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BEIHANG UNIVERSITY

Avionics Technology

B31353551

— *Aero Communication*

yunzhao@buaa.edu.cn

Spring Semester 2023 (20_Apr_T9)

（1） Some concepts

（2） VHF Communication

（3） Long-distance Communications

(2) VHF Communication

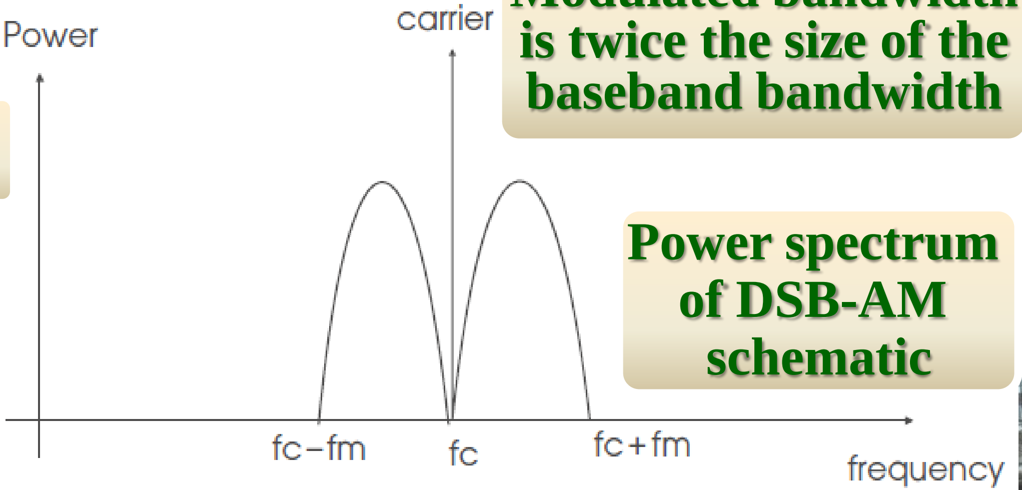
- *Amplitude Modulation* (AM) is when the amplitude of the carrier is directly proportional to the modulating (message) signal. The simplest form of AM is DSB-AM. DSB-AM can be described mathematically as:

$$f_c(t) = A\cos(2\pi f_c t + \phi)$$

$f_c(t)$: Modulated signal output

$$A = K + f_m(t)$$

K : A constant;
$f_m(t)$: Baseband signal



Modulated bandwidth is twice the size of the baseband bandwidth

Power spectrum of DSB-AM schematic

(2) VHF Communication

- The baseband signal can be described as:

$$f_m(t) = a\cos(2\pi f_m t)$$

***a*: Modulating signal amplitude**

- Therefore $f_c(t) = (K + a\cos(2\pi f_m t))\cos(2\pi f_c t + \phi)$
- Defining $m = \dfrac{a}{K}$

***m*: Amplitude sensitivity**

- Let initial phase $\Phi = 0$,

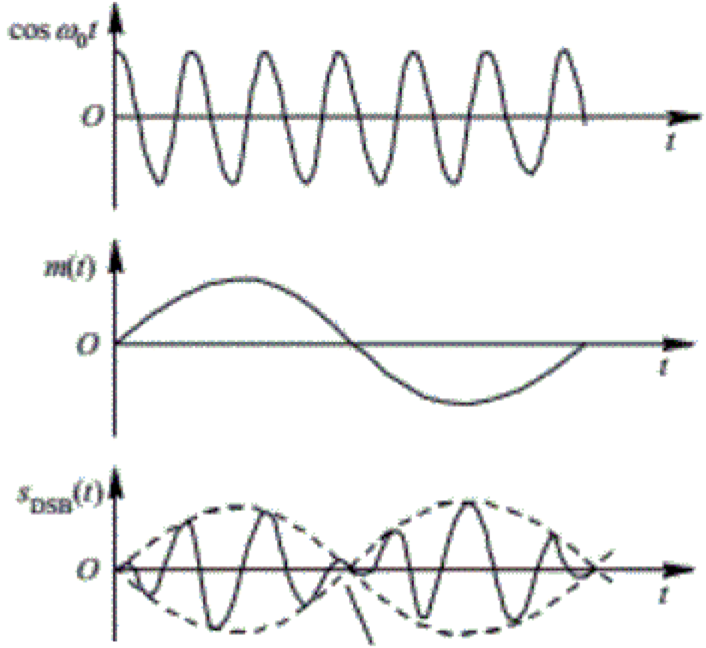
then $f_c(t) = K[\cos(2\pi f_c t) + \underbrace{0.5\, m\cos(2\pi(f_c - f_m)t)}_{\text{Lower sideband}}$

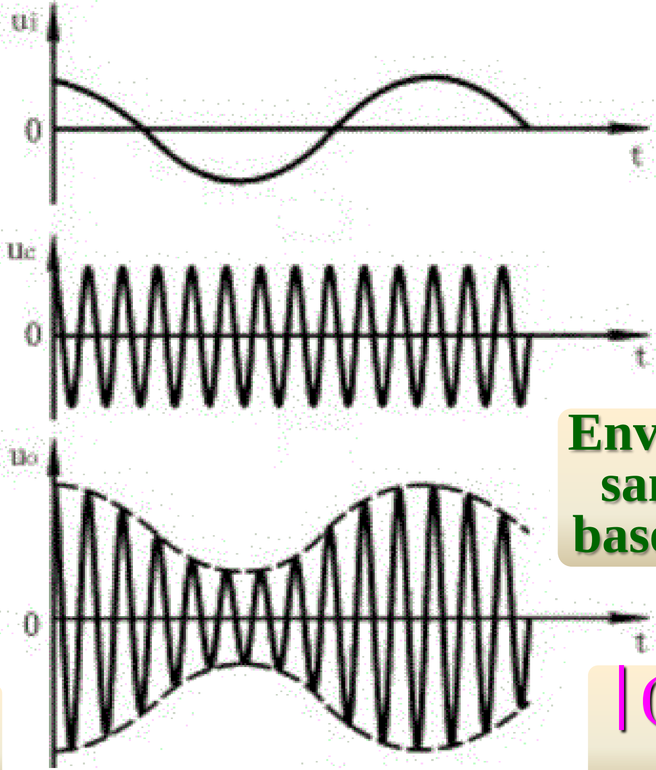
$+ \underbrace{0.5\, m\cos(2\pi(f_c + f_m)t)}_{\text{Upper sideband}}]$

