Handout and further Information to

Rohde & Schwarz at hackaTUM 2021

Satellite Constellation

Design the Orbits for a new Satellite Communication System

Orbits – Visibility – Coverage.

A tricky geometry problem!

Do you wanna join us?

WHAT IS THE GOAL?

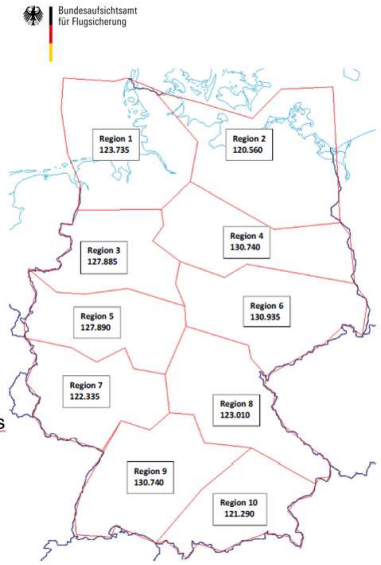
- You are the designer of a new satellite constellation.
- The satellites will be used to contact aircrafts from space.
- Don´t care about RF stuff – **this is not required here → just geometry in space.**
- We need your ideas → just to create the geometry for orbits allowing a global coverage.
- Let´s check it out now!

Don’t worry, we are talking about a mathematical problem exclusively linked to “Mechanics” which means orbit altitude, orbit planes, number of satellites, line of sight visibility from an orbit down to earth to find feasible sizes for sectors plus the suitable orbits etc.

The only analogue parameter which is part of the constraints is the Doppler effect. It can be easily calculated in the following: The frequency of 137MHz is shifted by 1ppm for a relative speed for 1000km/h. Satellites are cruising with typical 28000km/h, but not directly towards an aircraft below, but with some angles. With higher orbits visibility angles are better because a particular sector looks smaller from space. So we must stay below +- 2,5kHz Doppler shift to ensure that the existing radio system on board the aircrafts can remain unchanged

WHERE ARE WE TODAY?

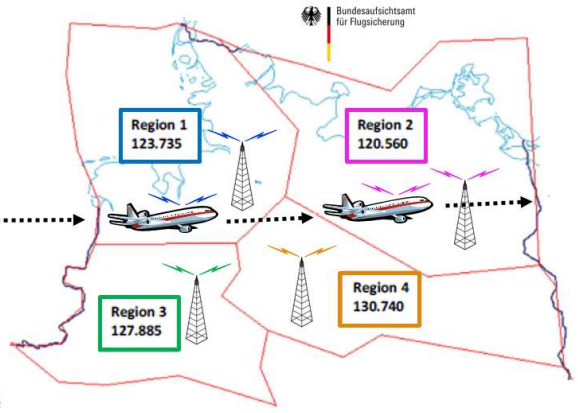
- 80% of all bigger passenger aircrafts are flying exclusively above land.
- The radio communication between pilots and controllers is done via terrestrial systems.
- The terrain below the aircraft is segmented into geographical reagions, called Flight Information Regions (FIR) or Sectors.
- Within each particular sector a flight controller is responsible to guide all aircrafts safely through this region.
- If a pilot wants to cross a sector he is selecting the VHF frequency assigned to this sector to be able to communicate with the responsible controller.
- Within each sector ONE single VHF Ground Station is installed which acts as counterstation for the onboard radio communication system.



The VHF comms system is using an analogue RF signal. Therefore it is important that only one transmitter (satellite) is transmitting into a particular sector on the associated frequency. Otherwise the aircrafts would hear several signal in parallel. → this is one of the key facts of this problem.

WHERE ARE WE TODAY?

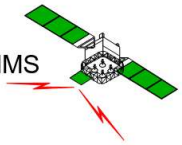
- Within each sector ONE single VHF Ground Station is installed which acts as counterstation for the onboard radio communication system.
- The pilot selects the VHF frequency of this particular sector he is crossing.
- Each sector is connected 24/7 just via this frequency.



