ZZS-12 Modulační syntéza

8. prosince 2014

- Amplitudová modulace
- Frekvenční modulace
  - Syntetické zvony
  - Jednoduché syntetické FM nástroje
  - Syntetické zvuky – vítr

Kruhová modulace

$$\sin\alpha \cdot \sin\beta = \frac{1}{2}\left[\cos(\alpha-\beta) - \cos(\alpha+\beta)\right]$$

$$\cos\alpha \cdot \cos\beta = \frac{1}{2}\left[\cos(\alpha-\beta) + \cos(\alpha+\beta)\right]$$

$$\sin\alpha \cdot \cos\beta = \frac{1}{2}\left[\sin(\alpha-\beta) - \sin(\alpha+\beta)\right]$$

$$\cos(2\pi f_m t)\cos(2\pi f_c t) = \frac{1}{2}\cos\left(2\pi(f_c - f_m)t\right) + \frac{1}{2}\cos\left(2\pi(f_c + f_m)t\right)$$

```
x = 0.5*cos(2*pi*750*t) + 0.5*cos(2*pi*450*t)

x = cos(2*pi*600*t).*cos(2*pi*150*t)
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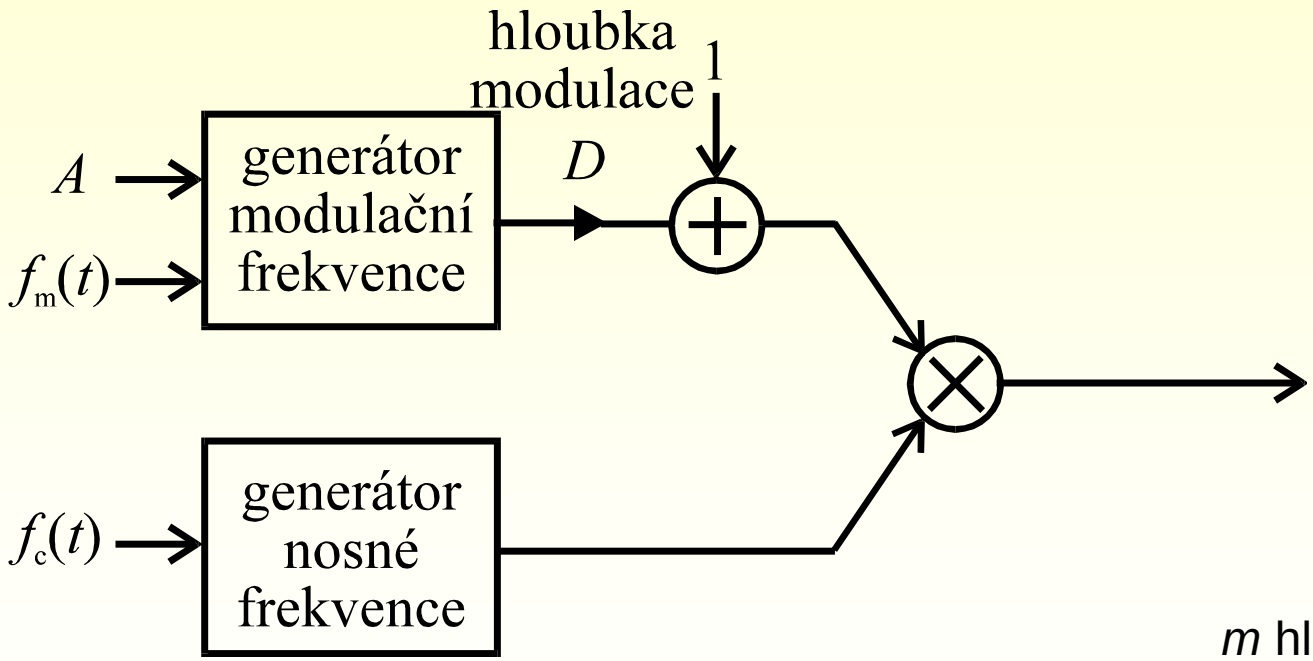
Amplitudová modulace

– **Změna amplitudy jiným signálem**



$$f(t) = \left(1 + m \cdot \sin 2\pi\, f_m t\right) \sin 2\pi\, f_c t$$

m hloubka modulace

f_c modulační frekvence

f_m nosná frekvence

Amplitudová modulace

$$\sin\alpha \cdot \sin\beta = \frac{1}{2}\left[\cos(\alpha-\beta) - \cos(\alpha+\beta)\right]$$

$$\cos\alpha \cdot \cos\beta = \frac{1}{2}\left[\cos(\alpha-\beta) + \cos(\alpha+\beta)\right]$$

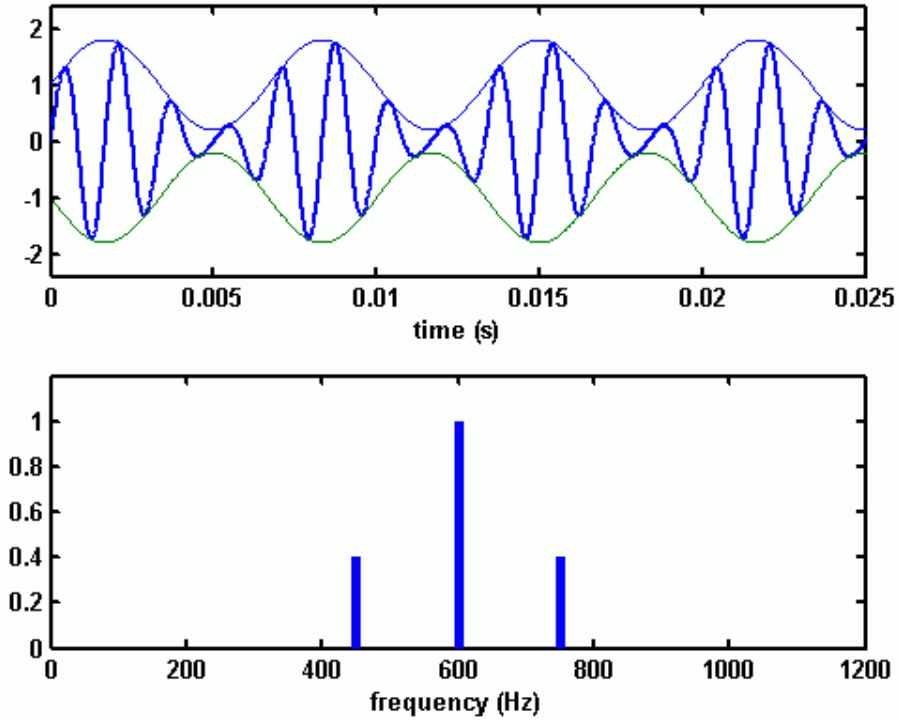
$$\sin\alpha \cdot \cos\beta = \frac{1}{2}\left[\sin(\alpha-\beta) - \sin(\alpha+\beta)\right]$$

$$\left(1 + m \cdot \sin(2\pi f_m t)\right)\sin(2\pi f_c t) =$$

$$\sin(2\pi f_c t) + m_d \cdot \sin(2\pi f_m t)\sin(2\pi f_c t) =$$

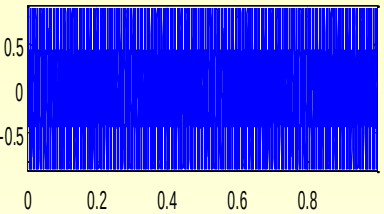
