

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

LULULEMON ATHLETICA CANADA INC. and LULULEMON USA
INC.

Petitioners

v.

NIKE, INC.

Patent Owner

Case IPR2023-00424

Patent 10,923,225

**DECLARATION OF SCOTT MCLEAN, PH.D., IN SUPPORT OF
NIKE, INC.'S PATENT OWNER'S RESPONSE**

lululemon v. NIKE, Inc. IPR2023-00424 Patent No. 10,923,225 Ex. 2004

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I, Scott McLean, Ph.D., declare as follows:

I. INTRODUCTION

1. I have been retained by Nike (“Patent Owner”) as an independent expert in this *inter partes* review (“IPR”) proceeding before the Patent Trial and Appeal Board (“PTAB”), which I understand involves U.S. Patent No. 10,923,225 (“the ’225 patent”). I have been asked to opine on technical issues related to the patentability of the ’225 patent. My areas of expertise include the technological field in which the ’225 patent resides.

2. I understand that this proceeding involves claims 1-10 and 12-19 (the “Challenged Claims”) of the ’930 patent. I further understand that lululemon athletica canada inc. and lululemon usa inc. (collectively, “lululemon”) raises five grounds in the Petition for *Inter Partes* Review based on combinations of the following three prior art references.

U.S. Patent Application Publication No. 2005/0070809 (“Acres”)	Ex. 1002
U.S. Patent No. 5,527,239 (“Abbondanza”)	Ex. 1003
U.S. Patent Application Publication No. 2005/0272564 (“Pyles”)	Ex. 1004

3. In Ground 1, lululemon alleges that claims 1–8, 10, 12–17, and 19 are anticipated by Acres. In Ground 2, lululemon alleges that claims 1–8, 10, 12–17, and 19 are rendered obvious by Acres. In Ground 3, lululemon alleges that claims 9 and 18 are rendered obvious by Acres in view of Pyles. In Ground 4, lululemon

alleges that claims 1–5, 7, 10, 12-14, 16, and 19 are rendered obvious by Abbondanza. And in Ground 5, lululemon alleges that claims 9 and 18 are rendered obvious by Abbondanza in view of Pyles. I have been asked to provide opinions for each of the grounds asserted in the Petition. My opinions are set forth below.

4. This declaration is based upon the information presently available to me. Should additional information become available, I hereby respectfully expressly reserve the right to supplement my opinions based upon information that may subsequently become available, which may include a review of information that may be produced, or from testimony or depositions that are subsequently taken.

5. The opinions I express in this declaration are based on my own personal knowledge and professional judgment. If called as a witness during this proceeding, I am prepared to testify competently about my opinions.

II. BACKGROUND AND EXPERIENCE

6. The following educational qualifications, work experience, and associated expertise speak directly to my ability to successfully and confidently opine on the issues outlined herein. My full CV is attached hereto as Attachment A.

7. I am currently a Principal within Exponent’s Biomechanics practice where I lead a team of consultants specializing in different wearable technology initiatives. In particular, efforts focus on characterizing, benchmarking, and implementing a broad range of state-of-the art wearable technology solutions. I

possess over 25 years of expertise and experience in the areas of biomechanics, gait and locomotion, human performance, health, and wellness. My experience includes utilizing a broad range of associated measurement and analysis techniques and supporting technologies, including but not limited to, motion capture and force plate-derived kinematic and kinetic analyses, muscle electromyography (EMG), 3-D imaging (e.g., MRI), computational modeling, wearable sensors, cadaveric testing, and robotics systems. I possess considerable expertise in being able to interpret and distill the often large and multi-faceted data sets derived from these approaches and technologies into easily understood and contextually relevant measures that can characterize and improve key performance, activity, and health outcomes based on the explicit use case of interest.

8. I have published extensively across the aforementioned fields, with over 50 peer-reviewed publications in high-impact academic journals and have brought in over 10 million dollars in funding from various national, government, and non-profit agencies to support my research. I have presented my work at various high-profile national and international conferences and symposia, being invited as the keynote speaker on multiple occasions. I have been on the editorial board of the Journal of Science and Medicine in Sport, and Medicine and Science in Sport and Exercise, and a peer reviewer for many scientific, engineering, and clinical journals. I am a previous chair of the American Colleges of Sports Medicine's Biomechanics

Interest Group, and a previous Executive Council Member of the International Society of Biomechanics.

9. I obtained my Ph.D. in Human Movement Studies in 2001, from the University of Queensland, Brisbane, Australia. My doctoral research focused on quantifying explicit human performance outcomes and mechanisms of lower limb, knee joint, and particularly anterior cruciate ligament injuries. I utilized what were considered at that time to be state-of-the-art technological approaches such as motion analysis and electromyography to conduct this research.

10. I completed my Postdoctoral Fellowship in 2001 within the Department of Biomedical Engineering at the Cleveland Clinic and was a Project Staff Scientist within the same department through 2006. During that time, I conducted extensive research into human performance and associated mechanisms of orthopedic injury and/or disease, utilizing a combination of human experimentation, cadaveric and computational modeling approaches, and state-of-the-art technologies and measurement techniques. This work led to several high-profile publications that pushed the associated fields of research forward at that time. For example;

11. In 2004, I published an article based on computational modeling techniques that challenged existing theories on anterior cruciate ligament injuries (Attachment A at 6 [McLean *et al.*, 2004]). At the time of this declaration, the article had been cited 593 times, with 14 of these citations being in 2023.

12. I co-authored a paper in 2005 that was based on cutting edge motion capture collection and analysis techniques to provide new insights into athletic knee injury causality (Attachment A at 6 [Hewett *et al.*, 2005]). This article won the American Orthopaedic Society for Sports Medicine O'Donoghue Award and had been cited 4296 times at the time of preparing this declaration, with 224 of those being in 2023.

13. As the Cleveland Clinic Sports Health and Orthopaedic Rehabilitation Research Director, I oversaw and drove targeted research efforts, again using state-of-the-art approaches and technologies to inform athlete performance, injury prevention, and rehabilitation. I used similar methods in my role as biomechanics consultant for Cleveland's professional sporting teams to support elite athlete performance monitoring and optimization, and injury prevention.

14. As a Professor of Biomechanics within the School of Kinesiology at the University of Michigan from 2007–2015, I furthered my work on human performance optimization, injury causality and prevention, and associated orthopedic disease (e.g., osteoarthritis) progression and mitigation, becoming an internationally renowned leader in the field. In 2014–2015, I developed a wearable sensor framework to monitor soldier performance in various battlefield simulations and activities. This framework, comprising a series of inertial measurement units (IMUs), could be worn by the soldier under or on clothing, and on complementary

equipment (e.g., armor, backpacks, weapons) to measure discrete performance characteristics during different activities. This work was funded by the U.S. military and resulted in multiple peer reviewed publications focused on the technology development and application (Attachment A at 2–3 [Cain *et al.*, 2016; Davidson *et al.*, 2016; McGinnis *et al.*, 2016]).

15. Prior to joining Exponent, I was the Director of Innovation at Fitbit from 2016–2018, where I led multiple phases of wearable device research and development. This work included key aspects of device ideation and design, including but not limited to: hardware, software, and sensor development and testing, algorithm development and characterization, device verification, validation, and benchmarking, and large-scale device integration for use-case specific (e.g., clinical patients) outcome monitoring. During my tenure at Fitbit, I supported multiple products from conception to market, with these products incorporating various wearable sensors to track and monitor different activity, physiological, and biomechanical outcomes on the user.

16. In my current role, I draw on the above credentials and extensive expertise and experience to support a broad range of wearable technology design, development, testing and evaluation, and large-scale adoption requirements. I design and undertake wearable sensor device testing and validation efforts to understand sensor and device capabilities in real-world conditions. I also advise

different entities on optimal wearable device determination and integration based on their overarching use-case requirements. For example, I currently support the U.S. military across several different efforts in the development, integration, and application of a scalable wearables system architecture for monitoring and optimizing soldier health, wellness, and performance. Specifically, my work focuses on the identification, testing and evaluation, and reporting of various wearable sensors to inform optimal solutions across different military use-cases and environments. I am also using similar techniques to determine optimal wearable device applications for other large-scale stakeholders in clinical and pharmaceutical sectors targeting patient outcome monitoring and optimization.

17. In preparing my declaration, I have relied upon: my expertise and experience as stated herein in the fields of biomechanics, biomedical engineering, and wearable sensor technology; my underlying knowledge of the principles of physics, physiology, and human performance and activity; my extensive personal research and experimentation; and books and publications across these and complementary fields. My opinions and conclusions are supported by established and accepted principles and practices in the fields of biomechanics, engineering, and human performance and activity testing.

III. COMPENSATION AND PRIOR TESTIMONY

18. I have been engaged at the rate of \$475 per hour for my work in connection with this proceeding. My compensation is in no way dependent upon the opinions that I offer or the outcome of this proceeding. I have no personal interest in the outcome of this proceeding.

19. Attachment B appended herewith is a list of cases in which I have provided testimony in the last four years. To the best of my knowledge, no court has ever excluded or prohibited me from providing trial testimony as an expert witness.

IV. MATERIALS CONSIDERED

20. All my opinions are based on my knowledge and professional judgment, and the following documents that I considered:

- lululemon's Petition for *Inter Partes* Review of U.S. Patent No. 10,923,225;
- Exhibits 1001-1013;
- Institution Decision in IPR 2023-00424; and
- All other materials discussed herein.

V. LEGAL STANDARDS

21. I am not an attorney. For the purposes of this Declaration, I have been informed by counsel about certain aspects of the law that are relevant to my opinions. My understanding of that law is summarized below.

22. I understand from counsel that a claim may be unpatentable over prior art under either an anticipation theory or an obviousness theory.

23. I understand from counsel that, to anticipate a claim, each and every element of that claim must be either expressly or inherently disclosed in a single prior art reference. I further understand from counsel that the claim elements must be arranged in the prior art reference as in the claim.

