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- (71) Applicant: **LUFTHANSA SYSTEMS GMBH & CO. KG** [DE/DE]; Am Prime Parc 1, 65479 Raunheim (DE).
- (72) Inventors: **HOMMEL, Peter**; Bommersheimerweg 35a, 61348 Bad Homburg (DE). **LIEBE, Jörg**; Kamilleweg 9, 65191 Wiesbaden (DE).
- (74) Agent: **VON KREISLER SELTING WERNER**; Deichmannhaus am Dom, Bahnhofsvorplatz 1, 50667 Köln (DE).

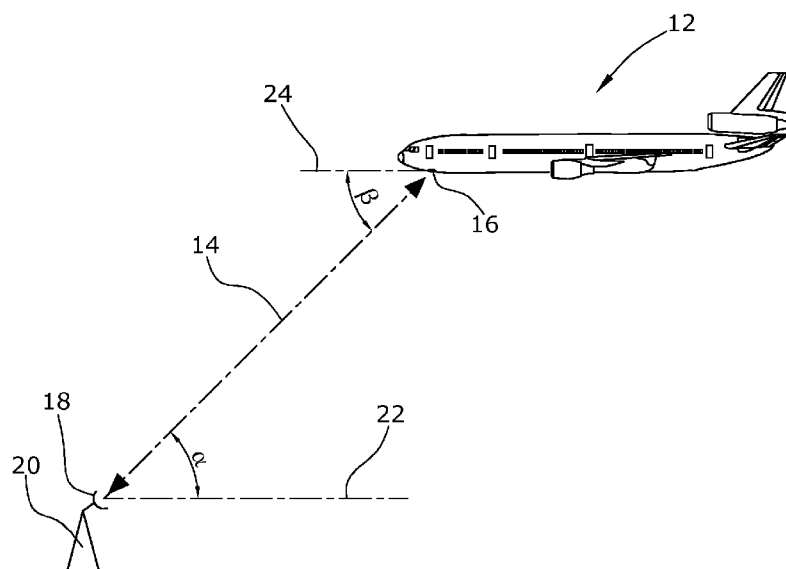
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(54) Title: DEVICE AND METHOD FOR AIR-TO-GROUND COMMUNICATION OF AIRCRAFT



**Fig.1**

(57) Abstract: A device for air-to-ground communication between an aircraft (12) and a ground station (20), said aircraft (12) and said ground station (20) each comprising antennas (16, 18) for directional radio data transmission (14), characterized in that the data transmission (14) is performed in a frequency band from 60 GHz to 90 GHz and that the antenna (18) of the ground station (20) transmits and receives data exclusively in a range of angles  $\alpha$  of at least 5 degrees in the upward direction relative to the horizontal plane (22).

Device and method for air-to-ground communication of aircraft

The invention relates to a method for data transmission between an aircraft and at least one ground station.

Data transmission between aircraft and ground stations is of importance particularly in the field of passenger aviation. There exists an increasing need of for data transmission techniques which make it possible for passengers of an aircraft to do telephone calls or to surf in the internet. In the present text, aircraft are understood to comprise particularly airplanes, helicopters and spacecraft.

In data communication between ground stations and aircraft, it is difficult to allow a large number of passengers to perform data communication with sufficient bandwidth.

It is an object of the invention to provide an improved device for data transmission between at least one ground station and an aircraft, and to provide a corresponding method.

Data transmission between the aircraft and the ground station is carried out by radio in a frequency band from 60 GHz to 90 GHz. In this regard, it is of particular importance that the ground station will radiate and receive the radio waves at a minimum of 5 degrees in the upward direction, whereas a smaller angle will not allow for transmission and reception of radio waves. Thus, during flight, aircraft are within the reception range of the ground station while possible users proximate to the ground level who use the same frequency range cannot receive the data from the ground station and cannot establish a data connection to the ground station. Consequently, in an angular range below 5 degrees relative to the horizontal plane, no data can

ground station.

