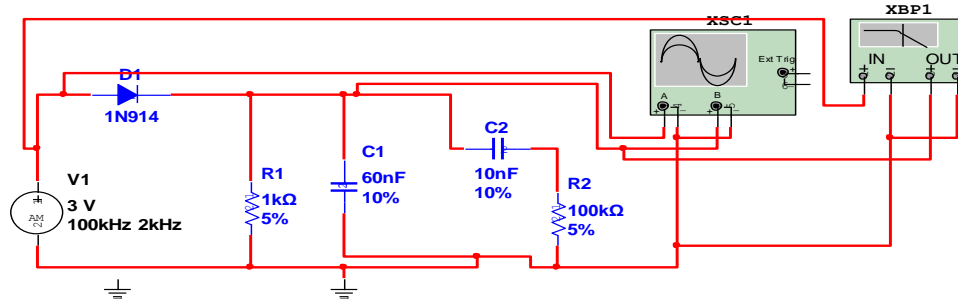


Figure 3: Diode detector circuit diagram

III. Results of the designed receiver circuit

The response of the receiving RF amplifier is as shown in Figure 5 giving an output voltage of 660mV, which is further amplified using the common source FET amplifier of Figure 2, to give an output of about 4.5V, as shown in Figure 6. The bode-plot response of the receiver to the incoming signals using a FET tuned circuit is as shown in Figure 7. The peak voltage measured is 4.5V. This voltage is enough to drive the AM diode detector whose forward voltage response is 0.7V. The bode-plot response of the receiver to the incoming signals using a FET tuned circuit of in Figure 7 shows that only frequencies above 470kHz and below 495kHz are allowed to pass through the network with a resonant frequency of 483.553 kHz and a gain of 27.734dB, while others are totally attenuated.

The output voltage from the diode detector circuit is 1.32V, as measured by the oscilloscope, and this voltage is amplified using the FET rf amplifier circuit of Figure 2. The output from the detector is the frequency shift keying signal transmitted from the OTS at a voltage of 8.5V and 7.4V as shown in Figure 8. The output from the detector is the frequency shift keying signal transmitted from the OTS at a voltage of 8.5V and 7.4V as shown in Figure 8. The detector output signal is fed to two separate band – pass filters (one for 10kHz and the other for 20kHz), with their component values calculated to give a response as shown in Figure 6. This shows that the 20 kHz was separated from the 10 kHz signal.

The output of the two separated parallel filters of Figure 9, was fed into a comparator circuit which gives a response shown in Figure 10. When the 20 kHz representing the mark frequency (or the High State of the transmitted information) passes through the circuit, a voltage of 5V is achieved and when the frequency is changed to 10 kHz, the voltage is in its reference voltage level of 0V.

This digital signal forms an input signal to the microcontroller circuit which is in serial form. The serial digital information from the receiver, being fed into the microcontroller is processed and transferred to the on – line microcomputer for interpretation. This digital signal can be used for many security information purpose including electronic coding of housing units in a decentralized community for electronic policing of an environment under surveillance, to solve the problems of household breaking –in and stealing, robberies and other crime preventive measures [15,16,17]. The reliability of the designed receiver circuit was calculated for a 1 year continuous operating period [19, 20], and was found to be 74.7%.

Table 1 : Measured Band pass frequencies and gain for resonant frequency of 20kHz.

Bandpass frequency in kHz	Measured gain in dB
18.29	- 42.037
19.055	- 37.494
19.449	- 33.718
19.851	- 26.789
20.261	- 23.76
21.108	- 34.519
22.445	-42.401
23.382	-45.272