24. I further understand from counsel that a patent claim is unpatentable if, at the time of the invention, it would have been obvious to a POSITA at the time the application was filed. I understand from counsel that it is not required (although it is acceptable) that each limitation of a patent claim be found in a single reference in order to find a patent claim obvious. Rather, for a patent claim to be found obvious, all the limitations of the patent claim must be found in teachings of one or more references that would have been combined by a POSITA with a reasonable expectation of success. I understand from counsel that a proper analysis of whether an invention is unpatentable for obviousness includes a review of the scope and content of the prior art, the differences between the patent claims at issue and the prior art, the level of ordinary skill in the field of the invention at the time of the invention, and other objective indicia considerations.

25. I understand from counsel that a showing of obviousness requires some articulated reasoning with a rational underpinning to support the combination of the

references. I understand from counsel that in consideration of the issue of obviousness, it is important to identify whether a reason existed at the time of the invention that would have led a POSITA to combine elements of the references in a way that yielded the claimed invention.

VI. LEVEL OF ORDINARY SKILL IN THE ART

26. I understand from the Petition that lululemon claims that a POSITA relevant to the '225 patent would have had (1) a bachelor's degree in engineering, computer science, industrial design, biomechanics, or a related field, and (2) at least two years of experience researching, developing, designing, and/or testing fitness or physiological sensors, wearable devices, physiological or biomechanical devices, remotely-controlled systems or interfaces, and/or network-based applications and/or equipment, or the equivalent experience or education. Petition at 5.

27. For purposes of this declaration, I am accepting lululemon's description of a POSITA. My agreement with the above description of a POSITA does not imply agreement at all times moving forward. I reserve the right to supplement my opinion should a new level of ordinary skill in the art be advanced by either party.

28. In view of my experience and qualifications noted above, I am well positioned to opine as to what a POSITA at the time of the invention would have understood and done.

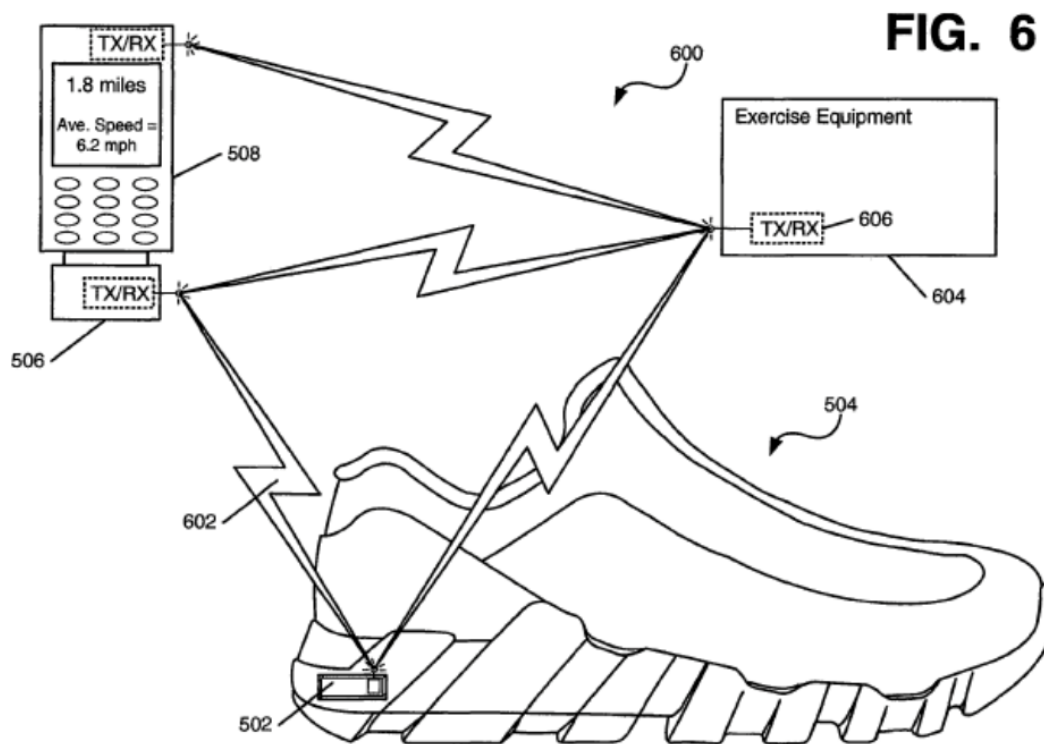
29. My opinions contained herein are from the perspective of a POSITA. My opinions reflect how a POSITA would have interpreted the claims, the prior art, and any available evidence.

VII. THE '225 PATENT

30. The '225 patent discloses an invention that relates to “Athletic performance sensing and/or tracking systems” (Ex. 1001 at Abstract), which “may include components for measuring or sensing athletic performance data and/or for storing and/or displaying desired information associated with the athletic performance to the user (or others).” *Id.* at 2:23-25. The '225 patent describes a portable sensor device or performance monitoring system that can transmit data from the user to the exercise equipment, as in the case of a treadmill, stationary bicycle, or weightlifting machine (*id.* at 17:56-59), such that it can be stored or displayed by the exercise equipment or be used to control different exercise equipment parameters such as resistance, incline, target distance, or speed. *Id.* at 19:51-55.

31. The claimed invention advances over the prior art performance monitoring systems. Specifically, while such systems were able to display activity performance data to the user, they could not use these data to control the workout equipment. *Id.* at 41:5–46. Further, prior art systems were also considered limited in their ability to be portable, customizable, and/or adaptable, which the '225 patent aims to target directly.

32. The '225 patent discloses a variety of sensors that may be affixed to a person's body, provided in an article of clothing, or provided within equipment used by the user, such as a "bicycle, bat, racket, club, vehicle, ball, etc." *Id.* at 10:15-16. An example embodiment of the claimed invention is provided in Figure 6, whereby the user wears or carries, such as in an article of footwear 504, a portable system that includes the performance sensing module 502.



Id. at Fig. 6.

33. As disclosed, "any or all of the [sensing] module 502, interface device 506, and/or electronic device 508 [e.g., a music player or cellular phone] may be configured to exchange data with one or more pieces of exercise equipment 604 or

other things” *Id.*, 17:51–55, 19:34–37. Data collected via the sensing module 502 (i.e. a “sensor”) can thus be transmitted directly to a piece of workout equipment 604.

34. A wide variety of information can be sent between the portable system and the exercise equipment 604. For example, data collected by the user’s portable equipment may be used, “at least in part, to control the exercise equipment or other workout or athletic performance setting 604.” *Id.* at 19:43–5. The same portable system can also be “programmed and adapted to send information to the exercise equipment 604, e.g., for display by the exercise equipment 604.” *Id.* at 20:3–5.

VIII. CLAIM CONSTRUCTION

35. I understand that in its Institution Decision (“DI”), the Board requested further briefing on the meaning of the term “data” that is recited in both independent claims 1 and 12.” DI, 9. I also understand from counsel and lululemon’s Petition that the parties agree that the ordinary and customary meaning applies here. Petition, 6. In my opinion, a POSITA in 2006 would understand that the ordinary and customary meaning of “data,” as recited in claims 1 and 12, properly viewed in light of the claims and specification of the ’225 patent, means “factual information that is sensed or collected, and from which decisions or subsequent actions can be made.”

A. The claim language of claims 1 and 12 provide context to the meaning of “data”

36. Each independent claim recites “a first set of data” (limitations 1B and 12C[ii]) and “a first set of activity data” (limitations 1C and 12C[iii]). Ex. 1001:45:12–18, 46:16–21. Notably, both types of “data” are sensed (i.e. measured) or collected by a “sensor,” and then transmitted to a piece of workout equipment. *Id.*, 45:9–20, 46:9–24. In my opinion, this is particularly important because a POSITA in 2006 would understand that a “sensor” measures or collects objective, factual information. *E.g., id.*, 4:13–17, 9:31–36, 9:43–49. Stated differently, “data” as used in the claims, is “factual information that is sensed or collected” by a “sensor.” *Id.*

37. The claims of the '225 patent also recite using “data” to control workout equipment. Claim 1 recites “a first set of data for operating a first function of the piece of workout equipment.” Ex. 1001, 45:12–14. Claim 5 recites that the “first function of the piece of workout equipment” includes increasing or decreasing “a time period associated with at least one workout activity in a workout routine.” *Id.*, 45:30–36. And claims 6–8 recites that the “first function of the piece of workout equipment” includes increasing or decreasing a resistance level, workout speed, or incline, respectively, of the piece of workout equipment. *Id.*, 45:37–59. Controlling workout equipment is a decision or subsequent action. In my opinion, a POSITA in

2006 would thus understand that the claims also use “data” as information “from which decisions or subsequent actions can be made.”

38. In my opinion, a POSITA in 2006 would understand that the ordinary and customary meaning of “data” in the context of the claims of the ’225 patent means “factual information that is sensed or collected, and from which decisions or subsequent actions can be made.”

B. The specification provides context to the meaning of “data”

39. Like the claims discussed above, the specification of the ’225 patent discloses using “data” as “factual information that is sensed or collected” by a sensor. For example, the specification discloses that “[t]he athletic performance data presented by the display system may include information *based on output from the sensor* (such as *speed information, distance information, timing information*, heart rate, pulse rate, etc.).” *Id.*, 5:27–30 (emphasis added); *see also id.*, 4:13–17, 9:31–36, 9:43–49. In my opinion, a POSITA in 2006 would thus understand that the specification also uses “data” as “factual information that is sensed or collected” by a “sensor.”

40. The specification of the ’225 patent also discloses using “data” to control workout equipment. *E.g., id.*, 1001, 19:61–65 (“Data collected as a workout progresses (e.g., via module 502, etc.) also may be used, if desired, to control the exercise equipment or other workout or athletic performance devices (e.g., to set or

change intensity or resistance levels, to shorten or lengthen workout times, etc.).”). Controlling workout equipment is a decision or subsequent action. In my opinion, a POSITA in 2006 would thus understand that the specification also uses “data” as information “from which decisions or subsequent actions can be made.”

41. In my opinion, a POSITA in 2006 would understand that the ordinary and customary meaning of “data” as recited in claims 1 and 12 in view of the specification of the ’225 patent means “factual information that is sensed or collected, and from which decisions or subsequent actions can be made.”

