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TEPEE/GReAT (General Relativity Accuracy Test in an Einstein Elevator): Ready to start

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Summary. — TEPEE/GReAT is an experiment aimed at testing the principle of equivalence at a level of accuracy equal to 5 parts in 10^{15} by means of a differential acceleration detector free falling inside a co-moving, cryogenic, evacuated capsule, released from a stratospheric balloon. The detector is spun about a horizontal axis during the fall in order to modulate the equivalence principle violation signal at the spin frequency. Thanks to the recent funding of the Italian side, the project is ready to enter its second phase. The main activities related to detector prototype (both non-cryogenic and cryogenic versions) development and testing, free-fall tests, signal extraction from noise (in particular related to the common-mode rejection factor) and flight model requirements are discussed.

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1. – Introduction

The principle of equivalence is at the very basis of currently accepted theories of gravitation. This special position among the hypotheses on the machinery of the physical world makes its verification particularly important and justifies the current improvement attempts. Over the years, different formulations of the equivalence principle have been given [1]. The basic version, which states that the *inertial mass* (or simply *mass*) is proportional to the *gravitational mass* (or *weight*), is called the Weak Equivalence Principle

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TABLE I. – *Comparison of GReAT performance with those of proposed space experiments.*

Name	Accuracy	Type	Funding institution(s)
STEP	10^{-18}	(drag-free satellite)	NASA
GG	10^{-17}	(drag-free satellite)	INFN/ASI
MicroScope	10^{-15}	(drag-free satellite)	CNES/ESA
GReAT	5×10^{-15}	(drag-shielded capsule)	ASI/NASA

(WEP). Another way of stating this principle is that the trajectory of a test body([1]) is independent of its internal structure and composition. This means that two different bodies, in the same gravitational field, will fall the same way: this fact is known as Universality of Free Fall (UFF). This type of test is, conceptually speaking, very simple and was the subject of studies by Galileo Galilei.

The independence of a gravitational trajectory from the particular body opens the way to a geometric view of (curved) spacetime. The Einstein's Theory of General Relativity, indeed, is based on a stronger formulation of the principle, the so-called Einstein Equivalence Principle (EEP), which includes WEP. An important part of our current knowledge of physical world is based on the WEP and, consequently, it is of primary importance to test whether (and at what scale) it could break down.

In the last decades several experiments were set up to test the validity of WEP (for a review see [1]). Apart from Lunar Laser Ranging (LLR) and free-fall experiments, the majority of them were performed on-ground, where several sources of noise (seismic noise among them) ultimately limit their accuracy. The environment offered by space is suitable for consistent improvements; at least three space experiments—MicroSCOPE, STEP, GG—were proposed, all of them based on accurate comparison of falling test masses.

However, space experiments are very costly and need a rather long time to be developed. The GReAT experiment described in this paper has the advantage of combining the relative low-noise environment, given by free fall in Earth's gravity, with repeatability, resulting in a competitive performance with respect to other ongoing projects. It aims at reaching an accuracy of 5 parts in 10^{15}, by measuring the differential accelerations acting on two masses that are free falling inside a capsule dropped from a balloon at a stratospheric altitude. In table I the performance of GReAT is compared with those of the above-mentioned space experiments.

The development of a differential accelerometer for the detection of a possible WEP violation has been funded by the Italian Space Agency. A new grant for further development of the accelerometer is pending.

In the following, we describe the experiment, focusing on its various parts (see also [2-5]) and its error budget.

2. – General description

The GReAT experiment aims to test the WEP to several parts in 10^{15} by releasing in free fall a very sensitive differential accelerometer inside a co-moving capsule. The

([1]) A test body is one sufficiently small to neglect tidal effects and not acted upon by other interactions such as electromagnetism.

