ETHFE

High Frequency Electronics

AARHUS UNIVERSITY
SCHOOL OF ENGINEERING

Indholdsfortegnelse

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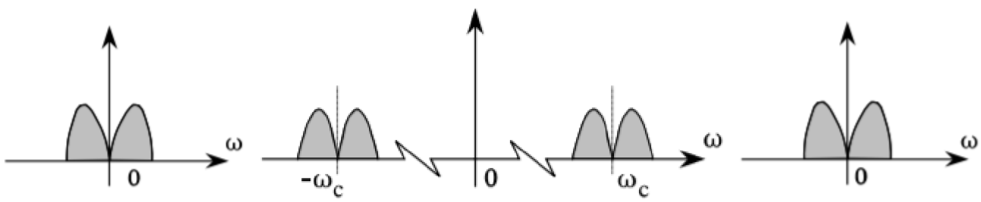
Amplitude modulation

1.1 Lektion 30-01-2018

1. Intro
2. AM Modulation/demodulation

- **Pensum:** JV, Ch 1 p 1-6
- **Opgaver:** P.I-1

1.1.1 Basic Modulation Types and Concepts



Original baseband signal

Transmitted bandpass signal

Reconstructed baseband signal

- **Modulation:** Hvordan signaler moduleres ind på bærebølger, der efterfølgende typisk sendes ud som elektromagtetiske signaler via et transmissionsmedie.
  - Bandpass signalet er det transmitterede signal til receiveren.
  - Flere baseband signals kan blive transmitteret samtidigt gennem den samme kanal ved forskellige carrier frequencies.

- **Demodulation:** Hvordan det sendte signal demoduleres så det originale signal gendannes.
  - Receiveren gendanner det low-frequency baseband signal.
  - Scopet af demodulationen afhænger af hvilken type data der bliver sendt.
    * *In a radio telephony channel it may suffice at the receiver site to get an output with a power spectrum that contains the dominant part of the input power spectrum.*
    * *In a television video channel it is important to reconstruct in time-domain the shape of the signal being send.*
    * *In digital transmissions, the goal is to rebuild a logical bitstream representation equivalent to the input stream.*

1.1.2 Amplitude Modulations

Typer af moduleringer der er egnet for RF communication kaldes continuous wave modulations, **CW**.

- Baseband information er overlagt en sinusoidal carrier wave med amplitude A_{c0} og vinkelfrekvens ω_c.
  - *Carrier* 1.1
  - *Modulated carrier* 1.2

$$y(t) = A_{c0}\cos(\omega_c t) \tag{1.1}$$

$$y(t) = A(t)\cos(\omega_c t + \phi(t) + \phi_0) \tag{1.2}$$

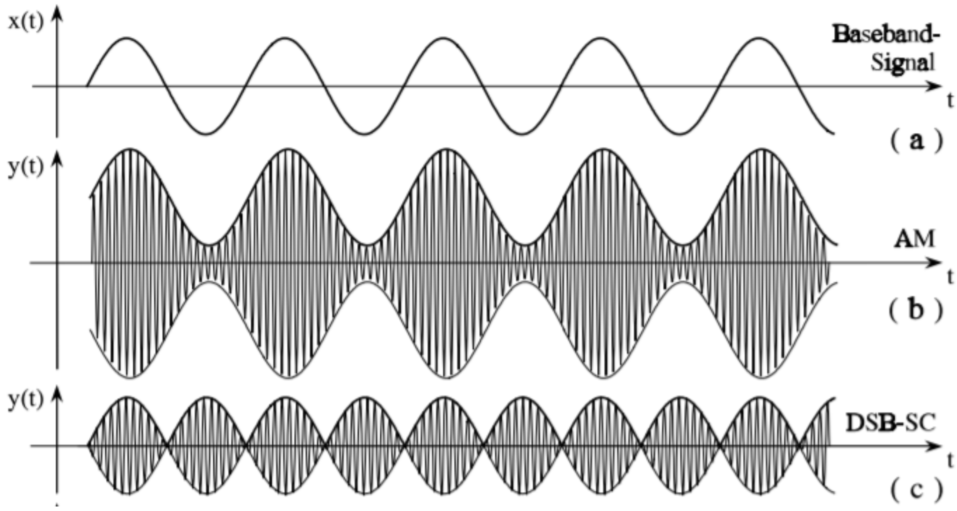
- *The time dependencies of $A(t)$ and $\phi(t)$ in 1.2 contain the baseband message and the angle ϕ_0 represents an offset phase for the carrier compared to the timing of the baseband message.*

