Initial Data from Balloon Borne Slow Antenna

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The benefits of combining the LMA with other instruments to enhance our understanding of lightning are already widely recognized [Coleman02]. Thus we report on progress toward the goal of using balloon-borne slow antenna measurements in conjunction with lightning mapping array data to study charge transport in lightning strokes. Our field-change electronics directly descends from traditional slow antennas.[Krehbiel79] While ours is not the first balloon-borne slow-antenna [Beasley00], it is the first capable of measuring all three vector components of field change, a capability that is not useful in a ground based instrument because of the well known effects of image charges on horizontal fields. The schematic in Fig. 1 documents one channel of our four-



channel design. Since the goal is to interpret charge overhead or in the channel of a stroke, we discuss amplifier performance with reference to charge. If negatively charged teflon is brought near the sense electrode (Fig. 4b) connected to J1, it induces +Q on the sense electrode and thus +Q on U1 out. The second stage amplifier inverts the signal so that the entire amplifier swings negative when new negative charge is introduced in its vicinity. Thus the sign of the

amplifier output has the same sign as the dominant "new" nearby charges. This is consistent with the "lightning convention" for electric field measurements. Figure 2 is a spreadsheet documenting some of the fundamental and derived design parameters. Our goal is flat response to charge for times t such that $1 s = t_H > t > 0.2 ms = t_L$. t_H and t_L were selected so that the entire field-change of most flashes could be observed without dedrooping and to prevent aliasing of the 10 kSample/sec A/D on the Diamond "Prometheus" single-board PC.

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THIS SPREADSHEET R	ECORDS THE ORIGIN	IAL DESIGN PARAMETERS BEHIND E-SONDE "A"
Adjustable Parameters		These values for C1, R1-R3 were used for ESONDE2/3 data sets of Summer 04
Emax	110 kV/m	The E-field at which you expect to pin the output of the op-amp
Vmax	0.8 V	The maximum (positive or neg,) output voltage desired at the op-amp at Emax
eta	1.8 dimensionless	Field enhancement ratio (2 for a cylinder at its center)
Α	100 cm^2	The plate area of the electrode
BW	5 kHz	Designed bandwidth (1st and 2nd stages)
Tau	1 s	Target time constant
R1, R2	1 Mohms	The larger valued resistance in the T-network
I-b	50 pA	Op-amp Input bias current
Derived Parameters		
Q	17600 pico Coul	Max induced charge on plate
C1	22000 pF	Capacitance to choose for feedback across front-end op-amp
Reff	45 Mohms	The effective resistance you need to support Tau
G1	0.0455 mV/picoCoul	Charge Gain of first stage
I-b-out	2.27 mV	Bias current offset
R3	22.5 kohms	The smaller valued resistance in the T-network
LSB	4.49 V/m	E-field corresponding to LSB on 16-bit A/D (Assumes 8V full scale)
G2	10 V/V	Gain of 2nd Stage Amplifier to take full scale signal to 8 V
Resistor Noise	0.060 mVrms	T-Network
Shot noise	0.006 mVrms	Shot noise at BW limit for 1/1000 full-scale disturbance
C2	3183 pf	Feedback cap in second stage to maintain desired BW
OUTPUT		G
Amp output (V)	1 V V	$-\rho FA \frac{O_2}{2}$
C1	22000 pf V OL	$V_T = \mathbf{c}_0 L \mathbf{n}$
Plate Area	100	\mathbf{C}_1
G2	10	
eta	1	
First stage output	0.1 TZ	$-1V - (8.86 \frac{pf}{V})(24800 \frac{V}{V})(0.01 m^2)$ 10
Input Charge	2200 pC	$-1v - (0.00 - 1/24000 - 1/(0.01 m)) = \frac{1}{22000 \text{ nf}}$
Field	24.8 kV/m	m m (22000 pj)
Figure 2		