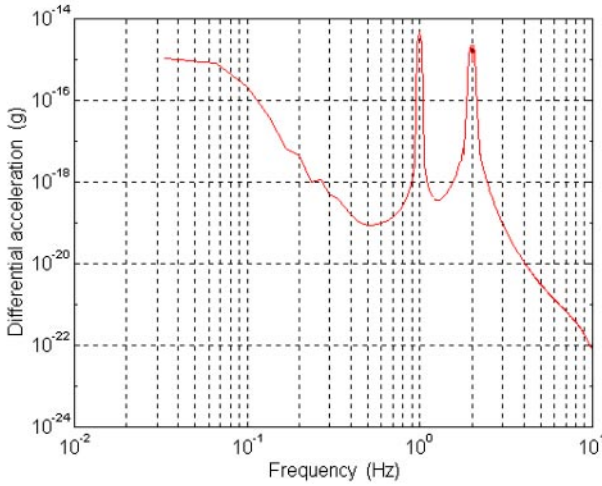

Fig. 1. – Numerical simulation for the gravity gradient due to the capsule and to the Earth on the differential accelerometer compared with the hypothetical WEP-violating signal at 1 Hz. The spectral analysis shows clearly two peaks, the left peak (at lower frequency) related to the WEP violation and the other peak (at higher frequency) related to gravity gradients.

capsule is already free falling after having been dropped from a balloon at an altitude greater than 40 km. The experiment will involve the precise measurement of differential accelerations between two masses made of different materials which are the proof-masses of a high-sensitivity differential accelerometer (*i.e.* the detector). The detector is housed inside an instrument package that will be slowly spun, before release inside the capsule, about a horizontal axis to modulate the differential acceleration signal generated by a WEP violation. The expected signal can be seen in fig. 1, where a numerical simulation is shown for a spin frequency of 1 Hz: the differential acceleration inside the capsule (based on a 4 μm displacement between the centers of mass of the two sensing masses) and a hypothetical WEP-violating signal are apparent in the spectrum. The experiment, with an estimated accuracy of 5 parts in 10^{15}, at 95% confidence level, will improve the accuracy in validating the WEP by about two orders of magnitude with respect to the most accurate tests conducted thus far.

The capsule (see fig. 2), with external dimensions of about 5 m in length and 1.5 m in diameter, is slightly decelerated by the rarefied atmosphere during the fall and, consequently, it moves slowly upward with respect to the detector that is in *real* free fall. The capsule contains an evacuated cryostat with inner dimensions of ca. 2 m length and 1 m diameter in which the instrument package free falls. In the up to 28 s interval in which the detector spans the internal length of the cryostat, the capsule falls by less than 4 km and reaches a maximum Mach number of 0.8. At the end of the fall, the capsule is decelerated by a parachute for retrieval and subsequent re-flights.

Cryogenic refrigeration is provided by the cryostat to obtain low Brownian noise, high thermal stability, low thermal gradients, and a high Q-factor of the acceleration detector. These are necessary conditions to achieve the desired measurement accuracy. The overall mass of the capsule is 1500 kg as a baseline; this mass is a fairly standard load for high-altitude balloons. Heavier capsules will provide a little longer free-fall times with the same internal dimensions.

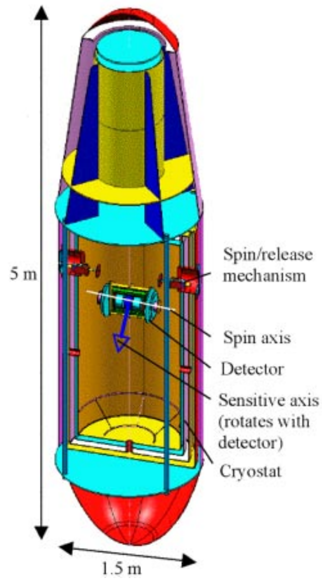

Fig. 2. – Sketch of capsule during free fall.

Our detector will be a differential accelerometer with an intrinsic noise spectral density of about $10^{-14}\,\mathrm{g}/\sqrt{\mathrm{Hz}}$. The detector will measure the differential acceleration between two sensing masses of different materials by measuring the variation of the capacitance between these masses when they move differentially under the influence of an external acceleration (*e.g.*, owing to a violation of the WEP). The detector is based on the experimental heritage of high-accuracy acceleration detectors developed in the last twenty years at IFSI (Istituto di Fisica dello Spazio Interplanetario). Its further development requires technology within the current state of the art.

3. – Experiment sequence

Upon reaching the balloon floating altitude of $\geq 40\,\mathrm{km}$ and checking the equipment status, the capsule is first released from the balloon; the instrument package, that is slowly spinning about its longitudinal (horizontal) axis, is released from the top of the capsule immediately thereafter.

