SCIENTIFIC REPORT ON THE EXCHANGE TRAVEL GRANT OF THE ESF NETWORK "NEWFOCUS"

February – August, 2014

Visit from TU Delft, The Netherlands to IT-Lisbon, Portugal

Topic: "Frequency Independent Patterns From Multiple Shell Lenses Fed by Leaky Wave Feeders"

Ozan Yurduseven

1. PURPOSE OF THE VISIT:

The goal in this project is to design a wideband leaky lens antenna capable of providing frequency independent patterns over a wide frequency band of operation, about one octave, using connected array of leaky slots as lens feeder in presence of a double shell lens. In addition to on-axis feeding, offset feeding is also studied in order to increase the scanning performance of the antenna system in frequency. The schematic of the proposed antenna design is demonstrated in Fig. 1.

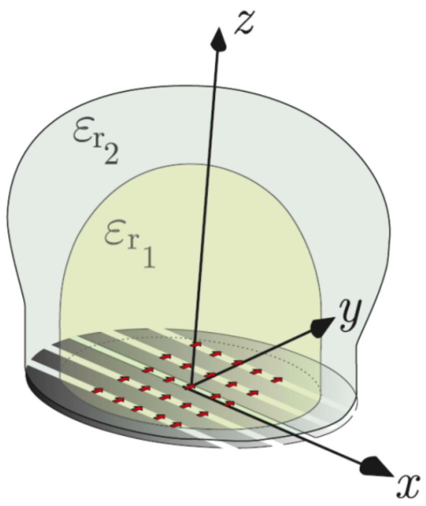
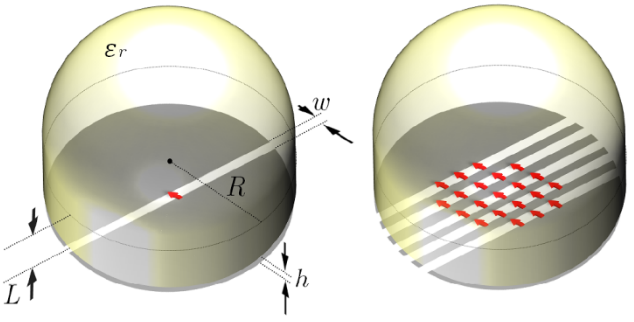


Fig.1 An example of the proposed double shell lens design in the presence of a connected array of leaky slot feed

2. DESCRIPTION OF THE WORK CARRIED OUT DURING THE VISIT:

Reflector systems fed by wideband antenna feeds are widely used for the applications such as radioastronomy and space observation [1]. For such applications, it is often required to maintain the illumination of the reflector as constant as possible at all frequencies within the large band of operation. Reflector feeds that can operate with high aperture efficiency over wide frequency ranges have been previously developed for low-frequency radio telescopes. Some examples are the focal plane array of tapered slot antennas [2] and the eleven antenna [3]. However, there is currently a need for wideband reflector feeds also at much higher frequencies, for Terahertz (THz) and mm-wave space instruments.

For THz space observation, dielectric lens antennas are typically used, due to their easy integration with the receivers. Elliptical or hyper-hemispherical shapes are frequently employed, which are typically fed efficiently only over a narrow band, e.g. by double slot antennas [4]. An improved solution is the leaky-lens antenna recently proposed in [5]-[7] which can achieve multi-octave bandwidth. This antenna consists of a leaky-wave slot kept at an electrically small distance from the dielectric lens, represented by *h* in Fig. 2(a), in order to obtain directive radiation inside the dielectric and, consequently, efficient illumination of the lens. Although well matched and with stable phase center over a very wide band, the leaky-lens antenna generates radiation patterns that become narrower and more directive when the frequency increases. For this reason, when used as reflector feed over wide bandwidths, this antenna would not lead to high aparture efficiency at all frequencies.



(a) (b)

Fig.2 (a) Geometry of extended hemispherical lens fed by a leaky-wave slot kept at distance h from the lens; (b) same lens fed by an array of connected leaky-wave slots.