Lower sideband

Upper sideband

（2）VHF Communication





Envelope has the same shape as baseband signal

$|(a/K)f_m(t)|>1$ for some t

Phase reversal
Envelope distortion

$|(a/K)f_m(t)|<1$ for all t

$$f_c(t) = (K + a\ \cos(2\pi f_m t))\cos(2\pi f_c t + \phi)$$

AM process illustration

(2) VHF Communication

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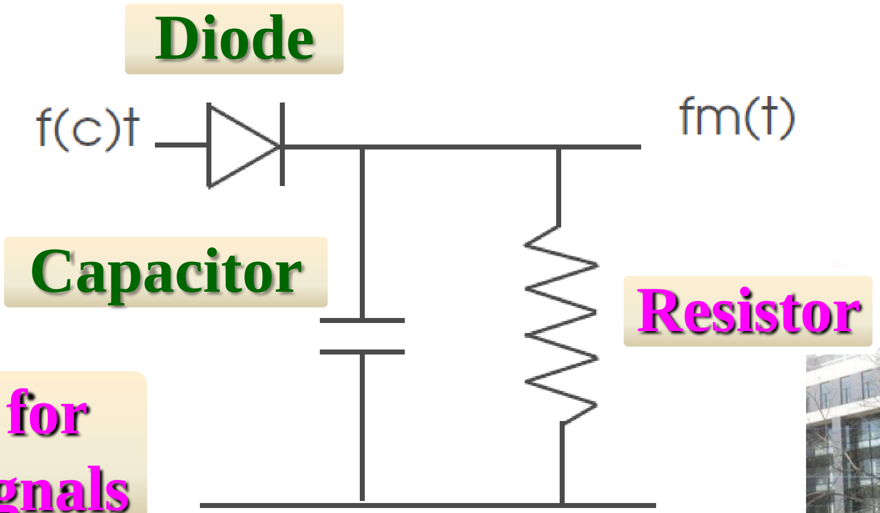
- DSB-AM demodulation—Envelope detector: A simple and yet highly effective circuit, which consists of a diode connected in series with the parallel combination of a capacitor and load resistor. The demodulator output developed across the load resistor is nearly same as the envelop of the receiving AM wave.

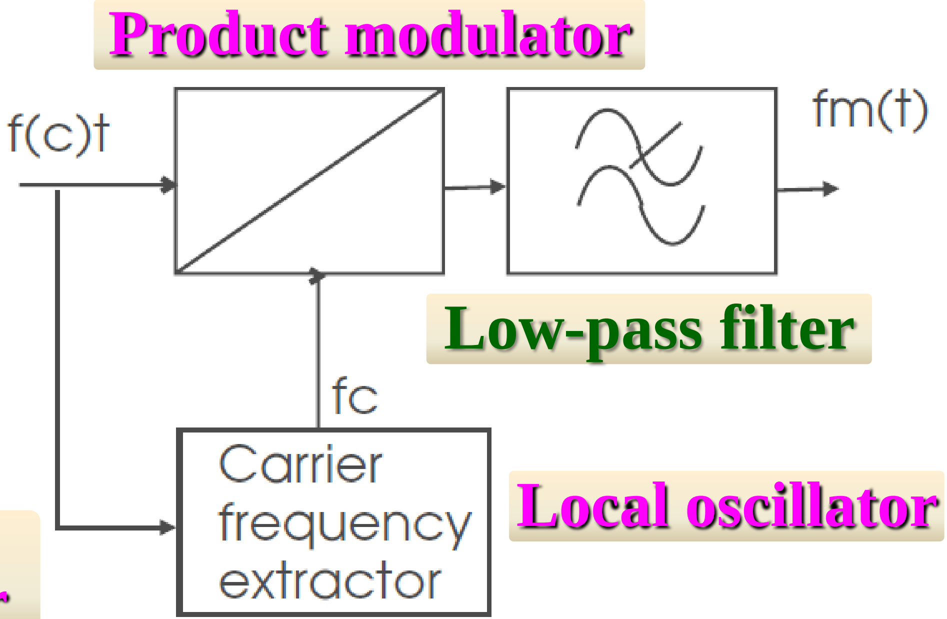


Envelope detector circuit for demodulating DSB-AM signals

(2) VHF Communication

- It can also be accomplished using a coherent detector or synchronous demodulator by first multiplying the DSB-AM wave with a locally generated wave and then low-pass filtering the product.

It is assumed that the local signal is exactly coherent or synchronized, in both frequency and phase, with the carrier wave.