The diameter of the capsule is important for tolerating vertical gradients of the lateral wind without the need for a propulsion system to compensate for their effect. The balloon will move at the speed of the local wind once the floating altitude has been reached. If the wind vertical profile were constant, the capsule and the instrument package would move laterally during the fall with the same initial lateral velocity and hence maintain the same lateral distance with respect to one another. Note also that the main Coriolis accelerations on the capsule and on the falling package are the same and, consequently, they do not affect their *relative* positions. However, if the wind vertical profile changes, the capsule will experience a lateral force that will change its lateral speed while the instrument package will not experience such force. A diameter of 1.5 m is large enough to guarantee that the instrument package does not touch the walls of the capsule with a lateral wind gradient up to 10 knots per kilometer of drop. If the balloon is launched during the periodically occurring wind reversal times, the vertical wind gradient is much smaller than the value indicated above.

Since the experimental package moves, at low speed, inside the capsule, the residual gas inside the capsule produces a small force on the free-falling package that can be expressed in terms of acceleration noise. Moreover, the high vacuum (10^{-4} Pa) inside the capsule attenuates strongly the propagation of disturbances from the wall to the free-floating detector. In a free-molecular regime, as it is inside the capsule, the acceleration level experienced by the instrument package due to the momentum imparted to the gas molecules by the vibrating walls can be expressed as follows:

$$a = \frac{A}{m}\frac{p}{\nu\omega}a_{\text{wall}}, \tag{1}$$

where A and m are the cross-section and the mass of the instrument package, ν is the thermal velocity of the residual gas, a and a_{wall} are the accelerations of the package and the wall, respectively, p is the pressure inside the capsule and ω is the angular frequency of the vibrating walls. If $p = 10^{-4}$ Pa and assuming that the residual gas inside the capsule is at the local external temperature, we obtain $a/a_{\text{wall}} \approx 10^{-10}$ at the signal frequency of our experiment. In other words, the high vacuum provides an excellent attenuation of the wall vibrations.

The maximum acceleration noise of the experimental package is therefore estimated to be less than 10^{-12} g, for a chamber pressure of 10^{-4} Pa, based on the acceleration level measured at the wall of the stratospheric drop system Mikroba. Consequently, our system of *double free* fall reduces the acceleration noise to values unmatched by any other Earth-based drop facility and comparable to values achieved on board drag-free satellites.

These acceleration noises produced by the residual gas are common-mode–type (*i.e.* they affect equally both test masses) accelerations and are further reduced by the common-mode rejection factor (CMRF) of the differential accelerometer. For a conservative value of 10^{-4} for the CMRF, the influence of these two accelerations on the differential measurement is made negligible.

It is also important to note that the acceleration noise components produced by the residual gas are proportional to the pressure inside the chamber. This means that the pressure can be reduced in successive flights if, for any unanticipated reasons, their influence on the measurement proves to be greater than estimated. It is, in fact, well within the state of the art to obtain pressures at room temperature as low as 10^{-6} Pa in large volumes.

4. – Differential acceleration detector

The differential acceleration detector (see fig. 3) measures the differential capacitance, and, consequently, the relative displacement along the sensitive axis x, between two double-faced capacitors: capacitive probe 1 is formed by sensing mass 1 and fixed plates As and A′s; capacitive probe 2 is formed by sensing mass 2 and fixed plates Bs and B′s. The displacement of sensing mass 1, for example, is detected by the series capacitors A and A′ which form one branch of a capacitive bridge while two additional reference capacitors form the other branch. The bridge is pumped by a quartz oscillator at a stable frequency of about 20 kHz in order to reduce the relevant noise temperature of the