$$\sin(2\pi f_c t) + \frac{m_d}{2}\cos\left(2\pi(f_c - f_m)t\right) - \frac{m_d}{2}\cos\left(2\pi(f_c + f_m)t\right)$$

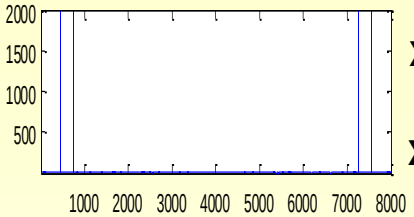
Amplitudové modulace



f_c	f_m
600	150
600	170
600	50
600	70
600	4
600	1

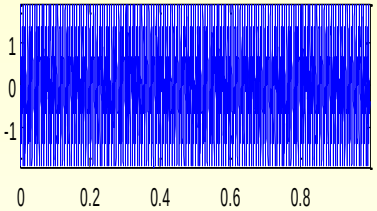
Amplitudové modulace

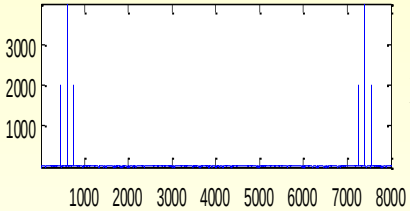




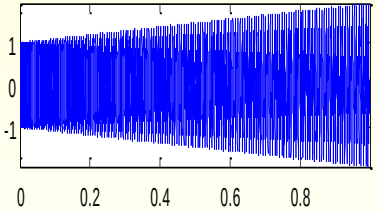
x = 0.5*cos(2*pi*750*t) + 0.5*cos(2*pi*450*t)

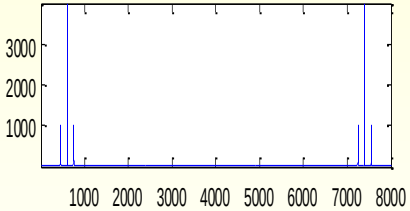
x = cos(2*pi*600*t).*cos(2*pi*150*t)





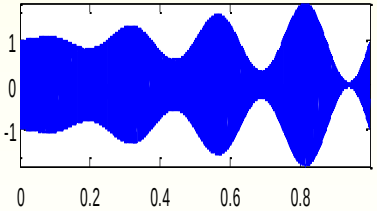
x = (1 + 1*sin(2*pi*150*t)).*sin(2*pi*600*t)

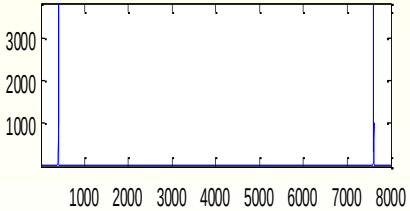




mi = 0…1

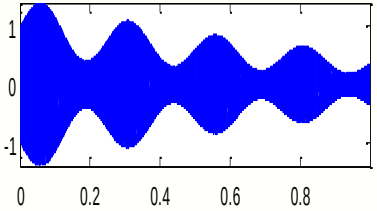
x = (1 + mi.*sin(2*pi*150*t)).*sin(2*pi*600*t)

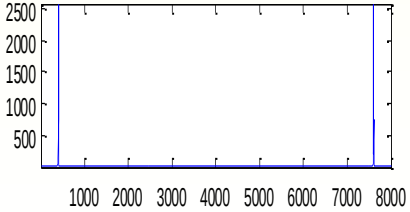




mi = 0…1

x = (1 + mi.*sin(2*pi*4*t)).*sin(2*pi*400*t)





mi = 0…1

x = (1 + mi.*sin(2*pi*4*t)).*sin(2*pi*400*t).*exp(-t)

Amplitudová modulace

Harmonické a neharmonické modulační frekvence, m = 0.5

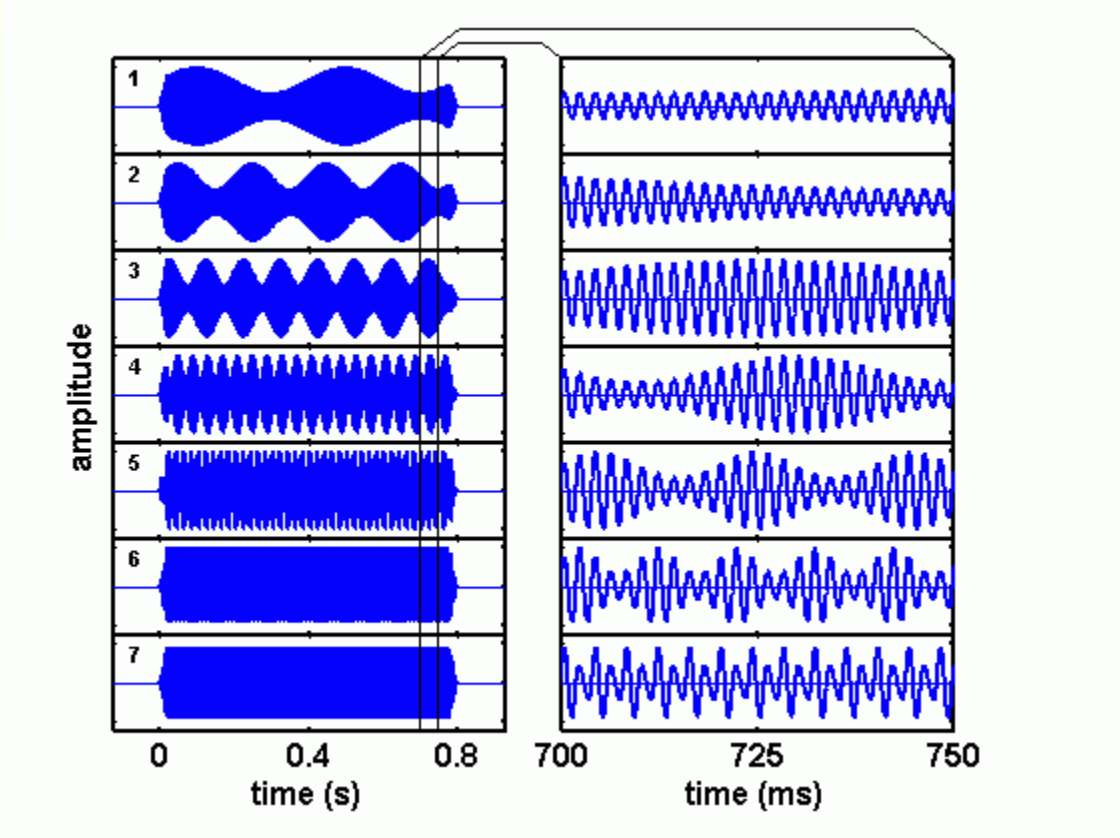
fc = 500Hz

fm = 2.5, 5, 10, 25, 50, 100, 250 Hz

fc = 500Hz

fm = 4.05, 8.09, 16.2, 40.5, 80.9, 162, 405 Hz

(.wav)



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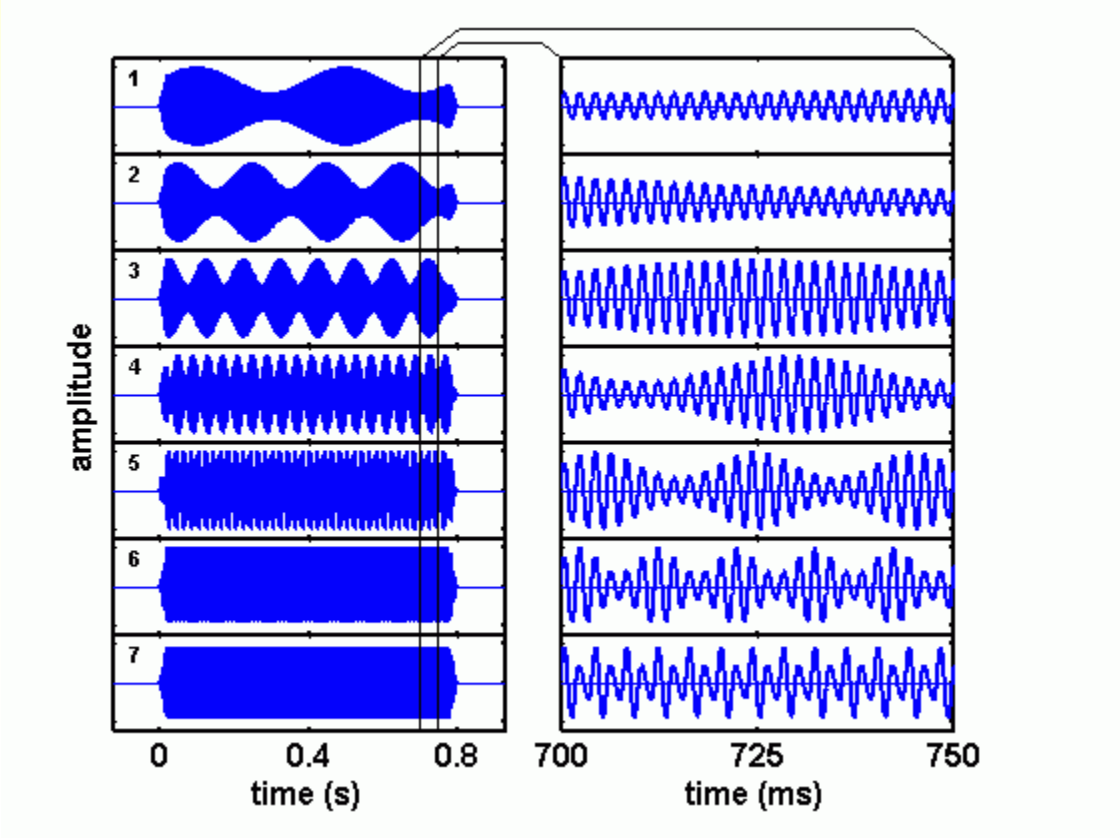

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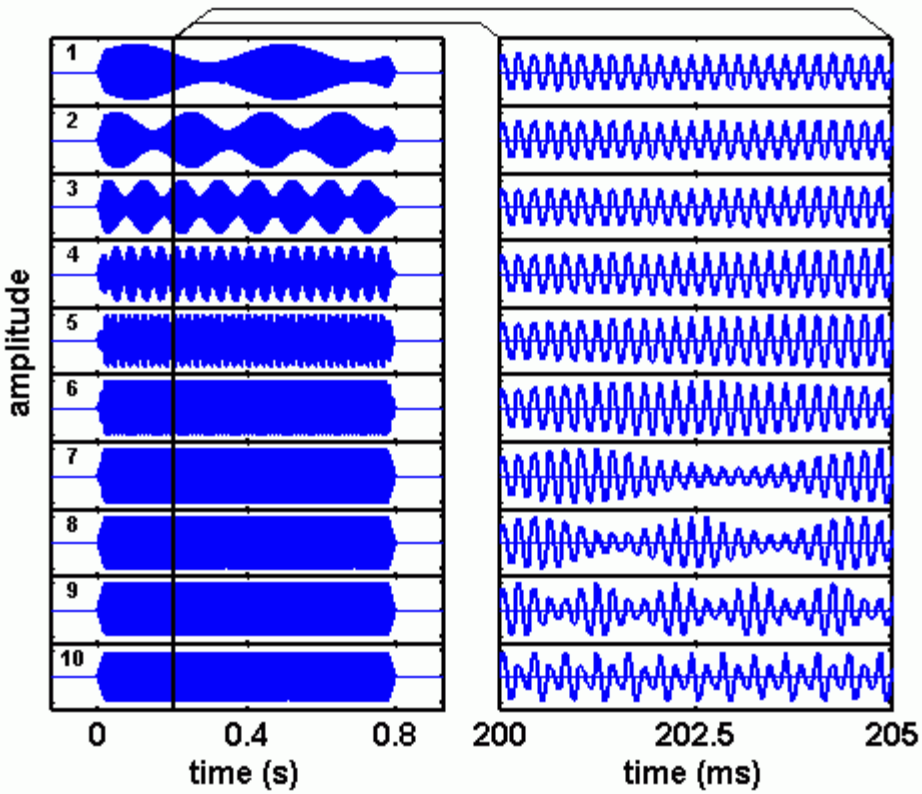
(.wav)



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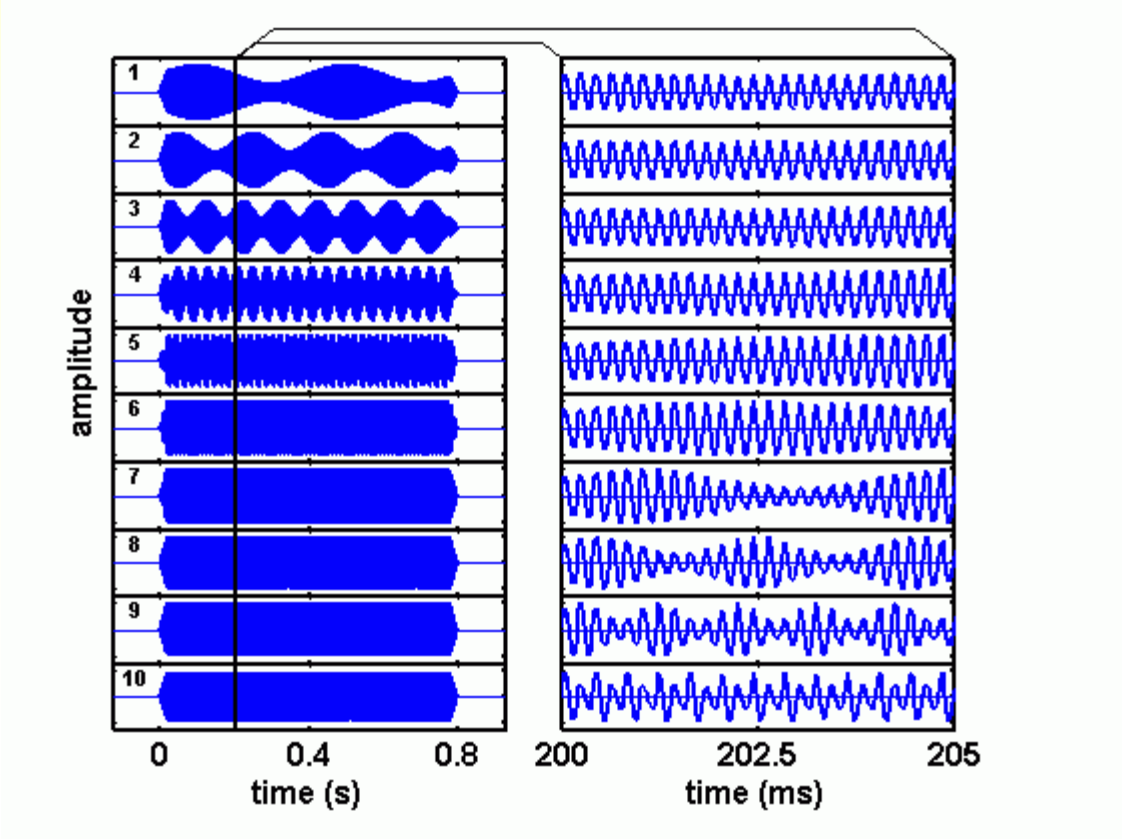

(.wav)

Amplitudová modulace

Zvětšení hloubky modulace, m = 0 .. 1

