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A MM-WAVE COLLISION WARNING SENSOR FOR HELICOPTERS

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SUMMARY

A short range collision warning radar for helicopters has been developed. The system consists of a pulsed radar sensor operating at 60 GHz, a rotating mirror to scan the front view (± 90° in azimuth and ± 15° in elevation) and a display. Field tests have shown that wires and cables are reliably detected within a range of 500 m.

1. INTRODUCTION

The Civil Aviation Authority (CAA) of the Federal Republic of Germany has reported the helicopter accidents in civil service during 1975 - 1980 (Table 1). The category containing the highest number of accidents is "collision with obstacles". "Obstacle" means here buildings, trees, masts, poles and wires. This shows, that timely warning of approaching obstacles is one of the most important tasks required for the safe navigation of helicopters.

Hitting the ground	17
Hard landing	6
Overturning	1
Collision on the ground	2
Collision with obstacles	23
Loss of control	5
Steering failure	6
Engine failure	20
Rotor failure	15
Personnel injured by rotors	3
Emergency landing	2
Others	4

Tab. 1. Analysis of 104 helicopters accidents during 1975-1980, /1/.

A more detailed analysis of Tab. 1 shows that the accidents of the first 5 categories are caused by the fact that the pilot, immediately before a crash, has had no exact information about his distance from the obstacle. If we lump together the first five categories, we see that 47% of all the reported accidents could have been avoided, if the pilot had obtained a warning in a suitable form in time.

There is a second requirement for a reliable obstacle warning system. Fig. 1 shows the increase of the number of helicopters up to 1982 together with an extrapolation to 1990. We can see that, even with a less optimistic opinion of the economic conditions, the helicopter market is expanding strongly. This - together with the increased variety of helicopter operations - gives an additional demand for more safety in navigation.

All collisions cause damages which can be classified as primary or secondary. Primary damages are defined as those that affect the crew and the aircraft, secondary ones concern ground personnel, non-operating personnel, buildings, power transmission and telephone lines, etc. The costs of these accidents are raised by disablement of the personnel involved, break down of power supply, etc.

Wires and wirelike objects are highly dangerous obstacles, since they are easily overlooked, even under good weather conditions, even with previous knowledge of their location. Therefore a warning system should meet the following requirements:

Reliable detection of wires such as high power transmission lines, antennas, telephone cables etc. with diameters greater than 3 mm.

Range of ca. 500 m.

All weather capability.

Weight and volume compatible with use in light helicopters.

Be able to operate in cojunction with existing navigation aids such as night vision devices.

2. PREVIOUS ATTEMPTS

There have been several attempts to solve this problem. Sensors of the magnetic field of a transmitting high power line /3/, laser diode device, working in the infrared range /4/ and cut-off-scissors acting at the moment of collision with the wire /5/. All these systems have characteristic disadvantages: Magnetic sensors cannot detect non transmitting cables; the performance of systems using lasers is seriously deteriorated under adverse weather conditions and, moreover, need heavy electronics to evaluate the measuring data. The use of cut-off scissors,as a last resort, demonstrates the urgent need of a reliable warning device.

3. PHYSICAL ASPECTS

Wavelength. If we consider a warning system based on the scattering of electromagnetic radiation which is the only reliable way of obtaining a timely warning, then the most important system parameter is the wavelength used for detection. There are several factors to be taken into account.

In order to obtain good resolution the wavelength should be as short as possible.

In order to obtain good atmospheric penetration, the wavelength should be, to a first approximation, as long as possible.

In order to keep the weight of the sensor as small as possible the source should be solid state.

In order to have a low probability of intercept (LPI), the effective range of the system should not be greater than 1000 m.

In order to avoid eye injuries, the power density of radiation should be as low as possible.

As the best compromise it was decided to use a system with a wavelength of ca. 0,5 cm, which corresponds to a frequency of 60 GHz.
The use of a lower frequency leads to loss of resolution, higher frequencies are not realizable with solid state sources of sufficient power. While, in general, the frequency of operation of millimeter wave radars is within the "windows" of atmospheric absorption, for instance 35 or 94 GHz, this radar operates in the region of a maximum of atmospheric attenuation, the oxygen absorption band. The high atmospheric attenuation of about 16 dB/km (at see level) helps to prevent interception and interference with radars in the neighbourhood. Rain, up to a rate of 15 mm/h, does not seriously influence the performance of the sensor.