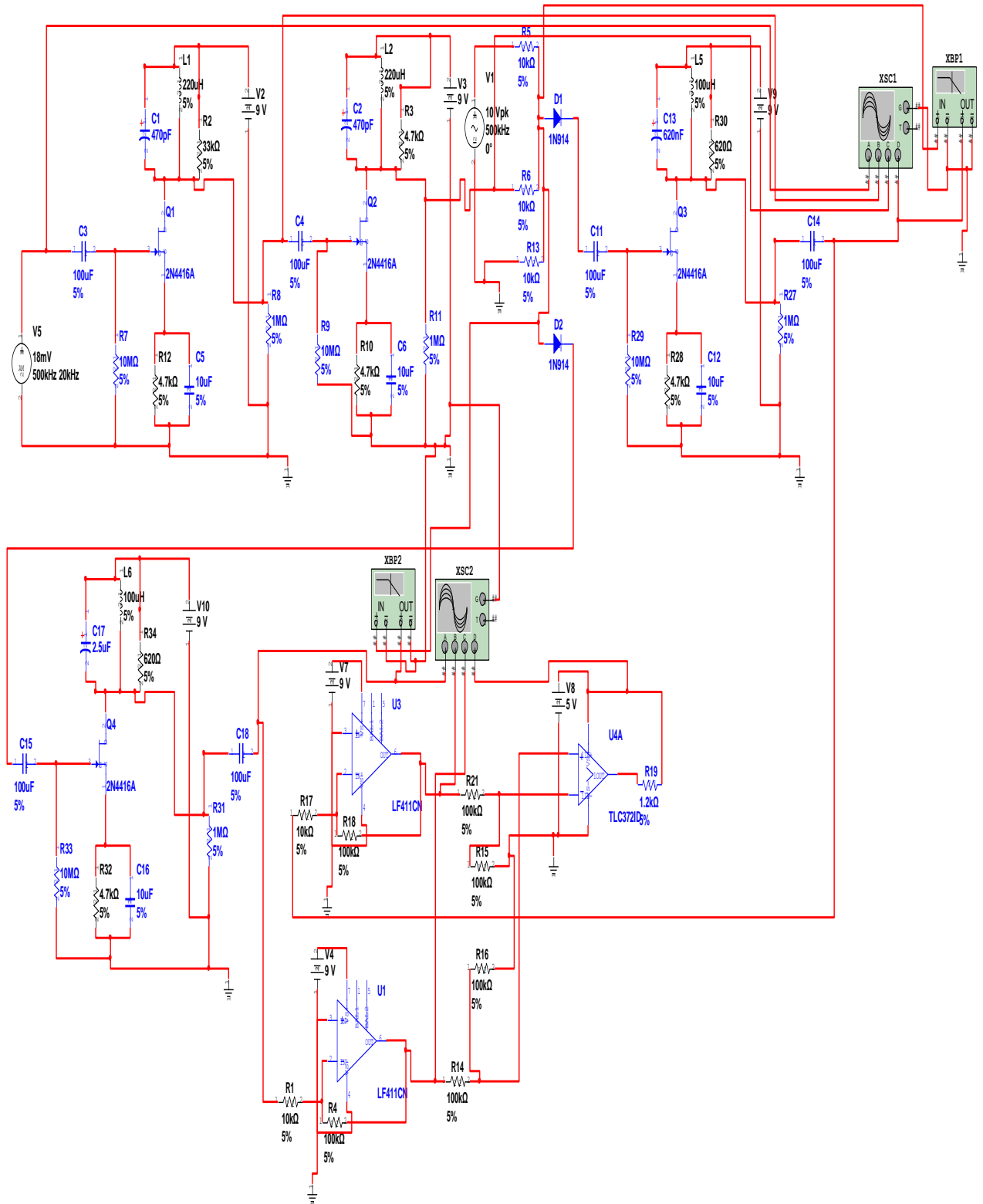


Figure 4: Receiver circuit for the medium frequency fsk circuit.