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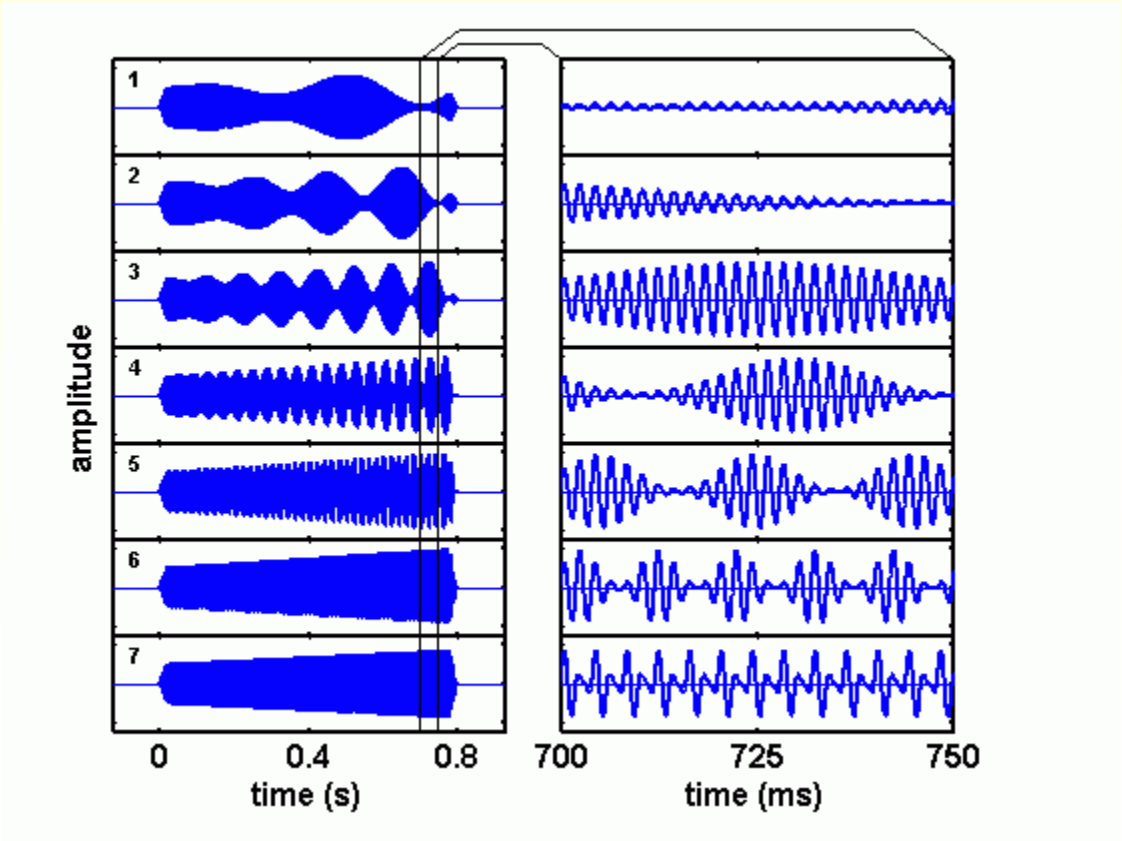

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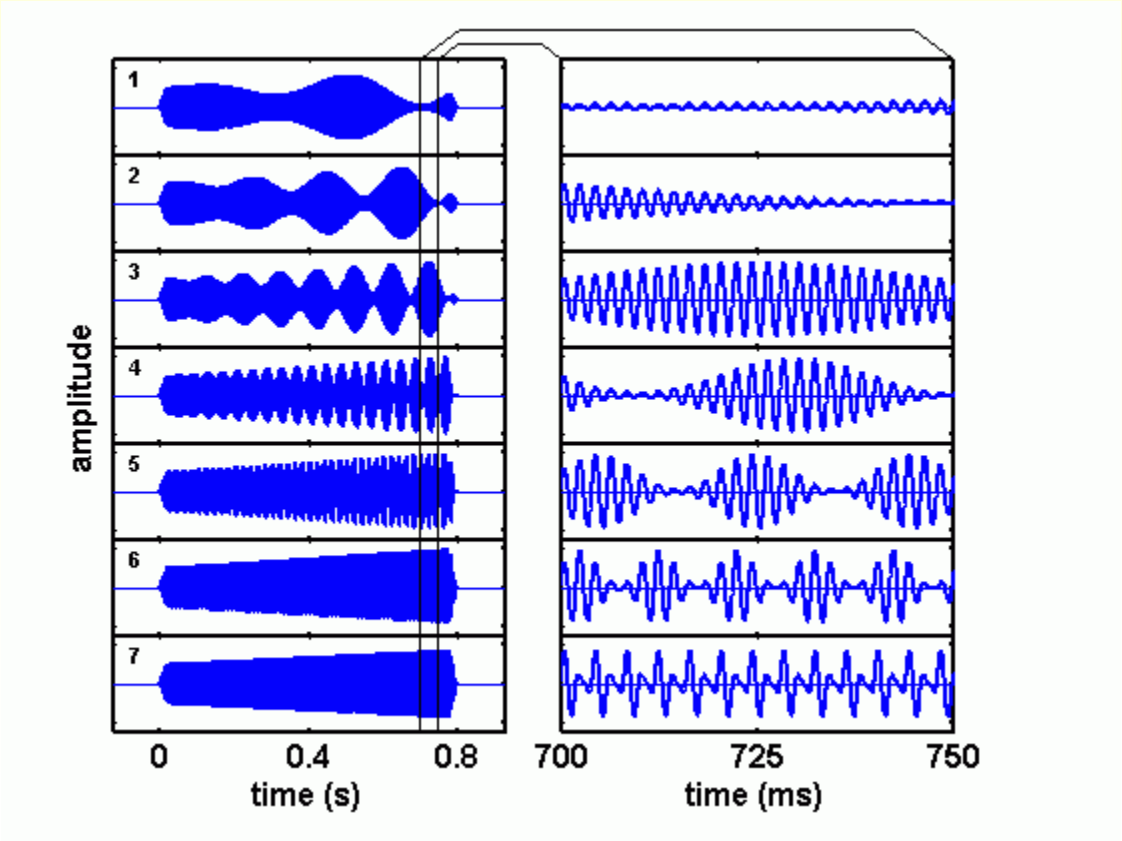

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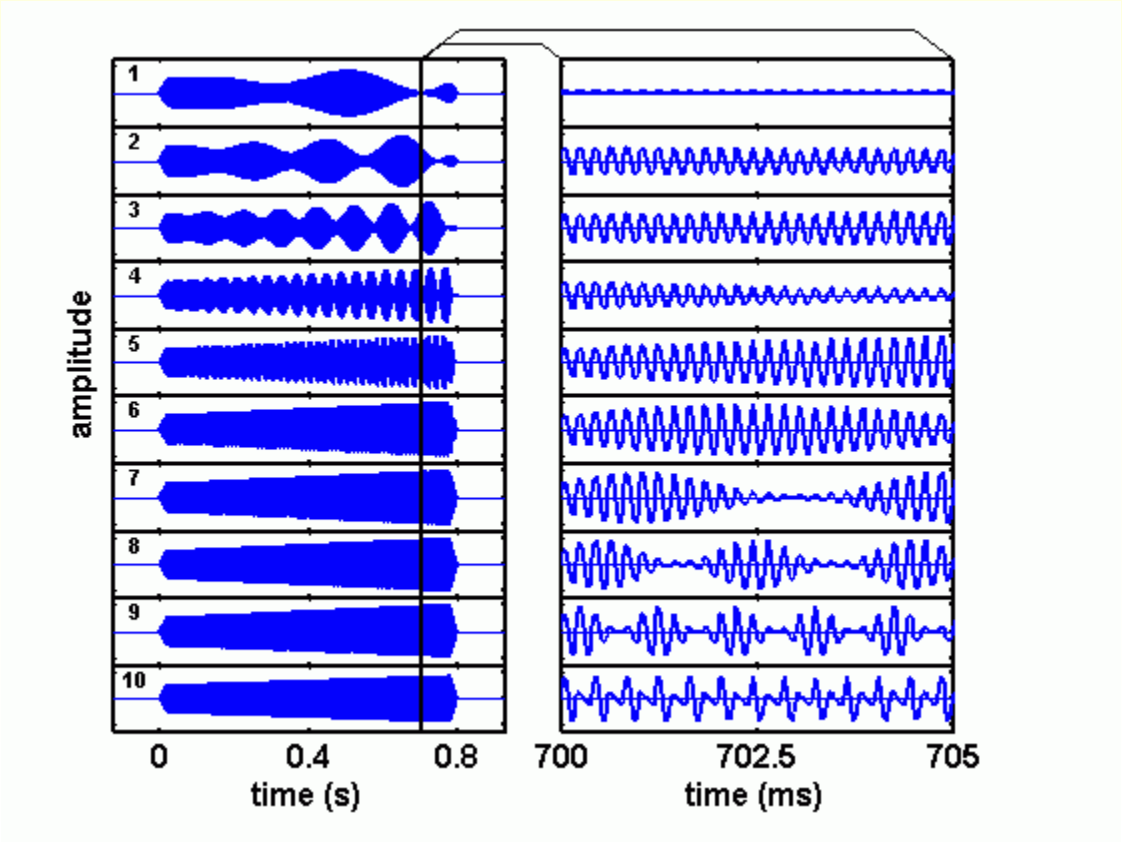
(.wav)



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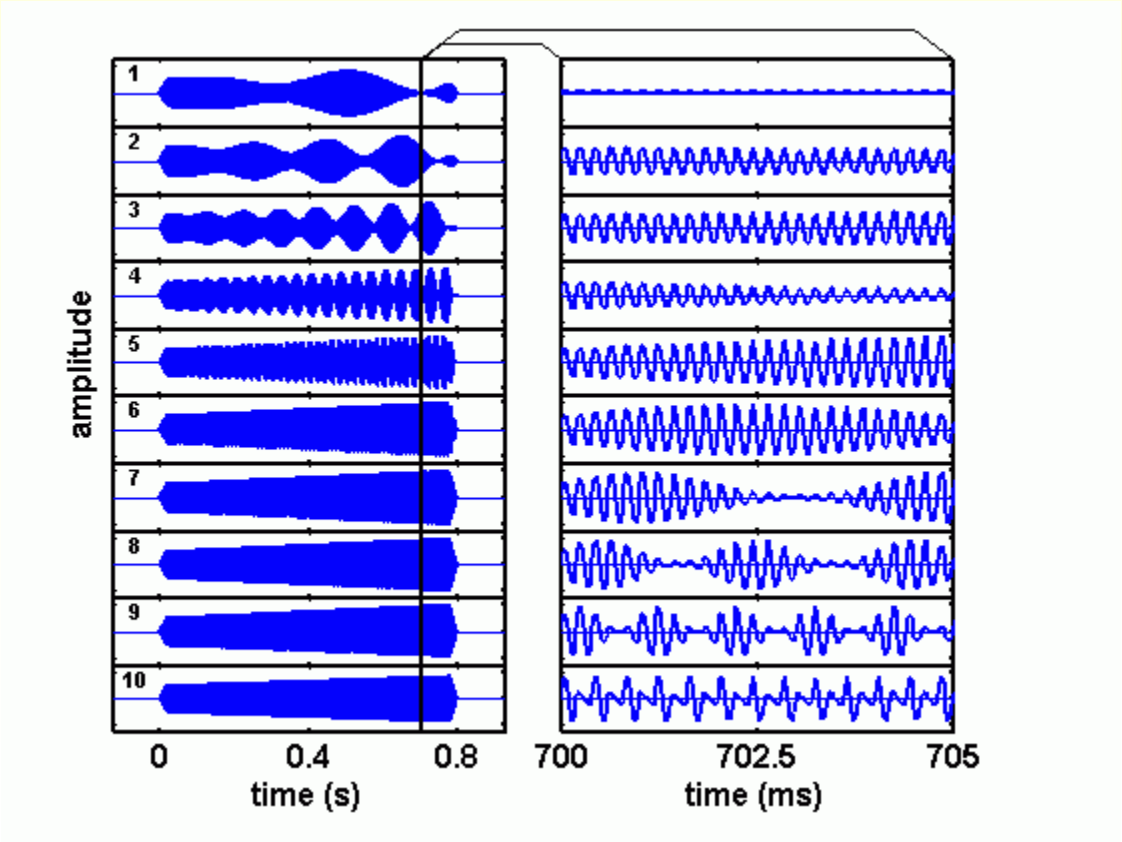
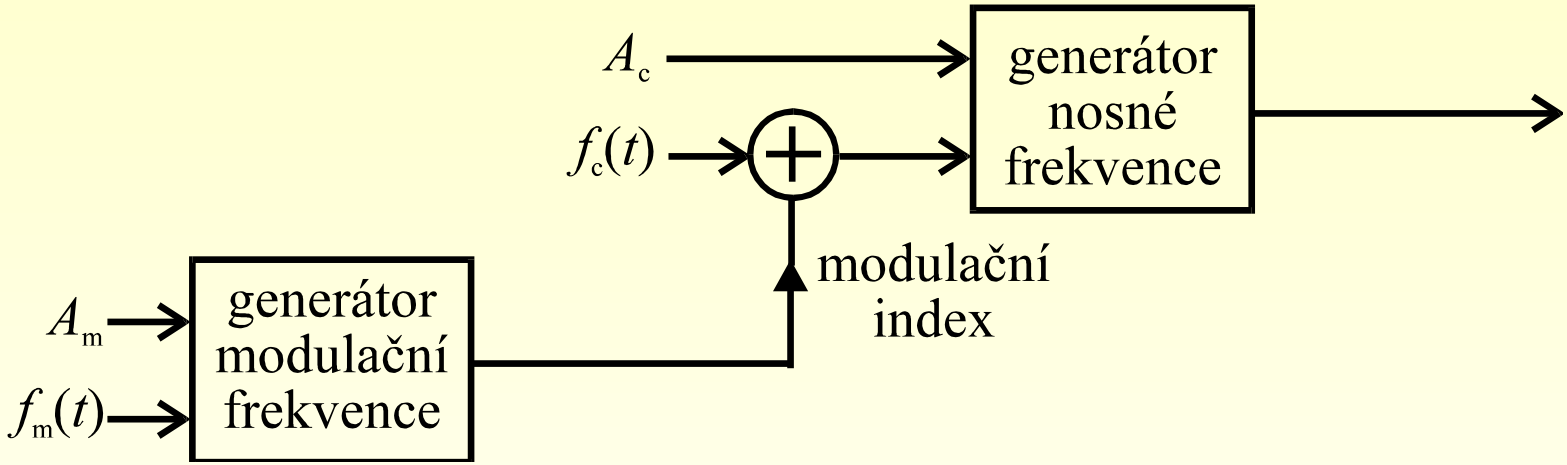


(.wav)

Frekvenční modulace

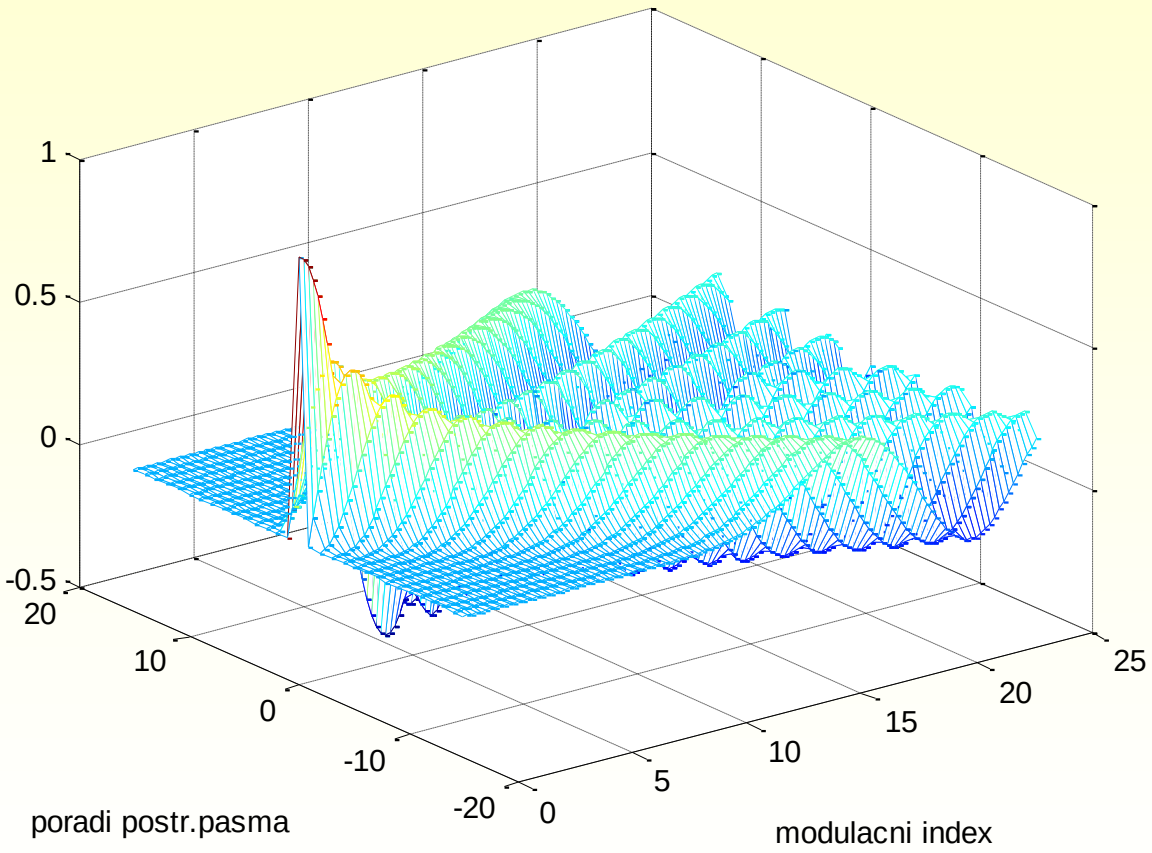


$$f(t) = \sin\left((2\pi\, f_c t) + m_i \cdot \sin(2\pi\, f_m t)\right)$$

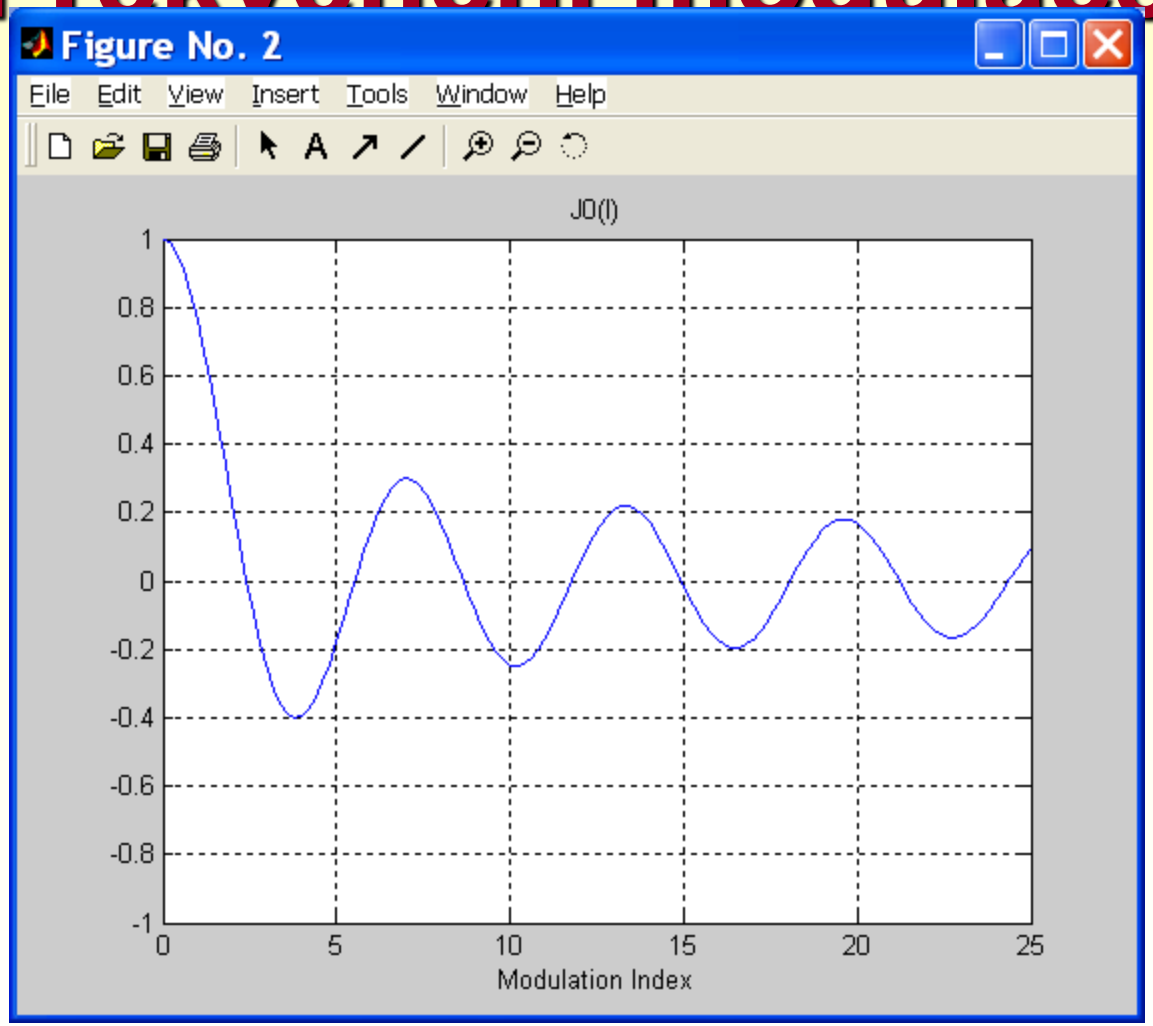
$$\sin\left(2\pi f_c t + m_i \sin(2\pi f_m t)\right) =$$

$$\sum_{k=-\infty}^{\infty} I_k(m_i) \sin\left(2\pi(f_c + k\, f_m) + \phi_k\right)$$

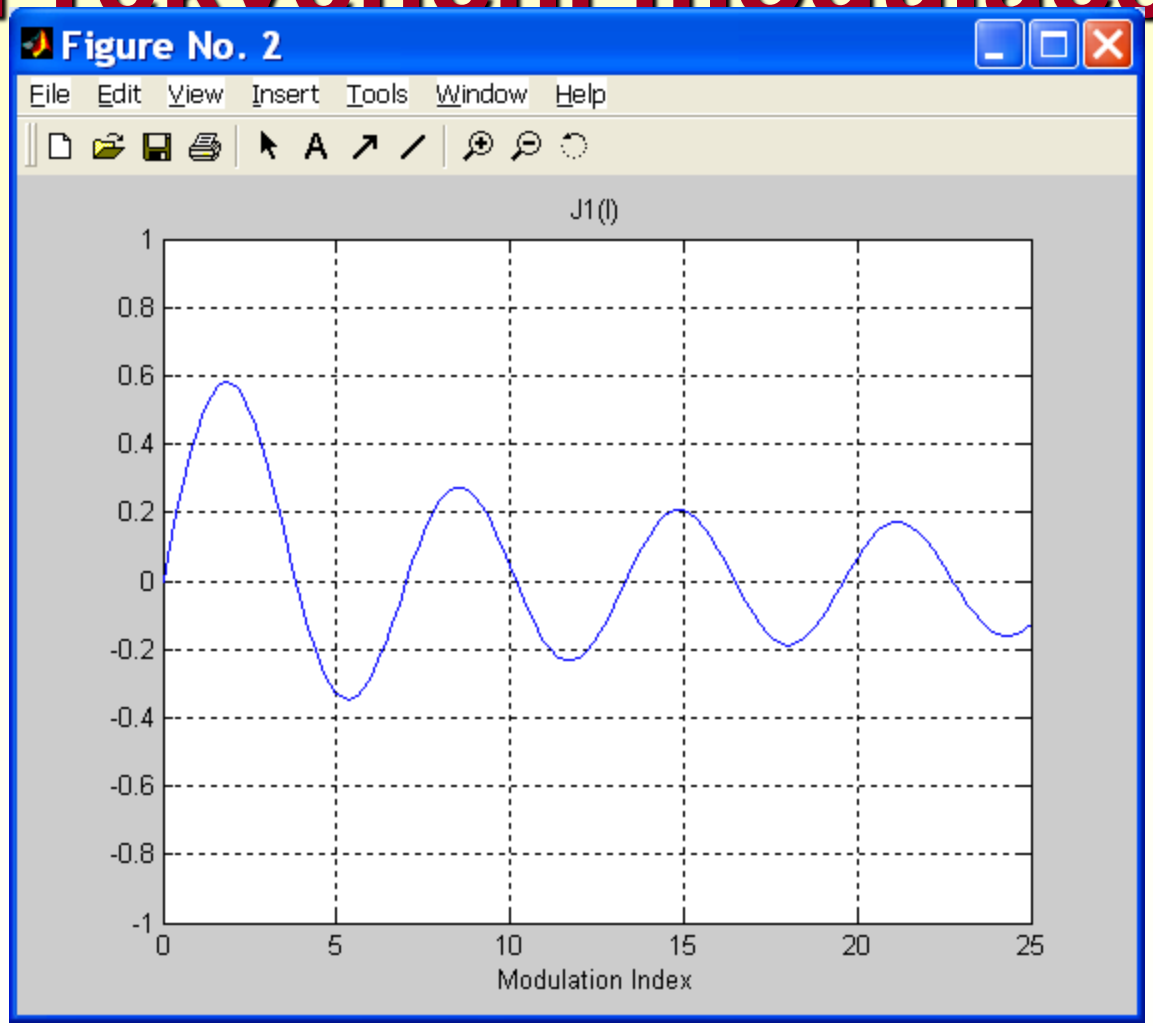
Frekvenční modulace



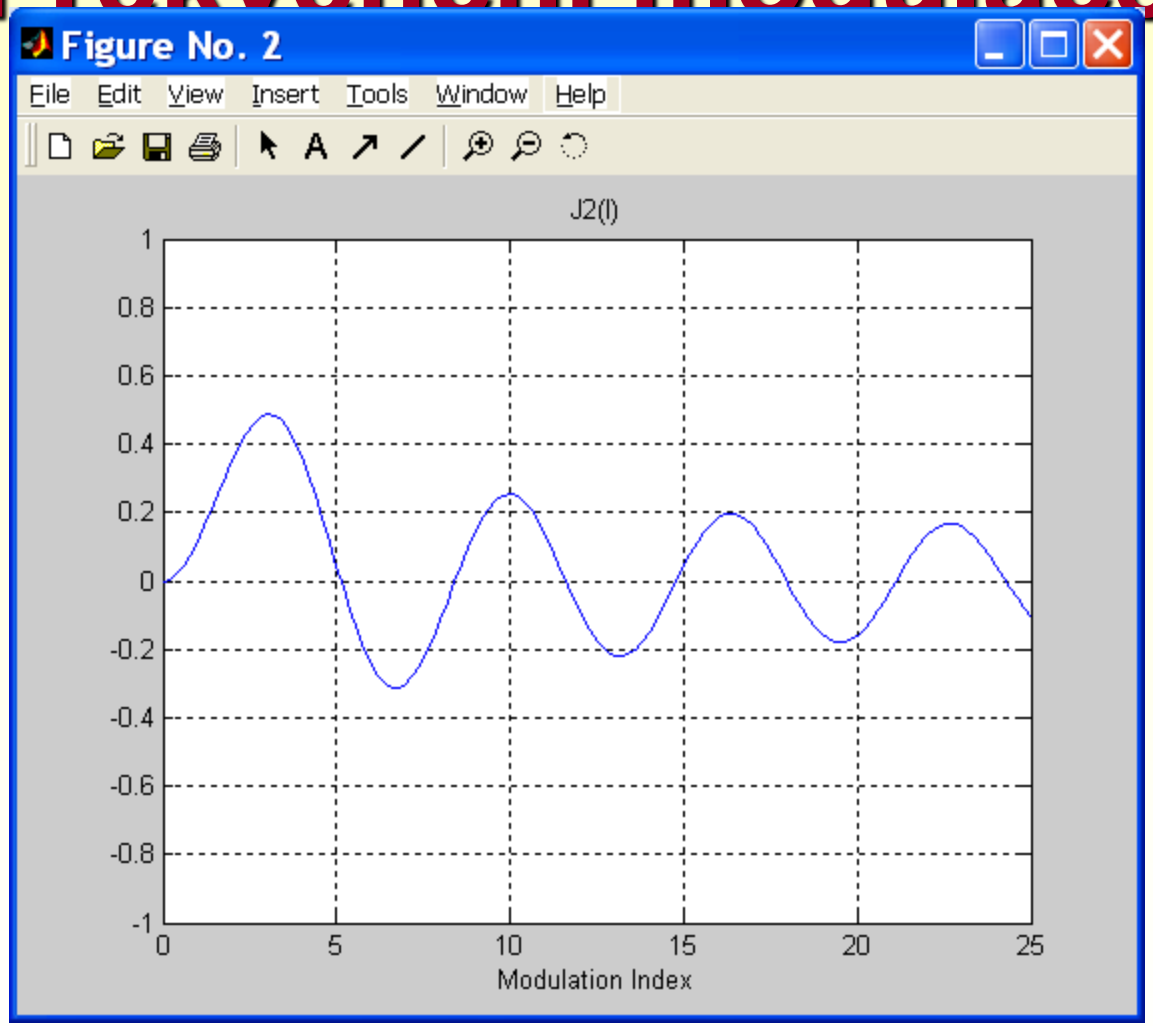
Frekvenční modulace



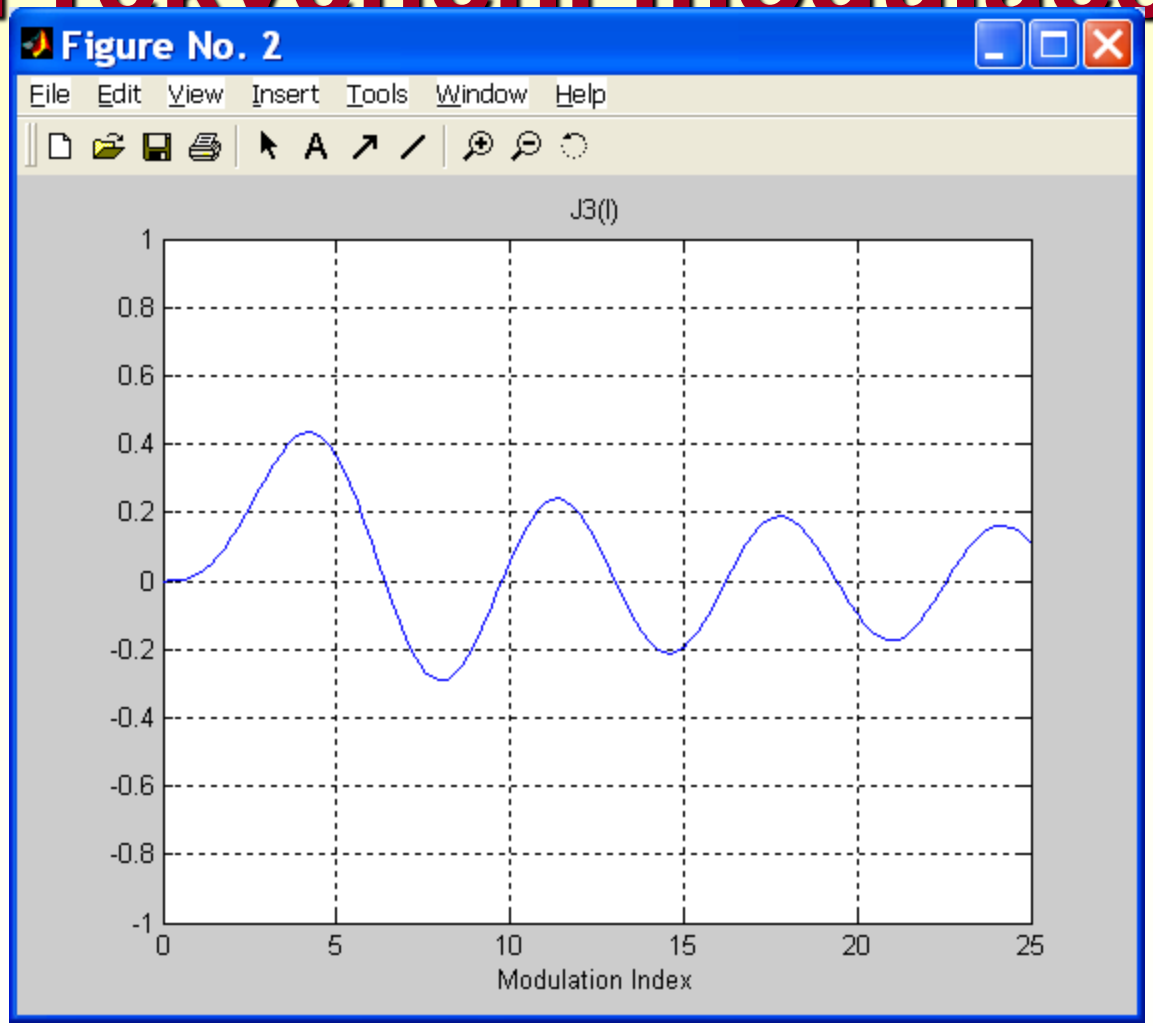
Frekvenční modulace



Frekvenční modulace



Frekvenční modulace



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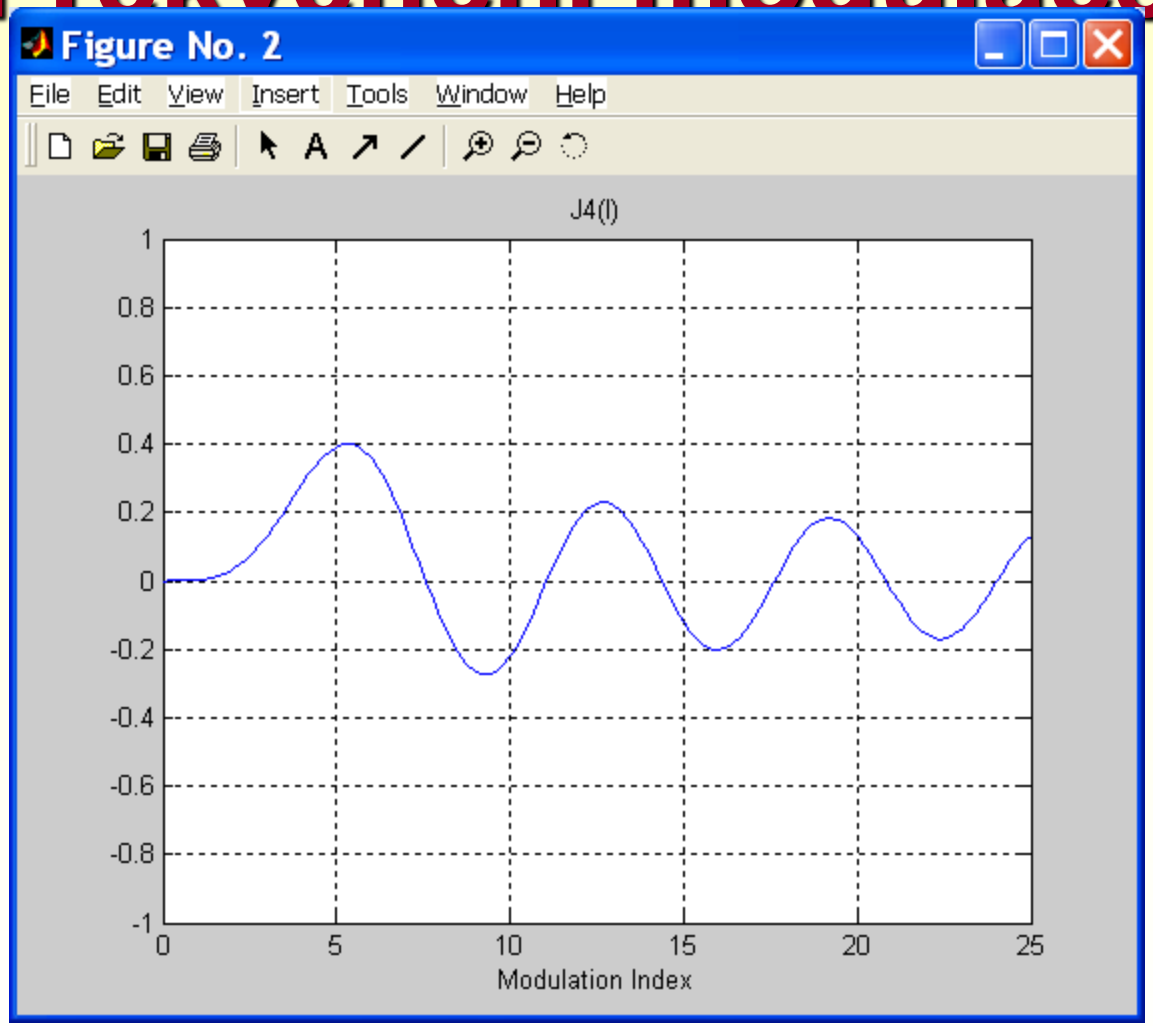

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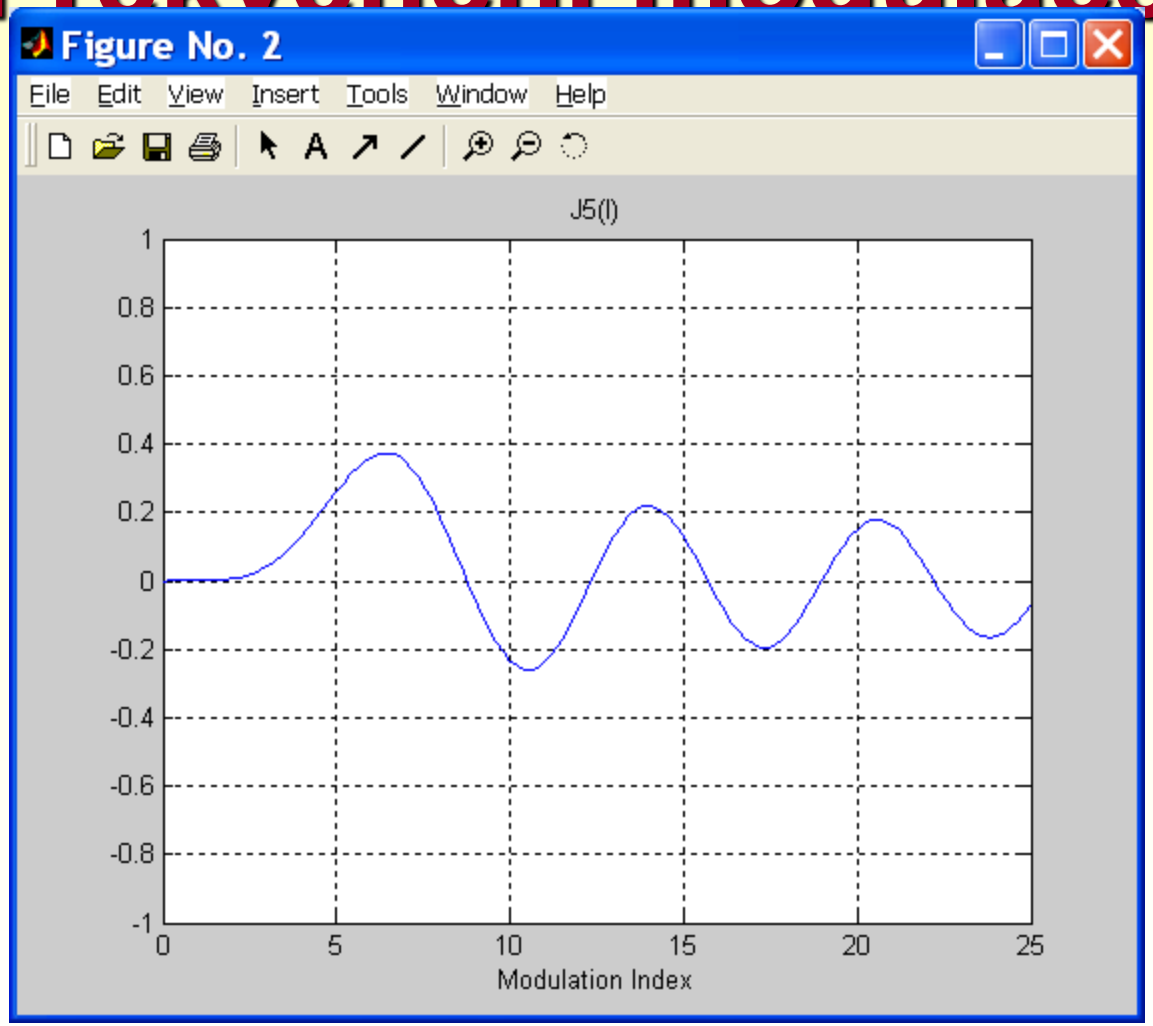

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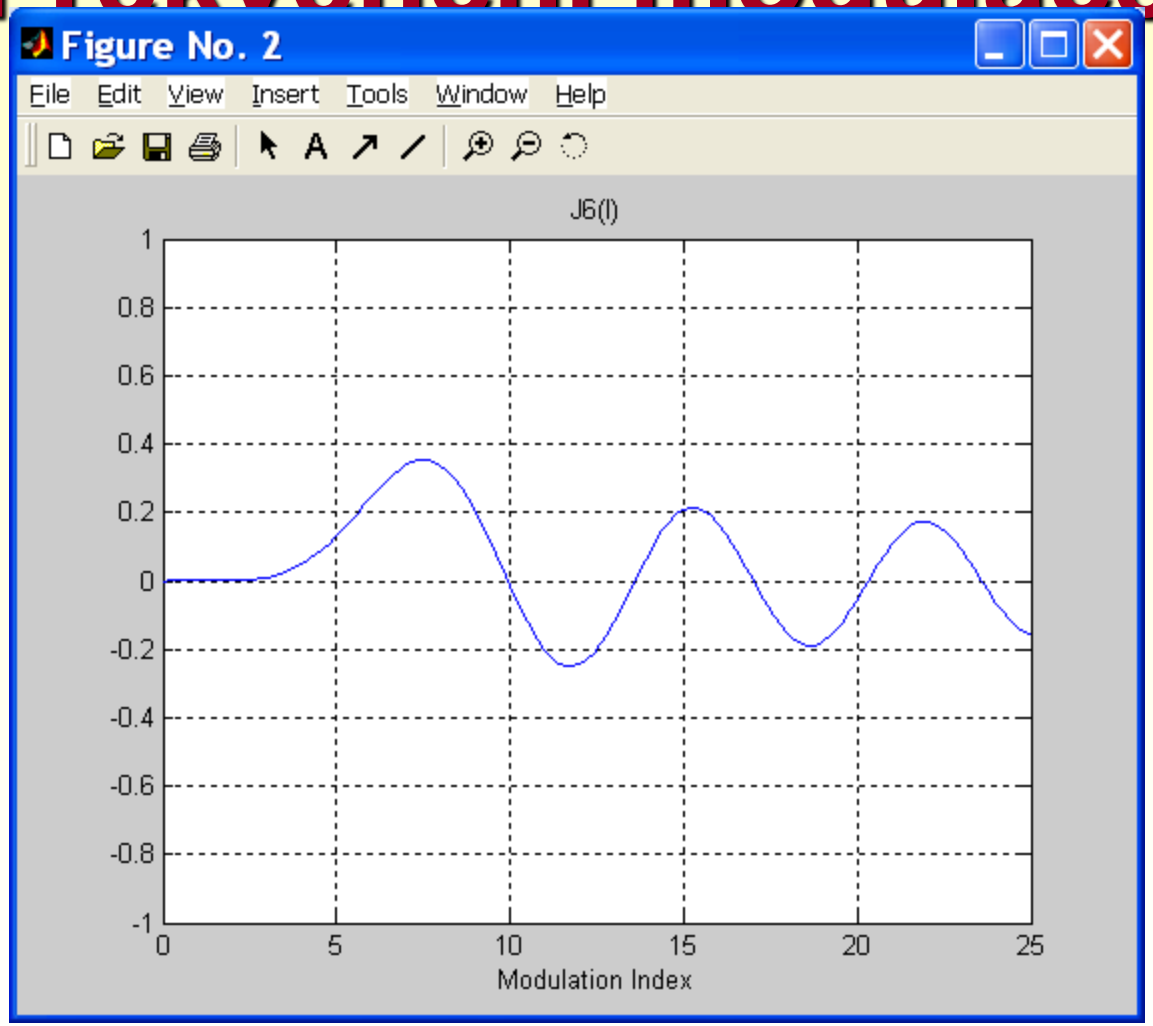

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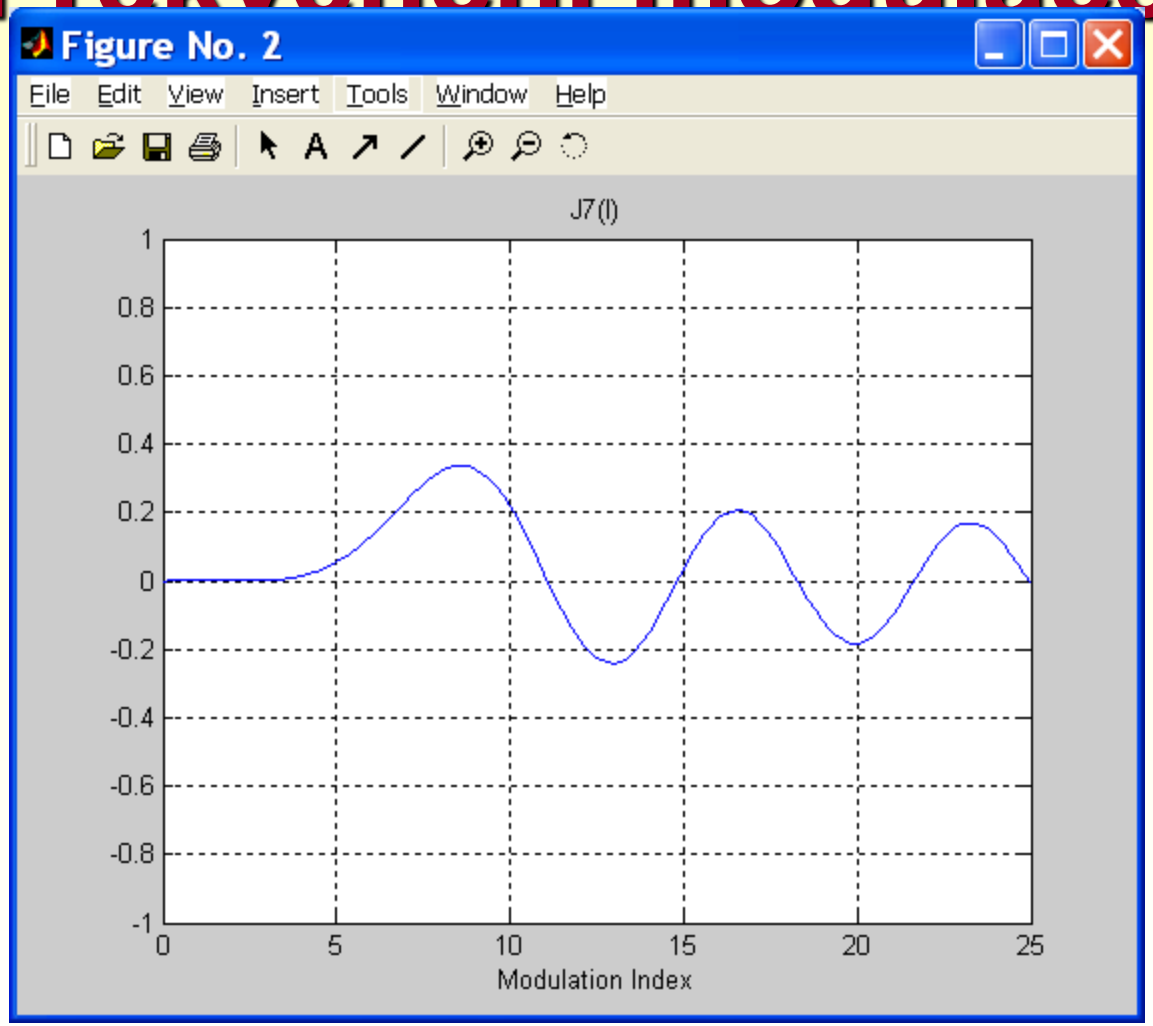

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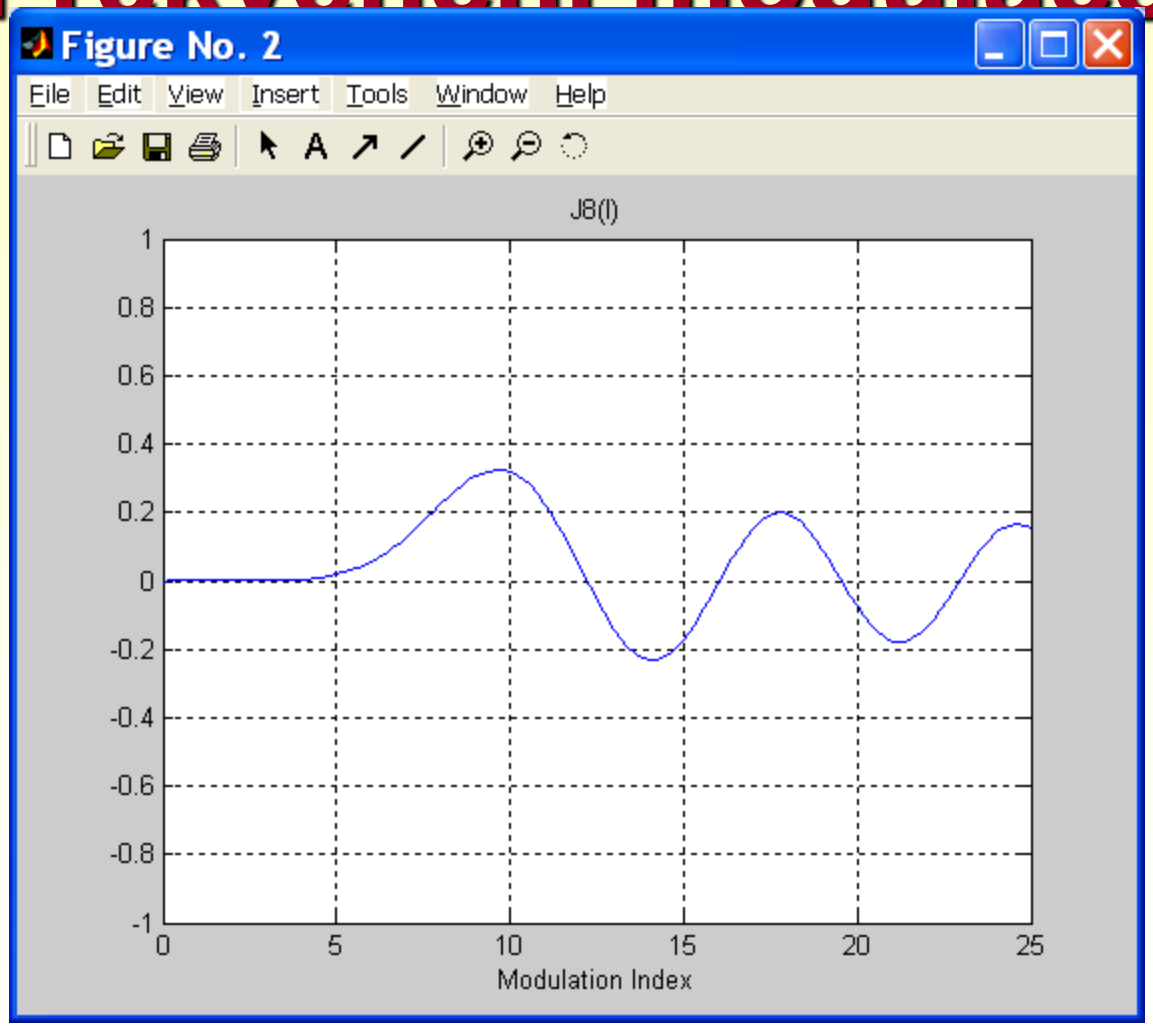

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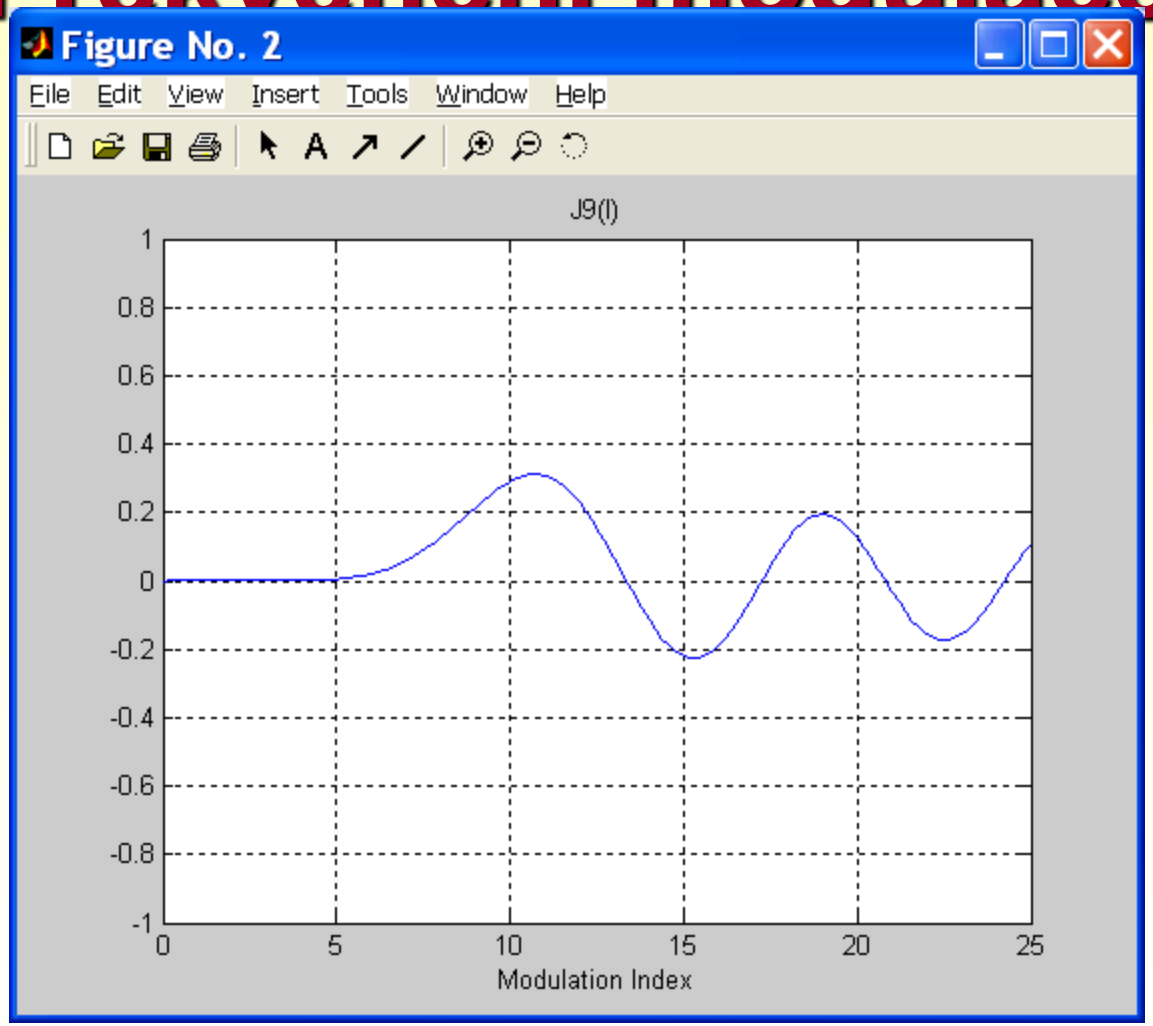
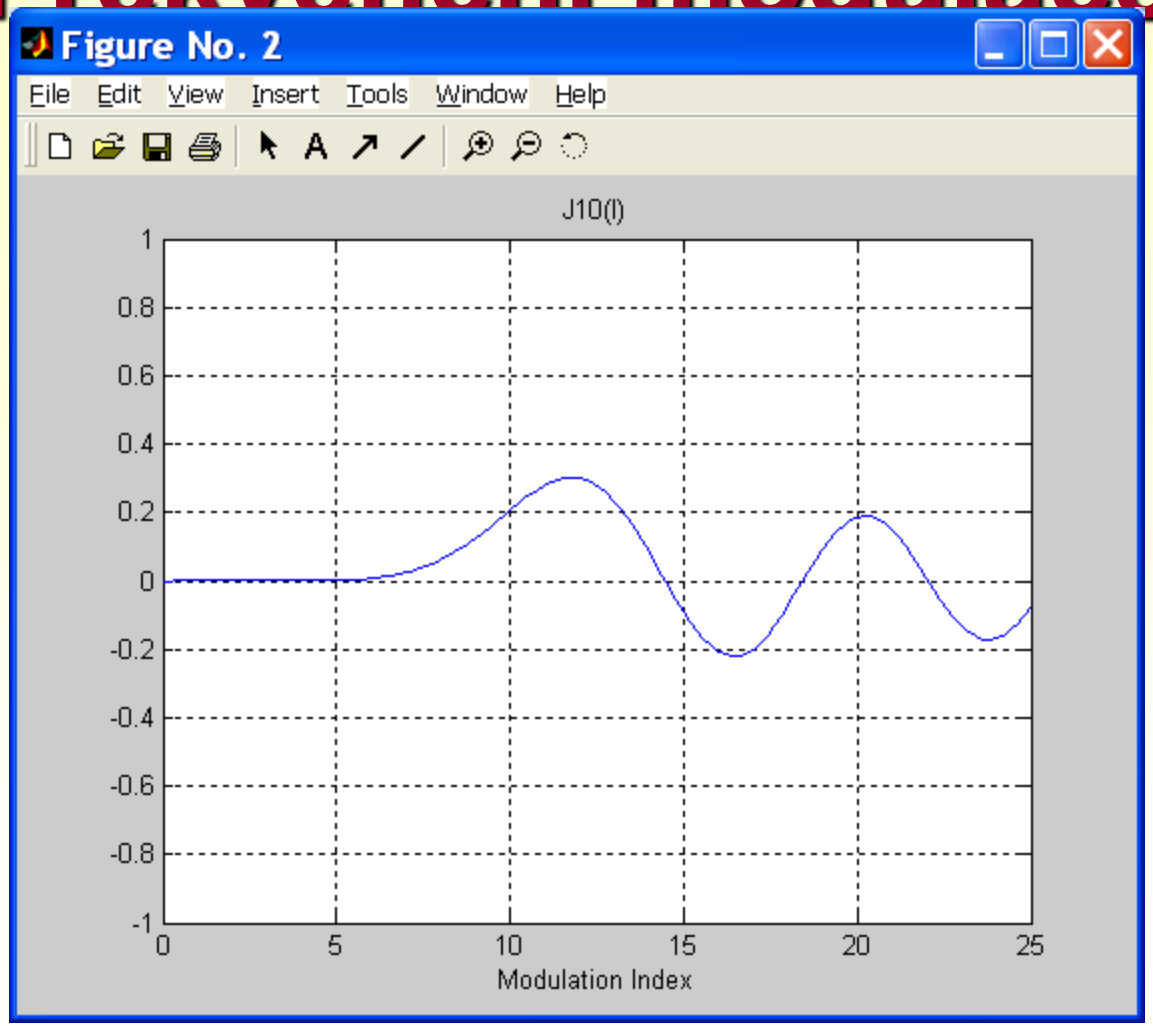


