ISA

Inertial Sensors and Applications

Exhibition Catalog

to celebrate the 60th Symposium in 2023

DGON

German Institute of Navigation
Deutsche Gesellschaft für Ortung und Navigation e.V.

Institut für Flugführung IFF

Technische Universität Braunschweig,
Institute of Flight Guidance

DGON Fachausschuss 8_**1965-1970**

Symposium Kreiseltechnik_**1971-1978**

Symposium Gyro Technology_**1979-2010**

DGON Inertial Sensors and Systems_**2011-2023**

DGON Inertial Sensors and Applications_**since 2024**

PREFACE

In 2023, the 60th symposium of the conference series "Inertial Sensors and Applications" took place. During the preparation of the symposium, members of the programme committee suggested to complement the conference with a small exhibition to illustrate the history and tradition of the conference as well as the technical development of inertial sensors and systems over the past decades. As a result, a representative selection of gyroscopes, accelerometers and inertial navigation systems from the collections of the University of Stuttgart, the TU Braunschweig and the companies Diehl, iMAR, Litef and Safran was put together and presented as part of the programme of the 60th Symposium.

In order to preserve this exhibition for posterity and to make it available to conference participants in future years, this catalogue of objects was compiled after the conference. I would like to thank *Ulf Bestmann, Andreas Fischer, Uwe Herberth, Edgar v. Hinüber, Thomas Löffler, Ofri Schmidtke and Jörg Wagner* for their contributions to the exhibition and this documentation. They have created a booklet that not only reflects the self-image of the conference series "Inertial Sensors and Applications", but also provides an extraordinary selection of technical devices and details for experts and laymen alike. I wish the catalogue many interested readers.

Peter Hecker

For most of human history, the speed of technological advancements was naturally slow. This changed enormously during the last two centuries. The field of inertial sensors and systems is a typical example of this phenomenon: Since the first usable gyro instruments were about 110 years ago, the scientific basis, accuracy, reliability, and applicability of inertial devices have undergone breathtaking evolutions, and it seems very unlikely that pioneers like H. Anschütz-Kaempfe, E. Sperry, or M. Schuler anticipated such development of their sphere of activity.

The main origin of inertial technology is the invention of the gyro with cardanic suspension by the astronomer J. G. F. Bohnenberger in 1810 and the discovery of L. Foucault around 1850 that this device is the basis of a whole class of different gyroscopes. The way of realizing Foucault's findings was, however, "full of obstacles with a tension in the ups and downs of disappointments and shining successes that is rarely found in major discoveries or inventions" (K. Magnus [1]). Therefore, it was a significant breakthrough when the companies Anschütz and Sperry brought the first gyro instruments for navigation to market at the beginning of the 20th century. During the following decades, mainly military requirements strongly supported a quick further development from gyroscopes to inertial platforms and led to navigation instruments, which were masterpieces of precision mechanics.

This background characterized the situation during the 1960s when gyro technology was increasingly regaining a foothold in Germany after World War II and research institutions, traditional and new companies (such as Bodenseewerk, Anschütz, Litton, and Teldix), as well as users from maritime transport, aviation, and surveying identified a considerable backlog for a national coordination in the research, development, and application of inertial sensors and systems. Therefore, this community and the German Institute of Navigation DGON started a conference series of annual symposia in 1965 to establish a regular scientific meeting place for designers and users of inertial technology [2]. Although the conferences were initially planned as national events, they attracted solid international attention from the beginning and exist until today under the current name "DGON Inertial Sensors and Applications." This success was not expectable, and it is a remarkable achievement that the symposia could cover a strongly changing character of inertial technology, which took place since 1965.

Retrospectively, one reason for the success of the symposia is that they were founded in a particular exciting period of the history of inertial technology, as the 1960s mark a twofold juncture: first, the completion of the transition from the pre-war to the post-war period (concerning World War II) and, second, the transition from precision mechanics to microelectronics and optics as the technical basis for realizing precise inertial navigation systems. Accordingly, the first 15 years of the symposia were still dominated by gyroscopes with spinning wheels, while ring laser and fiber optical gyroscopes shaped the following 15 years. For about three decades, optical gyroscopes and sensors based on vibrating structures have shared presentations at conferences, while civil and low-cost applications have reached substantial importance [3].

The 60th symposium took place in 2023. To illustrate the origin and tradition of the conference series and demonstrate the strongly altered character of inertial technology since the 1940s, the organizing committee decided to enrich this event with a small display of historical instruments. This booklet documents this exhibition in the form of a small catalog. It compiles a collection of inertial devices with a variety considered unique, even according to museum standards.

The exhibition consisted of loaned objects from collections of inertial sensors and systems (cf. [4], [5]). Lenders were the universities of Braunschweig and Stuttgart, as well as the companies Diehl, iMAR, LITEF, and Safran, which have supported the symposia for many years. Each object was accompanied by a small spreadsheet assembling technical details about this device. The booklet contains these tables and characteristic photos of all exhibited objects, supplemented by dimension indicators and short background information about each device. Some fields of the tables remain empty because their content currently cannot be found. Still, each booklet reader is invited to let the editor know if he or she knows missing or additional details to be considered in a future edition of this catalog.

The editor and symposium organizers hope that the booklet enriches the attendees' conference impressions, and they look forward to any feedback.

Jörg Wagner

References

[1] K. Magnus, "Zur Geschichte der Anwendung von Kreiseln in Deutschland," in Razvitie mechaniki giroskopičeskich i inercal'nych sistem, Moskva, USSR, Izdatel'stvo Nauka, 1973, pp. 285–306.

[2] J. F. Wagner and M. Perlmutter, "The ISS symposium turns 50: Trends and developments of inertial technology during five decades," in 2015 DGON Inertial Sensors Syst., Karlsruhe, Germany, 2015, pp. 0.1–0.20, doi: 10.5445/IR/1000064985.

[3] J. F. Wagner, "60 symposia on inertial sensors and systems: A remarkable series in the course of time," in 2023 DGON Inertial Sensors Syst., Braunschweig, Germany, 2023, pp. 0.1–0.22, doi: 10.1109/ISS58390.2023.10361919.

[4] M. Niklaus, K. Zhan, and J. F. Wagner, "Gyrolog – creating a 3-dimensional digital collection of classical gyro instruments," in 2019 DGON Inertial Sensors Syst., Braunschweig, Germany, 2019, pp. 1.1–0.23, doi: 10.1109/ISS46986.2019.8943640.

[5] H. Hügel, ed., Orientierung im Raum – 200 Jahre Maschine von Bohnenberger, Stuttgart, Germany, Universität Stuttgart / Landesamt für Geoinformation und Landentwicklung Baden-Württemberg, 2010, doi: 10.18419/opus-14900.

TABLE OF CONTENTS

The exhibited objects were grouped into categories that reflect their usage and technical principle. Inside each group they were numbered consecutively. This led to the following table structuring the exhibits for the display and for this catalogue on the following pages with one double page for each object.

(MEMS means Micro-ElectroMechanical Systems, IMU means Inertial Measurement Unit.)

TABLE OF CONTENTS

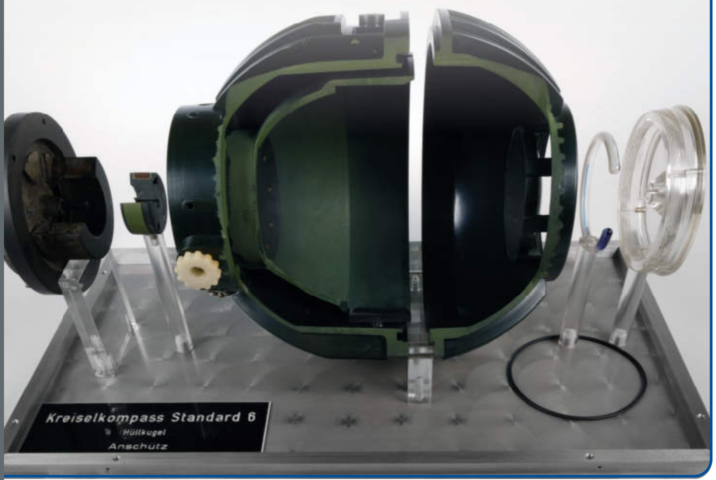
ANSCHÜTZ STANDARD 6

OBJECT 1

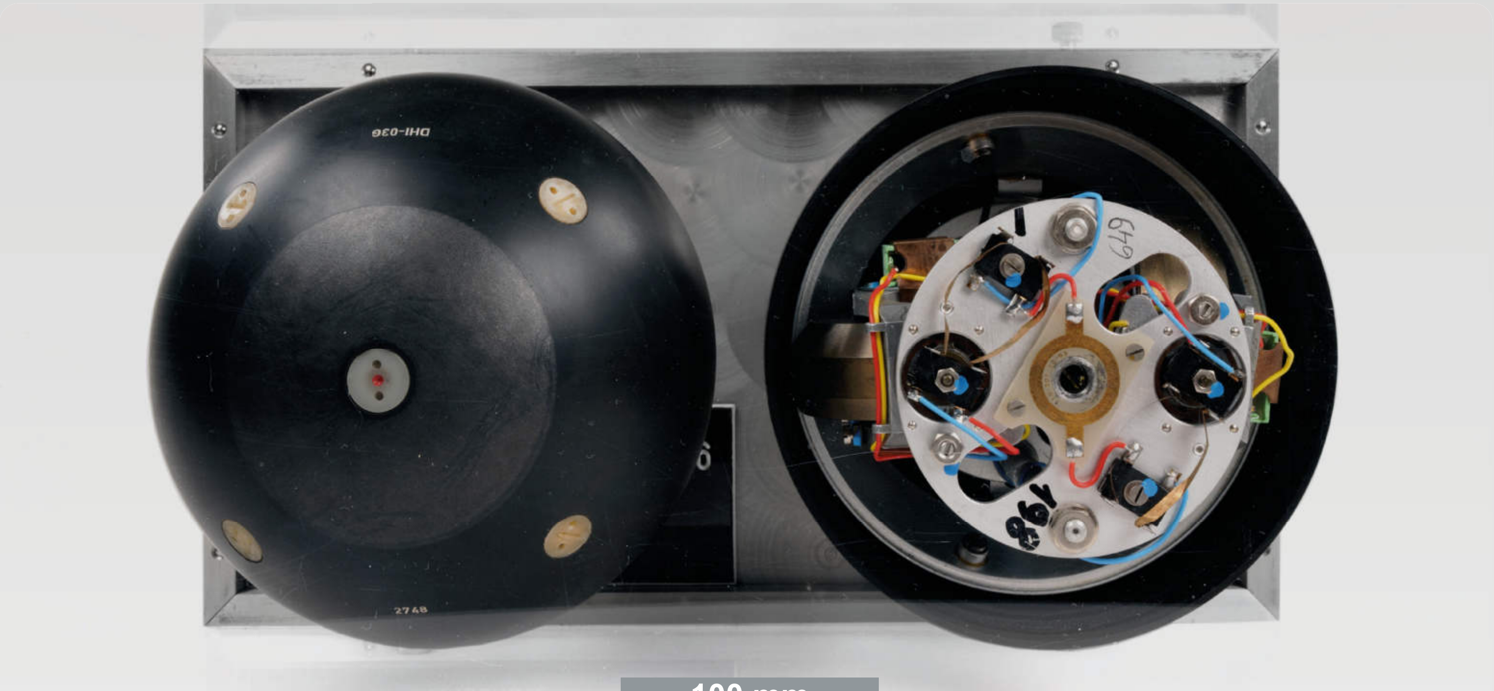
A loan from University of Stuttgart

Device type	**GYRO COMPASS**
Manufacturer	Anschütz GmbH, Kiel, Germany
Year of manufacture	around 1970
Dimensions	214 mm x 222 mm x 354 mm
Weight	6.0 kg
Accuracy	approx. 1.5 deg
Application	ship navigation
Life time	many years
Service interval	1 year

MECH RLG FOG MEMS



The two parts of the object shown are the opened inner sphere and the opened outer shell of the gyro compass Anschütz Standard 6. This navigation device represents the 3rd generation of Anschütz's worldwide well-known two-wheel gyro compass und was introduced into market in 1969. The object is a donation of Anschütz to the University of Stuttgart and war prepared for teaching purposes in gyro instruments.



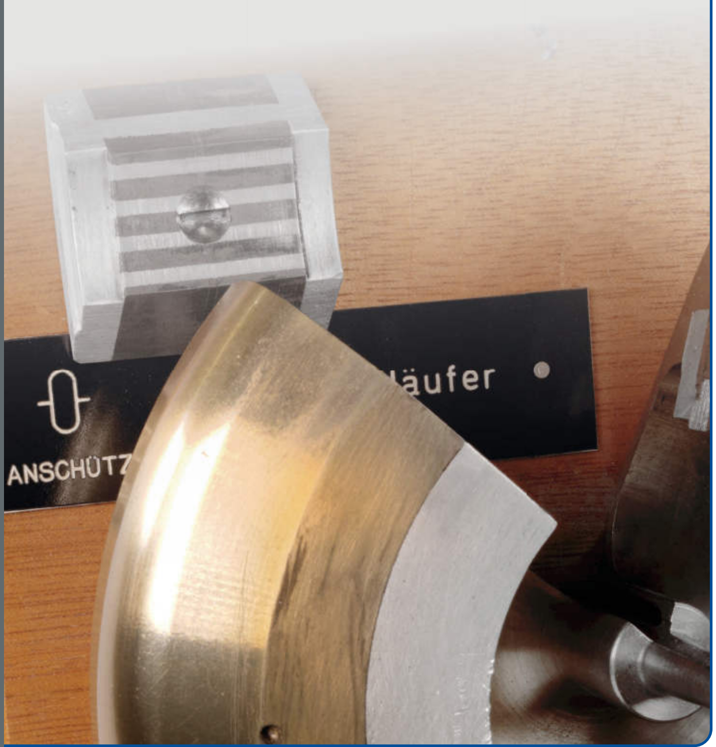
100 mm

ANSCHÜTZ GYROCOMPASS ROTOR AND STATOR

OBJECT 2

A loan from University of Stuttgart

Device type	**GYRO COMPASS**
Manufacturer	Anschütz GmbH, Kiel, Germany
Year of manufacture	probably 1950s
Dimensions	240 mm x 155 mm x 133 mm
Weight	2.7 kg
Accuracy	N/A
Application	ship navigation
Life time	many years
Service interval	N/A



MECH RLG FOG MEMS

The object illustrates the composition and electric drive of one rotor of the gyro compass Anschütz Standard 4, which represents the 2nd generation of Anschütz's worldwide well-known two-wheel gyro compass. This navigation instrument was introduced into market in the middle of the 1950s. The object is a donation of Anschütz to the University of Stuttgart in the 1960s and was prepared for teaching purposes in gyro instruments.