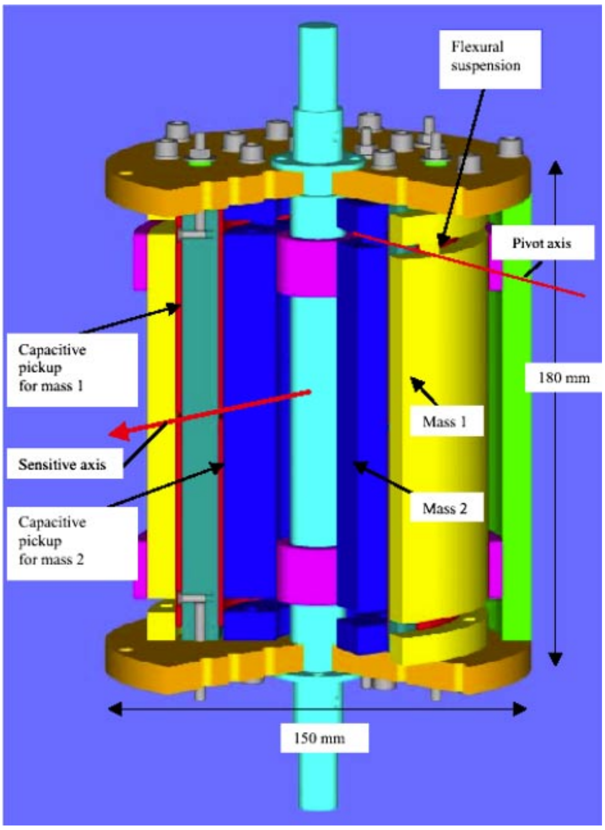

Fig. 3. – Outline of the differential accelerometer prototype.

preamplifier. The difference between the output signals from the capacitive probes 1 and 2 is amplified by a low-noise preamplifier, sent to a lock-in amplifier for phase-detection and eventually to a low-pass filter. There are also two more sets of fixed plates for each sensing mass that are used for feedback control.

Figure 3 shows the configuration of one of the differential detector prototypes built by our group at IFSI. The design of the proposed capacitive detector can accommodate a variety of sensing masses with different dimensions and materials. The differential detector must be designed as much as possible in a way that allows modifications from one flight to the next based on the lessons learned from the previous flight experience (much the same way as the adjustments made on instruments under development in a laboratory). Moreover, the centers of mass (CM) of the sensing masses are as close as technically possible to one another to minimize the effect of gravity-gradient forces, rotational motion, and linear accelerations upon the differential output signal. The two sensing masses of the flight detector will be made of different materials. The detector prototypes built and tested by IFSI, thus far, have used same-material sensing masses.

The two sensing masses are constrained by torsion springs to rotate about a common axis and their resonant frequencies are electrostatically controlled for frequency matching. On the one hand, the lower the resonant frequency the more sensitive the detector and the smaller the dynamic range. On the other hand, the higher the resonant frequency, the larger the dynamic range and the shorter the time constant of the transient oscillations. The value of the resonant frequency stems from a trade-off between sensitivity on one side and fast transient response and large dynamic range (and also tolerance to centrifugal forces) on the other side. A value of the resonant frequency in between 2–5 Hz strikes a balance between the above competing requirements. Once the instrument is built with a specific mechanical resonant frequency, this frequency can be lowered by supplying a constant voltage to the feedback-capacitor fixed plates. All the other modal frequencies of the instrument are at least two orders of magnitude higher than the controlled torsional frequency. This wide frequency separation allows most of the signal energy to excite the degree of freedom of interest. The sensing masses of this detector are not subjected to electrostatic charging because they are grounded to the instrument's case through the torsional springs. A high Q-factor is obtained by means of liquid-helium refrigeration and by eliminating dissipation sources, *i.e.* the torsion springs, the instrument's case and the capacitor moving plates are integrally machined from the same block of material.

The final design of the differential acceleration detector for the flight tests will capitalize on the experience gained in the laboratory from the various prototypes and numerical simulations carried out by our partners at the Harvard-Smithsonian Center for Astrophysics (CfA). The two sensing masses in fig. 3 consist of solid hollow right cylinders with spherical ellipsoids of inertia so as to cancel the 2nd-order gravity-gradient torques (quadrupole moments).

A configuration for the differential accelerometer that is particularly attractive for its insensitivity to gravity gradients and motion dynamics of the detector package is presented in [6]. In this configuration, the two concentric test masses are independenty pivoted in the middle (at their CMs) through torsional hinges. One sensing mass is made of two halves of different materials (on opposite sides of the hinges) and, consequently, it is rotationally sensitive to a WEP violation. The other test mass is made entirely of one material; it moves rotationally like the first test mass but it is not sensitive to WEP violations. Finally, the difference between the rotations of the two test masses is sensitive to a WEP violation and insensitive to almost everything else.