Frekvenční modulace



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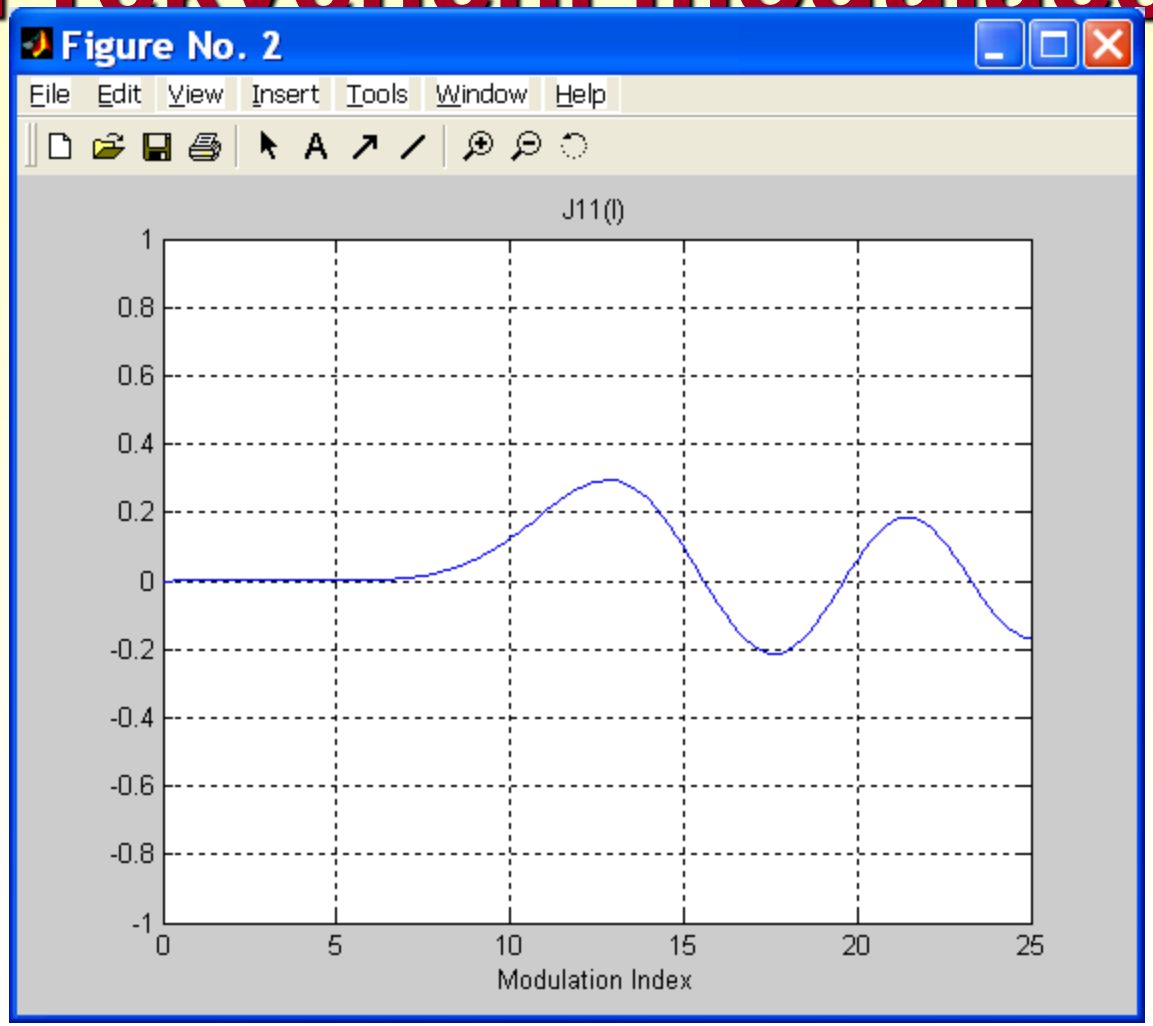

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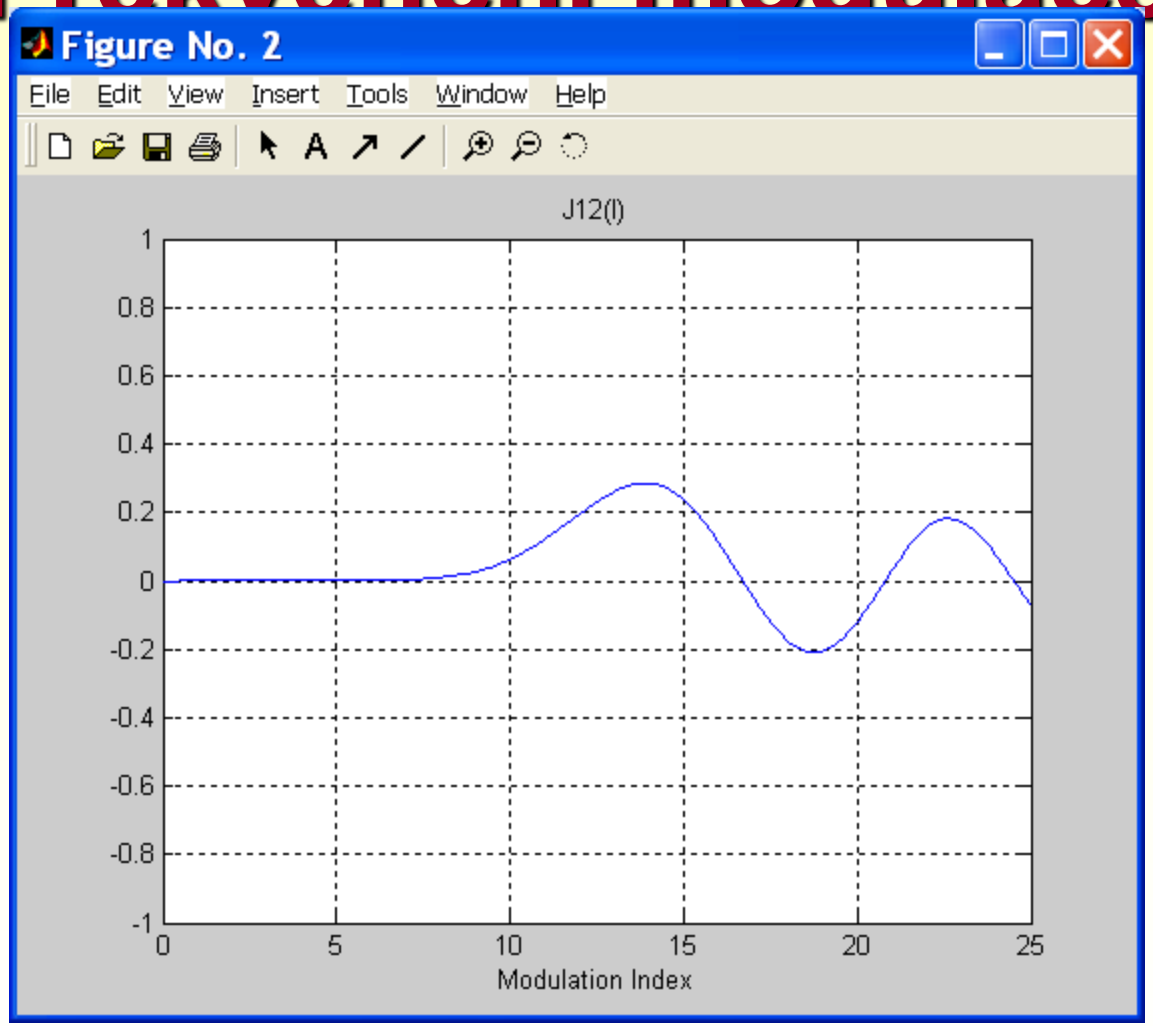

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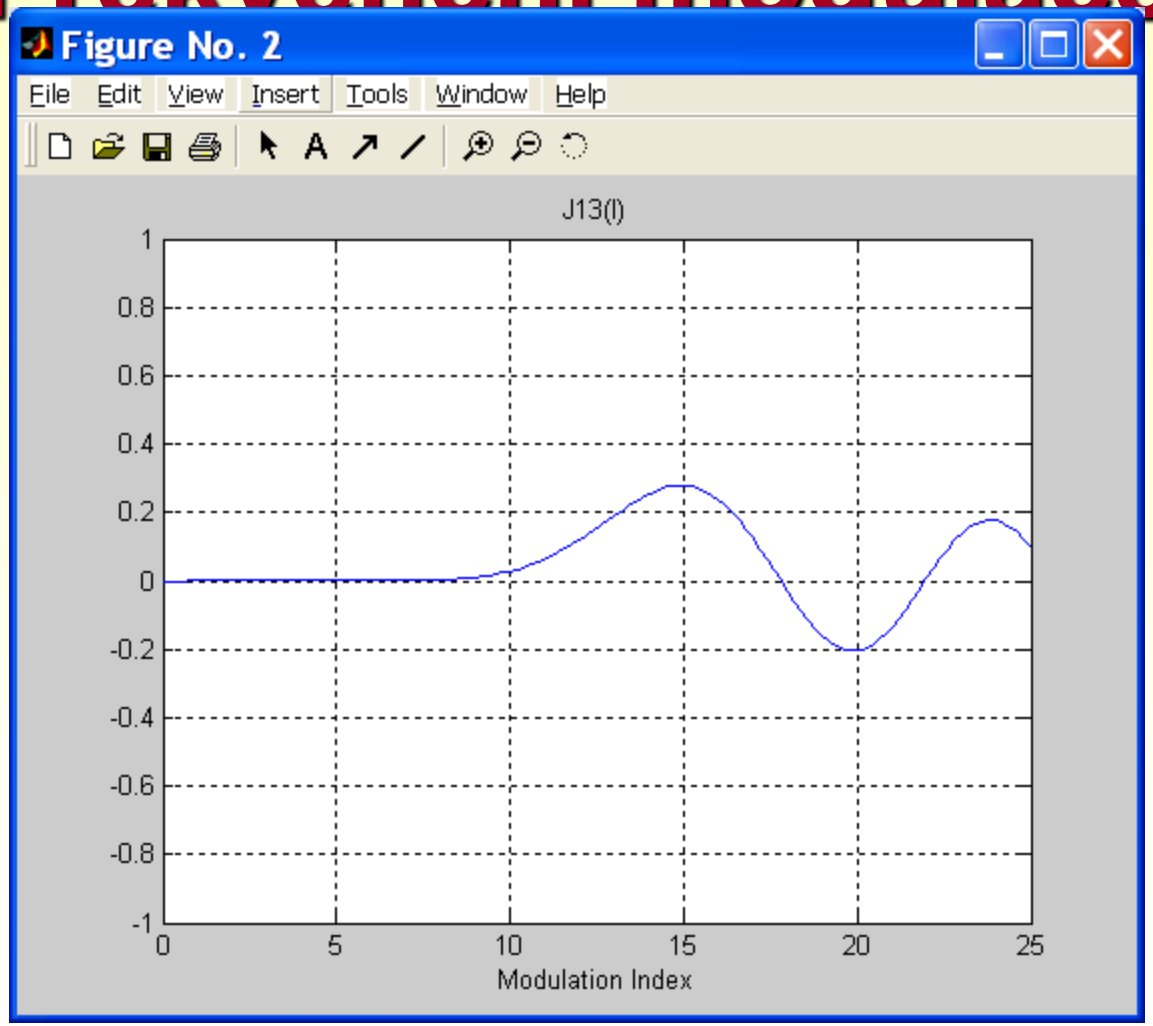
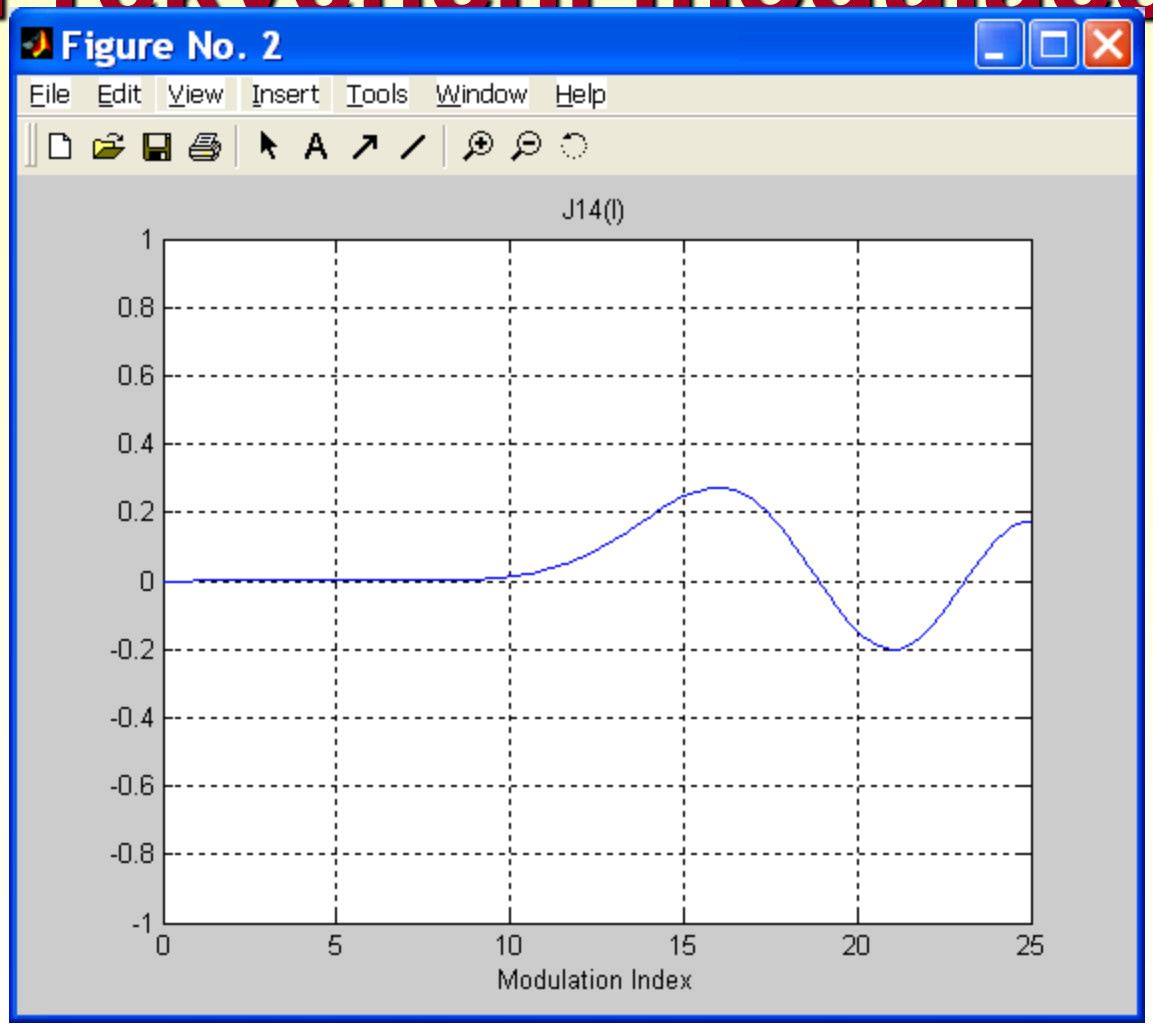
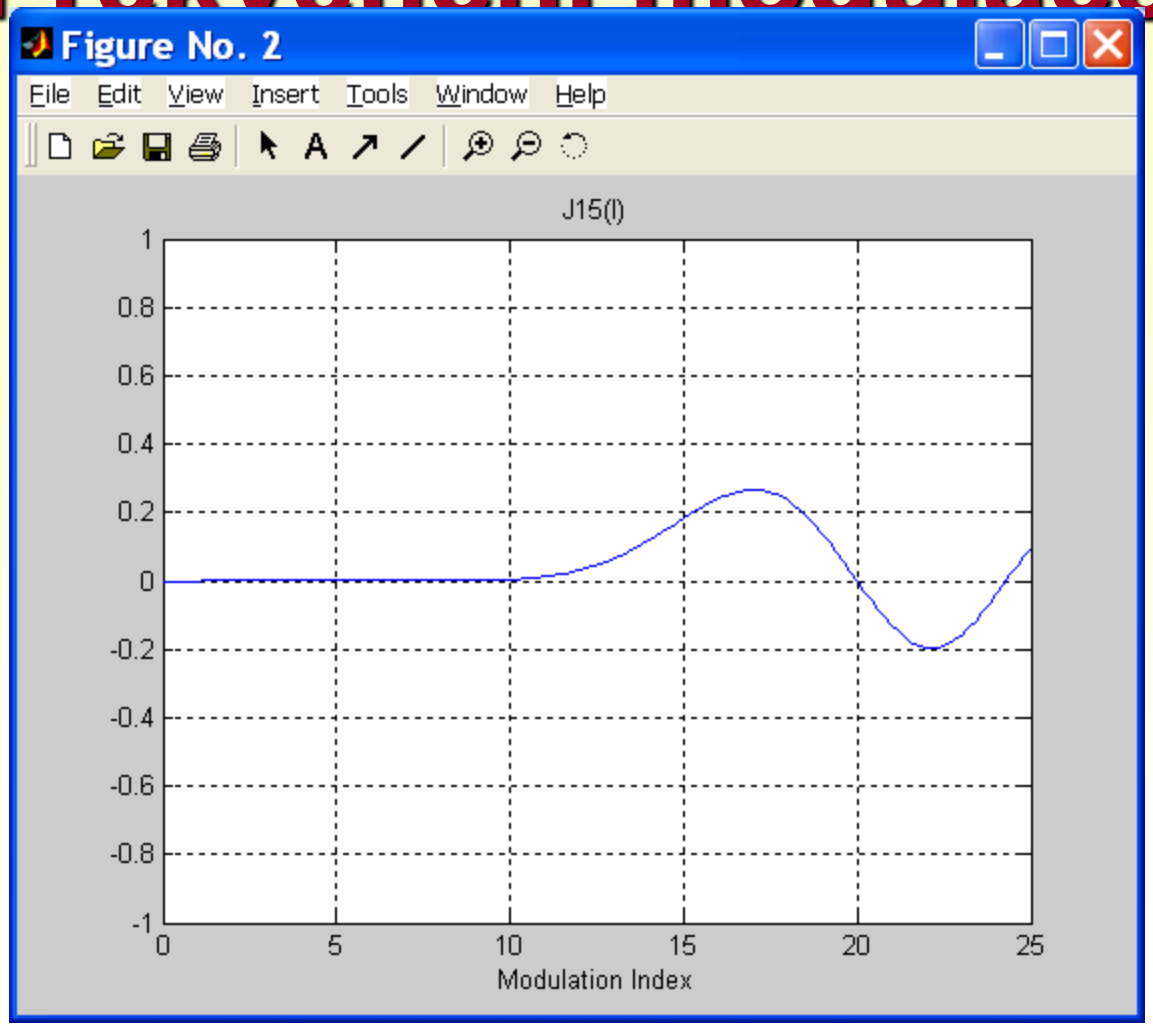


Frekvenční modulace



Frekvenční modulace



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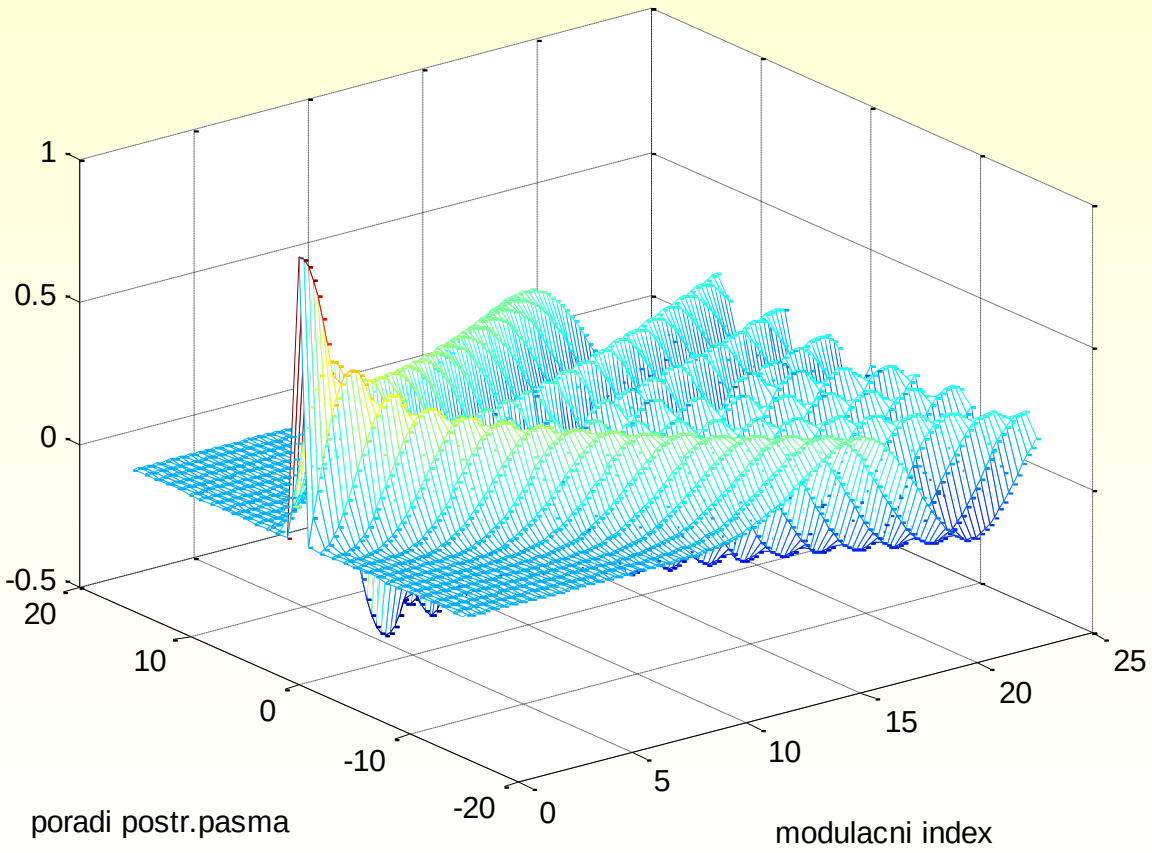
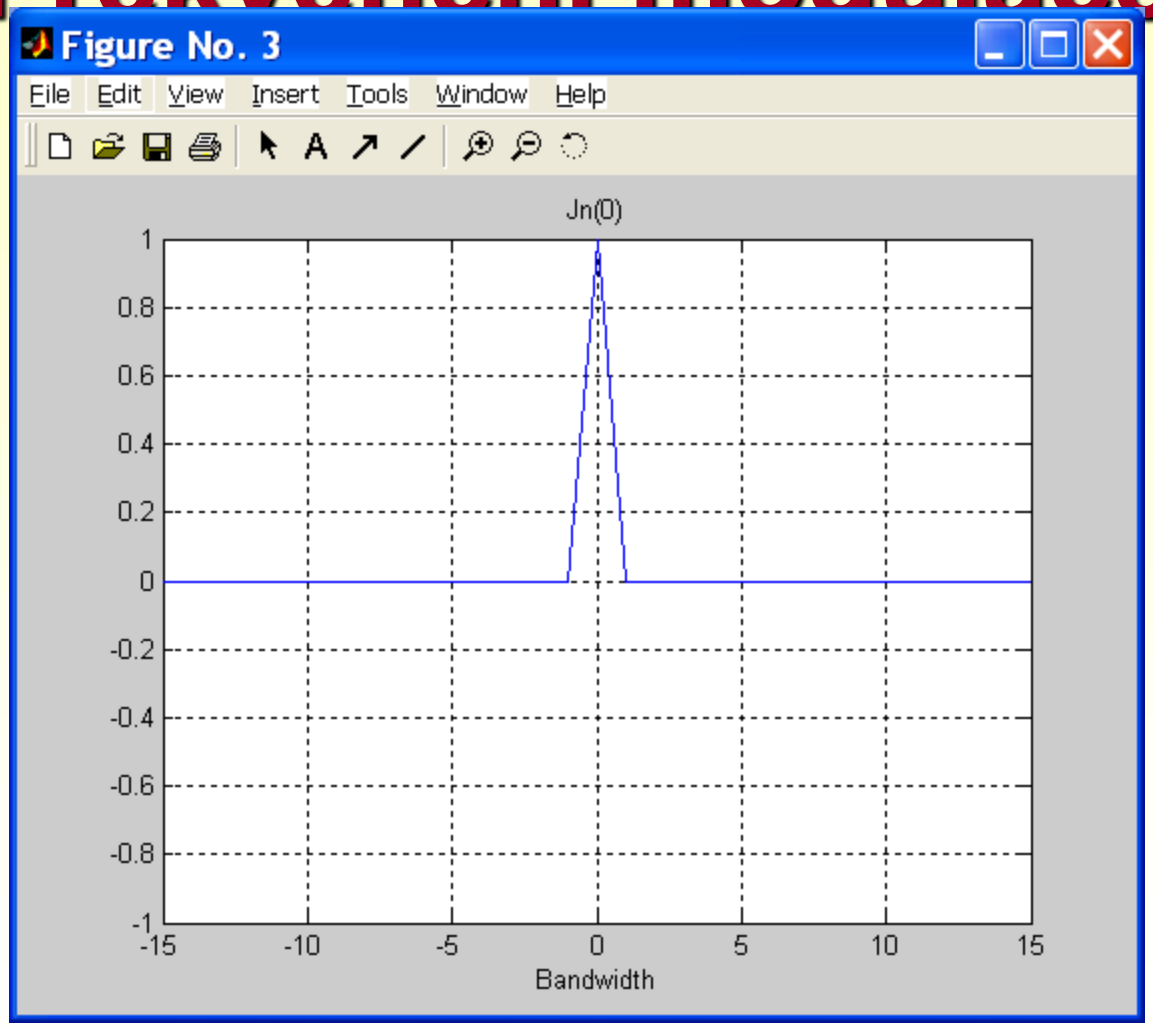
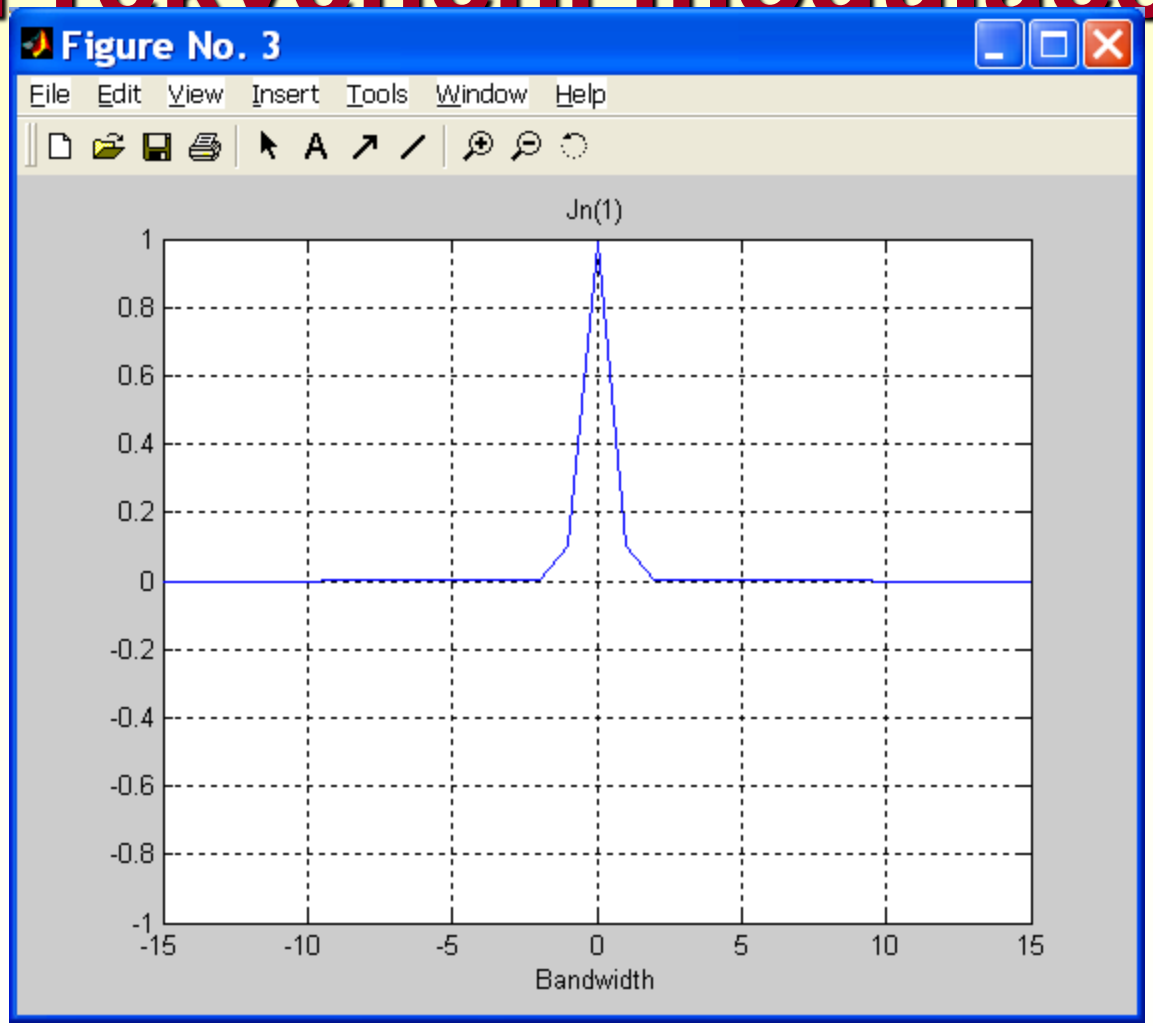


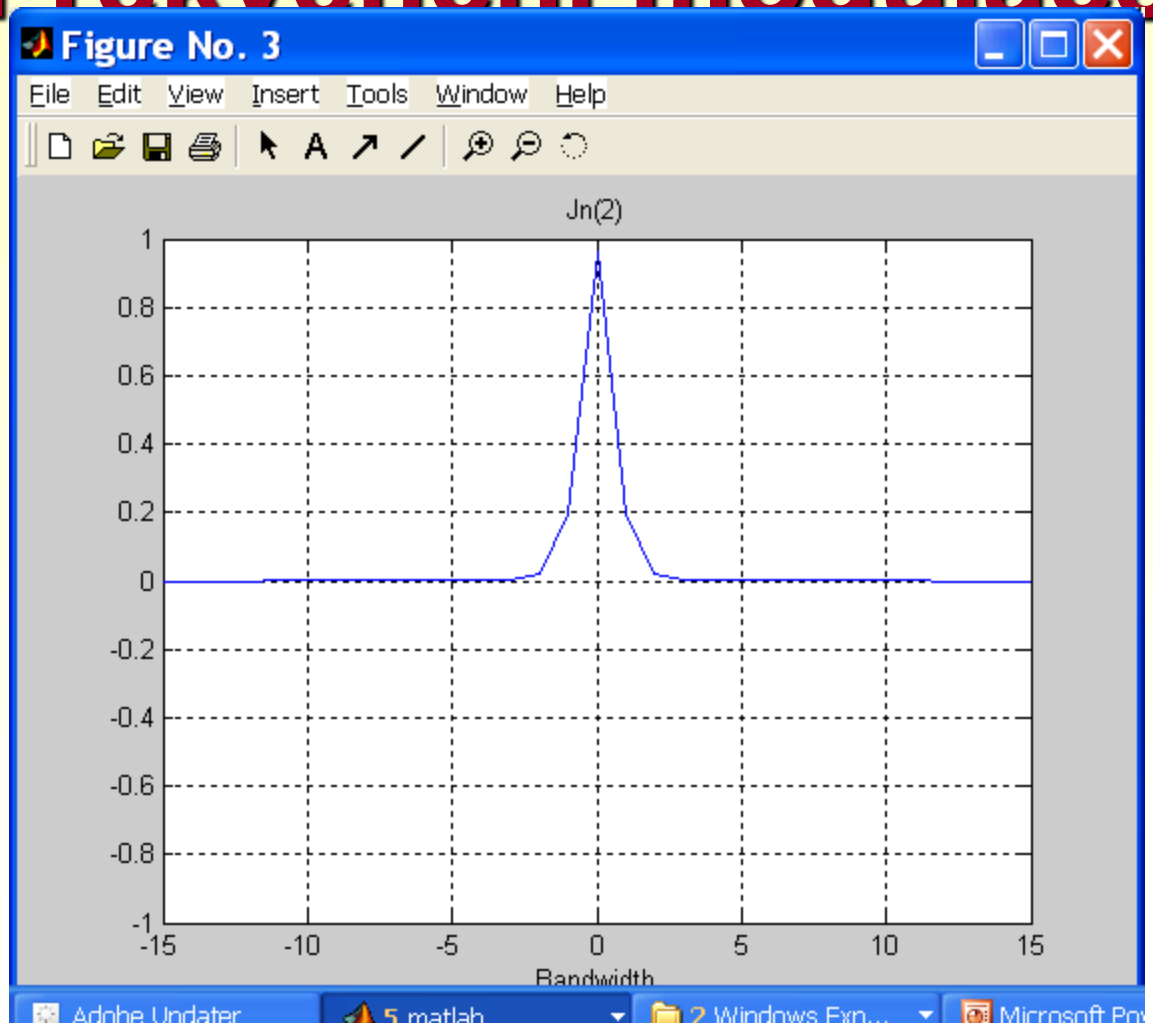
Frekvenční modulace



Frekvenční modulace



Frekvenční modulace



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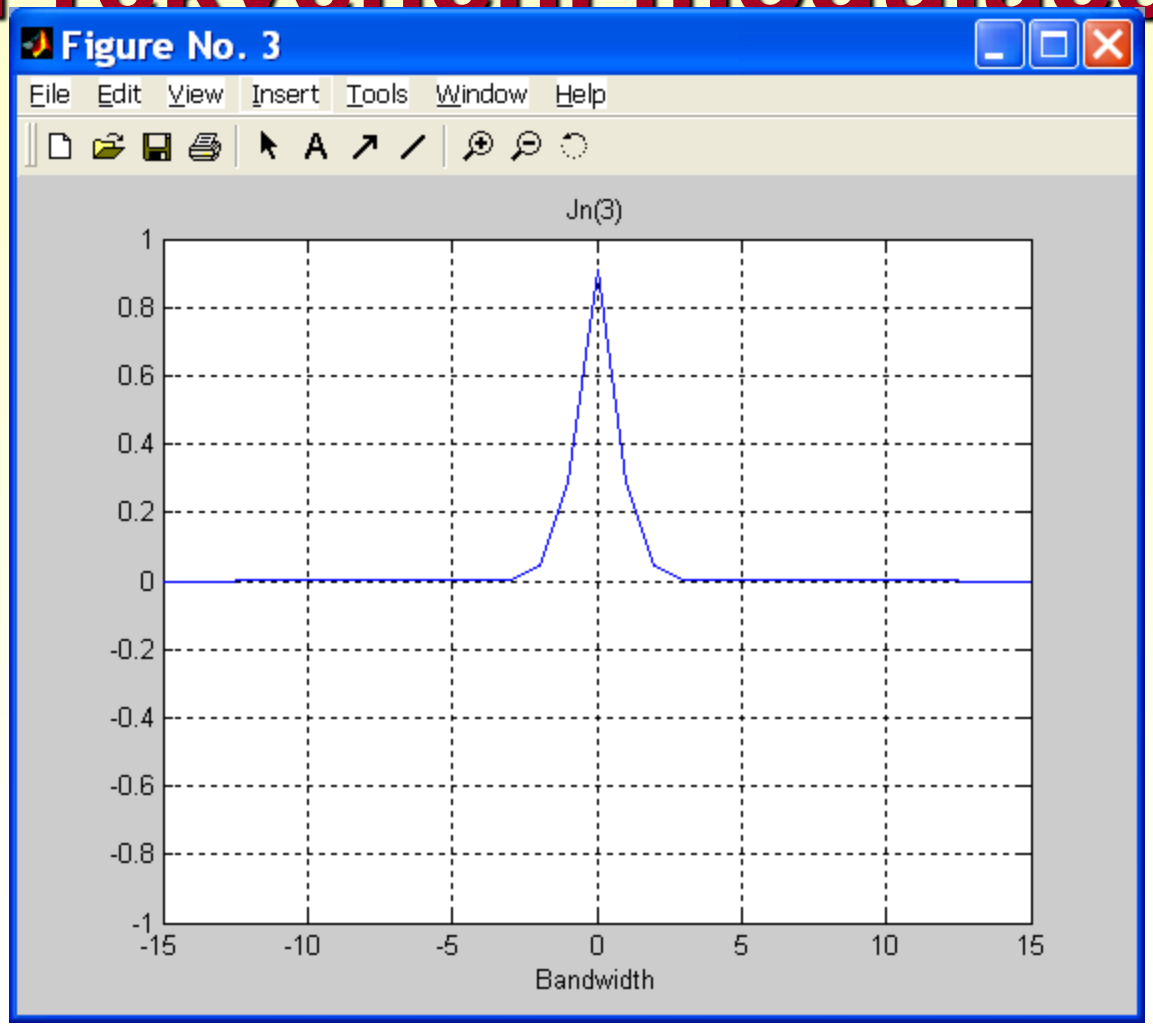

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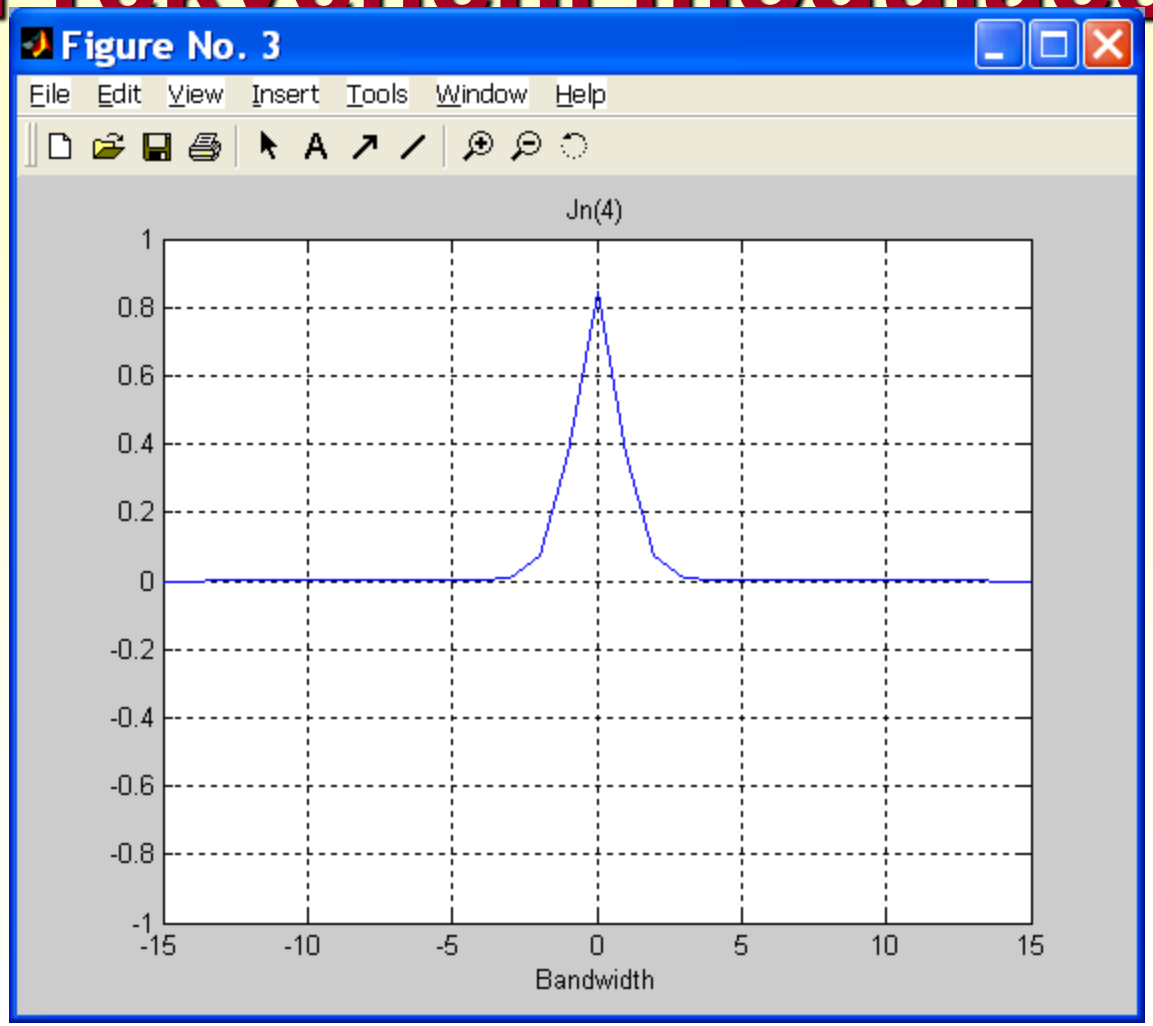

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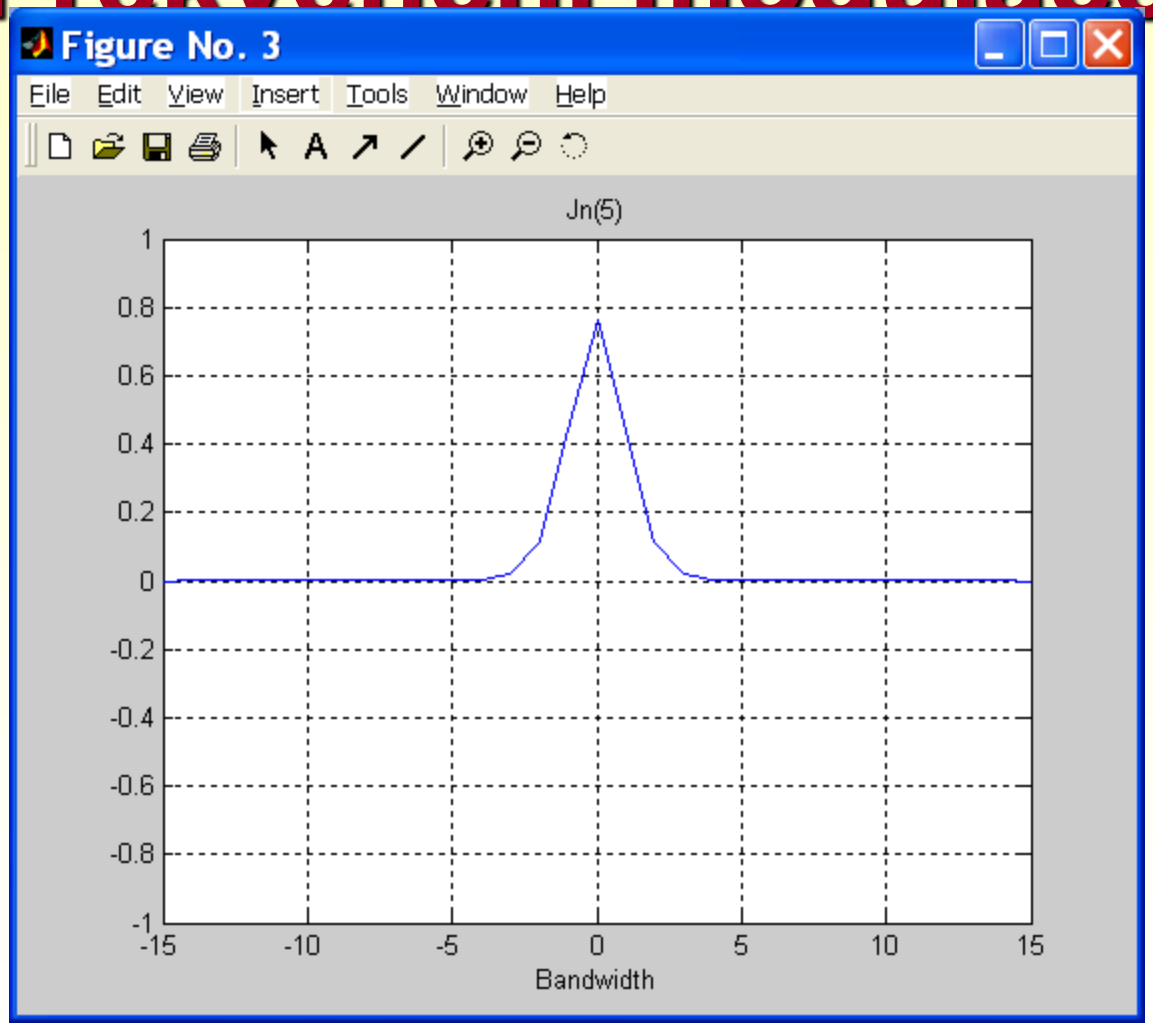

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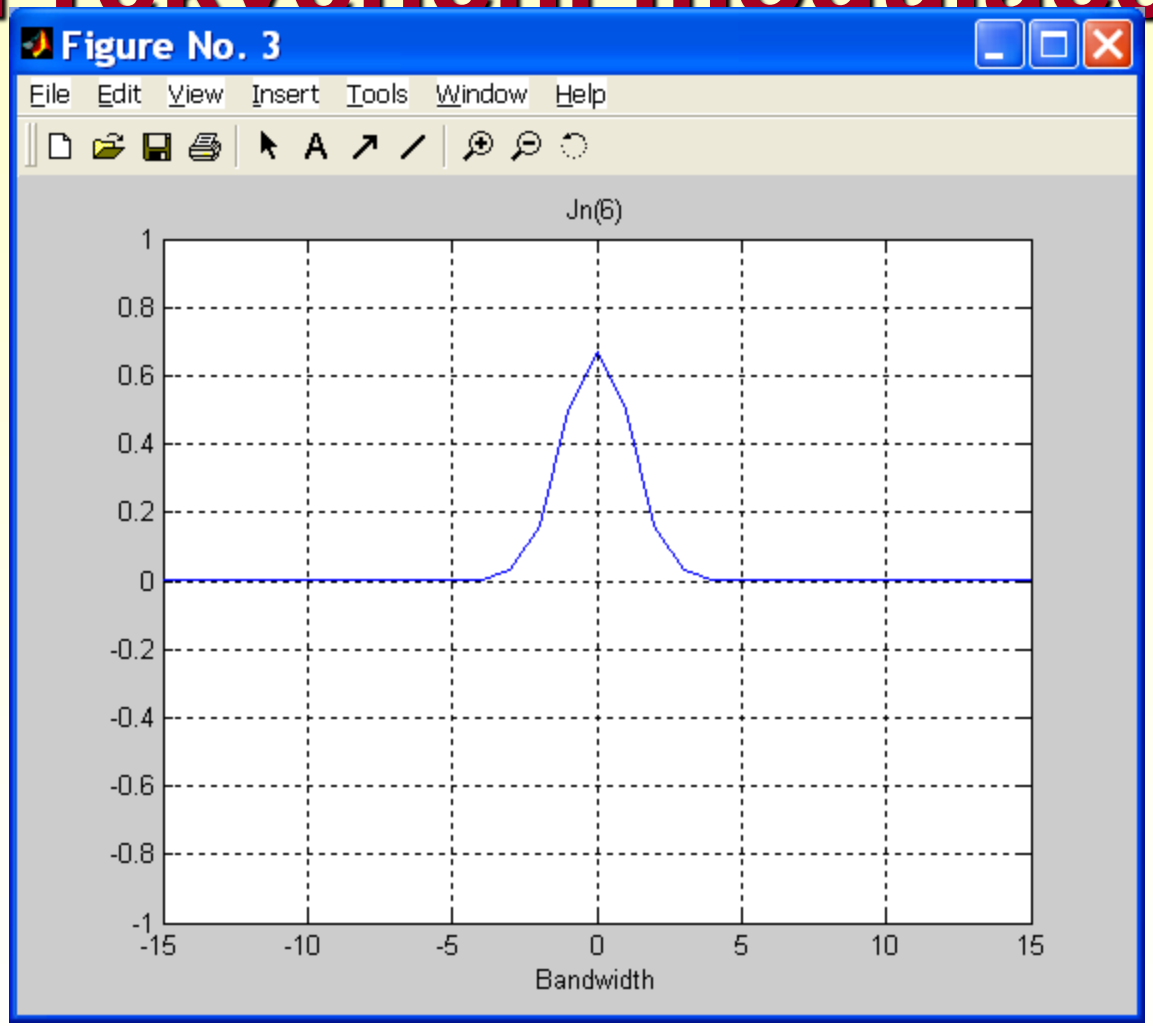
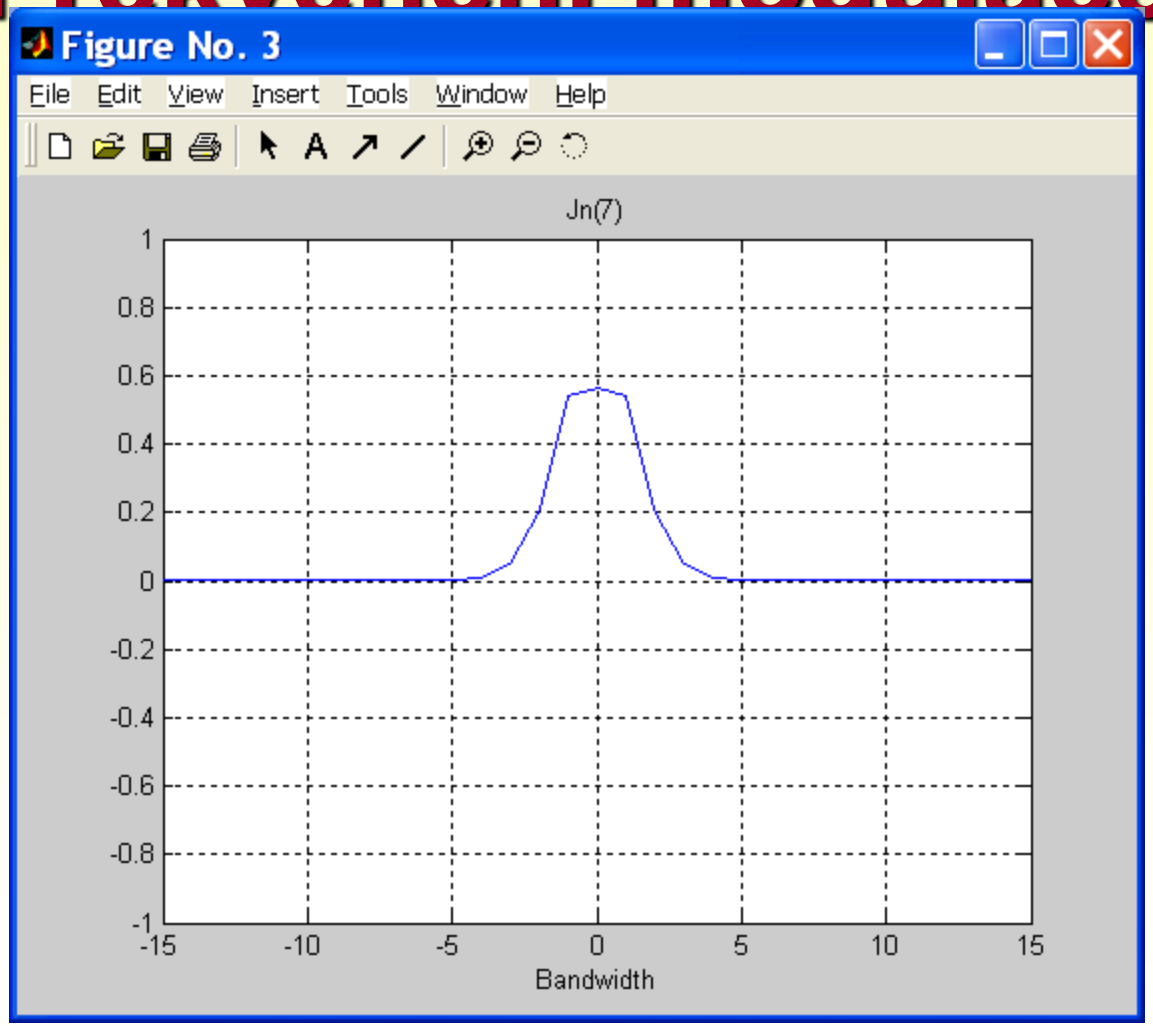
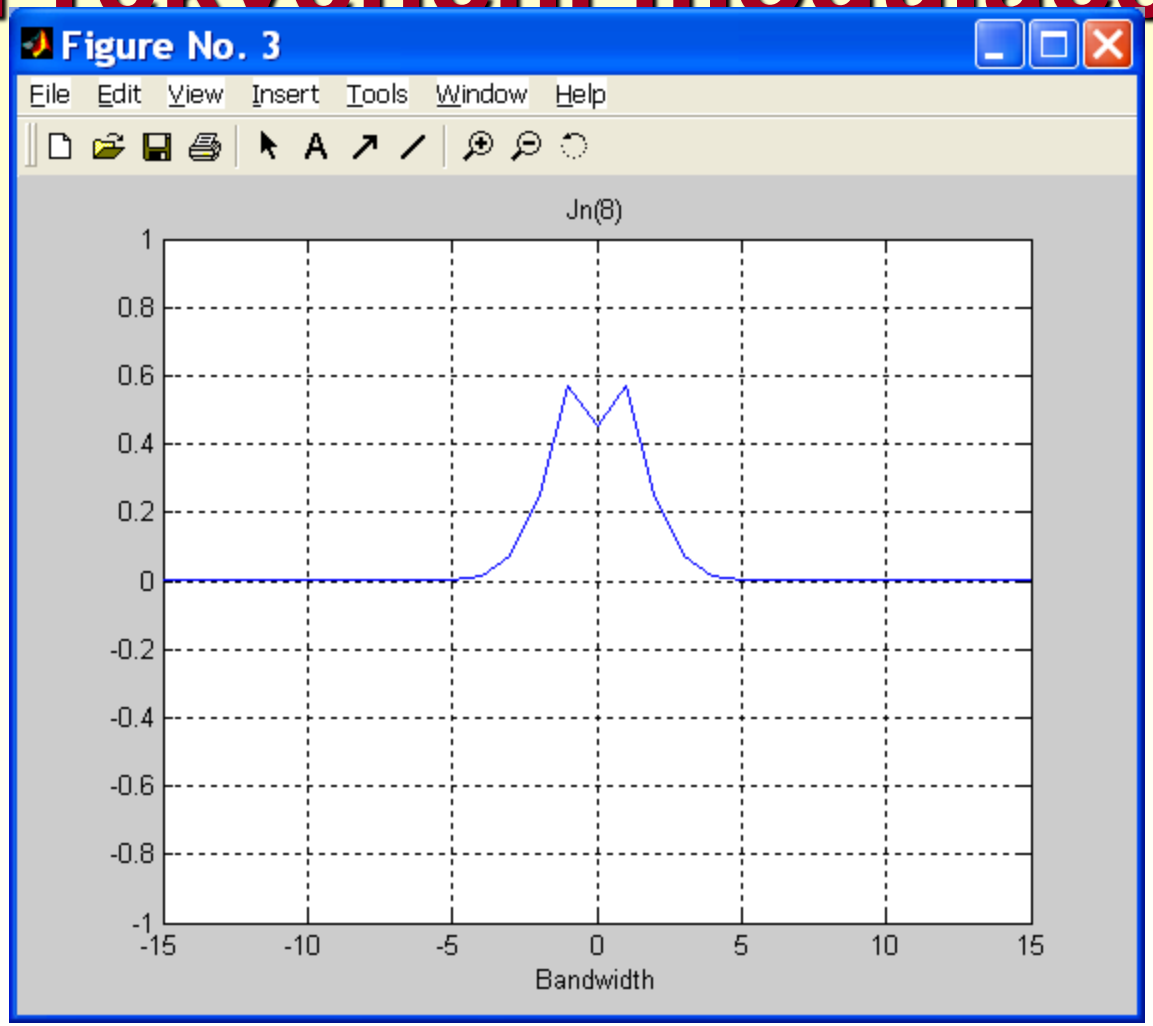


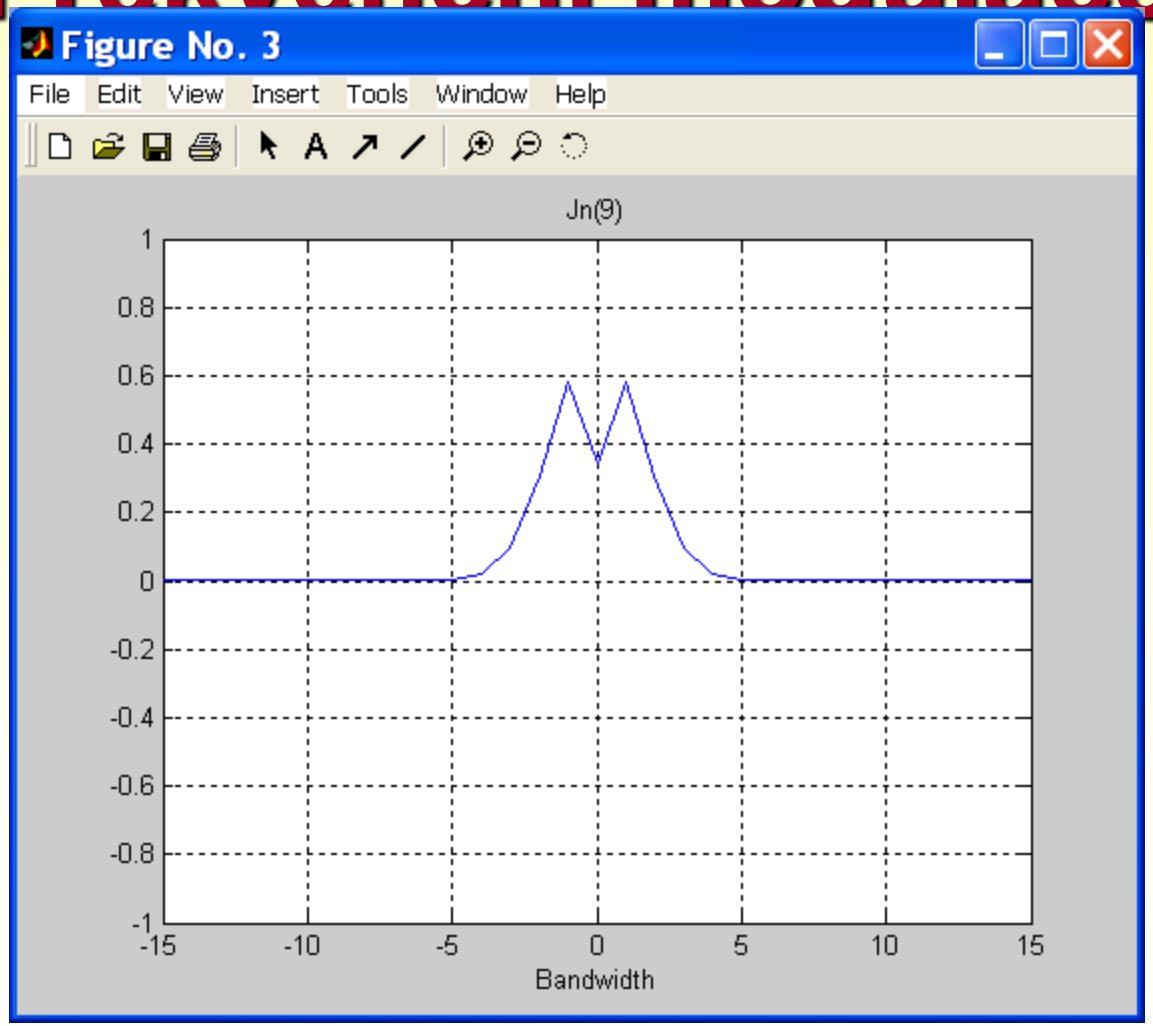
Frekvenční modulace



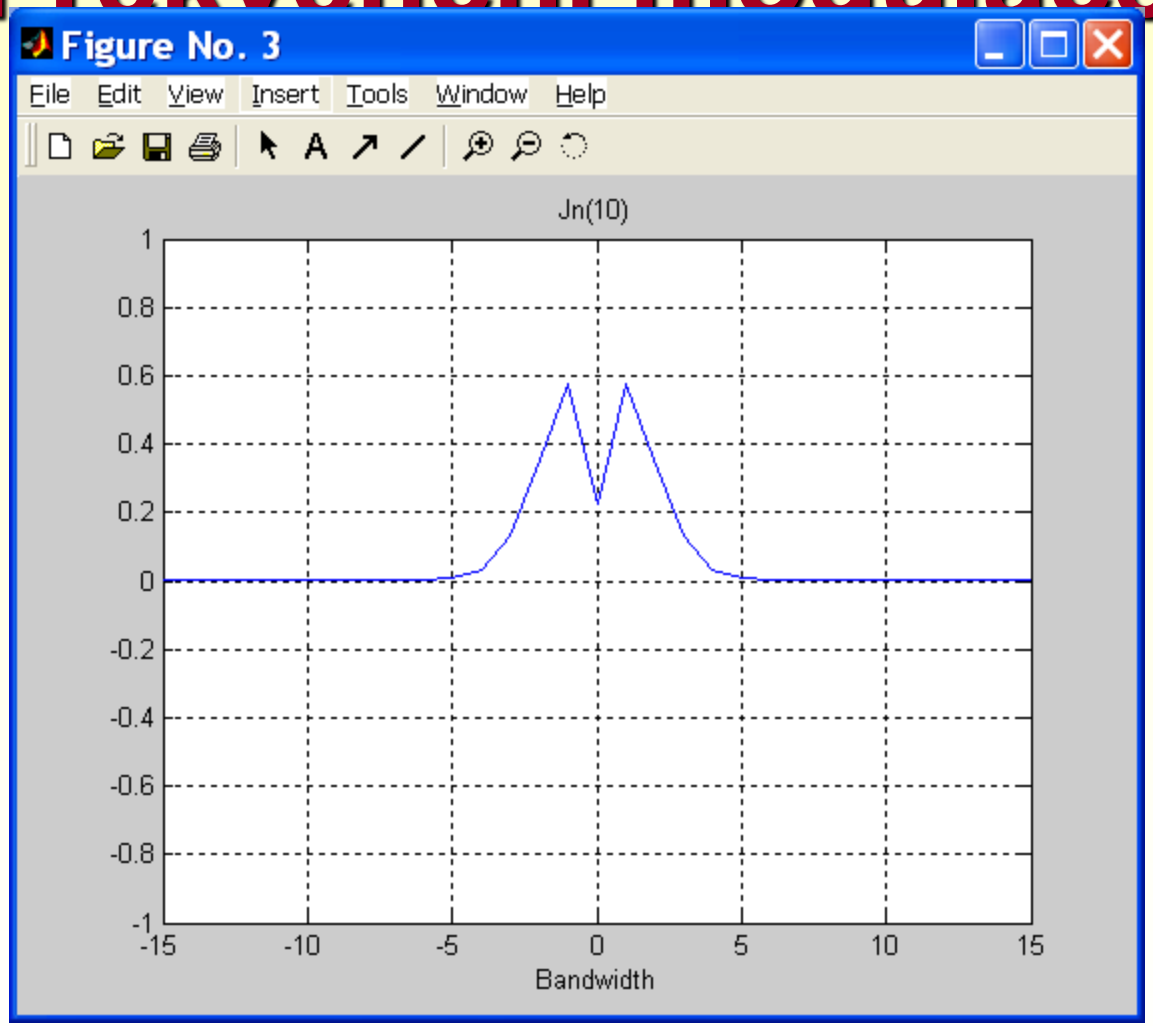
Frekvenční modulace



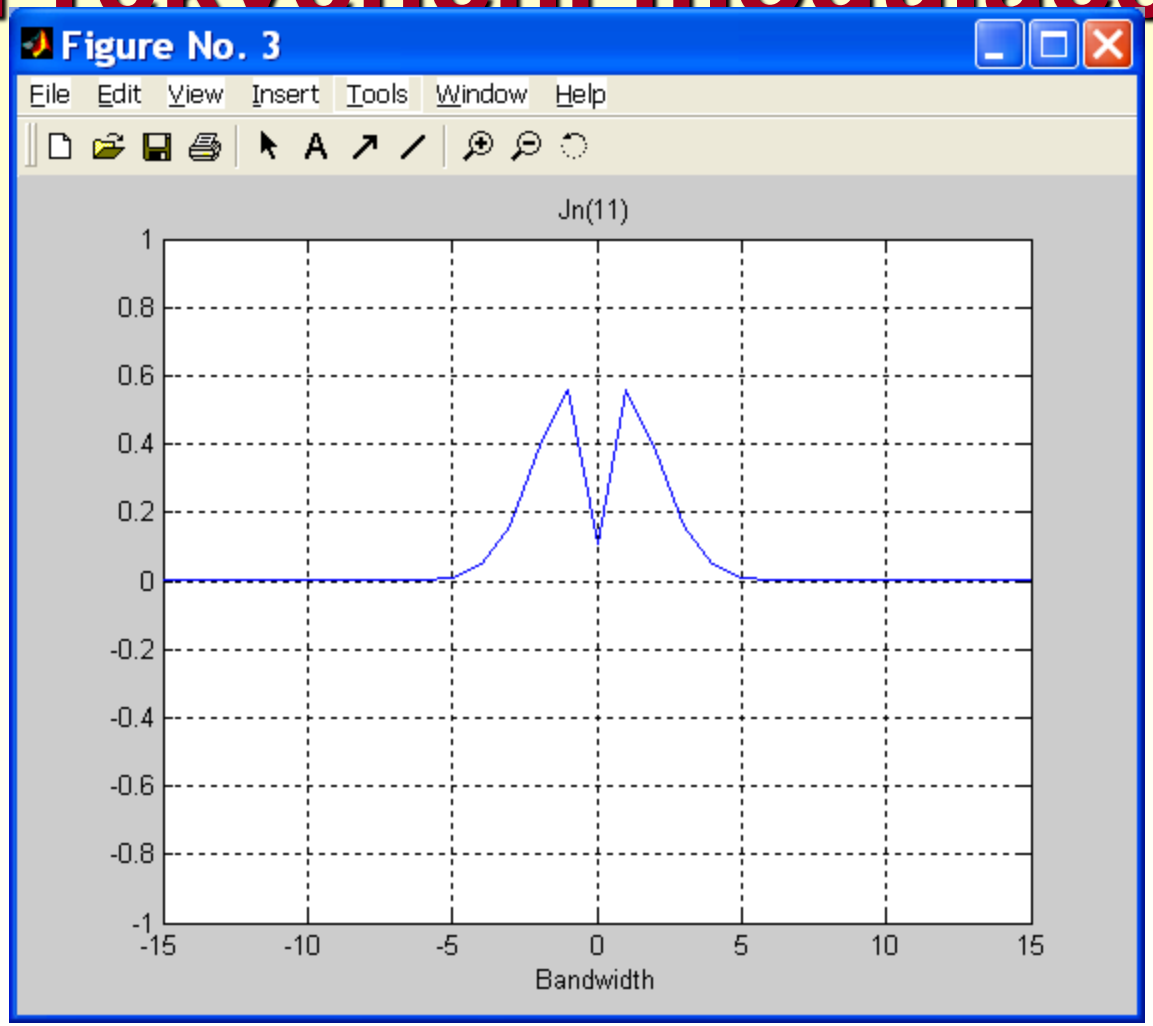
Frekvenční modulace



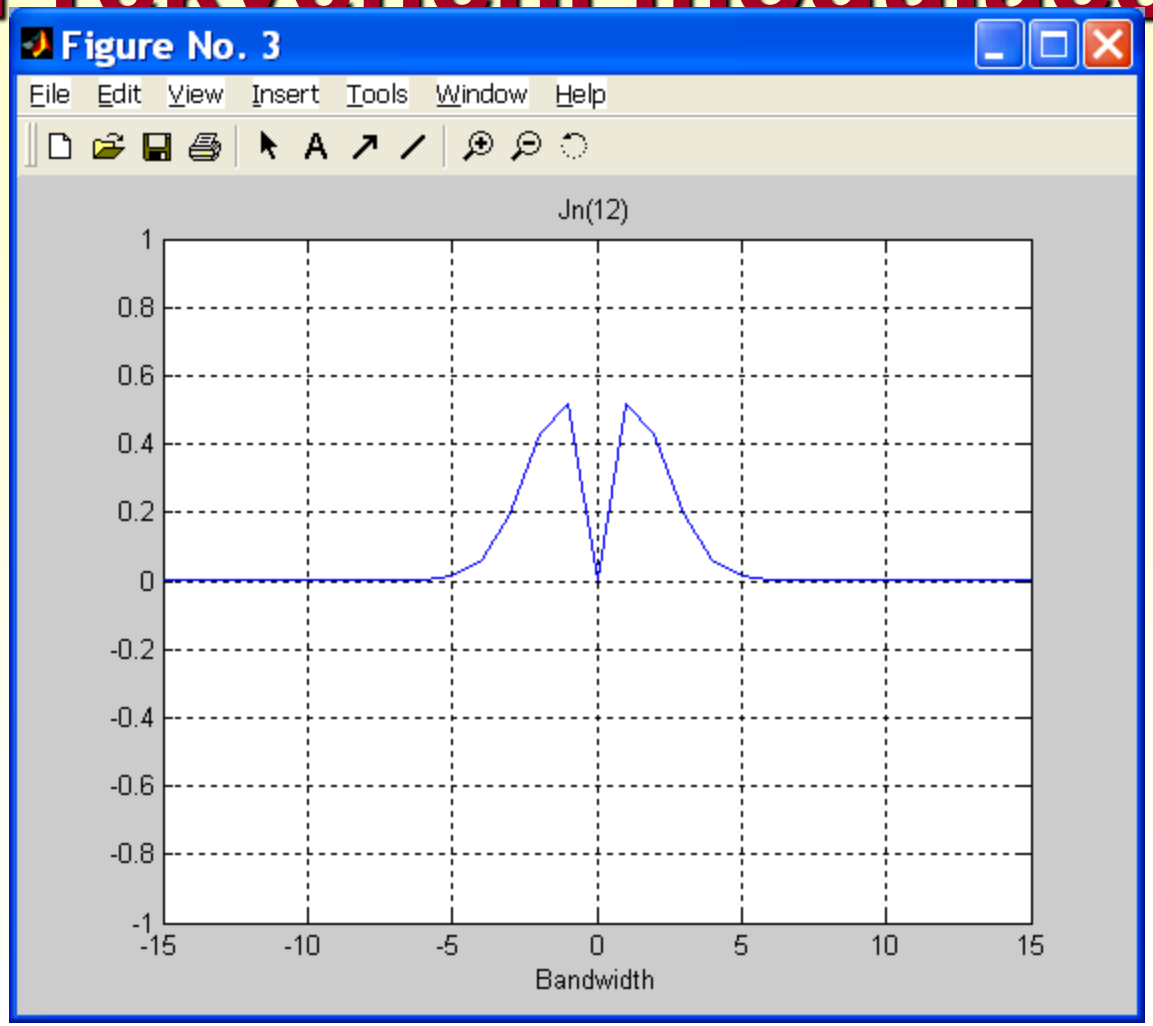
Frekvenční modulace



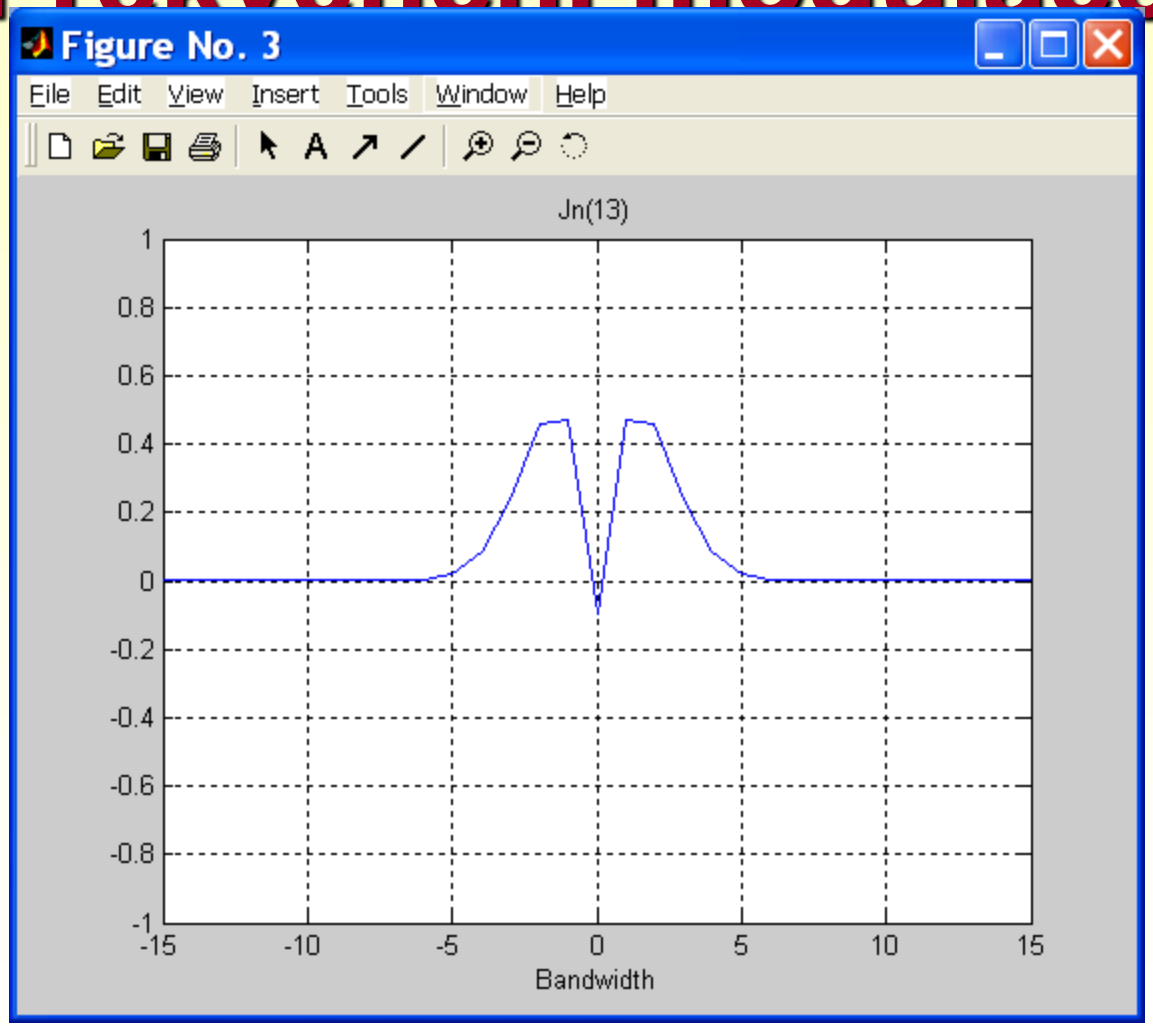
Frekvenční modulace



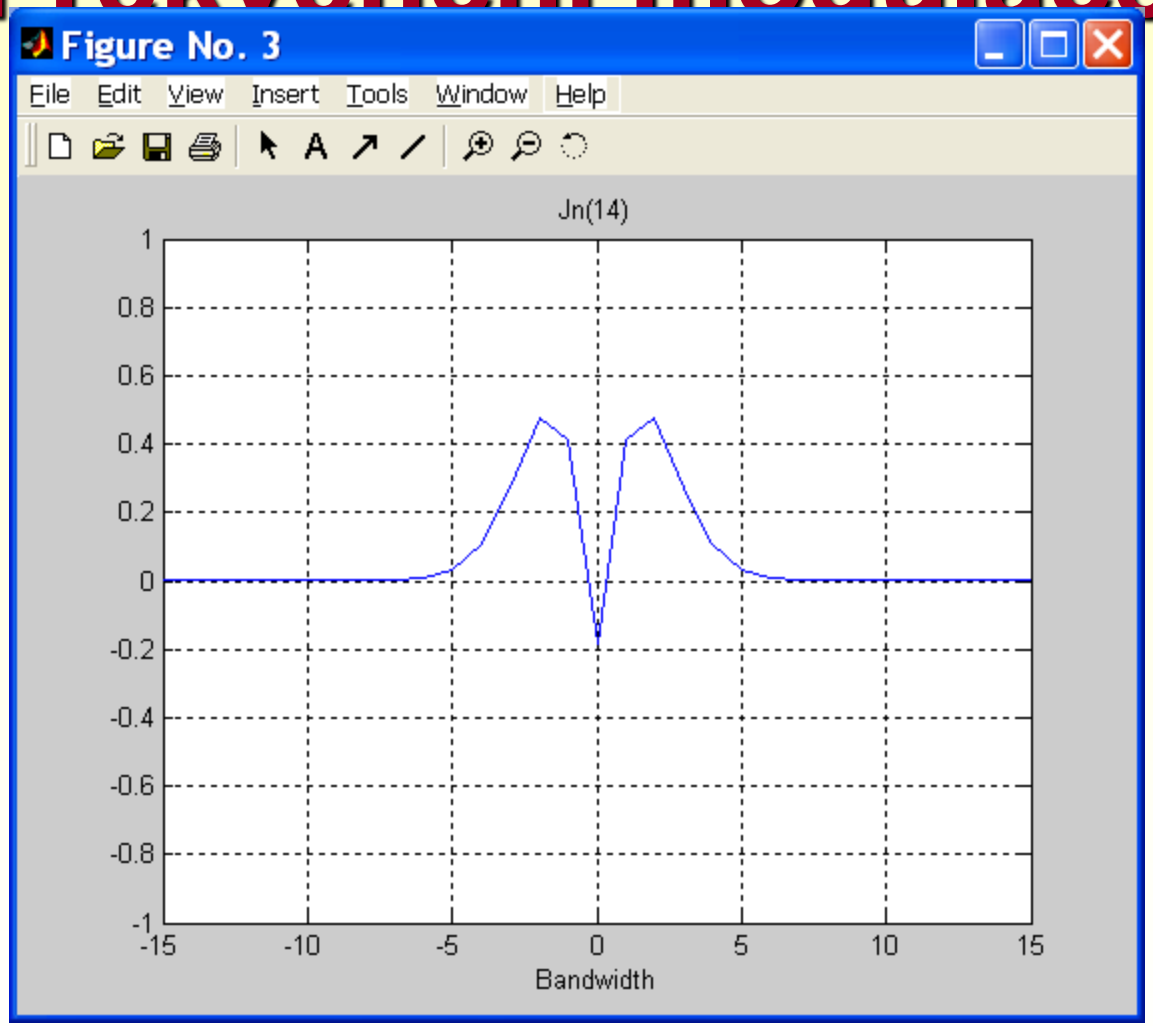