Coherent detector / synchronous demodulator

(2) VHF Communication

$$f_c(t) = A\cos(2\pi f_c t + \phi)$$

***$f_c(t)$*: Modulated signal**

$$A = K + f_m(t)$$

$$f_c(t) = A\cos(2\pi f_c t)$$

Assuming $\Phi = 0$

$$v(t) = a' A\cos(2\pi f_c t)\cos(2\pi f_c t + \varphi)$$

Multiplying with the locally generated signal $a'\cos(2\pi f_c t+\varphi)$

$$= \frac{1}{2} a' A\cos(4\pi f_c t + \varphi) + \frac{1}{2} a' A\cos\varphi$$

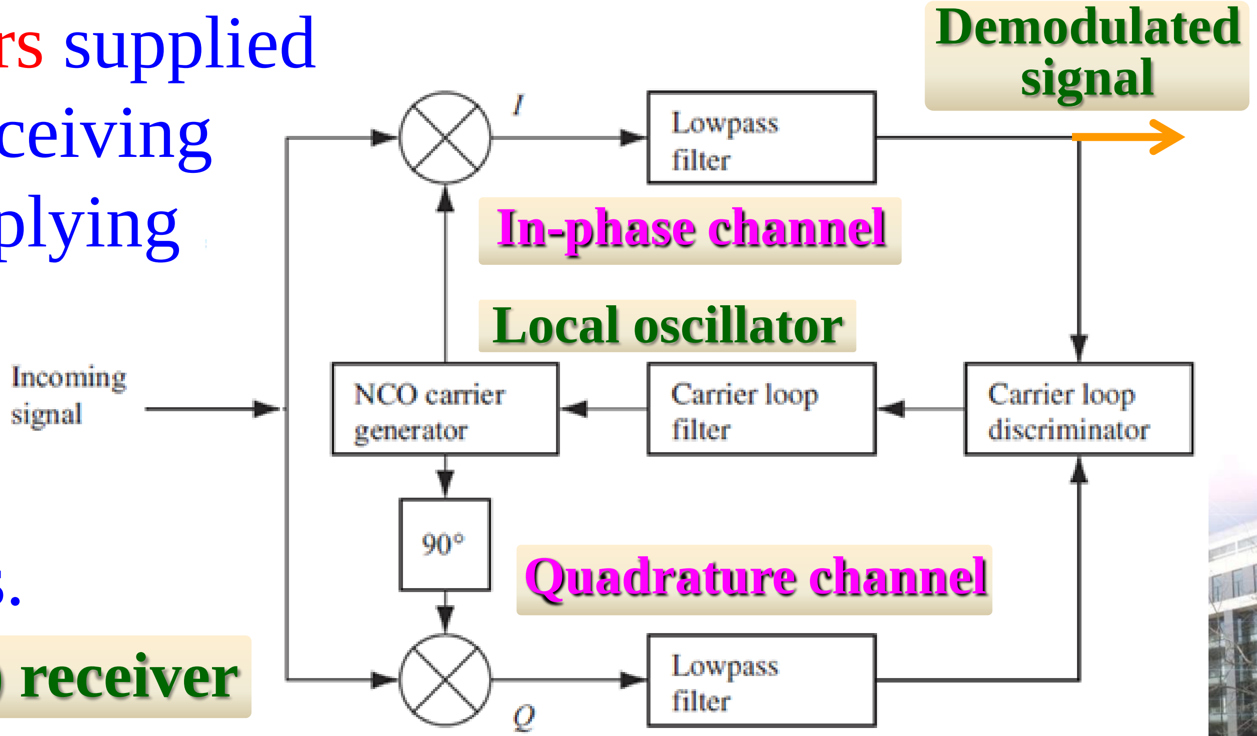
After low-pass filtering

$$v_o(t) = \frac{1}{2} a' A\cos\varphi$$

The demodulated signal output is proportional to baseband signal $f_m(t)$

(2) VHF Communication

- Obtaining a practical synchronous demodulation system can be to use a Costas receiver, which consists of two coherent detectors supplied with the same receiving signal, but multiplying with in-phase and quadrature individual local oscillator signals.



Costas (phase-lock) receiver

(2) VHF Communication

$$f_c(t) = A\cos(2\pi f_c t)$$

f_c is assumed known *a priori*

$$v_I(t) = \underline{a'} A\cos(2\pi f_c t)\underline{\cos(2\pi f_c t + \varphi)}$$

Multiplying with the local in-phase signal $a'\cos(2\pi f_c t+\varphi)$

$$v_Q(t) = \underline{a'} A\cos(2\pi f_c t)\underline{\sin(2\pi f_c t + \varphi)}$$

Multiplying with the local quadrature signal $a'\sin(2\pi f_c t+\varphi)$

After low-pass filtering

$$v_{oI}(t) = \frac{1}{2}a'\underline{A}\cos\varphi \qquad v_{oQ}(t) = \frac{1}{2}a' A\sin\varphi$$

Phase Discriminator

$$\varphi = \tan^{-1}(v_{oQ}/v_{oI})$$

Demodulated signal

Estimation of φ for the local oscillator

(2) VHF Communication

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- The radio spectrum is a fixed resource in the area of aero communication, so there is an incentive to employ technology to minimize the bandwidth used by services.
- As time went on and the technology improved, this methodology was extended further with 25 kHz channel spacing easily achievable. In 1979, WRC extended the AM(R)S allocation in the VHF band further to 117.975 ~ 137.000 MHz, which is where it is today with a theoretical 760 channels (i.e. 25 kHz channel spacing).

（2）VHF Communication

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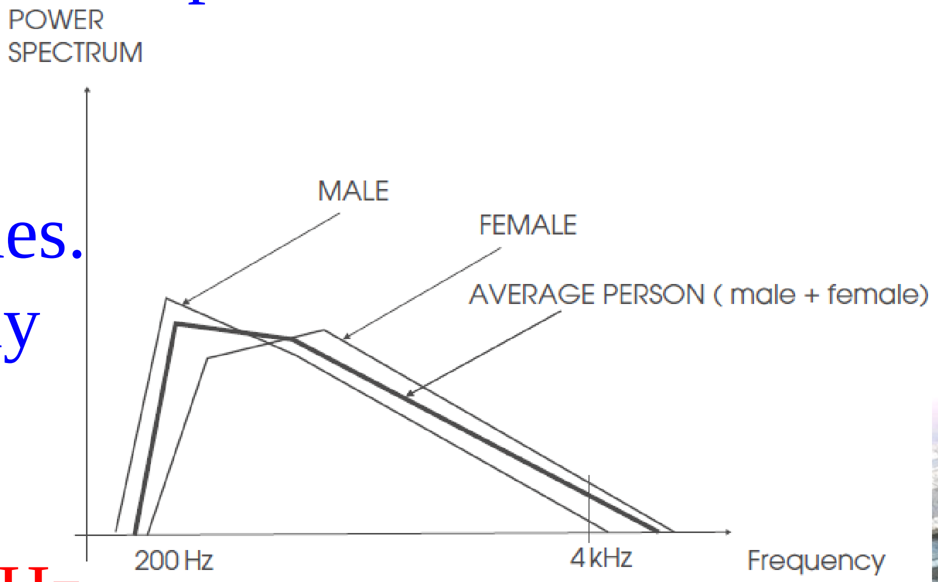
- A typical voice signal shows a spectral density with most of its power components above 200 Hz and below 4 kHz. There are some minor components between 5 and 20 kHz, and even if there was, the typical human ear loses sensitivity to these tones. So it is possible to accurately recover a voice signal by demodulating a signal with the bandwidth limited ±4 kHz.