5. – Intrinsic noise of detector

The most important internal noise sources for a high-accuracy mechanical detector like the one proposed for our WEP test are: 1) Brownian noise; and 2) preamplifier noise. The combined effect of these two noise components upon the acceleration spectral density S_a of the detector's output is given by the following equation for an instrument with $\omega_S < \omega_0$:

$$S_a = \left(\frac{\omega_0 k}{m_{\mathrm{eff}}}\left(\frac{4T}{Q} + 2T_A\frac{\omega_0}{\omega_S+\omega_P}\right)\right)^{1/2} \mathrm{ms}^{-2}/\sqrt{\mathrm{Hz}}. \tag{2}$$

The two terms in inner parentheses in eq. (2) correspond to the Brownian noise and the preamplifier noise, respectively; ω_0 is the detector resonant frequency; ω_S the signal frequency; ω_P the pumping frequency of the bridge; k Boltzmann's constant; T the temperature of the sensing masses; T_A the preamplifier noise temperature; Q the quality factor; and m_{eff} the effective mass of the sensing mass. The effective mass is linked to the real mass m; it simply converts a translational into a rotational degree of freedom. For this detector prototype, $m_{\mathrm{eff}} \approx 1.8\,\mathrm{m}$.

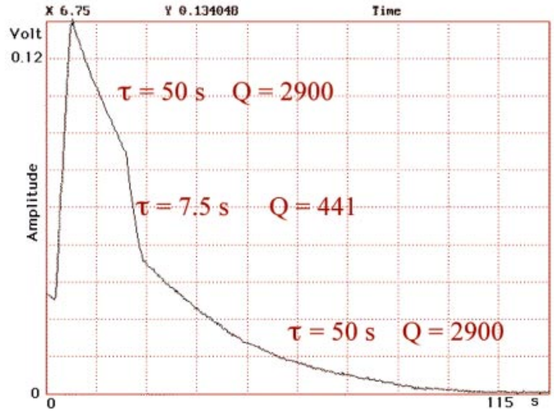

Fig. 4. – Damping of transient oscillations: amplitude *vs.* time showing accelerated damping when the Q-factor is reduced by the feedback.

Clearly, from eq. (2), the sensitivity of the detector increases by decreasing the resonant frequency and the temperature, and by increasing the effective mass of the sensing mass and the Q-factor. Liquid-helium refrigeration will be used to provide low Brownian noise, high thermal stability, low thermal gradients, and a high Q-factor which are necessary to attain the desired instrument's sensitivity.

6. – Signal modulation and transient response

The transfer function of the detector is the typical transfer function of a second-order, high-Q oscillator. Even if a signal at the resonant frequency were (advantageously) amplified by the Q-factor, it would take Q cycles to reach its steady-state amplitude. This is an important reason why most of the detectors proposed for WEP tests use off-resonant instruments ($\omega_S < \omega_0$) as is the case for our detector. Gravity signal modulation during free fall is obtained by spinning the instrument package, and hence the detector, around the longitudinal (and horizontal) axis (see fig. 2) at a frequency substantially smaller than the instrument resonant frequency before the instrument package is released into the capsule. The effect of the centrifugal forces due to a centering offset is perceived by the detector as a steady-state error. The ratio of spin frequency to resonant frequency of about 1/6 allows the detector to operate within its linearity range considering realistic values of mass centering. Values of 0.5 Hz for the spin frequency and 3 Hz for the resonant frequency are valid choices that limit the strength of centrifugal forces, provide a sufficient number of signal cycles in a free-fall drop and a fast abatement of the transient response.

Once the instrument package is released, the detector initial oscillations must be quickly damped before the measurement phase begins. Abatement of the sensing masses oscillations in a few seconds, immediately after release, is accomplished by electrostatic feedback control whereby the Q-factor is reduced from the high value of the measurement-phase to a value of about unity during the transient phase. The reduction of Q can be simply accomplished by utilizing an electrical resistance, in the control loop, which is then by-passed once the transient is abated. This technique (see fig. 4) has already been experimented successfully on a precursor accelerometer.

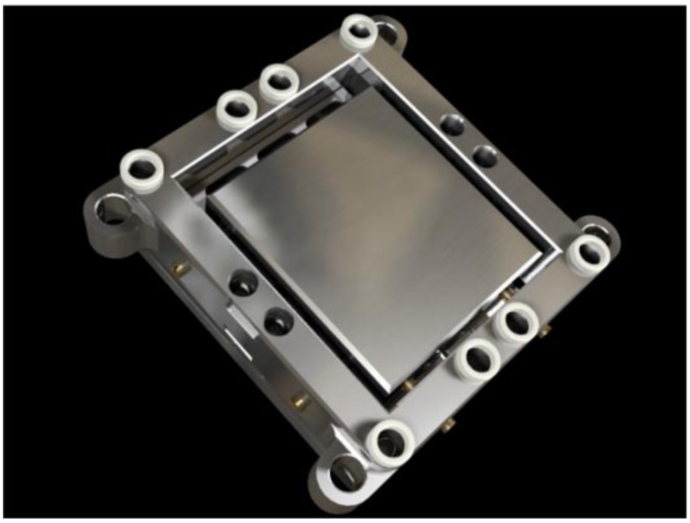

Fig. 5. – Mechanical part of the accelerometer.