The invention is based on the fundamental idea of allowing for a directional broadband radio data transmission between an aircraft and a ground station. The device of the invention for air to ground communication between an aircraft and a ground station comprises an aircraft station attached to the aircraft and a ground station, the aircraft station and the ground station communicating with each other. The broadband data transmission is possible in the frequency band from 60 GHz to 90 GHz while an interference with ground-proximate users of the same frequency range is prevented. In this frequency band, also referred to as E-band, data transmission is possible for a large number of passengers of an airplane with sufficient bandwidth for internet use. Thus, for air-to-ground communication, there is available, for the first time in an aircraft, a band width range of 30 GHz, i.e. a band width range exactly as large as the frequency range of 0 – 30 GHz which presently is used for radio communication in general.

With a channel width for air-to-ground communication (ATG) of only one GHz and a spectral efficiency 1, there is available, per aircraft, a data rate of one gigabit per second (Gbit/s). Assuming a number of 200 users among the passengers of the aircraft, this will result in a data rate of 50 Megabit per second (Mbit/s) per user/passenger.

A delay due to satellite communication does not occur because the data transmission between the ground station and the aircraft is carried out directly. Data transmission is performed in the manner of a pencil beam (pencil beam characteristic). A pencil-beam directional characteristic is understood to be a bundled directional characteristic in an angular range from  $\pm 0.5$  degrees and  $-0.5$  degrees around the main radiation direction. This means that the main lobe of the directional characteristic is in this angular range. Consequently, the main lobe of the directional characteristic of the antenna of the ground station cannot be pivoted below an angle of 5 degrees above the horizontal plane.

The pivoting of the main transmission/reception direction of the antennas of the ground station and/or of the aircraft is preferably possible by electronic beamforming. It is advantageous if the main transmission/reception direction can be pivoted about a vertical axis in any desired manner. Also a pivoting about a horizontal axis is of advantage wherein, for the antenna of the ground station, a pivoting to an angle smaller than 5 degrees relative to the horizontal line is not possible. In a corresponding manner, it is of advantage if the main transmission/reception direction of the antenna of the aircraft is possible only in an angular range from -5 degrees to -90 degrees about a horizontal axis in the downward direction.

An essential advantage of the use of the frequency band from 60 GHz to 90 GHz as proposed by the invention resides in that the usability and availability of licenses in this frequency range is much easier than in the conventionally used frequency ranges below 20 GHz or 30 GHz. Antennas for use of the E-band are simpler, less expensive and more easily installed than conventional antennas, especially than those of the Satcom technology. Data transmission, with about 20 ms, is much faster than that of the Satcom technology with about 600 ms. The bandwidth of the E-band is larger and, by electronic beamforming, interference or crosstalk with other ground stations or ground-proximate users of the E-band can be prevented.

Preferably, the E-band communication occurs within a frequency band of 70 to 80 GHz (E-band). This frequency band is characterized by intrinsic non-interference, inherent eavesdrop immunity and unlimited spectrum reusability because pencil beams are prerequisite to operate in MM spectrum.

The main advantage are the much larger bandwidth available at these higher frequencies and the consequent increase in data rates which can be provided. Additionally, transmission at E-band frequencies carries a very low risk of interference as it relies on highly focused, directive and narrow pencil beam transmissions. With spectrum allocation at 70-80 GHz, E-band offers a number of benefits including pencil beaming that enhances frequency re-

antennas are the key to achieve interference protection and the ability to tap into huge available spectrum bandwidth. The pencil beam property facilitates a high degree of frequency reuse in the deployment of air to ground links and reduces citizens' exposure to electromagnetic fields. This is a clear advantage from a regulatory point of view, since co-frequency sharing with other systems is a given and therefore regulators are expected to quickly provide air to ground authorizations. E-band spectrum is low cost and characterized through rapid license availability. Links are licensed under a "light license" process, whereby licenses can be obtained quickly and cheaply. Such licenses provide the full benefits of traditional spectrum licenses, but at a fraction of the cost and application time.