C. Technical dictionaries are consistent with the ordinary and customary meaning of “data” in the context of the ’225 patent

42. The Wiley Electrical and Electronics Engineering Dictionary from 2004 defines “data” as “[f]actual information, such as that derived from observation, experimentation, or calculation, especially that which is used for processing and/or further analysis.” Ex. 2002, 4. Similarly, the Oxford Dictionary of Computing (6th ed. 2008) (Ex. 2003, 3) notes that “[t]he distinction between program (instructions) and data is a fundamental one in computing.”¹ In my opinion, a POSITA in 2006

¹ The quoted definition of “data” in Oxford Dictionary of Computing (Ex. 2003) recites “*see Von Newmann Machine.*” Ex. 2003, 4 (defining “data”), 9 (defining “von Newmann machine”). Computers associated with workout equipment are von Newmann machines. *See, e.g., id.*, 9 (“The vast majority of present-day computers are von Neumann machines. The name is taken from that of the

would understand that these definitions are consistent with the ordinary and customary meaning of “data” in the context of the ’225 patent (i.e. “factual information that is sensed or collected, and from which decisions or subsequent actions can be made”).

43. The distinction between data, being factual information that is “sensed or collected,” and the ensuing decisions or actions made based on these data, is also conveyed and implemented, both conceptually and physically, in the relevant art. For example, the National Aeronautics and Space Administration’s (NASA) Lunar Reconnaissance Orbiter (LRO) considers and has an explicit system for handling “data” and “commands” (i.e. decisions and actions derived from those data) separately. This system is referred to as the “Command and Data-Handling System” (C&DH). The C&DH supports command processing and scientific data collection as separate functions. Specifically, the “LRO utilizes two radio frequency bands for its communications with Earth,” with one used for transferring command[s]” and the other for “high speed transfer of science data.” Attachment C, 2. A POSITA would understand that this physical separation of “data” and “commands” (or

American, John von.”); https://en.wikipedia.org/wiki/Von_Neumann_machine (“Von Neumann architecture, a conceptual model of nearly all computer architecture.”).

“instructions”) highlights that they are not only physically, but conceptually different.

44. In my opinion, a POSITA in 2006 would understand that these technical dictionaries are consistent with the ordinary and customary meaning of “data” as recited in the Challenged Claims (i.e. “factual information that is sensed or collected, and from which decisions or subsequent actions can be made”).

IX. OVERVIEW OF THE PRIOR ART REFERENCES

A. Acres

45. U.S. Patent Publication No. 2005/0070809 A1 (Ex. 1002, “Acres”), titled “System For Regulating Exercise and Exercise Network,” discloses “an automatic system for configuration, direction and recording of exercise program for an individual, based upon the attained heart rate of that person during an exercise period.” *Id.* at Abstract.

46. Acres notes that, “[e]xercise is an essential component of human health” but exercise “programs are difficult to configure and tracking an individual’s performance manually is often confusing and time consuming.” *Id.* at [0004]. Acres also teaches that “[a] key metric to exercise is heart rate.” *Id.* at [0005]. If someone’s maximum heart rate can be determined, fitness goals can be “set that specify a particular target duration of exertion at a heart rate that is some fraction of the maximum heart rate.” *Id.* at [0005].

47. Acres states that, unlike the prior art, “[e]mbodiments of the invention eliminate the need for exercisers to calculate appropriate heart rate targets or to monitor heart rate exertion levels during exercise sessions” *Id.* at [0012]. Embodiments of Acres can also “automatically configure compatible exercise equipment, and automatically increase or decrease its exertion settings.” *Id.* at [0012]. To this end, the exerciser uses a hardware component, called a “Bug” that is a portable electronic circuit. *Id.* at [0047].

48. Acres explains that “[t]ypically, the Bug 140 is worn on the clothing or held in a pocket of the person exercising.” *Id.* at [0047]. The Bug can wirelessly communicate “with an external heart rate monitor or the Bug can have a heart rate monitor integrated within itself.” *Id.* at [0025]. If an exerciser is carrying the Bug and has it enabled, then the user’s “physical activity, including heart rate data for each time period and any optional parameters, is monitored and logged.” *Id.* at [0025].

49. Additionally, “[t]he Bug is capable of configuring and monitoring exercise performance on compatible exercise equipment...” *Id.* at [0028], whereby “the Bug transmits signals to the exercise machine to increase or decrease the exercise workload in accordance with the dictates of the exercise program it carries and the current heart rate of the exerciser.” *Id.* at [0029]. Other embodiments of the

Bug allow it to control “the exercise equipment’s workload settings to keep the exerciser’s heart rate within a desired range.” *Id.* at [0030].

B. Abbondanza

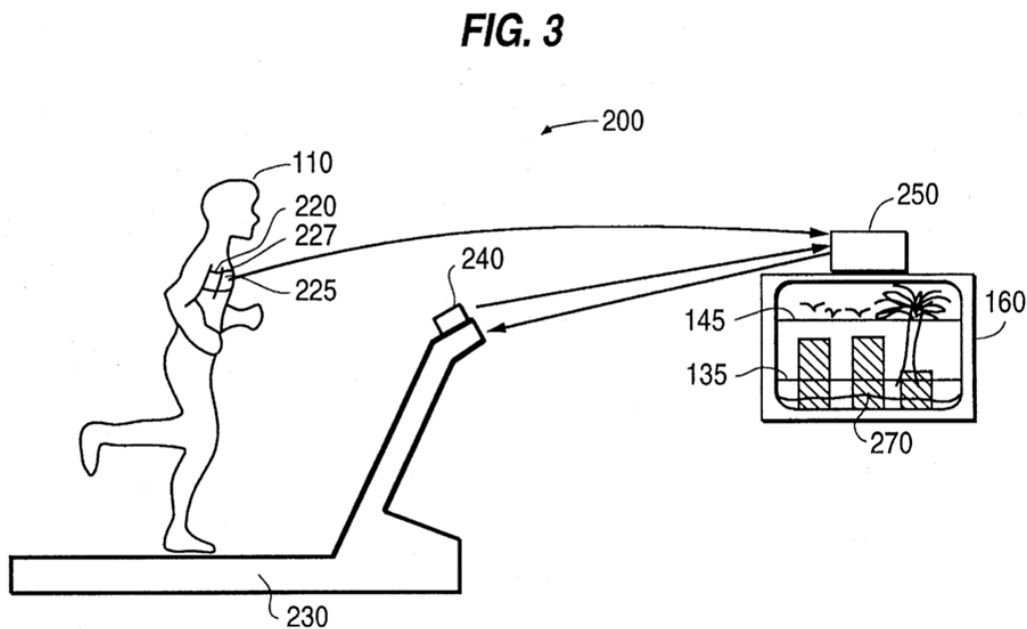
50. U.S. Patent No. 5,527,239 (Ex. 1003, “Abbondanza”), titled “Pulse Rate Controlled Exercise System,” discloses a pulse controlled exercise system incorporating “an exercise device, a monitor capable of displaying images formed from television signals, a pulse rate sensor for sensing the pulse rate of a user of the pulse controlled system, and a controller.” *Id.* at Abstract.

51. Abbondanza teaches that specific benefits can be obtained at different levels of aerobic exertion, where “[t]he amounts of effort that a person must realize in order to experience varying exercise effects directly relates to that person’s heart rate during his or her exercise regimen.” *Id.* at 1:63-66. Moreover, to achieve a specific exercise state or range (e.g., fat burning range), a person must “realize the identified heart rate ranges” (*id.* at 2:16-17), “commonly referred to as ‘target heart rate ranges which are percentages against a person’s maximum heart rate.’” *Id.*, at 2:18-19.

52. Abbondanza discloses an invention which enables a user to exercise within explicit target heart rate ranges through providing “a pulse controlled exercise system which allows a user of the system to constantly be aware of his pulse rate as he or she progresses through his or her workout regimen by displaying the user’s

pulse rate on a monitor...” *Id.* at 5:1-6. In doing so, Abbondanza purports to address key limitations of prior art devices being used with similar intent.

53. Figure 3 below illustrates one embodiment of Abbondanza where a user 110 is wearing a chest belt 220 equipped with a pulse rate sensor device 225 and an infrared pulse rate transmitter 227.



Id. at Fig. 3. During the activity, the pulse rate sensor 225 “senses user 110’s pulse rate and infrared pulse rate transmitter 227 transmits user 110’s pulse rate to base unit 250.” *Id.* at 10:63-64. The base unit 250, that rests on the monitor 160, “processes” the user’s pulse rate. *Id.* at 11:14-15. The base unit 250 determines whether the user’s pulse rate is within the appropriate target heart rate range and then generates an “instruction” that is transmitted to the treadmill causing the “treadmill device 230 to either speed-up or slow-down.” *Id.* at 11:18-19.

C. Pyles

54. U.S. Patent Application Publication No. 2005/0272564 A1 (Ex. 1004, “Pyles”), titled “Exercise Apparatus and Method for Tracking Number of Steps,” discloses “an exercise apparatus for use in accurately and automatically tracking number of steps taken by a user both on and off of an exercise machine.” *Id.* at Abstract.

55. Pyles teaches that individuals rely on physical exercise programs to “attain and maintain health.” *Id.* at [0001]. Many such programs require a minimum amount of daily exercise or activity such as in the case of the 10,000-step program which “requires that a person perform a minimum of 10,000 steps of walking, running or the like each day.” *Id.* at [0001]. Pyles also teaches that to achieve this goal, individuals will wear a pedometer type device “throughout their day to monitor the number of steps completed while walking about or running.” *Id.* at [0002]. However, a key challenge is acknowledged in the art “in enabling accurate tracking of the cumulative total steps achieved both on and off the exercise machine with minimal effort on the part of the person performing the exercise. *Id.* at [0002]. The invention of Pyles purports to address this challenge, and in doing so offsets limitations in the prior art devices.

56. In an exemplary embodiment of the invention, Pyles discloses “an exercise apparatus 100 comprising a step counter 200 and a console 200 of an

exercise machine 400.” *Id.* at [0024]. The exercise apparatus 100 tracks the “number of steps taken while exercising both on and off of an exercise machine 400.” *Id.* at [0024]. Specifically, the step counter 200, for example, a pedometer, “continually tracks a cumulative number of steps taken by the user since being reset.” *Id.* at [0027]. When a user initiates use with exercise machine 400, therefore, the step counter sends the pre-existing cumulative step count data 312 to the console 300. When the user is exercising on the exercise machine 400 and throughout the course of the exercise activity, the number of steps are continuously counted, with cumulative step count data 312 being “periodically communicated by the step counter 200 to the console 300[.]” *Id.* at [0029].