In order to achieve high reflector illumination efficiency over the desired bandwidth, we proposed a solution to obtain frequency independent patterns in [8]. In this work, the idea is to solve the problem by introducing a novel feed configuration rather than modifying the lens shape. The aim is to improve the reflector illumination efficiency of a single-slot-fed lens antenna by extending the leaky-slot radiation concept to be used in an array configuration [9] as shown in Fig. 2(b). To maintain the bandwidth wide, the slots are electrically connected so that the array is composed by a finite number of long slots, each excited at a finite number of points. This allows to obtain high mutual coupling, realizing the so called connected-array concept [10], [11]. The elements in Fig. 2(b) are coherently combined, so that they are associated with a single beam outside the lens. This coherent excitation of the array has the advantage of generating stable radiation patterns over a broad bandwidth, exceeding 1:2 ratios. This characteristic allows wideband illumination of a reflector with high aperture efficiency.

Using that concept, coherently fed array antenna located on the focal plane, can be considered as a highly efficient solution for the case when we want to illuminate a reflector with a constant aperture illumination efficiency. However, for this scenario, the reflector is illuminated by only one pixel since all the elements are coherently fed which does not allow us to us to have multi-pixel solution. In other words, scanning is not possible with that solution. For this purpose, another approach could be to design a multiple shell lens such that the refraction interfaces from the shells are adequately shaped to form frequency stable patterns. A solution of this problem is given [12] where a double shell lens design was presented. By using this concept, one may design an array with many pixels such that each pixel is able to generate more or less a frequency independent beam.

In this project, it is aimed at designing a double shell lens to be used directly as an imager over a wideband frequency band, about 1:2. Due to its wide band characteristics, a connected slot array antenna with many pixels is used as a lens feeder where each pixel is associated to an independent beam illuminating the double shell lens.

This allowed us to study two cases:

i) Double shell lens optimization considering the case when the lens is fed from the center position.

ii) Maximizing the scanning performance of the leaky lens antenna in terms of scanning loss and beamwidth stability in frequency by using one pixel at a time which is shifted from the center along or orthogonal to the slot.

3. DESCRIPTION OF THE MAIN RESULTS OBTAINED

In this project, an Integrated Lens Antenna Shaping tool (ILASH), which was developed at Instituto de Telecomunicações-IST [13], is used in order to design and optimize the double lens shape. It includes GO tools for quick design of these types of lenses subject to a number of different target specifications, GO/PO tools for the computation of the lens equivalent surface currents and radiation pattern, and a Genetic Algorithm optimization tool for advanced lens design.

In the study, considering the leaky slot type of feeding antenna geometry in order to illuminate the top part of the lens, a dielectric with a relatively high permittivity is needed for the inner lens [5]. Therefore, in the optimization, the inner lens was assumed to be silicon with a permittivity of 11.9. The outer lens, however, has lower dielectric constant which was assumed to be Fused Quartz having a permittivity of around 3.82 in the lens design.

The requirements in the project considered in the optimization are listed below:

- The bandwidth should cover one octave. In the project, it was aimed at designing the lens within a band starting from 30GHz to 60GHz
- Since the lens is planned to be used directly as an imager itself, the secondary beams after the lens should be highly directive and relatively narrow (About 1deg HPBW).
- Due to high directivity requirement, the rays should exit in parallel after the lens. So, a collimated type of double shell lens is considered in the design.
- Considering the scanning scenario as well, the antenna should have as many pixels as possible. In this work, the aim is to have a total pixel number about 529 (23x23 pixel matrix) which corresponds to a maximum scanning angle approximately 11^0 from each side (22^0 in total assuming each pixel has a scanning angle of about 1^0).

Regarding to the requirements listed above, first, a connected array of leaky array antenna was designed within the proposed frequency band. The feed antenna array can be seen in Fig. 3.

