Amplitude modulation essay sample

Sociology, Communication

Today, communication has entered into our daily lives in so many different ways that it is very easy to overlook the multitude of its facets. From the radios and televisions to the mobile phone in our hand, all are capable of providing us with rapid communication from every nook and corner of the world. In the most fundamental sense, communication deals with transmitting and receiving information from one point to another through a channel. But we can't transmit information as such from one place to another. The message signal is needed to undergo a process called modulation before being transmitted due the following reasons: 1. To send a signal over long distance, it requires more energy. Energy and frequency are related by the Planck's formula E = hν (1. 1)

where E = energy of the signal h = Planck's Constant ν = frequency of the signal So when the frequency is low, energy will be obviously low. To increase the energy of the signal, we have to use a high frequency signal, which is done by modulation. 2. To decrease the antenna height. We know that for transmitting a signal of wavelength λ , the antenna height must be λ/4. So if we want to send 1 Hz (λ = 3 × 108 m)signal using an antenna, its height must be 3

75, 000 km. It is impossible to build such a huge antenna. Suppose , if the same signal is modulated to some high frequency say 88 MHz (λ = 3. 4m), antenna height needed is 0. 8522 m only which is quite easy to construct. Thus, we can see that the message signal which we have to send must be modulated before its transmission. In the process called modulation, we use a high frequency signal called carrier whose parameters may be varied in accordance with the message signal. We may classify the modulation schemes into continuous-wave modulation and pulse modulation. In continuous-wave modulation, we have three types of modulation schemes, namely, amplitude , frequency and phase modulation. In amplitude modulation, the amplitude of the carrier wave is varied in accordance with the message signal. AM is the scheme which are used in broadcasting radio programs. In this project, we would be trying to implement an analog medium wave modem, which uses a super heterodyne receiver and would try to generate, transmit, receive and demodulate the AM signal and retrieve the message signal.

Chapter 2

Theory

Before designing the AM modem, the first step we have to do is to make a mathematical model of the system so that we can analyse it easily. In Amplitude modulation, we would be varying the amplitude of the carrier signal in accordance with the message signal. So, let m(t) denote the message signal and M (f) its Fourier transform. Let us denote the carrier frequency to be ωc and the carrier amplitude to be Ac . Then the carrier signal is given by $c(t) = Ac \cos(\omega c\ t)$ (2. 1) Now we are modulating the amplitude of the carrier signal c(t) with the message signal m(t). So, $A(t) = Ac + m(t)$ where A(t) is the amplitude of the modulating signal. Now, we can write the equation of the modulated signal as $x(t) = A(t)\cos(\omega c\ t)$ Substituting A(t), $x(t) = (Ac + m(t))\cos(\omega c\ t)$ ie, $x(t) = Ac\ (1 + m(t)$

$Ac\ )\cos(\omega c\ t)$

(2. 2)

(2. 3)

Now, we define mn (t) as the normalised message signal and Am as max(m(t)). So, the above equation can be modified as 5

x(t) = Ac (1 +

Am mn (t))cos(ωc t) Ac

Now, we can define another term k such that, k= Am Ac (2. 4)

This k is called the modulation index which is a measure of the modulation done. It is a quantity which gives a measure of how much the modulated parameter (the amplitude in this case) of the carrier signal varies around its unmodulated level. Now, substituting k in the equation , we obtain x(t) = Ac (1 + kmn (t))cos(ωc t) The picture given below show an amplitude modulated signal. (2. 5)

Figure 2. 1: a. Carrier Signal b. Message Signal c. AM signal

From equation (4) and (6), we get A(t) = Ac (1 + kmn (t)) . ∴ we get, Amax = Ac (1 + k) Amin = Ac (1 − k) as the minimum and maximum values of the normalised message signal m(t) or mn (t) to be precise is -1 and +1 respectively. Applying componendo and dividendo we get k= Amax − Amin Amax + Amin (2. 6)

Now, we can further simplify the equation for AM by considering the normalized messaged signal mn (t) to be cos(ωm t) where ωm is the message frequency. Now the modulated signal becomes x(t) = Ac cos(ωc t) + kAc 2 cos((ωc

+ ωm)t) +

kAc 2 cos((ωc

− ωm)t)

Now, for transforming it into frequency domain, we take Fourier transform. X(f) = Ac (δ(f − fc) + δ(f + fc)) + kAc (M (f − fc) + M (f + fc)) (2. 7) 2

