Characterization of Cryogenic Flexible Transmission Lines Designed for the GUSTO IF Harness

Marko Neric, Hamdi Mani, Thomas Mozdzen, and Chris Groppi

***Abstract*—Cryogenic flexible printed circuit ribbons based on stripline transmission lines have been custom designed, fabricated, and characterized for an upcoming NASA Class-D balloon mission. The Galactic/Extragalactic Ultra-Long Duration Balloon (ULDB) Spectroscopic Terahertz Observatory (GUSTO) will make use of 8-channel flex ribbons to transmit Intermediate Frequency (IF) from 0.3-4 GHz while at cryogenic temperatures and in flight. In this configuration one individual flexible ribbon can replace up to 8 semi-rigid SS-SS coaxial cables that are 20 inches in length. The GUSTO focal plane array consists of 24 pixels that would otherwise require an equal number of coaxial cables. Similar performance can be achieved using only 3 sets of flex ribbons, each of which is comprised of two circuits in series. This will not only reduce the weight and form factor of the IF harness, but also provide improved thermal performance. The ground planes of the flex circuit have been reduced to minimize heat transfer into a cryogenic system which can extend mission lifetime by mitigating coolant boil off. Each channel of the flex circuit conducts a quarter of the heat that a coaxial cable would. To accommodate the unique design of the GUSTO cryostat three pairs of flex ribbons will be RF coupled to provide the necessary length and shape for routing between IF components. Flex circuits were designed with a staggered array of SMP type press on connectors instead of SMA which makes coupling 8 channels achievable in one easy maneuver. The circuits can be clamped together to prevent separation in flight or other high vibration conditions all in less time than it would take to install coax. All RF testing was done using a closed cycle vacuum cryogenic station with the test bed held at 20 K. Each pair of flex ribbons was thermally coupled to the 20 K stage. The flexible transmission lines showed an average insertion loss of 3.07 dB/ft at 5 GHz, while the industry standard SS-SS UT-85 coax loss is 2.80 dB/ft. The GUSTO IF system will use state of the art ASU cryogenic low noise amplifiers to more than make up for the higher insertion loss. Any future systems that can correct for, or accept the additional loss will benefit more from the other features of the flex circuit design. The custom made cryogenic flexible transmission lines are still the preferred method of signal transmission for applications that require complex routing, lightweight components with small form factor, easy assembly, lower heat transfer, and flexibility.**

***Index Terms*—RF, Cryogenics, Transmission Lines.**

I. Introduction

The intermediate frequency (IF) harness of the Galactic/Extragalactic Ultra-Long Duration Balloon Spectroscopic Terahertz Observatory (GUSTO)[1] has been designed, fabricated, and characterized. GUSTO is a NASA balloon mission that will observe THz signals from within the Milky Way and the Large Magellanic Cloud. GUSTO will have a 24 pixel focal plane made up of three separate 8 pixel arrays. Each array is housed inside the same vacuum cryogenic system. The IF harness must transmit the signals of 24 independent pixels from within the cryogenic station to an outside interface.

Two choices for a harness were considered. The first was 24 sets of stainless steel - stainless steel (SS-SS) semi rigid coaxial cables. The benefits of semi-rigid coax include their well characterized performance, and their repeated use in commercial and space applications which gives coax a long heritage. Stainless steel is often chosen for transmission in and out of vacuum cryogenic systems due to its low thermal conductivity despite more signal loss than alternatives. The drawbacks to using coax become more evident as the pixel count in an instrument increases. The resulting increase in pixels requires an increase in transmission lines. For a system using coax this means each cable must be individually installed to the same specifications. This increases the risk of individual failure while also increasing the overall form factor of the harness and installation time. The industry standard SS-SS semi rigid coax is UT-085 which has an outer diameter of 0.087”. Smaller cables than this are available but tend to be more fragile and higher in loss. Semi-rigid cables can be more difficult to route through a cryogenic system since they cannot accommodate paths with sharp turns or some narrow spacing. It often becomes necessary to install hermetic vacuum feed-through adaptors at several points within a cryostat to complete the harness which further increases the number of coax lines and potential areas of failure.

The second option considered was to make the IF harness using ASU cryogenic flexible transmission line ribbons[2]. The ASU flex ribbons use a stripline design as a base and can incorporate several channels in a single ribbon. A prototype 8-channel ribbon was designed previously with the GUSTO mission in mind and to test key features that would give the flex ribbons an edge over coax. The prototypes were 8-channel circuits in either a straight ribbon or a curved ribbon to test the effects of in-plane turns on the individual channels. Each prototype had a width of 1.1”, and a total length of 20”. The ribbons were populated with press on connectors that allow fast an easy connections. They can be custom designed to meet the specific routing needs of the mission without significant signal loss. The prototypes achieved similar RF performance to coax, and transfer significantly less heat into the cryogenic system which has a limited supply of coolant. The drawbacks to this approach are that the best RF performance is achieved when the ribbon is at cryogenic temperatures, and that is still slightly higher in signal loss than SS-SS coax. Low noise amplifiers can be used to boost the IF signals to make up

M. Neric, H. Mani, T. Mozdzen, and C. Groppi are with the School of Earth and Space Exploration, Arizona State University, Tempe, AZ, 85287 USA e-mail: mneric@asu.edu.