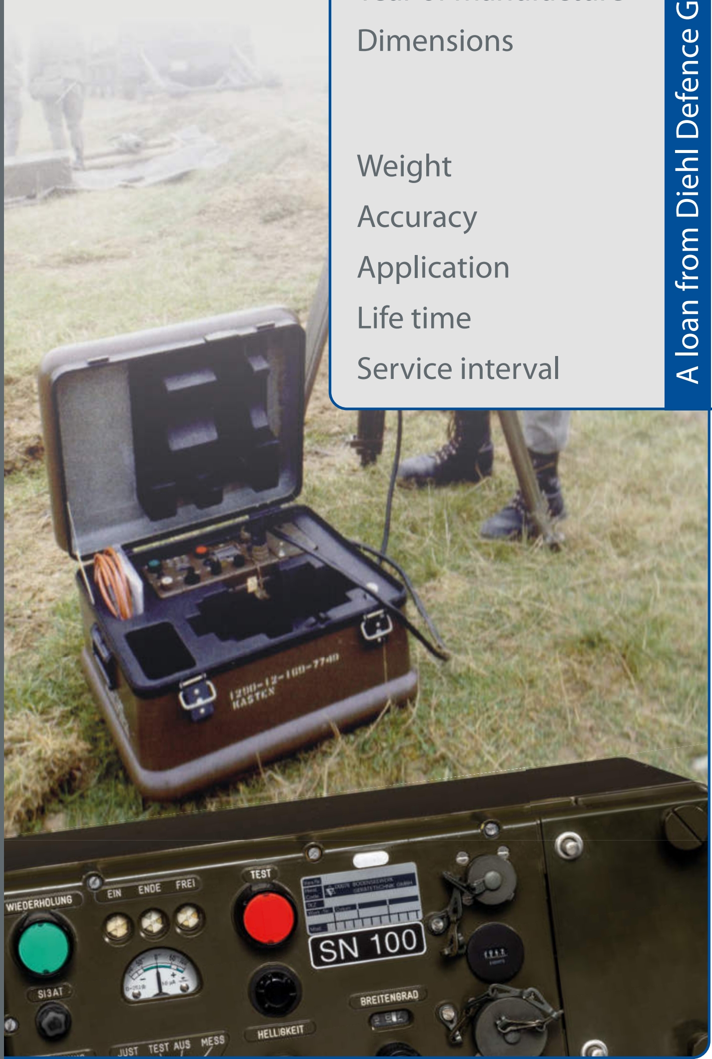

Kreiselstator
KREISELKOMPASS
100 mm

BODENSEEWERK MK 10-2 WITH ROTOR

OBJECT 3

A loan from Diehl Defence GmbH & Co. KG

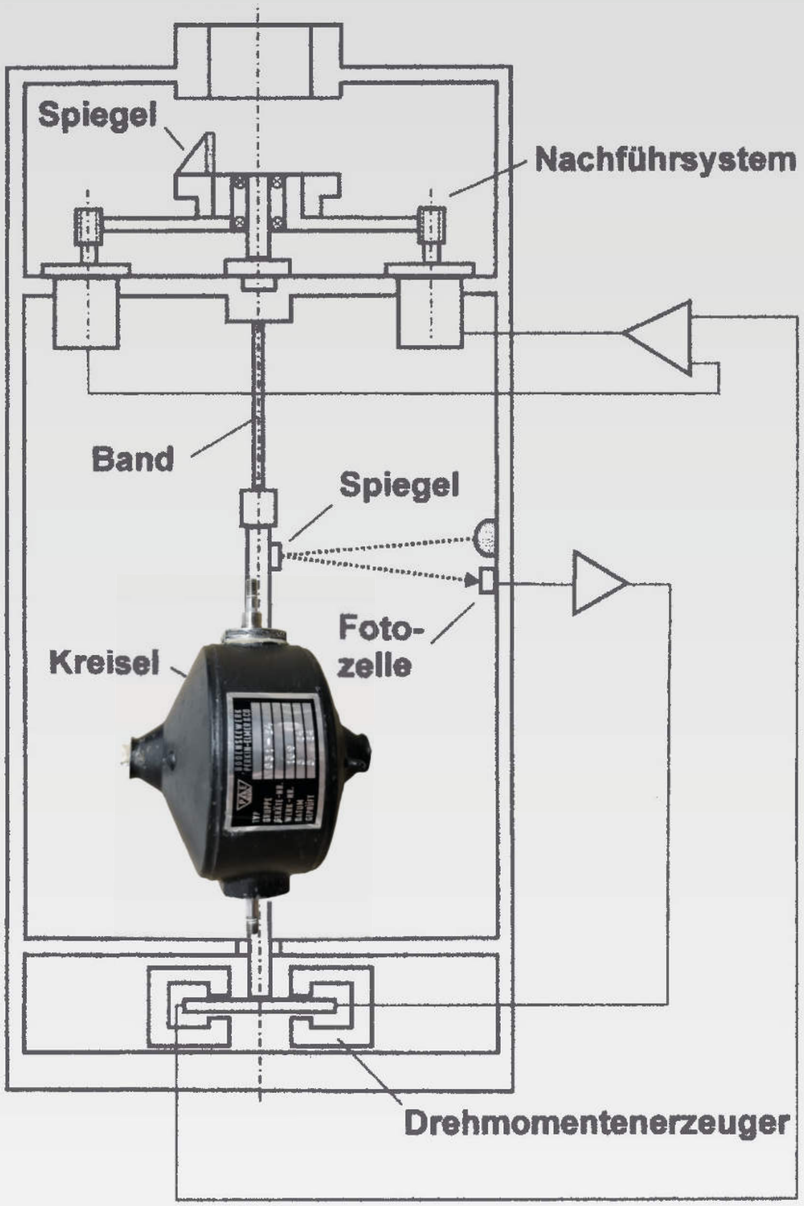
Device type	**MERIDIAN GYROSCOPE**
Manufacturer	Bodenseewerk Gerätetechnik GmbH, Überlingen, Germany
Year of manufacture	1970s and 1980s
Dimensions	gyro unit: Ø130 mm, h 335 mm, rotor: 55 mm x 48 mm x 76 mm control unit: 330 mm x 180 mm x 125 mm
Weight	25 kg rotor: 0.35 kg
Accuracy	3 arcmin
Application	north seeking for army applications
Life time	several years
Service interval	



MECH RLG FOG MEMS

The MK 10-2 is a north-seeking gyro instrument ("Meridiankreisel"), which is based on a wire-suspended rotor that aligns itself to true north due to its spin and the earth's rotation. The principle of "tying" the gyro to the housing and measuring the necessary alignment torques drastically reduces the required measuring time. Mounted on a leveled tripod and combined with a theodolite, it can be used for aiming and surveying-purposes in severe environmental conditions. Starting in 1974, more than 1,000 MK 10-2 were delivered to national and international customers.

Basic design of the meridian gyroscope

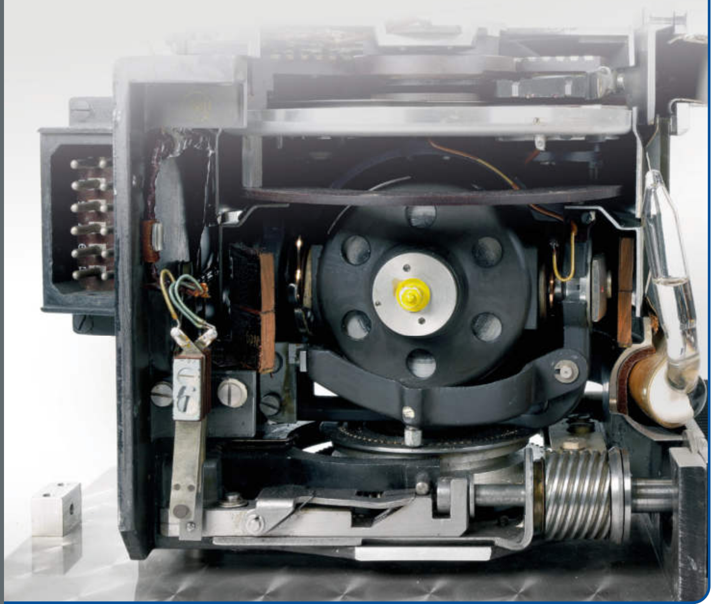


100 mm

OBJECT 4

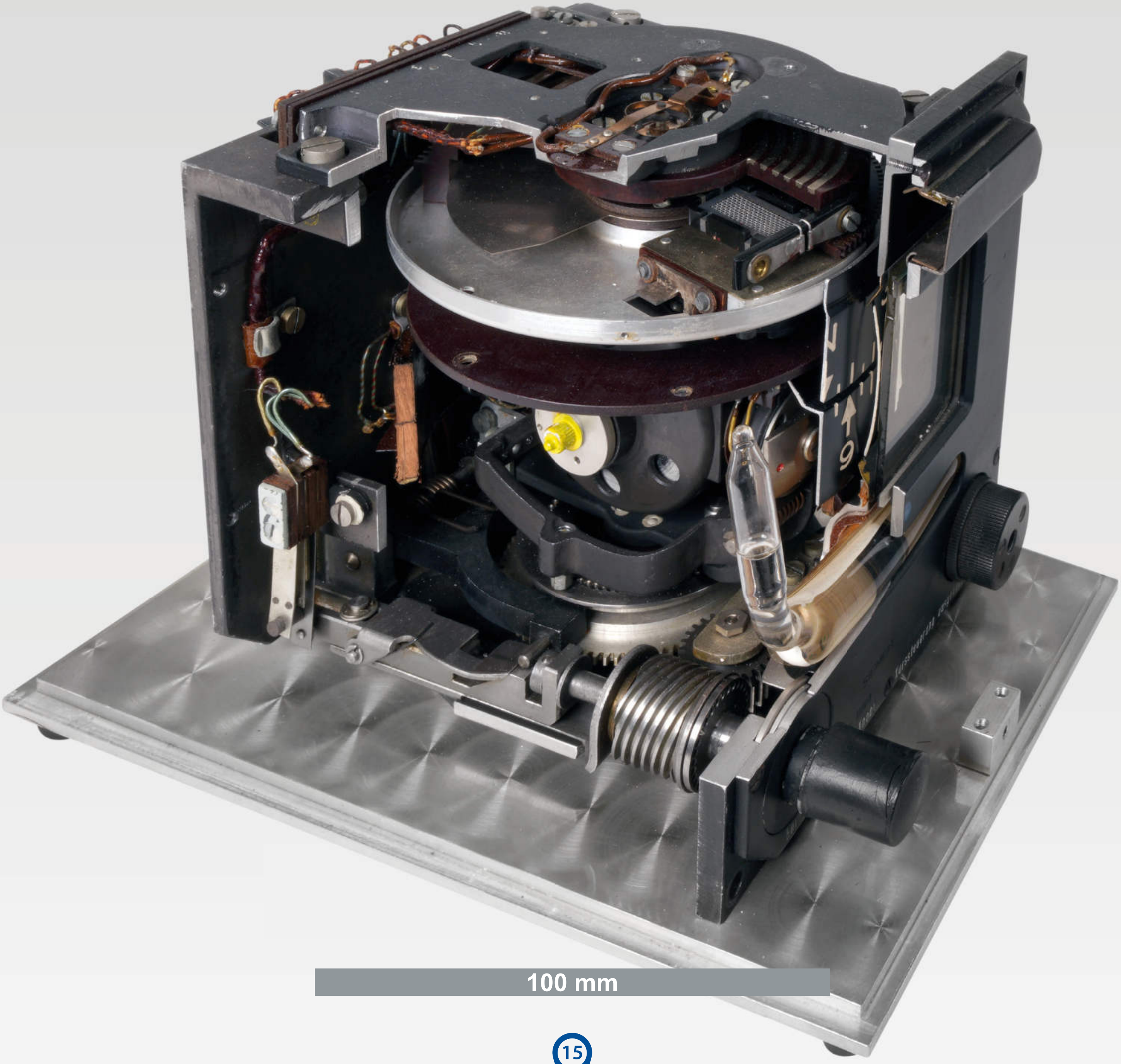
A loan from University of Stuttgart

Device type	**DIRECTIONAL GYRO**
Manufacturer	Siemens-Luftfahrtgerätewerk Hakenfelde, Berlin, Germany
Year of manufacture	World War II
Dimensions	137 mm x 120 mm x 184 mm
Weight	2.2 kg
Accuracy	approx. 1 deg within 20 min
Application	aircraft navigation
Life time	several years
Service interval	



MECH RLG FOG MEMS

The Siemens LKu4 directional gyro was a standard instrument of the German Air Force during the Second World War and was part of the automatic course control system Siemens K 4ü. It could be aided by a magnetic compass. In the 1960s, Siemens donated a remaining stock of the LKu4 to the University of Stuttgart, where the devices were used for research and teaching in gyro dynamics. Later, this object was cut open for illustration purposes.



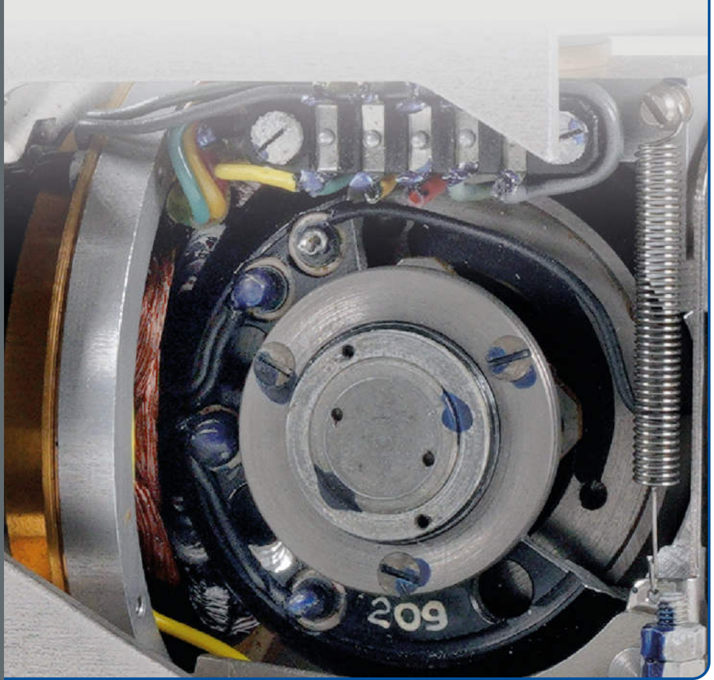
100 mm

S.F.I.M. BEZU COMPAS GYROMAGNÉTIQUE 9551

OBJECT 5

A loan from University of Stuttgart

Device type	**DIRECTIONAL GYRO**
Manufacturer	S.F.I.M. BEZU, France
Year of manufacture	around 1957
Dimensions	114 mm x 120 mm x 213 mm
Weight	2.2 kg
Accuracy	
Application	aircraft navigation
Life time	several years
Service interval	



MECH RLG FOG MEMS

The BEZU Compas Gyromagnétique 9551 is typical for the state of the art of directional gyros with magnetic aiding at the end of the 1950s. It was employed mainly for military aircraft. The object probably is a donation of the German Air Force to the University of Stuttgart in the 1960s. Later, it was modified for teaching purposes in gyro instruments.

