TRIGGERED LIGHTNING TESTING OF AN AIRPORT RUNWAY LIGHTING SYSTEM

M. Bejleri (bemirela@yahoo.com), **V.A. Rakov** (rakov@ufl.edu), **M. A. Uman** (uman@ece.ufl.edu), **K. J. Rambo** (rambo@ufl.edu), **C. T. Mata** (cmata@lightning.ece.ufl.edu), **M. I. Fernandez** (markivan@prodigy.net).

Department of Electrical and Computer Engineering, University of Florida, Gainesville, USA

Abstract: The interaction of rocket-triggered lightning with an airport runway lighting system has been studied. The system included a buried counterpoise and vertical ground rods for protection from lightning. Experimental data for voltages and currents at various locations in the lighting system due to direct lightning strikes are presented along with the causative lightning current. The data include the first measurements of the responses of an underground bare conductor (counterpoise) to direct lightning strikes, which can serve as a ground truth for the testing of the validity of various models of counterpoise.

Keywords: triggered lightning, airport runway, lightning protection, counterpoise, ground rods.

1. INTRODUCTION

The experiments presented in this paper were conducted in 1997-1998 at the International Center for Lightning Research and Testing (ICLRT) at Camp Blanding, Florida (e.g., Uman et al. 1997; Rakov et al. 1998) [1,2]. The ICLRT is an outdoor facility that occupies an area of about 1 x 1 km^2 and is located about 40 km north-east of Gainesville (home of the University of Florida). ICLRT was constructed in 1993 for studying various aspects of lightning and lightning protection using artificially-initiated (triggered) lightning. The purpose of the experiment described here was to study the interaction of lightning with the airport lighting system shown in Fig. 1. The system was subjected to a total of 16 lightning strikes, 12 of which contained one or more return strokes. The total number of return strokes was 47 (24 in 1997 and 23 in 1998). Lightning current injection points were (1) the pavement, (2) one of the stake-mounted lights, (3) the counterpoise, and (4) the ground directly above the counterpoise or between the counterpoise and the edge of pavement. The system was energized using a generator and a current regulator for some of the tests and unenergized for others. The total lightning current and the currents and voltages at various points on the lighting system were measured.

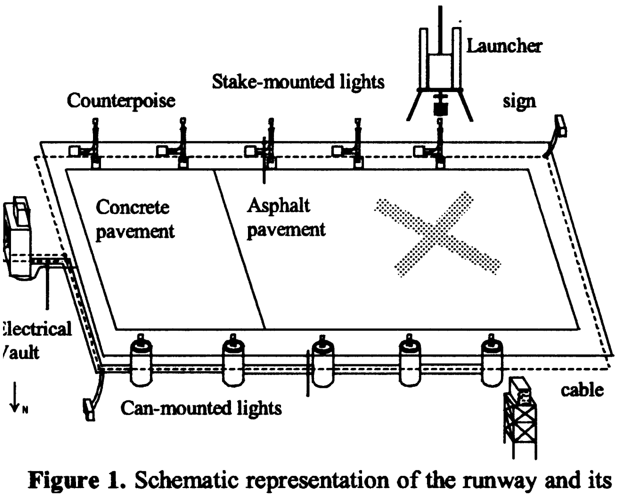

Figure 1. Schematic representation of the runway and its lighting system.

2. EXPERIMENTAL SET-UP

2.1 Runway Lighting System

The runway is located in the southeastern part of the ICLRT. The pavement is approximately 100 m long and 25 m wide and oriented east-west. The eastern one-third of the pavement is concrete, and the western two-third asphalt, as shown in Fig. 1.

