Avionics Technology

B31353551

— *Aero Communication*

yunzhao@buaa.edu.cn

Spring Semester 2023 (13_Apr_T8)

V. Aero Communication

（1）Some concepts

（2）VHF Communication

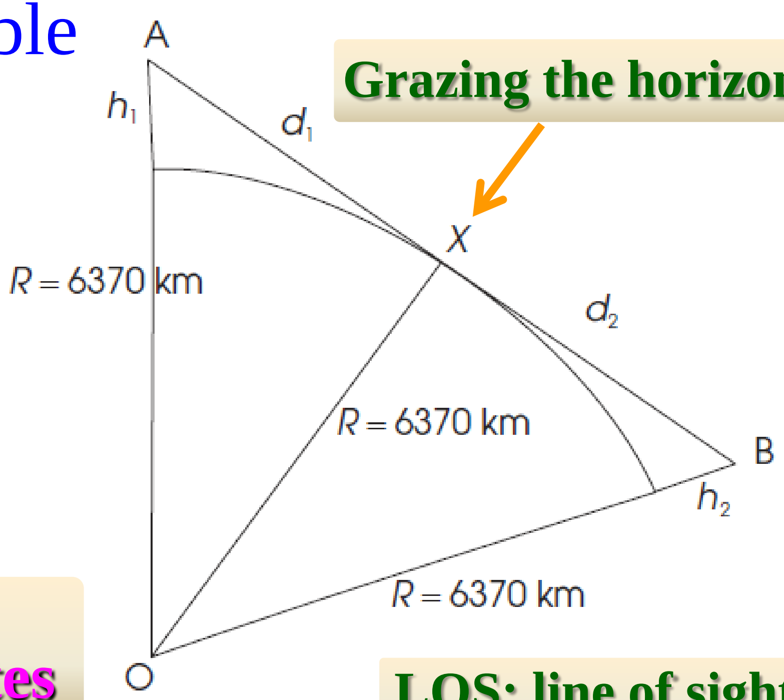
（3）Long-distance Communications

(1) Some concepts

- Extending the argument to another airborne antenna at a point at B or a high-tower mast h_2 above the mean sea level, the LOS distance achievable between two points (i.e. the limit where the communication ray grazes the horizon) can be defined by

$$D \approx d_1 + d_2 = (2Rh_1)^{0.5} + (2Rh_2)^{0.5}$$

Radio horizon geometry for two aircraft or two 'high'-elevation sites

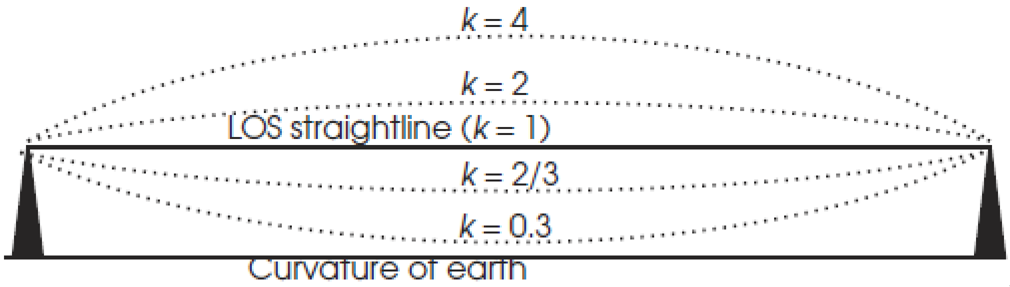


Grazing the horizon

LOS: line of sight

(1) Some concepts

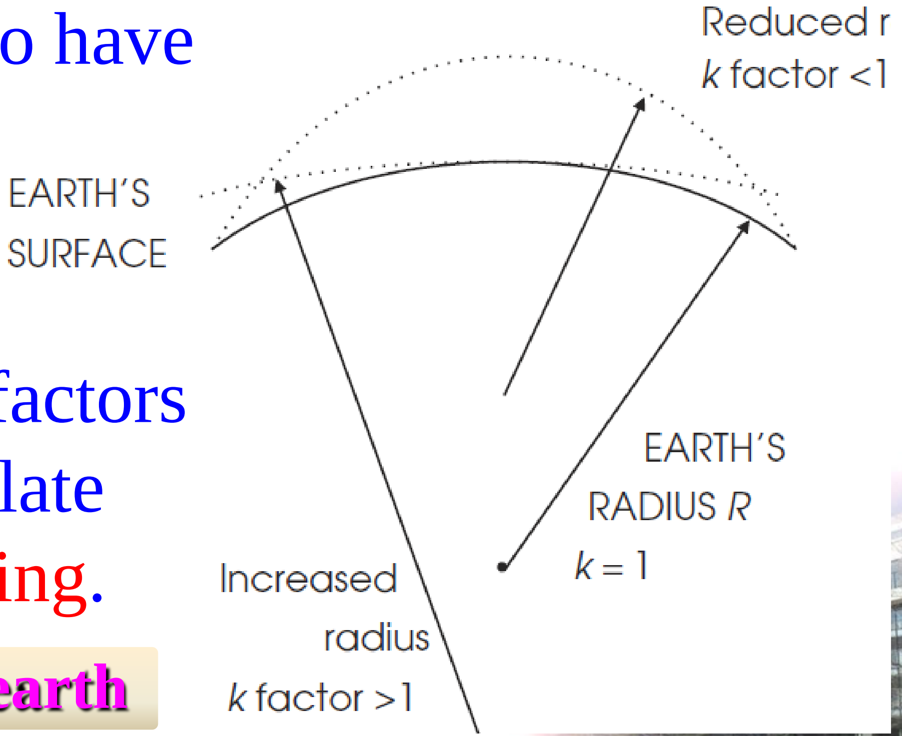
- Earth bulge factor (k factor): In some instances, it is found that radio waves do not propagate directly between the two points. They refract like light and generally tend to bend out from the earth but on occasion they bend towards the earth. This phenomenon can be described by incorporating what is called a k factor, which tends to be more significant for horizontal and terrestrial radio paths.



