Coaxial Cables Support the LISA Gravitational Observatory in Space

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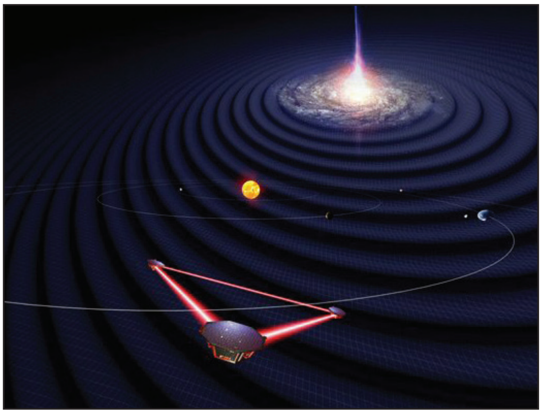
The company SSB-Electronic GmbH from Lippstadt, Germany, specialized in high frequency solutions, is working with the University of Florida and supporting the team at the Precision Space Systems Laboratory (PSSL) on a new space project, the development of a special charge management device for the ESA and NASA Laser Interferometer Space Antenna (LISA) space mission. SSB-Electronic's coaxial cables are used to evaluate conformity with the strict timing requirements of the LISA project.



▲ Fig. 1 Artist's rendition of LISA once deployed in orbit. *Source:* University of Florida

LISA is the first gravitational wave observatory in space[1] and one of three large-class missions in ESA's "Cosmic Vision 2015-2025" program. The LISA mission, led by ESA, is a collaboration between ESA, NASA and an international consortium of scientists from 20 ESA member states, including the Max Planck Institute for Gravitational Physics in Hanover, DLR Institute of Space Systems in Bremen as well as numerous universities and institutes worldwide such as the University of Florida in Gainesville.[2]

LISA will consist of three identical spacecraft, separated by 2.5 million km, which will trail the Earth on their orbit around the sun in a triangular formation (see ***Figure 1***).[3] These three spacecraft will be connected by laser beams forming a

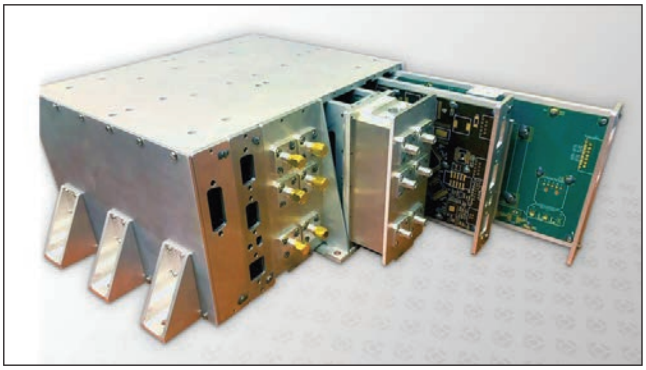


Fig. 2 LISA charge management device prototype. *Source:* University of Florida.

high-precision laser interferometer with millions of kilometer-long laser arms. Compared to the already existing ground-based gravitational waves observatories like Geo 600, LIGO or VIRGO,[4] LISA will address the much richer frequency range between 0.1 mHz and 1 Hz, which is inaccessible on Earth due to arm-length limitations and terrestrial gravity gradient noise arising from terrestrial gravity fluctuations. These fluctuations are caused by seismic activity, atmospheric disturbances (e.g. wind, rain, cloud movement) and anthropogenic activities (industry, busy roads or train routes).[4,5] From space, LISA can avoid the noise from Earth and access regions of the gravitational wave spectrum that are inaccessible from Earth due to its extremely long arms.[1]

The aim of the LISA mission is to complement terrestrial detectors in investigating new areas of the gravitational wave spectrum.[1] Like ground-based detectors, LISA is based on heterodyne laser interferometry. The three LISA spacecraft relay laser beams back and forth between them and the signals are combined to search for gravitational wave signatures that come from distortions of spacetime. The gravitational wave sources that LISA would discover include supermassive black hole mergers, neutron star mergers and other major astrophysical events such as the Big Bang.[3] Gravitational wave detection with LISA will complement our knowledge about the beginning, evolution and structure of our universe.[3]

The LISA mission is scheduled to be launched in 2034. From there, the LISA spacecraft will take approximately a year to reach and enter orbit around the sun and will then collect scientific data over a period of at least eight to 12 years.