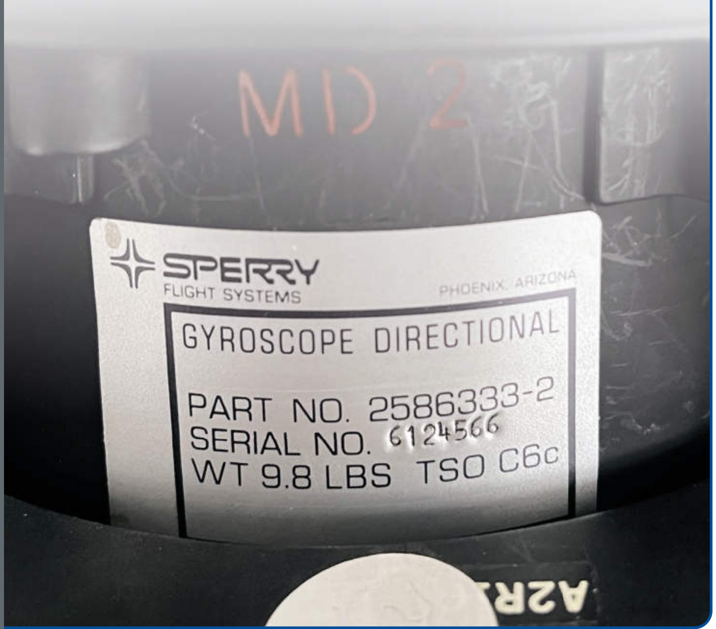

100 mm

SPERRY C-12 ROTORACE DIRECTIONAL GYRO

OBJECT 6

A loan from TU Braunschweig

Device type	**DIRECTIONAL GYRO**
Manufacturer	SPERRY Flight Systems, Brentford, UK
Year of manufacture	1960s
Dimensions	211 mm x 186 mm x 176 mm
Weight	4.5 kg
Accuracy	±1 deg/h
Application	aircraft navigation
Life time	several years
Service interval	



MECH RLG FOG MEMS

This directional gyro has an exceptional low drift because of its Rotorace bearings that consist of two-ply ball bearings. The ring in the middle of the two plies is alternately turned by a motor to reduce the static friction of the bearings with the effect of the reduction of the free gyro drift. A flux valve served for the magnetic aiding of the gyro and had an electrical compensation for the magnetic interference of the vehicle. It was produced both in Great Britain and the USA.

100 mm

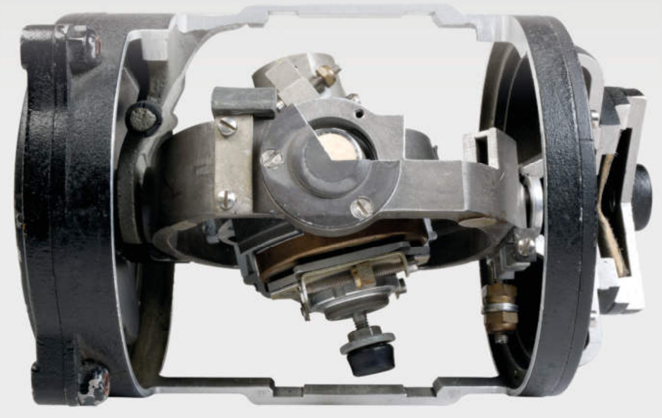
GENERAL MOTORS AN5736-1

OBJECT 7

A loan from University of Stuttgart

Device type	**ARTIFICIAL HORIZON**
Manufacturer	SPERRY / General Motors / Ternstedt, USA
Year of manufacture	1940s
Dimensions	115 mm x 112 mm x 197 mm
Weight	1.5 kg
Accuracy	
Application	aircraft navigation
Life time	
Service interval	

MECH RLG FOG MEMS



This gyro horizon was a licensed production from Sperry and is characterized in particular by a rotor drive and a rotor alignment with compressed air. It was used in numerous bombers and fighter planes of the US Air Force during the WW II. This object probably is a donation of the German Air Force to the University of Stuttgart in the 1960s. Later it was modified for teaching purposes to illustrate its mechanical principle, the air line routing, and the rotor alignment.

100 mm

BENDIX ATTITUDE INDICATOR J-8

OBJECT 8

A loan from University of Stuttgart

Device type	**ARTIFICIAL HORIZON**
Manufacturer	Bendix, USA / Air Equipment, Asnieres, France
Year of manufacture	around 1955
Dimensions	100 mm x 120 mm x 210 mm
Weight	1.3 kg
Accuracy	approx. 3 deg
Application	aircraft navigation
Life time	
Service interval	500 – 1000 h

MECH RLG FOG MEMS

The J-8 was used as horizon indicator in numerous aircraft and helicopters of several air forces mainly during the 1950s and 1960s. Its rotor alignment is based on a drag ball mechanism. This object is a donation of probably the German Air Force to the University of Stuttgart in the 1960s. For teaching purposes in gyro instruments, it was modified but kept operational.

100 mm

S.F.E.N.A. / BODENSEEWERK HORIZON GYRO

OBJECT 9

A loan from Diehl Defence GmbH & Co. KG

Device type	**ARTIFICIAL HORIZON**
Manufacturer	Bodenseewerk Perkin Elmer & Co. GmbH, Überlingen, Germany; license production from S.F.E.N.A.
Year of manufacture	around 1965
Dimensions	84 mm x 84 mm x 164 mm
Weight	
Accuracy	approx. 1 deg
Application	aircraft navigation
Life time	several years
Service interval	

MECH RLG FOG MEMS

Bodenseewerk initially started production of gyro horizons under license from the French company SFENA. This object is such an attitude indicator and is characterized by a sophisticated drag ball mechanism to keep the rotor axis vertical. The mechanism includes a deactivation during high acceleration phases to enable a quick return of the axis to its nominal attitude after short, sharp aircraft maneuvres. The heart of the instrument is a rotor with emergency running properties in the event of a power failure. A total of over 8,800 gyro horizons were produced.


LIZENZFERTIGUNG
BODENSEEWERK
PERKIN-ELMER & CO GMBH
200 V
S.F.E.N.A
Type
Date
Amp
PHASENFOLGE
CANNON
460

100 mm

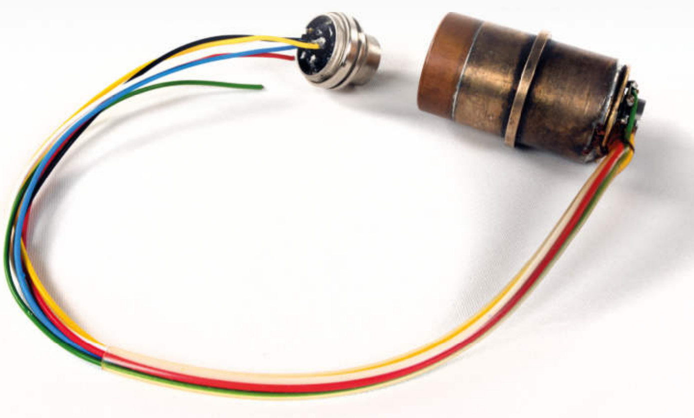
BENDIX / TELDIX RWK-100

OBJECT 10

A loan from University of Stuttgart

Device type	**P RATE GYRO**
Manufacturer	TELDIX, Heidelberg, Germany
Year of manufacture	around 1969
Dimensions	Ø 25.5 x 51 mm (sensor)
Weight	0.12 kg (sensor)
Accuracy	2 deg/s
Application	missile navigation
Life time	300 h
Service interval	N/A

MECH RLG FOG MEMS



The RWK-100 type was part of a whole series of angular rate sensors for aircraft and missiles. It represents the lower limit of the size of such angular rate gyroscopes with spinning wheels. Special features are the power supply of a two-phase alternating current and the high rotor speed of 36,000 rpm. Teldix donated several copies of this sensors to the university of Stuttgart during the 1970s, where they were used for research and teaching in gyro instruments.


Torsionswelle
Geber-Rotor
Ausgleichsrad mit Auswuchtschrauben
Geber-Stator
Gestell (Gehäuse)
Volumausgleich
Motor-Stator
Motor-Rotor
Kappe
WENDEKREISEL
Bendix USA
Antrieb:
9V 1200 Hz 36 000 U/min
50 mm

CF ELECTRIQUE TYPE 100

OBJECT 11

A loan from University of Stuttgart

Device type	**RATE GYRO, TURN AND SLIP INDICATOR**
Manufacturer	CF Electrique, France
Year of manufacture	around 1959
Dimensions	102 mm x 103 mm x 142 mm
Weight	1.0 kg
Accuracy	
Application	aircraft navigation
Life time	several years
Service interval	

MECH RLG FOG MEMS

This object is typical for the state of the art of turn and slip indicators at the end of the 1950s. Due to its solid precision mechanics with a careful balanced rotor, it is still operational. The only electrical component is the rotor drive (current consumption 0.1 A at 27 V). The object probably is a donation of the German Air Force to the University of Stuttgart in the 1960s. It was modified for teaching purposes in gyro instruments.

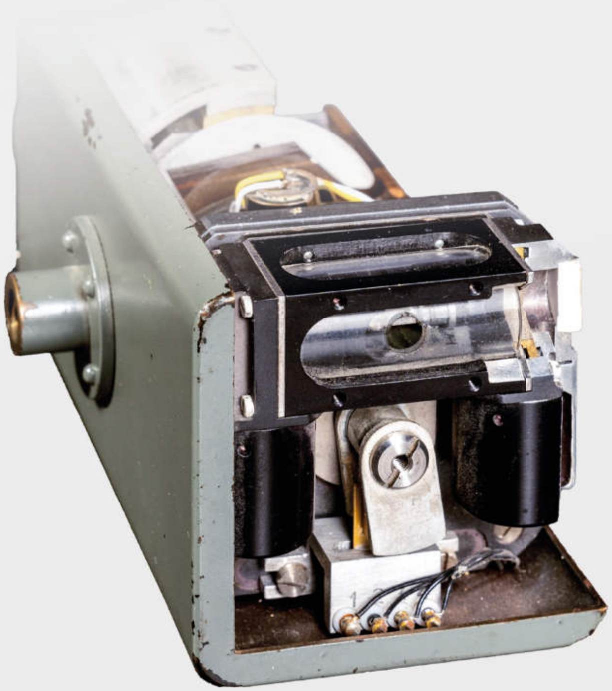
100 mm

BODENSEEWERK PID GYRO 865 05

A loan from Diehl Defence GmbH & Co. KG

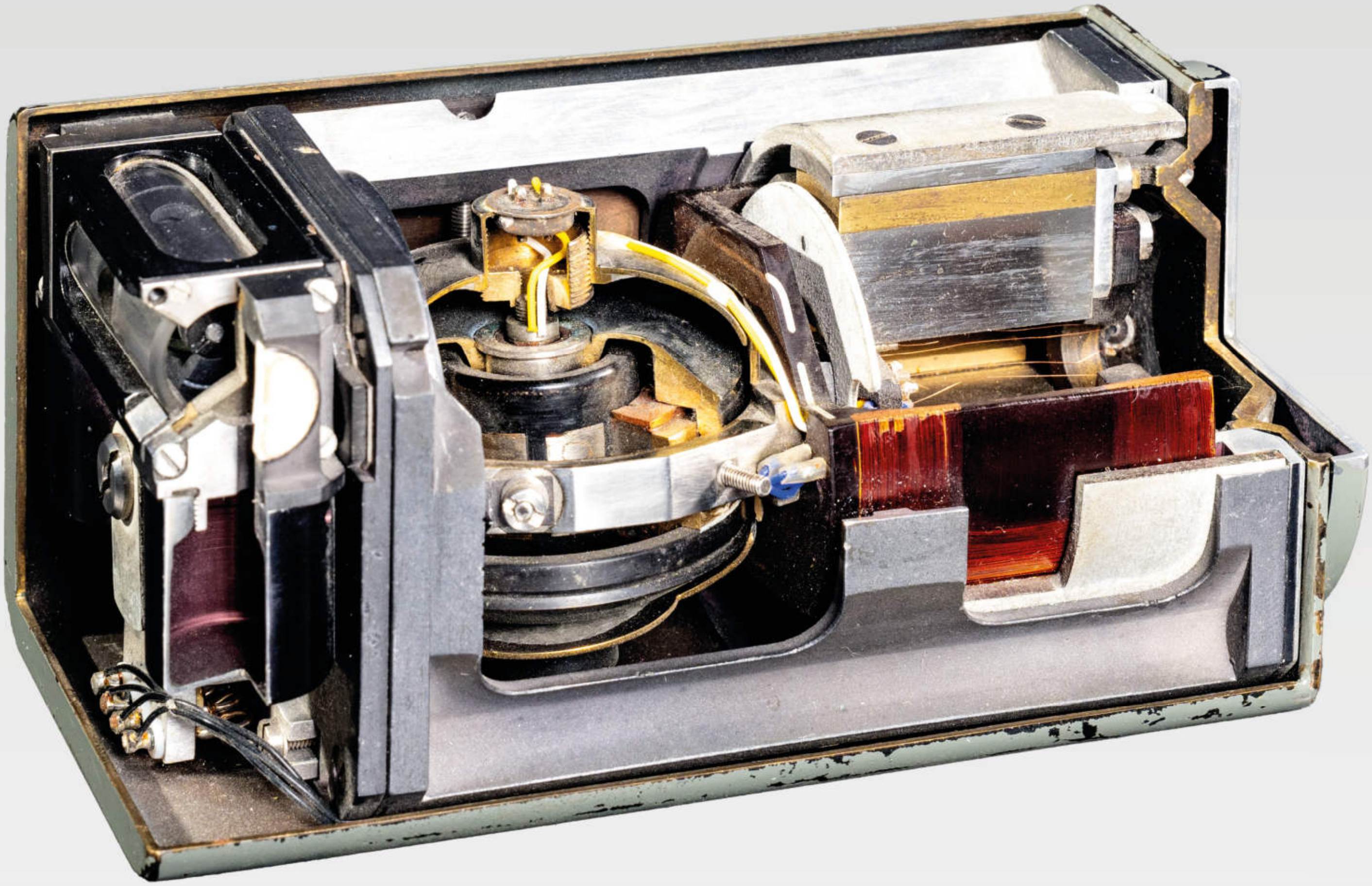
OBJECT 12

Device type	**PID RATE GYRO**
Manufacturer	Fluggerätewerk Bodensee GmbH, Überlingen, Germany
Year of manufacture	1960s
Dimensions	56 mm x 56 mm x 119 mm
Weight	
Accuracy	
Application	aircraft applications
Life time	several years
Service interval	



MECH RLG FOG MEMS

The PID gyro 865 05 was used for providing sensor signals being essential for flight control, and was the basic sensor for a large number of flight control systems in the 1960s. The instrument outputs its measured angle, its angular rate and its angular acceleration. Technically, this combination of required measurements could be realized by replacing the usual mechanical spring of the gimbal of a rate gyro with an air spring. The displacement of the piston in the air spring cylinder is a measure of the captured angle, i.e. the integration of the rotation rate.