Thus, we can see that in the case of a single tone modulation the frequency spectrum essentially consists of impulses at three distinct frequencies, namely ωc , ωc + ωm (called the upper sideband as it is of higher frequency), ωc − ωm (called the lower sideband as it is below the carrier frequency), each being weighted by the above mentioned amounts. We can now calculate the energies provided by different frequencies. c Total Power = A2 + 2

Ac 2 k 2 4

∴ the efficiency is η=

k2 2 + k2

(2. 8)

Chapter 3

Principles and Circuits Used

AM Generation Circuit

From the mathematical model of the system that we have developed , we find that the resultant signal consists of three distinct frequencies (assuming that both carrier and message are pure sinusoids). Hence we have a system that takes in two frequencies and gives out three frequencies. No system that behaves linearly can produce new frequency components from existing ones. So the physical implementation of amplitude modulation has to be done using non-linear systems. We can use BJT as a non-linear circuit. In order to have low power consumption , we will use class C amplifier.

To make the output current of a Class C amplifier proportional to the "modulating voltage, we apply this voltage in series with any of the dc supply voltages for this amplifier. This property can be utilized to produce an amplitude modulated signal. To obtain the required amplitude modulation, the Class C BJT amplifier is modified. The carrier is given as the input signal by applying to the base of the BJT using a capacitive coupling. Since the frequency of the input is high, a BJT capable of high frequency operation like BF195 is to be used. A resistance of high value is connected across the base-emitter junction so as to keep the time period of the capacitor discharging very high. As a result, the capacitor will charge quickly, via the capacitor-base-emitter loop (which will essentially be a very low resistance path), but discharges very slowly via the capacitor-resistor loop as its time constant is designed to be very high. The capacitor now acts almost like a constant voltage source, shifting the base voltage level so as to drive the transistor to Class C operation.

The BJT is initially biased in cutoff and reaches active region only when input signal reaches appropriate levels owing to the charged capacitor connected in series to it. The amplitude of the output signal must vary with the message signal. The output of the amplifier depends upon the VCC , the bias voltage, as well as the input given. So the modulating signal is applied at the collector via transformer coupling i. e., using an Audio Frequency Transformer (since the message signal has a frequency which is in the AF range). A tank circuit is also connected in series between the collector terminal and the message signal. The tank circuit is incorporated in the circuit by using an Intermediate Frequency Transformer (IFT).

The tank circuit together with the amplifier constitute a tuned amplifier. The resonant frequency of the tank circuit is set to be the frequency of the carrier signal. The output at the collector terminal of the BJT is a series of current pulses with their amplitudes proportional to the modulating signal. The current pulses initiates damped oscillations in the tuned circuit. Each oscillation produced in this manner would have an initial amplitude proportional to the size of the current pulse and a decay rate dependent on the time constant of the circuit. The train of pulses fed to the tank circuit would generate a series of complete sine waves proportional in amplitude to the size of the pulses. Thus the output from the tank would be an amplitude modulated signal. Also, high power is required for amplitude modulated signal generation. The class C amplifier has very high efficiency and is used in high frequency, high power applications.

Super Heterodyne Receiver

From the AM generation circuit, the modulated signal is sent to the receiver through a lossy channel. So, the signal which reaches the receiver would be corrupted by noise and hence it has to undergo certain processes before being demodulated. This is done by a super-heterodyne receiver which consists of an RF-tuned amplifier , which amplifies and passes only the carrier frequency from the received signal , Mixer which mixes the carrier frequency and a particular frequency generated from an oscillator to produce an intermediate frequency which is generally 455 kHz , which is then passed through an IF-tuned amplifier to pass and amplify only the intermediate frequency which is then fed to the demodulation circuit.

Figure 3. 1: A Super heterodyne receiver

Oscillator-Colpitts' Oscillator

Figure 3. 2: Colpitts' Oscillator

The AM modulated signal received is amplified by RF amplifier and then is fed to mixer which is connected to the Colpitts' oscillator to produce a particular frequency. The frequency of the Colpitts' oscillator is set to a particular frequency, usually higher than the received frequency such that after mixing it produces the intermediate frequency. $f_{MIXER} = f_{COLPITTS} - f_{AM}$ (3. 1)

We have preferred LC oscillators over other RC oscillators becaue they have high Q-value compared to RC oscillators. Colpitts' is preferred over Hartley oscillator because the latter uses two inductors. The design of the oscillator will be discussed in detail in the design section.