Flat earth equivalence

(1) Some concepts

- The k factor is a multiplier for the earth's radius to give an 'effective earth's radius'. For k factors of less than 1, the earth will be considered to have a virtual radius of less than R (i.e. $k = 1$), an exaggerated curvature for a given length of radio path. Conversely, k factors of greater than 1 would simulate the earth's curvature decreasing.



Apparent curvature of earth

（1）Some concepts

- The subsequent LOS range of a radio link reduces or increases: apparent earth's radius = kR
- Statistical measurements have been collected as to the proportion of the time k moves up and down for different frequencies and for different climate zones.
- The consideration of k factor (2/3 or even 0.5 sometimes taken for high reliability) should be incorporated in design of radio links, particularly terrestrial point-to point links or for low-flying scenarios.

(1) Some concepts

Radio spectrum

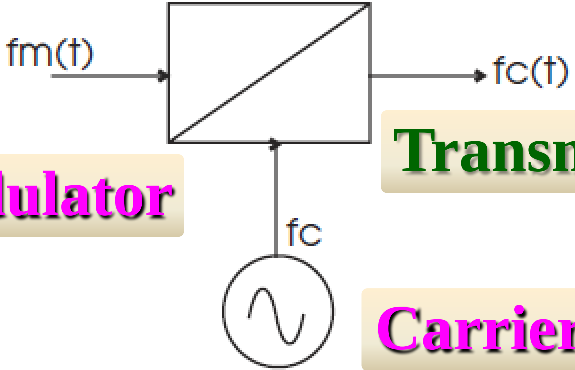
$\lambda = c / f$, c (speed of light) $\approx 3 \times 10^8$ m/s

Band name	Abbreviation	Frequency	Wavelength	Band name	Abbreviation	Frequency f	Wavelength λ
Extremely low frequency	ELF	3 – 30 Hz	100,000–10,000 km	High frequency	HF	3 – 30 MHz	100–10 m
Super low frequency	SLF	30 – 300 Hz	10,000–1,000 km	Very high frequency	VHF	30 – 300 MHz	10–1 m
Ultra low frequency	ULF	300 – 3000 Hz	1,000–100 km	Ultra high frequency	UHF	300 – 3000 MHz	100–10 cm
Very low frequency	VLF	3 – 30 kHz	100–10 km	Super high frequency	SHF	3 – 30 GHz	10–1 cm
Low frequency	LF	30 – 300 kHz	10–1 km	Extremely high frequency	EHF	30 – 300 GHz	10–1 mm
Medium frequency	MF	300 – 3000 kHz	1000-100 m	Tremendously high frequency	THF	300 – 3000 GHz	1–0.1 mm

(1) Some concepts

- In radio communication, radio waves are used to carry information across space from a transmitter to a receiver by modulating the radio signal.