57. The exercise apparatus 100 may also include “a memory means 500 for storing user-specific historical data, that is, data on cumulative step count 312 by date by time period or the like.” *Id.* at [0047]. Further, in instances where the exercise apparatus 100 may be used by multiple users within a single household, unique user ID’s may be “communicated to the console 300 from the user’s step counter 200 when the exercise machine 400 is used.” *Id.* at [0050]. As such, historical data by user may also be stored in memory means 500 in addition to date and time.

X. Ground 1: Acres does not disclose transmitting, by the sensor device and to the piece of workout equipment, “a first set of data for operating a first function of the piece of workout equipment,” as recited by claim limitations 1B and 12C[iii]

58. Limitation 1B recites “transmitting, by the sensor device and to the piece of workout equipment, a first set of data for operating a first function of the piece of workout equipment.” Ex. 1001, 45:12–14.² In my opinion, a POSTA in 2006 would understand that Acres does not disclose transmitting, by the sensor device and to the piece of workout equipment, “a first set of data for operating a first function of the piece of workout equipment.” lululemon relies on Acres’ disclosure of “commands that adjust parameters of an exercise machine.” *See* Petition, 11–12, 22. This disclosure is insufficient for the reasons I discuss below.

59. In the Acres system, rather than “a first set of data,” the “Bug” device sends “a command” to the exercise equipment. Ex. 1002, ¶89 (“[T]he Bug 601 sends a command to the treadmill 150 telling it to increase speed to a specific amount”). But importantly, the Bug generates and sends those “commands” only *after* it has received and processed the user’s heart rate data. *See id.* The “commands” in Acres are thus not transmitted by the sensor, as the claims require. Ex. 1001, 45:12–14, 46:16–18. And the “commands” of Acres are not “a first set of data”—they are

² Independent claim 12 recites a similar limitation. *Id.*, 46:16–18.

subsequent actions performed in response to the receipt of data, i.e., the “exerciser’s heart rate.”

60. The term “command” appears only twice in the ’225 specification. Ex. 1001, 9:65–10:4; 13:6–9. First, the specification discloses that the system “receives input *data*” in various ways, including “semi-automatically in response to a user’s *command*.” *Id.*, 9:65–10:4 (emphasis added). Second, the specification discloses that the user may provide “voice *commands*” to “control” “system elements.” *Id.*, 13:6–10. Neither use of “command” is consistent with “factual information that is sensed or collected, and from which decisions or subsequent actions can be made.” Instead, “command” as used in the specification of the ’225 patent means an action taken by the user.

61. The specification of the ’225 patent discloses that data collected by the sensing module 502 (i.e. a “sensor”) is transmitted directly to a piece of workout equipment. *See id.*, 17:51–55. Specifically, “[d]ata also may be transferred from the user’s portable equipment (e.g., [sensing] module 502, interface device 506, and/or electronic device 508) to the exercise equipment or other workout or athletic performance setting 604.” *Id.*, 19:34–37; *see also id.*, 19:61–64 (“[d]ata collected as a workout progresses (e.g., via [sensing] module 502, etc.) also may be used, if desired, to control the exercise equipment or other workout or athletic performance devices.”). Thus, unlike Acres’s “commands,” the “first set of data” is not used to

generate new “commands” prior to being transmitted to the piece of workout equipment

62. I disagree with lululemon’s argument that the “commands” in Acres are the same as “a first set of data” in the ’225 patent. *See* Petition, 11–12 (citing Ex. 1001, 19:41–46, 54–55, claims 3, 7, 8). The ’225 patent discloses that the “data” is used to “adjust the parameters of an exercise machine.” Ex. 1001, 45:13–14. lululemon’s argument ignores Acres’s disclosure that a “command” is generated and sent to the workout equipment only after the heart rate data is collected and processed by the Bug. Ex. 1002, ¶89 (“If the Bug 601 senses, based upon the exerciser’s heart rate, that exertion level should increase because the exerciser’s heart rate is below the target, the Bug 601 sends a command to the treadmill 150 telling it to increase speed by a specific amount.”). In contrast, in the ’225 patent, the data *itself* “operate[s] a first function of the piece of workout equipment.” Ex. 1001, 45:13–14.

63. In my opinion, a POSITA in 2006 would understand that the “commands” in Acres are different from the “first set of data” recited in claims 1 and 12 of the ’225 patent.

XI. Ground 3: A POSITA Would Not Have Been Motivated To Replace Acres' Storage At A "Central Site" With Pyles "Storage Of User-Specific Historical Data At An Exercise Machine."

64. In Ground 3, lululemon argues that a POSITA would have been motivated to replace Acres' storage at a "central site" with Pyles "storage of user-specific historical data at an exercise machine." Petition, 29. lululemon argues that Pyles' local storage in an exercise machine "offers a simplified structure by reducing the number of separate components and eliminates the need to transfer activity data over an internet connection." *Id.*, 31. I disagree with lululemon's argument that a POSITA would have been motivated to replace Acres' storage at a "central site" with Pyles "storage of user-specific historical data at an exercise machine" for at least three reasons.

65. First, lululemon's proposed modification would render the claimed method and system less portable by tying the user, through their data, to a specific piece of workout equipment. Put another way, lululemon's proposed modification eliminates the ability to port data from that piece of equipment to other pieces of equipment, or similarly integrate and aggregate data from different pieces of workout equipment. As a result, it is my opinion that a POSITA in 2006 would understand that by storing the data at the level of the exercise machine, the utility of those data beyond that machine is lost.

66. Second, by storing data on a single piece of equipment versus a central site, it is my opinion that a POSITA in 2006 would understand that the risk of data corruption or loss is increased, since it is directly dependent on the integrity and security of that machine.

67. Third, in my opinion, a POSITA in 2006 would understand that data aggregation and storage on such a central cite promotes broader data access to more pieces of equipment and more people.

68. A POSITA in 2006 would not have been motivated to replace Acres' storage at a "central site" with Pyles "storage of user-specific historical data at an exercise machine."

XII. Ground 4

A. Abbondanza does not disclose "transmitting, by the sensor device and to the piece of workout equipment, a first set of data for operating a first function of the piece of workout equipment" as recited by claims 1B and 12C[ii]

69. Limitation 1B recites "transmitting, by the sensor device and to the piece of workout equipment, a first set of data for operating a first function of the piece of workout equipment." Ex. 1001, 45:12–14.³ lululemon relies on Abbondanza's disclosure of "instructions" from the base unit that "instruct treadmill

³ Independent claim 12 recites a similar limitation. *Id.*, 46:16–18.

device 230 to either speed-up or slow-down.” *See* Petition, 35 (citing Ex. 1003, 11:16-23). This disclosure is insufficient for the reasons I discuss below.

70. In my opinion, a POSITA in 2006 would understand that the “instructions” that lululemon relies upon in Abbondanza are not “a first set of data.” The “instructions” in Abbondanza are not transmitted by the sensor as recited in the claims. Ex. 1001, 45:12–14, 46:16–18. Abbondanza’s “instructions” are *generated* by the base unit. Abbondanza explains that “the user’s pulse rate” is “received” by “a controller that resides in base unit 250” “via infrared pulse rate transmitter 227.” Ex. 1003, 11:11–25. The controller then “processes” the data and “determines if the user’s pulse rate is within that user’s target heart rate range.” *Id.* Next, controller *generates* “instructions” that cause the “treadmill device 230 to either speed-up or slow-down.” *Id.* A POSITA in 2006 would thus understand that Abbondanza’s “instructions” are themselves subsequent actions performed in response to receiving the “user’s pulse rate.” *Id.*

71. As I explained above, the specification of the ’225 patent discloses that data collected by the sensing module 502 (i.e. a “sensor”) is transmitted directly to a piece of workout equipment. *See* Ex. 1001, 17:51–55. Specifically, “[d]ata also may be transferred from the user’s portable equipment (e.g., [sensing] module 502, interface device 506, and/or electronic device 508) to the exercise equipment or other workout or athletic performance setting 604.” *Id.*, 19:34–37; *see also id.*,

19:61–64 (“[d]ata collected as a workout progresses (e.g., via [sensing] module 502, etc.) also may be used, if desired, to control the exercise equipment or other workout or athletic performance devices.”) Thus, unlike Abbondanza’s “instructions,” the “first set of data” is not used to generate new “instructions” prior to being transmitted to the piece of workout equipment.

72. In my opinion, a POSITA in 2006 would understand that the “instructions” in Abbondanza are different from the “first set of data” recited in claims 1 and 12 of the ’225 patent.

B. Abbondanza does not disclose establishing, by a “sensor” device, data communication with a piece of “workout equipment” as recited by claims 1A and 12C[i]

73. Independent claim limitations 1A and 12C[i] both recite a “sensor” that establishes data communication with the piece of workout equipment. Ex. 1001, 45:10–11, 46:12–15. lululemon does not identify a “sensor” that establishes data communication with the piece of workout equipment. Instead, lululemon contends that “Abbondanza’s base unit establishes a data communication with the treadmill.” Petition, 34. But Abbondanza’s base unit is not a “sensor.” The specification of the ’225 patent discloses that a “sensor” is a device that senses or collects a parameter or condition. Ex. 1001, 5:20–24, 9:23–39, Fig. 1. Abbondanza’s base unit, on the other hand, “processes” “the user’s pulse rate received via [a separate] infrared pulse rate transmitter.” Ex. 1003, 11:11–16. Abbondanza’s base unit itself does not sense

any parameter or condition. *Id.*, 11:11–25. Thus, in my opinion, a POSITA in 2006 would understand that Abbondanza’s base unit is not a “sensor.”

74. It is also my opinion that POSITA in 2006 would not understand the claimed “sensor” to be met by the *combination* of Abbondanza’s base unit and pulse rate sensor. Nothing in the claims or specification supports lululemon’s position. Instead, a POSITA would understand the claimed “sensor” to be a single contained component.