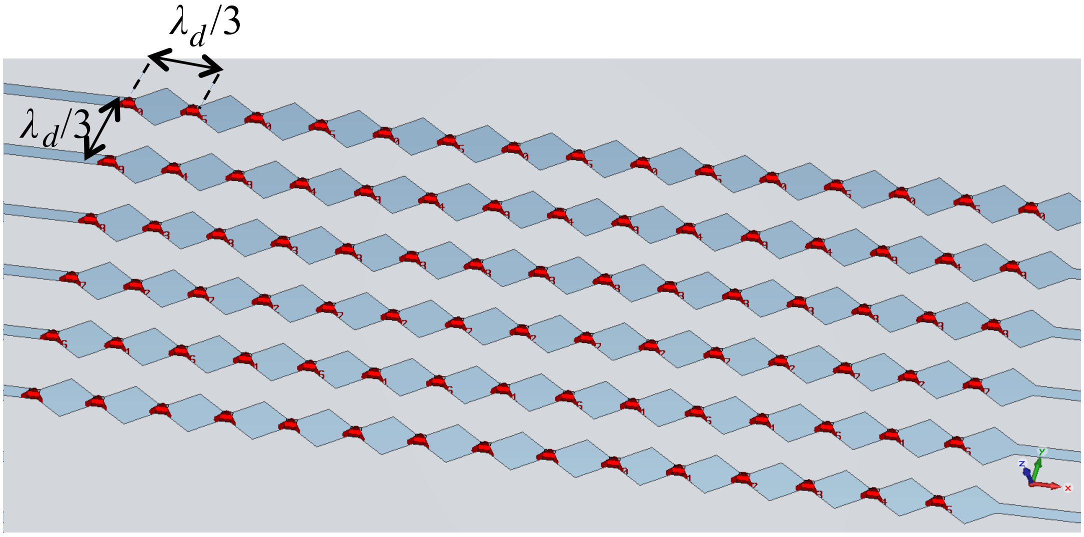


Fig.3 Connected array of leaky slot antenna as a lens feeder

The feed was designed such that it has many feed elements packed very close to each other, $\lambda_d/3$, where λ_d is the wavelength in the denser dielectric at the lowest frequency, 30GHz. One important aspect to mention here is that the slot has a kind of tapering shape in order to reduce the mutual coupling between the elements. As it can be seen in Fig. 4, the antenna is well matched within the entire frequency band and has a maximum mutual coupling level about -14dB.

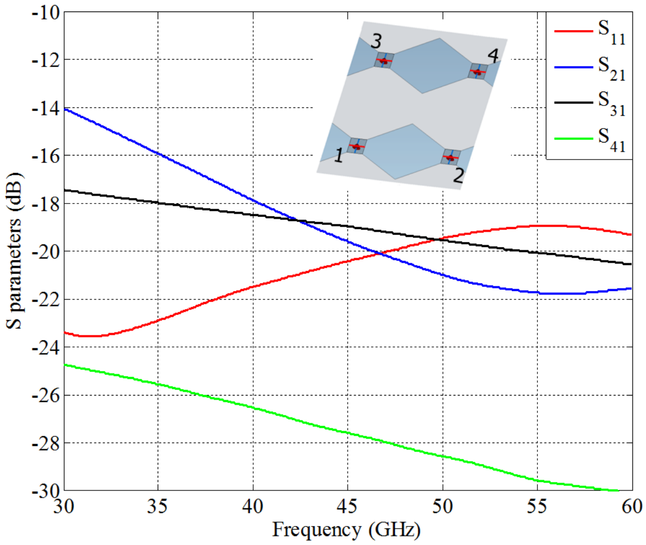


Fig.4 Connected array of leaky slot antenna as a lens feeder

After the feed design, the lens optimization was performed considering the requirements for the proposed project. In the optimization process, it was assumed that there is an electrically small air-gap between the leaky array feed and the lens due to the radiation mechanism of the leaky slot antenna [5]. Here, the air-gap is $0.03\lambda_0$, where λ_0 is the wavelength at the lowest frequency.

As a result of the optimization process, the optimized lens shape is shown in Fig. 5. It is important to remind here that, due to the requirements of the project, the lens should provide collimated beams not only for the onaxis feeding but also for the scanning scenario as well. Therefore, the lens geometry has a kind of modified abbe shape lens geometry which is able to generate highly directive beams and provide high scanning performance as we shift the position of the feed from the center.