7. – Experimental activity and heritage of detector

Our group at IFSI has built a number of precursor detectors for the measurement of non-differential and differential accelerations. The basic element of these prototypes is a high-sensitivity accelerometer that utilizes the concept of the double-faced capacitor introduced previously.

The mechanical part of the accelerometer consists of a sensitive proof-mass (the central mobile plate) which is connected to the external rigid frame by a torsional spring (fig. 5). This structure has been obtained by machining a single plate of aluminum AL 6061. In this way, a high mechanical Q-factor is achieved to reduce the thermal motion of the harmonic oscillator well below the signal level. The spring restraint of the proof-mass is due to the torsion of the suspension elements which provide a low resonance frequency (4 Hz in this prototype) and a high mechanical Q-factor. In response to an acceleration the proof-mass twists the suspensions, and the resulting displacement relative to the rigid frame is detected by capacitive sensors. The mass of accelerometer is 0.2 kg, the section of the torsion arms is $1 \times 1\,\text{mm}^2$ and their length 15 mm.

The read-out and control system of the accelerometer (fig. 6) consists of two series of capacitors formed by the central plate (the proof-mass of the accelerometer) and four additional plates mounted on opposite sides of the accelerometer, as described previously. Two of these capacitors (sensing capacitors C_1 and C_2) are modulated mechanically by the motion of the central plate at the signal frequency ω_S and are used to sense the signal. The other set (control capacitors C_3 and C_4) is used to provide an internal force that recenters the sensing mass and lowers the mechanical resonance frequency. The signal is extracted by the capacitive bridge which consists of two sensing capacitors, C_1 and C_2, and two fixed external capacitors, C_a and C_b. The bridge is driven by the pump frequency (100 V at 20 kHz). In order to reduce the residual output voltage of the bridge (carrier suppression), fine balancing of the bridge is implemented by a slight change of the sensing capacitors, obtained by adjusting the voltage across the control capacitors.

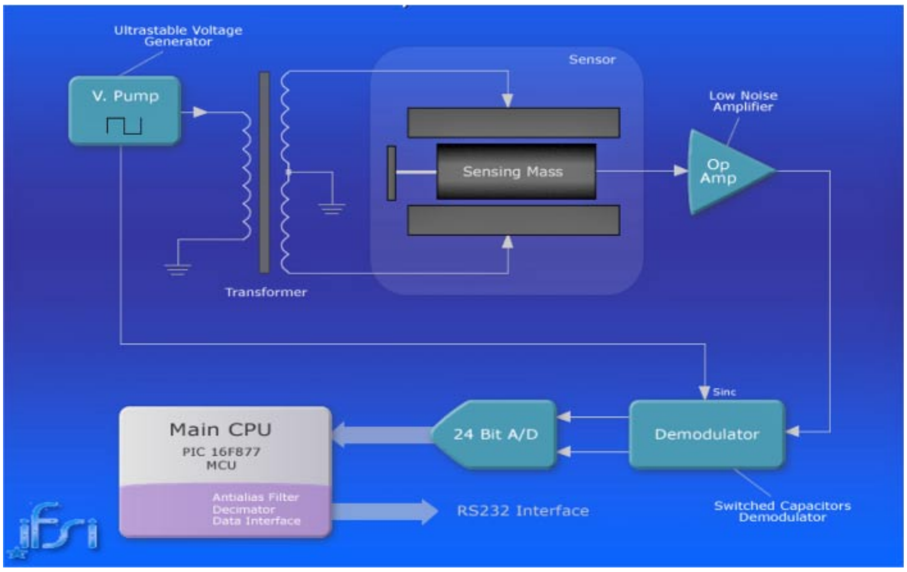

Fig. 6. – Read-out and control system of the accelerometer.

The output signal is the unbalanced signal of the bridge. The output signal is amplified by a low noise amplifier, demodulated, sampled by an analog-to-digital converter and stored in the computer memory.