While the largest fields recorded aloft exceed 200 kV/m, more typical values in ballooning are ~150 kV/m [Marshall91]. As we hope to get close to flashes. The amplifier is designed to saturate at +/- 110 kV/m field change on a single plate. The overall 1channel gain

$$V_{OUT} = \boldsymbol{e}_0 E A \frac{G_2}{C_1}$$

is set by the initial feedback capacitor, electrode area and second stage voltage gain of 10. This design gives a parallel plate calibration of 24.8 kV/m, as shown at bottom right of Fig. 2. Though the design may appear rather insensitive, our



approach was to use the large dynamic range of the A/D's to see small events rather than using the "sensitive" and "insensitive" analog channels of older designs. Note that calculated analog noise and a 16-bit A/D should enable seeing changes down to the least-significant bit (LSB) value of 4.5 V/m. While second stage gain rolls off at 5 kHz via a 3200 pf capacitor, the design is intended to run at 100 kHz simply by changing filter capacitor C2. All calculations in Figure 2 assume a flat-plate field sensor with an E-field purely normal to the plate at ∞ . Precise calibration factors for our sonde relative to the simpler plate geometry are not yet measured, though we expect the cylindrical geometry makes the sonde ~2X as sensitive to transverse fields as a simple flat electrode. Fig. 3 at left shows the board at approximately twice actual size. Surface mount components were used to reduce cost and to allow room for further miniaturization. The board implements four identical channels of charge amplifier of the design shown in figure 1, using two quad op-amps. The board is powered by unregulated +/- 9V batteries.



Ballooning



Telemetry experiments in Summer 2003 [Sonnenfeld03] lead us to conclude that a 1 Watt balloon transmitter and a tracking antenna used with our MaxStream modems would provide reliable telemetry out to 60 km range. A 1 Watt, 900 MHz amplifier was incorporated into the sonde, while a Meade LX-200 telescope mount was fitted with a Yagi Antenna (Fig 4b). While the 100 mW telemetry rig with a dipole antenna began dropping packets at 12 km range, we saw no lost packets out to 30 km in this summer's flights. Because the 19.2 kBaud telemetry is far too slow to transmit field change, it is used to transmit position, temperature, pressure and other diagnostic information. The scientific software also scans the flash every thirty seconds and telemeters the maximum field change that was recorded in the prior interval.

Figure 7c shows the balloon trajectory on the LMA data plot. The double humped trajectory and lack of ability to climb despite 100% free lift are attributed to icing conditions on the polyethylene balloon.

One of the more important parts of the balloon package is the damper (Fig. 4a, 4c). Because vector Efield change is needed, the absolute orientation of the sonde with respect to an earth-fixed frame must be known. The sonde includes a three-axis B-field sensor. However, if the sonde is tipped beyond 10 degrees from vertical, a rotation about the sonde's symmetry axis becomes indistinguishable from a precession motion about a vertical axis. Only if the sonde is nearly vertical can horizontal B-field components be unambiguously interpreted to measure angular orientation. The damper accomplishes this. Version 1.0, a flat piece of plastic strung between two dowels did not perform well, but crossshaped damper 2.0, made of rip-stop nylon kept the sonde well oriented vertically.

Results – Time Synchronization



An advantage of running a full single board computer with Linux on our Esonde is the availability of network-time protocol (NTP). NTP has the capability to discipline the system clock both by the ASCII data strings from a GPS and by the millisecond accurate pulse-per-second output generated by GPS. (Microsecond accurate GPS units are available). During flight the A/D multiplexes continuously thru 8 channels at precisely 80,000 channels/second and streams data to system memory. Every two seconds, acquisition pauses for the data packet to be written to the compact flash (CF) onboard storage. Latencies of a few tenths of a second occur in writing the packet. A method is needed to embed time directly in the data. As each packet is written to CF, the system time before and just after the writing is appended to the file. Channels 0-3 collect E-field data at 10 kSamples/sec, while 5-7 are B-field data. Channel 4 digitizes the PPS output of the GPS at 10 kSample/sec. Thus each packet contains embedded time. When Esonde data is processed, the digitized PPS is used to correct the time stamp to within the accuracy of the GPS unit used. A first test of our time quality is in Fig. 5. The blue curve is ground-based E-field data (which if multiplied by 10 give kV/meter) measured with an E-100 field-mill [Winn75]. The field-mill data is also collected on a computer disciplined with NTP. The upper blue curve is identical to the lower one, but offset so as not to be covered by the black Ez data from the Esonde.