Mixer

Figure 3. 3: Mixing Process Mixer is usually a multiplier which multiplies two frequencies and produce the sum and difference frequencies. If you have two signals say, one from local oscillator and the other, the received signal, $x1$ (t) = $A1 \cos(\omega 1\ t)$ $x2$ (t) = $A2 \cos(\omega 2\ t)$

$\therefore x1 (t).\ x2 (t) =$

$A1\ A2\ 2 (\cos(\omega 1$

$- \omega 2)t) + \cos(\omega 1 + \omega 2)t))$

From this, we filter out the the difference frequency and is fed to the IF tuned amplifier.

IF Amplifier

The output from the mixer is only half the amplitude (one-quarter the power) of the individual inputs; thus, there is a loss of 6 dB in this ideal linear mixer. (In a practical multiplier, the conversion loss may be greater than 6 dB, depending on the scaling parameters of the device. Here, we assume a mathematical multiplier, having no dimensional attributes.) Therefore, there is a need to amplify the output. Therefore, we use IF-tuned amplifier which tunes it to the intermediate frequency and amplifies that.

Demodulation

In an AM wave, the envelope of the transmitted signal carries the information of the message signal, the envelope being generated by the sinusoidal variations of the high frequency carrier. In order for the analysis, we have to rewrite the equation of the Am wave in inphase-quadrature form, ie, $x(t) = Ac(t)(1 + kmn(t))\cos(\omega c\, t + \varphi)$

$\therefore x(t) = Ac(t)(1 + kmn(t))\cos(\varphi)\cos(\omega c\, t) + Ac(t)(1 + kmn(t))\sin(\varphi)\sin(\omega c\, t)$ Writing the previous equation in inphase-quadrature form, we get $x(t) = mI(t)\cos(\omega c\, t) + mQ(t)\sin(\omega c\, t)$ where $mI(t) = Ac(t)(1 + kmn(t))\cos(\varphi)$ and $mQ(t) = Ac(t)(1 + kmn(t))\sin(\varphi)$

The envelope of the signal E is given by $E= mI(t)2 + mQ(t)2 = Ac + kAc\, mn(t)$

Thus, the envelope function E is proportional to the variations in the message signal. So, if we detect the envelope , we can get back the message signal. But we need only positive or negative part of the envelope. So to get one of these parts we can use a diode to clip off the positive or negative parts. Then we have to hold on to the current peak value until the next peak comes. This would mean a charging element that charges up very quickly but discharges

at a very slow rate so that between peaks the voltage is fairly constant. We can use a capacitor and a resistance combination with a high discharge time constant for this so that the capacitor charges up during the positive rise of the AM and discharges until the next positive rise comes. But this is only a rough approximation we can't be sure of. So we must arrive at an expression that relates the time constant of the capacitance-resistance block to the message frequency and the modulation depth so that we would sure that this circuit would be able to detect the envelope.

Figure 3. 4: Envelope Detector The voltage across the capacitor vc = Ee− RC where E is the envelope of the AM. Since the time constant(RC) is very much greater than the 1 interval between two cycles of the carrier(ωc), we can apply Taylor series to the equation. ∴ vc = E(1 − t RC)

In order for the capacitor to follow the envelope, the magnitude of the slope of RC must be greater than the magnitude of the slope of E(t). ie, dvc dt

| dE | ∴ dt

E RC

| dE | dt

Now, from above we know that E = Ac + Ac mn (t). Taking single tone modulation, we can substitute mn (t) as cos(ωm t) ∴ dE dt

= −kωm Ac sin(ωm t) ∴ we can write, Ac (1+kcos(ωm t) ωm Ac sin(ωm t) ∴ RC 1+kcos(ωm t) RC ωm sin(ωm t)

The worst case is when the right side is minimum which happens when cos(ωm t) = −k. Substituting this condition we get, √ 1 − k2) (3. 2) RC (ωm k Thus we can see that the RC of the envelope detector depends on the maximum message frequency and the modulation index.

In usual transmissions before envelope detectors there will be different amplifier stages and the signals will have variable strength levels with low and very high strength components. If normal amplifiers are used both the low strength as well as the high strength signals will be amplified to the same amount leading to a suppression of the low strength part which might contain valuable information. To resolve this issue we use a system called Automatic Gain Control(AGC). In AGC, we take the dc offset that is present in the detected envelope and feed it back to the amplifier stage so as to control its gain in such a way so that for the stronger signal components the gain is reduced. To realize this we take the ripple free envelope output but with the dc offset and pass it through a low pass filter. The same resistor capacitor combination as described above can be used but with the time constant now much greater than the time period of the message signal so that we get a nearly dc voltage at the output of the AGC terminal. This is the concept of AGC.