C. Abbondanza does not disclose claims 5 and 14

75. Claim 5 recites the system of claim 1 “wherein adjusting the one or more settings of the piece of workout equipment comprises one of: increasing a time period associated with at least one workout activity in a workout routine; or decreasing the time period associated with at least one workout activity in the workout routine.” Ex. 1001, 45:30–36.⁴

76. To meet this limitation, lululemon points to Abbondanza’s base unit “terminating the program in the middle of a workout regimen.” Petition, 40. But, as I discussed above, the component that lululemon identifies as performing the “transmitting”—Abbondanza’s base unit—is not a “sensor” (and the claimed

⁴ Claim 14, which depends from claim 13, recites the same limitation. Ex. 1001:46:29–35.

“sensor” is not taught by the *combination* of Abbondanza’s base unit and pulse rate sensor).

77. I reserve the right to supplement my opinion if new information becomes available.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code.

Dated: October 10, 2023

A handwritten signature in dark ink, appearing to read 'S. McLean', with a long horizontal flourish extending to the right.

Scott McLean, Ph.D.

Attachment A



Exponent[®]
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Professional Profile

Dr. McLean's areas of expertise include injury biomechanics, gait and locomotion and human performance assessment and modification, publishing extensively in each of these fields. He has more than two decades of experience in analyzing and countering injury mechanisms via a combination of human experimentation, cadaveric and computational modeling approaches. In particular, he has targeted joint and soft tissue injuries and resultant disease risk in response to dynamic high impact loading scenarios. His related research foci include sports-specific joint injury mechanisms and prevention, high-impact soft tissue mechanical analyses and lower limb anatomical and neuromechanical adaptations to loads across the lifespan. Through this work, he has obtained extensive expertise in utilizing state-of-the-art 3-D motion analysis techniques, wearable inertial sensor technologies and integrated 3-D imaging and computational (Finite Element) modeling methods.

Dr. McLean also has considerable expertise in applying state-of-the-art wearable technologies to the optimization of human movement and performance within a variety of clinical, sporting and military settings. His strengths in this area lie specifically in the ability to interpret and distil the often large and unique data sets derived from these technologies into easily understood baseline metrics that successfully characterize and can be used to improve key performance outcomes.

Prior to joining Exponent, Dr. McLean was the Director of Human Innovation Research at Fitbit, where he derived and lead a number of key research initiatives focusing on characterization and improvement of wearable product accuracies and performance on a global scale. He was also a Professor at the University of Michigan, where he drove a number of high-profile research studies geared towards human performance optimization and injury assessment and prevention within naturalistic military and sports environments. During his tenure at Michigan, Dr. McLean gained considerable teaching experience in the areas of biomechanics, imaging and computational analysis and modeling, both at the undergraduate and graduate levels. He initially was a Project Staff Scientist and the Director of Sports Health and Orthopedic Rehabilitation at the Cleveland Clinic, where he was the team biomechanical consultant for Cleveland's professional sporting teams.

Academic Credentials & Professional Honors

Ph.D., Human Movement Studies, University of Queensland, Australia, 2001

M.Sc., Human Movement Studies, University of Queensland, Australia, 1994

B.Sc., Human Movement Studies, University of Queensland, Australia, 1991

Post-Doctoral Research Fellow, Bioengineering, Cleveland Clinic Foundation, 2001

Chair, American College of Sports Medicine, Biomechanics, 2011

Executive Council, International Society of Biomechanics, 2011-2015

Academic Appointments

Adjunct Professor, School of Health and Life Sciences, University of Ballarat (Federation University), 2005-2006.

Prior Experience

Director, Human Innovation Research, Fitbit, 2016-2018

Director, Human Performance and Innovation Laboratory, University of Michigan, 2007-2015

Professor, School of Kinesiology, University of Michigan, 2007-2015

Director, Sports Health and Orthopaedic Rehabilitation, Cleveland Clinic, 2005-2006

Staff Scientist, Department of Biomedical Engineering, Cleveland Clinic, 2001-2006

Professional Affiliations

National Consumer Technology Association (voting member)

American Society of Biomechanics (member)

American College of Sports Medicine (fellow)

International Society of Biomechanics (member)

Publications

Fox AS, Bonacci J, McLean SG, Saunders N. Exploring individual adaptations to an anterior cruciate ligament injury prevention program. *Knee* 2017; 25:83-98.

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McLean SG, Neal RJ, Myers PT, Walters MR. Knee joint kinematics during the sidestep cutting manoeuvre: potential for injury in females. Medicine and Science in Sports and Exercise 1999 31: 959-968.

McLean SG, Myers PT, Neal RJ, Walters MR. A quantitative analysis of knee joint kinematics during the sidestep cutting maneuver. Implications for non-contact anterior cruciate ligament injury. Bulletin for Hospital of Joint Disease 1998 57: 30-38.

Presentations

Invited Presentations and Seminars

McLean SG. Changing the landscape of injury prevention - Invited Symposium. American Society of Biomechanics Annual Congress, Columbus, OH, August 5, 2015.

McLean SG. Field-based assessment of warfighter performance and performance degradation via a novel body-worn IMU array. American College of Sports Medicine Featured Science Session. Orlando, FL, May 28, 2014.

McLean SG. Taking the lab to the game: Towards innovative field-based injury screening and prevention. IOC World Conference: Prevention of Injury and Illness in Sport. Monaco, April 13, 2014.

McLean SG. Application of innovative technologies to assess injury risk and performance degradation in naturalistic settings: Moving beyond the lab. Invited Visiting Professor, Steadman Phillipon Research Institute, Vail, CO, June 3, 2013.

McLean SG. Effects of maturation on lower limb female joint morphologies: Implications for short- and long-term joint health. Invited Faculty Presentation, University of Aalborg, Aalborg, Denmark, November 14, 2012.

McLean SG. Preventing what we don't know. Modifiable and non-modifiable ACL injury risk factors. Feature Scientific Presentation. National Athletic Trainers Association Annual Meeting, St. Louis, MO. June 26 – 28, 2012.

McLean SG. Interactive morphological and mechanical contributions to knee joint health. Invited Visiting Professor Presentation, University of Oregon, Eugene, OR. April 13, 2012.

McLean SG. Evolving theories pertaining to the mechanism/s of non-contact ACL injury: Integrating the modifiable and non-modifiable factors. Invited Faculty Presentation, University of Limerick, Limerick, Ireland. March 12, 2012.

McLean SG. Fatigue contributions to knee loading during high-impact landings. Training the brain to protect the ACL. Invited Keynote Speaker, The Future of Fatigue: Defining the Problem, Bathurst, Australia. August 22-26, 2011.

McLean SG. Modelling individual-specific neuromuscular and morphologic contributions to knee injury: moving beyond homogeneous prevention models. Invited Symposium Speaker, European College of Sports Science, Liverpool, UK. July 6-9, 2011.

McLean SG. Training for a Stronger ACL: Integrative Anatomical and Ultrastructural Considerations. Invited Keynote at the Oslo Sports Trauma Research Center's Annual Spring Retreat, Oslo, Norway. May, 2011.

McLean SG. The ACL injury enigma: A complex problem requiring an equally complex solution. Invited Keynote Address, Second Muscletech Network Workshop, Barcelona, Spain. September, 2010.

McLean SG. Integrative morphologic and mechanical contributions to knee health across the lifespan. Invited Faculty Presentation, University of North Carolina, Greensboro, NC. April, 2010.

McLean SG. Anatomical predictors of high-risk knee joint loading states. Invited Symposium Speaker and Chair, 2nd World Congress on Sports Injury Prevention. Tromso, Norway, June 25-28, 2008.

McLean SG. The ACL injury enigma: We cannot prevent what we don't understand, Research Retreat IV – ACL Injuries: The Gender Bias, Greensboro, NC. April 3-5, 2008.

McLean SG. A combined assessment of the ACL injury mechanism: Where do we go from here? Invited visiting professor, Department of Physical Therapy, The University of Delaware, April, 2006.

McLean SG. Identifying the ACL injury mechanism: An integrative approach to a complex problem. Invited Symposium Chair, The American College of Sports Medicine Annual Conference, Denver CO, June, 2006.

McLean SG. The ACL injury dilemma: Prevention is impossible if we don't know the cause. Invited Keynote presentation at the Australian Conference of Science and Medicine in Sport, Melbourne Australia, 2005.

McLean SG, Huang X, Su A, van den Bogert AJ. Neuromuscular control contributions to ACL injury: Identification via computer simulation. Invited to present at the AESS Exercise and Sports Science Conference, Brisbane Australia, April, 2004.

Myers P, McLean SG, Neal R (1998). The Cutting Manoeuvre: Kinetics, Kinematics and Caution. Invited to present at the Football Australasia: Reducing the Injury List Conference. Melbourne, Australia, July, 1998.

Selected Published Abstracts and Conference Proceedings (from 112 Total)

Fox A, Cain SM, McGinnis RS, Davidson SP, Vitali R, Perkins NC, McLean SG. Ability of body worn inertial measurement units to detect changes in performance during a loaded step task. 7th World Congress of Biomechanics, Boston, MA, July 6-11, 2014.

Davidson SP, McGinnis RS, Cain SM, Vitali R, McLean SG, Perkins NC. Validating internal measurement units as a method for determining rifle aiming performance. 7th World Congress of Biomechanics, Boston, MA, July 6-11, 2014.

Cain SM, McGinnis RS, Davidson SP, Vitali R, McLean SG, Perkins NC. An IMU-based method for

quantifying gait: algorithm development and comparisons to motion capture and instrumented treadmill data. 7th World Congress of Biomechanics, Boston, MA, July 6-11, 2014.

McGinnis RS, Cain SM, Davidson SP, Vitali R, McLean SG, Perkins NC. Validation of IMU-based method for tracking warfighter motion during jumping maneuver. 7th World Congress of Biomechanics, Boston, MA, July 6-11, 2014.

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Cain SM, McGinnis RS, Davidson SP, Vitali R, Perkins NC, McLean SG. Using Inertial Measurement Units to Quantify Gait Performance. Dynamic Walking. Zurich, Switzerland, June 10-13, 2014.

