Satellite Communication
Assignment 2

EEE F472

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Problem 1

- Write the algorithm to compute position of the Friendship 7 spacecraft in the form of pseudocode (or present a flowchart)
- Write a computer program (in MATLAB) to compute position of the Friendship 7 spacecraft

Pseudocode

1. Declare constants
2. Input date, time (precisely)
3. convert into fractional day with the value of time (fractional day = hh/24+mm/1440+ss/86400)
4. if month <=2, year = year -1 ; month = month + 12
5. Calculate Julian date with obtained params
6. Calculate various orbital parameters
7. Convert to cartesian co-ordinates from obtained angular orbital parameters. Alpha and Delta is obtained from here
8. Compute GST with its empirical formula
9. Make sure GST is in the range [0,360)
10. Calculate L=GST - Alpha
11. L = wrapTo180(L)
12. Print Delta and L (lat. and long.)

MATLAB Code

```
clear
close all
clc

%%%%%%%%%%%%%%%%%%%%
%Required constants%
%%%%%%%%%%%%%%%%%%%%

a = 6589116;
e = 0.007589;
i = 32.54;
Omega = 235.2;
omega = 181.2;
M0 = 228.5;
T0 = 2437716.11642;

GMe = 3.986004415 *10^(14);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Taking required input from the user%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

disp("Enter the precise date and time needed to find latitiude and longitude of the ...
    Friendship 7 spacecraft")

date = input("Enter the required date: ");
month = input ("Enter the required month(in number format): ");
Y = input ("Enter the required year: ");
hh = input("Enter the required hour of the day (24h format): ");
mm = input("Enter the required minute of the hour: ");
ss = input("Enter the required second of the minute: ");

d = ((hh/24)+(mm/1440)+(ss/86400));
D = date + d;
if month≤2
    month = month+12;
    Y = Y -1;
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Calculation of the Julian day
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

A = floor(Y/100);
B = 2 - A + floor(A/4);

t = (floor(365.25*(Y+4716))+floor(30.6001*(month+1))+D+B-1524.5);
% t = 2459580;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Calculating required orbital parameters
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

n = (86400/(2*pi))*sqrt(GMe/a^3);
M = deg2rad(M0) + 2*pi*n*(t-T0);

syms E_sym
eqn = M == E_sym - e*sin(E_sym);
E_r = solve(eqn,E_sym);
E = rad2deg(double(E_r));
f = double(2*atand(sqrt((1+e)/(1-e)) * tan (E/2)));
u = omega + f;

```

```
r = a*(1-e*cosd(E));

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Converting orbital parameters to Latitude and Longitude
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%cartesian conversion

x = r*((cosd(u)*cosd(Omega))-(sind(u)*sind(Omega)*cosd(i)));
y = r*((cosd(u)*sind(Omega))+(sind(u)*cosd(Omega)*cosd(i)));
z = r*sind(u)*sind(i);

Alpha = atan2d(y,x);
Delta = asind(z/r);

T = ((t-2451545)/36525);

GST_d = (280.46061837 + (360.98564736629*(t-2451545)) + (0.000387933*T^2) - ...
    ((T^3)/38710000));
GST = mod(GST_d,360);

L = wrapTo180(alpha - GST);
psi = Delta;

psi_s = angl2str(psi,"ns","degrees2dms");
L_s = angl2str(L,"ew","degrees2dms");

sprintf("The latitude of the spacecraft at this time is %s ",psi_s)
sprintf("The longitude of the spacecraft at this time is: %s\n",L_s)
```

Problem 2

- Consider a satellite non-linear power amplifier (e.g., TWTA) with the following voltage transfer characteristic:

$$v_{out} = b_1 v_{in} + b_3 v_{in}^3$$

  Where $v_{in}(t) = \cos(2\pi f_1 t) + \cos(2\pi f_2 t) + \cos(2\pi f_3 t)$.

  Here, $f_1 = 3.8\text{GHz}$, $f_2 = 3.95\text{GHz}$, and $f_3 = 4.05\text{GHz}$.

- Assume that the satellite transponder bandwidth is from $f_\ell = 3.7\text{GHz}$ to $f_u = 4.2\text{GHz}$

- Determine the amplitude and location of all intermodulation (IM) products within the transponder bandwidth resulting from the power amplifier action on the input signal v_{in}. **Note:** Present your final answers in the form of a table

Solution

Given

$$v_{out} = b_1 v_{in} + b_3 v_{in}^3 \tag{1}$$

We have:

$$v_{in} = \cos(\omega_1 t) + \cos(\omega_2 t) + \cos(\omega_3 t) \quad \text{where} \quad \omega_1 = 2\pi f_1, \quad \omega_2 = 2\pi f_2, \quad \omega_3 = 2\pi f_3 \tag{2}$$

We know that:

$$(a+b+c)^3 = a^3 + 3a^2b + 3a^2c + 6abc + 3ac^2 + b^3 + 3b^2c + 3bc^2 + c^3 \tag{3}$$

