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Lightning Interferometry Using RAPID

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Abstract

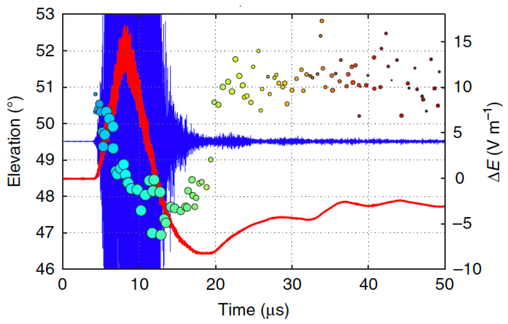
Recent studies have demonstrated that high-speed, broadband radio frequency (RF) interferometers are particularly useful to advance lightning physics [e.g., Stock et al., J. Geophys. Res., 119, 3134, 2014; Rison et al., Nat. Commun., 7, 10721, 2016; Tilles et al., AE12A-03, AGU Fall Meeting, 2016]. This is because RF signals can propagate through clouds with minimal attenuation and RF electronics can achieve high temporal resolution and dynamic range. In addition, the physical parameters (e.g., current and charge) of lightning processes can be inferred from RF measurements.

The Radio Array of Portable Interferometric Detectors (RAPID) instrument is a radio imaging array recently developed by MIT Haystack Observatory [Lind et al., IEEE International Symposium on Phased Array Systems & Technology, 676, 2013]. It features a flexible architecture, highly integrated giga-sample per second digitizers, and cloud-based signal processing and data analysis. It can work with a variety of antennas, such as those commonly used for astronomical studies, e.g., Square Kilometer Array (SKA) and Long Wavelength Array (LWA), to capture RF signals and their polarization. The instrument is portable and can be deployed to a radio-quiet environment to study the physical processes of interest.

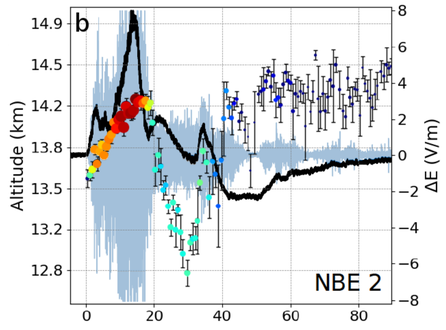
A demonstration of this technology applied to lightning imaging was conducted by MIT Haystack Observatory and UNH using prototype RAPID hardware, SKALA antennas, and LWA antennas in the summers of 2017 and 2018. The system was deployed at MIT Haystack Observatory, and a few thunderstorms were observed during those periods. In this talk, we report the RAPID observations of selected lightning events and the interferometric analysis of the data by using the method developed by Stock et al. [2014] and Tilles et al. [2016]. Although only three or four array nodes were employed during the test, our study indicates that a RAPID-based interferometric system with many nodes will be very useful for lightning studies. We propose such a system called Radio Interferometer For Thunderstorm Studies (RIFTS). RIFTS has 16 array elements, adjustable bandwidth up to 1600 MHz, flexible data acquisition configurations, and advanced imaging algorithms. The design goal of RIFTS is to be capable of imaging lightning at a resolution ten times better than current systems.

Recent Broadband Radio Interferometric Studies of Lightning

Broadband RF interferometers can provide the required high temporal/spatial resolution and dynamic range to resolve the electrical breakdown/discharge processes that are critical for lightning initiation and propagation. The recent observations made by the INTF interferometer developed by NM Tech represent what can be achieved with high-speed RF interferometers [e.g., Stock et al., 2014; Rison et al., 2016; Tilles et al., 2016, 2017].



The INTF observation indicates that narrow bipolar events are caused by fast positive breakdown [Rison et al., 2016].

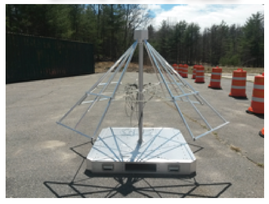


NBEs can also be caused by fast negative breakdown [Tilles et al., 2016].