- *If there is no synchronism between the two, the offset may be set to zero without loss of generality. Eq. 1.2 is called the envelope-phase representation of a modulated signal.*

Den største forskel mellem forskellige modulation typer er hvordan et baseband signal $x(t)$ indeholder det overlagte signal $y(t)$ som er moduleret. Amplitude modulations indebærer **AM** and **DSB-SC**.

AM

- Skalering af signalniveauerne beregnes ved modulation index m.
- Med et normaliseret baseband signal $|x(t)| \leq 1$, indebærer betingelsen $m \leq 1$ (eller 100%) et undistorted reproduction af baseband signalet.
  - m: modulation index
- Det er let at gendanne baseband signalet fra en AM modulated wave i en receiver med det simple envelope detector circuit.



Figur 1.1: Examples of modulation waveshapes (AM and DSB(-SC)) from a sinusoidal baseband signal $x(t)$.

- Amplitude modulation, $\phi(t) = 0$
  - *amplitude modulation, AM* 1.3
  - *double-sideband (supressed carrier), DSB/DSB-SC* 1.4

$$y(t) = A_{c0}(1 + mx(t))\cos(\omega_c t) \tag{1.3}$$

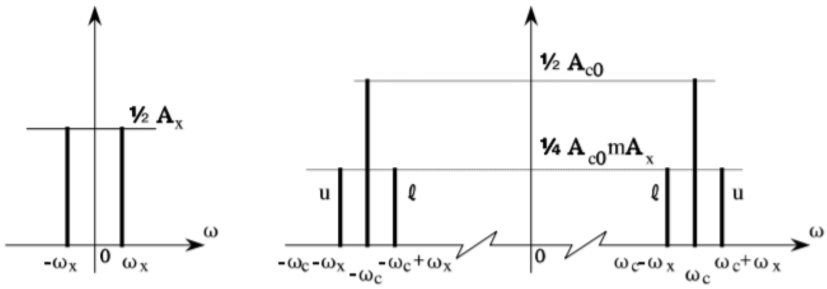
$$y(t) = A_{c0}x(t)\cos(\omega_c t) \tag{1.4}$$

- Envelope detectorens low-pass filter bandwidth skal være højere end envelope frekvensen.

- En AM modulated wave har spektrale komponenter fra baseband signalet over og under carrier signalet.

$$y(t)_{|AM} = A_{c0}(1 + mA_x \cos \omega_x t) \cos \omega_c t \Rrightarrow \tag{1.5}$$

$$A_{c0} \cos \omega_c t + \frac{A_{c0}}{2} mA_x \cos(\omega_c - \omega_x)t + \frac{A_{c0}}{2} mA_x \cos(\omega_c + \omega_x)t \tag{1.6}$$



Figur 1.2: Spectral components in a double-sided amplitude spectrum of the sinusoidal baseband signal and the AM modulated waveform from Eq. 1.6. u and l are the upper and lower sideband components.