Principle of Operation. The basic idea of the sensor is the following:
A highly directed radar beam scans the front field of view of the pilot, see Fig. 2. When a radar pulse hits an obstacle perpendicularly, the echo is reflected to the antenna. From the time of flight of the pulse the distance to the obstacle can easily be determined. The bearing of the obstacle is given by the azimuth and elevation of the scanner. Large obstacle, such as houses, trees, forests and thick cables are easily detected, however, a special investigation was carried out to study the case of thin wires.

Thin Wires. Extensive investigations were made to determine the radar cross section of thin wires. The result showed that the radar cross section for perpendicular incidence of infinite, straight wires is given by the geometrical average of the radar cross sections of an infinite flat plate and a sphere having the wire's diameter d:

$$\sigma = \sqrt{R^2\pi} \cdot \sqrt{\pi d^2/4} = \pi d R/2$$

R = distance from the radar to the wire.
The formula applies only for wavelengths lower than the wire's circumference $\pi \cdot d$. This formula shows that the radar cross section increases with increasing range R, thus reducing the usual $1/R^4$-dependence of the received radar power to $1/R^3$.

Fig. 3 shows measured reflection cross sections of wire samples using the 60 GHz radar. The measurement distance was fixed at 16 m. The tested wire samples have a length of about 1 m thus being 2 times longer than the 3 dB beam diameter at this distance. As can be seen, the agreement of theoretical and measured data is quite good.

Twisted Cables. An additional effect occurs when the beam strikes a high power transmission line which consists of a twisted bundle of wires. When the radar is scanning we observe more than one echo, as shown in Fig. 4a. The explanation of this effect is, that the twisted bundle acts as a diffraction grating with the property that the first diffraction order and specular reflectance occurs at the same angle of incidence, see Fig. 4b.
This effect supports reliable detection of these wires.

4. SYSTEM DATA

Beam generation and scanning device. A block diagram of the system is given in Fig. 5. The radar is an incoherent pulsed radar with a pulse length of 20 nsec. The time between transmission of a pulse and reception of the echo gives the range of the target.
The radar beam with an angular beamwidth of 1.6° is generated by a parabolic antenna of 20 cm diameter and strikes a mirror, which is tilted at 45° with respect to the beam axis and can rotate through 360° about the beam axis, where 180° (± 90° from the flight path direction) are used to cover the front view of the pilot. The mirror can also tilt ± 7,5° from its 45° position to cover ± 15° in elevation. Fig. 6 is a schematic diagram of the scanning mechanism. Fig. 7 shows a sketch of the sensor mounted in the nose of an aircraft.

Field of view. The field of view is therefore ± 90° in azimuth and ± 15° in elevation. The signal received when the antenna is pointing backwards can be used to measure the height over the ground, so that an additional altimeter is not necessary.

The unambiguous range is determined by the pulse repetition frequency (PRF), e.g. 250 kHz corresponds to 600 m. The scanning rate of 900 rpm in azimuth and 15° per second in elevation, will lead to an information repetition rate of 1 Hz.

Resolution. The angular resolution in both azimuth and elevation is given by the beamwidth of 1,6° or 27 mrad. The range resolution is given by the pulse length of the transmitted pulse which is 20 nsec corresponding to a resolution of 3 m. Thus we obtain the resolution cell shown in Fig. 8. e.g. 100 m from the radar the resolution cell appears as a cylinder of ca. 3 m diameter and 3 m length. Two or more targets within this cell are not resolved and will appear as one target.
Considering this, together with the azimuth and elevation angles , our field of view is resolved into ca. 110 x 20 pixels. With our frequency of 60 GHz the diffraction effects from obstacles with characteristic dimensions of several centimeters can be neglected and the system can be analysed using geometric optics. This approach shows that strong echos are obtained only from surfaces which are perpendicular to the beam. (It is very important to keep this fact in mind since it is the reason why this radar sensor does not produce TV like pictures).

