Individual Project

ECE 478/ECE 570 Principles of Communication Systems

SIU Southern Illinois University CARBONDALE

Date: 02/26/2025
Due date: 04/04/2025
Section: Design of Amplitude and Frequency Modulators
Number of problems: Three
Submission requirements: Upload a single Zip file with solutions, figures, and slides

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Question (01): SO2-DESIGN: KPI - 2.1 (8 factors) and 2.2 (multiple solutions)

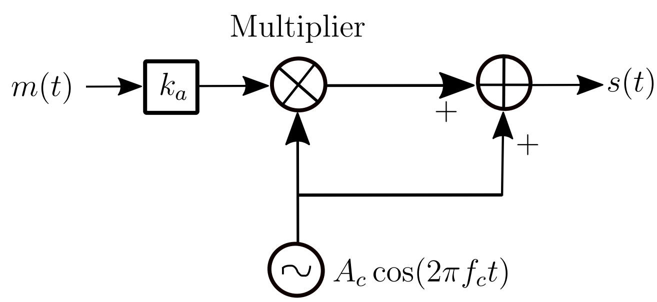

Figure 1: A schematic of an amplitude modulator

Consider the schematic diagram of an amplitude modulator (AM) shown in Fig. 1. Let the information-bearing signal $m(t)$ to the AM modulator in Fig. 1 be a periodic square-wave shown in this Fig. 2. You are asked to design two AM modulators by adhering to the two following specifications.

- 80% modulation
- 120% modulation

By using your designs for the AM modulator, complete the following assignments.

(a) By using an analytical approach, plot the output signals of your AM modulators in time-domain. Thereby, identify and discuss the appropriate receivers for decoding

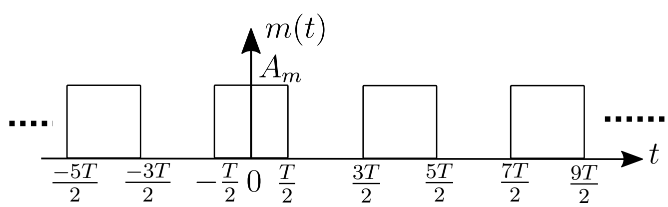

Figure 2: A periodic information-bearing signal

the information-bearing signals from the corresponding AM signals by considering the underlying design complexity and reliability.

(b) By evaluating the Fourier transform of the time-domain AM signals, analytically quantify the amplitude spectrum. Thereby, discuss the transmit power and bandwidth requirements of the AM modulator designs.

(c) Suggest suitable design modifications for your AM modulator designs to reduce the transmit power, bandwidth requirement, reliability and receiver complexity. Based on your suggestions, modify your AM modulator designs by clearly demarcating your multiple design objectives/solutions. Thereby, analytically quantify the output signals of the modified AM modulators both in time-domain and frequency-domain. Plot the output signal in time-domain and amplitude spectrum in frequency-domain. Hence, quantify the transmit power and bandwidth requirements of your modified/secondary designs.

(e) Verify your analytical design approach and numerical values for the transmit power and bandwidth requirements corresponding to the above multiple designs by developing Matlab programs to simulate the input signals, amplitude modulation operations, output signals, transmit power and transmission bandwidth.

(f) By considering your AM modulator designs and their underlying key performance metrics, including transmit power, bandwidth, reliability and complexity, choose the appropriate design for the following applications by providing adequate justifications.

- To implement tele-medicine in public health sector with high reliability
- To broadcast national traffic and road closure information to ensure driver safety
- To broadcast information about welfare benefits, including social security, medicare, unemployment insurance, and worker's compensation
- For a radio transmitter that operates with renewable energy having an objective of reducing global warming
- To broadcast cultural music with high fidelity
- To broadcast social information about diversity and demographics for a broader audience
- To broadcast daily news for rural communities with a low budget
- For broadcasting radio services to a global audience with high fidelity

Question (02): SO4-JUDGE: KPI - 4.1 (ethics) and 4.2 (four impacts)

Recall that in the lectures, you learned about various design trade-offs among key parameters of a communications system, including transmit power, coverage range, transmission bandwidth and implementation complexity. The performance of communication systems can be improved by optimizing these trade-offs. The underlying communication engineering solutions with competing objectives will have substantial impact in global, economic, environmental, and societal contexts.

Assume that the task of designing a simulator to generate frequency modulated (FM) signals for a public broadcasting service is assigned to two communication engineers. It is worth noticing that these FM simulators will be used to verify key performance metrics prior to synthesizing and implementing the actual FM transmitter. The two Matlab-based simulators, which had been designed independently by the two engineers, are given below.