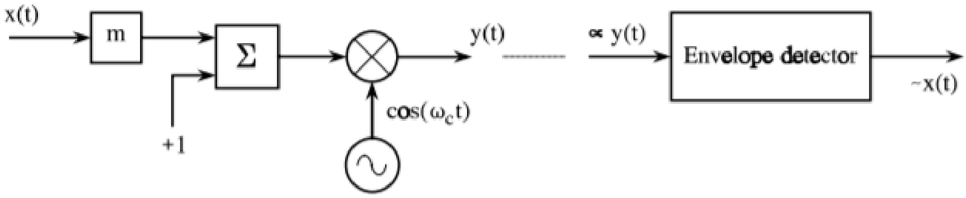
With maximum undistorted modulation, i.e. $m = 1$ and $A_x = 1$, the power of the AM modulated wave, say it is a voltage across a $1\,\Omega$ resistor, becomes;

$$P_{|AM} = \underset{carrier}{2\frac{A_{c0}^2}{4}} + \underset{envelope}{4\frac{A_{c0}^2 m^2 A_x^2}{16}} \tag{1.7}$$

$$P_{|AM} = \frac{1}{2}A_{c0}^2 + \frac{1}{4}A_{c0}^2 \tag{1.8}$$

so at most 33% of the transmitted power contains the message from the baseband signal.

- AM modulated signal i frekvens domænet:
  - Anvender eulers formel ($\cos 2\pi t \rightarrow e^{j2\pi\omega_c t} + e^{-j2\pi\omega_c t}$)
  - Fourier transform (gange i tidsdomænet $\cdot$ og folde i frekvenssdomænet $\circledast$)



Figur 1.3: Block schemes for simple AM modulation (left) and demodulation (right).

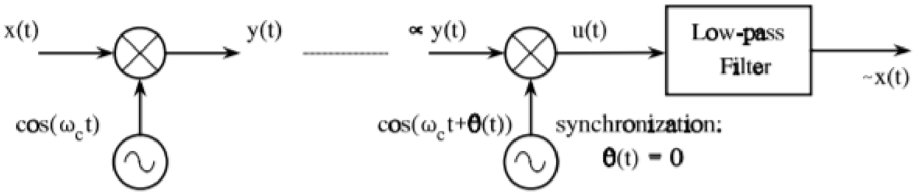
DSB-SC

DSB moduleringen fra Eq. 1.4 har ingen carrier component deraf kommer betegnelsen *suppressed carrier* eller SC.

$$y(t)_{|DSB-SC} = A_{c0}A_x \cos\omega_x t)\cos\omega_c t \tag{1.9}$$

$$y(t)_{|DSB-SC} = \frac{A_{c0}A_x}{2}\cos(\omega_c - \omega_x)t + \frac{A_{c0}A_x}{2}\cos(\omega_c + \omega_x)t \tag{1.10}$$

- Carrier componenterne indeholder ingen information, derfor er det mere kompliceret at gendanne baseband signalet i receiveren.
- For at kunne detektere baseband signalet fra et DSB moduleret signal, skal dette signal igen multipliceres med en carrier.
  - Hvis fasen $\phi(t)$ er forskellig fra nul vil cosine enten reducerer eller forvrænge signalet.
  - For at få et predictable result skal oscillatoren i demodulatoren være synkroniseret med carrier af det modtagede signal.
  - *A simple method is to let a fragment of the full carrier - a pilot carrier - follow the signal.*
    * Gøres ved at indsætte en konstant < 1 istedet for 1.



Figur 1.4: Block schemes for simple DSB-SC modulation (left) and demodulation (right).

Vinkel modulation

2.1 Lektion 06-02-2018

1. Vinkel modulation
2. Phasor repræsentation

- **Pensum:** JV, Ch 1 p 6-13, p 13-18
- **Opgaver:** P.I-2

2.1.1 Vinkel modulation

Vinkel modulation er processen når frekvensen eller phase af carrieren varrierer i forhold til baseband informationen. Her er amplituden A_{c0} konstant. En vigtig fordel ved PM og FM modulation er at de mere imun overfor channel noise, nonlinear distotion og amplitude fading i forhold til AM modulation. Vinkel modulation kræver en dobbelt så stor båndbredde som AM modulation $(2 \cdot W)$.