Frekvenční modulace



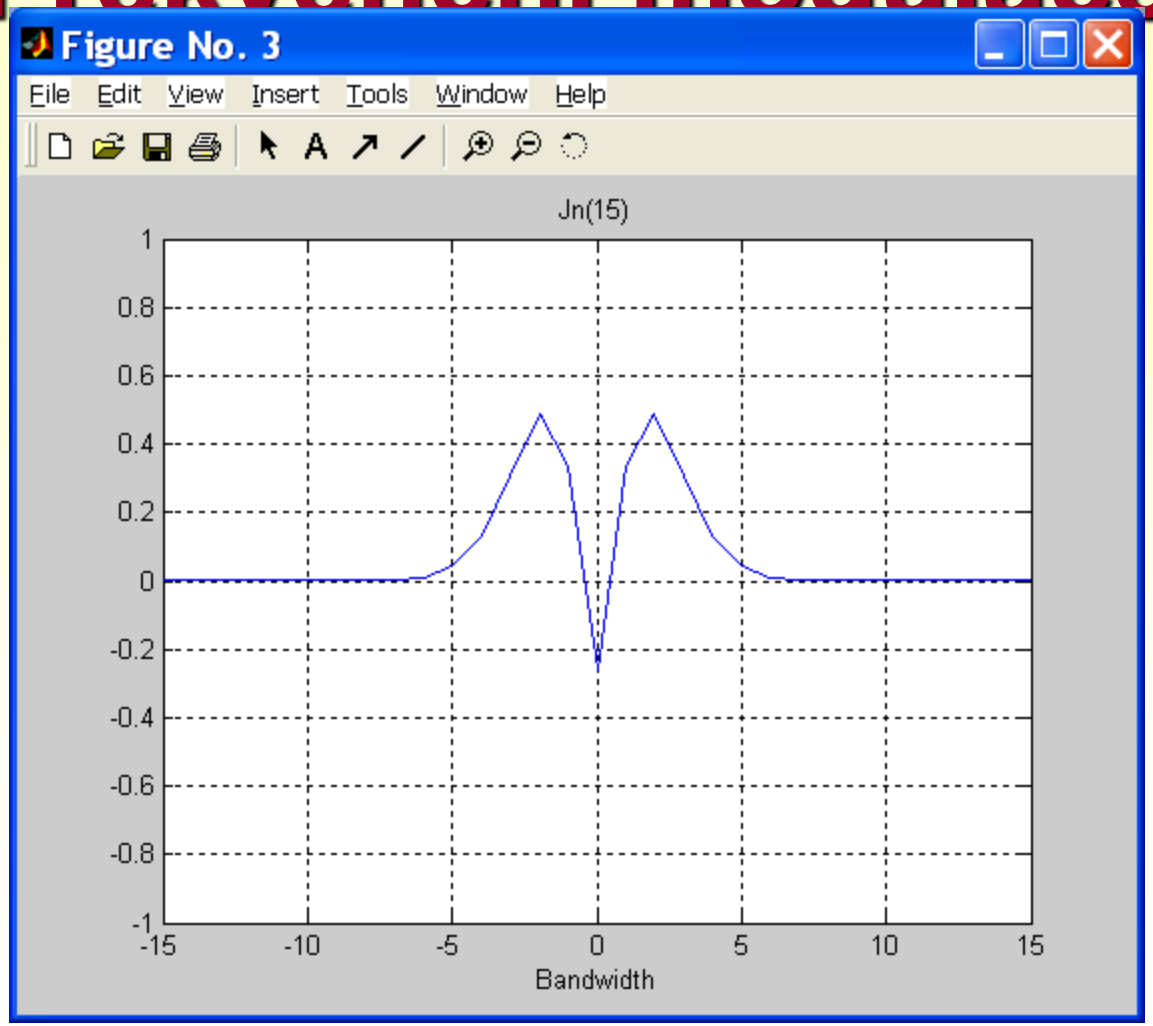
Frekvenční modulace



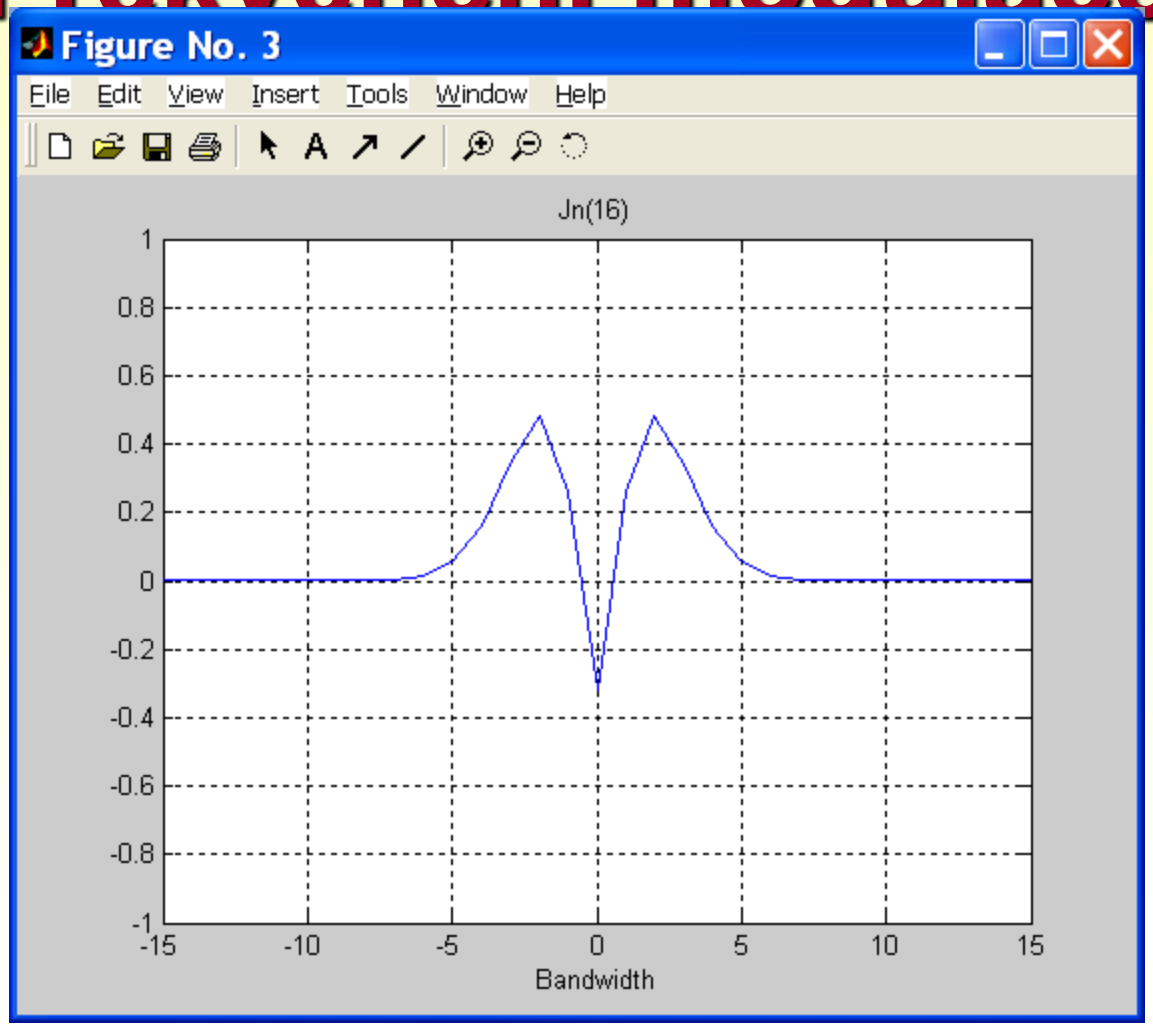
Frekvenční modulace



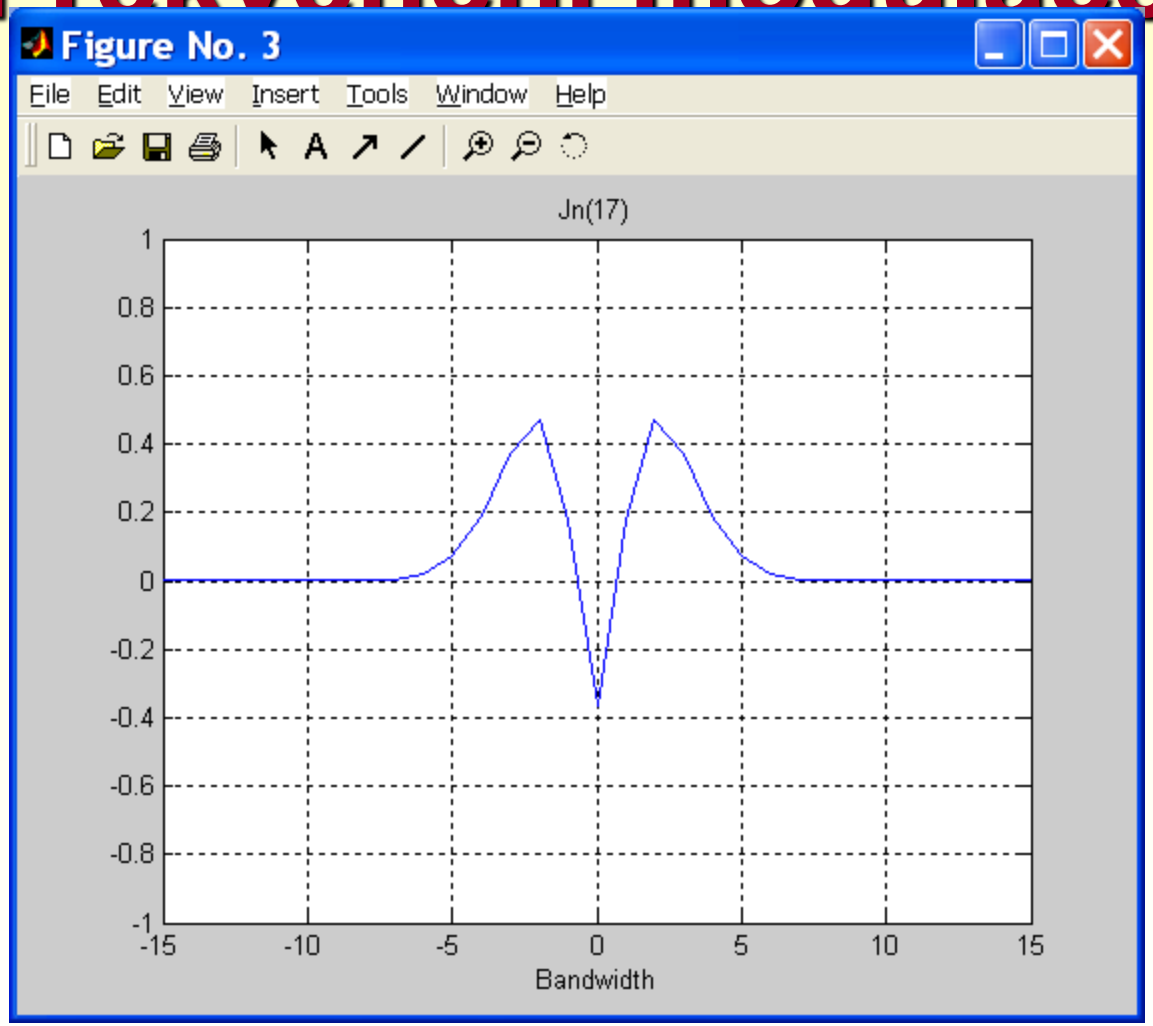
Frekvenční modulace



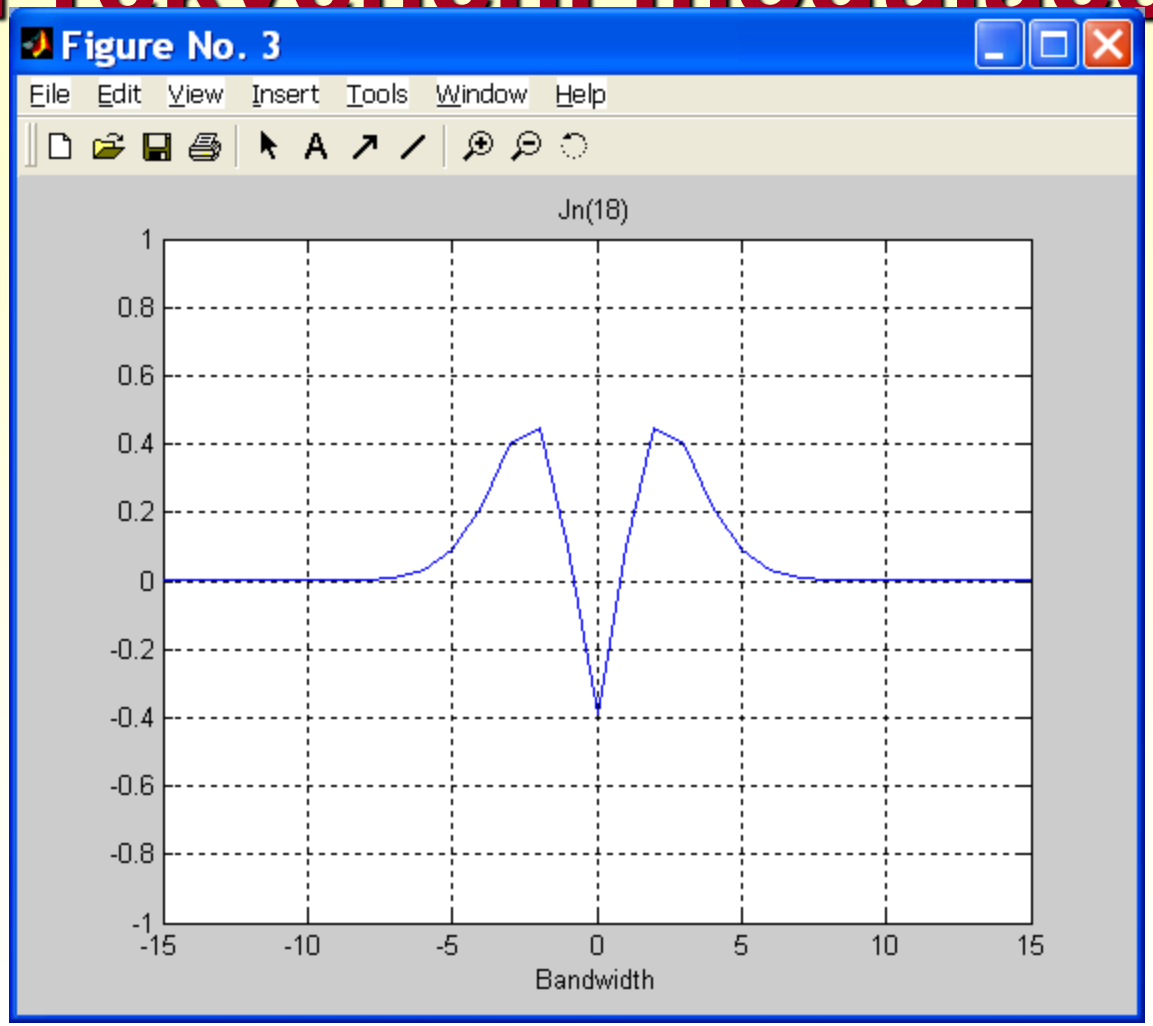
Frekvenční modulace



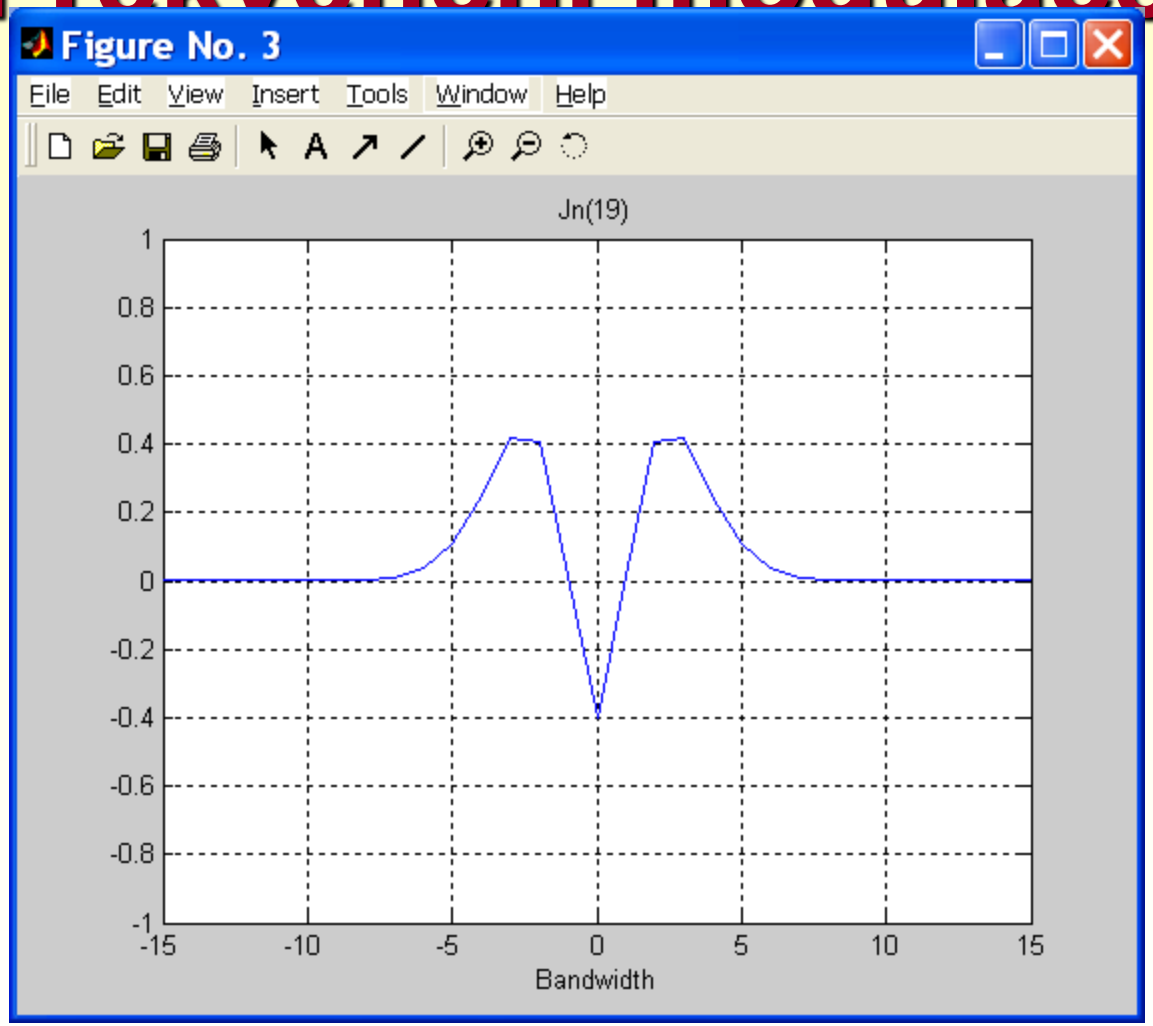
Frekvenční modulace



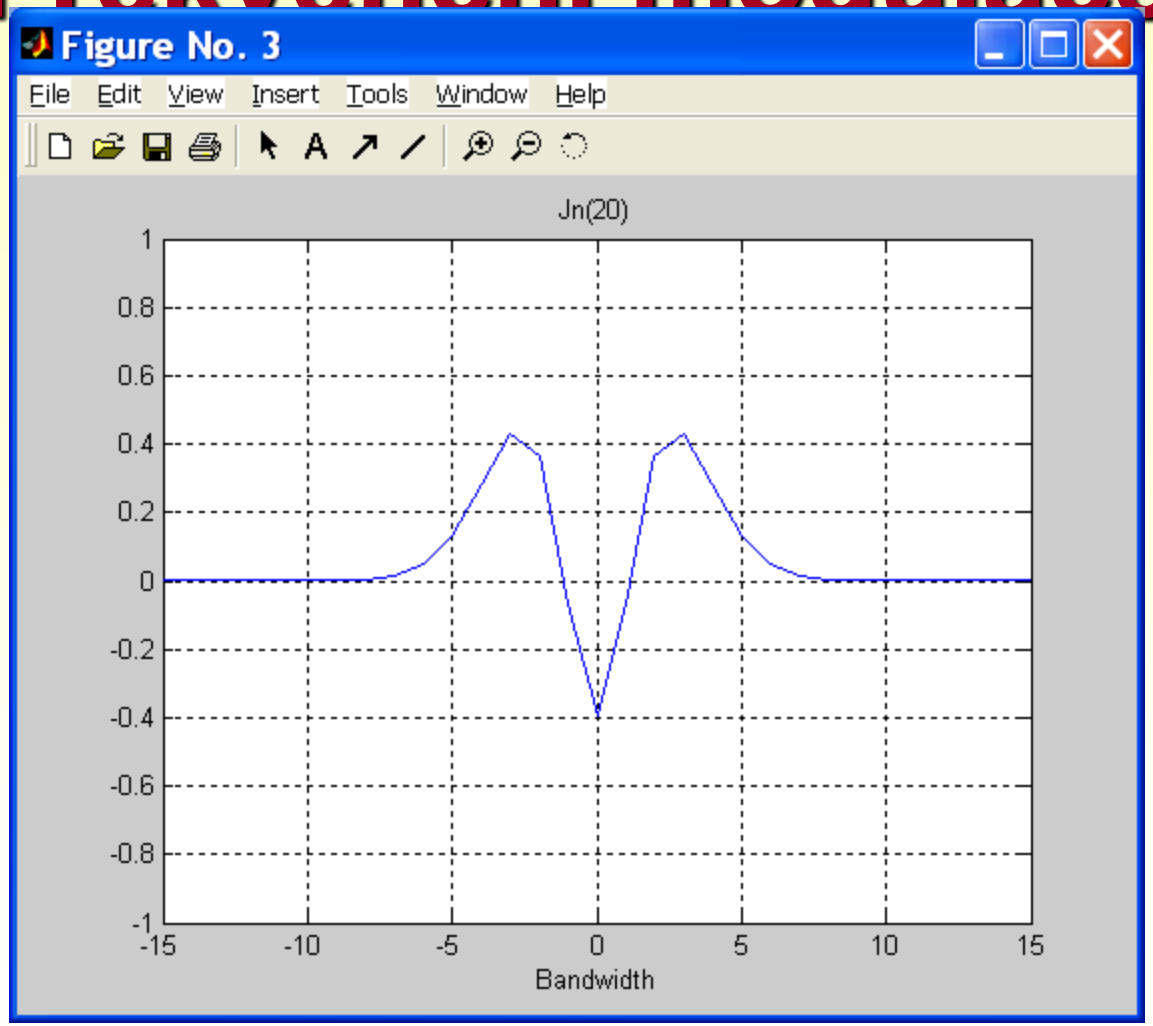
Frekvenční modulace



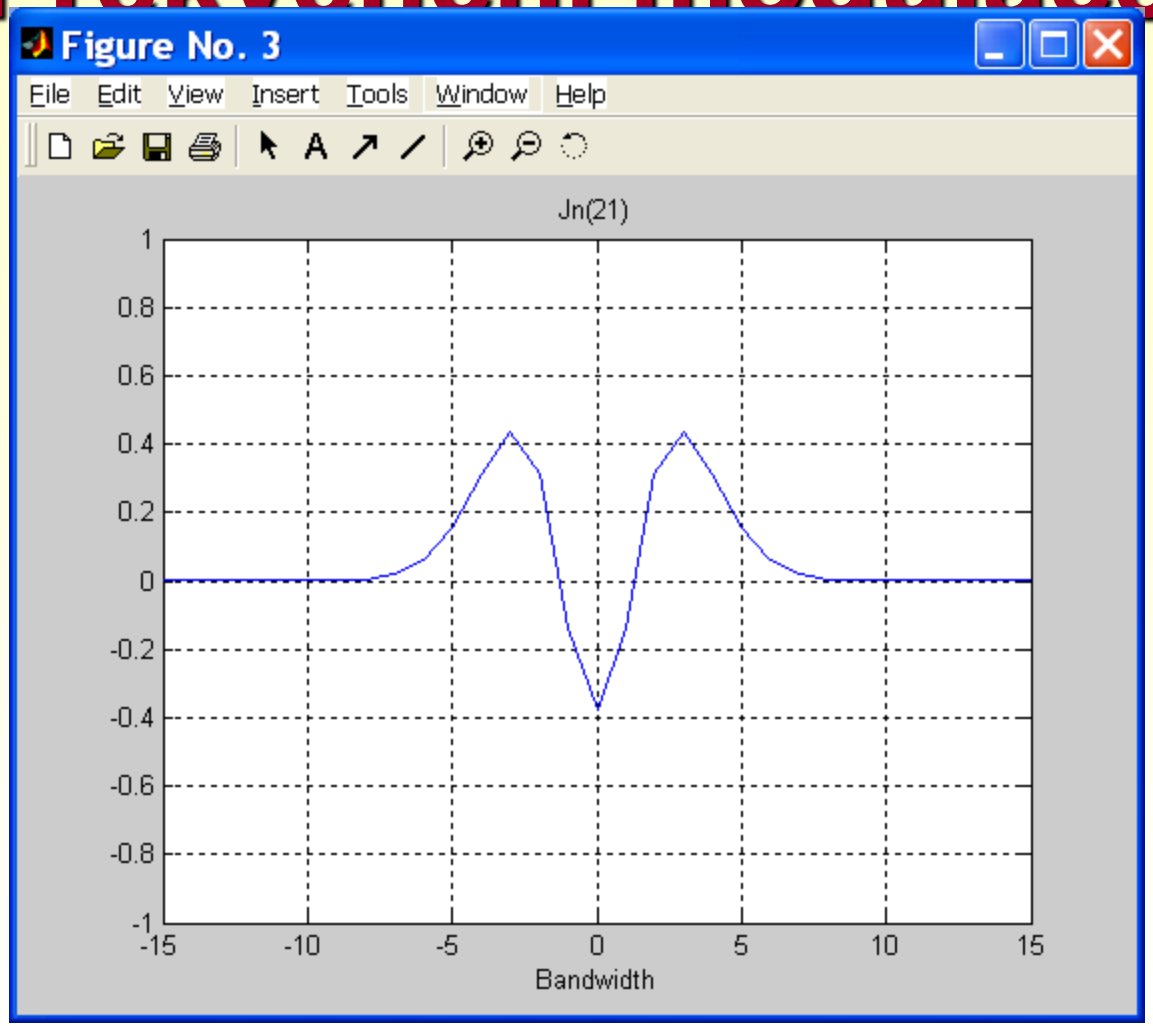
Frekvenční modulace



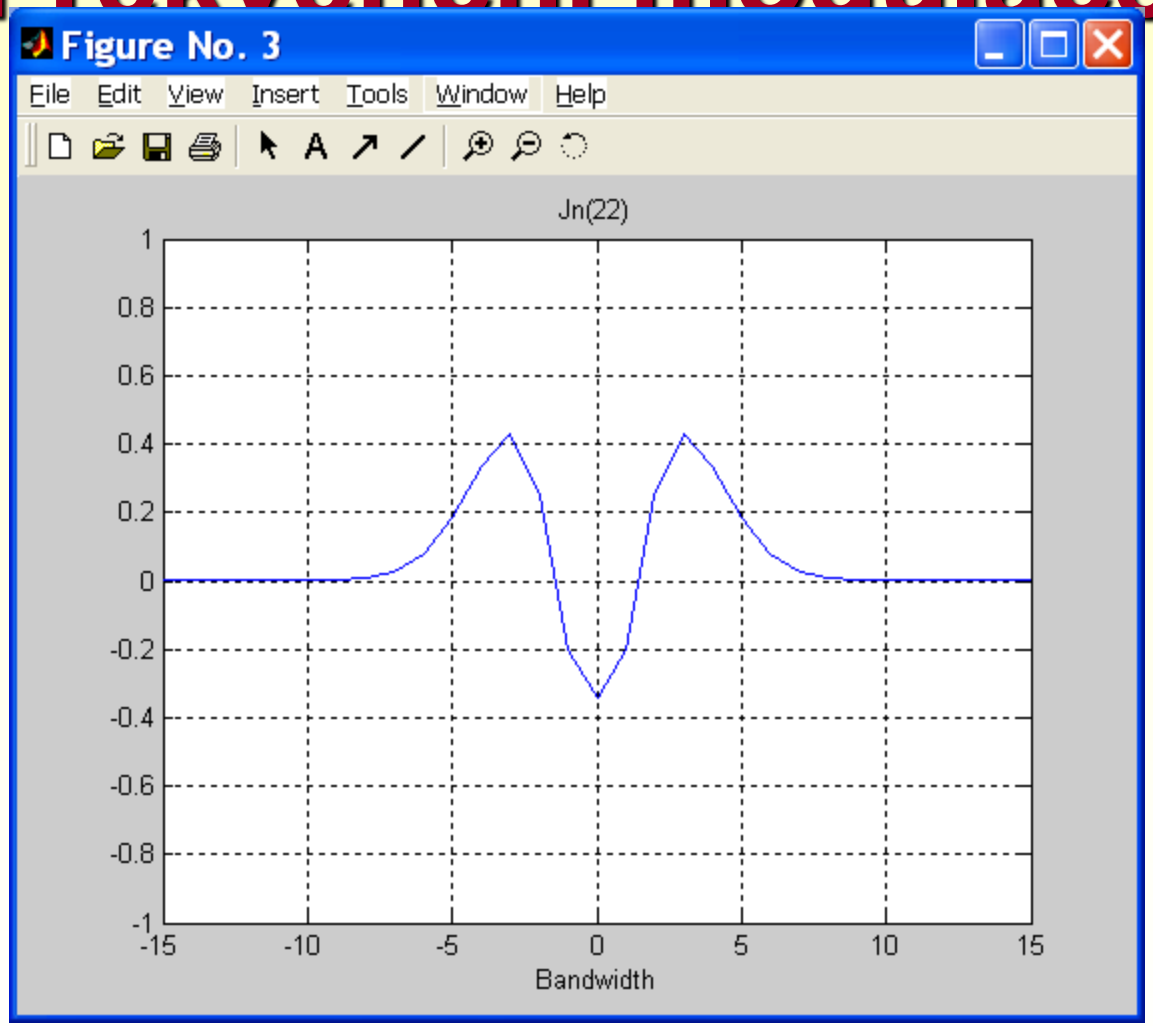
Frekvenční modulace



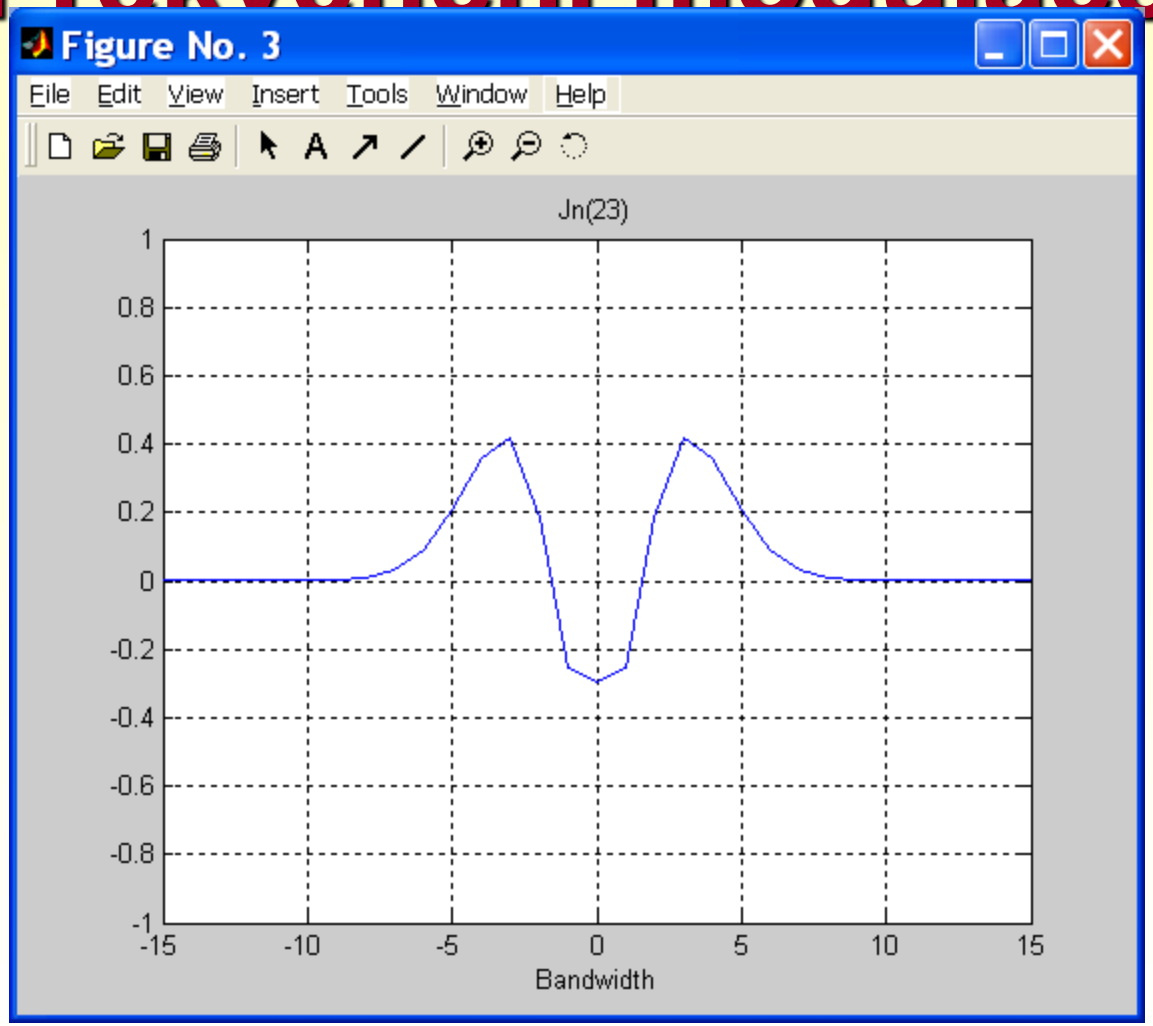
Frekvenční modulace



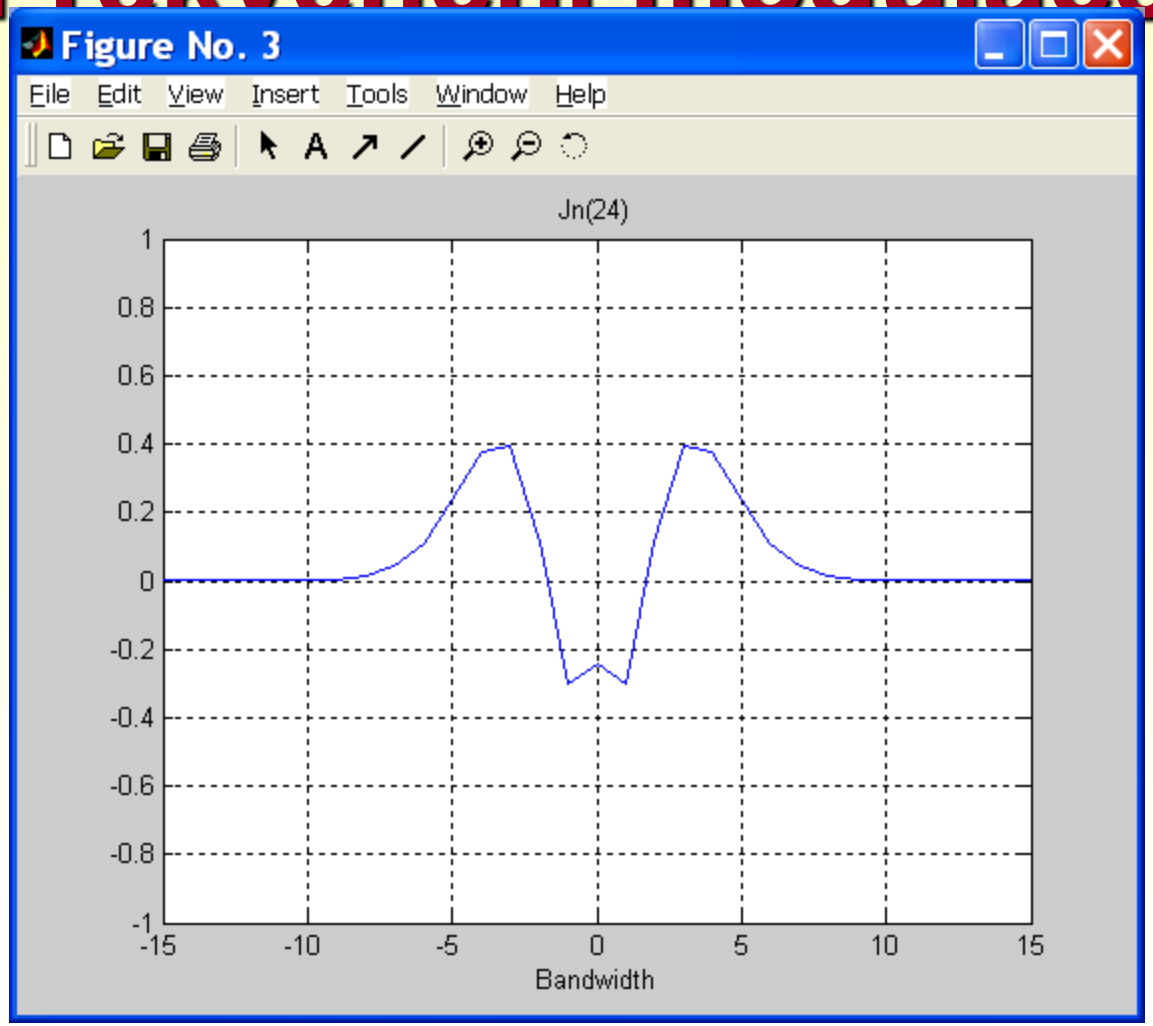
Frekvenční modulace



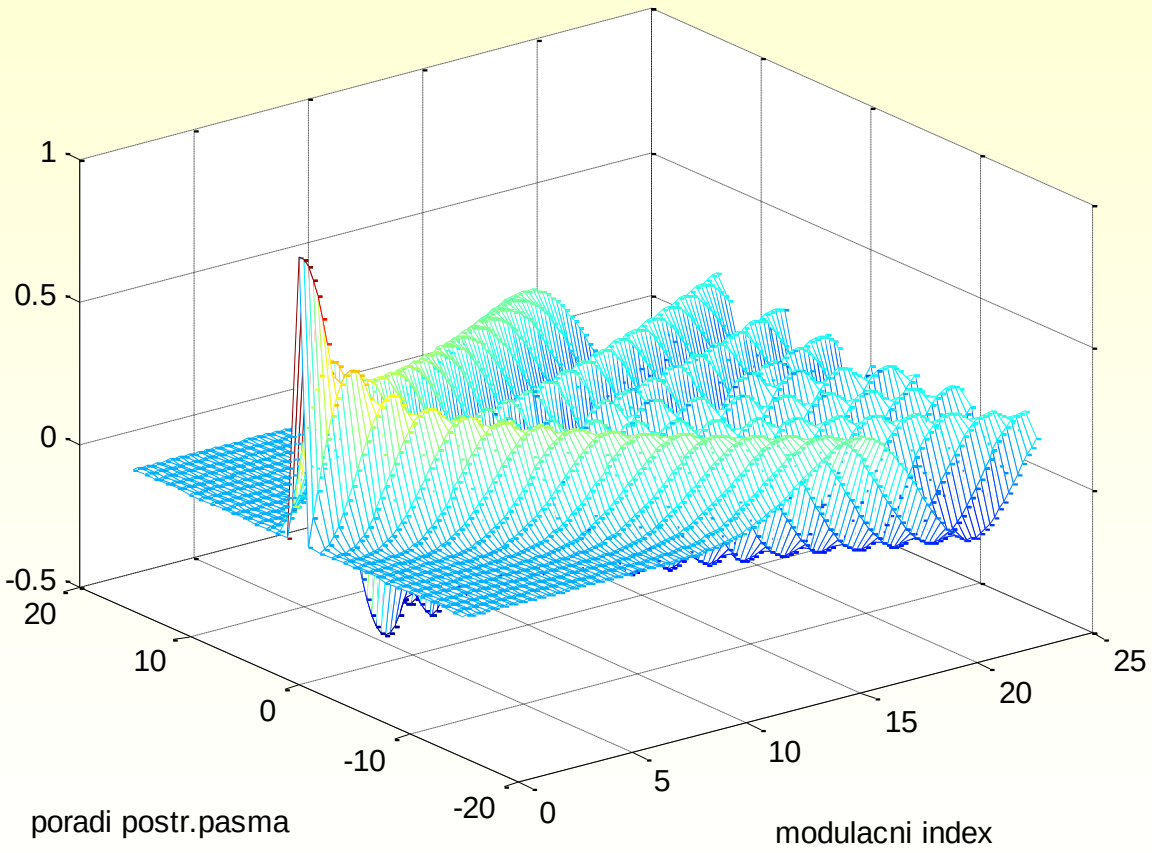
Frekvenční modulace



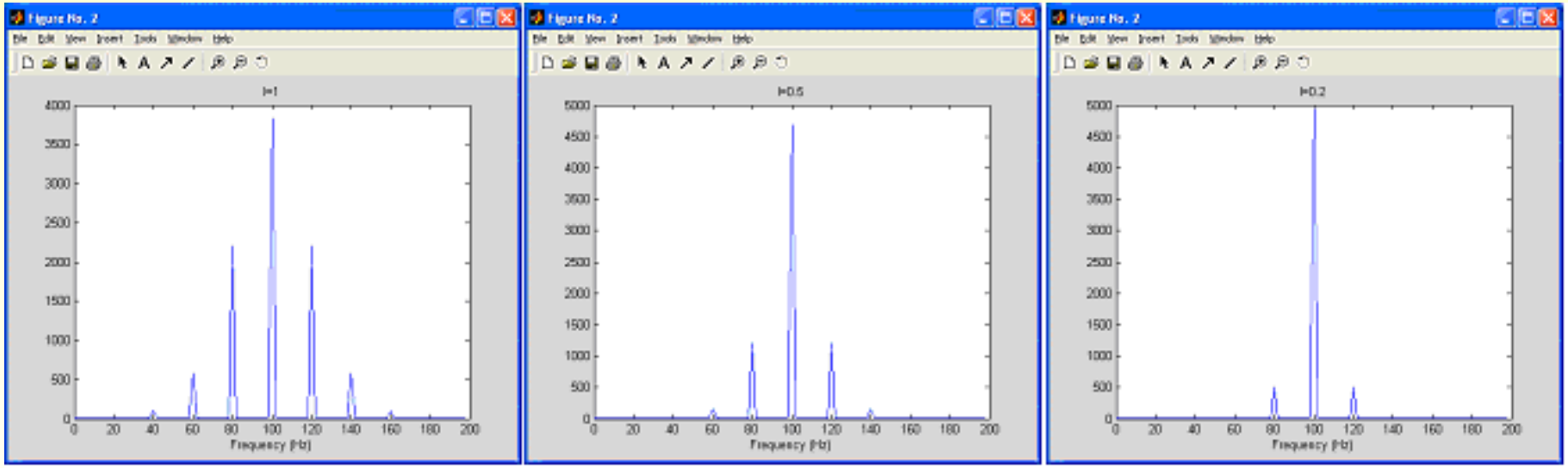
Frekvenční modulace



Frekvenční modulace

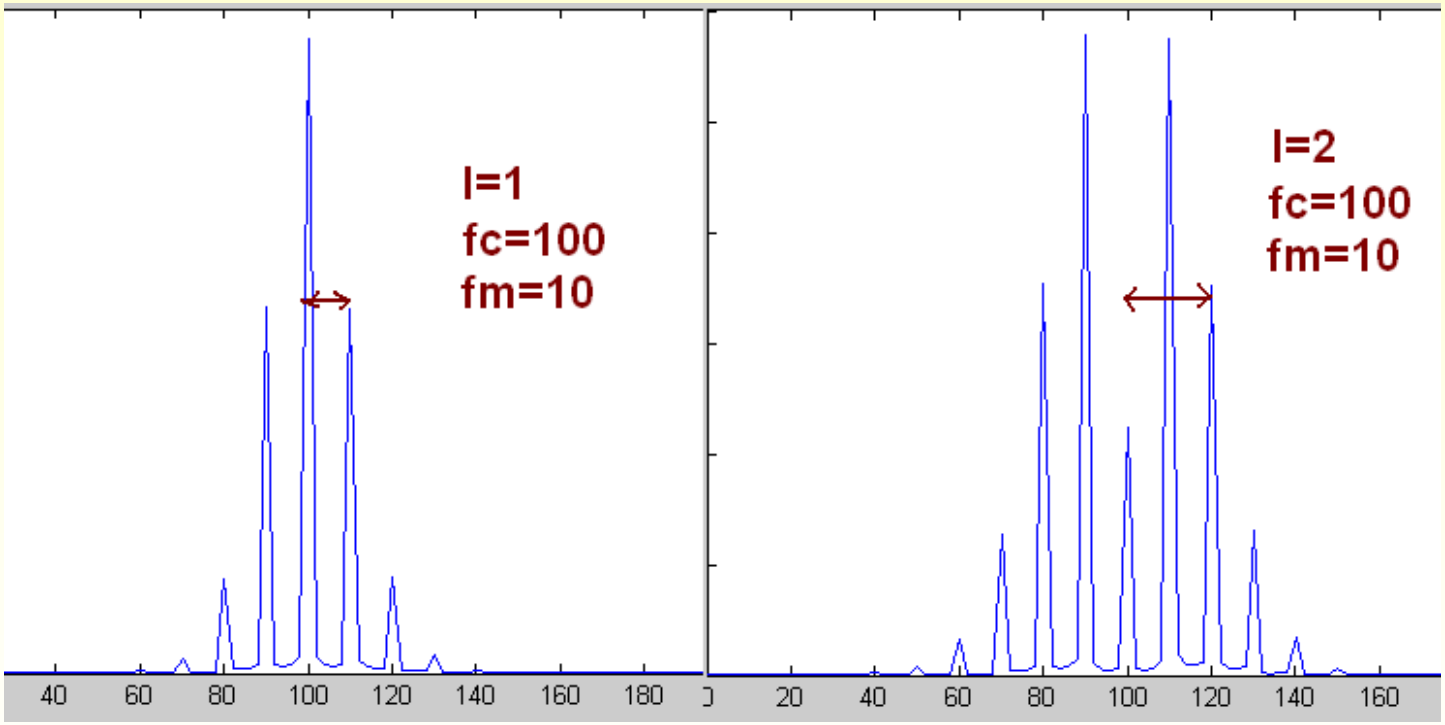


Frekvenční modulace

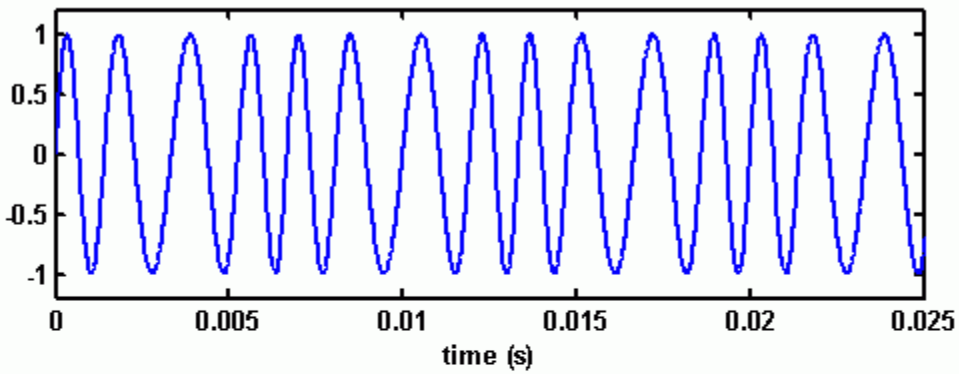


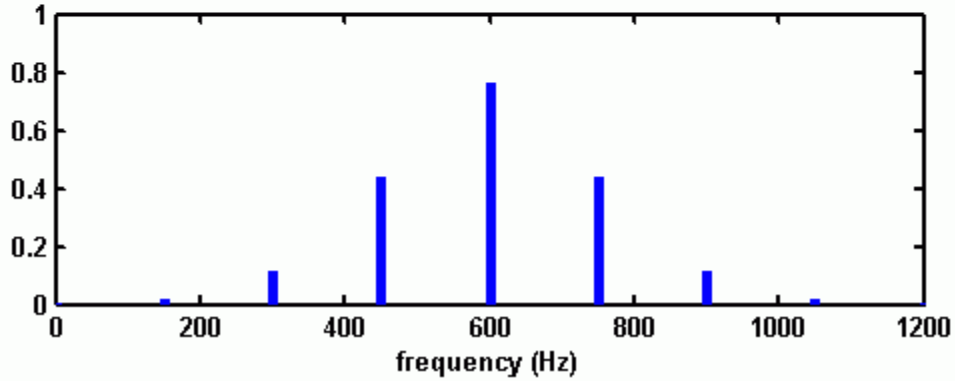
I=1 *I=0.5* *I=0.1*

Frekvenční modulace



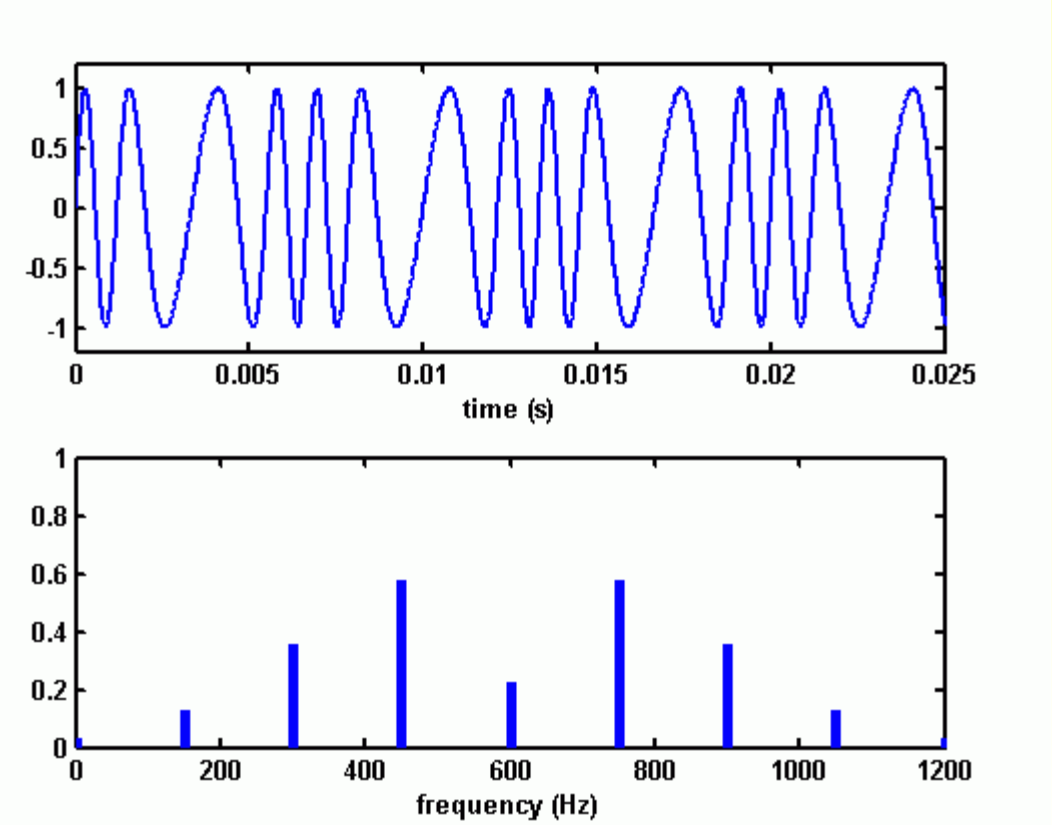
Frekvenční modulace





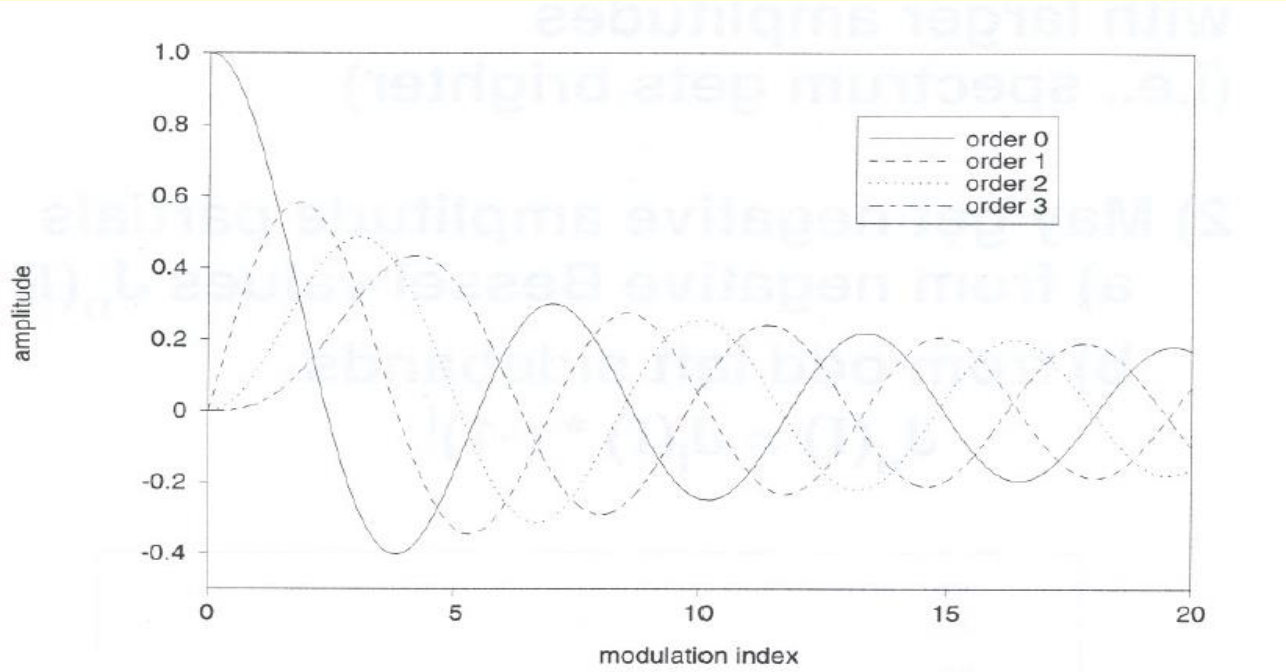
f_c	f_m	m_i
600	150	1
600	1	1
600	4	1
600	50	1
600	70	1

Frekvenční modulace



f_c	f_m	m_i
600	150	2
600	170	2

Frekvenční modulace



Frekvenční modulace

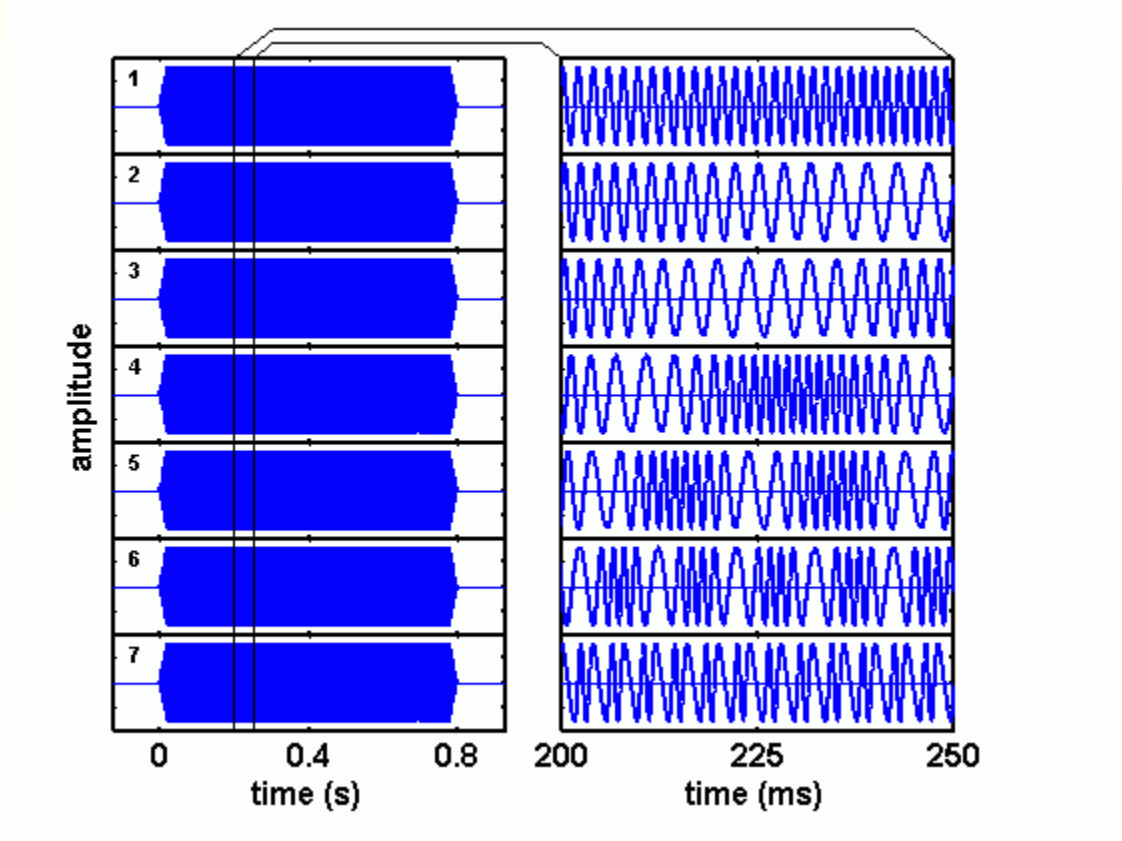
Harmonické a neharmonické modulační frekvence

fc = 500Hz

fm = 2.5, 5, 10, 25, 50, 100, 250 Hz

fc = 500Hz

fm = 4.05, 8.09, 16.2, 40.5, 80.9, 162, 405 Hz

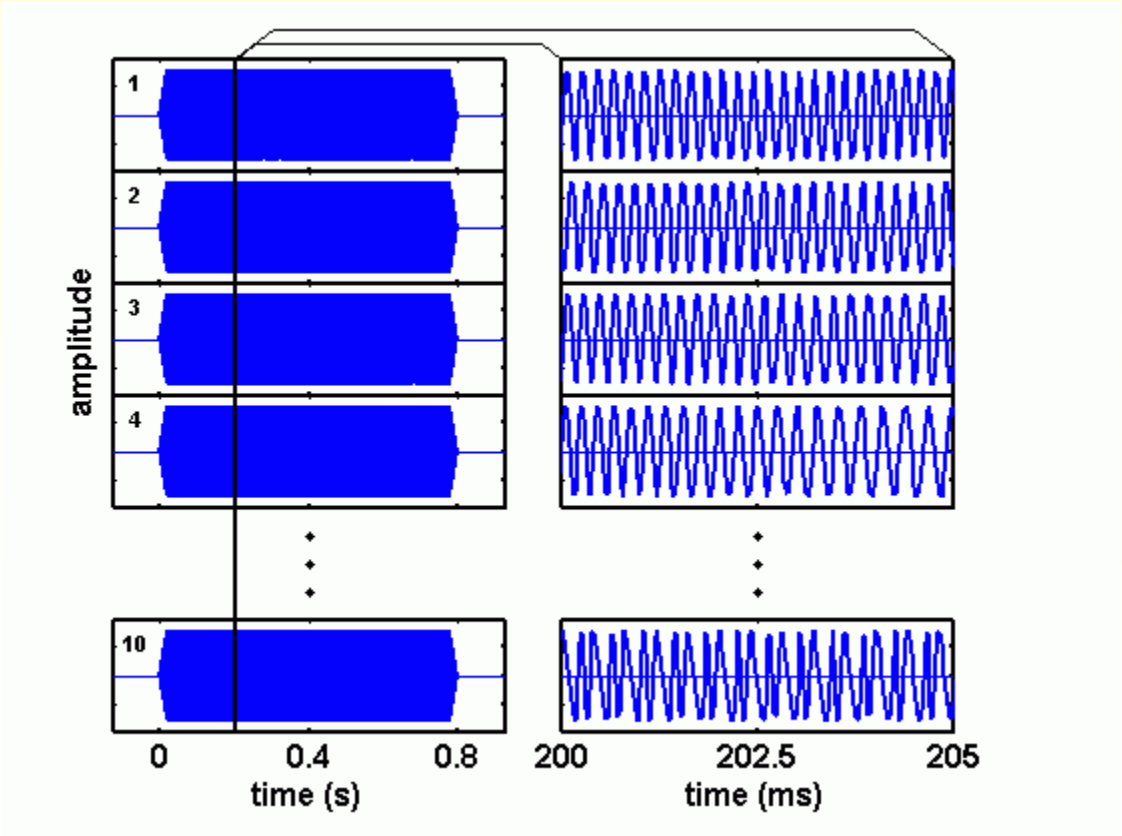


Frekvenční modulace