Using 3 we have v_{in}^3 to be:

$$\begin{aligned} v_{in}^3 &= \cos^3(\omega_1 t) + 3\cos^2(\omega_1 t)\cos(\omega_2 t) + 3\cos^2(\omega_1 t)\cos(\omega_3 t) \\ &+ 6\cos(\omega_1 t)\cos(\omega_2 t)\cos(\omega_3 t) + 3\cos(\omega_1 t)\cos^2(\omega_3 t) + \cos^3(\omega_2 t) \\ &+ 3\cos^2(\omega_2 t)\cos(\omega_3 t) + 3\cos(\omega_2 t)\cos^2(\omega_3 t) + \cos^3(\omega_3 t) \end{aligned} \tag{4}$$

Applying the trigonometric identities given below:

$$\cos^3 x = \frac{\cos(3x) + 3\cos x}{4} \tag{5}$$

$$\cos^2 x = \frac{\cos(2x) + 1}{2} \tag{6}$$

We can simplify 4 as follows

$$\begin{aligned} v_{in}^3 = &\frac{\cos(3\omega_1 t) + 3\cos(\omega_1 t)}{4} + \frac{\cos(3\omega_2 t) + 3\cos(\omega_2 t)}{4} + \frac{\cos(3\omega_3 t) + 3\cos(\omega_3 t)}{4} \\ &+ \frac{3\cos(\omega_1 t)\cos(\omega_2 t) + 3\cos(\omega_1 t)\cos(\omega_3 t) + 3\cos(\omega_2 t)\cos(\omega_3 t)}{2} \\ &+ \frac{3\cos(\omega_1 t)\cos(\omega_2 t)\cos(\omega_3 t)}{4} \end{aligned} \tag{7}$$

Simplifying further, we arrive at:

$$\begin{aligned}
v_{in}^3 = &\frac{1}{4}\left(\cos(3\omega_1 t) + \cos(3\omega_2 t) + \cos(3\omega_3 t)\right) \\
&+ \frac{3}{4}\big[\cos\{(2\omega_1+\omega_2)t\} + \cos\{(2\omega_1-\omega_2)t\} \\
&\quad + \cos\{(2\omega_1+\omega_3)t\} + \cos\{(2\omega_1-\omega_3)t\} \\
&\quad + \cos\{(2\omega_2+\omega_1)t\} + \cos\{(2\omega_2-\omega_1)t\} \\
&\quad + \cos\{(2\omega_2+\omega_3)t\} + \cos\{(2\omega_2-\omega_3)t\} \\
&\quad + \cos\{(2\omega_3+\omega_1)t\} + \cos\{(2\omega_3-\omega_1)t\} \\
&\quad + \cos\{(2\omega_3+\omega_2)t\} + \cos\{(2\omega_3-\omega_2)t\}\big] \\
&+ \frac{3}{2}\big[\cos\{(\omega_1+\omega_2+\omega_3)t\} + \cos\{(\omega_1+\omega_2-\omega_3)t\} \\
&\quad + \cos\{(\omega_1-\omega_2+\omega_3)t\} + \cos\{(\omega_1-\omega_2-\omega_3)t\}\big] \\
&+ \frac{15}{4}\big[\cos(\omega_1 t) + \cos(\omega_2 t) + \cos(\omega_3 t)\big]
\end{aligned} \tag{8}$$

Hence the final value of v_{IM} is (accounting only for frequencies in the range $f_\ell = 3.7\text{GHz}$ to $f_u = 4.2\text{GHz}$):

$$\begin{aligned}
v_{IM} = &\left(b_1 + \frac{15}{4}b_3\right)\left(\cos(\omega_1 t) + \cos(\omega_2 t) + \cos(\omega_3 t)\right) \\
&+ \frac{3}{4}b_3\left[\cos(\{2\omega_2-\omega_1\}t) + \cos(\{2\omega_2-\omega_3\}t) + \cos(\{2\omega_3-\omega_2\}t)\right] \\
&+ \frac{3}{2}b_3\left[\cos\{(\omega_1+\omega_2-\omega_3)t\} + \cos\{(\omega_1-\omega_2+\omega_3)t\} + \cos\{(\omega_1-\omega_2-\omega_3)t\}\right]
\end{aligned} \tag{9}$$

Presenting the frequencies received in a tabular format:

Amplitude	Location	Frequency
$b_1 + \frac{15}{4}b_3$	f_1	3.8GHz
	f_2	3.95GHz
	f_3	4.05GHz
$\frac{3}{4}b_3$	$2f_2 - f_1$	4.1GHz
	$2f_2 - f_3$	3.85GHz
	$2f_3 - f_2$	4.15GHz
$\frac{3}{2}b_3$	$f_1 + f_2 - f_3$	3.7GHz
	$f_1 - f_2 + f_3$	3.9GHz
	$f_1 - f_2 - f_3$	4.2GHz

Table 1: IM frequencies