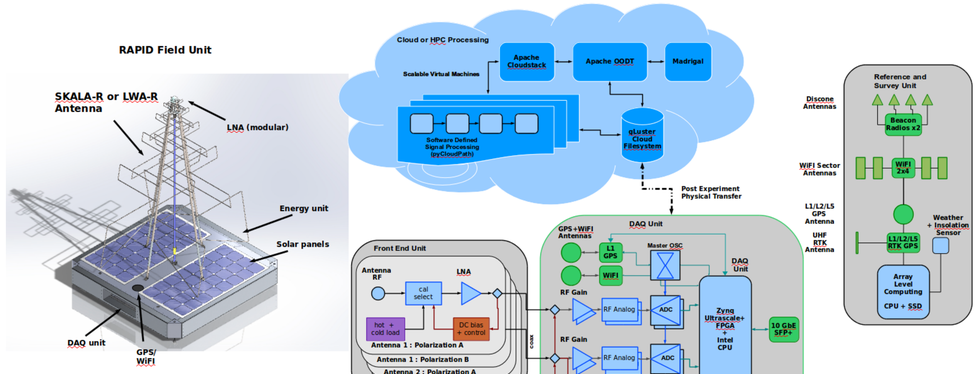
Radio Array of Portable Interferometric Detectors (RAPID)

The RAPID system is an advanced software radio imaging array that is currently under development at MIT Haystack Observatory under the support of an NSF MRI award. The system uses solar and battery power in combination with Square Kilometer Array or other antennas, highly integrated giga-sample per second digitizers, and cloud based signal processing and data analysis [e.g., Lind et al., 2013]. It is capable of supporting between 80 and 100 RF channels (i.e., 40 to 50 simultaneous antennas) and can be deployed easily to remote locations and reconfigured to optimize radio imaging for specific scientific applications.

LWA 10-70 MHz

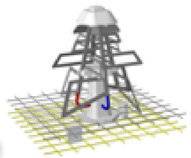


SKALA 48-615 MHz



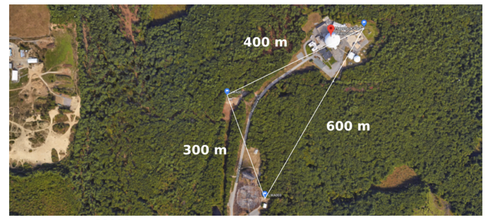
Multiple Antennas can be used with a single DAQ Unit

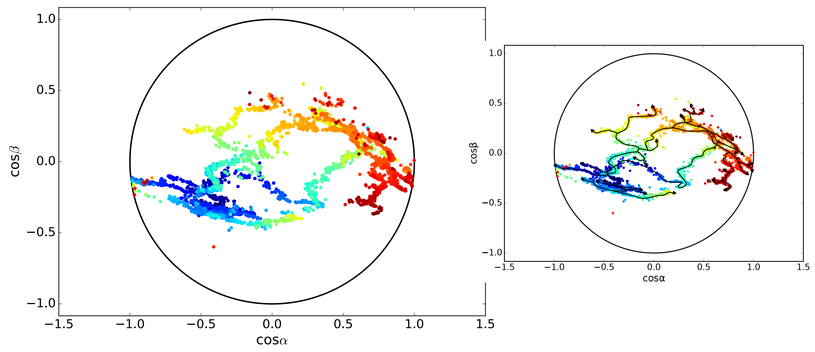
MFAA 150-1300 MHz

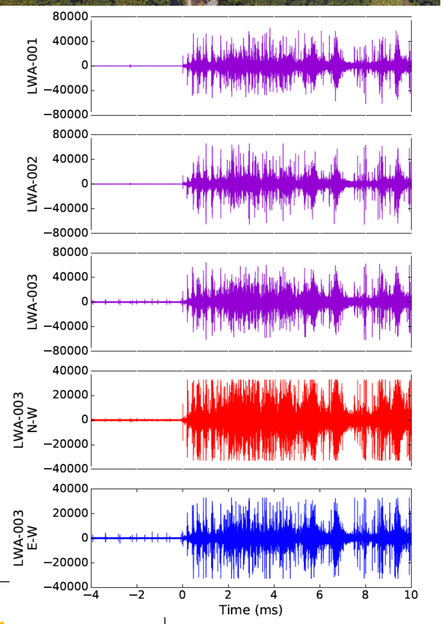


Interferometric Studies of Lightning Using RAPID

In the summers of 2017 and 2018, field tests of an interferometric system based on RAPID were conducted at MIT Haystack Observatory. In 2018, the interferometer array consists of three Long Wavelength Array (LWA) antennas, operating at a center frequency of 45 MHz and with 50 MHz bandwidth, with baseline lengths of 335 m, 469 m, and 606 m. Each crossed-dipole LWA antenna was operated in dual polarization (North-South and East-West). The signal from each antenna was digitized with a separate Ettus X300 radio at 200 MSps IQ with 14 bit resolution, and the signals from the three antennas were time-aligned (+/- 30 ns) using a local GPS disciplined oscillator (Ettus Octoclock).