The ground station (base station) may be comprised by  $n$  (natural number) individual radio segments each covering  $\frac{1}{n}$  of 360 degrees in azimuth and/or elevation. For example, 4 or 8 individual radio segments could cover either 90 degrees (4 segments) or 45 degrees (8 segments) in azimuth and 90 degrees in elevation. The base station can either handle a 90 or 45 degrees segment configuration. The base station is software controlled and the configuration is loaded at boot time. The base station houses a radio module and a phased array antenna module in one assembly. It manages one or more E-band channels which equates to approximately 1 Gbit/s per channel. The same spectrum is reused by the other base stations. Each individual radio phased array antenna has a number of antenna elements to form an electronically steerable pencil beam. The decision for 4 or 8 sector base station configuration roll-out is dependent on the expected aircraft density within the airspace. Each base station can entertain up to 8 aircraft stations by means of TDD beam switching. This totals to 64 aircraft stations per base station with 8 individual radio segments.

The aircraft station may have 4 switchable antenna sectors for basic directivity. The antenna sectors house a low noise amplifier and a phased array antenna. The electronically steerable phased array antenna covers 90 degree in azimuth and pitch. Each antenna sector may have 64 phased ar-

the aircraft fuselage.

The aircraft station has a memory in which a map with the geographical coordinates (elevation over sea level, longitude and latitude) of all base stations is stored. This map is loaded at boot time. The aircraft station knows its own (the aircraft's) coordinates (height over sea level, longitude and latitude). The aircraft station is connected to the aircrafts' ARINC bus and reads the permanently updated positional data of the bus.

For initial target acquisition, the aircraft inertia navigation system (INS) determines the actual position, acceleration and deceleration of the aircraft within the airspace. The INS is connected to the ARINC bus and writes the permanently updated positional data to the bus. With positional and acceleration/deceleration data the aircraft station is computing the trajectory of the aircraft. Target acquisition is initiated by the aircraft station.

If no base station is active, every 30 ms the aircraft station sends a radio ping to the nearest base station and switches then into receive mode receiving from a certain base station direction only. The pings are repeated for the duration of 10 s. If no response is received during the 10 s ping cycle, the next nearest base station inside the aircraft stations receive radio is pinged and so on, until a base station is establishing a TDD connection with the aircraft station. The ping is comprised of the actual position and trajectory of the aircraft station. The base station is switching to the house keeping cycle every second for the duration of 50 ms. The base station switches to Omni-directional receive mode during the house keeping cycle. If a base station is receiving and registering the radio ping of an aircraft station, it reads the positional and trajectory data. The base station establishes a TDD radio connection with the aircraft station by generating a pencil beam towards the expected position of the aircraft station. After connection establishment, the house keeping cycle is synchronized across the base station and the aircraft station.

itor and control system (CMCS) which will optimize and rearrange the connections as needed. The CMCS generates a 3D map of all base stations and connected aircraft. The CMCS optimizes the connections and load distribution of all base stations on a per base station basis. The switch procedure is the same as for initial target acquisition except that it's initiated by the CMCS.

For target tracking, after TDD connection establishment, the aircraft station is permanently sending its updated positional and trajectory data to the base station. The base station steers the beam position according to the updated positional and trajectory data of the aircraft station for precise alignment. The base station is forwarding the updated positional data, as received by the aircraft station, to the CMCS. Doppler shift compensation and avoidance is performed with factoring in the trajectory data of the aircraft station. The central monitor and control system (CMCS) is calculating a 3-dimensional airspace map of the air traffic from the received positional and trajectory data of the aircraft station received via the base station. The CMCS optimizes the connections and load distribution of all base stations on a per base station basis.

If all aircraft in a given airspace were to participate on the E-band air to ground system of the invention, the 3-dimensional airspace map could be used by air traffic control to control the traffic of the aircraft since all aircraft and their trajectory are present in the map and can be displayed.

In addition, the air to ground communication channel of the invention can be used by qualified personnel to control the aircraft from ground, for example in cases of emergency where the flight deck crew is incapacitated or the aircraft is hijacked. The air to ground aircraft radio would connect to the flight management system (FMS) or the autopilot (AP) through the ARINC bus. Also, a direct cable connection could be wired to establish a tamper proof direct connection.

tail hereunder with reference to the Figure.