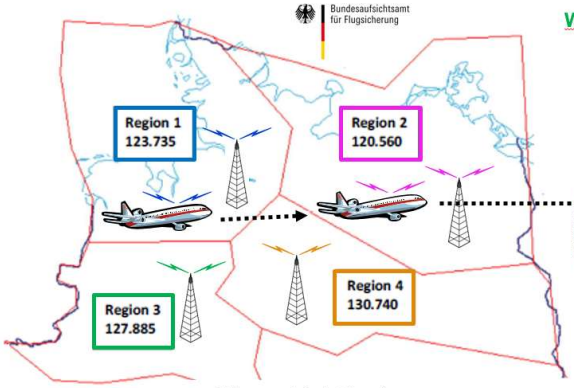
- The used VHF communication waveform is purely analogue and does not know any identity of users.
- Connectivity is only given by an assigned frequency for a particular geographical region.

We cannot use a digital waveform as mobile radios are doing because the analogue system is there and shall be unchanged. In a mobile phone system the aircrafts and/or the base station would do a handover, which is not possible here. Therefore we must design the orbits very carefully to ensure that one satellite can transmit into a sector for a sufficiently long time (some minutes) and then all satellites are changing to the frequency of this sector they are passing next.

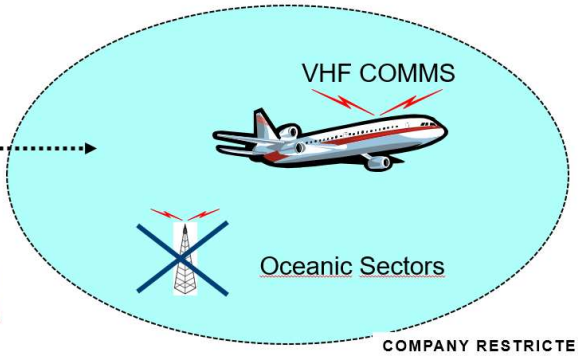
WHAT DO WE WANT TO ACHIEVE ?



- We go now over the oceans where no terrestrial infratsurcture is available.
- We are now designing a „space based VHF communication system“ with the goal that no aircraft needs a special satellite communication equipment.



We want to ensure that the aircrafts can remain unchanged



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The satellites are above the aircraft and not below as terrestrial stations are. This is not a problem as long as the satellites are within the elevation angles given in page 9.

Text 14 pt, z.B. Kapitel-Nr. & -Überschrift

SPACE-BASED VHF COMMUNICATION SYSTEM

- Moving a well-established terrestrial VHF communication system into space.
  - Satellites take the role of terrestrial radio towers.
- Air space is divided into many sectors and each sector is assigned to a VHF frequency.
- Air planes are crossing through multiple sectors during their flight.
- The pilot selects the pre-defined frequency of that sector he is currently crossing.
- Then, all airplanes in the current sector can be contacted by the regional ground control stations.

What we finally want to achieve:

- Airplanes and controllers do not see a any difference to known procedures using a well-established terrestrial VHF communication system.
- Aircrafts can use their standard communcation system without modification.
- All Aircrafts can cross oceans without special certification or special equipment.

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The overall goal is that the aircrafts which are currently not allowed to fly across oceans can do that now by using their standard onboard VHF comms system. Otherwise an aircraft has to install a satellite terminal which has to be avoided here.

Text 14 pt, z.B. Kapitel-Nr. & -Überschrift

CHALLENGE

- Coverage of a **non-equatorial** section by satellites
  - at any coordinates on the globe
- **Design of a satellite constellation**
  - Number of satellites
  - Orbits of satellites
    - → Only **geometrical** considerations
- WE NEED YOU AS **SATELLITE CONSTELLATION DESIGNERS**

Any coordinate on the globe shall be possible. It is part of the challenge to define the right size of sectors using the same frequency for all aircrafts within.