Harmonické a neharmonické modulační frekvence

fc = 5000Hz
fm = 2.5, 5, 10, 25, 50, 100, 250, 500, 1000, 2500 Hz

fc = 5000Hz
fm = 4.05, 8.09, 16.2, 40.5, 80.9, 162, 405, 809, 1618, 4045 Hz



Frekvenční modulace

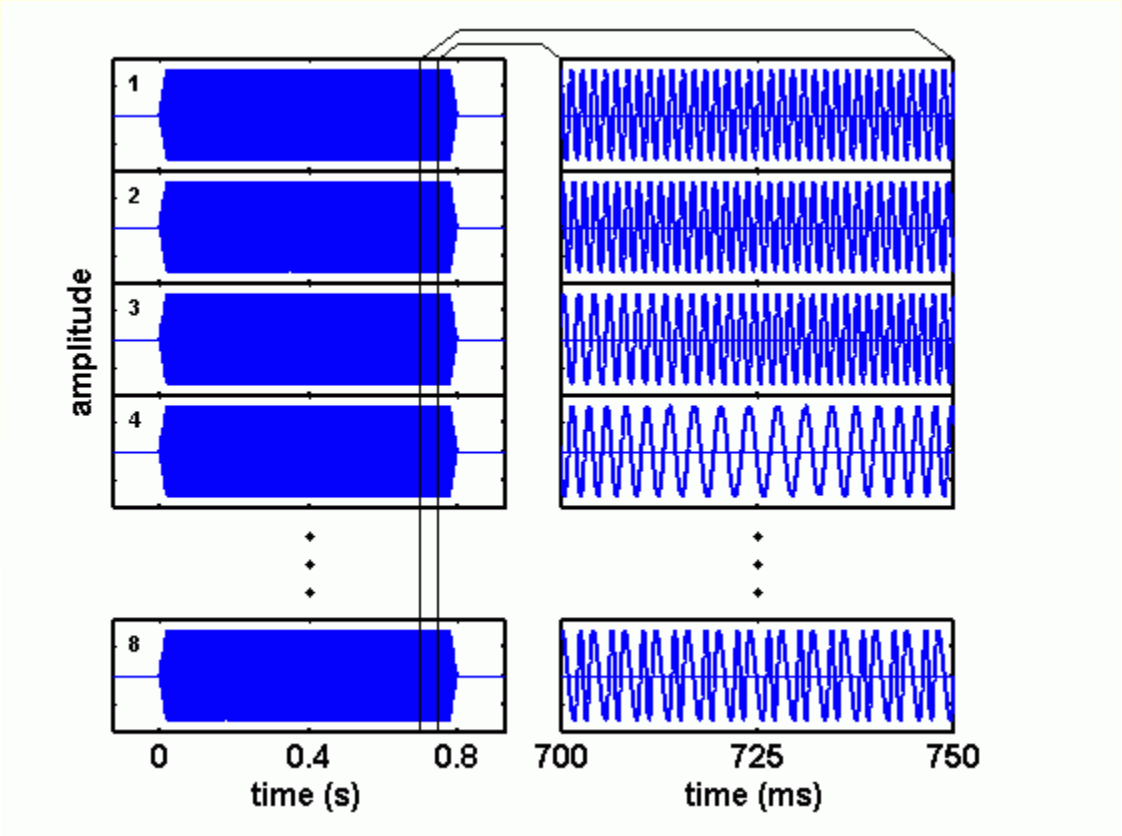
Zvětšení modulačního indexu

fc = 500Hz

fm = 2.5, 5, 10, 25, 50, 100, 250 Hz

fc = 500Hz

fm = 4.05, 8.09, 16.2, 40.5, 80.9, 162, 405 Hz

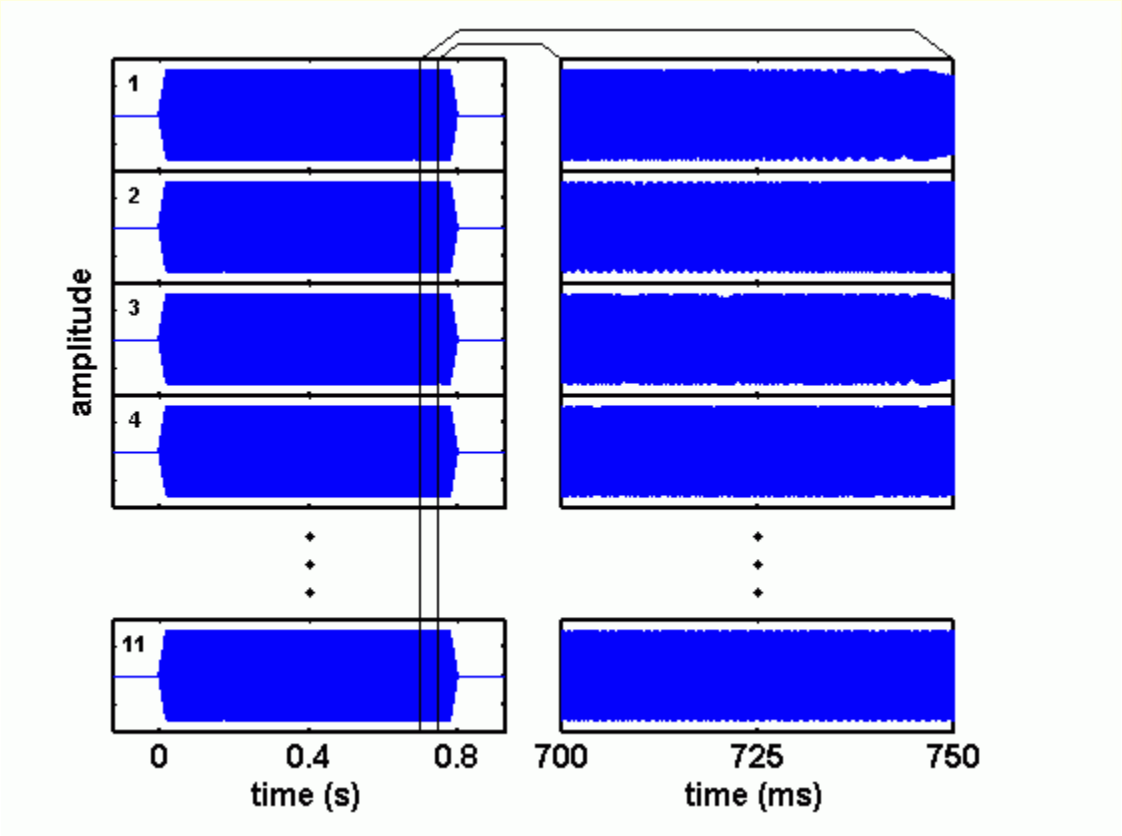


Frekvenční modulace

Zvětšení modulačního indexu

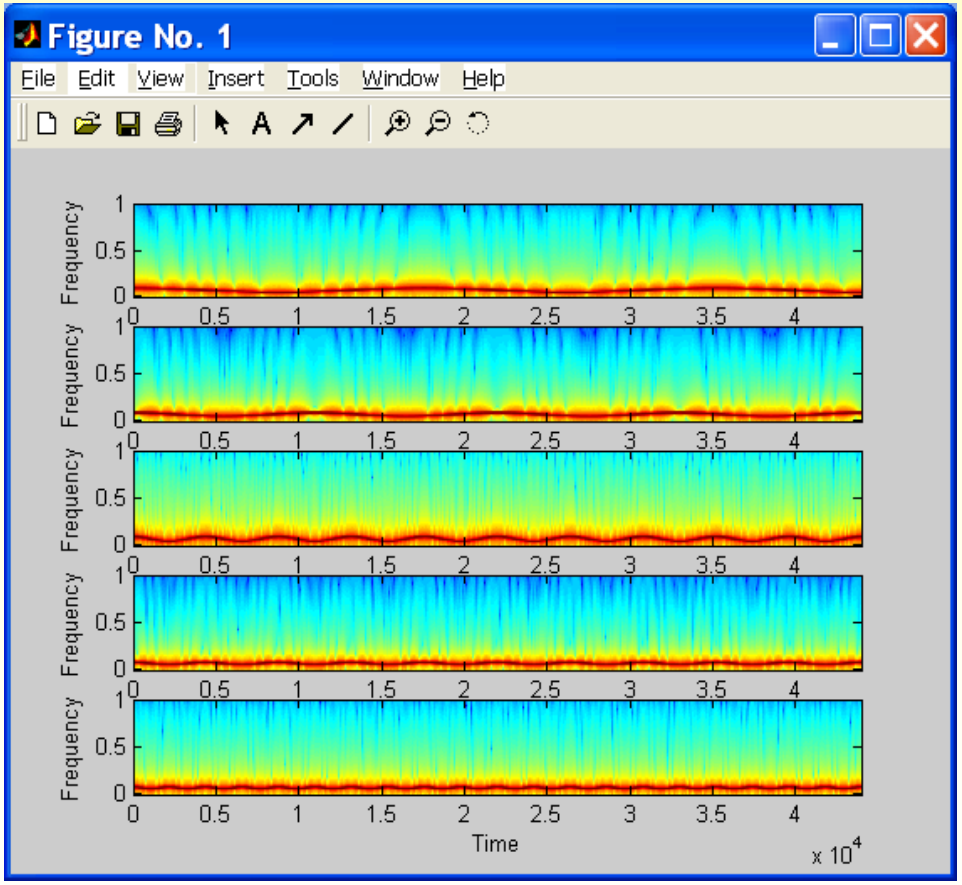
fc = 5000Hz
fm = 2.5, 5, 10, 25, 50, 100, 250, 500, 1000, 2500 Hz

fc = 5000Hz
fm = 4.05, 8.09, 16.2, 40.5, 80.9, 162, 405, 809, 1618, 4045 Hz



(.wav)

Varovné signály



mi	f_c	f_m
400	1500	1,25
200	1500	2
100	1500	5
50	1500	10
20	1500	25

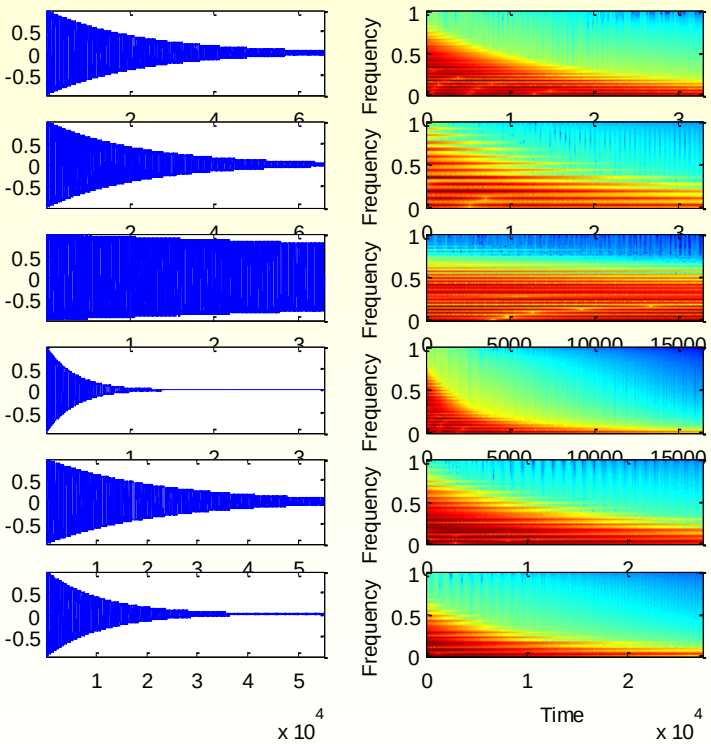
square

sawtooth

Syntetické zvony

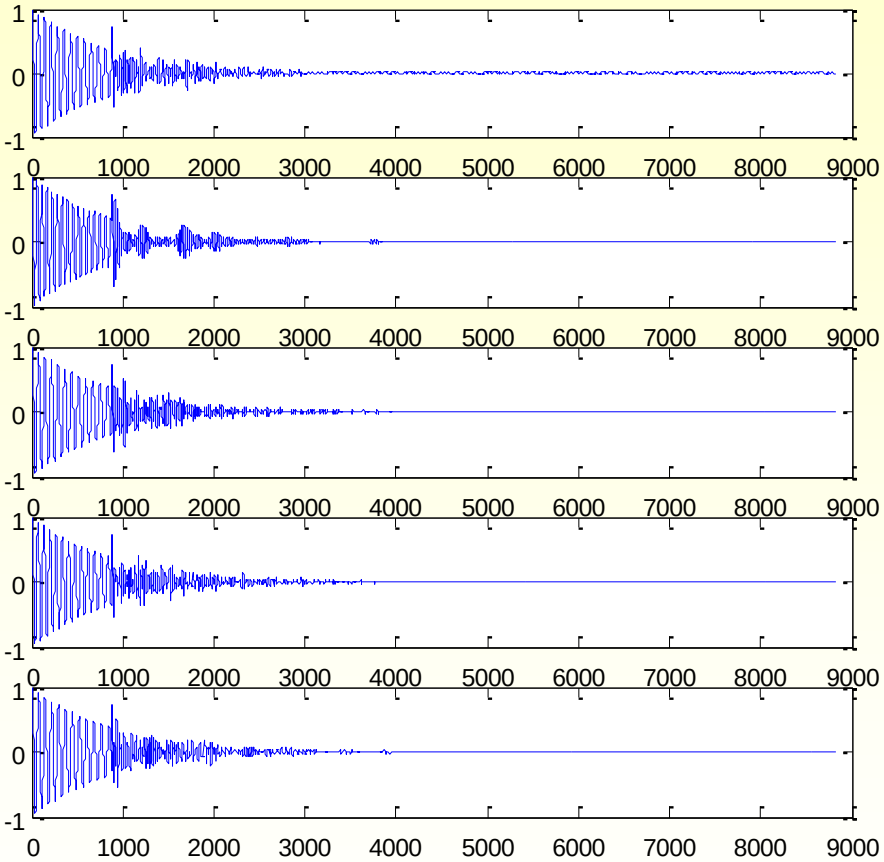
obalka = exp(-t/tau(k));

mi = Io(k)*exp(-t/tau(k));



τ	I	f_c	f_m
2	10	110	220
2	5	220	440
12	10	110	220
0.3	10	110	220
2	5	250	350
1	3	250	350

Kapky vody



$T_{obálky}$ = 20 ms

mi= 20

f_m = 7 Hz

1. část 20 ms

f_c = 700 + 100randn

2. část 180 ms

5 spektrálních složek

f_c = 1500+300randn

Kapky vody

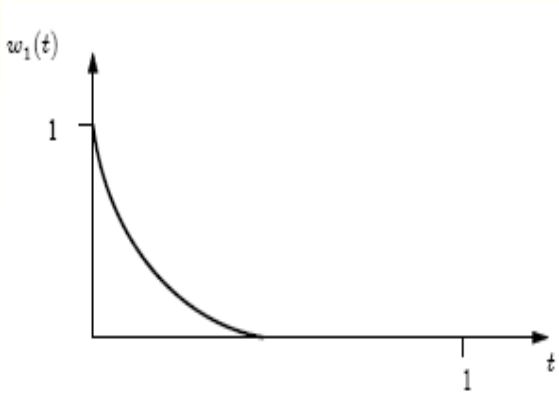
```
% synteticke kapky vody
% RC, 15.prosince 2008
clear, close all
fs     = 44100;
doba1 = 0.02;          % doba trvani prvni casti
doba2 = 0.18;          % doba trvani druhe casti
t1     = 0:1/fs:doba1-1/fs;
t2     = 0:1/fs:doba2-1/fs;
t      = 0:1/fs:doba1+doba2-1/fs;
fm     = 7;
mi     = 20;
tau    = 0.02;