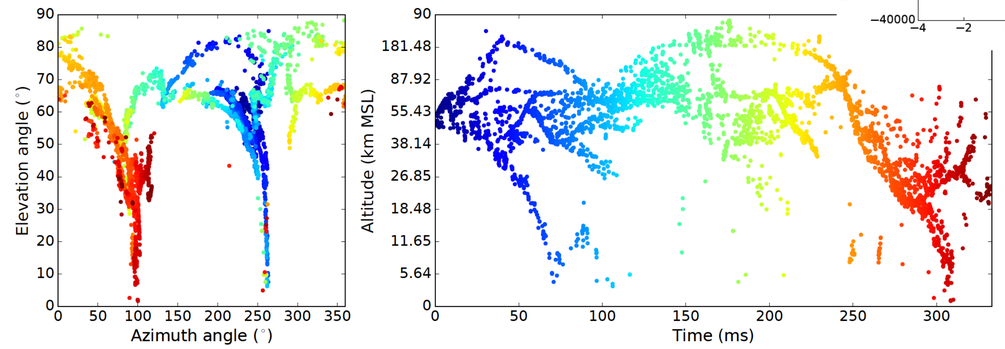






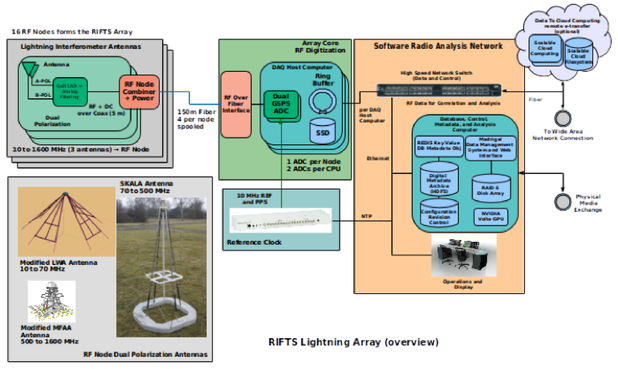
An extensive intra-cloud flash observed on 2018/07/17. The flash started around 17:32:35.01 UT, and the corresponding NLDN record is: 2018-07-17 17:32:35.900 42.2070 -72.5314 +2.3 C.

Each point represents the average location of VHF emission source over a 40 us time window, and the shift between windows is 20 us.



Radio Interferometer For Thunderstorm Studies (RIFTS)

The field tests indicate that a RAPID-based interferometric system with many nodes will be very useful for lightning studies. We propose the Radio Interferometer For Thunderstorm Studies (RIFTS) instrument that will have 16 array elements, adjustable bandwidth up to 1600 MHz, flexible data acquisition configurations, and advanced imaging algorithms. RIFTS will be capable of imaging lightning at much better resolution to further our understanding of thunderstorm electrical discharges.



Summary and Conclusion

1. Our study has demonstrated that the RAPID system can be used for lightning mapping and imaging. The RAPID system is easily deployable and reconfigurable, and it also works with commonly-used antennas for radio astronomy. The flexibility allowed by the RAPID system can be very useful for lightning research.

2. The study also indicates that the RAPID system configured with broad bandwidth, long baseline lengths (multiple hundred meters), and local clocks works for observing lightning. The configuration can achieve great angular resolution, and it will be very useful for imaging lightning processes, such as leaders, that propagate at moderate speeds.

3. Although not explored in this study, the polarization measurement may provide additional information about the lightning process, as demonstrated by a recent study by Shao et al. [2018].

Acknowledgments

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References

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Tilles, J. N., P. R. Krehbiel, M. A. Stanley, W. Rison, F. Lyu, S. Cummer, N. Liu, J. R. Dwyer, R. G. Brown, and J. G. Wilson (2017), Broadband VHF interferometer observations of an energetic in-cloud pulse (EIP), in *AGU Fall Meeting*, New Orleans, LA.