Furthermore, the IFSI group built non-cryogenic *differential* accelerometer prototypes and carried out various differential measurements. Figure 7 shows the (seismic) spectra of the output signals from two accelerometers in differential configuration and the differenced signal (called "Rejection" in the figure). The differenced signal has a spectral

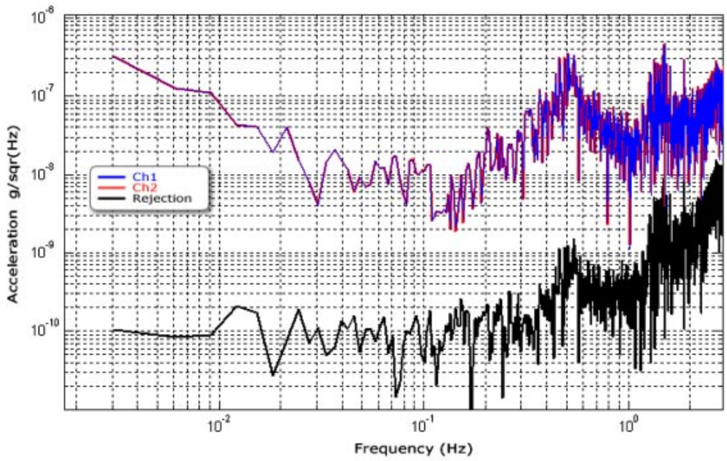

Fig. 7. – Spectral densities of individual signals (upper lines) and differenced signal (lower line) for a seismic excitation.

TABLE II. – *Characteristics of precursor accelerometers and WEP detector requirements.*

Item	Characteristic	Requirement
Temperature	ambient	Liquid He
Q-factor	1000(*)	$> 10^5$
Resonant frequency, ω_0	4 Hz	2–5 Hz
Sensing mass	0.2 kg	> 1 kg
Amplifier noise temperature	10 K	≤ 100 mK
Frequency range	Wide band 10^{-5}–1 Hz	Monochromatic signal at 0.5 Hz
External acceleration noise	$10^{-10}\,\mathrm{g}/\sqrt{\mathrm{Hz}}$	$\leq 10^{-12}\,\mathrm{g}/\sqrt{\mathrm{Hz}}$
Common-mode rejection, χ	10^{-4}	$\leq 10^{-4}$
Linearity range	10^6	$\geq 10^6$
Acceleration noise (diff.) spectral density	$10^{-10}\,\mathrm{g}/\sqrt{\mathrm{Hz}}$	$\leq 10^{-14}\,\mathrm{g}/\sqrt{\mathrm{Hz}}$

(*) The Q-factor is artificially kept low to prevent saturations by using a low vacuum inside the instrument.

density of ca. $10^{-10}\,\mathrm{g}/\sqrt{\mathrm{Hz}}$ in the frequency window of 0.01–0.4 Hz, having attenuated the individual signals by a factor of about 100 over a rather broad frequency range. To our knowledge these are the best differential acceleration measurements of this type ever attained with a non-cryogenic instrument.

Table II compares the characteristics of the precursor accelerometers to the requirements of the differential accelerometer for the proposed WEP test.

8. – Required improvements/modifications

In order to attain the detector accuracy required by this WEP test, we must develop an instrument that meets the requirements shown in the third column of table II. The modifications needed to achieve this accuracy are within the state of the art. They are as follows:

1) increase the value of the quality factor, which can be obtained by reducing the pressure inside the instrument and decreasing the temperature;

2) increase the sensing mass to a value greater than 1 kg;

3) use a J-FET (commercially available) preamplifier with a noise temperature less than 100 mK;

4) build a differential acceleration detector with the machining precision required by the WEP test.

With reference to point a), a Q of 11600 was measured on an instrument similar to the precursor accelerometer at the Harvard-Smithsonian Center for Astrophysics at the temperature of 77 K and a pressure of ca. 10^{-3} Pa. Q values as high as 10^7 are reported in the literature (see for example [7]) for proof-masses operated at liquid-helium temperature. With reference to point d), the machining accuracy is related to the value of the common-mode rejection factor. For the instrument design proposed here, a CMRF ratio smaller than 10^{-4} implies an offset of the sensing mass CM with respect to the torsional axis of the instrument $< 4\,\mu$m. This is well within the state of the art in machining.