Message signal

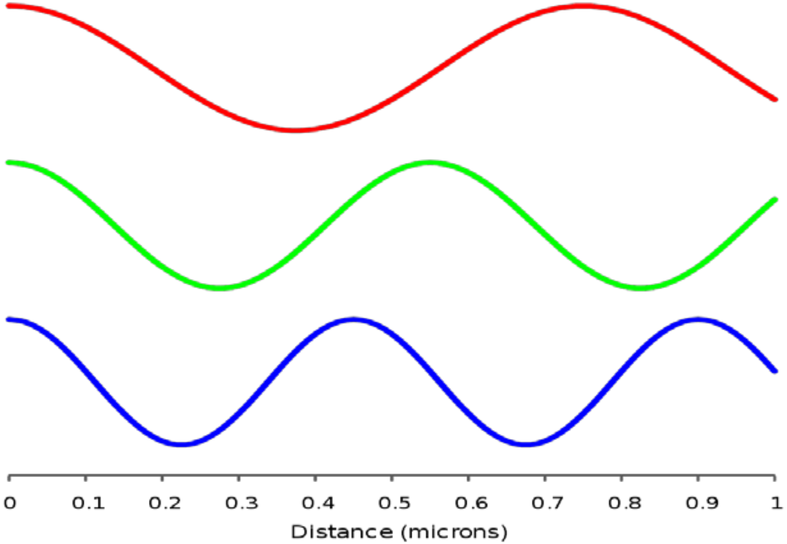


Modulator

Transmitted signal

Carrier wave

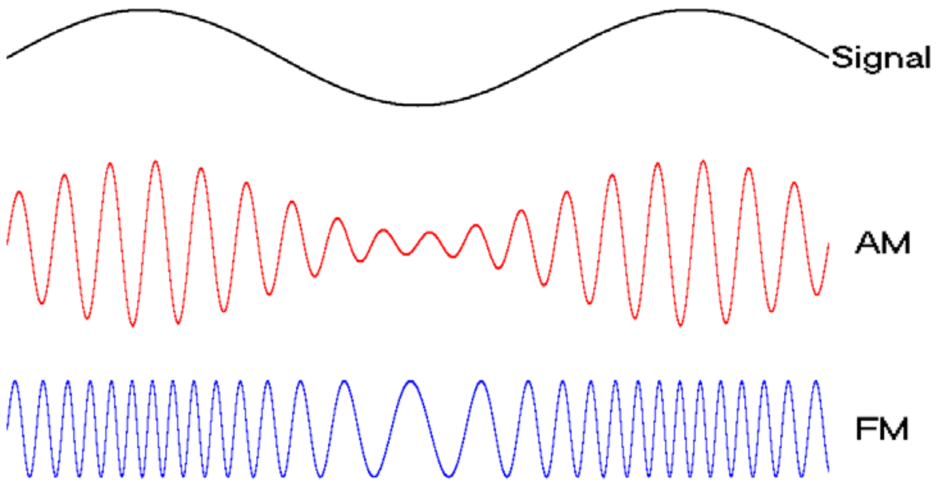
Modulation schematic



Radio signals with different frequencies

(1) Some concepts

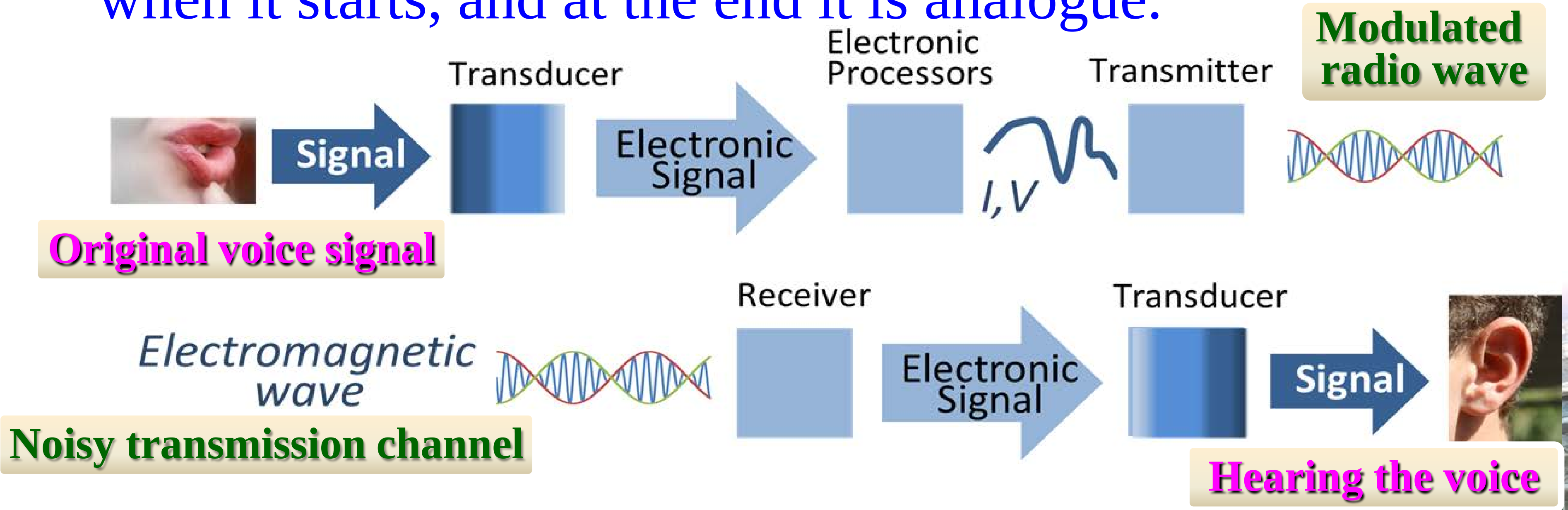
- *Modulation* is when the message signal that is to be conveyed is transposed into a suitable form (varying some aspect of radio wave) so that it can be transmitted over the media involved (usually plain air). The reverse process '*demodulation*' is when the transmitted message is extracted from the modulated carrier.