The LISA mission needs many new key technologies to work including high-end optics and micro-thrusters.[2] Various systems and components are being developed for the mission in numerous projects around the world. For example, the scientists of the Cluster of Excellence Quantum Universe at the University of Hamburg are working on an electronic phase measurement system, a phase meter for ultra-precise laser-based length measurements at low frequencies, as well as optical components for the ground equipment.[3]

DEVELOPMENT OF THE CHARGE MANAGEMENT DEVICE AT THE UNIVERSITY OF FLORIDA

Another example is the project at the University of Florida. A team of researchers, professors and students at University of Florida led by John W. Conklin and Peter Wass (Department of Mechanical & Aerospace Engineering) in collaboration with Professor Dr. Guido Mueller (Department of Physics) has been awarded a $12.5 million NASA contract to build and test a prototype of a charge management device for the space mission by July 31, 2025 (see ***Figure 2***).

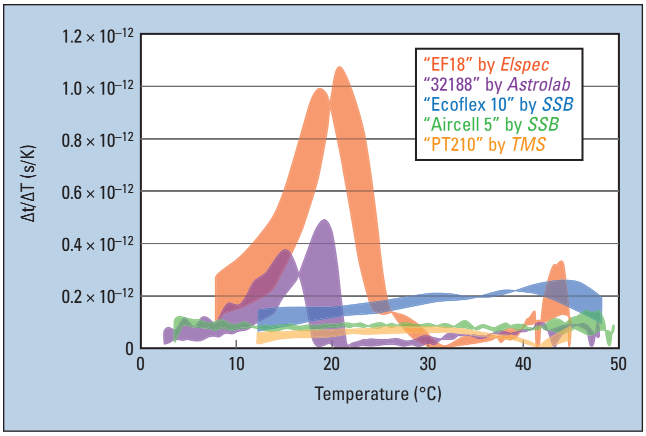


Fig. 3 Phase stability of five cables. *Source:* Simon Barke.[8]

This charge management system is a ultraviolet (UV) light device that can monitor electrical charges of the free falling test masses inside the three LISA spacecraft. These test masses are cubes made of a gold-platinum alloy, each with an edge length of 46 mm and a weight of 2 kg. The charge management device will shine the appropriate amount of UV light on the test masses to keep their charges at zero, preventing unwanted motion.[6] The job of the University of Florida team is to ensure nothing but gravitational waves move the particle masses and that the discharge of the test masses does not generate any undesirable side effects.[6]

Two internal test masses per spacecraft are used, each one dedicated to a single interferometry arm.[7] Every spacecraft uses high-precision heterodyne laser interferometry to measure extremely small distance variations (pm to nm) between the test masses caused by gravitational waves. All test masses inside the three spacecraft will be in free fall along the lines of sight between the spacecraft and serve as inertial sensors for estimating position.[4] The test masses are shielded by the containing spacecraft against external perturbations. Capacitive sensors surrounding each test mass will monitor their positions and orientations with respect to the spacecraft. To keep each satellite centered on the test masses the tiny orbital and attitude corrections will be determined by a drag-free attitude control system using the measurements of inertial sensors. This system of regulating the satellite position enables new missions which, for example, will also be used to measure the effects of climate change on the planet in the future. LISA will detect gravitational waves with three independent interferometric combinations of the light travel time measurements between the test masses along the sides of a triangular configuration.[7]

COAXIAL CABLES FROM SSB-ELECTRONIC EVALUATE COMPLIANCE WITH THE PROJECT REQUIREMENTS

The coaxial cables of SSB-Electronic are used at the PSSL of the University of Florida for test stands that will evaluate the LISA charge management system under the NASA contract. According to Simon Barke, one of the technical directors of the PSSL, the success of the PSSL team, but also of the entire LISA mission, depends on the phase stability of high frequency signals that help track changes in distance between the test masses. Gravitational waves are expected to affect this distance by just a few picometers. Changes in distance will be translated to slow (mHz) phase shifts on the order of microradians in a 20 MHz electrical detection

TABLE 1
TEST CABLE SPECIFICATIONS[8]