5. RESULTS OF FIELD TESTS

The sensor has been tested extensively on a site where all characteristic features of interest were present, such as high power transmission lines, 220 V cables, free standing trees, bushes and a forest. The essential results of these experiments are:

High power lines of 21 mm diameter are reliably detected at a distance of 400 m. The echo strength obtained can be extrapolated to be sufficient for a detection in 600 m distance.

220 V cables containing 4 lines with rubber insulation are seen at a distance of 400 m.

Free standing trees and bushes give echos up to 600 m.

A 220 V cable parallel to the edge of a forest is resolved, if the distance of the cable from the forest is more than 6 m.

Masts, poles and buildings give echos of sufficient strength up to 600 m.

The problem of more than one target in the same direction is eliminated by considering only the echo from the nearest obstacle.

Data processing procedures in order to make target classification possible are under development.

7. DISPLAYS

The radar system obtains information from the target in three coordinates: range, azimuth and elevation angle. The problem is how to convey this information to the helicopter crew.
During a mission, the pilot has a very heavy workload so that introduction of yet another source of information must be carefully planned in order to avoid overstressing him.

Acoustical warning. When the slant range to an obstacle is below a minimum value, no matter in what direction, an acoustical buzzer should give a warning. This form of warning must be combined with one of the following optical devices.

Optical warning. Firstly the optical display must be adaptable to the special tasks the helicopter is used for. For example, a rotorcraft serving as transport helicopter on defined flight paths would need only a simple display, e.g. a red lamp indicating to the pilot that a critical distance to a dangerous obstacle such as cable car suspensions etc. is reached. In this case the flight paths are well known and a warning is only needed as a reminder to the pilot.
On the other hand, a military aircraft with sophisticated avionics, e.g. night vision capability using infrared sensors would use the millimeter wave radar in addition to FLIR, LLL TV etc.. Multifunction displays are available in this helicopter and the collison warning could be shown on one of the present screens.
In between these two extreme cases there will be a need for a display especially for obstacle warning. Two possible display methods are:

a) Projection of the front view with the coordinates azimuth and elevation (C-Scope), Fig. 9a.

The informations about distances could be shown by special symbols, for instance

• obstacle is more than 400 m away
● obstacle between 200 and 400 m
◉ obstacle closer than 200 m

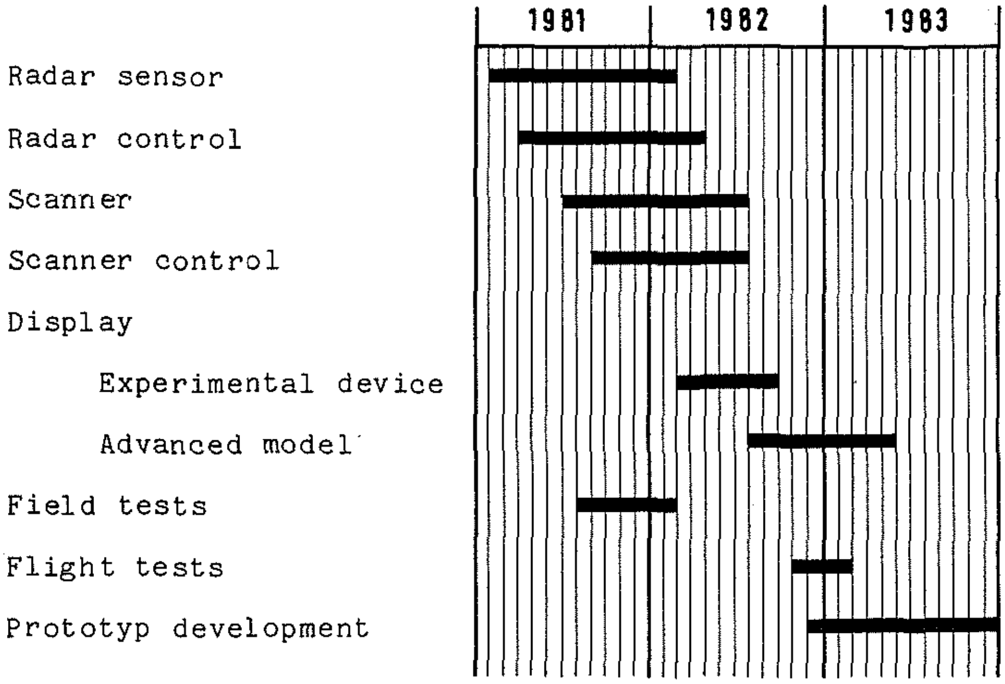
If a colour display is available, the symbols could be shown in different colours.

b) Projection of the ground area as would be seen by the pilot in a maplike manner (Plan Position Indicator, PPI). Here azimuth and distance are shown and the elevation angle must be indicated in a similar manner as described in a) for the range, Fig. 9b.