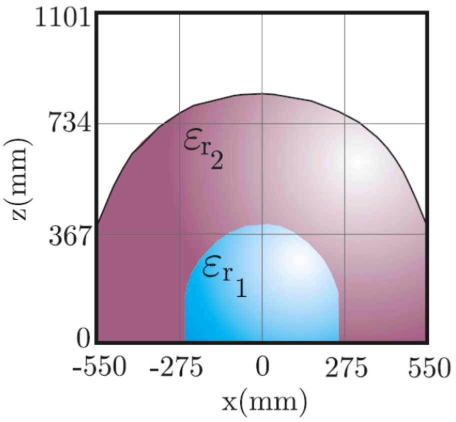
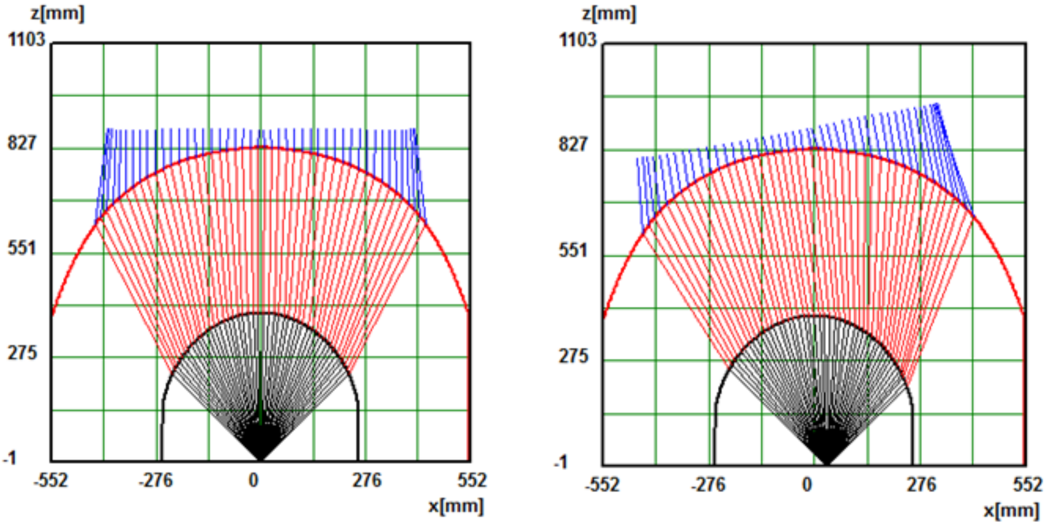


Fig.5 2D cut of the optimized double shell lens geometry. Permittivity values of the inner and outer shells are highlighted by ε_{r1} and ε_{r2}, respectively.

As it was mentioned before, since the modified abbe shape is a kind of a collimated lens, one may expect to have parallel rays outside the lens in case of feeding the lens from the center, or from an offset position, with a point source. In Fig. 6, two feeding positions have been chosen; one is at the center whereas the other one is shifted by 33mm which corresponds to the last pixel of the feed array. As it can be seen from Fig. 6, indeed, the rays due to a point source located at the center of the lens and shifted position on the feed plane exit the lens almost parallel which is very useful in order to have frequency stable beams as we scan the position.



(a)

(b)

Fig.6 Ray distributions when the lens is fed by a point source which is placed at (a) the center of the lens, whereas, (b) 33mm shifted from the center to the edge

In order to compare the performance of the double shell lens antenna, to take as a reference, a single shell hyper hemispherical silicon lens was designed such that it has similar gain and beamwidth as the double shell one at the center frequency. The lens has a radius of *R*=446mm and an extension length L=0.35R.

The lens can be seen with its design parameters in Fig. 7.