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
FM signal simulator - Design-1
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
clear all;
clc;
disp('=================================================================');
disp('FM modulation: Design-1');

%% parameters
Pt = 105000; % transmit power (watts)
fc = 103.3*10^6;    % carrier frequency -----------  Carrier ...
    frequency (FM range is 88 MHz - 108 MHz)
Ac = sqrt(2*Pt); % amplitude of carrier signal (volts)
Fs = 2^30;  % sampling rate
fm = 38000;      % modulating frequency -------------  (50Hz to ...
    15kHz) (pilot carrier 19kHz)
Ts = 1/Fs;       % sampling period
t = 0:Ts:10^(-6);        % observation period
L = length(t);
beta = 1;     % modulation index ---------------------------- set ...
    it to 1 to make the bandwidth less than 200kHz  (max = 5)
Am = 1; % amplitude of the modulating signal (volts)
Deltaf = beta*fm; % frequency deviation
kf = Deltaf/Am; % modulator sensitivity
FFTsize = 4096;

%% generate modulating signals (message signals)
m_t  = Am*cos(2*pi*fm*t);

%% generating intergrate signal
theta = 2*pi*fc*t + 2*pi*beta*cumsum(m_t)*Ts;

%% generating FM Modulated signal
s_t  = Ac*cos(theta);

%% generating spectrum of FM wave
n = 2^nextpow2(L);
```

```
dim = 2;
Y = fft(s_t,n,dim);
Freq = 0:(Fs/n):(Fs/2-Fs/n);

P2 = abs(Y/L);
P1 = P2(:,1:n/2+1);
P1(:,2:end-1) = 2*P1(:,2:end-1);

bw = 2*Deltaf*(1+1/beta);
fprintf('Transmission bandwidth = %d Hz \n',bw);
fprintf('Transmit power = %d W \n',Pt);

%% plot the results
% plotting massage signal
figure(3)
% subplot(2,1,1);
plot(t, s_t);
grid on;
title ('FM Signal');
xlabel ('time (ms)');
ylabel ('Amplitude');
% axis([0 0.5 -1.5 1.5]);

% plotting carrier signal
figure(4)
% subplot(2,1,2);
stem(Freq,P1(:,1:n/2))
% stem(Freq, (Sm_f));
grid on;
title ('spectrum of FM wave ');
xlabel ('frequency');
ylabel ('Amplitude spectrum');
% xlim([95 105 ]);

%% Path-loss calculation
c = 3*10^8; % speed of light
lambda = c/fc; % wavelength
d0 = 1; % reference distance in meters
eta = 3; % path-loss exponent
d = 100*10^3; % distance in meters
PL = ((4*pi*d0/lambda)^2)*((d/d0)^eta);
Pr_min = -110; % dBm receiver sensitivity
Prm = 10^(Pr_min/10); % mW receiver sensitivity
Pr = Prm*10^(-3); % W receiver sensitivity

d_cov = ((Pt/Pr)^(1/eta))*d0*((lambda/(4*pi*d0))^2);

fprintf('Coverage = %.2f km (with receiver sensitivity = %.1f dBm ...
    and path-loss exponent = %.1f) \n',d_cov/1000,Pr_min,eta);
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
FM signal simulator - Design-2
```

```
%==================================================================
clear all;
clc;
disp('======================================================');
disp('FM modulation: Design -2');

%% parameters
Pt = 0.5; % transmit power (watts)
fc = 10^9;    % carrier frequency
Ac = sqrt(2*Pt); % amplitude of carrier signal (volts)
Fs = 1024;  % sampling rate
fm = 2;     % modulating frequency
Ts = 1/Fs;      % sampling period
t = 0:Ts:120;       % observation period
L = length(t);
beta = 10;     % modulation index
Am = 1; % amplitude of the modulating signal (volts)
Deltaf = beta*fm; % frequency deviation
kf = Deltaf/Am; % modulator sensitivity
FFTsize = 4096;

%% generate modulating signals (message signals)
m_t = Am*cos(2*pi*fm*t);

%% generating intergrate signal
theta = 2*pi*fc*t + 2*pi*beta*cumsum(m_t)*Ts;

%% generating FM Modulated signal
s_t = Ac*cos(theta);

%% generating spectrum of FM wave
n = 2^nextpow2(L);
dim = 2;
Y = fft(s_t,n,dim);
Freq = 0:(Fs/n):(Fs/2-Fs/n);