Method a) would be suitable for fast flights whereas method b) could be for helicopters flying Search And Rescue (SAR) or similar sorties, where little detailed information about the area is known. This short discussion has explained the requirements for a display of the obstacle warning information for helicopter use. What kind of display is used for a special task is a matter of practical experience.

8. STATE OF DEVELOPMENT

Tab. 2 shows the proposed development time scale. After completion of the various subsystems, sensor and scanner, and a first prototype of a front view display the complete laboratory model will start flight-test evaluation in a BO 105 helicopter at MBB facilities in Ottobrunn.
Fig. 10 shows the sensor, millimeter wave device plus scanner (without radome) ready to be clamped to the helicopter.



Tab. 2. Time schedule of work

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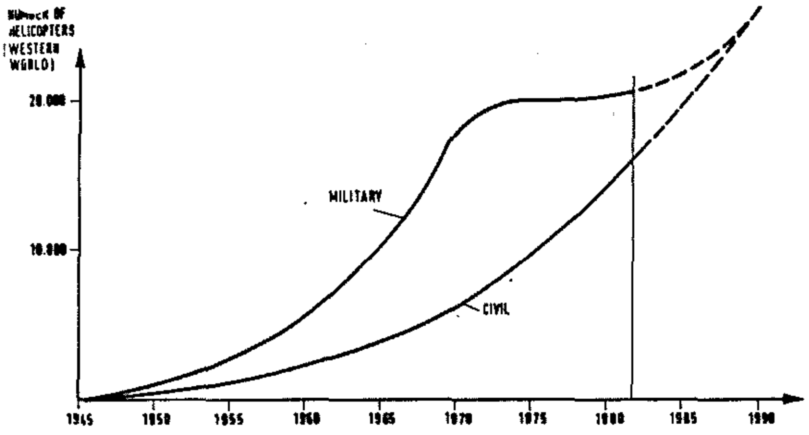


Fig. 1
Number of helicopters in the western world from 1945 to 1982 and extrapolation to the nineties, Ref. /2/.

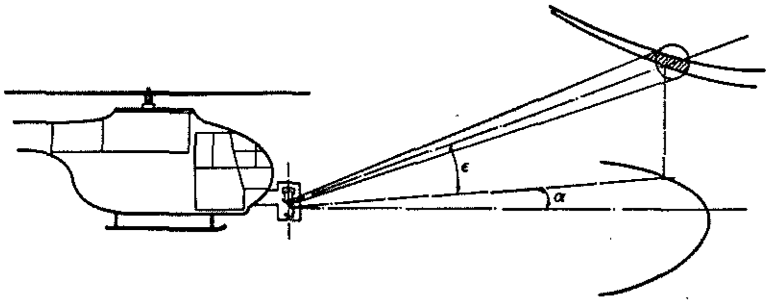


Fig. 2
Principle of scanner motion through azimuth α and elevation angle ε.