TABLE III. – *Current error budget for the PE test.*

Noise source	Max. diff. acceleration	Frequency content
Brownian noise	1×10^{-14} g/$\sqrt{\text{Hz}}$	white
Amplifier noise	4×10^{-15} g/$\sqrt{\text{Hz}}$	white
Capsule's vibrations	10^{-17} g/$\sqrt{\text{Hz}}$	white
Drag in capsule	6×10^{-17} g	$1/t_{\text{int}}$
Proof-masses magnetic disturbances	$< 10^{-17}$ g	f_S
Radiometer effect	2×10^{-16} g	f_S
Earth's gravity gradient torques	10^{-16} g 10^{-12} g	f_S $2f_S$
Higher-order gravitational coupling to capsule mass	$< 10^{-16}$ g	f_S, $2f_S$, $3f_S$, ...
Others	$< 10^{-17}$ g	various
Error sum (rms), $t_{\text{int}} = 20$ s	2.4×10^{-15} g	f_S

Symbols: t_{int} = integration time, f_S = signal frequency.

9. – Experiment error budget

Error sources are internal and external to the detector. The most important internal sources are: 1) amplifier noise; 2) thermal noise; and 3) viscous drag due to residual gas inside the capacitors. The most important external noise sources are: 1) the Earth's gravity gradient force and torque; 2) the Earth's magnetic field interaction with the ferrous impurities in the sensing masses; and similarly 3) paramagnetism of the proof-masses coupled to the magnetic moment of the capsule-fixed electrical equipment.

The proposed experimental technique is such that the hypothetical WEP violation signal has either a frequency well separated from narrow-band noise sources or a strength much larger than the broad-band noise sources. Table III provides a summary of the most important noise sources and their frequency content for an instrument with a quality factor $Q > 10^5$. Our error analysis shows that a proposed detector that meets the characteristics specified here will be capable to carry out a test of the equivalence principle with an accuracy of 5 parts in 10^{15}, with 95% confidence level, in a 20 s integration time.

10. – Balloon launch facility and launch campaign

The drop system can be operated from any balloon launch facility that permits the operations of a drop system. A possibility is to use the Trapani (Sicily) launch base owned and operated by the Italian Space Agency (ASI). This balloon base is on the coast and it is specialized in launching heavy payloads and routinely recovering them over the water. ASI has also conducted ballon flights involving drops of heavy payloads off the East coast of Sardinia. Alternatively, the balloon launches could take place from the NASA balloon base in Palestine, Texas which also had experience with dropping heavy payloads (*e.g*, in this case a reentry capsule for the Jet Propulsion Laboratory) and recovering them over land.

Once our experiment is operational, we envision a series of balloon launches separated by time intervals of a few months. One possibility is to follow the wind time reversal which occurs twice per year and schedule one or two launches for each wind reversal period. The times between launches will be devoted to data analysis, refurbishment of the flight hardware, and correction of any problem. Each launch (or couple of launches) will capitalize on the experience gained during the previous launch(es) and, if necessary, improve the experiment performance.

11. – Conclusion

Among the ongoing experiments to test the WEP, TEPEE/GReAT offers a significant improvement in accuracy with respect to current limits on the Eötvös ratio η with moderate cost and the important advantage of reusability. Its development is based on a well-established expertise on acceleration sensors and an overall design that was analyzed and conceived for a strong isolation of the detector from the main sources of noise. The experimental activity and the simulations performed so far have shown that a hypothetical WEP-violating signal could be well distinguished at the level of 5 parts in 10^{15} by using this technique.

REFERENCES

[1] Will C. M., *Living Rev. Relativity*, **9** (2006) 3. URL (cited on 9 February 2009): `http://www.livingreviews.org/lrr-2006-3`.
[2] Iafolla V. *et al.*, *Rev. Sci. Instrum.*, **69** (1998) 4146.
[3] Iafolla V. *et al.*, *Class. Quantum Grav.*, **17** (2000) 2327.
[4] Lorenzini E. C. *et al.*, *Nuovo Cimento B*, **109** (1994) 1195.
[5] Lorenzini E. C. *et al.*, *37th COSPAR Scientific Assembly* (2008).
[6] Shapiro I. I. *et al.*, *Int. J. Mod. Phys. D*, **18** (2007) 2227.
[7] Kimura S. *et al.*, *Phys. Lett. A*, **81** (1980) 302.