Amplitude / Frequency modulation scheme

(1) Some concepts

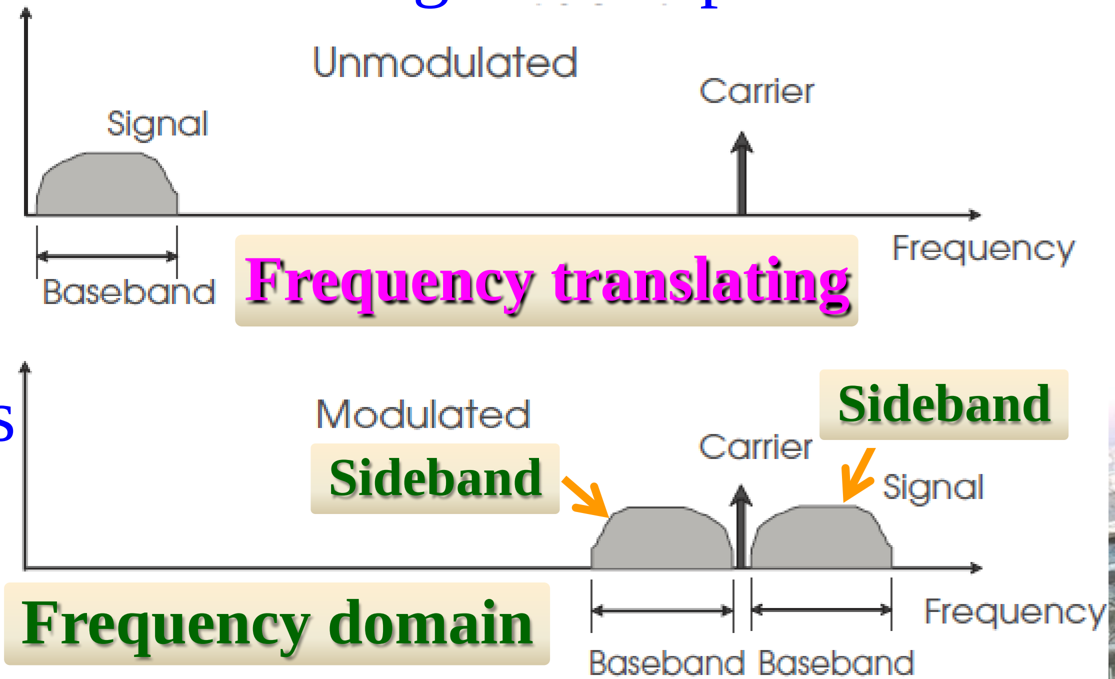
- The raw data or voice signal (usually called the baseband) can be modulated onto a ‘carrier frequency’.
- With voice over legacy radio systems, it is analogue when it starts, and at the end it is analogue.



(1) Some concepts

- A modulated radio wave, carrying an information signal, occupies a range of frequencies. The width in hertz of the frequency range that the radio signal occupies is called its bandwidth.

A given amount of bandwidth can carry the same amount of information regardless of where in the radio spectrum it is located.



（2）VHF Communication

- It was not until the 1940s that radio became generally available on aircraft. Moreover, it was unreliable due to the high frequency (HF) band, which were prone to atmospheric noise. In 1940s the VHF band was utilized due to its relative immunity to atmospheric noise, reliable communications abilities and relatively high ranges to the horizon. The VHF band 118 ~ 132 MHz was set aside by WRC in 1947 for the Aeronautical Mobile (Route) Service or AM(R)S.

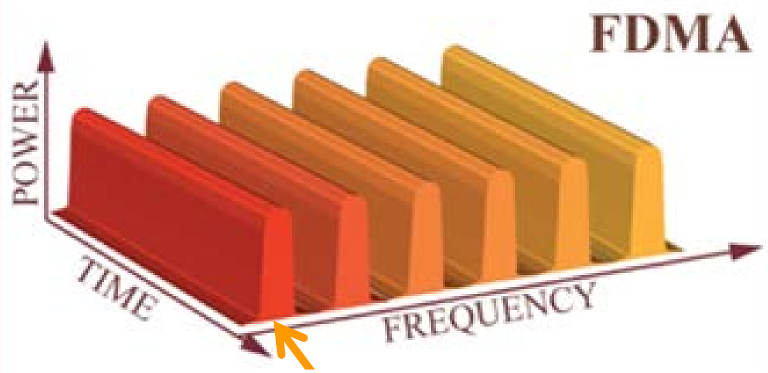
WRC: world radio conference

Aircraft's VHF antenna

（2）VHF Communication

- The AM(R)S system was planned to use 200 kHz channel spacing, thus 70 channels were accommodated over the whole band. It employed DSB (Double Side Band)-AM (Amplitude Modulation).
- *Multiplexing*: Each radio transmission occupies a portion of the total bandwidth available. Radio bandwidth is regarded as a radio channel resource.