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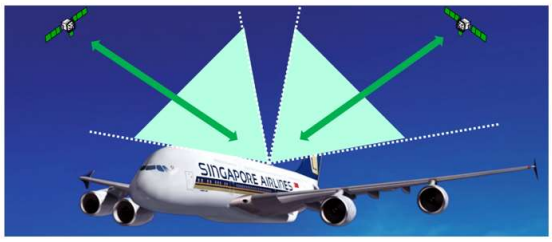
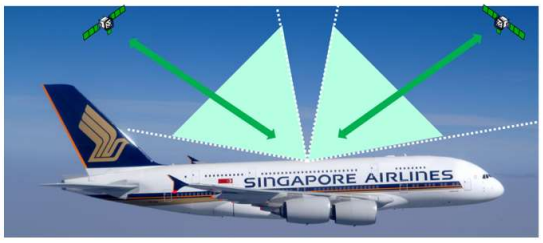
CONSTRAINTS I

- Communication frequency is **137 MHz**
- Doppler shift must be **less than +- 2.5 kHz**
- Elevation angle between airplane and satellite must be between **10° - 75°** for successful communication





The Doppler problem is easily calculated, see comment to slide #3. Therefore the complete problem is “reduced” to a 3D dynamic geometry problem without electrical parameters.

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CONSTRAINTS II

- Multiple airplanes are flying in the same sector and use the same frequency to communicate
- All Airplanes in a sector must communicate through exactly one satellite for t.b.d. minutes
- After this time another satellite provides this frequency
- An individual Aircraft can be called by the controller by just using it´s callsign – spoken.
  - All aircrafts hear the controller at the same time in parallel
  - All aircrafts can hear all other aircrafts within the sector and it´s associated frequency
- An Aircraft can call the controller by just pressing the microphone button

THE FIRST STEP TO A SOLUTION

- We will start first with a single sector located close to the equator.
- ONE Satellite will serve sector 1 for a few minutes.
- When a Sat is leaving the visibility of sector 1 → the next Sat will takeover and the previous Sat is free for a new sector.
- Start with a sector of a size of e.g. 1000km (east – west) and 500km (north – south).
- Start with a satellite constellation in the equator plane and propose an orbit altitude plus a number of satellites.

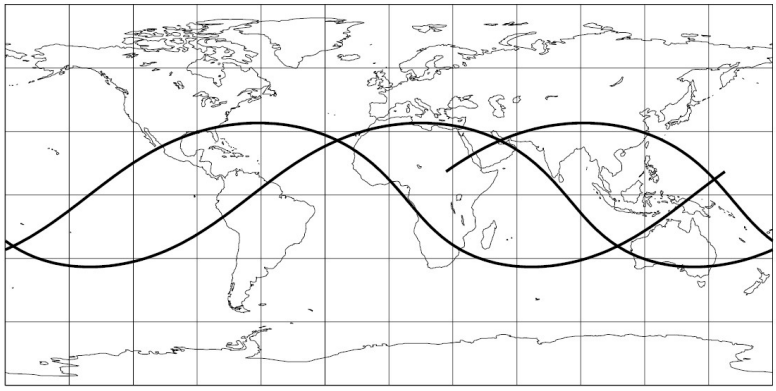
- The satellites are 3 axis stabilized and can always point into the sector.

It is good to get started with a first constellation within the equator plane. The axis of the plane is identical to the axis of the earth. Therefore all satellites are passing the same geographical areas during the complete orbit period. The satellites are normally orbiting from west to east (same direction as earth). This is normaly taken to save energy for the launch. But also the opposite direction would be possible if it helps for the orbit constellations.

THE SECOND STEP TO A SOLUTION

- Now we are adding more planes to reach sectors far away from the equator.
- These planes have an inclination and therefore a satellite will not come again over the same area after one orbit because the earth has moved to the east below the satellites plane.
- Therefore we will need more planes to ensure a 24/7 coverage.

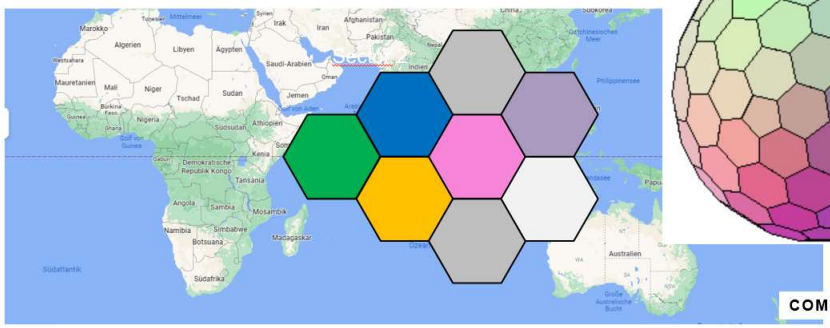
Now the earth is rotating aside to the orbital plane which means that after one orbit the satellites appear at different locations. The footprint looks like the following for one plane