IV. Conclusion

The GUSTO mission will showcase several of the best features and abilities of the ASU cryogenic flex ribbons. Upcoming instruments that have a high pixel count, complicated or limited routing space, and have need of compact and lightweight solutions for their IF system will benefit from using the ASU flex ribbon. The lessons learned from the GUSTO mission will drive further innovation of the flex ribbon that already offers comparable performance to industry standard semi-rigid coax with other measurable benefits. The ASU flex ribbon exceeds all design specifications that were set for the GUSTO mission. They achieve a bandwidth that includes 0.3 - 4 GHz with an insertion loss at cryogenic temperatures that is 3.07 dB/ft and Isolation much greater than 30 dB over the entire bandwidth.

Acknowledgment

The authors would like to thank Bob Giambrone, and Hector Ramirez of Coast to Coast circuits for their help and support during the fabrication of the flexible test circuits. The authors would also like to thank David Good, Gary Abramczyk, and Suzette Martinez of GMA Manufacturing for their help and support with the board assembly.

References

[1] C. Walker, C. Kulesa, P. Goldsmith, C. Groppi, F. Helmich, D. Hollenbach, J. Kawamura, W. Langer, G. Melnick, D. Neufeld, J. Pineda, G. Stacey, A. Stark, A. Tielens, M. Wolfire, H. Yorke, and E. Young, "GUSTO: Gal/Xgal U/LDB Spectroscopic-Stratospheric TeraHertz Observatory," Amer. ASTRO. Soc., AAS, 231, 2018

[2] P. McGarey, H. Mani, C. Wheeler, C. Groppi, "A 16-channel flex circuit for cryogenic microwave signal transmissions," SPIE, 9153, 2014

Marko Neric graduated from Arizona State University (ASU) in 2014 earning a B.S. in Physics. He is currently a Ph.D. candidate in the School of Earth and Space Exploration (SESE) at ASU. He is pursuing his Ph.D. in astrophysics, and an M.S. in electrical engineering. His focus is on THz astronomy, and instrument building.

Hamdi Mani has been an engineer at the ASU radio astronomy lab for the past 8 years. His main areas of research: design of wideband cryogenic low noise RF/ Microwave amplifiers and receivers, development of microwave and millimeter wave instrumentation, electronics packaging and cryogenic systems design . Prior to joining ASU, he worked at Caltech/JPL on developing SiGe cryogenic low noise amplifiers and wideband radio astronomy receivers.

Thomas J. Mozdzen received the B.S. in Physics in 1978 and the M.S. in Electrical Engineering in 1980 from the University of Illinois Urbana-Champaign, the M.S. in Physics from the University of Texas at Dallas in 1985, and the PhD in Astrophysics from Arizona State University in 2017. He has worked in the semiconductor industry for several years beginning as a reliability engineer at Mostek Corp, Dallas, Tx., and then mainly as a circuit design engineer at Siemens, Munich Germany, and at Intel, Chandler, Arizona. His PhD. Thesis focused on reducing systematic error in experiments to detect the sky-averaged redshifted 21 cm epoch of reionization signature. He holds several engineering related US patents and has authored several papers in both electrical engineering and astrophysics. He is currently employed at Arizona State University as a Postdoctoral researcher.

Christopher E. Groppi received the B.A. degree in astronomy (with honors) from Cornell University in Ithaca, NY, in 1997 and the Ph.D. degree in astronomy with a minor in electrical and computer engineering from the University of Arizona in Tucson, AZ, in 2003. In 2003, he joined the National Radio Astronomy Observatory as a Director's Postdoctoral Fellow. He then moved to the University of Arizona as an assistant staff astronomer in 2005. In 2006, he received an Astronomy and Astrophysics Postdoctoral Fellowship from the National Science Foundation. In 2009, he joined the Arizona State University School of Earth and Space Exploration in Tempe, AZ as an assistant professor. He became an associate professor in 2015. He is an experimental astrophysicist interested in the process of star and planet formation and the evolution and structure of the interstellar medium. His current research focuses on the design and construction of state of the art terahertz receiver systems optimized to detect the light emitted by molecules and atoms in molecular clouds, the birthplace of stars. He also applies terahertz technology developed for astrophysics to a wide range of other applications including Earth and planetary science remote sensing, hazardous materials detection and applied physics.