Putting multiple channels into one radio band



One sub-band per user

Frequency Division Multiple Access /Frequency Division Multiplexing

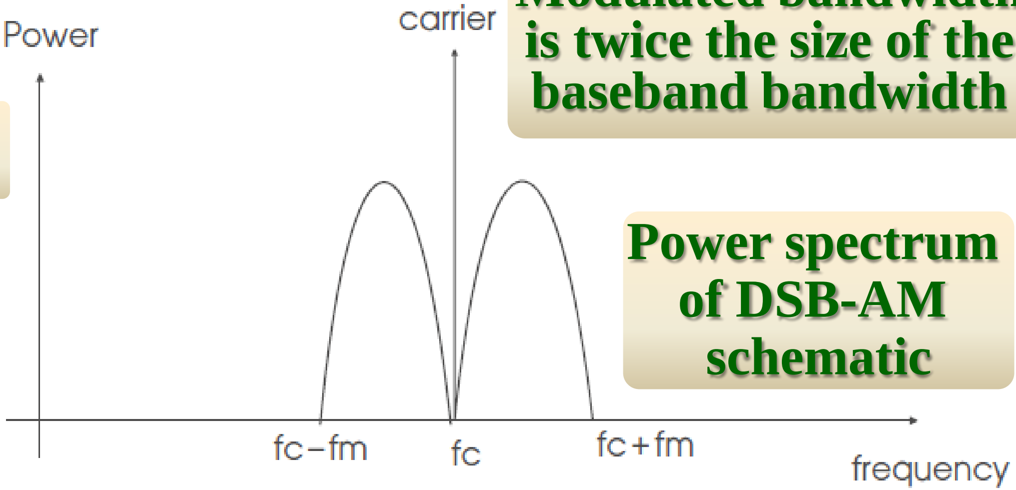
- *Amplitude Modulation* (AM) is when the amplitude of the carrier is directly proportional to the modulating (message) signal. The simplest form of AM is DSB-AM. DSB-AM can be described mathematically as:

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

$f_c(t)$: 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:

$$f_{\mathrm{m}}(t) = a\cos(2\pi f_{\mathrm{m}} t)$$

a: Modulating signal amplitude

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

m: Amplitude sensitivity

- Let $\Phi = 0$,

Lower sideband

then $f_{\mathrm{c}}(t) = K[\cos(2\pi f_{\mathrm{c}} t) + \underline{0.5\, m\cos(2\pi(f_{\mathrm{c}} - f_{\mathrm{m}})t)}$

$$+ \underline{0.5\, m\cos(2\pi(f_{\mathrm{c}} + f_{\mathrm{m}})t)}]$$

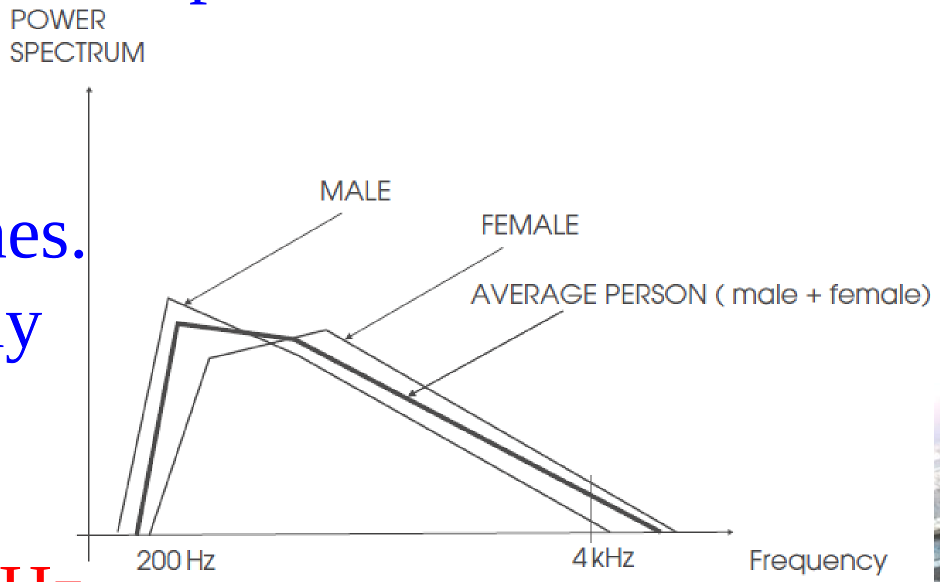
Upper sideband

(2) VHF Communication

- 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.

(2) VHF Communication

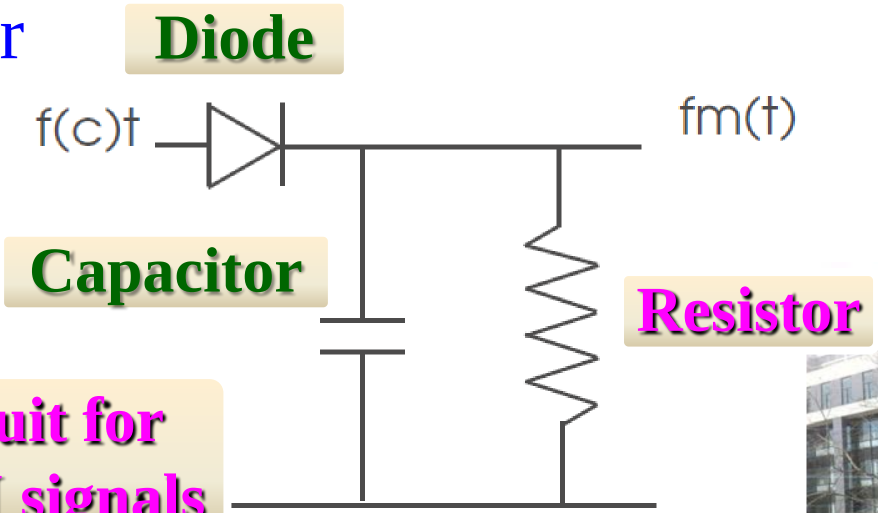
- A typical voice signal shows a spectral density with most of its power components above 200 Hz and below 4 kHz. There are some minor components between 5 and 20 kHz, and even if there was, the typical human ear loses sensitivity to these tones. So it is possible to accurately recover a voice signal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