P2 = abs(Y/L);
P1 = P2(:,1:n/2+1);
P1(:,2:end-1) = 2*P1(:,2:end-1);


bw = 2*Deltaf*(1+1/beta);
fprintf('Transmission bandwidth = %.2f Hz \n',bw);
fprintf('Transmit power = %.2f W \n',Pt);

%% plot the results
% plotting massage signal
figure(3)
% subplot(2,1,1);
plot(t, s_t);
grid on;
title ('FM Signal');
xlabel ('time (ms)');
ylabel ('Amplitude');
```

```
    axis([0 0.5 -1.5 1.5]);

    % plotting carrier signal
    figure(4)
    % subplot(2,1,2);
    stem(Freq,P1(:,1:n/2))
    % stem(Freq, (Sm_f));
    grid on;
    title ('spectrum of FM wave ');
    xlabel ('frequency');
    ylabel ('Amplitude spectrum');
    xlim([95 105 ]);

    %% Path-loss calculation
    c = 3*10^8; % speed of light
    lambda = c/fc; % wavelength
    d0 = 10; % reference distance in meters
    eta = 4; % path-loss exponent
    d = 100; % distance in meters
    PL = ((4*pi*d0/lambda)^2)*((d/d0)^eta);
    Pr_min = 10; % dBm receiver sensitivity
    Prm = 10^(Pr_min/10); % mW receiver sensitivity
    Pr = Prm*10^(-3); % W receiver sensitivity

    d_cov = ((Pt/Pr)^(1/eta))*d0*((lambda/(4*pi*d0))^2);

    fprintf('Coverage = %.2f km (with receiver sensitivity = %.1f dBm ...
        and path-loss exponent = %.1f) \n',d_cov/1000,Pr_min,eta);
```

(a) [SO4.1] Run the above simulators and generate the output FM signals. Thereby, identity the transmit power, transmission bandwidth and the FM channel number of each of the two designs. Based on the outputs of these two designs, determine which communication engineer has complied to the engineering code-of-ethics by adhering to the standards specified by the US Federal Communication Commission (FCC) for FM broadcasting. Justify your choice of design as much as possible by discussing the ethical conduct and responsibilities of an engineer involving in communication system designs. [Hint: refer to the standards specified in "Fixed and Base Station FM Transmitters - NIJ Standard-0201.O1"].

(b) [SO4.2] Recall that in the lectures, you learned that the available frequency-spectrum for communication systems is a scarce resource, it is expensive and shared/allocated among many service providers. To this end, FCC is responsible for allocating frequency channels within a specific band to various services for communication service providers. These service providers need to purchase a license to use the frequency channels with a minimum bandwidth requirement for a particular communication service by the FCC. Moreover, the FCC specifies maximum transmit power thresholds that a radio transmitter can be configured to ensure public safety as a radio transmitter with an excessive transmit power is harmful to all living-beings in its vicinity.

(b.1) Discuss the trade-offs among bandwidth, transmit power, coverage, reliability and implementation complexity of the above two FM modulator designs. In answering this question, as a design engineer of a communication system, you must pay a special attention to transmission bandwidth, power, and radio coverage area in the context of global, social, environmental and economic factors.

(b.2) Based on your discussion, determine which of the above designs would be more favorable for the following use-cases. Also provide design modifications/system-parameters to better suit the FM modulator designs to the specific use-cases below. Justify your choices as much as possible.

- To establish a energy-efficient/greener communication initiative for FM broadcasters by aiming to reduce the emission of green-house gases to slow global-warming
- To safely provide FM radio broadcasting services about social-welfare benefits
- To reduce the FM transmitter deployment density in a given geographical area
- To broadcast high fidelity musical programs to a broader community with a low-budget

Question (03): SO3-Communicate: KPI - 3.1 (clear and concise), 3.2 (references) and 3.3 (second audience)

Prepare a presentation of 12 slides on the advantages and disadvantages between FM-based and AM-based communications by strictly adhering to the following instructions.

(SO3.1) Be clear and concise in preparing your slides.

(SO3.2) Your slides must be technically accurate and linguistically sound. Provide citations for all references according to the IEEE citation guidelines (`https://ieee-dataport.org/sites/default/files/analysis/27/IEEE%20Citation%20Guidelines.pdf`).

(SO3.3) The last two slides must consist of a re-explanation of your technical facts to a non-expert audience at newspaper level defined as 6.0-8.0 grade on Flesch-Kincaid Grade Level. [Hint: Use Flesch-Kincaid feature offered by Microsoft to verify the reading grade of your last two slides.]