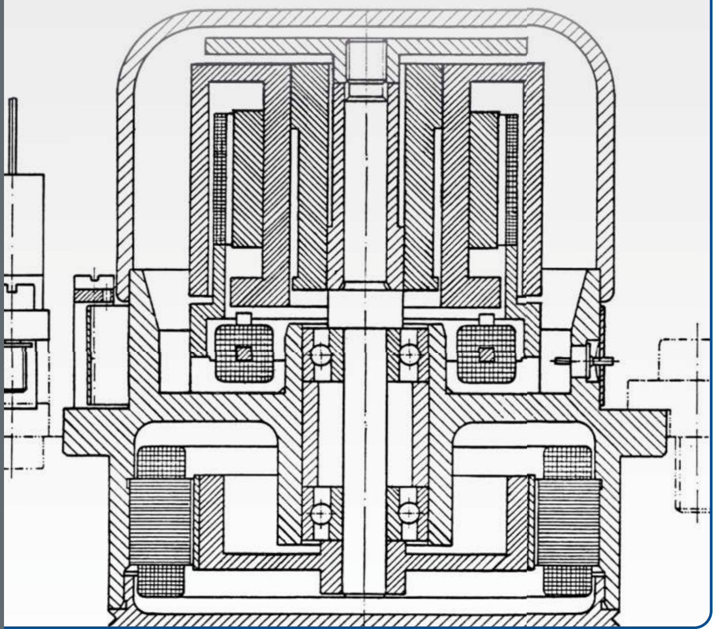
100 mm

LITEF K-273

OBJECT 13

A loan from Northrop Grumman LITEF GmbH

Device type	**DYNAMICALLY TUNED GYRO**
Manufacturer	Northrop Grumman LITEF GmbH; Freiburg i.Br., Germany
Year of manufacture	(since) 1976
Dimensions	45 mm x 54 mm
Weight	0.2 kg
Accuracy	0.25 deg/h rms
Application	aircraft navigation, stabilization
Life time	25 years
Service interval	none



MECH RLG FOG MEMS

Litef developed the K-273 in the 1970s to fulfil the requirements of the emerging strapdown technology for the European market. Intended applications were attitude and heading reference systems, low grade inertial navigation systems, and stabilizations devices for, e.g., optical sights. The rotor the K-273 is supported and decoupled from the rotating shaft by a tuned gimbal suspension system. Its attitude is measured and rebalanced by electromagnetic elements. This design was so successful, that the K-273 is marketable until today.


K–273
GYROSCOPE
PN 114440–732
SN 15338 REV A
LITEF
D4856
50 mm

BODENSEEWERK BDK802

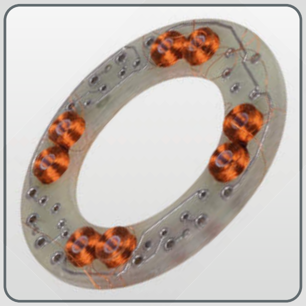
OBJECT 14

A loan from iMAR Navigation GmbH

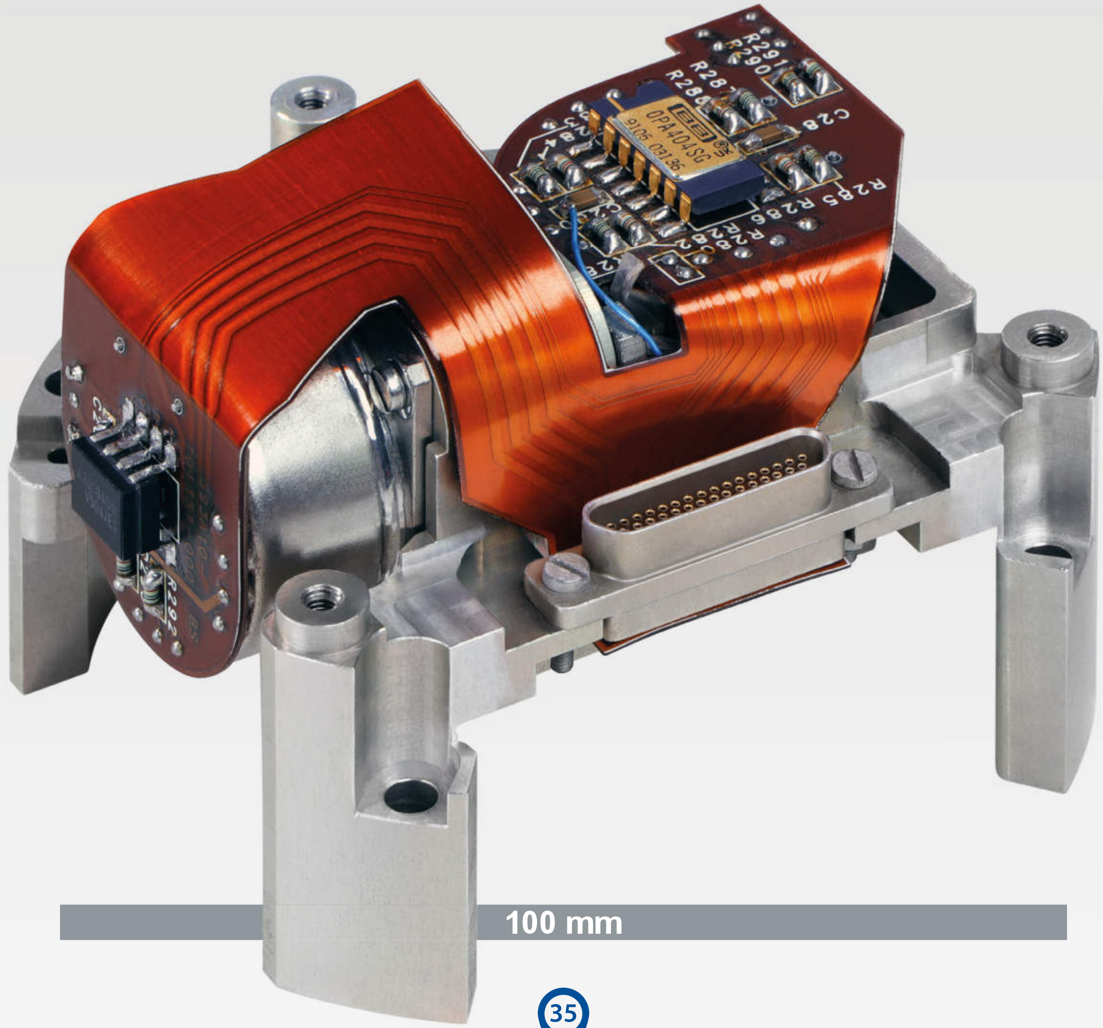
Device type	**DYNAMICALLY TUNED GYRO** here: setup with 2 x 2 axes
Manufacturer	Bodenseewerk Gerätetechnik, Überlingen, Germany
Year of manufacture	1989
Dimensions	Ø 33 mm, h 33.5 mm
Weight	approx. 0.108 kg
Accuracy	range 200 deg/s: bias < 0.3 deg/h, random drift 0.05 deg/h mass unbal. 20 deg/h/g (0.1 deg/h/g repeat.)
Application	navigation & control
Life time	> 10,000 h
Service interval	maintenance free

MECH RLG FOG MEMS

Bodenseewerk Gerätetechnik (BGT) entered the technology of dynamically tuned gyroscopes by taking over the licensed production of the Gyroflex gyroscope from the US company Singer Kearfott. Through further developments and own patents, BGT succeeded in separating itself from the US patents. On this basis, BGT could develop gyros both for platforms and for strapdown systems. The BDK gyros are characterized by a high shock resistance, long lifetime, automatic calibration, compactness, and a short run-up time. The BDK802 was designed for strapdown applications of high dynamics. The pictured assembly contains two BDK802 units with overall 4 measurement axes.






100 mm

HONEYWELL GG1342

OBJECT 15

A loan from iMAR Navigation GmbH

Device type	**RING LASER GYRO**
Manufacturer	Honeywell, Minneapolis, MN, USA
Year of manufacture	approx. 1987
Dimensions	approx. 170 mm x 140 mm x 40 mm
Weight	approx. 1.2 kg
Accuracy	< 0.002 deg/h, < 0.0015 deg/sqrt(hr) at 369 Hz dither frequency
Application	navigation & control
Life time	several years
Service interval	maintenance free

MECH RLG FOG MEMS

The GG1342 was Honeywell's first ring laser gyroscope for the civil market and was developed in the late 1970s. Due to its robust design and wide dynamic range, it is especially suitable for strapdown systems and became one of the early serious competitors of classical mechanical gyroscopes. Initially used for the inertial reference system of the Boeing 757/767 program, it became Honeywell's workhorse as a high-production, high-reliability, cost-effective aircraft gyroscope. Many thousands of this gyroscope have been built during its production period of more than three decades.

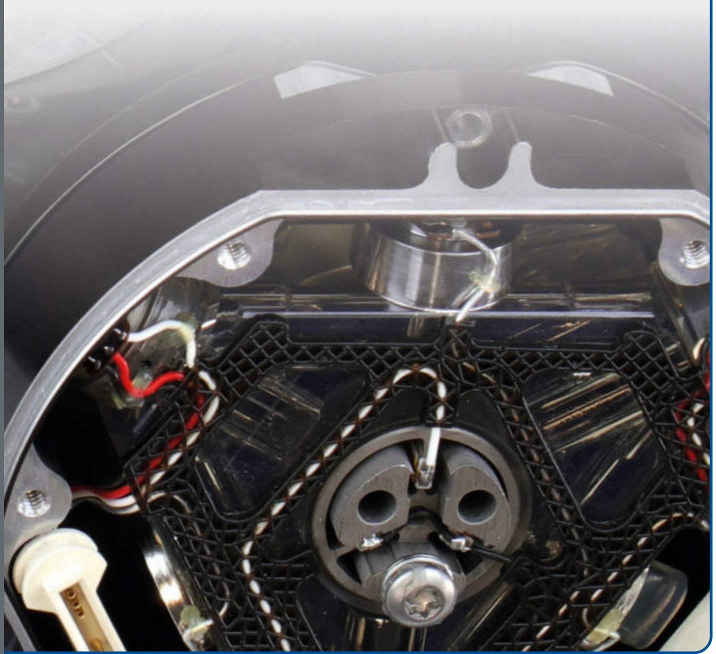

iMAR
NAVIGATION & CONTROL
Honeywell
HeNe Ring Laser Gyro
100 mm

HONEYWELL GG1320AN

OBJECT 16

A loan from iMAR Navigation GmbH

Device type	**RING LASER GYRO**
Manufacturer	Honeywell, Minneapolis, MN, USA
Year of manufacture	1997
Dimensions	Ø 88 mm, h 45 mm
Weight	0.45 kg
Accuracy	< 0.003 deg/h, < 0.0015 deg/sqrt(hr) at 575 Hz dither frequency
Application	navigation & control
Life time	several years
Service interval	maintenance free



MECH RLG FOG MEMS

The GG1320AN is a digital RLG (ring laser gyroscope) and the successor to the analog, bigger, and heavier GG1342 RLG. More than 500,000 devices have been produced up to today, with more than 8 billion recorded flight hours. Before the GG1320AN was introduced to commercial avionics in 1995, the lasers had been powered by an external power supply of up to 2,000 V, and the gyro output – a series of pulses – had to be processed by external electronics. For the GG1320AN, only 15 V standard power is needed, and it provides direct digital output. This means a greatly simplified handling.

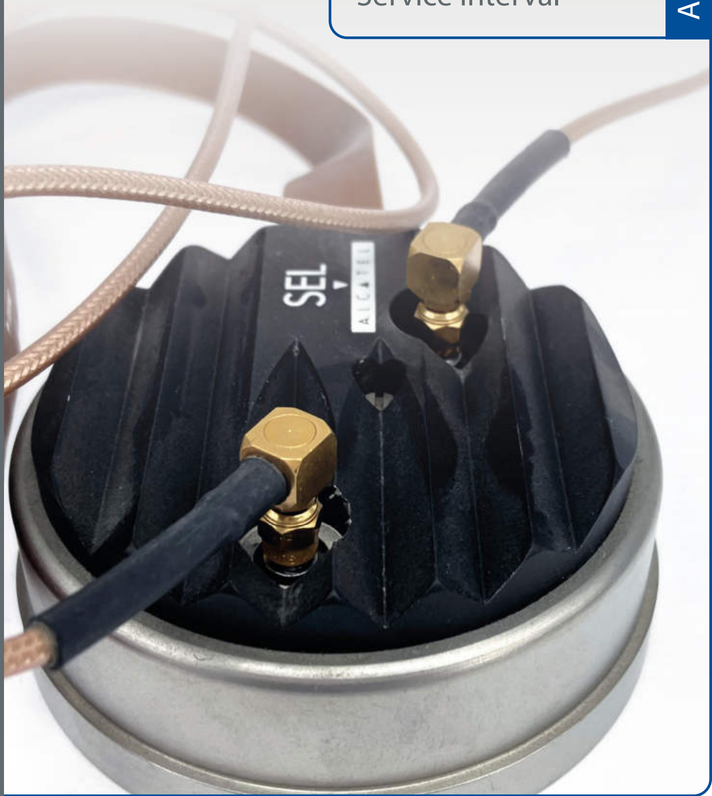
iMAR
NAVIGATION & CONTROL
Honeywell
HeNe Ring Laser Gyro
100 mm

ALCATEL SEL FOG-PM-1-DE

OBJECT 17

A loan from Safran Electronics & Defense

Device type	**FIBER OPTICAL GYRO**
Manufacturer	Alcatel SEL, Stuttgart-Zuffenhausen, Germany
Year of manufacture	1987
Dimensions	coil (circular, 100m): Ø 80 mm, h 34 mm
Weight	coil: 0.4 kg
Accuracy	10 deg/h
Application	navigation & control
Life time	several years
Service interval	maintenance free



MECH RLG **FOG** MEMS

In the early 1980s, the former German manufacturer of communication electronics Standard Elektrik Lorenz (SEL, later Alcatel SEL) decided to establish a navigation equipment portfolio consisting of fiber optical gyroscopes (FOG) and GPS receivers. The FOG-PM-1-DE was the first marketable FOG of SEL. It is a phase modulated, open loop optical sensor with a compact and simple design, a short fiber length, and a good price-performance ratio of the 1980s. A quantity of 200 units were manufactured between 1988 and 1991.