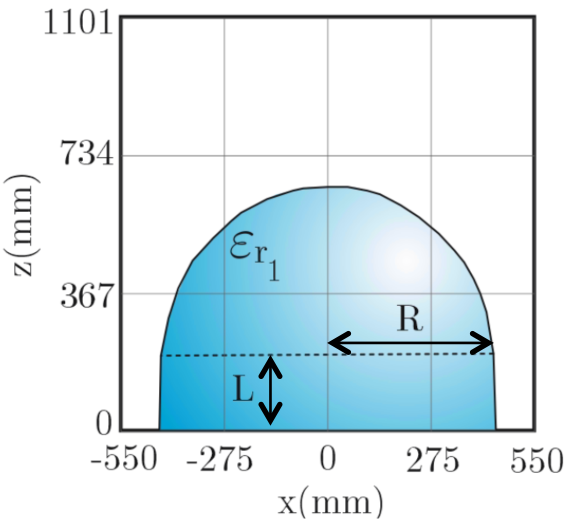
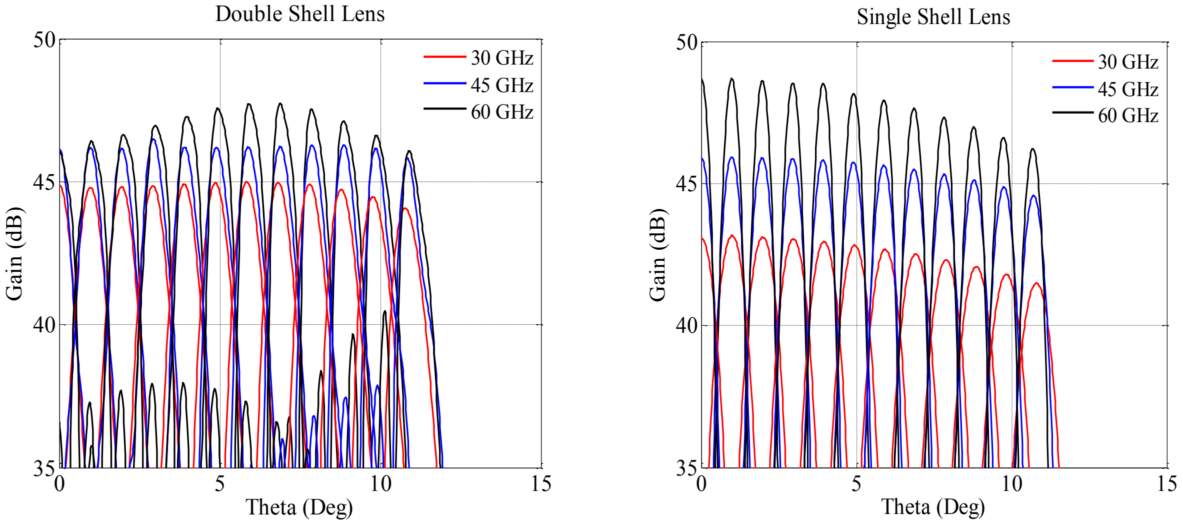


Fig.7 2D cut of the single shell lens geometry designed to take as a reference for the secondary beam comparisons.

Secondary beams generated by the double shell lens and single shell lens can be seen in Fig. 8 for 30, 45 and 60 GHz which are selected three frequencies within the band of operation. It is clear that double shell lens is able to provide much more stable secondary beams in terms of gain variation within the frequency band.

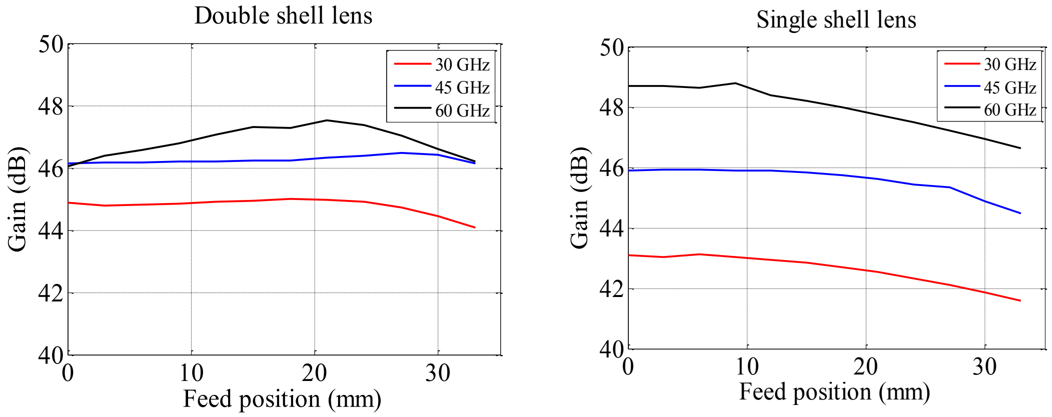


(a)

(b)

Fig. 8 Secondary beams due to the two different kinds of lens design: (a) Double shell lens, and, (b) single shell one.

In order to make it more specific, maximum gain variation is highlighted in Fig. 9. It can be seen from the Fig. 9 that maximum variation in gain is about 2.7dB for optimized double shell lens geometry whereas the variation becomes higher and it goes up to 6dB for the single shell lens design.



(a)

(b)

Fig. 9 Gain variation as a function of feed position for (a) double shell lens and (b) single shell lens.