Vinkel modulation er delt op i frekvens (**FM**) og phase (**PM**).

- Vinkel modulation, $A(t) = A_{c0}$
  - *phase modulation, PM* 2.1
  - *frequency modulation, FM* 2.2

$$y(t) = A_{c0} \cos(\omega_c t + \beta x(t)) \tag{2.1}$$

$$y(t) = A_{c0} \cos(\omega_c t + \phi(t)) \tag{2.2}$$

Phase informationen findes ved at differentere.

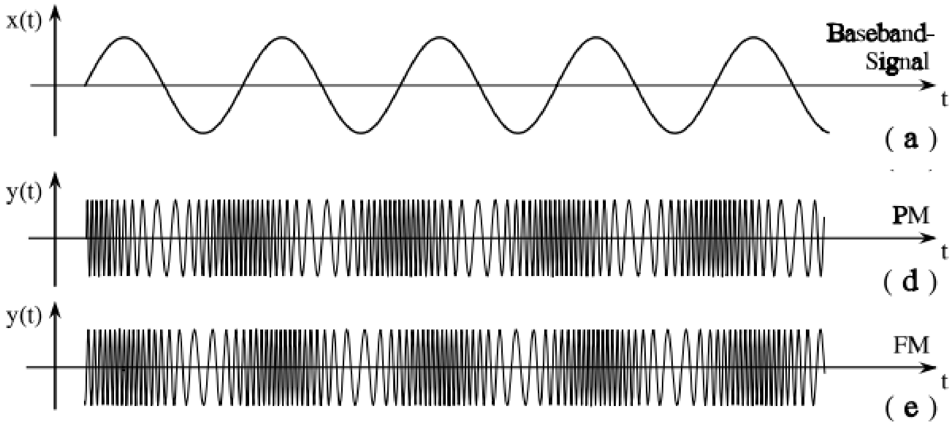
$$\frac{d\phi}{dt} = \Delta\omega(t) = \Delta\omega_{max}x(t) = 2\pi\Delta f_{max}x(t) \tag{2.3}$$

$\beta = \frac{\Delta f_{max}}{f_x}$ maximum phase deviation from the carrier phase

Δf_{max} peak frequency deviation

f_x baseband frequency component

The change in phase, changes the frequency of the modulated wave. The frequency of the wave also changes the phase of the wave.



Figur 2.1: Examples of modulation waveshapes (PM and FM) from a sinusoidal baseband signal $x(t)$.

PM

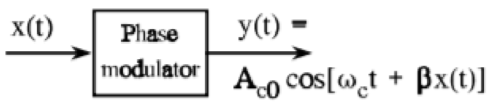
$$\theta(t) = \omega_c t + \beta x(t) + \phi_0 \tag{2.4}$$

$x(t)$ Baseband signal

$\omega_c t$ Angle of Unmodulated carrier wave

$\beta = \frac{radian}{volt}$ Phase sensitivity (const.)

$\phi_0 = 0$ Initial angle



Figur 2.2: PM angular modulation.

FM

Indirect FM

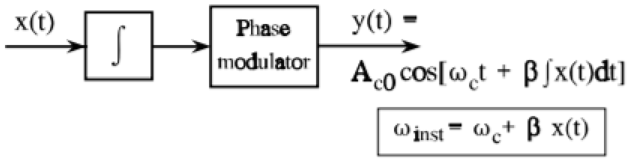
$$y(t) = A_{c0} \cos[\omega_c t + \beta \int x(t)dt] \tag{2.5}$$

$x(t)$ Baseband signal

$\omega_c t$ Angle of unmodulated carrier wave

$\beta = \frac{radian}{volt}$ Phase sensitivity (const.)

$\omega_{inst} = \omega_c + \beta x(t)$ instantaneous frequency.