Figure 1 is a schematic view of the exemplary embodiment.

The aircraft 12 in the exemplary embodiment is a passenger airplane with several hundreds of passengers, each of them using, e.g. per smartphone or tablet PC, a radio data connection 14 between an antenna 16 of aircraft 12 and an antenna 18 of the ground station 20. The antennas 16, 18 are E-band antennas whose main radiation/reception direction is variable through electronic beamforming. Aboard aircraft 12, the passengers can receive, on their terminals and e.g. per WLAN, the data picked up by antenna 16. Data transmission 14 is performed in the E-band, i.e. in a frequency range from 60 GHz to 90 GHz.

The antenna 18 of ground station 20 transmits and receives the data of data transmission 14 at an angle  $\alpha$  of about 30 degrees above the horizontal plane 22. According to the invention, the angle  $\alpha$  cannot be smaller than 5 degrees. At an angle  $\alpha$  below 5 degrees (main radiation direction), the antenna 18 of ground station 20 will not transmit and receive data. By electronic beamforming, the main radiation/reception directions of ground antenna 18 and airplane antenna 16 are automatically adjusted to each other in such a manner that a direct connection exists and will be maintained between the antennas 16, 18 while the aircraft 12 is moving. In Fig. 1, the antenna 16 of aircraft 12 transmits the data of data transmission 14 at an angle  $\beta$  of -20 degrees (main radiation direction) below the horizontal plane 24. Said angles  $\alpha$  and  $\beta$  correspond to each other as alternate angles. While the aircraft 12 is moving over ground station 20, an electronic beam control is performing an automatic follow-up of the directional characteristics and the main lobes of antennas 16, 18, thus maintaining the direct data connection 14.



Claims

1. A device for air-to-ground communication between an aircraft (12) and a ground station (20), said aircraft (12) and said ground station (20) each comprising antennas (16, 18) for directional radio data transmission (14),

characterized in that

said data transmission (14) is performed in a frequency band from 60 GHz to 90 GHz and that the antenna (18) of the ground station (20) transmits and receives data exclusively in a range of angles  $\alpha$  of at least 5 degrees in the upward direction relative to the horizontal plane (22).

2. The device according to claim 1, characterized in that the directional characteristic of the antennas (16) of the ground station (20) and of the aircraft (12) is variable by electronic beamforming.
3. The device according to any one of the preceding claims, characterized in that the main lobe of the ground antenna (18) can be arbitrarily pivoted about a vertical axis and is pivotable about a horizontal axis not below said angle  $\alpha$  of 5 degrees.
4. The device according to any one of the preceding claims, characterized in that the main lobe of the antenna (16) of the aircraft (12) is arbitrarily pivotable about a vertical axis.
5. The device according to any one of the preceding claims, characterized in that the main lobe of the antenna (16) of the aircraft (12) is pivotable exclusively in a range of angles  $\beta$  from -5 degrees to -90 degrees relative to a horizontal plane.

in that the data transmission (14) is performed exclusively in the E-band.

7. The device according to any one of the preceding claims, characterized in that the antennas (16) of the ground station (20) and of the aircraft (12) are each designed to radiate radio waves in a pencil beam.
8. The device according to any one of the preceding claims, characterized in that the ground station (20) and the aircraft (12) are designed for direct data transmission (14) between the antennas (16, 18) of the ground station (20) and of the aircraft (12).
9. The device according to any one of the preceding claims, wherein the antennas (16, 18) of the aircraft (12) and the ground station (20) are divided into  $n$  segments each covering  $\frac{1}{n}$  of 360 degrees in azimuth and/or in elevation, respectively.
10. The device according to any one of the preceding claims, characterized by a data storage memory of the aircraft (12), which memory comprises the geographical locations of a plurality of ground stations (20).
11. The device according to any one of the preceding claims, further comprising a central monitor and control system being adapted to generate a 3-dimensional map of a plurality of ground stations (20) and of at least one aircraft (12) communicating with said central monitor and control system via radio.
12. A method for data transmission (14) between a ground station (20) and an aircraft (12), said ground station (20) and said aircraft (12) being each provided with a radio antenna for directional radio data transmission between each other, characterized in that the ground station (20) does not radiate the data below an angle  $\alpha$  of at least 5 degrees relative to a horizontal plane (22) and that the data transmission

the aircraft (12) is performed exclusively in a frequency band from 60 GHz to 90 GHz.