One other important parameter in order to see the scanning performance is the scanning loss. The variation in the scanning loss should be kept at minimum to have stable performance as the feed position is being shifted from the center. For this purpose, scanning loss is also calculated and Fig. 10 shows the scanning loss for both lenses as a function of frequency. It is clear that proposed double shell lens design improves the scanning loss compared to the single shell one.

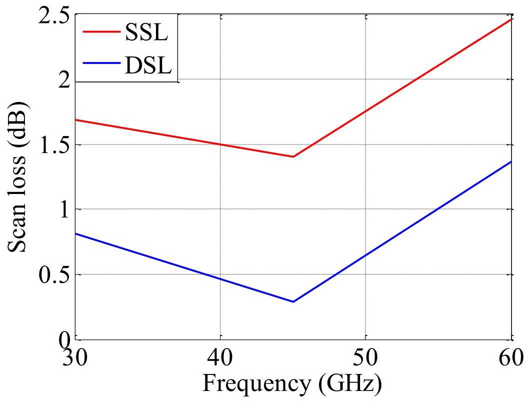
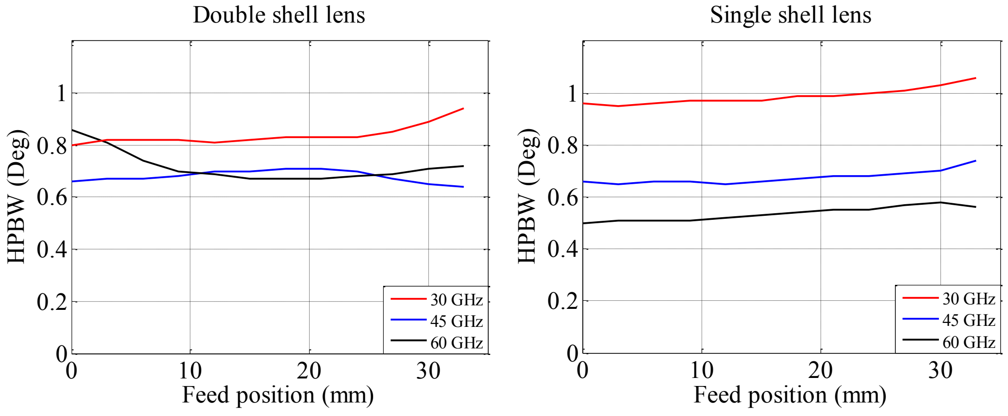


Fig. 10 Scanning loss as a function of frequency for double shell and single shell lenses.

The beamwidth variation should be as least as possible as we aim at providing a solution in order to have have frequency stable beams by means of shaping the lens. To see how much the double shell lens solution improves the beamwidth stability compared to single shell lens, Fig. 11 shows the beamwidth comparison results.



(a)

(b)

Fig. 11 Beamwidth variation as a function of feed position for three frequencies within the band for (a) double shell, and, (b) single shell lenses.

As a conclusion, considering the all results have been shown before, we have proved that the concept we provide works and double shell lens design, indeed, improves frequency stability of the beams for both broadside radiation and scanning configurations as well.

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4. FUTURE COLLABORATION WITH HOST INSTITUTION (IF APPLICABLE)

After demonstrating the concept works depending on the simulation results, the next step will be manufacturing the antenna. Preliminary evaluation of the dielectric material has been started and, during the manufacturing process, it is planned to be in collaboration with the host institution.

Besides, for the future, it is also possible to do another collaborated project with the host university within the scope of another project grant.

5. PROJECTED PUBLICATIONS

Within the duration of the visit, there was no published article yet. Right now, it is planned to submit a conference paper for EuCAP 2015 and, for the future, we are planning to write a journal article in collaboration with the host institution.

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Thu 20 Feb 14 23:10 Lisbon (Lisboa, Portugal)

Class: Economy
Flight number: KL 1697
Aircraft type: Boeing 737-800 | view seat map
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Total travel time 3h00

Passengers

Mr Ozan Yurduseven (adult) Please note that your name is spelled "OZAN MR YURDUSEVEN" on your ticket

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E-mail address	ozanyds@yahoo.com.tr
Ticket number	074-2468275866

Price specification

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Carrier-imposed international surcharge	32,00
Airport Passenger Service Charge	15,40
Security charge	12,77
Airport Passenger Service Charge	8,49
Security tax	4,03
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Number of passengers	1