Figur 2.3: FM indirect modulation.

Direct FM

$$y(t) = A_{c0} \cos[\omega_c t + 2\pi K_V \int x(t)dt] \tag{2.6}$$

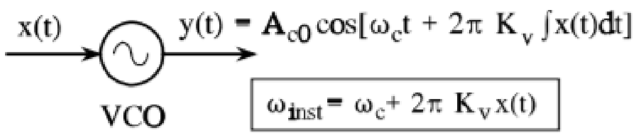
$x(t)$ Baseband signal

$\omega_c t$ Angle of unmodulated carrier wave

$\beta = \frac{radian}{volt}$ Phase sensitivity (const.)

$K_V = \frac{hertz}{volt}$ Frequency gain (const.)

$\omega_{inst} = \omega_c + 2\pi K_V x(t)$ instantaneous frequency.



Figur 2.4: FM direct modulation using VCO.

Wideband FM

Tilnærmelsen fra NBFM er ikke gældende ved wideband og derfor gælder følgende. Dette introducerer Bessel funktioner.

$$\cos(\beta_{eff} \sin \omega_x t) = J_0(\beta_{eff}) + \sum_{n-2,even}^{\infty} 2J_n(\beta_{eff}) \cos n\omega_x t \tag{2.7}$$

$$\sin(\beta_{eff} \sin \omega_x t) = \sum_{n-1,odd}^{\infty} 2J_n(\beta_{eff}) \sin n\omega_x t \tag{2.8}$$

$\beta_{eff} \ = \beta A_x$ effective modulation index

$n_{99\%} \ \approx \beta_{eff} + 1$

β_{eff}=0	1	2	3	4	5	6	7	8	9	10	n
1.0000	0.7652	0.2239	-0.2601	-0.3971	-0.1776	0.1506	0.3001	0.1717	-0.0903	-0.2459	0
	0.4401	0.5767	0.3391	-0.0660	-0.3276	-0.2767	-0.0047	0.2346	0.2453	0.0435	1
	0.1149	0.3528	0.4861	0.3641	0.0466	-0.2429	-0.3014	-0.1130	0.1448	0.2546	2
	0.0196	0.1289	0.3091	0.4302	0.3648	0.1148	-0.1676	-0.2911	-0.1809	0.0584	3
	0.0025	0.0340	0.1320	0.2811	0.3912	0.3576	0.1578	-0.1054	-0.2655	-0.2196	4
	0.0002	0.0070	0.0430	0.1321	0.2611	0.3621	0.3479	0.1858	-0.0550	-0.2341	5
		0.0012	0.0114	0.0491	0.1310	0.2458	0.3392	0.3376	0.2043	-0.0145	6
		0.0002	0.0025	0.0152	0.0534	0.1296	0.2336	0.3206	0.3275	0.2167	7
			0.0005	0.0040	0.0184	0.0565	0.1280	0.2235	0.3051	0.3179	8
			0.0001	0.0009	0.0055	0.0212	0.0589	0.1263	0.2149	0.2919	9
				0.0002	0.0015	0.0070	0.0235	0.0608	0.1247	0.2075	10
					0.0004	0.0020	0.0083	0.0256	0.0622	0.1231	11
					0.0001	0.0005	0.0027	0.0096	0.0274	0.0634	12
						0.0001	0.0008	0.0033	0.0108	0.0290	13
							0.0002	0.0010	0.0039	0.0120	14
							0.0001	0.0003	0.0013	0.0045	15
								0.0001	0.0004	0.0016	16
									0.0001	0.0005	17
										0.0002	18

Figur 2.5: $J_n(\beta_{eff})$, expansion coefficients from Bessel functions.