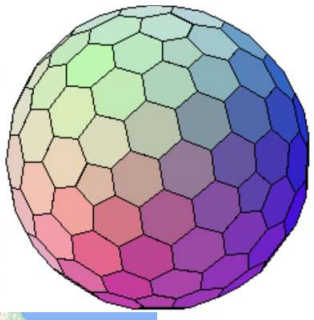


As a reference “Iridium Next” is using 66 satellites within 6 planes of 11 satellites each at an altitude of 780km to reach a global coverage. But they are using digital waveforms with handover and they are designing the ground segment also new. In our problem the ground segment – which are the aircrafts – is already existing and shall remain unchanged. So all “difficult” problems are placed to the space segment. In our case the orbit constellation

THE FINAL STEP TO THE FULL SOLUTION

- Now we are adding even more planes to reach a global coverage
- We need a 24/7 coverage for each sector by one particular satellite for a t.d.b. time e.g. some minutes
- How many satellites in how many planes do we need?
- What orbit altitude do you see as best?
- What sectorization of the earth do you see best?





The sectorization is very important. Smaller sectors lead to lower orbits and more satellites. In our case it does not matter how many satellite we – you – may find. Just find a working constellation, if such a constellation is existing!

SUMMARY OF WHAT WE NEED

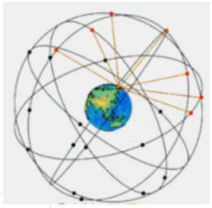
- The geometrie of a satellite constallation.
- How many satellites in which orbits?
- Global coverage for analogue VHF communication.
- The earth shall be segmented into sectors with t.b.d. size and shape.
- Each sector gets an individual VHF Frequency in the order of 137MHz assigned.
- One satellite operates this frequency exclusively for one sector for a t.b.d. time (some minutes).
- After this time another satellite takes over and we have a 24/7 coverage of each sector.
- The responsible satellite must be seen from the aircraft between 10° and 75° elevation above the horizon.
- All aircrafts within a sector can hear the same satellite and are contacted by the controller just via spoken callsign.
- All aircarfts within a sector can reach the responsible controller just by pressing the microphone button.
- The doppler shift of a satellite to all aricrafts within the sector shall be maximum 2.5kHz

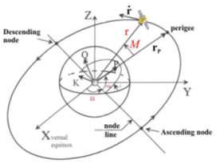
- It is finally the visibility of at least one satellite for each sector for some minutes – nothing more.
- The geometry counts, so angles, orbits, relative speed etc. are the important facts.

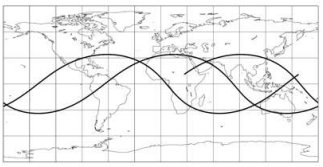
HOW TO SHOW US YOUR IDEAS

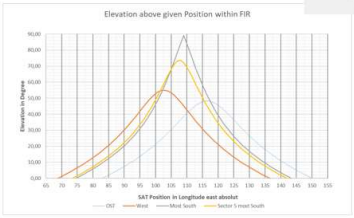
- It does not matter how you present your ideas, we just have to understand your concept.
  - Hand drawn sketches, power point slides, mathlab, excel (see pictures below as eaxample), orbit visualisation tools, or anything else …….

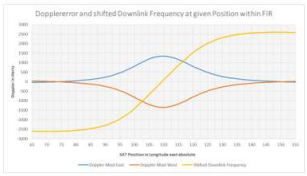
Everything is ok!











Take what you have. We will anyway see your presentations and will see what you have found. For handing over documents, files etc. please format it to “something normal” that we can also view it. For your presentation you can take what you want. In the internet there are some “orbit visualization tools “ available, they may help, but you have to decide what you want to use.

Good luck!