13. The method according to the preceding claim, characterized in that the ground station (20) and the aircraft (12) are each designed for data transmission (14) in the E-band.
14. The method according to any one of the preceding claims, characterized in that the transmission and reception direction of the antenna (16, 18) of the ground station (20) and/or of the aircraft (12) is pivotable at random about a vertical axis.
15. The method according to any one of the preceding claims, characterized in that the transmission/reception direction of the antenna (18) of the ground station (20) can be pivoted about a horizontal axis not below said angle  $\alpha$  of 5 degrees.
16. The method according to any one of the preceding claims, characterized in that the transmission and reception direction of the antenna (16) of the aircraft (12) can be pivoted exclusively in a range of angles  $\beta$  from -5 degrees to -90 degrees relative to a horizontal plane.
17. The method according to any one of the preceding claims, characterized in that the data transmission (14) between the antenna (16) of the aircraft (12) and the antenna (18) of the ground station (20) is performed directly.
18. The method according to any one of the preceding claims, characterized in that, after leaving the transmission and reception range of the ground station (20), the aircraft (12) automatically seeks and establishes contact to a further ground station in whose transmission and reception range the aircraft (12) is located.

antennas (16, 18) of the aircraft (12) and the ground station (20) comprise phased array antenna segments each covering  $\frac{1}{n}$  of 360 degrees in azimuth and/or elevation.

20. The method according to any one of the preceding claims, wherein the aircraft (12) comprises a data storage memory in which the geographical locations of a plurality of ground stations (22) are stored, wherein a central monitor and control system within the aircraft (12) generates a map comprising the locations of said ground stations and of the aircraft.
21. The method according to any one of the preceding claims, wherein a central monitor and control system calculates a 3-dimensional airspace map showing the positions of a plurality of ground stations (20) and at least one aircraft (16), which map is used to control air traffic of the aircraft shown in the map.
22. The method according to any one of the preceding claims, used to remote control the aircraft (12) from the ground.
23. The method according to any one of the preceding claims, wherein the main lobe of the aircraft antenna (16) and/or of the ground antenna (18) is steered into the direction of a respective aircraft antenna (16) or ground antenna (18) by employing positional and trajectory data of the aircraft (12) and the ground station (20) stored and frequently updated in a central monitor and control system.