Results

For example, the first peak at 201214 UTC is seen to be a +2 kV/m by the field-mill, and as approximately +6 kV/m by the ESonde. The Ez curve is calculated by summing the raw voltages from Channels 2, 3 (the upper two field plates) and subtracting Ch 0, 1 (the lower plates). Thus a 1 V swing, rather than representing 24.6 kV/m as calculated in the instrument section, represents only ¹/₄ the field change, as all four plates contribute their charging area. The sums and differences approach is fundamental to the sonde design and is used in figure 8 to calculate the transverse component of the E-field (pink). The green curve in Fig. 5 represents Q, the total charge change on the sonde. We assume that the sonde should remain neutral, or slowly charge, rather than charging rapidly enough to show spikes on the green curve. The existence of these spikes is suggestive of corona discharge, and this is our current interpretation. Note that they do NOT correlate well to the field mill. In the 30 minutes of data and 20 major flashes analyzed for this poster, we saw little correlation between Q and LMA or ground data. At present, we use the existence of Ez in the absence of Q as a criterion for a valid flash. There are instances when both Q and Ez swing, which could be caused by localized corona or slight imbalance in gains between the 4 channels.

A more strenuous timing test is provided by the LMA data of Figure 6. Note the good agreement between the LMA RF sources (6a) and E-field peaks (6b) over a two-minute period.

Figs 7a-b take the comparison to the threshold of interesting science. The Esonde data (7b) has not been aligned by eye to the LMA data (7a). The two simply agree to better than 100 msec. Note the red points at the end of the flash which can be seen to correspond with dendritic branching crossing the balloon track (blue line in Fig. 7b with red "+" indicating instantaneous balloon location.) at 46.00-46.20 seconds. Figure 8c shows Ez at the sonde during precisely this time interval



The small jumps in Ez during this interval are consistent with a normal negative polarity multiple CG flash [Rakov90], but it isn't evident from the LMA that there is such a flash. Our initial belief is that these are negative polarity IC flashes going near to the sonde, as indicated by the red dendrites



Results

- cross the sonde's path. The initial dip in field seen in Fig 8b is consistent with a negative polarity flash (the green structure in Fig 7c) seen from outside the reversal distance. As the flash gets closer, we see the field change going positive.
- Other data from this flight showed clear IC flashes with continuing currents. Clearly the analysis of this interesting new instrument is just beginning.

Future Work

- The science on this program is still ahead. We have just reached the point of understanding time and data processing well enough to look for consistency and inconsistency between our LMA and Esonde data sets.
- As of December 2004, we have used time correlations with LMA and ground-based field detectors to verify that our data-stamped time is identical to UTC to within 100 millisec. Further analysis should enable us to confirm accuracy to 100 microseconds, or to find our experimental errors.
- Our initial sonde design has a tendency toward corona discharging in a high-field environment. We believe we can detect this via the "Q" channel, but more careful rounding of edges in version 2 should cure the problem at the source.
- We have worked through the issues surrounding decoupling the sonde rotation from the transverse E-field data. One intriguing thing we observed is that as the sonde slowly rotates in the presence of a static transverse field, there are large escalations in the field "change". This makes perfect sense, was used before [Winn74] and may allow us to detect DC fields without "moving parts".

Conclusions

A new balloon borne slow antenna has been flown into three storms and been retrieved intact each time.

The vector field-changes measured are consistent with prior ground-based data.

Structure in the field-records became readily apparent for flashes that came within 5-10 km of the sonde. We have seen several instances in which the flash crossed our balloon track.

Simple processing techniques have been developed which enable the suppression, or at least the detection of corona effects and the validation of E-field data.

Times measured for flashes have correlated well with times measured with ground-based meters and the Langmuir Lab compact LMA.

Preliminary identification of features like K-changes and continuing current have been made in the field data and LMA data.

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