Typical voice spectral density

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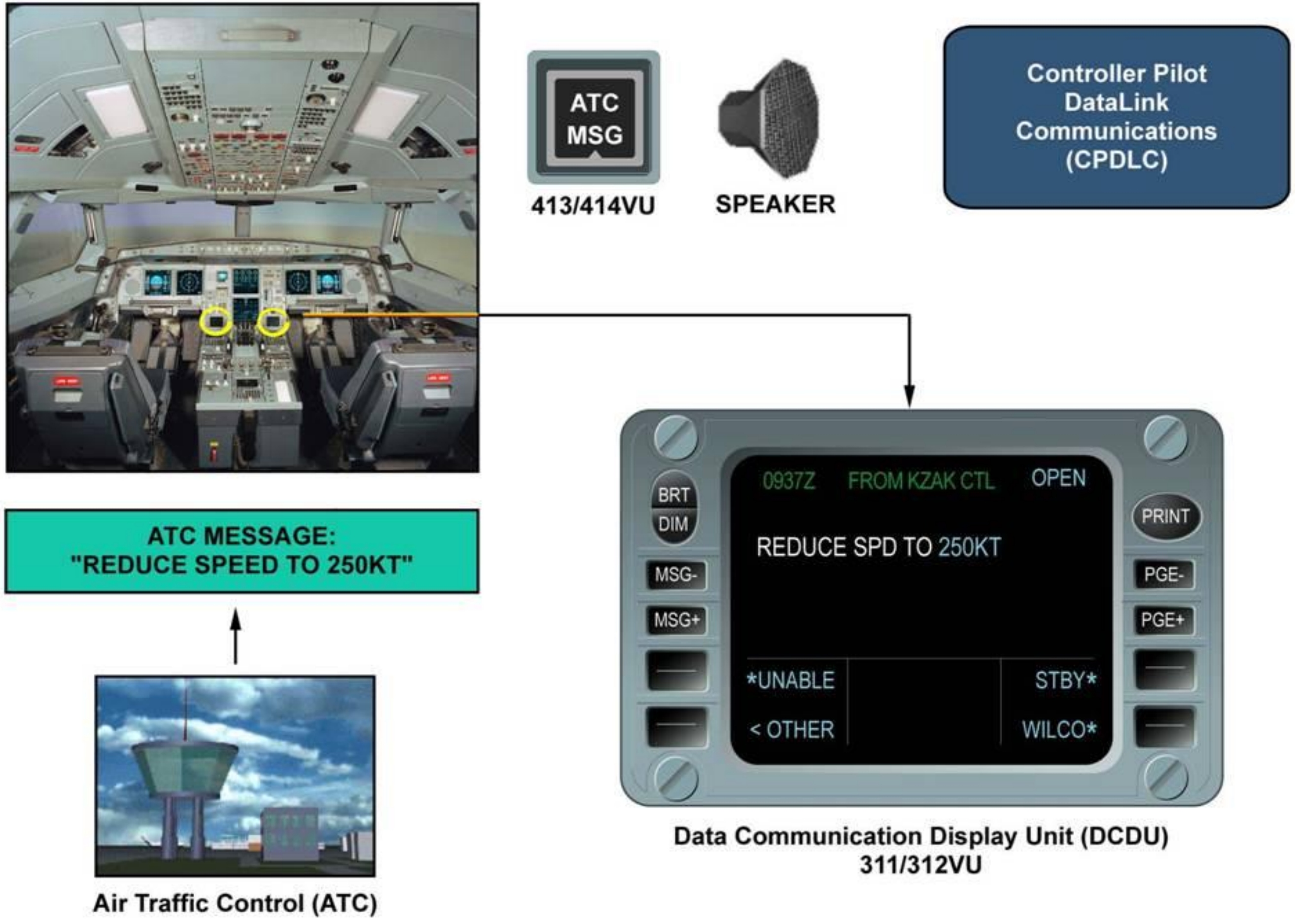
- Being driven by an increase in air traffic and consequently demand on VHF channels, a further channel split to 8.33 kHz was proposed firstly in 1996. This gives a theoretical 2,280 channels achievable. The choice of 8.33 kHz was chosen as it was the minimum practical size to support DSB-AM modulation (if the ±4 kHz voice limiting is applied, a modulated channelization of 8 kHz can be obtained). Nowadays the AM(R)S is in 25-kHz and 8.33-kHz co-habitation form.

(2) VHF Communication

- Limitations with VHF voice communication: As the technology to support data applications became readily available in the radio communications industry in the late 1980s, it became apparent that an aero mobile datalink system could be realized. The datalink offered an opportunity to move some of the more routine, repetitive, superfluous, verbose and cumbersome voice functions traditionally conveyed over the air traffic controller voice channel to a VHF datalink.

(2) VHF Communication



A VHF datalink application example

(2) VHF Communication

- For some applications the datalink could reduce the scope for error of interpretation, reduced air traffic controller workloads and it also could act as an affirmation channel for voice instructions. Today the VHF datalink is used to pass routine air traffic services messages such as weather and pressure information, and also be used to pass engineering information between aircrafts and their fleet, which could lead to improved automation with likely consequential operational safety improvements.

（2）VHF Communication

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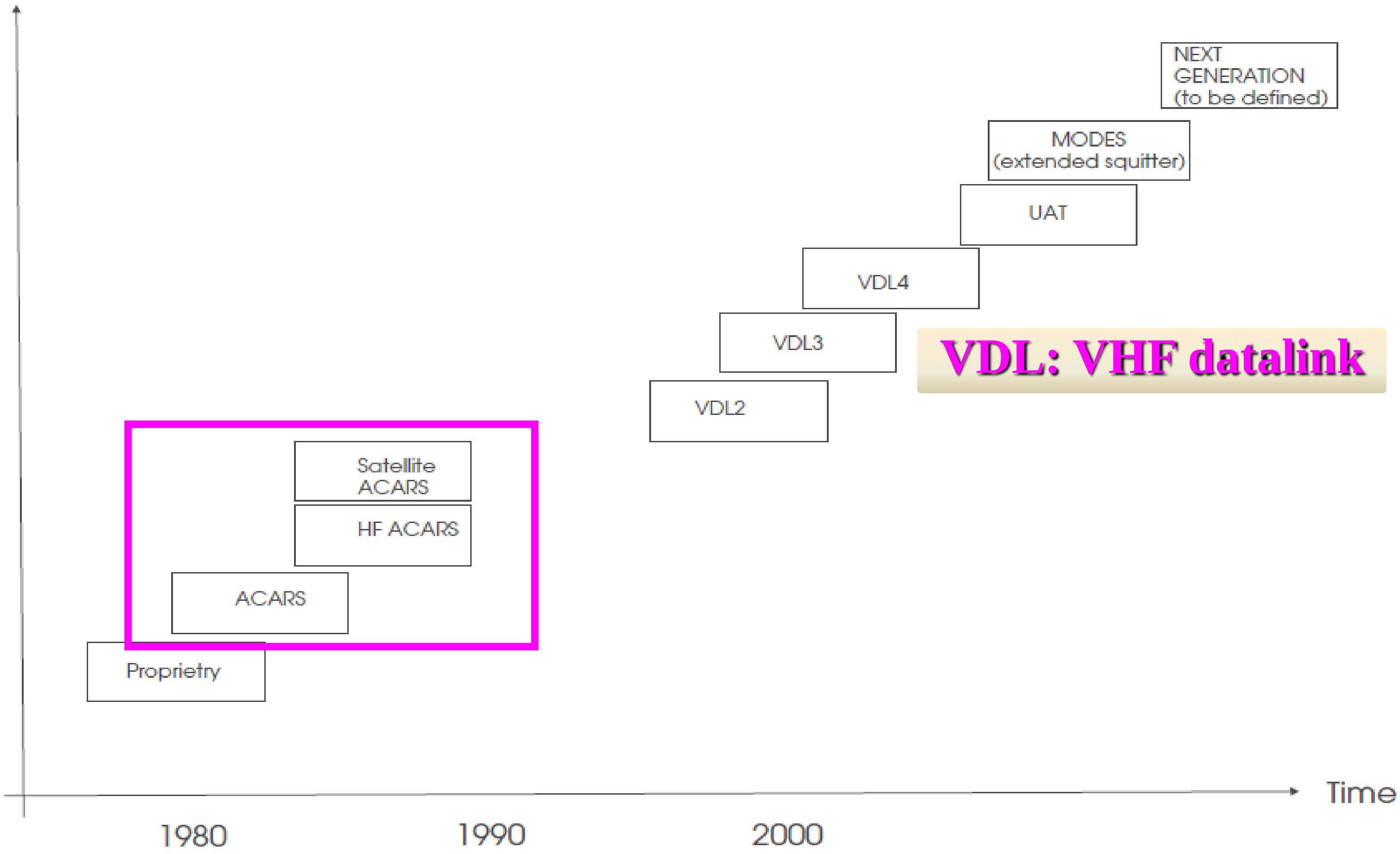