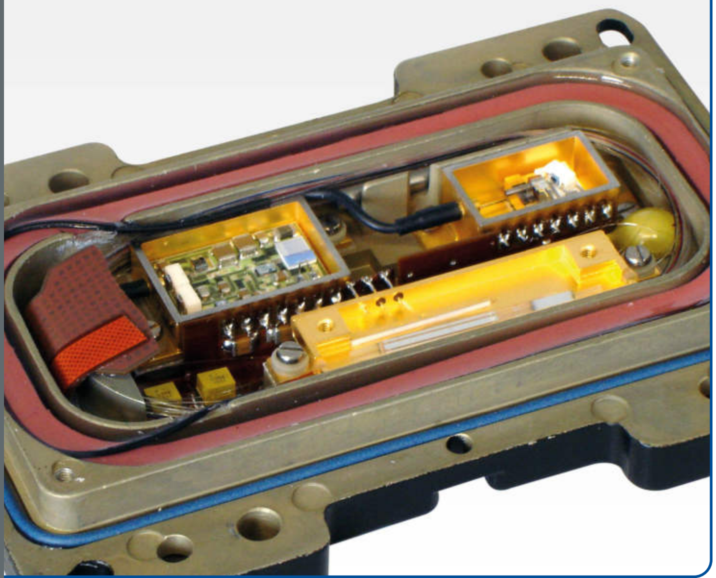

SEL
ALCATEL
100 mm
41

SFIM INDUSTRIES DEUTSCHLAND FOG-P1-E

OBJECT 18

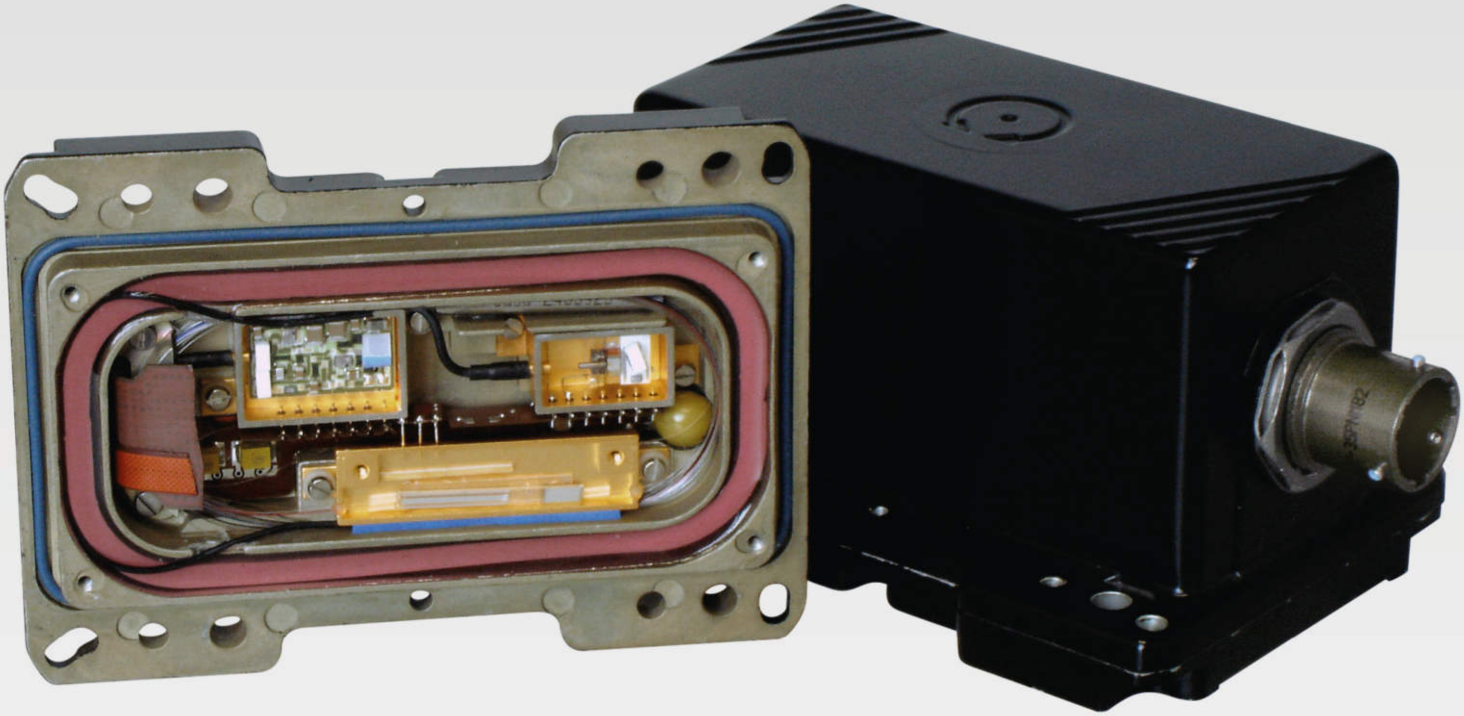
A loan from Safran Electronics & Defense

Device type	**FIBER OPTICAL GYRO**
Manufacturer	SFIM Industries Deutschland GmbH, Murr, Germany
Year of manufacture	1995
Dimensions	110 mm x 58 mm x 70 mm; coil: rectangular, 100 m
Weight	0.8 kg
Accuracy	< 25 deg/h, < 1.500 ppm
Application	flight stabilization, EC 135 helicopter
Life time	several decades
Service interval	maintenance free



MECH RLG **FOG** MEMS

The P1-E is an improved derivative of the FOG PM-1-DE (object 17) and embodies the transition that led to the later FOG-1S of SFIM Industries Deutschland (object 18). Design criteria were good packaging, high bandwidth, good shock resistance, and a scalable accuracy that was based on a sophisticated error modeling. The sensor has a built-in-test capability which monitors both sensor initialization and sensor operation. Numerous units of the FOG-P1-E were sold over many years, notwithstanding the fact that the SEL navigation department had been acquired by the French company SFIM (which is now part of SAFRAN) during the 1990s.



100 mm

SFIM INDUSTRIES DEUTSCHLAND FOG-1S

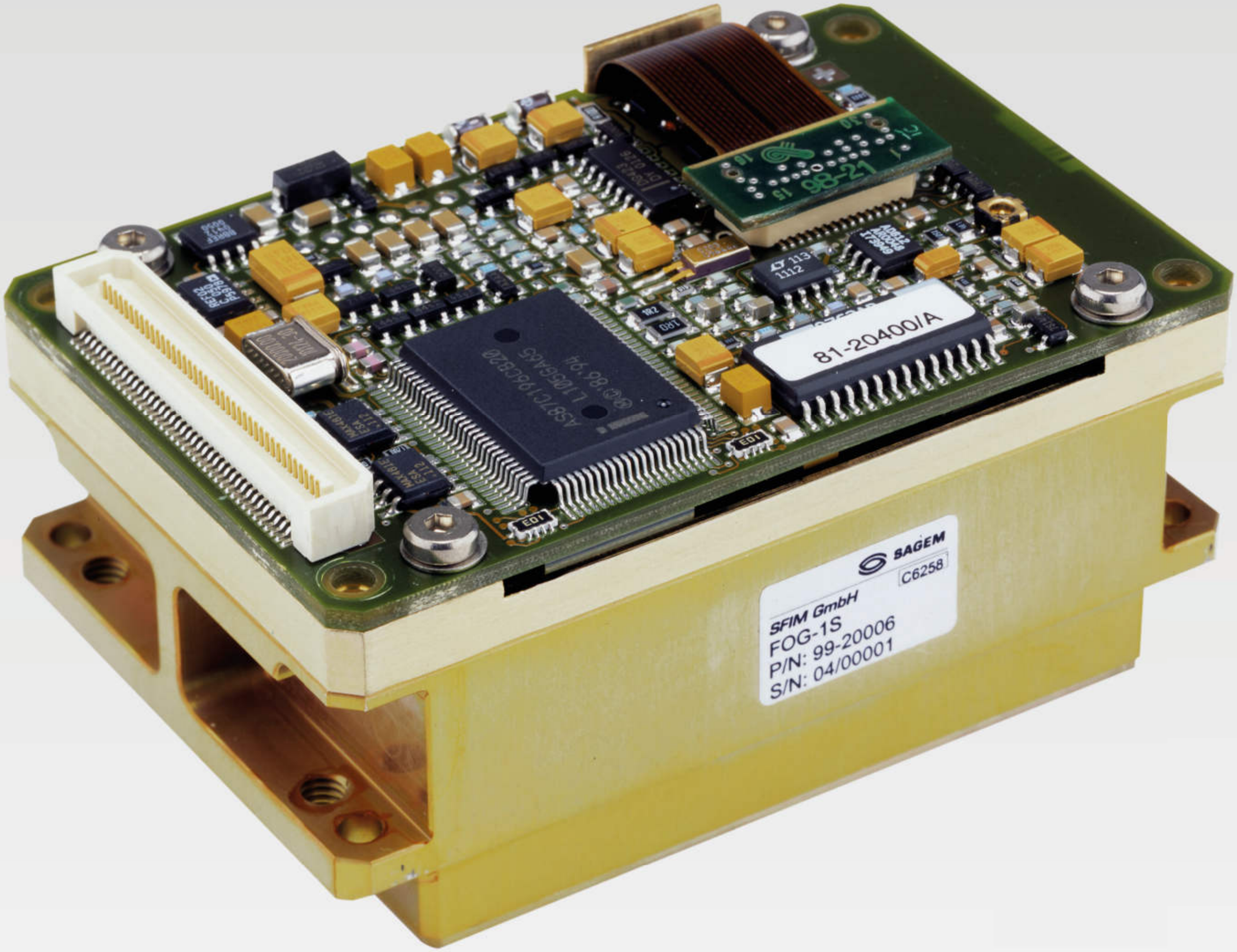
A loan from Safran Electronics & Defense

OBJECT 19

Device type	**FIBER OPTICAL GYRO**
Manufacturer	SFIM Industries Deutschland GmbH, Murr, Germany
Year of manufacture	2000
Dimensions	52 mm x 38 mm x 80 mm; coil: elliptic, 100 m
Weight	0.28 kg
Accuracy	< 3 deg/h, < 500 ppm
Application	flight stabilization, Airbus A340
Life time	several decades
Service interval	maintenance free

MECH RLG **FOG** MEMS

Two decades after starting to develop and to manufacture fiber optical gyroscopes (FOG), the former navigation department of Alcatel SEL, then SFIM Industries Deutschland, had established a family of FOGs and IMUs that based on a design concept of modular, identical components like light source, power splitter, modulator, and detector. This enhanced not only the reliability, production flexibility, and performance scalability of the gyroscopes, but simplified also procedures such as certification and spare parts logistics. The FOG-1S is a typical representative of this design with a closed loop configuration.



50 mm

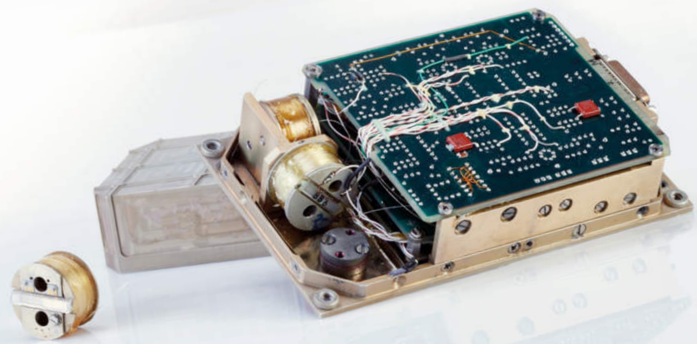
LITEF FOG SYSTEMS LFS-90 AND LI.FOG F14

OBJECT 20

A loan from Northrop Grumman LITEF GmbH

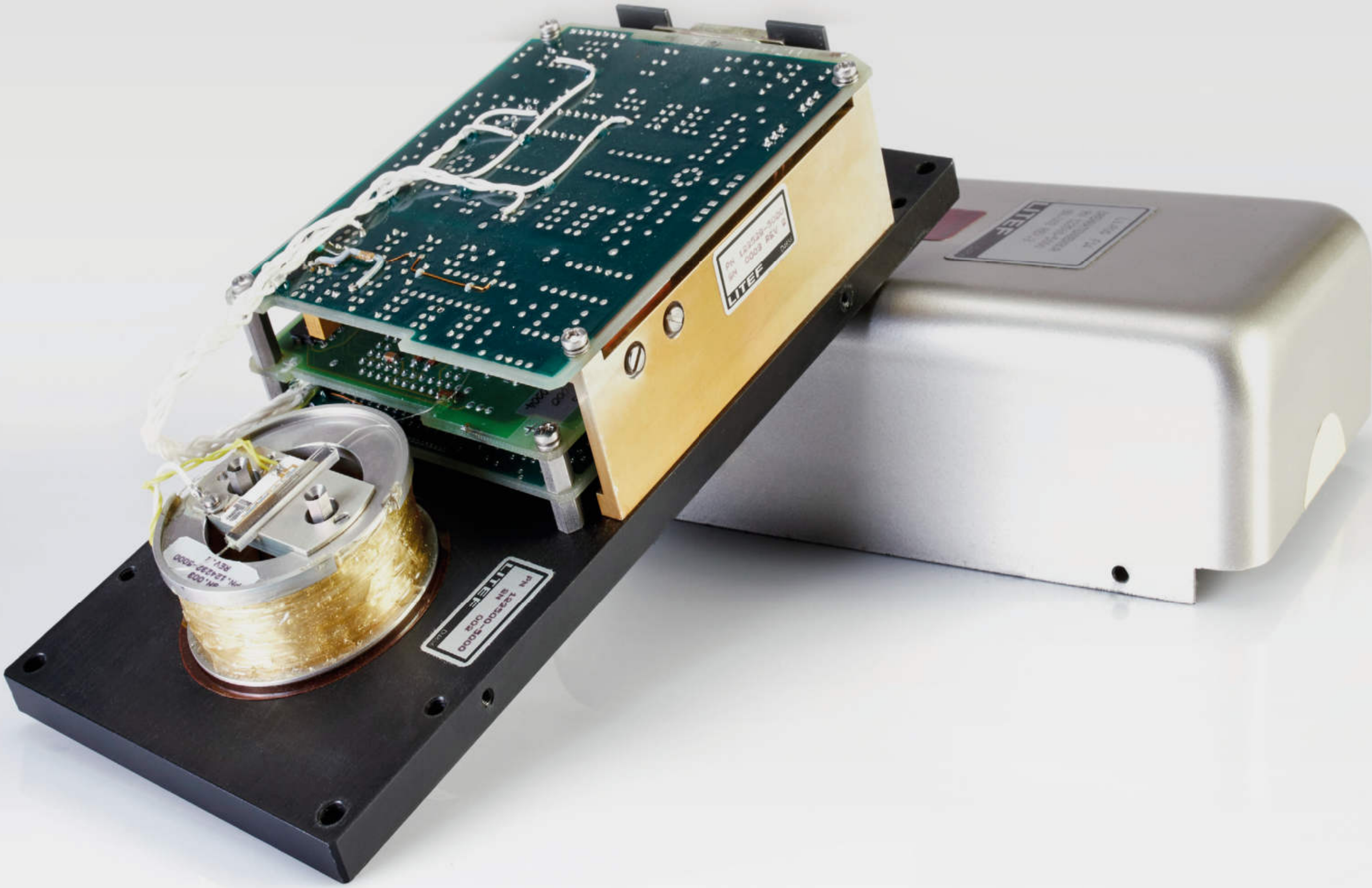
Device type	**FIBER OPTICAL GYRO**	
Manufacturer	Northrop Grumman LITEF GmbH Freiburg i. Br., Germany	
Year of manufacture	**1992 (LFS-90)**	**1990 (LI.FOG F14)**
Dimensions	160 x 100 x 35 mm	190 x 108 x 52 mm
Weight	< 0.7 kg	< 1 kg
Accuracy	100 deg/h	4 deg/h
Application	flight control	autonomous vehicle
Life time	10 years	10 years
Service interval	none	none

MECH RLG **FOG** MEMS



LFS-90

The LFS-90 is a small three-axes rate gyro unit, which also includes all electronics required for the scaled, error compensated digital rate outputs. The development of this fiber optical device was started early in 1990 and led to a modular design with only one single light source for all three orthogonal sensing coils, one coupler array, and three photodetectors. Like the LFS-90, the Li.FOG F14 is also an early fiber optical sensor unit from Litef but with only one input axis. It includes the Sagnac interferometer, a control circuit for closed-loop operation, a processor for error compensating of the output signal, and built-in test routines.