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Myers, P., McLean, S. and Neal, R. The cutting manoeuvre as a mechanism of non-contact ACL injury. Presented at The Australian Knee Society Annual Conference. Perth, Western Australia, 1996.

Project Experience

Principal Investigator on large-scale research effort utilizing state-of-the-art wearable technologies to develop, analyze and optimize complex warfighter performance metrics in a variety of naturalistic military environments.

Lead a series of experiments for high-profile sports company investigating impact of new sports-specific apparel designs on resultant performance outcomes and injury risk via novel wearable technologies.

Lead a successful research initiative for the National Football League examining effects of game-induced neuromuscular fatigue on key performance outcomes and the subsequent risk of lower limb injury.

Lead a government funded research project adopting complex 3-D computational modeling methods to evaluate mechanisms of knee joint injury and disease risk in at risk female sports populations.

Editorships & Editorial Review Boards

Editorial Board, Journal of Science and Medicine in Sport, 2005 – 2011

Editorial Board, Medicine and Science in Sports and Exercise, 2006 – 2011

Peer Reviewer

Medicine and Science in Sports and Exercise, 2003 – present

Journal of Science and Medicine in Sport, 2004 – present
American Journal of Sports Medicine, 2004 – present
Clinical Biomechanics, 2004 – present
Journal of Biomechanics, 2004 – present
Annals of Biomedical Engineering, 2005 – present
Journal of Athletic Training, 2005 – present
Journal of Orthopaedic Research, 2006 – present
Journal of Motor Behavior, 2006 – present
British Journal of Sports Medicine, 2006 – present
Journal of Biomechanical Engineering, 2006 – present
Journal of Mechanics in Medicine and Biology, 2012 – present

Attachment B

McLean Testimony List – 2019 to 2023

Case Name	Venue	Date	Type
Nike, Inc. v Lululemon USA, Inc., et al.	Southern District of New York, US District Court	Dec 06, 2022	Deposition

Attachment C

A HIGH PERFORMANCE COMMAND AND DATA HANDLING SYSTEM FOR NASA'S LUNAR RECONNAISSANCE ORBITER

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A high performance, modular and state-of-the-art Command and Data Handling (C&DH) system has been developed for use on the Lunar Reconnaissance Orbiter (LRO) mission. This paper addresses the hardware architecture, the operational performance, and the fabrication technology.

I. Introduction

LRO is the first mission in NASA's Vision for Space Exploration which is a plan to return to the moon and then to travel to Mars and beyond. LRO will launch in early 2009 with several key objectives: to find safe landing sites, locate potential resources, characterize the radiation environment, and demonstrate new technology. LRO will spend at least a year mapping the surface of the moon. Data from the orbiter will help NASA select safe landing sites for astronauts, identify lunar resources and study how the moon's environment will affect humans¹.

The C&DH was developed by NASA's Goddard Space Flight Center and is the heart of the LRO avionics. It is designed to support uplink command processing and execution, telemetry generation, guidance and control algorithms, provide interfaces to all of the avionics data interfaces, and collect science data from the instruments. It also provides autonomous failure detection and handling capabilities including a low level watchdog hierarchy, provides the spacecraft with a timing pulse, and provides data storage of 384 Gigabits between telemetry passes. The C&DH has been successfully environmentally tested and delivered to the LRO spacecraft for the flight Integration and Test.

The LRO C&DH design is also used on the Lunar Crater Observation and Sensing Satellite (LCROSS). LCROSS is managed by NASA Ames Research Center and will travel to the Moon as a co-manifested payload aboard the Atlas 5 launch vehicle along with LRO². In addition, several key elements of the LRO C&DH design are baselined for future NASA missions such as Global Precipitation Measurement (GPM) and Magnetospheric MultiScale (MMS).

The LRO spacecraft architecture utilizes reliable standard data buses for data transfers and control. A SpaceWire network is used for high speed data transfers and a MIL-STD-1553 bus for lower data rate transfers. This versatile system allows the C&DH to incorporate a hybrid implementation in which the SpaceWire network, the 1553 bus, legacy serial data connections, and a PCI bus are all utilized to interconnect the C&DH with the spacecraft subsystems and instruments. LRO will be the first mission in space to use the full network capability of SpaceWire.

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⁶ Digital Design Engineer, Flight Data Systems and Radiation Effects Branch, GSFC/Code 561, AIAA non-member

II. C&DH System Overview

The implementation of the LRO C&DH is based on a cost and schedule driven approach, capitalizing on strong in-house heritage designs and expertise. The system architecture is designed to utilize standardization, small physical size, low-power, high-performance capability and high reliability for space applications. To achieve the LRO mission success criteria, three areas important to the C&DH design were identified. These areas are (1) telemetry generation and command processing, (2) collection of science data from instruments, (3) and storage of science and housekeeping data between telemetry downlink passes. These areas have been extensively architected and implemented.

III. C&DH FEATURES

The C&DH team capitalized on extensive experience with hardware and software with PCI bus design, SpaceWire networking, Actel FPGA design, digital flight design techniques, and the use of VxWorks for the real-time operating system. The resulting hardware architecture depicted in Figure 1 was implemented to meet the LRO mission requirements.

In addition, the use of industry standard interfaces (SpaceWire, 1553, PCI, RS-422) allows access to relatively inexpensive and commercially available data simulators for ground support equipment. Intellectual Property (IP) was also available commercially for the cores for the digital designs. Several IP items were developed at Goddard and were used in the C&DH design of various Actel field programmable gate arrays (FPGA), specifically the Four-Port SpaceWire Router Core and the PCI interface core. Digital logic was designed to maximize the use of the Actel radiation-tolerant RTAX-2000 FPGA as much as possible.

A. Telemetry and Command

LRO utilizes two radio frequency (RF) bands for its communications with Earth. The S-Band is used for command and telemetry of housekeeping data. The Ka-Band is used for high speed data transfer of science data. To accommodate this, the C&DH utilizes two similar designs on a single assembly, with each design dedicated to a single band.

B. Collection of Science Data

The extensive use of SpaceWire European Cooperation for Space Standardization (ECSS-E-50-12A) and MIL-STD-1553 allows for expandability and scalability. Late addition of additional nodes can be accommodated anywhere in the spacecraft and attached to the C&DH SpaceWire network seamlessly.

The C&DH provides a mission unique interface to the LAMP instrument as well as providing timing synchronization to all the instruments.

C. Data Storage

The C&DH provides a mass storage system for the LRO spacecraft with a storage capacity of 48 Gigabytes (GB). Data collected from the instruments and the avionics housekeeping data is kept within this storage system prior to playback during a telemetry pass.

D. System Architecture

Figure 1 depicts the C&DH Subsystem with its ten sub-assemblies. The figure illustrates a top-level block diagram of the C&DH with the LRO Avionics and instrument interfaces. It also shows the interconnections between the C&DH sub-assemblies and other subsystems: the Ka-Band transmitter, S-Band transponder, and seven LRO instruments.

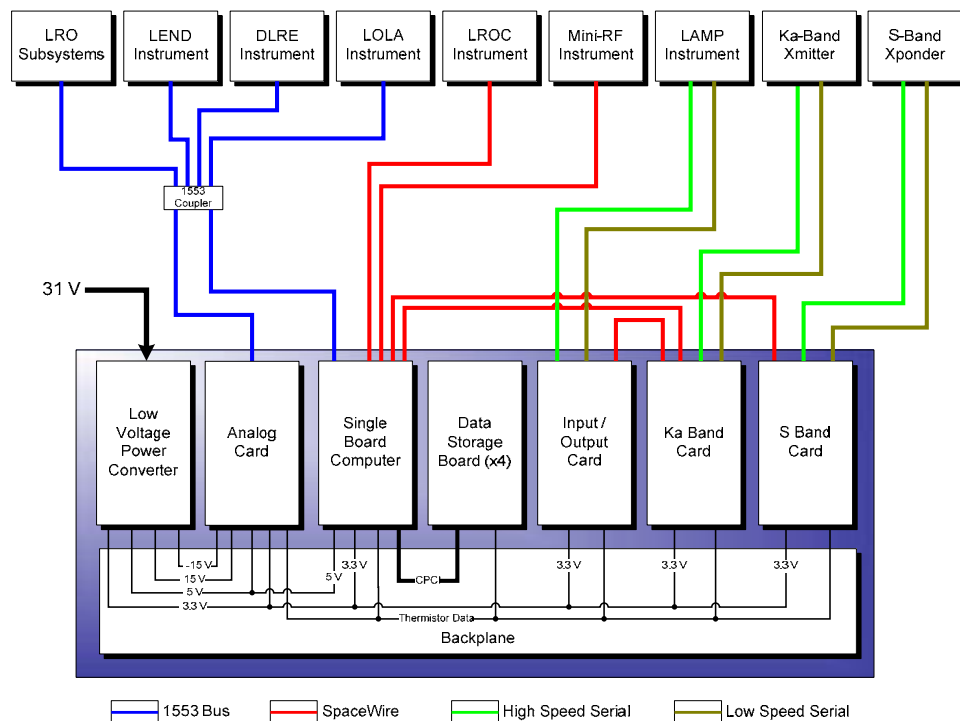


Figure 1. C&DH Architecture.

IV. C&DH SUB-ASSEMBLIES

The C&DH is comprised of an enclosure, a backplane, a low voltage power converter, a single board computer, a communications interface board, four data storage boards, a housekeeping and digital input/output board, and an analog data acquisition board. These components are all contained within the same C&DH enclosure. All electrical connections between these components are made via the backplane for internal power distribution and PCI bus data transfers. The interfaces between the C&DH and the instruments and avionics are connected through a SpaceWire network, a MIL-STD-1553 bus, and a combination of synchronous and asynchronous serial data transfers over RS-422 and LVDS electrical interfaces. The C&DH acts as the spacecraft data system with an instrument data manager providing all software and internal bus scheduling, ingestion of science data, distribution of commands, and performing science operations in real-time.

Figure 2 shows the fabricated engineering test unit versions of the sub-assemblies. Seven of the sub-assemblies were designed at GSFC. Only the single board computer (SBC) was procured commercially.