VDL: VHF datalink

Aero VHF datalink evolution

Overview of VDL mode

	ACARS/VDL0/VDLA	VDL1	VDL2	VDL3	VDL4
Standardization complete	Not standardized	NA	1997	2000	2000
In operation	Since late 1970s	Obsolete	2002	Experimental networks since 2003	Imminent
Modulation	AM-ASK	AM-ASK	8DPSK	8DPSK	GFSK
Air interface format + protocol	Unstructured	CSMA	TDMA-CSMA	TDMA	S-TDMA
Air interface speed	2.4 kbps	2.4 kbps	31.5 kbps	31.5 kbps	19.2 kbps
Payload (speed)	300 bps	300 bps	>10 kbps	Up to 4×4.8 kbps (19.2 kbps)	<19.2 kbps
Prioritization	Not supported	Not supported	Not supported	Supported	Supported 4 levels
Data services supported	✓	✓	✓	✓	✓
ATC (DCL, D-ATIS, OCM)	✓	✓	✓	✓	✓
AOC			✓	✓	✓
Link 2000+					✓
Navigation and Surveillance functions					
Voice services supported	No	No	No	Yes	No
Service providers	ARINC/SITA	ARINC/SITA		SITA	
Channelization	25 kHz + guard bands	25 kHz + guard bands	25 kHz + guard bands	25 kHz	25 kHz + guard bands
Deployment region	All	None	All	North America	Europe
Channel capacity (users)		Typical 600+ per channel	Dependent on coverage volume	Theoretically up to 4500 users, not validated	
Rx sensitivities					

（2）VHF Communication

- As the first air to ground data radio solution, and still very much in practice today ACARS (Aircraft Communications Addressing & Reporting System) was available in the late 1970s.