100 mm

LI.FOG F14

BOSCH AUTOMOTIVE GYRO PACKAGE

OBJECT 21

A loan from iMAR Navigation GmbH

Device type	**MEMS GYRO / ACCELEROMETER PACKAGE** Prototype and Production Unit
Manufacturer	Bosch, Reutlingen, Germany
Year of manufacture	1999
Dimensions	approx. 72 mm x 80 mm x 33 mm
Weight	approx. 0.15 kg
Accuracy	< 0.5 deg/s, < 30 mg
Application	automotive vehicle control
Life time	unknown
Service interval	maintenance free

MECH RLG FOG **MEMS**

In 1995, Bosch Reutlingen started to deliver MEMS sensors for automotive purposes. Three years later, the company launched this simple IMU on the market, which consists of a single yaw rate gyroscope (±100 deg/s measuring range) and a single accelerometer for lateral vehicle accelerations (±2 g measuring range). Both sensors were manufactured by silicon micromachining, which aims at mass production and high-performance applications like the Vehicle Dynamic Control System VDC BOSCH.


BOSCH
0 265 005 219
LU 001 540 44 17
0001784 99354
FOV 001 542 9018
078
Made in Germany 168
Stoss-
empfindlich

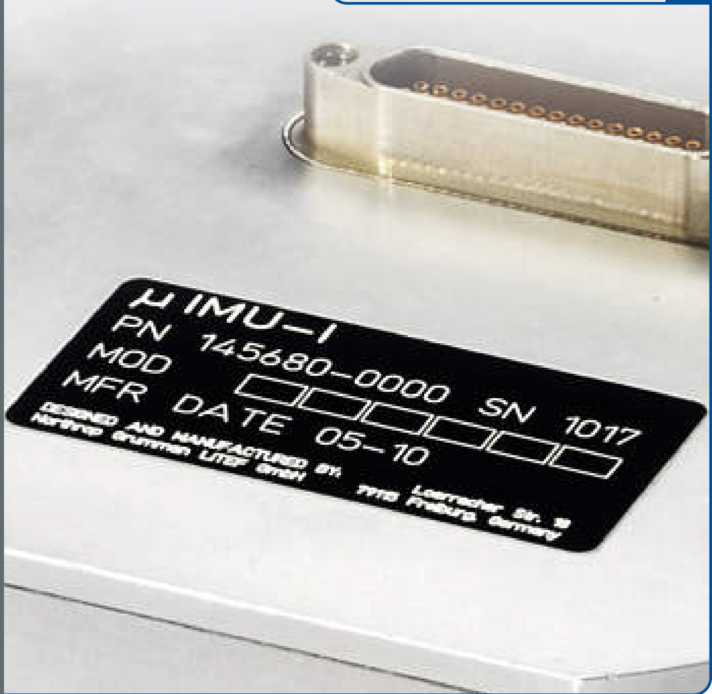
100 mm

LITEF µIMU-1

OBJECT 22

A loan from Northrop Grumman LITEF GmbH

Device type	**MEMS IMU**
Manufacturer	Northrop Grumman LITEF GmbH Freiburg i. Br., Germany
Year of manufacture	(since) 2012
Dimensions	Ø 85 mm, h 69 mm
Weight	0.68 kg
Accuracy	4 deg/h rms, 1.5 mg at ranges up to ±1500 deg/s, ±70 g
Application	aircraft navigation, stabilization
Life time	25 years
Service interval	none



MECH RLG FOG **MEMS**

Based on LITEF's broad experience with its IMUs, its fiber optic gyroscopes (object 20) and its tri-axis MEMS accelerometer B-290 (object 25), the µIMU-1 was designed. The unit is characterized by an integrated, self-contained configuration of three MEMS rate gyroscopes, three MEMS accelerometers, electronics, and power supply in a sealed housing. Furthermore, it includes standard digital interfaces, an output of fully compensated data (incl. temperature and misalignment), and extensive built-in-test procedures.


µIMU-I
PN 145680-0000 SN 1017
MOD
MFR DATE 05-10
uIMU-I UNIT
PN 152160-0000
REV – SN 1017
Northrop Grumman LITEF GmbH
79115 Freiburg, Germany
D4856

100 mm

HONEYWELL GG22B-1

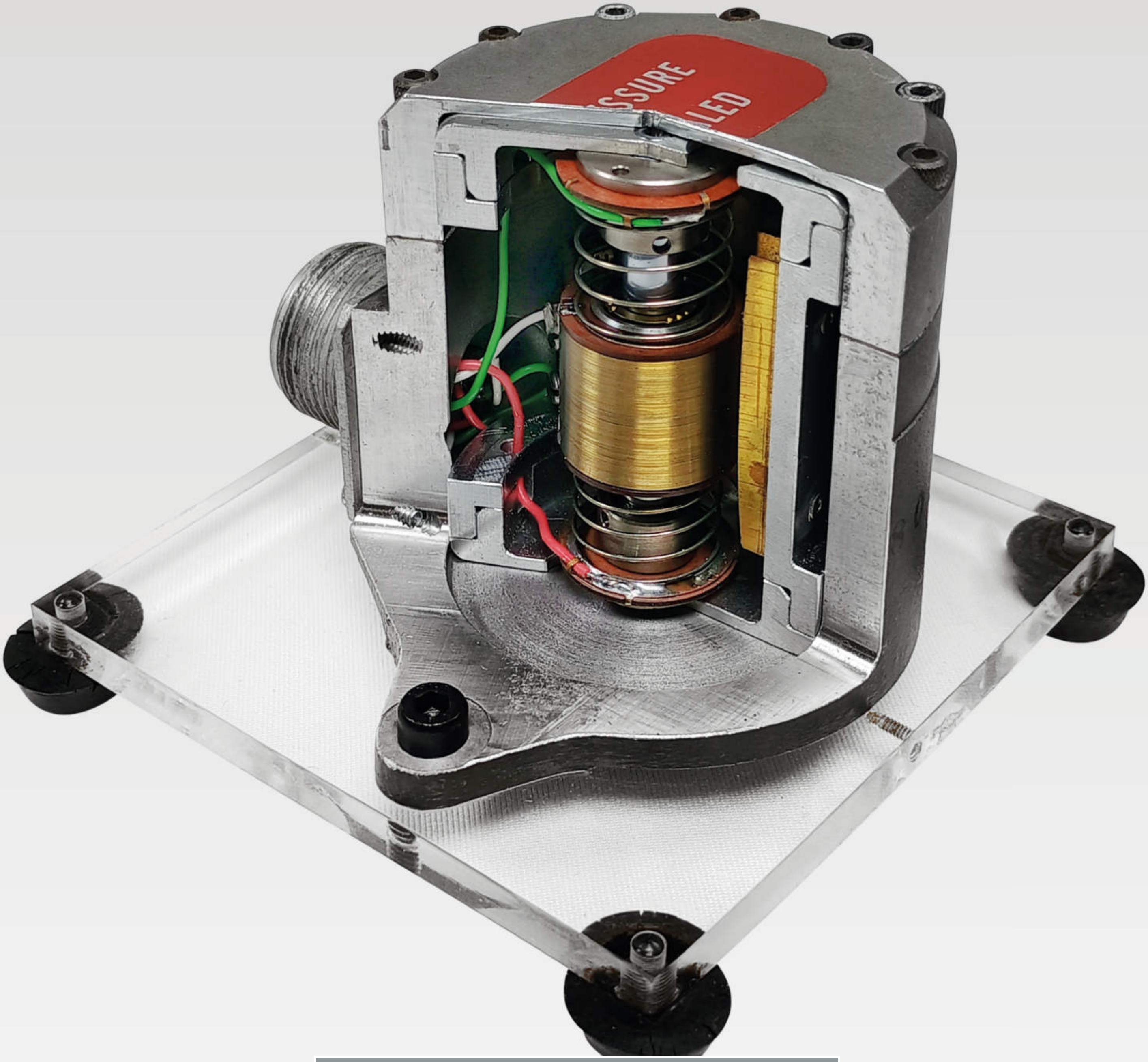
OBJECT **23**

A loan from University of Stuttgart

Device type	**ACCELEROMETER**
Manufacturer	Honeywell Regulator Co., Minneapolis, USA
Year of manufacture	1950s
Dimensions	137 mm x 120 mm x 184 mm
Weight	0.40 kg
Accuracy	
Application	aircraft navigation
Life time	
Service interval	

MECH RLG FOG MEMS

The Honeywell GG22B-1 is typical for the state of the art of accelerometers during the 1950s and 1960s. Initially, it was a bombing fire control component of military aircraft. The object is a donation of the German Air Force to the University of Stuttgart in the 1960s. Later, it was modified for teaching purposes in inertial sensors and inertial navigation systems.



100 mm

LITEF A-200

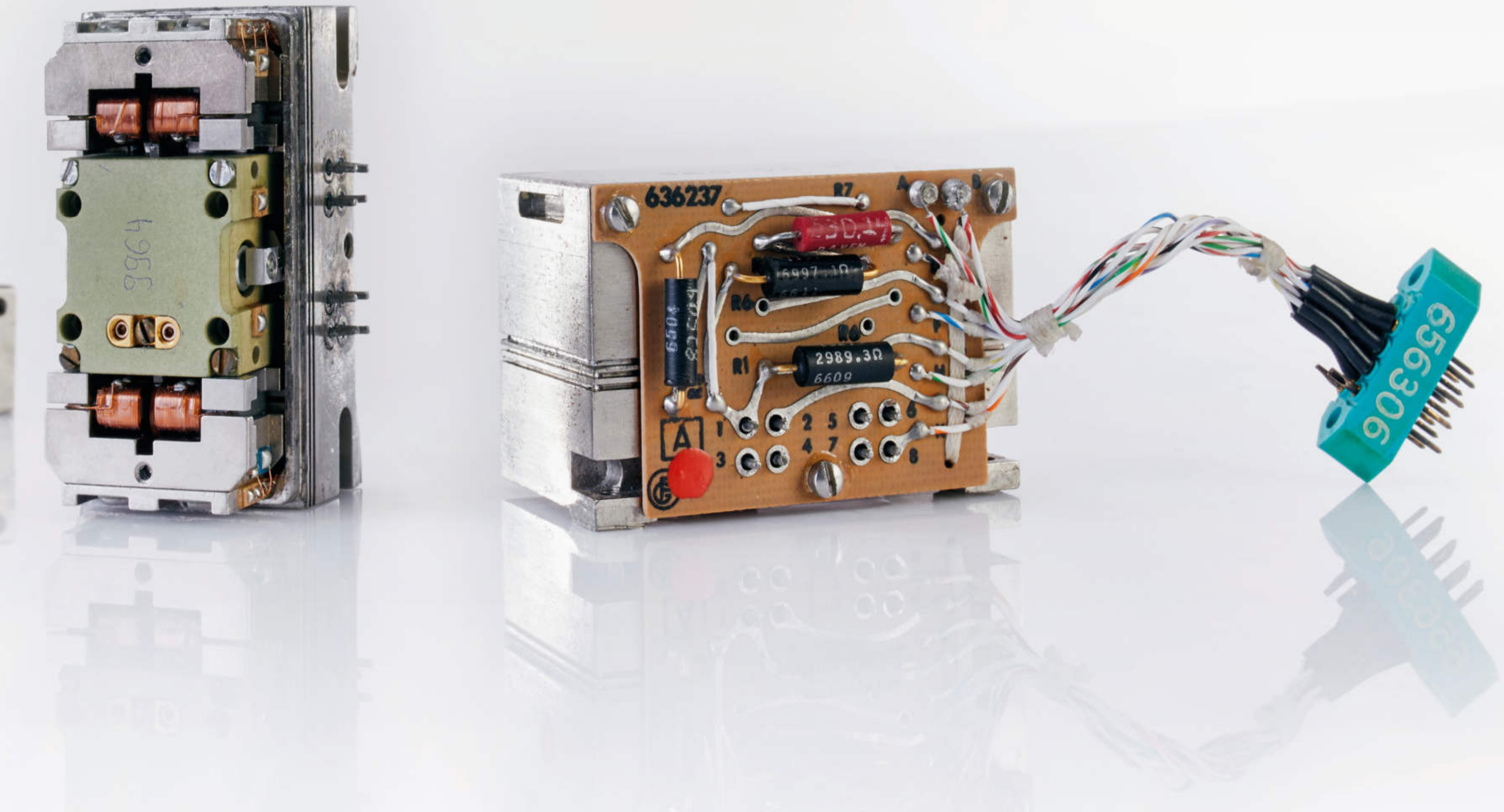
OBJECT **24**

Device type	**ACCELEROMETER**
Manufacturer	Litton LITEF, Freiburg i. Br., Germany
Year of manufacture	1963
Dimensions	25 mm x 28 mm x 45 mm
Weight	0.19 kg
Accuracy	1.5 mg for a measuring range of ±10 g
Application	aircraft navigation, stabilization
Life time	25 years
Service interval	none

A loan from Northrop Grumman LITEF GmbH

MECH RLG FOG MEMS

The Litef A-200 represents the state of the art for accelerometers from the early 1960s. It was used, among other applications, for the inertial platform Litton LN3 (object 26) and is based on an electromagnetically restrained pendulum. The electromagnetic force that is required to suppress the pendulum swing – caused by the acceleration along the input axis – is a measure of the sensed acceleration. The A-200 has to be powered by an alternating current of 7.5 V and 4.5 kHz. Its bandwidth is 100 Hz.