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Mr Ozan Yurduseven	1 piece(s)	The total of 1 pieces consists of: • 0 piece(s) standard • 1 pieces currently added as extra baggage • EMD number 074-8204053504	**EUR 15,00**

Total price for extra baggage **EUR 15,00**

Total price for flights

MasterCard : **EUR 206,19**

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Card number	************7484
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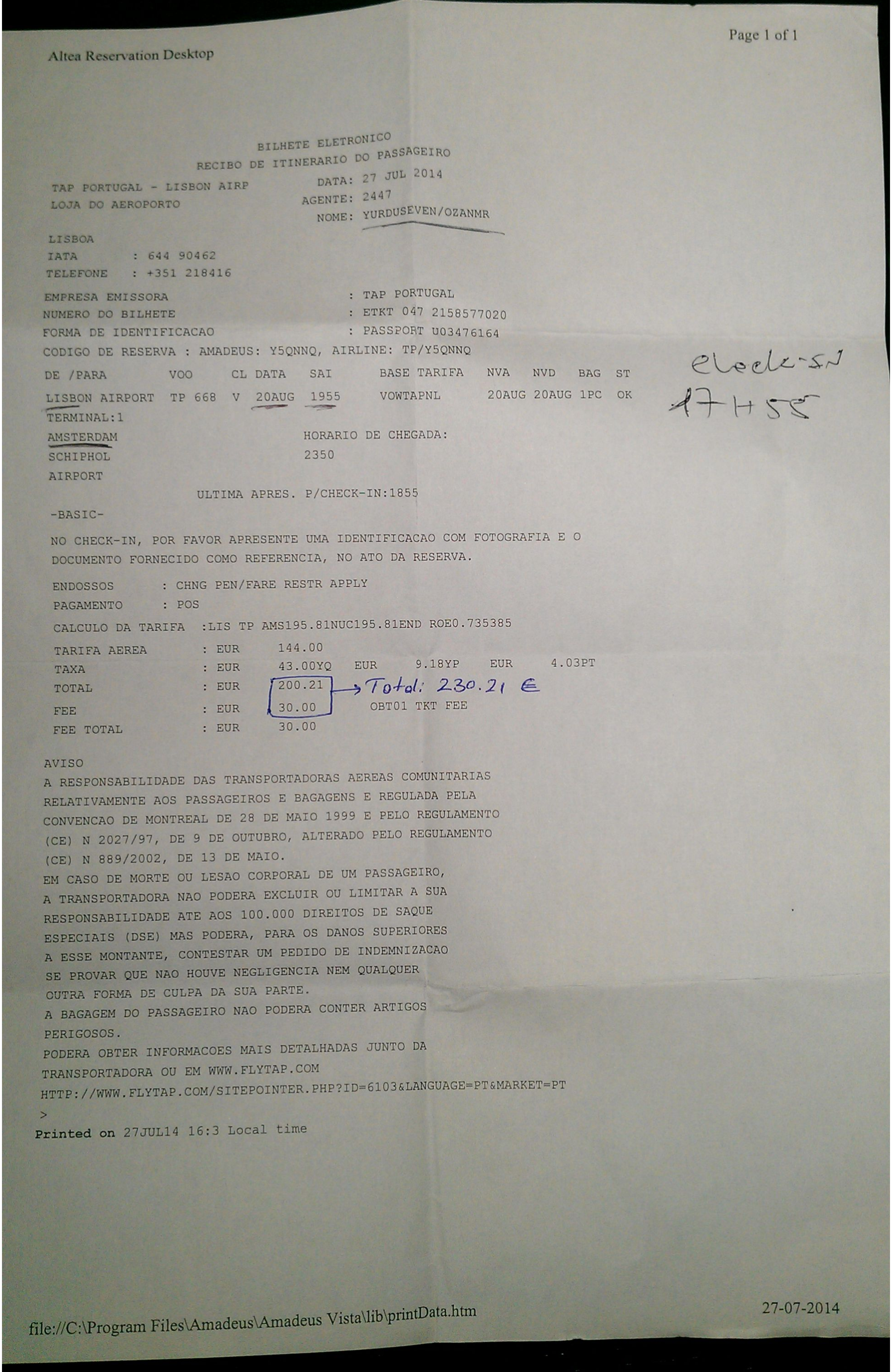

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