Cable Name (Manufacturer)	Dielectric Material	Operating Temperature (°C)	Maximum Frequency (GHz)	VoP (%)	$\Delta t/\Delta T$ (s/K)
EF18 (Elspec)	Low Density PTFE	-40 to 85	18	77	1.2×10^{-12}
32188 (Astrolab)	Low Density PTFE	-55 to 200	27	86	4.9×10^{-13}
Ecoflex 10 (SBB)	Low Density PE	-55 to 85	6	85	2.6×10^{-13}
Aircell (SBB)	Low Density PE	-55 to 85	10	82	1.4×10^{-13}
PhaseTrack 210 (TMS)	Proprietary TF4™	-55 to 85	29	83	8×10^{-14}

signal. The phase of a 20 MHz signal will be tracked with subpicosecond precision over hours.

Spurious phase noise caused by any device in the measurement chain would spoil these delicate measurements. One limiting noise source is electrical cables. Temperature fluctuations can change the length and electrical properties of the cable, which results in a phase change of the signals. For the LISA project, cables must be used that will not change the phase of an electrical signal over temperature.

To evaluate the phase stability of different test cables, the change in signal arrival time (Δt) over temperature change (ΔT) per meter cable is measured.[8] A 2 GHz signal is split and passed through the cable under test and a reference cable of equal design and length. With a special device, a 28 cm section of the cable under test is heated and cooled in the range of 5°C to 50°C, which is the temperature range expected inside LISA spacecraft.[8] The phase of both signals is measured after mixing them down to a more convenient frequency of 1.6 GHz. Five candidate cables of three different types are used for the test, distinguished by different dielectric layers: polytetrafluoroethylene (PTFE), low density polyethylene (PE) or TF4™ (proprietary fluorocarbon dielectric material from the company TMS).

Figure 3 shows the results of measurements to evaluate the phase stability of the test cables. The width of each trace reflects the range of the calculated timing stability coefficients that are different for cooling and heating periods.

The results show that the cables with dielectrics based on PTFE exhibit an inherent, non-linear phase change when the material passes through the temperature range of 15°C to 25°C. These cables are therefore unsuitable for the LISA project.

The coaxial cables from SSB-Electronic using a PE dielectric, especially the cables of the Aircell 5 series, offer a flat temperature coefficient of maximum. $\Delta t/\Delta T = 1.4 \times 10e^{-13}$

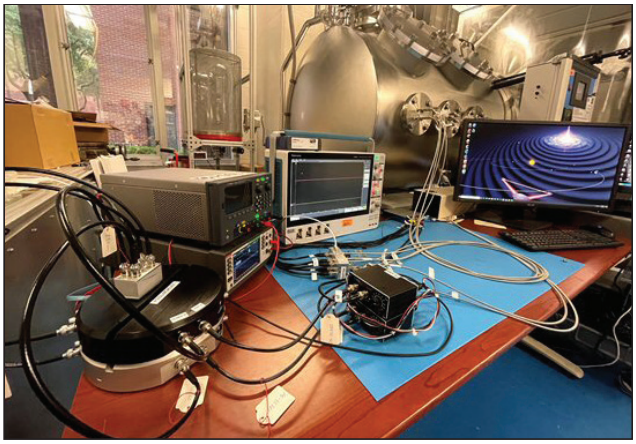


Fig. 4 Test stand at PSSL. *Source:* University of Florida.

over a wide temperature range from 5°C to 50°C. These are among the most phase stable cables in the industry. Specifications of the cables under test, including the measured maximum timing stability coefficients per meter, are summarized in ***Table 1***.

Based on the measurement results, PSSL chose Aircell 5 cables for use in a test stand to evaluate the LISA charge management system under the NASA contract. Aircell 5 cables are used to carry electrical pulses from a frequency reference and photomultipliers tubes to Moku:Lab phasemeters. ***Figure 4*** shows the setup of the test stand at the PSSL, University of Florida. The cables enable confirmation that the light pulses emitted by the charge management system and detected by the photomultiplier tubes conform to the strict timing requirements of the LISA project.

CONCLUSION

Coaxial cables from SSB-Electronic are used in current basic research projects and are also suitable for space applications due to their phase stability. They are an attractive alternative to TF4 cables, especially for ground support equipment and test stands. ■

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