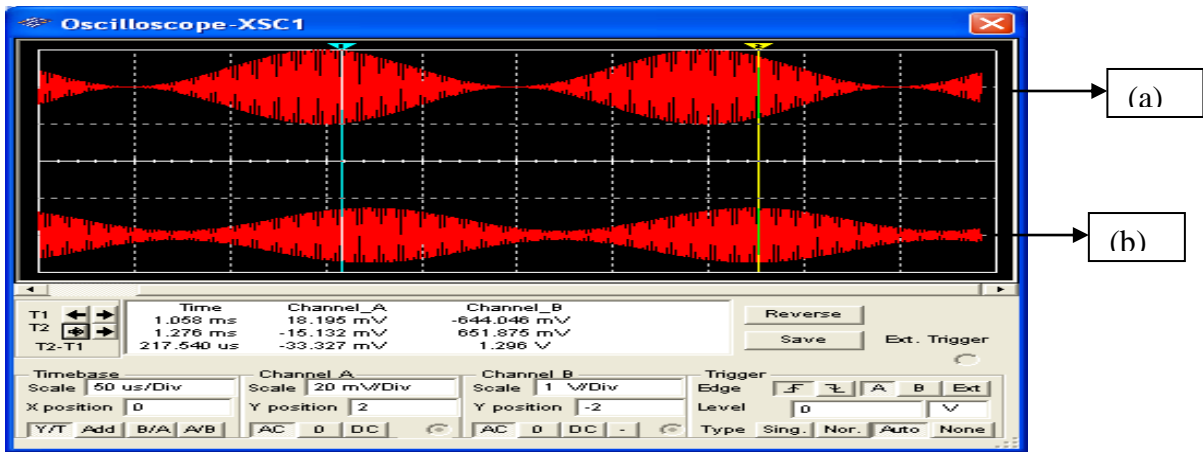


Figure 5: Waveform of the FET receiving amplifier response

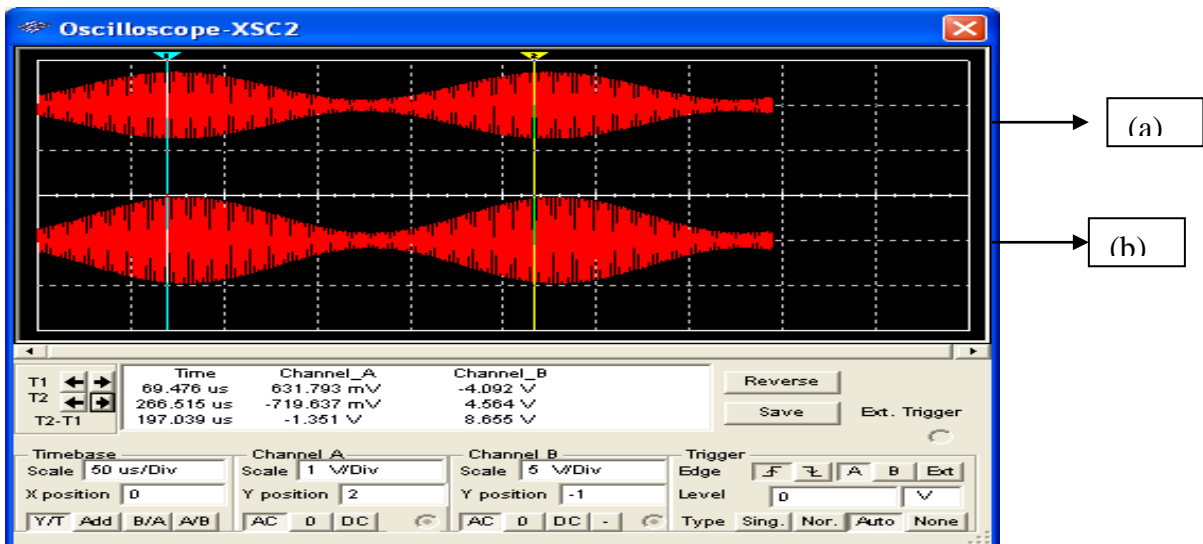


Figure 6: Amplification of RF amplifiers output voltage to 4.5V using FET amplifier.

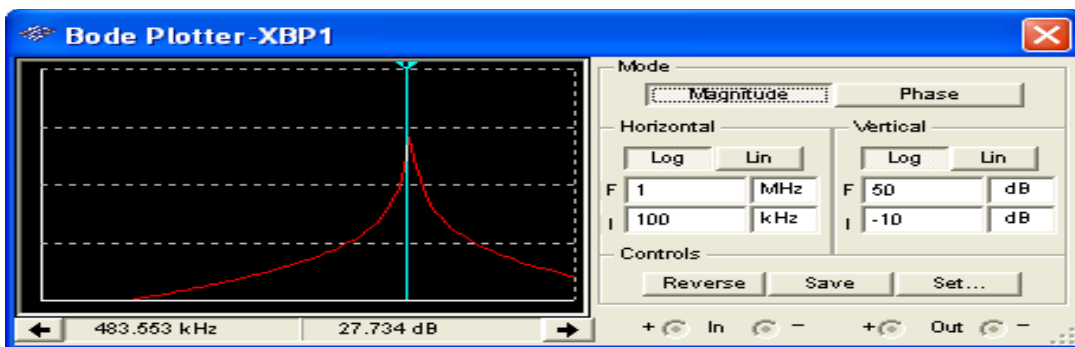


Figure 7: Bode plot of the receiving rf amplifier circuit response

Table 2: Measured Band pass frequencies and gain for resonant frequency of 10kHz.

Bandpass frequency in kHz	Measured gain in dB
9.12	- 52.385
9.698	- 48.116
10.00	- 44.970
10.312	- 39.583
10.633	- 19.688
11.307	- 42.074
12.023	- 48.954
14.017	- 56.330