Typical voice spectral density

(2) VHF Communication

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



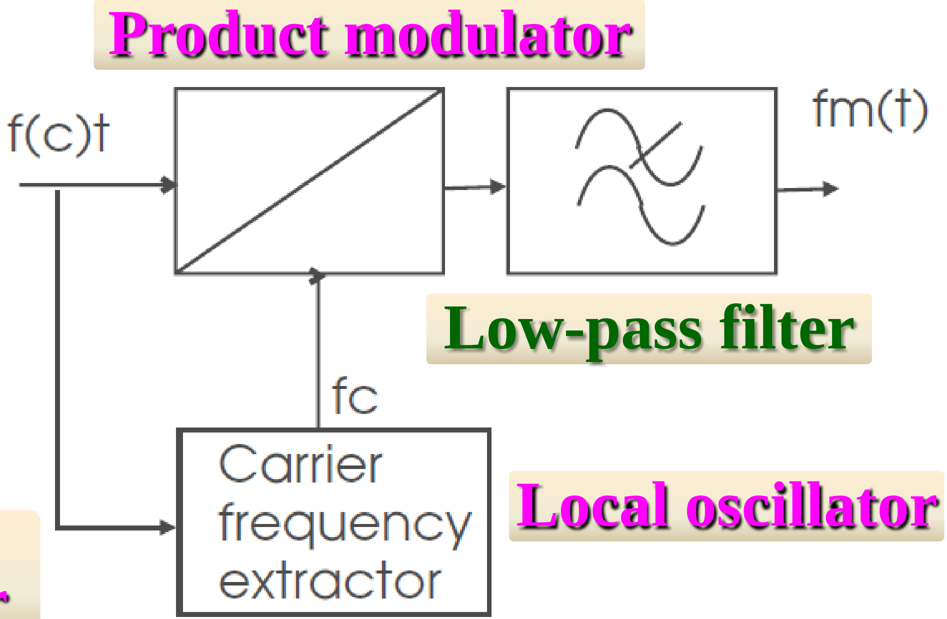
Envelope detector circuit for demodulating DSB-AM signals