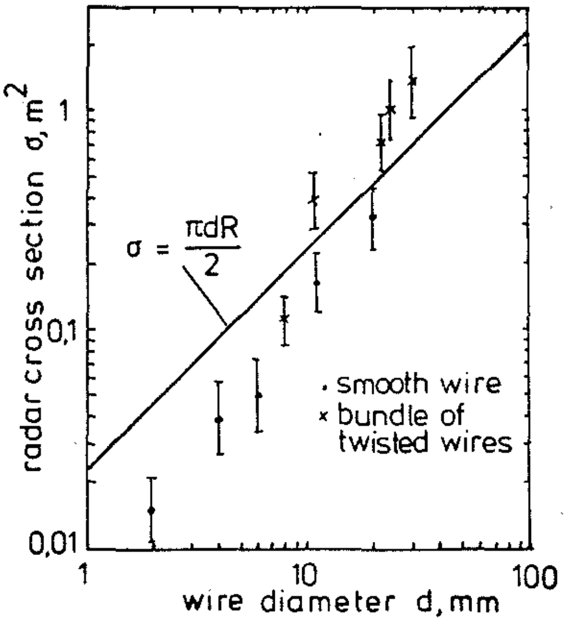
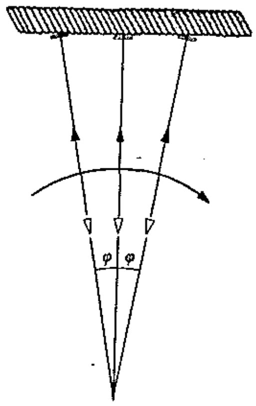
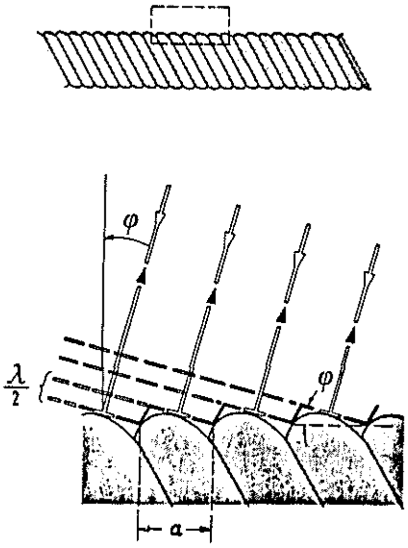


Fig. 3
Measured radar cross sections of straight wires of different diameters



4a



4b

Fig. 4a and b
Reflection from twisted cables. In addition to the reflections occuring at normal incidence there are two other echos (Fig. 4a) resulting from diffration. These additional echos occur when the diffraction equations $a \cdot \sin \varphi = \lambda/2$ is satisfied (Fig. 4b)

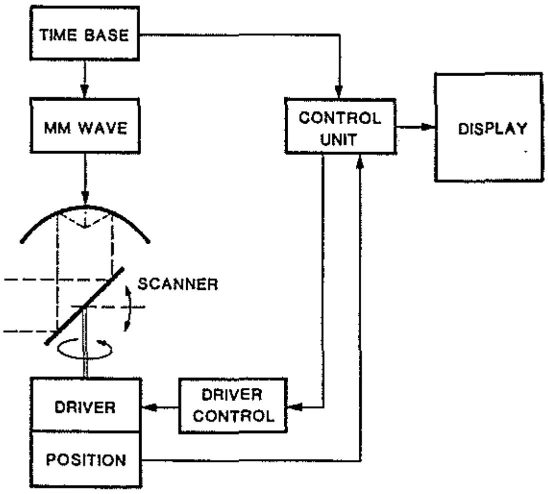


Fig. 5
Blockdiagram of the system

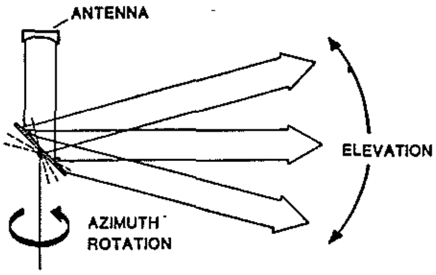


Fig. 6
Motions of the plane mirror required in order to scan the front field of view