According to ARINC620 standard:
Flight Identifier: FM652
Aircraft Number: B-2153
CAS (speed): 248 knots
Position: 45.628 N, 126.266 E
ALT (altitude): 24,644 feet
UTC (time): 04:21:05

```
┌ QU SHAUOFM
.BJSXCXA 302359
┐ M14
FI FM652/AN B-2153
DT BJS PVG 302359 M20A
-   PRESENT POSITION REPORT
CAS 0248,LAT N 45.628,LON E126.266,
ALT 24644, UTC 042105┘
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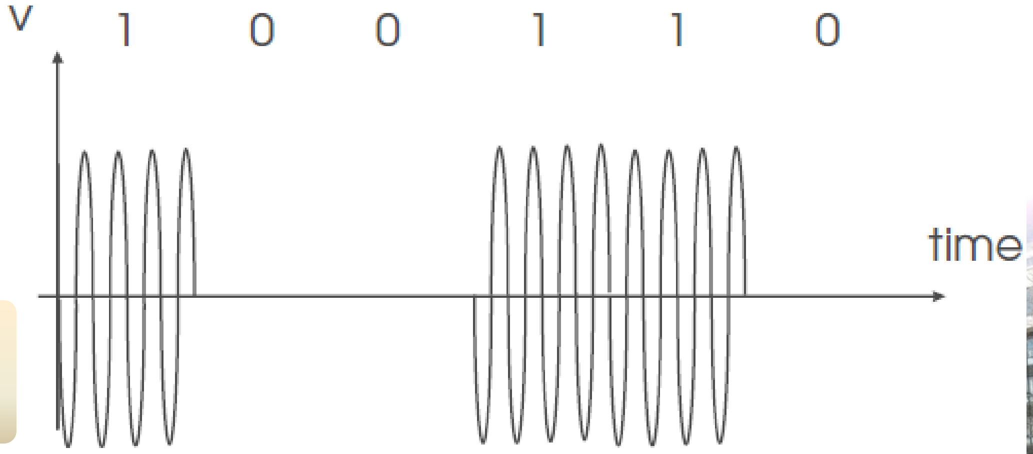
ACARS messages (partial)

(2) VHF Communication

- ACARS uses character-oriented data (ASCII based; certain characters are reserved for datalink control), and the air interface using amplitude-modulated minimum shift keying. Amplitude modulation in the digital domain is known as Amplitude Shift Keying (ASK): a digital 1 turns on the modulation of a fixed carrier frequency and a digital 0 turns it off.

Binary ASK (2ASK)



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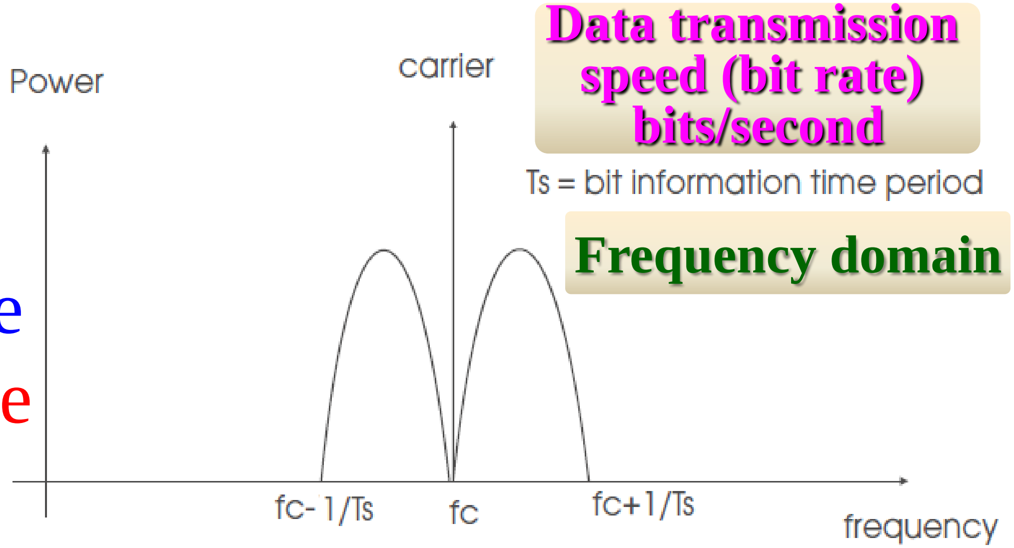
- ASK can be considered analogously with analogue AM. The bandwidth of ASK is double that of the raw data. ASK is rarely used in aviation. The main reason is to do with setting the amplitude detection threshold between what constitutes a 1 and what constitutes a 0. As attenuation increases, at some point it will become impossible to differentiate between a 1 and a 0.



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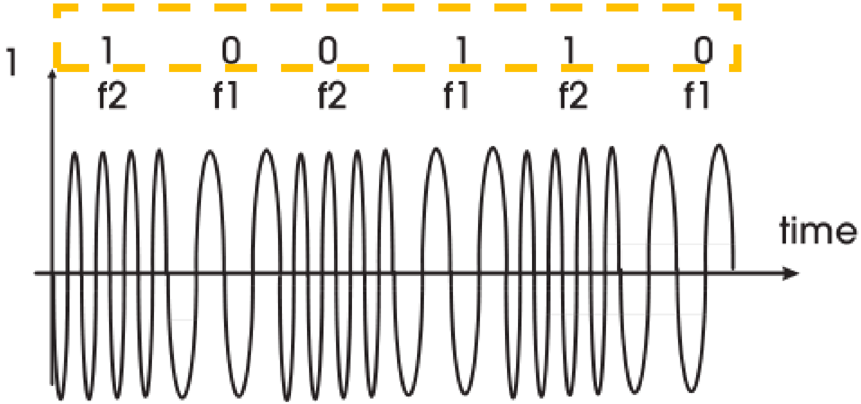
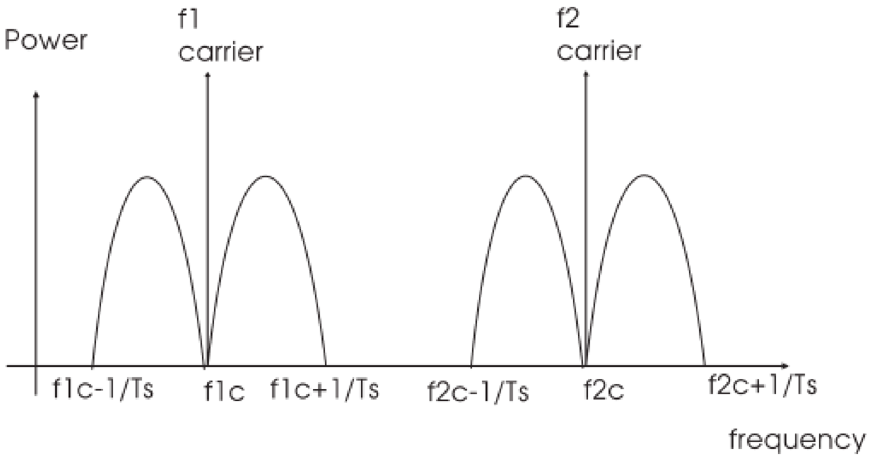
- Amplitude Modulated Minimum Shift Keying (AM–MSK): using two tones f_1 and f_2: f_1 indicates a bit change from the previous bit, and f_2 indicates no bit change from the previous bit.