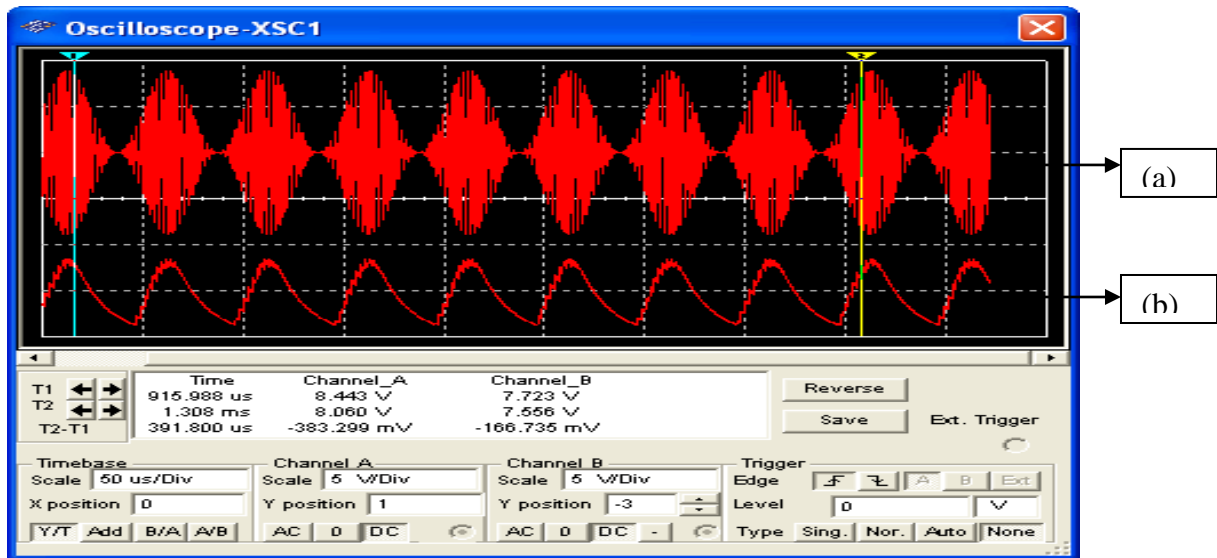


Figure 8: Diode detector output response a). Input b). Output

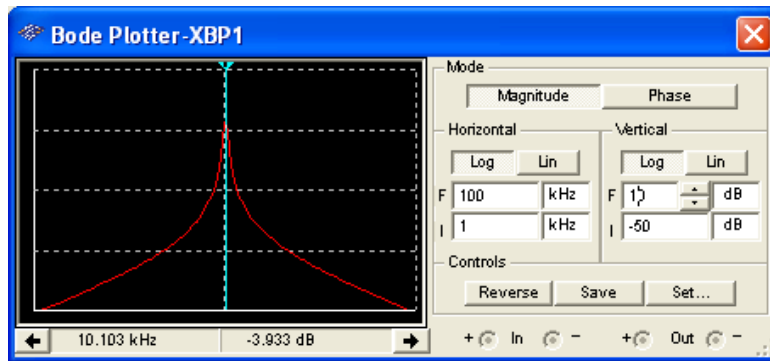


Figure 9: Band –pass network response diagram to extract the 10kHz signal.

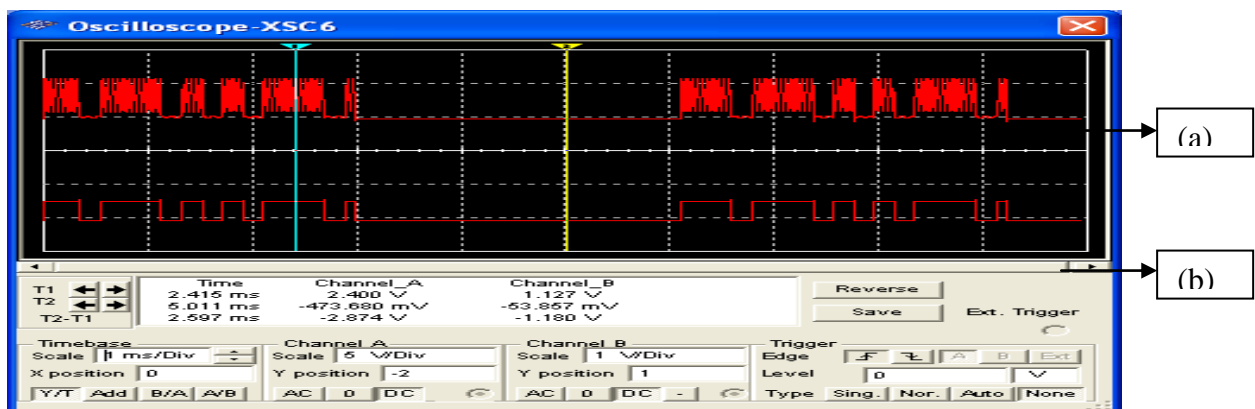


Figure 10: a).Output from the 20kHz filter, b). The comparators output giving the digital signal

IV. Conclusion

The receiver circuit designed receives an fsk signal at 500 kHz, the receiving amplifier filters the incoming signal and amplifies the input voltage to a useable level at 4.5V. The output from the filters through the comparators gives the digital equivalent of the coded signals sent by the transmitter circuit, and this can be transferred to a microcontroller circuit, to act as a coded signal representing information from the transmitting end. The reliability of the designed receiver circuit was calculated for a 1 year continuous operating period, and was found to be 74.7%. This digital signal can be used for many security information purpose including electronic coding of housing units in a decentralized community for electronic policing of an environment under surveillance, to solve the problems of household breaking –in and stealing, robberies and other crime preventive measures.

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