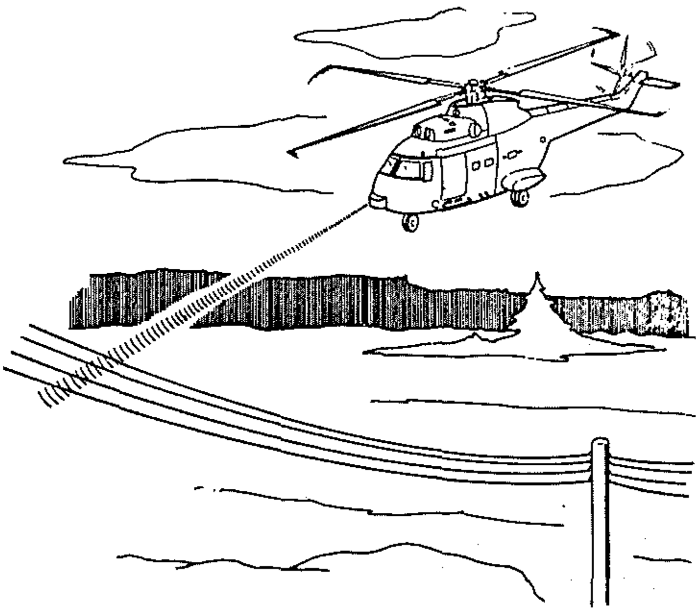


Fig. 7
Sketch of a helicopter with sensor mounted

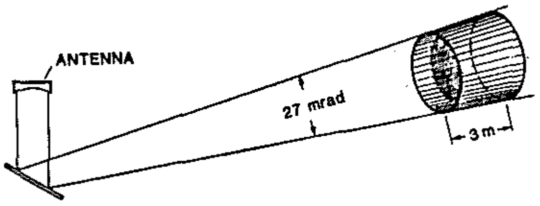
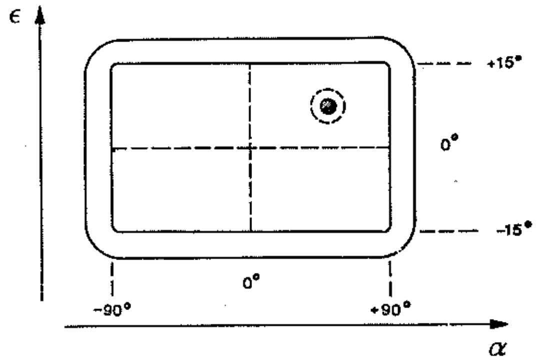
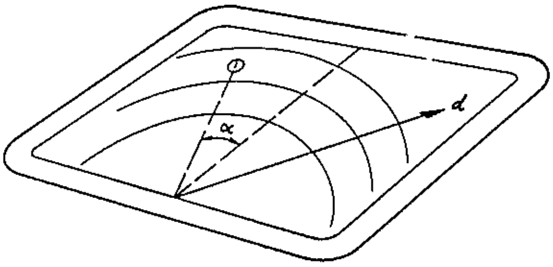


Fig. 8
Schematic view of the resolution cell of the radar



9a



9b

Fig. 9a and 9b
Front view projection (9a) and map projection (9b) of the 3 coordinates range, azimuth and elevation angle

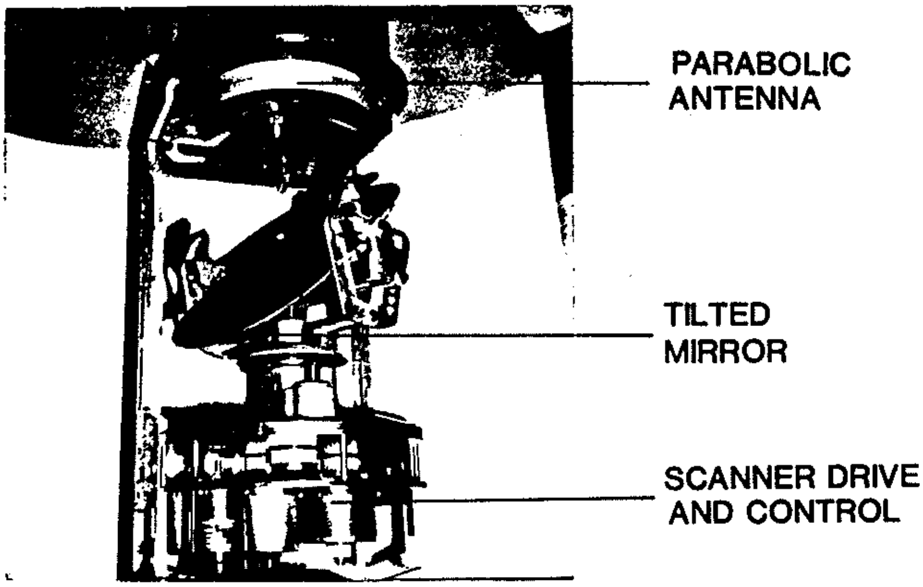


Fig. 10
The front end (without radom) ready for mounting to the helicopter