AM-MSK modulation

Minimum Shift: continuous phase



AM-MSK spectrum (two carrier frequency)

(2) VHF Communication

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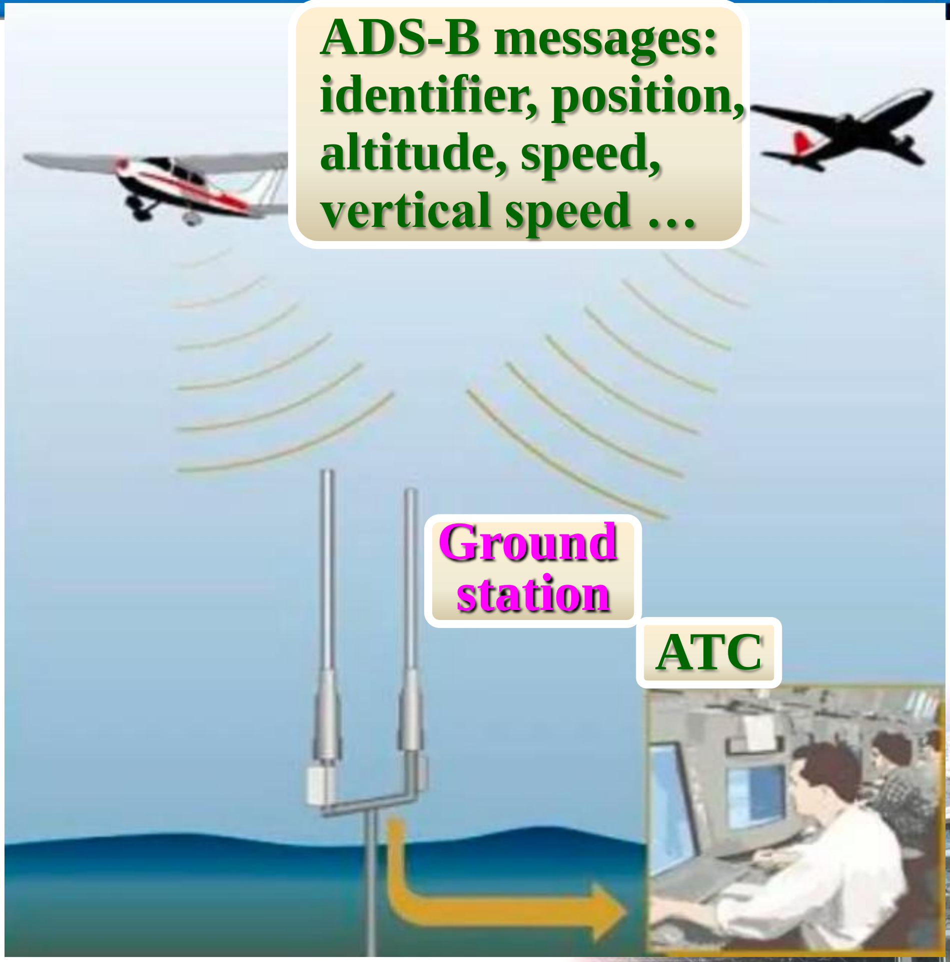
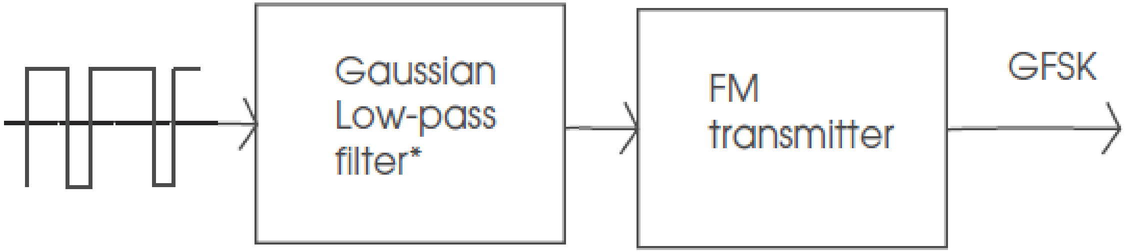
- VDL 4 /ADS-B (Broadcast of automatic dependent surveillance): an aircraft periodically (0.5 ~ 5s depending on importance) broadcasts its ADS-B messages, enabling it to be tracked. “Automatic” refers to that no pilot or no external input is required.

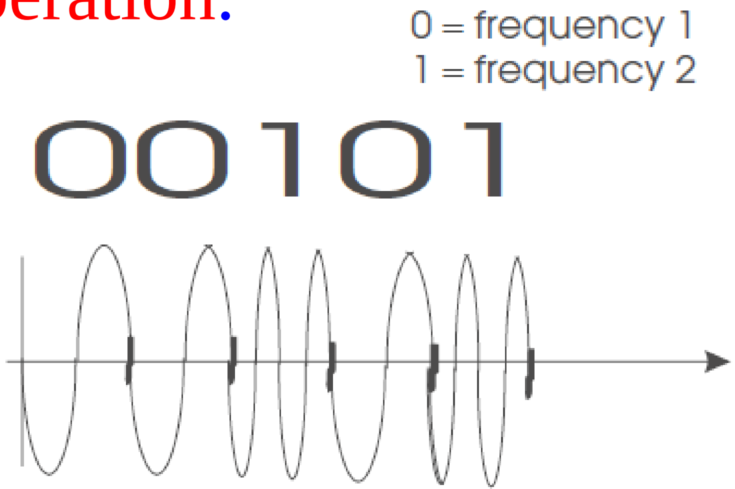


(2) VHF Communication

- GFSK (Gaussian Frequency Shift Keying): a signal composed of binary 1 and 0 states is applied to the FSK modulator, and a pre-modulation Gaussian pulse shaping filter is set for the reduction of the side lobe levels of the spectrum to ensure the channel seperation.



GFSK Modulation

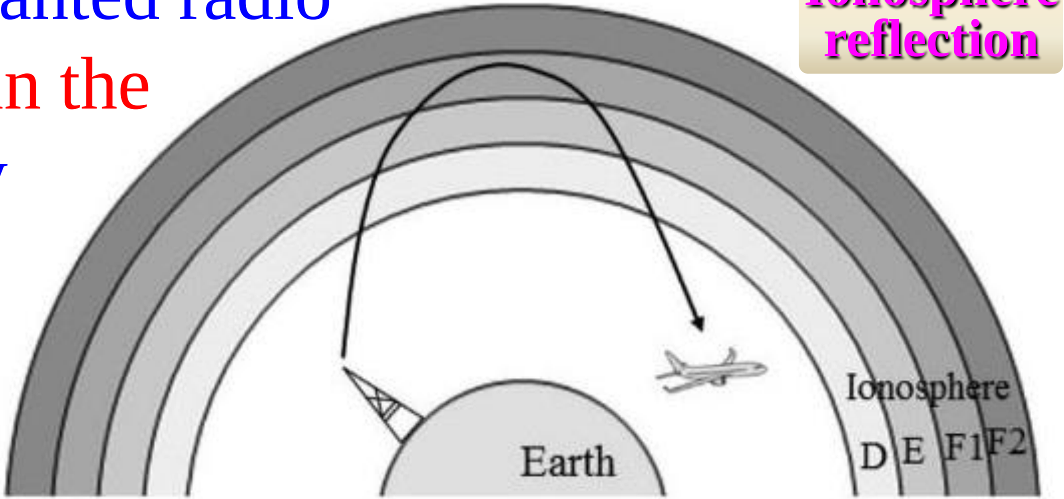


Binary FSK (2FSK)

（3）Long-distance Comms

- The HF band lends itself to extensive range propagation with a low loss of reflection possible from the ionosphere, enabling various ‘modes’ to propagate thousands of kilometres. However it can also equally be a hindrance in that unwanted radio transmissions (e.g. lift in the noise floor) can equally propagate a long way.

Ionosphere reflection



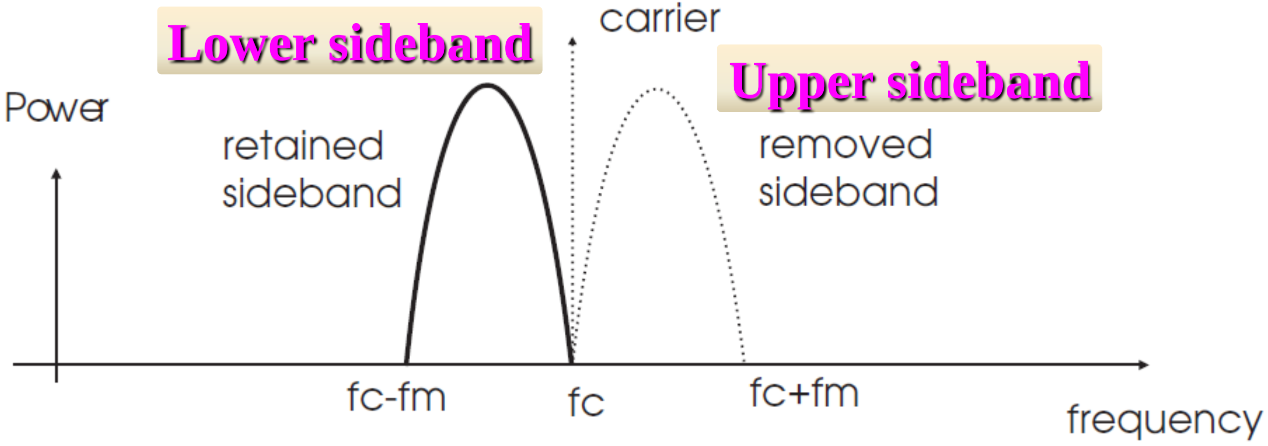
‘Over the horizon’ comms achieved by HF radio system

(3) Long-distance Comms

- Aviation has been awarded spectrum allocations right across the HF band between 2.8 and 30.0MHz. In approximately 27MHz of spectrum, civil aviation has been allocated 1.5MHz in total.