100 mm

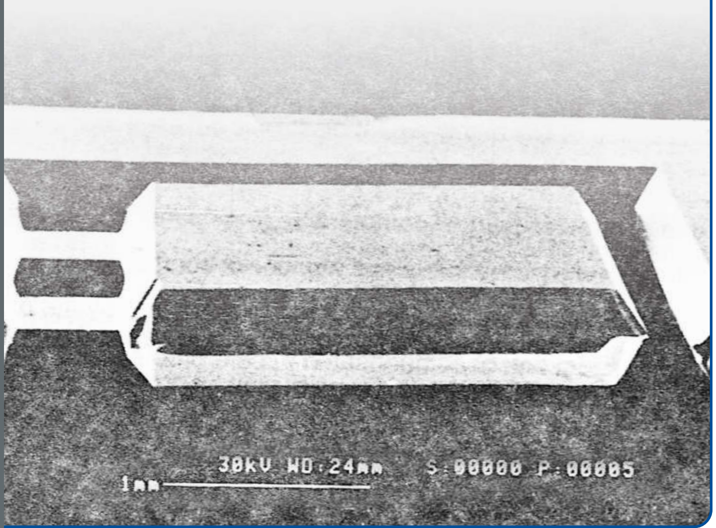
LITEF B-290

A loan from Northrop Grumman LITEF GmbH

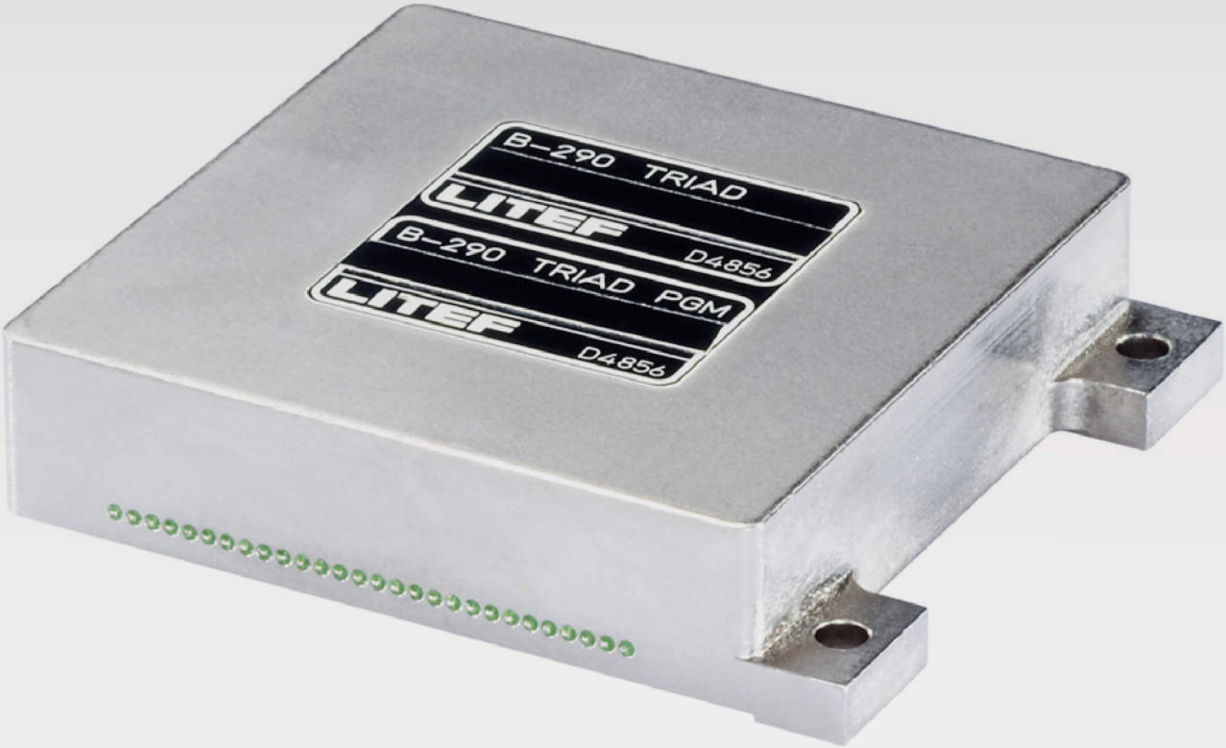
OBJECT 25

Device type	**tri-axis MEMS ACCELEROMETER**
Manufacturer	Northrop Grumman LITEF GmbH Freiburg i. Br., Germany
Year of manufacture	(since) 1990s
Dimensions	50 mm x 50 mm
Weight	0.080 kg
Accuracy	0.5 mg to 3.0 mg at ranges ±20 g to ±75 g
Application	aircraft navigation, stabilization
Life time	25 years
Service interval	none

MECH RLG FOG **MEMS**



The pictured B-290 triad consists of three accelerometers and is designed for applications like Attitude and Heading Reference Systems and Inertial Navigation Systems. The sensitive element of each accelerometer consists of an elastically suspended pendulum being fabricated from silicon by micro mechanical techniques. The pendulum swing, which is caused by the acceleration along the input axis, is sensed by a capacitive bridge and then balanced by a digital control loop via electrostatic forces. The signal of the controller is a measure of the sensed acceleration and includes a temperature compensation of bias and scale factor.



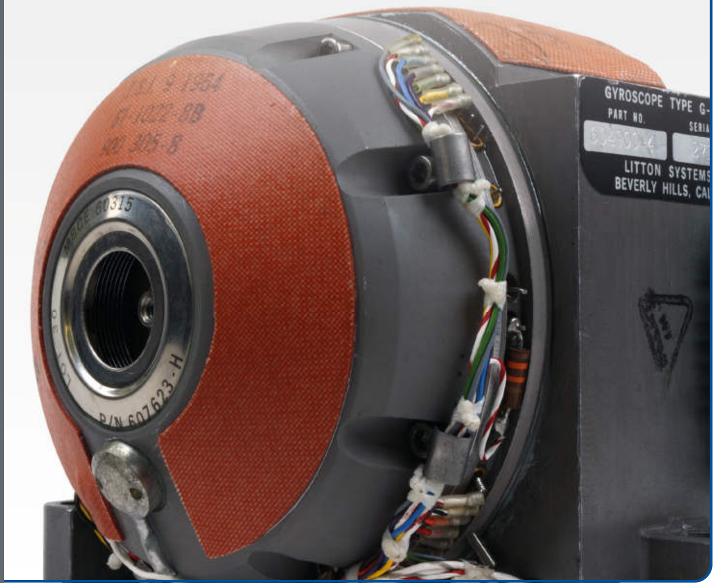
50 mm

LITTON LN3-2A

OBJECT 26

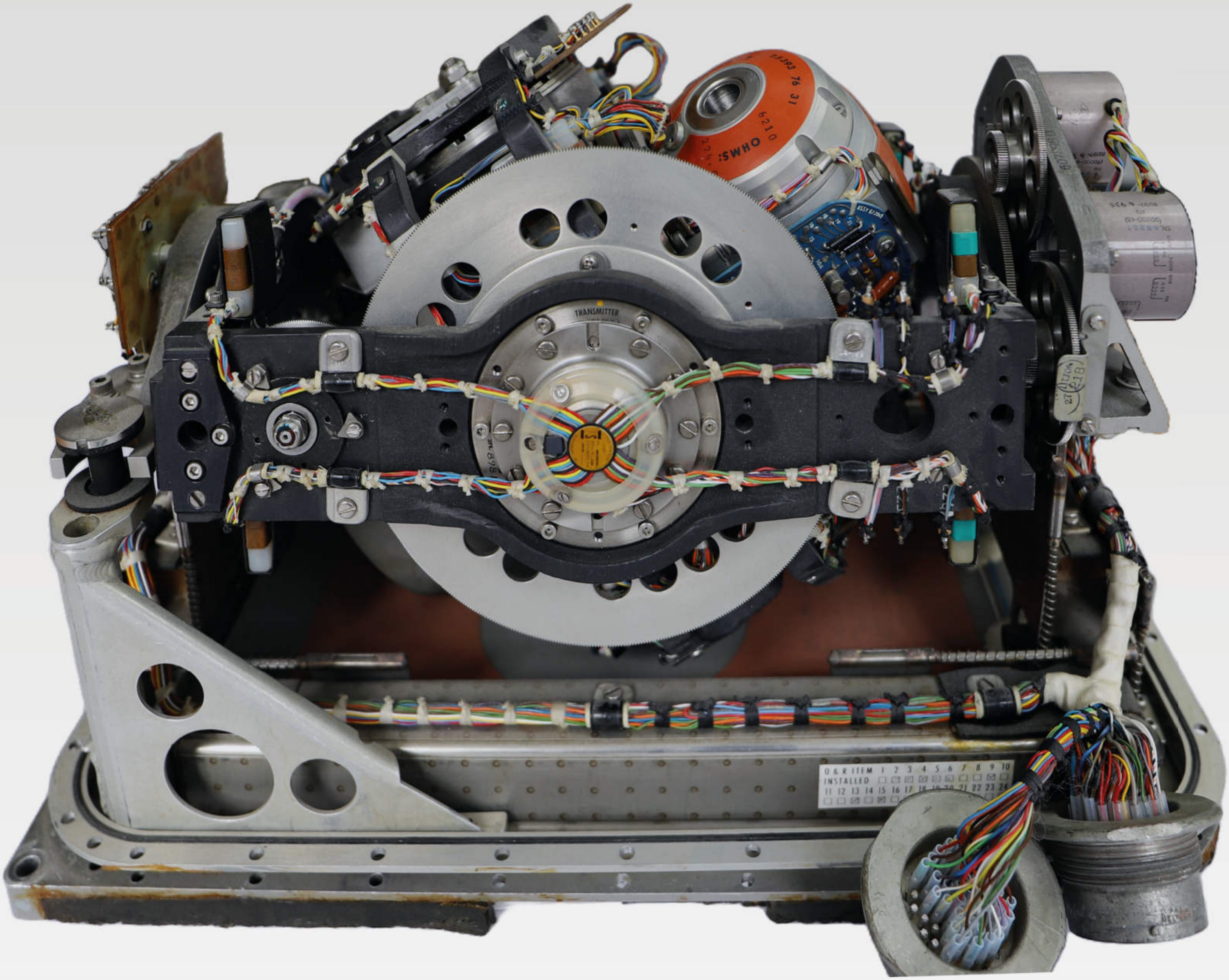
A loan from TU Braunschweig

Device type	**MECHANICAL PLATFORM**
Manufacturer	Litton, Freiburg i. Br., Germany
Year of manufacture	1966
Dimensions	350 mm x 250 mm x 250 mm
Weight	10 kg
Accuracy	2 NM/h (c.e.p.)
Application	inertial navigation for F-104G Super Starfighter
Life time	several years
Service interval	



MECH RLG FOG MEMS

The LN-3 is an inertial navigation system (INS) and was the first INS of Litton Industries. It had been developed in the early 1960s with participation of the German company C. Plath, Hamburg, and was designed for the Lockheed F-104G Starfighter aircraft of several European air forces. The LN-3 is based on a platform being stabilized by two 2-degrees-of-freedom gyros G-200 (encapsulated rotor with electromagnetically realized cardanic support). The platform carries three accelerometers A-200 (object 24) and is embedded in four gimbals to avoid a gimbal lock.