(2) VHF Communication

北京航空航天大学 BEIHANG UNIVERSITY

- 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

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

$$\downarrow$$

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

Assuming $\phi = 0$

$$\downarrow$$

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

Multiplying with the locally generated signal

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

$$\downarrow$$

After low-pass filtering

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

The demodulated signal output is proportional to the baseband signal

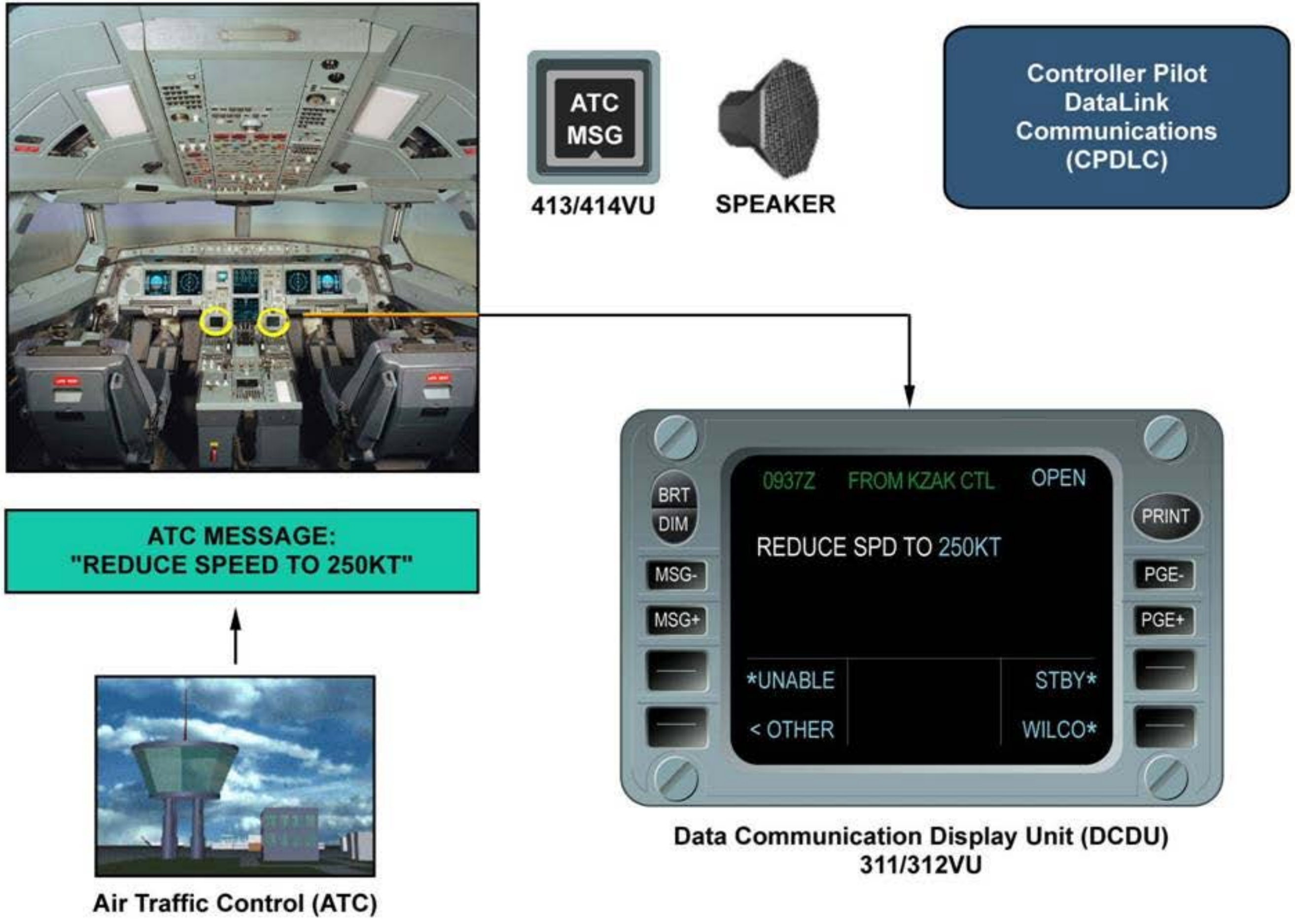
（2）VHF Communication

- 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), and it theoretically provided a threefold increase in voice channel capacity.

（2）VHF Communication

- Limitations with VHF Voice: As the technology to support data applications became readily available in the radio communications industry in the late 1980s, it became apparent that an aeronautical 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



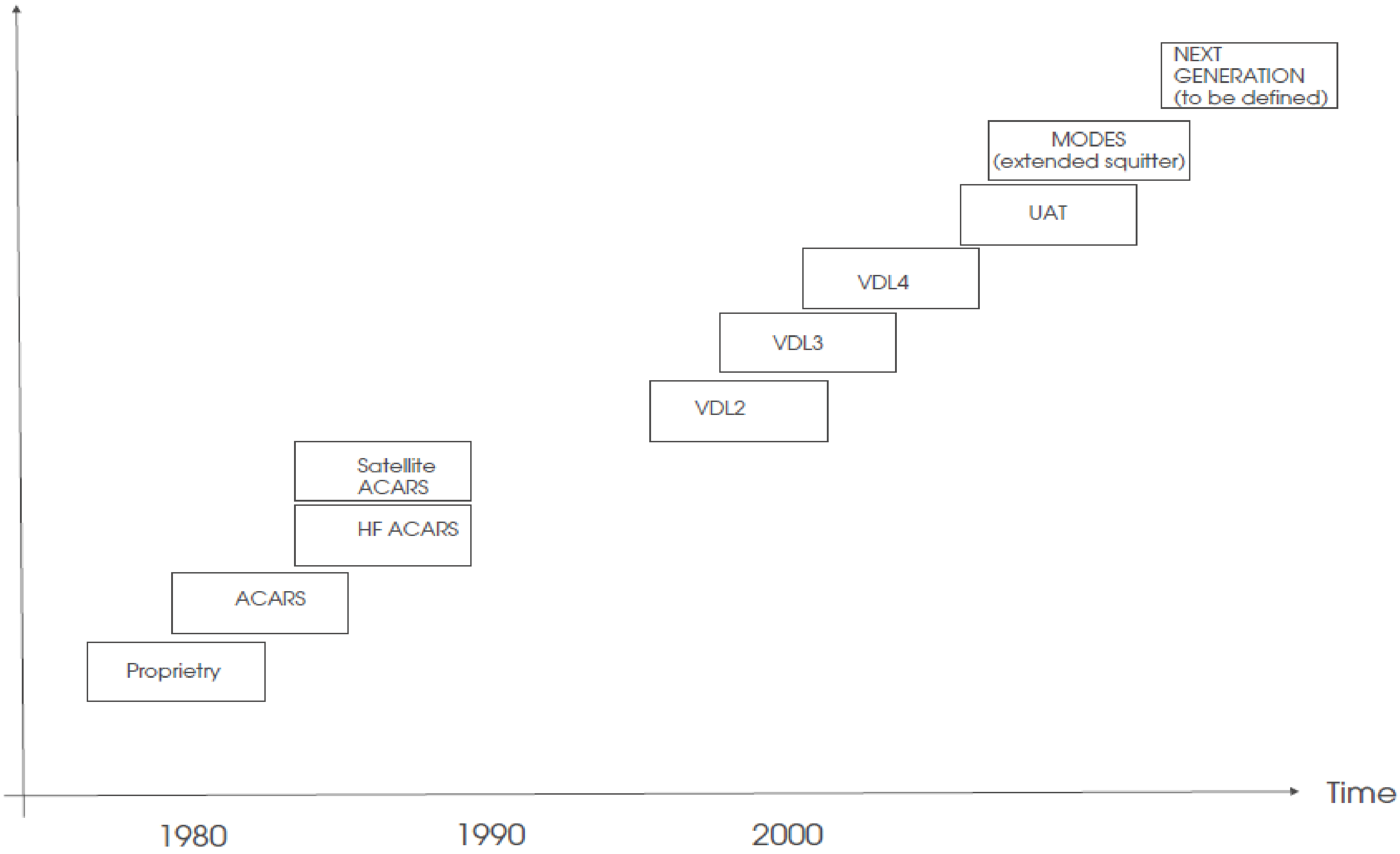
A VHF datalink application example

（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

Aero VHF datalink evolution



(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
CAS (speed): 248 knots
Position: 45.628 N, 126.266 E
ALT (altitude): 24,644 feet
UTC (time): 04:21:05