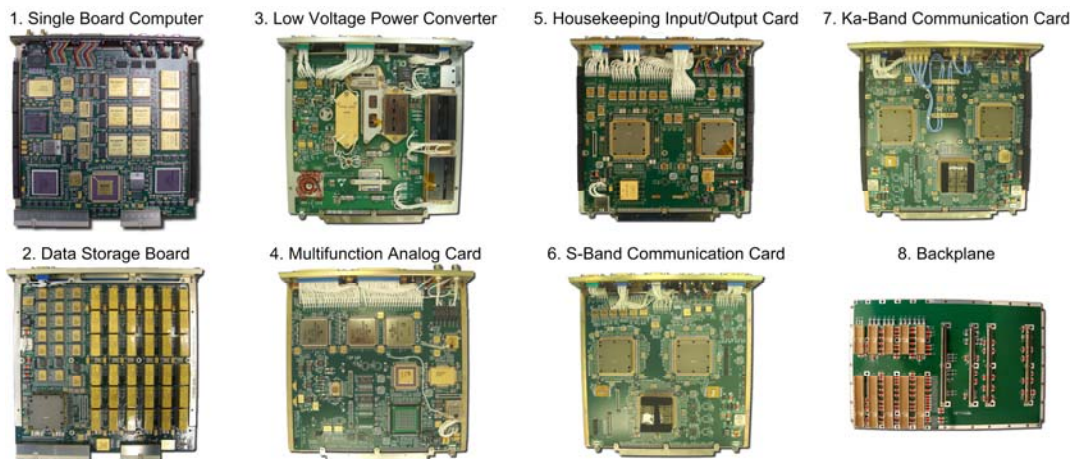


Figure 2. C&DH Sub-assemblies.

A. Single Board Computer

The SBC is the processing platform for the flight software (FSW) and the attitude control software (ACS). The SBC utilizes the RAD750 processor, operating at a frequency of 133 Megahertz (MHz). The SBC is designed to be immune to latchup and sustain up to 50 Krads of total ionizing dose. For memory, the SBC contains 36 megabytes of (MB) of Static Random Access Memory (SRAM) for storing executable code and housekeeping data, 64 kilobytes of Start Up Read Only Memory (SUROM) for storing essential bootstrap code, and 4 MB of Electrically Erasable Programmable Read Only Memory (EEPROM) for storing application code. The EEPROM is arranged as two banks to store two copies of the application code. The SBC operates as the bus controller for the 1553B bus to communicate with LRO subsystems and the instruments. Four SpaceWire interfaces are provided and are used to communicate with the LROC and Mini-RF instruments and both communication cards (S-Band and Ka-Band). The backplane connector provides a compact PCI bus interface which is utilized to transfer data with all four data storage boards.

B. Housekeeping Input/Output Board

The HKIO is a mission unique board and provides three functions within the C&DH: distribution of the 1 pulse per second (PPS) signal to LRO, maintain a mission elapsed timer (MET), and to provide an interface for the LAMP instrument.

The 1 PPS signal is generated within the HKIO by using a 20 MHz clock from one of the two ultra stable oscillators (USO). The MET is used to maintain the time of received uplink commands and as a mechanism for time synchronization.

Two interfaces are provided to the LAMP science instrument. Because LAMP is derived from an earlier instrument used on the New Horizons mission to Pluto (ALICE), the LAMP instrument's interface was not altered to reduce schedule risk and cost to LRO. The HKIO provides electrical and data connectivity to the LAMP instrument through two serial interfaces, one high speed interface using low voltage differential signaling (LVDS) and one low speed interface using the RS-422 standard. The science data and commands to and from the LAMP instrument go through the HKIO board and flows to the SBC using a SpaceWire link.

C. Multi-Function Analog Card

The MAC provides all analog connectivity for the C&DH for its internal telemetry for voltage monitoring and internal thermistors in addition to all the analog data from the LRO spacecraft. The analog data from the LRO spacecraft includes all thermistors, platinum resistance thermometers, hinge potentiometers, coarse sun sensors, various analog telemetry points, and pressure transducers. The MAC digitizes all the analog data and generates telemetry and receives commands over the 1553 bus.

In addition to providing analog telemetry values, the MAC also provides five switched power services. The services provide the spacecraft bus voltage to various heaters located near the LROC instrument and are controlled by flight software.

D. Data Storage Boards

The four DSBs are designed to be part of a file system which handles the storage and retrieval of files. The DSBs provide 384 gigabits at Beginning of Life (BOL) of memory capacity for storing science and housekeeping data during a 17.5 hour time interval between Ka-Band downlink passes. The file system mechanisms are supported by the SBC using the FAT32 file system.

The DSB contain error detection and correction (EDAC) logic circuitry to correct up to 2 nibbles (4 bits per nibble for a total of 8 bits) in error and to detecting three or more nibbles in error. The EDAC is implemented using a form of short Reed Solomon coding. In addition to the EDAC, the DSB provides a hardware based scrubber which will go through all the memory locations and clear out any bit errors. The scrubber is designed to be completely autonomous and does not need additional software support.

The DSBs utilizes synchronous dynamic random access memory (SDRAM) packaged in flight qualified high density memory modules as the memory storage element. The DSB can turn off all SDRAMs on a single board to conserve power when needed. All data transfers and configuration of the DSBs take place using the compact PCI interface through the backplane connector.

E. Ka-Band Communications Card

The Ka-Comm card provides high-speed telemetry to Earth using Ka-Band frequencies. For LRO, the Ka-Comm card is connected to the SBC via a SpaceWire link. During a Ka-Band pass, the data from the SBC flows directly into the Ka-Comm card at the SpaceWire link rate of 132 megabits per second (Mbps). The telemetry data rate itself

is 100 Mbps. Once the data is received by the Ka-Comm card from the SBC, the Ka-Comm card then proceeds to encode the data for transmission. The encoding is done as per Consultative Committee for Space Data Systems (CCSDS) recommendations for telemetry encoding. The Ka-Comm card also splits the telemetry stream into two streams for offset quadrature phase shift keying (OQPSK) modulation. The two streams are sent to the Ka-Band transmitter, which in turn modulates the data onto a radio-frequency (RF) carrier and is finally transmitted through the high gain antenna (HGA).

In addition to providing telemetry to the Ka-Band transmitter, the Ka-Comm card also provides command and control and receives housekeeping telemetry from the Ka-Band transmitter itself. This is accomplished by using an asynchronous low rate serial interface with RS-422.

F. S-Band Communications Card

The S-Comm card provides telemetry and receive commands to and from Earth using S-Band frequencies. For LRO, the S-Comm card is connected directly to the SBC via a SpaceWire link. During a pass, the data from the SBC flows directly into the S-Comm card at the SpaceWire link rate of 10 Mbps, where the telemetry data rate is a maximum 1 Mbps.

Once the data is received by the S-Comm card from the SBC, the S-Comm card then proceeds to encode the data for transmission. The encoding is done as per CCSDS recommendations for telemetry encoding. The S-Comm card provides a single data stream for Bi-Phase Shift Keying (BPSK) modulation in the S-Band transmitter. The data stream is sent to the S-Band transponder, at various data rates up to 1.093 Mbps (2.186 Mbps symbol rate), which is in turn modulated onto a RF carrier and transmitted through the HGA or omni-directional antennas.

For commands, S-Comm card accepts CCSDS telecommands from the S-Band transponder at various rates up to 4 kilobits per second (Kbps). The S-Comm card also generates a timing pulse upon receipt of command for time correlation with the ground stations.

The S-Comm card also provides command and control and receives housekeeping telemetry from the S-Band transponder itself. This is accomplished by using an asynchronous low rate serial interface over RS-422.

Finally, the S-Comm card provides the ability to process hardware decoded commands and are executed directly by the S-Comm card itself. Up to eight hardware-decoded commands are provided, four of which are RS-422 outputs and four are low voltage TTL.

G. Low Voltage Power Converter

The Low Voltage Power Converter (LVPC) is required to convert an input voltage with an operational range of +21 volts DC to +35 volts DC from the LRO spacecraft to provide voltage outputs of +3.3 VDC, +5 VDC and +/-15 VDC with EMI filtering. The LVPC also contains circuitry that drives the magnetic relays which provide power for several components of LRO's RF system. These RF components include the S-Band antenna transfer switch and the Ka-Band Traveling Wave Tube Amplifier (TWTA) power relay.

H. Backplane

The backplane provides interconnectivity for the nine cards in the LRO C&DH System within the confines of the C&DH enclosure. These cards include the S-Band and Ka-Band communication cards, the HK/IO card, the MAC, the LVPC, the SBC, and four DSB cards. The backplane accommodates each card that connects to it with a unique interface. The backplane distributes the voltage outputs from the LVPC. The backplane provides +5 VDC to the SBC and the MAC. In addition, +3.3 VDC is provided to all of the boards within the C&DH enclosure and +15 VDC to the MAC and the DSBs, and -15 VDC to the MAC.

The backplane also provides a compact PCI bus interface between the SBC and the four DSBs and is rated for 33 MHz data transfers. Thermistor data from all the boards is also provided and distributed through the backplane to the MAC as part of the housekeeping data collection.

I. Enclosure

The C&DH enclosure (Figure 3) acts as the mechanical housing for the C&DH unit and contains all of the C&DH hardware assemblies. The C&DH is 16.00 in (L) by 11.50 in (W) by 9.75 in (H) in dimensions and weighs 46 pounds with all its subassemblies installed. The C&DH box is mounted on the iso-thermal panel (ITP) of LRO's avionics deck. The flange at the base of the C&DH

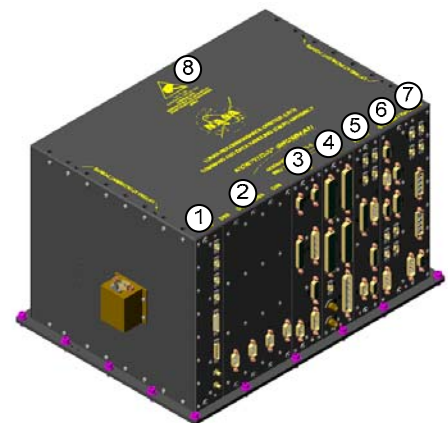


Figure 3. C&DH Enclosure.

enclosure is used to attach the C&DH to the LRO structure with twenty (20) fasteners.