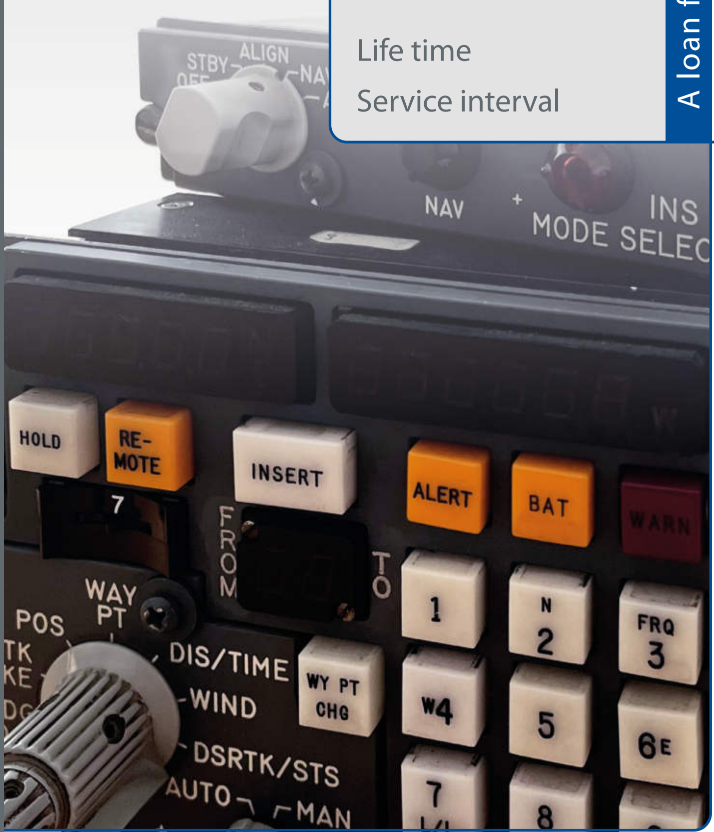
100 mm

DELCO CIV A III INERTIAL NAVIGATION UNIT

OBJECT 27

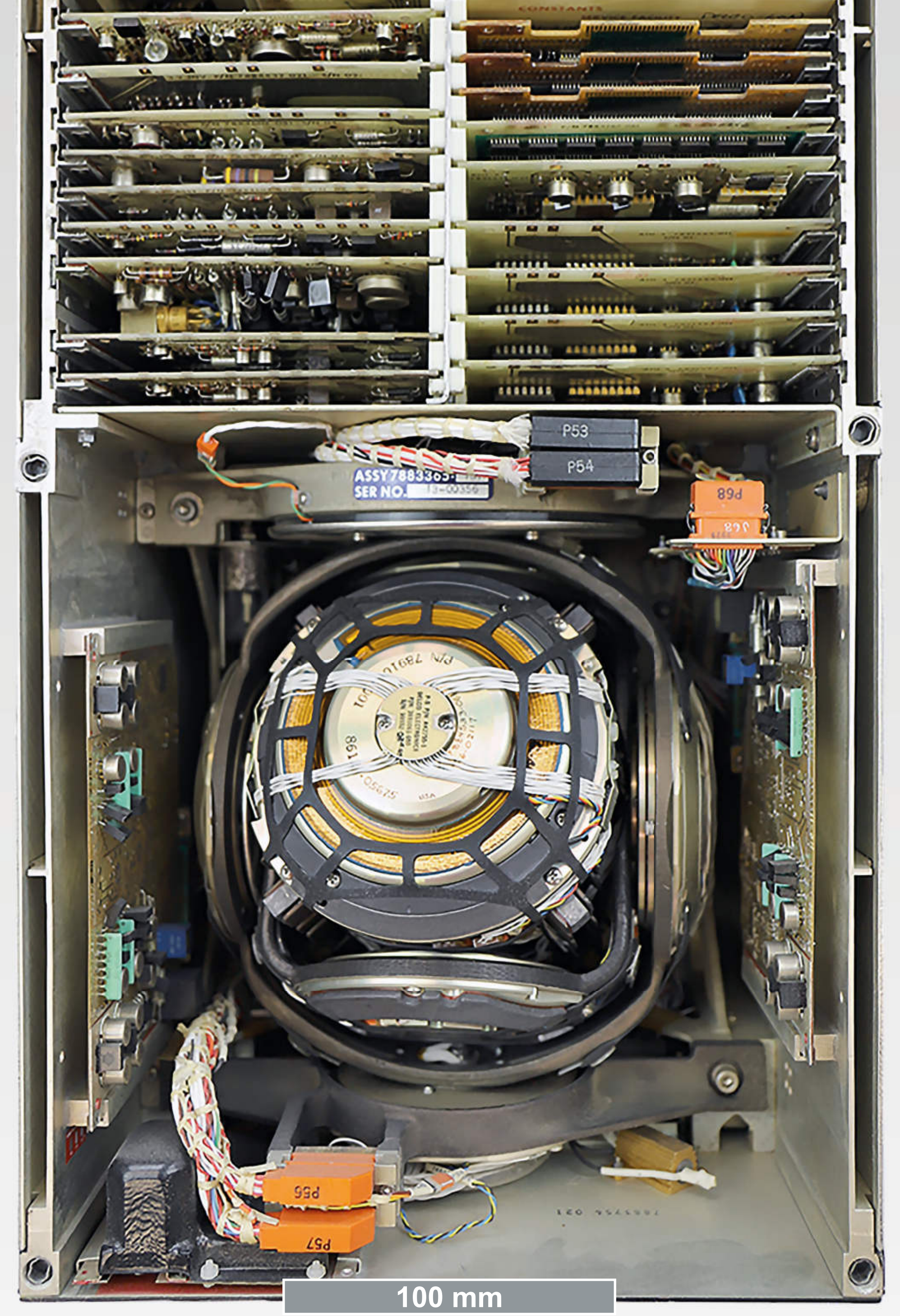
A loan from TU Braunschweig

Device type	**MECHANICAL PLATFORM**
Manufacturer	Delco Electronics Corporation, Kokomo, IN, USA
Year of manufacture	1980
Dimensions	500 mm x 255 mm x 190 mm
Weight	22 kg
Accuracy	2 NM/h
Application	inertial navigation for B747, B707, DC-10, L-1011 etc.
Life time	several years
Service interval	



MECH RLG FOG MEMS

The Delco CIV A III was developed in the late 1960s and represents the first factory-fitted INS in commercial aircraft. It is based on a platform carrying three mechanical rate integrating gyros with gas bearings and three accelerometers in a temperature stabilized environment. It allows to automatically navigate along a series of waypoints, which have to be entered by the pilots via a control console. Typically, the aircraft were equipped with two or three Delco CIV A III for redundancy. The name of the system originates from the design feature that the platform is rotated 360° every 60 seconds to increase accuracy by compensating systematic errors.

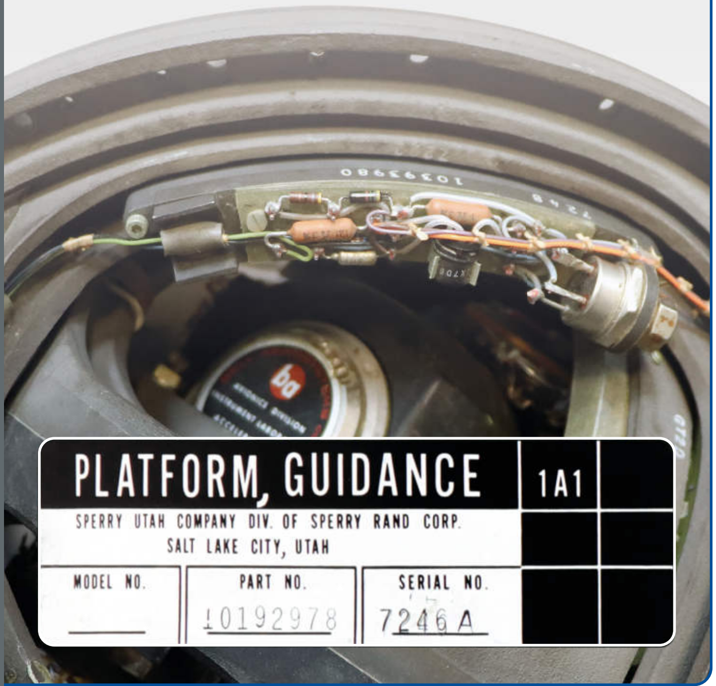

P53
P54
SER NO.
100 mm

SPERRY GYRO PLATFORM

OBJECT 28

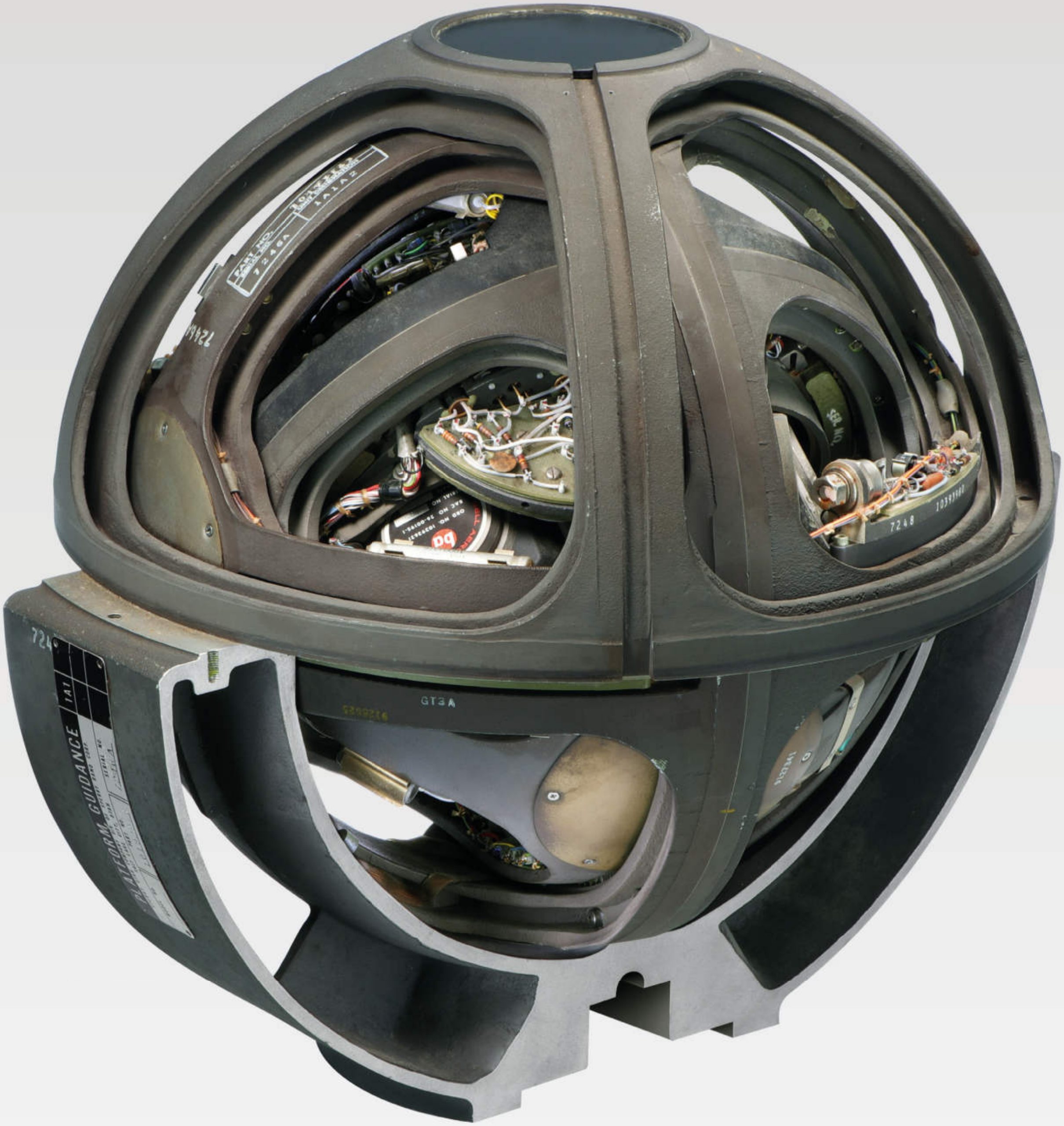
A loan from iMAR Navigation GmbH

Device type	**MECHANICAL PLATFORM**
Manufacturer	SPERRY Utah Co., Div. of SPERRY RAND Co., Salt Lake City, UT, USA
Year of manufacture	before 1979
Dimensions	approx. 390 mm x 370 mm x 340 mm
Weight	N/A (parts missing)
Accuracy	
Application	navigation / guidance
Life time	
Service interval	



MECH RLG FOG MEMS

Sperry Utah Engineering Laboratory played a key role in the development of inertial navigation systems (INS) for intercontinental ballistic missiles (ICBMs) during the 1950s and 1960s, particularly for the Minuteman missile programs of the U.S. Air Force. Detailed information about the gyro platform is not public, but the system was likely manufactured in the early 1970s but not later than 1979 when Sperry Rand was renamed to Sperry Corporation (see type plate).



100 mm

iMAR iDIS-FC

OBJECT 29

A loan from iMAR Navigation GmbH

Device type	**STRAPDOWN PLATFORM** with early FOGs, aiding: GNSS and optional external magnetometer
Manufacturer	iMAR Navigation GmbH, St. Ingbert, Germany
Year of manufacture	1993
Dimensions	approx. 290mm x 220 mm x 160 mm
Weight	approx. 7.4 kg
Accuracy	< 10 deg /h, < 0.5 deg heading, < 5 mg, < 0.1 deg roll/pitch
Application	automotive and military vehicles
Life time	several years
Service interval	maintenance free

MECH RLG **FOG** MEMS

The iDIS-FC is the first strapdown INS for automotive testing. Its development was initially contracted by Mercedes-Benz, and the solution replaced mechanical platforms. The system is equipped with 3 closed-loop fiber optic gyros FOG-P1-A1 from SEL/SFIM, 3 servo-accelerometers Sundstrand QA700, an integrated GPS receiver, and an external fluxgate magnetometer. While usual spinning platforms could be damaged by sudden power loss during automotive tests, the strapdown technology proved to be robust against such outages and could also cope angular rate overranges. Production started in 1993; the pictured system is from 1999, and the window inside the cover had been applied for the exhibition of this catalog.

100 mm

	Object	
University of Stuttgart Chair of Flight measuring Technology	01 02 03 04 05 07 08 10 11 14 23 24 26	**University of Stuttgart** Chair of Flight Measuring Technology Pfaffenwaldring 31 70569 Stuttgart, Germany
DIEHL Defence	03 09 12	**Diehl Defence GmbH & Co. KG** Alte Nußdorfer Straße 13 88662 Überlingen, Germany
Technische Universität Braunschweig	06 26 27	**Technische Universität Braunschweig** Institute of Flight Guidance Hermann-Blenk-Str. 27 38108 Braunschweig, Germany
LITEF	13 20 22 24 25	**Northrop Grumman LITEF GmbH** Lörracher Straße 18 79115 Freiburg, Germany
iMAR NAVIGATION & CONTROL	14 15 16 21 28 29	**iMAR Navigation GmbH** Im Reihersbruch 3 66386 St. Ingbert / Germany
SAFRAN	17 18 19	**Safran Electronics & Defense Germany GmbH** Gottlieb-Daimler-Strasse 60 71711 Murr, Germany

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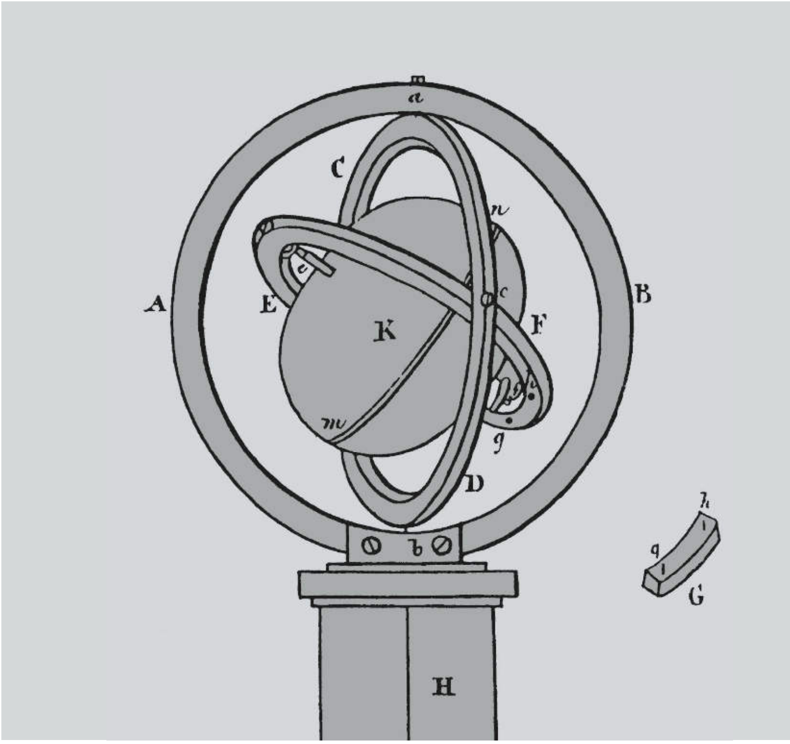

First gimbal-mounted gyroscope,
Johann Gottlieb Friedrich von Bohnenberger (1810)

1965-1970	DGON Fachausschuss 8
1971-1978	Symposium Kreiseltechnik
1979-2010	Symposium Gyro Technology
2011-2023	DGON Inertial Sensors and Systems
since 2024	DGON Inertial Sensors and Applications

DGON