pocet_kapek = 5;
y=[];
```

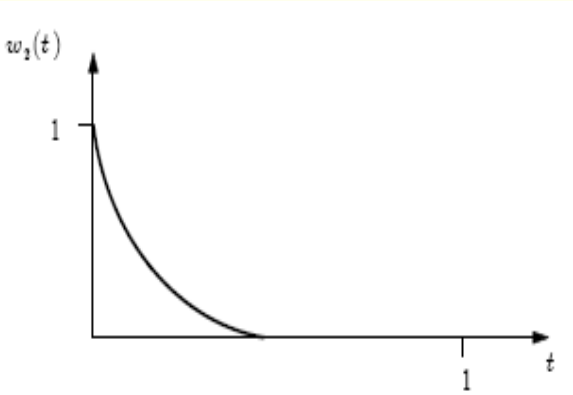
Kapky vody

```
for por_kapky     = 1:pocet_kapek,
    fc1       = 700+100*randn;
    cast1 = sin(2*pi*fc1*t1 + mi*cos(2*pi*fm*t1));
    A=0.4;
    cast2=zeros(1,length(t2));
    for h=1:5
        fc2    = 1500+300*randn;
        cast2 = cast2 + A*sin(2*pi*fc2*t2 +
                                  mi*cos(2*pi*fm*t2));
    end;
    kapka(por_kapky,:)=[cast1 cast2].*exp(-t/tau);
    subplot(pocet_kapek,1,por_kapky),
     plot(kapka(por_kapky,:))
    sound(kapka(por_kapky,:),fs), pause(1)
    y=[y kapka(por_kapky,:) zeros(1,fs)];
end;
```

Jednoduché syntetické FM nástroje

ZVON	délka	f_c	$H = f_m/f_c$	I_{max}	I_{min}
	15	200	1.4	10	0



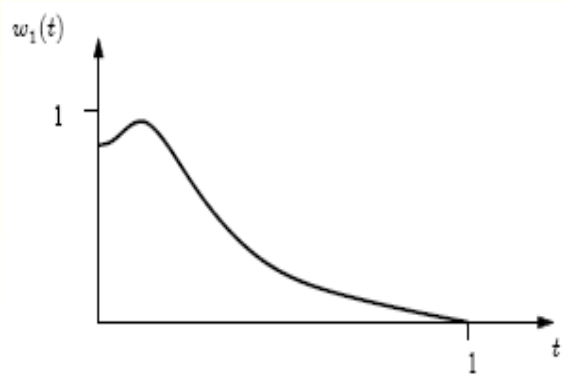


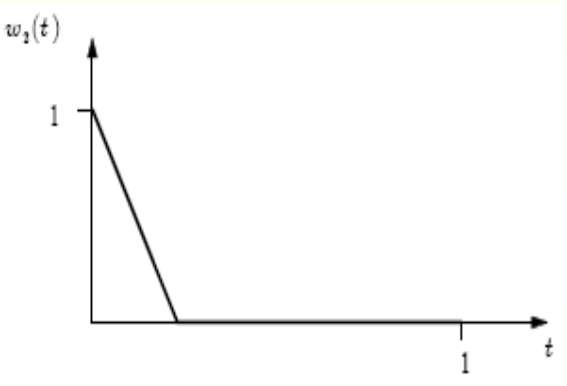
Amplitudová obálka

Obálka modulačního indexu

Jednoduché syntetické FM nástroje

BICÍ	délka	f_c	$H = f_m/f_c$	I_{max}	I_{min}
	0.2	80	0.688	25	0



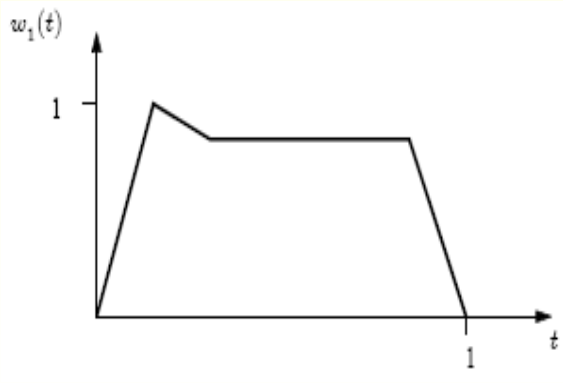


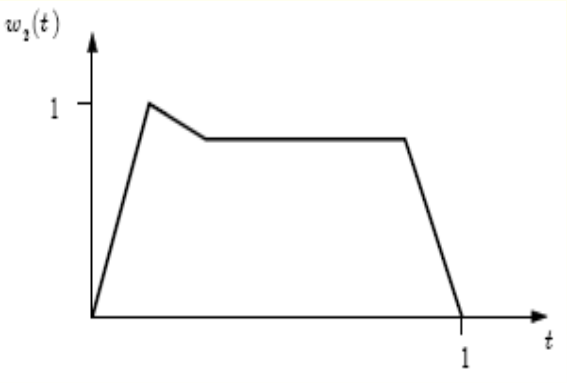
Amplitudová obálka

Obálka modulačního indexu

Jednoduché syntetické FM nástroje

ŽESTĚ	délka	f_c	$H = f_m/f_c$	I_{max}	I_{min}
	0.6	440	1.0	5	0



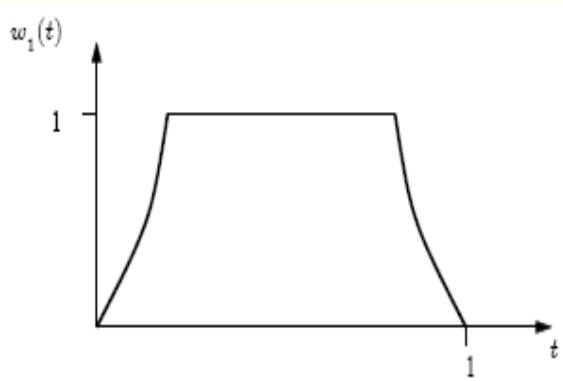


Amplitudová obálka

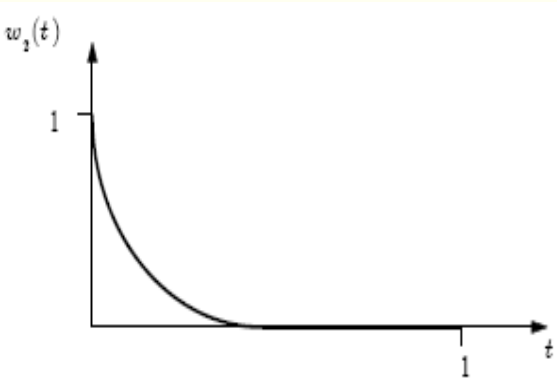
Obálka modulačního indexu

Jednoduché syntetické FM nástroje

KLARINET	délka	f_c	$H = f_m/f_c$	I_{max}	I_{min}
	0.5	900	0.667	4	2



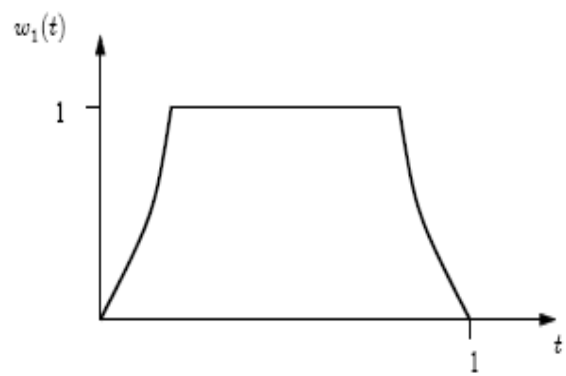
Amplitudová obálka

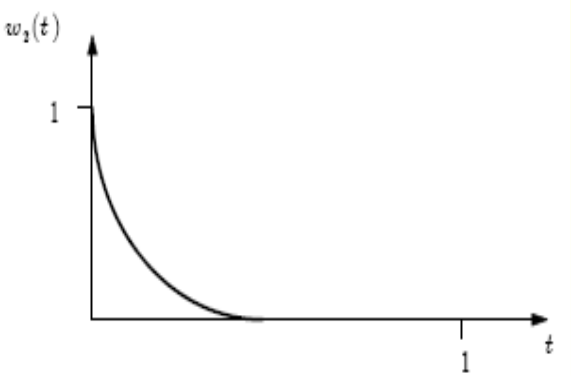


Obálka modulačního indexu