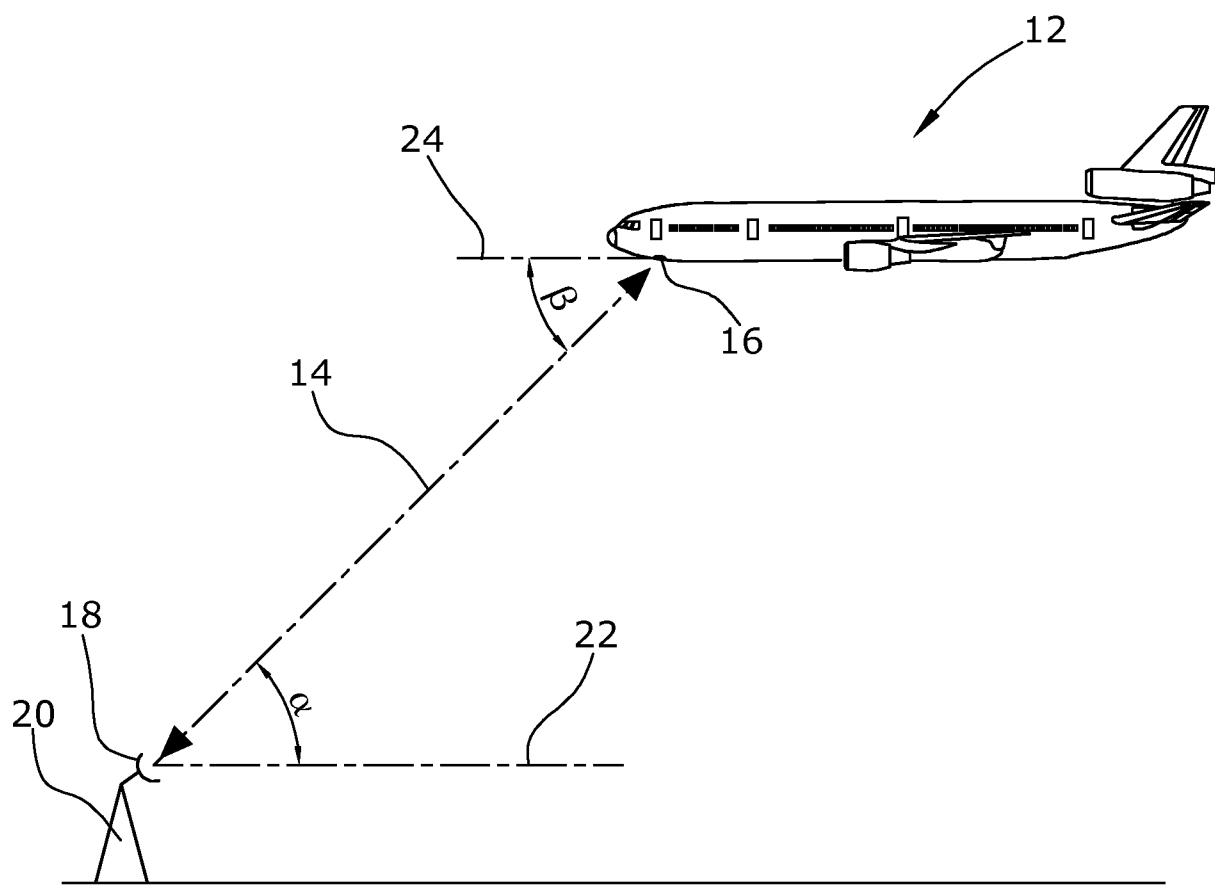


Fig.1

## INTERNATIONAL SEARCH REPORT

International application No  
PCT/EP2015/061273

A. CLASSIFICATION OF SUBJECT MATTER  
INV. H04B7/185  
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)  
H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

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X	US 2009/186611 A1 (STILES W HERSCHEL [US] ET AL) 23 July 2009 (2009-07-23)	1-5,7,8, 10
Y	paragraph [0002] - paragraph [0008] paragraph [0015] paragraph [0041] - paragraph [0045] paragraph [0050] - paragraph [0052] paragraph [0056] paragraph [0066] - paragraph [0068] figures 1,6	6,12,13, 17,18, 22,23
Y	----- WELLS J: "Faster than fiber: The future of multi-G/s wireless", IEEE MICROWAVE MAGAZINE, IEEE SERVICE CENTER, PISCATAWAY, NJ, US, vol. 10, no. 3, 1 May 2009 (2009-05-01), pages 104-112, XP011255946, ISSN: 1527-3342 the whole document ----- -/-	6,12,13, 17,18, 22,23



Further documents are listed in the continuation of Box C.



See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search

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European Patent Office, P.B. 5818 Patentlaan 2  
NL - 2280 HV Rijswijk  
Tel. (+31-70) 340-2040,  
Fax: (+31-70) 340-3016

Authorized officer

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## INTERNATIONAL SEARCH REPORT

International application No  
PCT/EP2015/061273

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	----- DYADYUK V ET AL: "Implementation of wideband digital beam forming in the E-band: Towards a hybrid array", MICROWAVE CONFERENCE (EUMC), 2010 EUROPEAN, IEEE, PISCATAWAY, NJ, USA, 28 September 2010 (2010-09-28), pages 914-917, XP031786551, ISBN: 978-1-4244-7232-1 abstract page 914, left-hand column, line 1 - right-hand column, line 21 -----	1,12

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2015/061273

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