- With DSB-AM, it is found that the upper sideband is a perfect reflection of the lower sideband; i.e. the same information is carried by both. By removing one of the sidebands and by removing the carrier, therefore, no information is lost.

(3) Long-distance Comms

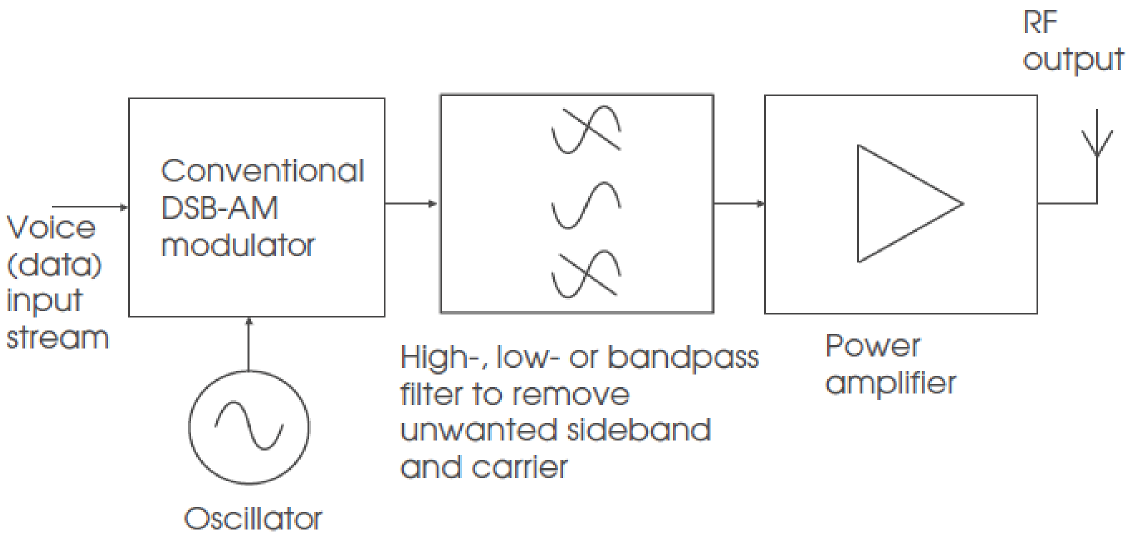
- Single sideband amplitude modulation (SSB-AM): removing one of the sidebands and the carrier of DSB-AM, and the SNR (signal-to-noise ratio) increases for a given transmit power as all the transmitted energy is concentrated into the information signal.



SSB-AM modulation illustration

（3）Long-distance Comms

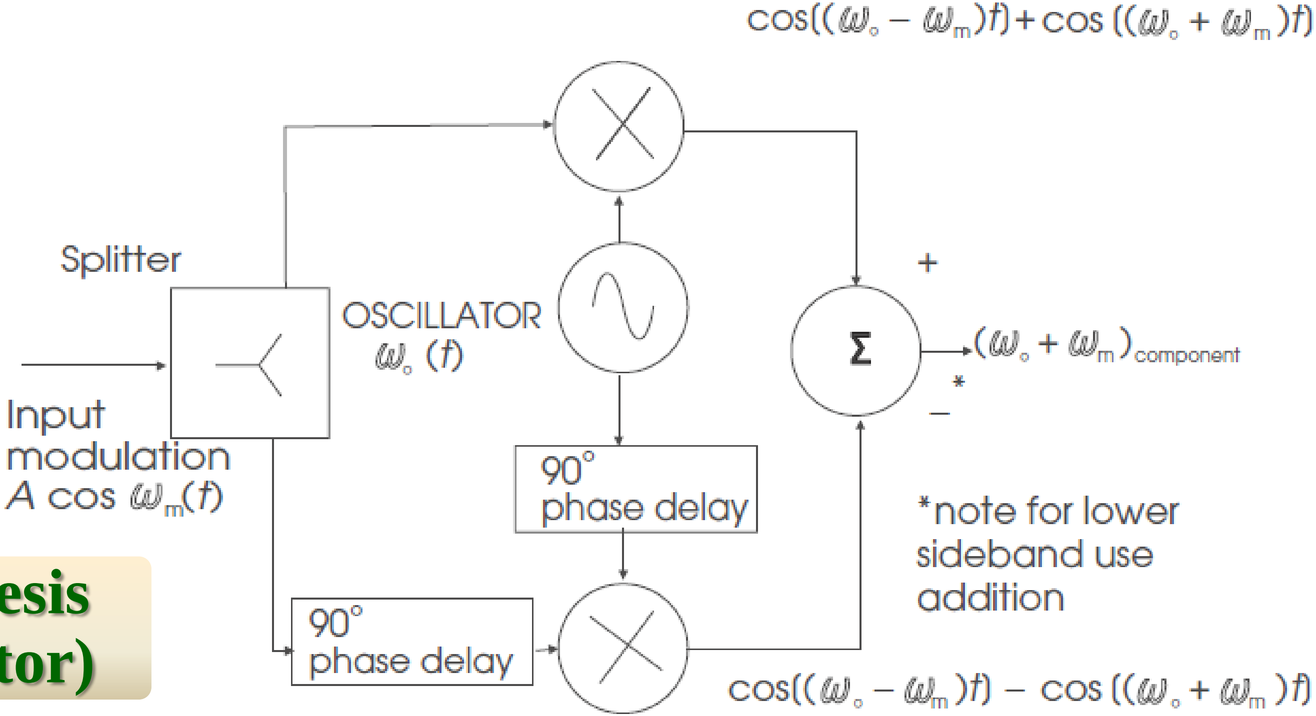
- The construction of an SSB is fractionally more complicated than that of DSB-AM.
- A SSB signal can be synthesized by using basic DSB-AM modulator and filtering out the unwanted carrier and sideband (usually done at a IF).



SSB indirect synthesis and filtering

(3) Long-distance Comms

- A SSB direct synthesis method is to use **Hilbert modulator**, which essentially cancels out the unwanted sideband and carrier.



SSB direct synthesis (Hilbert modulator)

（3）Long-distance Comms

- Input signal: $v(t) = A\cos(2\pi f_m t) \xrightarrow{90^o \text{ shift}} v_{ps}(t) = A\sin(2\pi f_m t)$
- $v(t)$ multiplies with local oscillator's signal component $k\cos(2\pi ft)$: $v_I(t) = 0.5k\{\cos[2\pi(f - f_m)t] + \cos[2\pi(f + f_m)t]\}$
- $v_{ps}(t)$ multiplies with local oscillator's signal component $k\sin(2\pi ft)$: $v_Q(t) = 0.5k\{\cos[2\pi(f - f_m)t] - \cos[2\pi(f + f_m)t]\}$
- Then, the output signal of modulator:

$$v_{out}(t) = v_I(t) - v_Q(t) = k\cos[2\pi(f + f_m)t]$$

One (retained) sideband