Jednoduché syntetické FM nástroje

FAGOT	délka	f_c	$H = f_m/f_c$	I_{max}	I_{min}
	0.5	1100	0.2	1.5	0



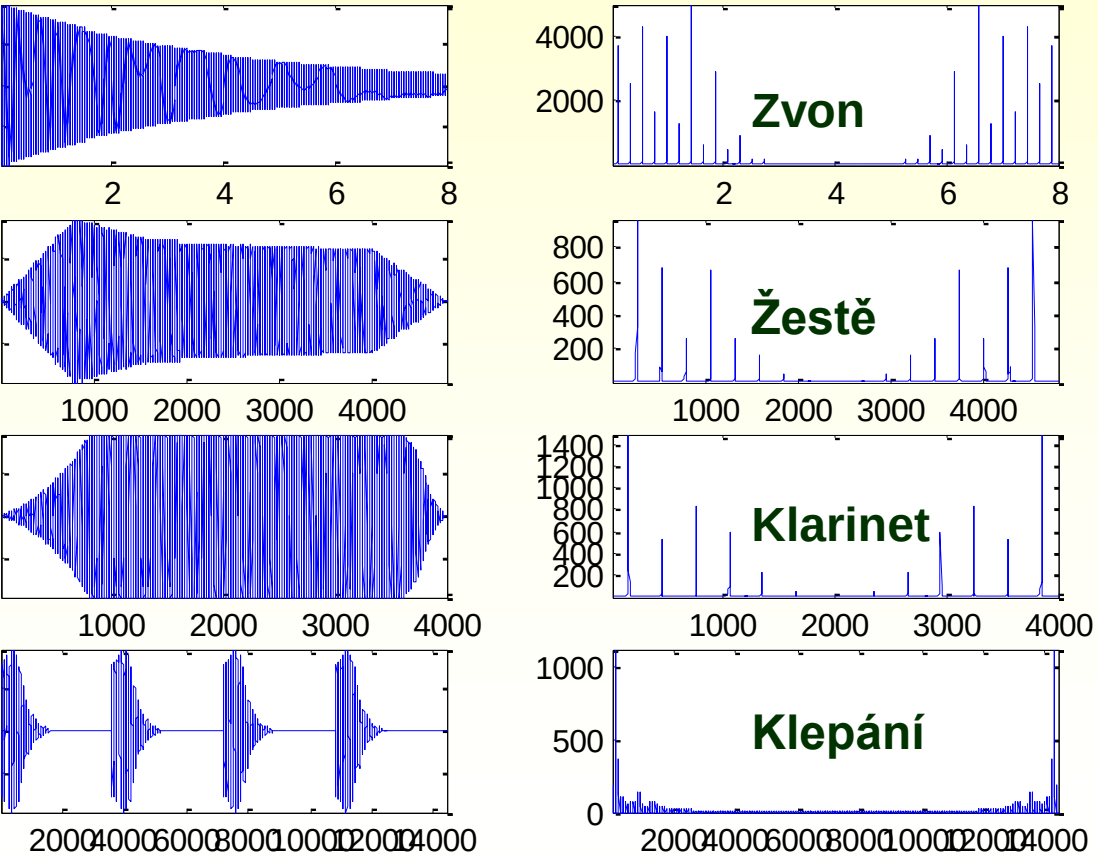


Amplitudová obálka

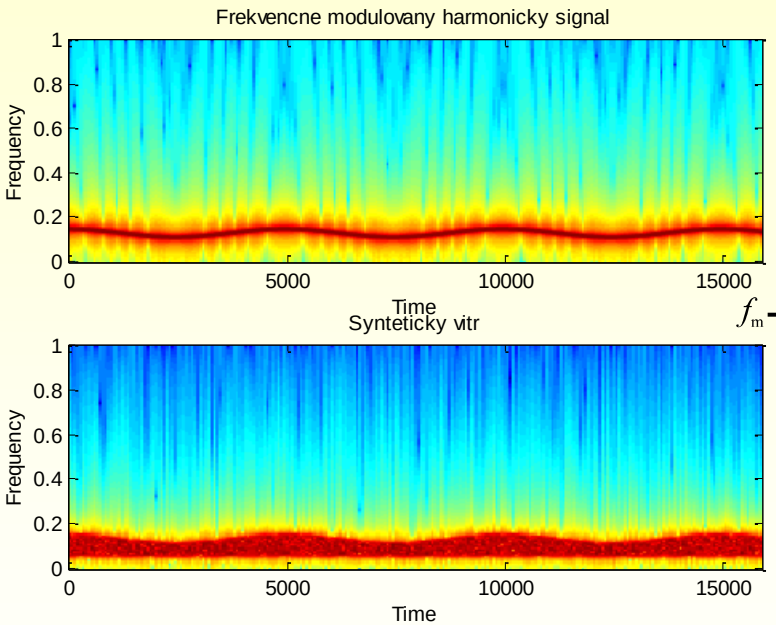
Obálka modulačního indexu

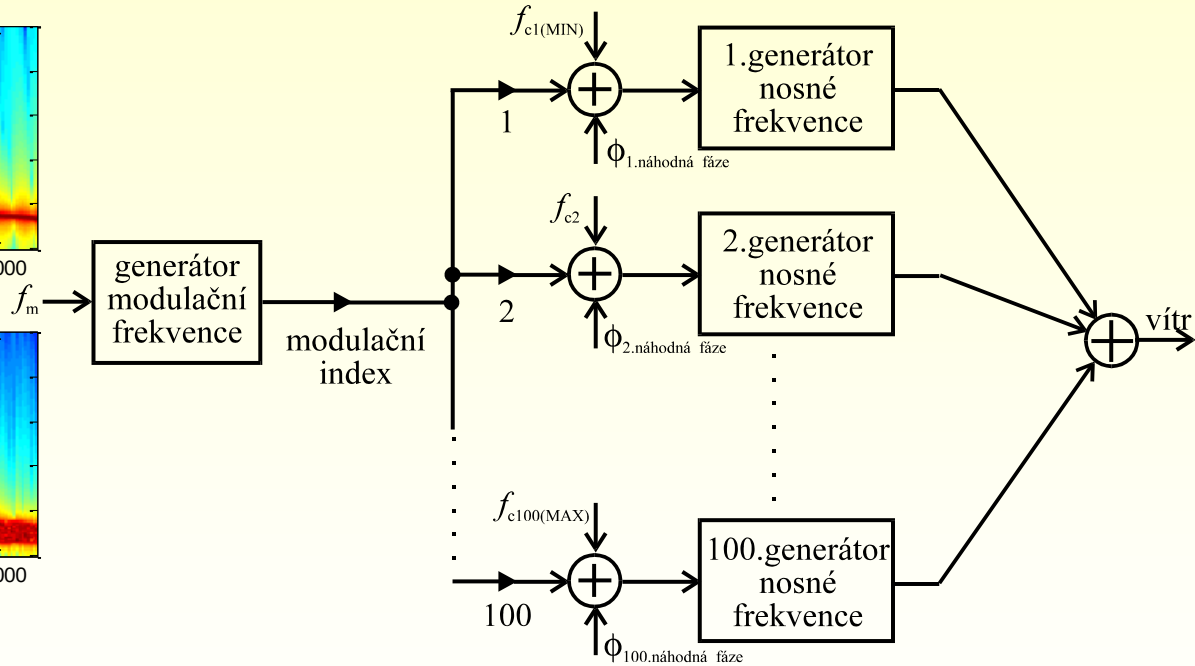
Jednoduché syntetické FM nástroje

	I	f_c	f_m
Zvon	10	110	210
Žestě	5	900	300
Klarinet	5	900	600
Klepání	25	80	55



Syntetické zvuky - vítr





Modulační syntéza

Ukázky semestrálních prací

Dvořák Jan	**Syntéza zvuků telefonu (oznamovací tón, DTMF volba, 6x různé typy vyzvánění, oznámení o SMS zprávě)** *AM, FM, aditivní a filtrační syntéza*	
Gregor Pavel	Kostel v horách *zvony vytvořené FM modulací, přidaná AM modulace + echo, vítr vytvořený filtrační syntézou*	
Chlumecký Martin	**Policejní konvoj** *FM, AM*	
Pazdera František	**Hasičská siréna** *FM + echo + dozvuk*	

Vibráto

$$x(t) = O.*\sum_{n=1}^{9} \alpha_n \sin\left(2\pi\, n\, f_c t + 7\sqrt{n}\cdot\sin(2\pi\, f_m t)\right)$$

$$f_c = 440Hz,\ f_m = 5Hz$$

$$\alpha_n = 1000, 300, 0.01, 0.01, 0.01, 3, 0.5, 1, 4$$

$$O...X = [0\ .2\ .8\ .95\ 1], Y = [0\ 1\ \ .3\ .1\ 0]$$

Vibráto

```
% vibrato
clear all; close all;
fs = 22050; f0 = 440; fm = 5; doba = 5;
t = 0:1/fs:doba-1/fs;
alfa = [1000 300 .1 .1 .1 3 .5 1 4];
% vibrato s aditivni syntezou
x = zeros(1,length(t));
for n = 1:9
   x = x + alfa(n)*sin(2*pi*f0*n.*t + 7*sqrt(n)*sin(2*pi*fm.*t));
end
% obalka
X = [0 .2 .8 .95 1].*t(end); Y = [0  1 .3 .1  0]; O=interp1(X,Y,t);
x = x.*O; x = .98*x/(max(abs(x)));
sound(x,fs);
```

Zvuky

http://www.soundsnap.com/