Bessel funktioner indsættes.

$$y(t)|_{FMorPM} = A_{c0} J_0(\beta_{eff}) \cos(\omega_c t) \tag{2.9}$$

$$y(t)|_{FMorPM} = A_{c0} \sum_{n=-\infty}^{\infty} J_n(\beta_{eff}) \cos(\omega_c t + n\omega_x t) \tag{2.10}$$

Accumalted power

$$p_{ac,n}(\beta_{eff}) = \frac{P_{ac,n}}{\frac{A_{c0}^2}{2}} = J_0^2(\beta_{eff}) + \sum_{i=1}^{n} 2J_i^2(\beta_{eff}) \tag{2.11}$$

Bandwidth for 99% power

- *phase modulation, PM* 2.12
- *frequency modulation, FM* 2.13

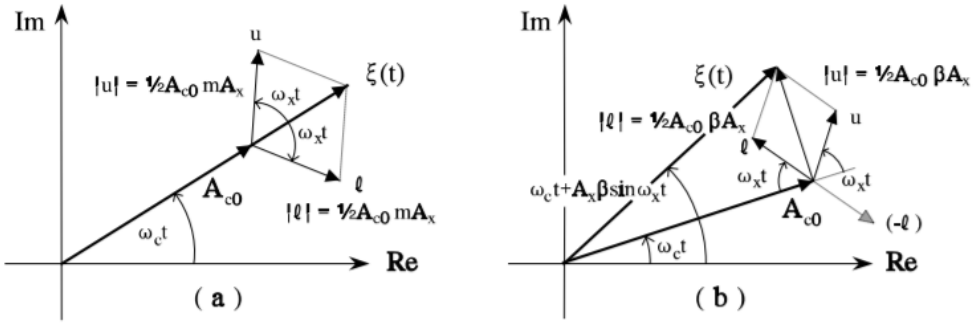
$$W_{99\%} = 2\omega_x(\beta_{eff} + 1) = 2\omega_x[\beta A_x + 1] \tag{2.12}$$

$$W_{99\%} = 2\omega_x(\beta_{eff} + 1) = 2[\Delta\omega_{max} A_x + \omega_x] \tag{2.13}$$

β_{eff}=0	1	2	3	4	5	6	7	8	9	10	n
1.0000	0.5855	0.0501	0.0676	0.1577	0.0315	0.0227	0.0901	0.0295	0.0082	0.0605	0
	0.9728	0.7154	0.2975	0.1665	0.2462	0.1758	0.0901	0.1396	0.1285	0.0643	1
	0.9992	0.9643	0.7701	0.4316	0.2505	0.2938	0.2718	0.1651	0.1705	0.1939	2
	1.0000	**0.9976**	0.9612	0.8017	0.5167	0.3201	0.3279	0.3346	0.2360	0.2008	3
		0.9999	**0.9960**	0.9598	0.8228	0.5759	0.3777	0.3568	0.3769	0.2972	4
		1.0000	0.9997	**0.9947**	0.9592	0.8381	0.6198	0.4258	0.3830	0.4068	5
			1.0000	0.9995	**0.9936**	0.9590	0.8499	0.6538	0.4665	0.4072	6
				1.0000	0.9993	**0.9926**	0.9590	0.8593	0.6809	0.5011	7
					0.9999	0.9990	**0.9918**	0.9592	0.8670	0.7032	8
					1.0000	0.9999	0.9987	**0.9911**	0.9594	0.8735	9
						1.0000	0.9998	0.9985	**0.9905**	0.9596	10
							1.0000	0.9998	0.9982	**0.9900**	11
								1.0000	0.9997	0.9980	12
									1.0000	0.9997	13
										1.0000	14

Figur 2.6: $p_{ac,n}(\beta_{eff})$, accumulated relative power of frequency components to and including order n in size. Figures in bold indicate the first 99% bound passing.

2.1.2 Phasor repræsentation



Figur 2.7: Phasor representation showing how the lower and upper sideband components, l and u, add to the carrier A_{c0} in (a) AM modulation, and (b) narrowband FM. The modulated wave becomes $y(t) = Re(\zeta)$.