ACARS messages (partial)

┌ QU SHAUOFM

.BJSXCXA 302359

┐ M14

FI FM652/AN B-2153

DT BJS PVG 302359 M20A

\- PRESENT POSITION REPORT

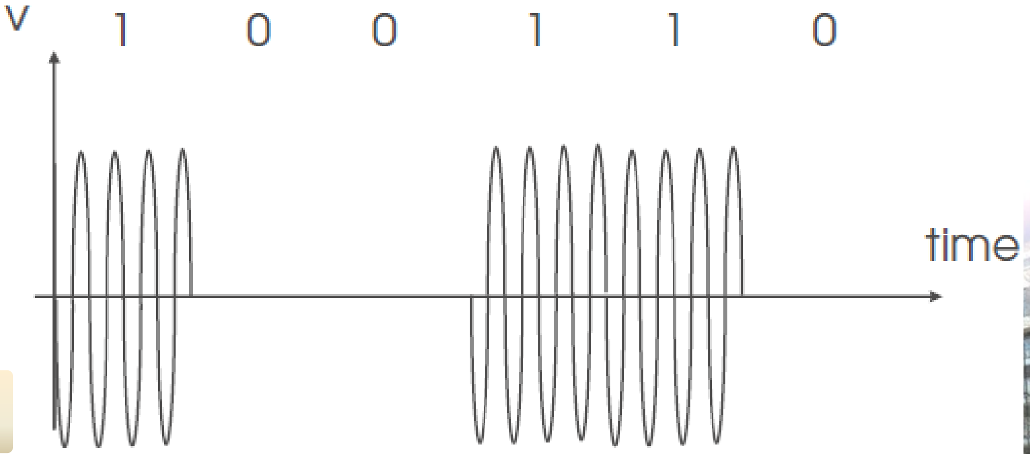
CAS 0248,LAT N 45.628,LON E126.266,

ALT 24644, UTC 042105└

（2）VHF Communication

北京航空航天大學 BEIHANG UNIVERSITY

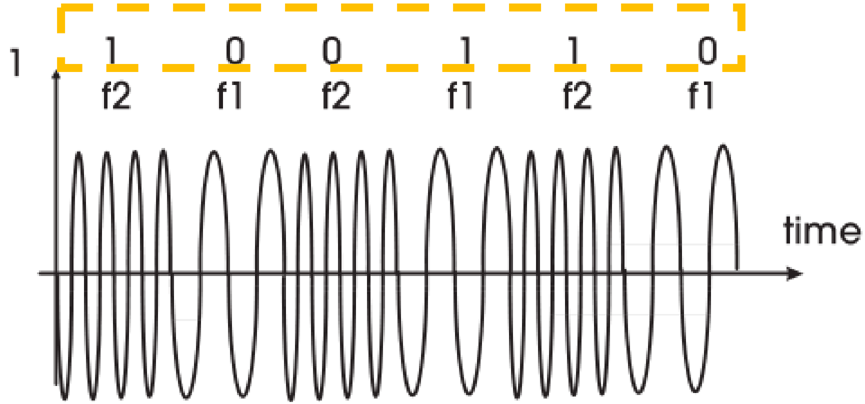
- ACARS uses character-oriented data (ASCII based; certain characters are reserved for datalink control), and the air interface using amplitude-modulated minimum shift keying. Amplitude modulation in the digital domain is known as Amplitude Shift Keying (ASK): a digital 1 turns on the modulation of a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



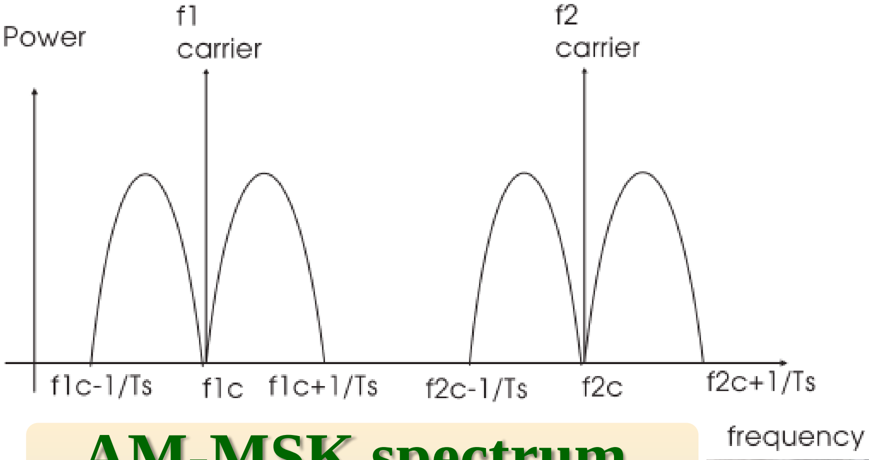
ASK

（2）VHF Communication

- 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



AM-MSK spectrum (two carrier frequency)