IV. SYSTEM OPERATIONAL PERFORMANCE

The flight C&DH unit for the LRO mission has successfully completed box-level environmental testing and comprehensive testing at the spacecraft level for hundreds of hours of spacecraft operation. The following sections highlight several significant operational performance metrics during the LRO integration and test (I & T) phase.

A. Spacecraft Autonomy

The baseline on-orbit LRO ground contact plan is four Ka-band downlink passes per day (duration of 45 minutes each) and twelve S-Band downlinks/uplinks contacts (duration of at least 30 minutes each) per day. Between the ground contacts, the flight software hosted by the C&DH provides autonomous operation of the spacecraft by issuing preplanned commands uploaded by ground into the processor's stored command memory. The flight software monitors the spacecraft house-keeping data for anomalies and responds to them with appropriate actions. Under worst case conditions, the spacecraft is designed so that it is able to miss ground contacts for periods of up to 28 hours and will be capable of sustaining itself without disrupting normal operations.

B. Processor Utilization and Power Dissipation

The C&DH is required to maintain less than 80% processor utilization under worst case conditions. The C&DH processor utilization is measured to be an average slightly less than 80% while a Ka-Band pass is active at 100 Mbps in addition to performing normal operational functions and collecting and processing science data. In this configuration, the C&DH consumed a steady state power draw of 95 Watts.

C. Watchdog Strategy

LRO utilizes a single string design architecture except where safety and reliability concerns require additional protection. As a result, the C&DH is built with minimal hardware redundancy. To mitigate the risk associated with a single string design, the watchdog strategy for the C&DH is implemented in both hardware and software. Several layers of protection are provided to handle processor faults and memory anomalies caused by software and/or hardware errors, including Single Event Upset (SEU) and latchup. The watchdog strategy utilizes a layered hierarchy that provides increasing levels of intervention and protection. The first layer is a software based watchdog in the flight software, followed by a second layer software based watchdog on the SBC. The last layer is the hardware watchdog on the S-Comm Card which recycles the power to the C&DH by issuing a command the LVPC as a last resort. This watchdog strategy for fault detection and correction has been successfully tested throughout integration and testing.

D. Science Data Collection

Data from all the science instruments is collected into files in the C&DH's data storage system. These files are constantly created while LRO orbits the moon. The science data is downlinked as much as possible during the Ka-Band passes by using the CCSDS file delivery protocol (CFDP). The use of the CFDP ensures that the science data is transferred in its entirety and error free before it is removed from the data storage system to free up space for new science data.

E. Ultra Stable Oscillators

The C&DH supports two Ultra Stable Oscillators (USO). One is designated as primary and the other as redundant. Only one of the oscillators is powered at any given time. Each oscillator provides two 20 MHz clock signals. One signal goes to the C&DH HKIO card for 1 PPS generation, and the second signal goes directly to the LOLA instrument.

The primary USO was chosen to meet a frequency stability factor of 10 parts per billion (ppb) over one millisecond (ms). The redundant USO was chosen to meet a frequency stability factor of 0.3 parts per million (ppm) over one millisecond (ms). The oscillators were chosen to provide sufficient stability to meet the needs of the laser ranging system component of the LOLA instrument.

V. FABRICATION TECHNOLOGY APPROACH

Due to the complexity of the design and a large amount of components needed to implement the design, the selection of the fabrication process was a challenge to the design team. To meet LRO requirements for weight and size, the C&DH was drastically reduced in weight and size during the design process compared to a system built

utilizing conventional fabrication methods. Three proven fabrication processes for spaceflight use were selected: the use of surface mount technology (SMT) components, ceramic column grid array (CCGA) packaging for semiconductor devices, and the use of two sided printed wiring board assemblies (PWA) with a heat sink core.

The following sections discuss these three processes in addition to addressing the vibration and thermal design problems.

A. Surface Mount Technology

Most of the C&DH subassemblies are populated with SMT components. A variety of SMT package styles such as flat-packs, quad flat-packs and leadless chip carrier (LCC) are utilized on the C&DH subassemblies. The use of SMT has two significant advantages, which are the small physical size of the components and the ability to use an automated assembly process. The use of automated assembly has helped to significantly improve the quality of the sub-assemblies by providing consistency throughout the assembly process. However, for space flight use, even SMT manufacturing processes must pass crucial thermal cycling qualification based on the mission environment profile. SMT components must withstand hundreds of thermal cycles over the mission's design life.

B. Ceramic Column Grid Array Design

CCGA array packaging was selected for the field programmable gate array device (FPGA) on the DSB. This packaging technology provided a sufficient number of input/output (I/O) pins for the DSB design in addition to providing a considerably smaller footprint with a comparable FPGA utilizing the ceramic quad flat-pack (CQFP) packaging.

The DSB is made more rigid by attaching a stiffening frame to the heatsink to meet the CCGA structural design criteria. For a CCGA device, the card deflection ratio must be sufficient with margin to ensure that the solder joints of the CCGA device do not fail. Figure 4 shows the structural analysis at 337 Hz to demonstrate that the board deflection is acceptable at the three sigma level.

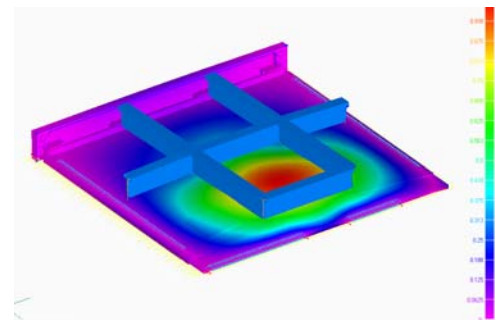


Figure 4. Structural analysis of DSB first mode with simple fixity at 337 Hz.

C. Two-Sided Printed Wiring Board Assembly

Each C&DH sub-assembly consists of a double-sided or single-sided printed wiring board (up to 12 layers 6U-160 mm), a heat sink plate, two wedge locks, an edge connector, a stiffener and a front panel. The aluminum heat sink is sandwiched between the two PWBs. The wedge locks are mounted on both long edges of the heat sink. For the DSBs and the SBC, the assembly is electrically and physically connected to the backplane through a HyperTronic cPCI connector. The remaining boards (HKIO, MAC, Ka-Comm, S-Comm) utilize a MEB 184-pin edge connector. A stiffener is attached to the heatsink to reduce the board deflection and dynamic stresses due to vibration.

Electrical connections between two PWBs on the same assembly are provided by z-wires. The use of z-wires is minimized where possible to improve the reliability of the overall assembly. The solder joint of the z-wire is also thoroughly inspected during manufacturing. The use of z-wires can reduce the overall signal length by providing a more direct path between two connection points. Signal integrity analysis was used to optimize the layout process.

A finite element analysis (FEA) was performed to help determine a suitable fabrication technique to mount the SDRAM packages onto the DSB assembly. The FEA showed that the stresses on the corners of the SDRAM devices required the addition of an epoxy to bring down the stress levels to within allowable limits for vibration levels.

D. Signal Integrity

Due to the use of high speed signals with fast edge rates, signal integrity (SI) analysis was performed on all of the digital PWB designs of the C&DH. The prevalence of the high speed digital logic elements necessitated an analysis of all the signal interconnects for all the boards to ensure that the signals were within specifications with regard to monotonicity, overshoot, and undershoot. The signal integrity analysis was performed during the board layout and signal routing phases to determine whether signals needed to be terminated to address signal integrity. The analysis ensured that all digital signals were within the component's electrical specification. In addition to signal quality, the effects of crosstalk on all signals were analyzed and mitigated where possible.

E. Thermal Design

The C&DH is designed for an operating temperature range of -10 to +40 C and a survival temperature range of -20 to +50 C. The qualification test base plate temperature for the LRO C&DH was performed from -20 to +50 C. The thermal analysis models for the chassis and board shown in figures 5 and 6 are based on conducted cooling through the base plate to the spacecraft mounting surface controlled to a constant 50 C. The main thermal paths of the modules are through the top and bottom wedge lock interfaces at the thermal steady state condition.

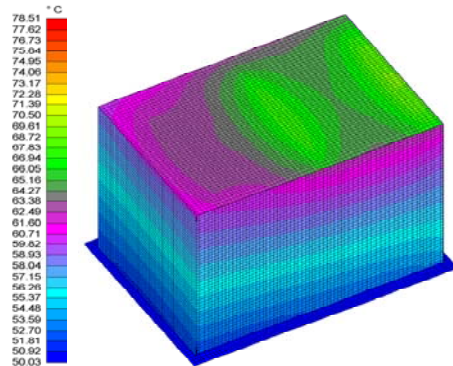


Figure 5. C&DH Thermal Profile.

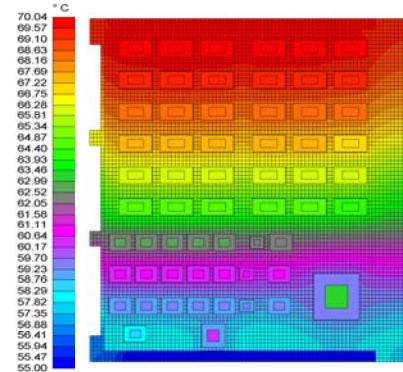


Figure 6. DSB Thermal Profile.

VI. CONCLUSIONS

The C&DH hardware and software performed well throughout the LRO integration and test phases. The C&DH is relatively small in size and light in weight, but it is capable of performing several sophisticated tasks.

The underlying philosophy utilized by the design team was to guarantee the design by simulation (for both digital designs and signal integrity) as much as possible. The testing of the completed sub-assemblies was intended to validate the design. This design approach reduced the risk of surprise of design errors and inadequacies.

The C&DH utilizes a versatile architecture and industry standards to provide high performance in a small reliable package. The C&DH is a spacecraft data system with the capability to collect science data from the instruments and store it in its data storage system for the LRO mission. Due to its flexibility and modularity, it can be reused on other NASA missions with similar requirements and architecture.

REFERENCES

¹<http://lunar.gsfc.nasa.gov/index.html>

²<http://lcross.arc.nasa.gov/overview.htm>