Chapter 4

Design

AM Generation Circuit

In this circuit, we use a high frequency BJT BF195, an AFT and an IFT tuned to 550 KHz using an external capacitance of 10 pF. A resistance of high value(1 MΩ) is connected across the base-emitter junction so as to keep the time period of the capacitor discharging very high and a capacitor of 0. 1μF is used so that time period is very high. Actually, we should be transmitting the signal in RF(500-1500 kHz)and therefore , we should replace the IFT with

RFT. The carrier, generated from an oscillator, is applied to the capacitor and the message signal to the AFT. The output of the RFT/IFT is connected to the transmitting antenna. We have to take care of the antenna impedance also while tuning the RFT which would be in the range of 75Ω. Power supply of 12 V have been supplied. Our aim is to get a modulation index of 0. 7 and the message signal applied is 2 kHz and the carrier signal to be applied is 550 kHz.

Super Heterodyne Receiver

In order to design the receiver, we have to take care of the loading effects from the other parts. So, we have to start designing from the envelope detector

Envelope Detector

From the equation

√

RC

(

1−k2 ωm k)

we have to find the value of R and C. We know that we designed the transmitter for ωm = 2 KHz and k = 0. 7. Substituting these values, we get R= 33 kΩ and C = 2 nF. For the diode , we use a high frequency diode OA79. After the diode and capacitor resistor sections, we need the ripple remover circuit. This is a series combination of a capacitor and resistor with output taken across the capacitor. The time constant of this section must be much greater than the ripple time period. R1 C1 = 100T R1 C1 = 100 f1c R1 = 2. 2k C1 = 0. 1μF

Figure 4. 1: Envelope Detection After all these sections we get the message signal with an offset dc voltage. So at the terminal section a blocking capacitor Cb = 4. 7μF. In the lab we would make this T-circuit to π circuit.

For getting the AGC voltage we need the dc offset message signal and it needs to be passed through a capacitor-resistor section whose time period is much greater than that of message. So effectively the dc-offset voltage is obtained. R2 C2 = 100T R2 C2 = 100 f1 R3 = 3k C3 = 10μF m

IF Amplifier

Figure 4. 2: IF Amplifier Here, we use an amplifier circuit with an IF-transformer which is tuned to 455 KHz. Let Vcc = 12V and we take the load to be 1 k and let us assumeVCE = 0. 5Vcc = 6V and Ic = 2 mA. We assume that Ic IE . Now, applying voltage analysis, VC = VCC − Ic RC VC = 10V. VE = VC − VCE = 4V. ie, IE RE = 4V RE = 2k.

RF Mixer

Here also , BJT can used to design the circuit. At the output(collector) side in order to flter out the required output difference frequency an IFT can be kept. Now in order to take care of the problem of loading we have to give a substantial amount of resistance at the emitter of the transistor,

Figure 4. 3: Mixer where the oscillator output will be fed. The input frequency will be given to the base of the transistor so that the base-emitter voltage will be the difference of these two voltages. There has to be a resistor from collector to base for giving the necessary bias. The dc biasing is designed as below. BF195 high frequency transistor is used. C IC = 4mA, VCC = 12V, VCE = 8V, β = 60 IB = Iβ = 66. 6μA VCC − RE (β + 1)IB − V CE = 0 RE 1k VCC = IB RB − 0. 95 = IE RE RB 62k

The capacitors used for coupling are 0. 1uF each.

Colpitts’ Oscillator

In the superheterodyne receiver, we use colpitts’ oscillator as the oscillator whose frequency would be 455 KHz more than that of modulated frequency. the design of the colpitts’ oscillator is done by analysing its small signal model. For the sake of simplicity in analysis, we have neglected Cμ and the input resistance Rπ . In order to find the loop gain, we break the circuit at the base, apply an input volatage Vπ and find the output voltage obtained at the input. Writing nodal equation, sC2 rπ + gm Vπ + (Taking Vπ common we get, s3 LC1 C2 + LC2 2 1 s + s(C1 + C2) + (gm +) = 0 R R (4. 2) 1 + sC1) (1 + s2 LC) = 0 R (4. 1)

Figure 4. 4: Colpitts’ Oscillator Now substituting s= jω, we get LC2 1 − ω2) + j(ω(C1 + C2) − ω 3 LC1 C2) = 0 (4. 3) R R For oscillations, both imaginary and real part should be zero. Hence, we (gm +

Figure 4. 5: Small Signal Model get two conditions. ω0 = 1

C L C11 C22 +C

(4. 4)

gm R =

C2 C1

(4. 5)

For getting oscillations with higher amplitude, we have to design the amplifier part with high gain. Let A= 185. LetIc = 4mA (for BF195) For the transistor BF195, typical β = 60. Ic gm = VT = 0. 1538 ∴ Rc 1. 2K Now if we take thevenin equivalent of R1 and R2 at the base of the transistor we get the base emitter equations as : C VT H − Iβ . RT H − VBE (on) − β+1 IC RE = 0 β VCC = 12V VCE = 6V RE = 300Ω For stability, RT H = 0. 1(β + 1)RE ∴ we get, R1 = 47K, R2 = 10K We have designed a colpitts' oscillator for 550 KHz frequency for carrier signal and 1 MHz for mixer. For 550KHz frequency, we used L = 690μH and C1 = 470pF and C2 = 163pF . For 1MHz, L = 138μHandC1 = 470pF and C2 = 330pF .

Chapter 5

Observations and Results

At first , we generated a carrier signal of frequency 550 KHz using Colpitts' oscillator. This was fed to the AM generation circuit and we obtained an AM signal of modulation index 0. 5 and with maximum amplitude 3 V. We applied message signal of 1V from CRO to the circuit. Then it was transmitted. In the beginning we did not get the output. We varied the message signal, but the output was not not varying with it. When we checked the connections , it was seen that the terminals of AFT has been interchanged. We corrected it and the output was obtained. In order to make sure that the modulation was proper over a range of message amplitude values, the amplitude of the message was varied.

The modulation depth was observed to be very small, so the function generator was replaced and then the amplitude of the output was observed to change in accordance with the message signal over a wide range of message amplitudes and frequencies. In the receiver part, though it was easy to set up all the individual circuits, we had to redesign the values of each and every circuit based on the loading effects. We had designed a Colpitts' oscillator with frequency 1 MHz for the mixer and we got about 995 MHz. But getting a perfect sinusoidal from the oscillator was the toughest job. At first, we got a damping oscillation and we understood that the pole was on the left side of the imaginary axis and more power have to be given to push the poles to the imaginary axis. So we increased the gain of the amplifier and also increased the power. Then we got a sine wave but with some distortion in the positive half cycle. We understood that it was due to the frequency distortion caused due to the low Q factor of the inductance box. So, we changed the inductance box and used color-coded specific value inductor. This reduced the distortion to the minimum.

In the mixer, we applied an AM signal of frequency 550 KHz and an sinusoidal signal of frequency 1 MHz. Then we got an output frequency of 477 KHz. Here also, in the beginning we did not get the output. We could not understand the problem and debugged the circuit. But we could not find any mistakes in our circuit. But, when we checked the amplitudes of the carrier and the message signal, it was seen that the amplitude of the message signal was too small compared to the carrier. So, we made both the amplitudes comparable and then we got the output. We also had designed for an IF amplifier tuned to the intermediate frequency and we got an output of 455 KHz at the output with an apprx. gain of 20. Also, the demodulation part as also working sucessfully.

When AM signal was given to the envelope detector, it detected the message signal successfully. But, when we connected all the blocks of the receiver together, it did not work due to loading effects. We could not obtain the output from the mixer, with Colpitts' connected to it. We could only see some feeble oscillations at the output. We tried to remove the loading effects, but it gave us no result. We connected a capacitor of high value in series so as to reduce the load, but no output was observed from the demodulator. Again, we checked the individual circuits, but all of them were working.

Conclusion

Amplitude Modulation is one of the simplest modulation schemes used. Though it has many disadvantages like noise interference and all, it is one of the cheapest modulation scheme. Nowadays when various digital systems are being made, analog communication may seem to be obsolete. But it is one of the important part of every communication scheme. This project gave us an insight to the concepts that we need to have in order to design analog circuits. It made us experience the problems really faced by the designers in designing such circuits. Now, when we look at a radio, we can no longer see it as a simple radio but can rather see the hard works of the designers and their creativity behind the making of such a wonderful object. We can now understand that it is not at all a technician's job but the beauty of an engineer's creativity knowing all the concepts behind this. We were afraid at the beginning whether we would get the output or not, but it gave us a confidence to face such problems in the future. It is a reality that we did not get the the final output but the insight it has given us about the circuit design is much more precious than the output. To get the output is of course important, but now we are confident that we would get the output the next time we do this circuit.

Bibliography

1. Simon Haykin, Communication Systems, 3/e, John Wiley and Sons, 1998 2. B. P. Lathi, Modern Digital and Analog Communication, 3/e, Oxford University Press, 1998. 3. A S Sedra and K C Smith , Microelectronic Circuits, Oxford University Press, 1998 4. John G Proakis and Masoud Salehi, Communication Systems Engineering, Prentice Hall, 1994.