The lighting system includes a generator, a current regulator (CCR), both placed in the electrical vault, a buried series 6.6-A lighting cable feeding, via current transformers, five equally spaced stake-mounted lights on the south side, five equally spaced can-mounted lights on the north side of the runway, and two signs in NE and SW corners of the runway, and buried counterpoise connected to three vertical ground rods (see Fig.1). The cable is a single stranded copper conductor AWG #8 (diameter is 3.26 mm) covered with XLP (crosslinked polyethylene) insulation with rated basic insulation level (BIL) of 5 kV. It conforms to the requirements of the US Federal Aviation Administration (FAA) standard AC 150/5345-7, which gives the specifications for cables to be used in lighting systems of airport runways. The cable is buried at a depth of about 0.4 m and at a horizontal distance of 3 m from the pavement edge making a large loop around the runway. It is placed inside PVC pipe on the north side and buried directly on the south side (see Fig. 1). The counterpoise, a #6 buried bare copper wire with an outer diameter of 4.11 mm, is placed 10 cm or so above the cable and conforms to the requirements of the FAA standard AC 150/5370-10, which gives the specifications for the counterpoise. The counterpoise is connected, as shown in Fig. 1, to three vertical ground rods. Each ground rod is made of copper and has a diameter of 1.56 cm and a length of 2.4 m. Ground rods on the south and north sides of the runway are each located approximately 55 m from the ground rod at the electrical vault (see Fig. 1).

2.2 System Configurations

In Summer 1997, three different test configurations were used, as outlined in Table 1. In configuration #1, the part of the system thought to be best protected was struck, that part containing the can-mounted lights with the current transformers placed inside the metallic cans and the cable between cans being inside PVC pipe. The launcher was located at the northern edge of the concrete pavement, and lightning current was injected into the concrete pavement via a short air gap. In configuration #2, the launcher was moved from the pavement to a point on the ground centered between the northern edge of the runway and the counterpoise. A metallic cable was used to connect the launcher directly to the counterpoise, so that the total lightning current could be injected into the counterpoise. In configuration #3, the launcher was placed on the south side, off the asphalt pavement, so that it was directly over the westernmost stake-mounted light, as seen in Fig. 1. Tests using configuration #3 were begun at the end of summer 1997, and on September 26, 1997 one flash was initiated that lowered positive charge to ground and apparently did not contain return strokes. During summer 1998, tests began with configuration #3, described above, and continued with configuration #4. In configuration #4, the stake, the light, and the current transformer under the launcher were removed from the system, while the launcher remained at the same location in order to simulate lightning strikes to the earth's surface above the cable and the counterpoise. Thus in configuration #4 the systems contained five can-mounted and four stake-mounted lights. In the Summer 1998 tests, configuration #3 was subjected to four lightning strikes (three of them containing return strokes) and configuration #4 to two strikes, both containing return strokes. In the following, we primarily consider system configuration #4, shown in Fig. 2, for which most of the data were obtained. A detailed description of data for all system configurations is found in Bejleri (1999) [3]. For configuration #4 we measured lightning channel current (I_{L1}), currents at four different locations along the counterpoise (I_{ctp1}, I_{ctp2}, I_{ctp3}, and I_{ctp4}), currents at four different location along the cable (I_{c1}, I_{c2}, I_{c3}, and I_{c4}), currents in ground rods (I_{gr2} and I_{gr3}), voltages between the cable and counterpoise at three different locations (V_1, V_3, and V_4), voltage across can-mounted light bulb filament (V_{can}), as well as the voltage between the metallic stake and the light bulb filament of one of the stake-mounted lights (V_{fixt}) (see Fig. 2). Macrodyne Lightning Transient Recorders (LTRs) with up to 5 MHz sampling rate and Nicolet Pro 90 digitizing oscilloscopes with a sampling rate of 10 or 20 MHz were used to measure the currents and the voltages. The 20 MHz sampling rate was used for measuring V_1.

Table 1. Configurations of the test system in 1997-1998

Configuration Number	*Year*	*Position of the Launcher*	*Remarks*
1	1997	On the concrete pavement at its northern edge.	The system was not energized. CCR was replaced by a 2 Ω resistor.
2	1997	Centered between the northern edge of the concrete pavement and the buried counterpoise.	A metallic cable was used to connect the launcher directly to the counterpoise. System was not energized.
3	1997-1998	At the south side off the asphalt pavement, over the most westerly stake-mounted light.	System was either energized or not energized.
4	1998	Same as for configuration #3, but with one of the stake-mounted lights being removed.	System was energized.

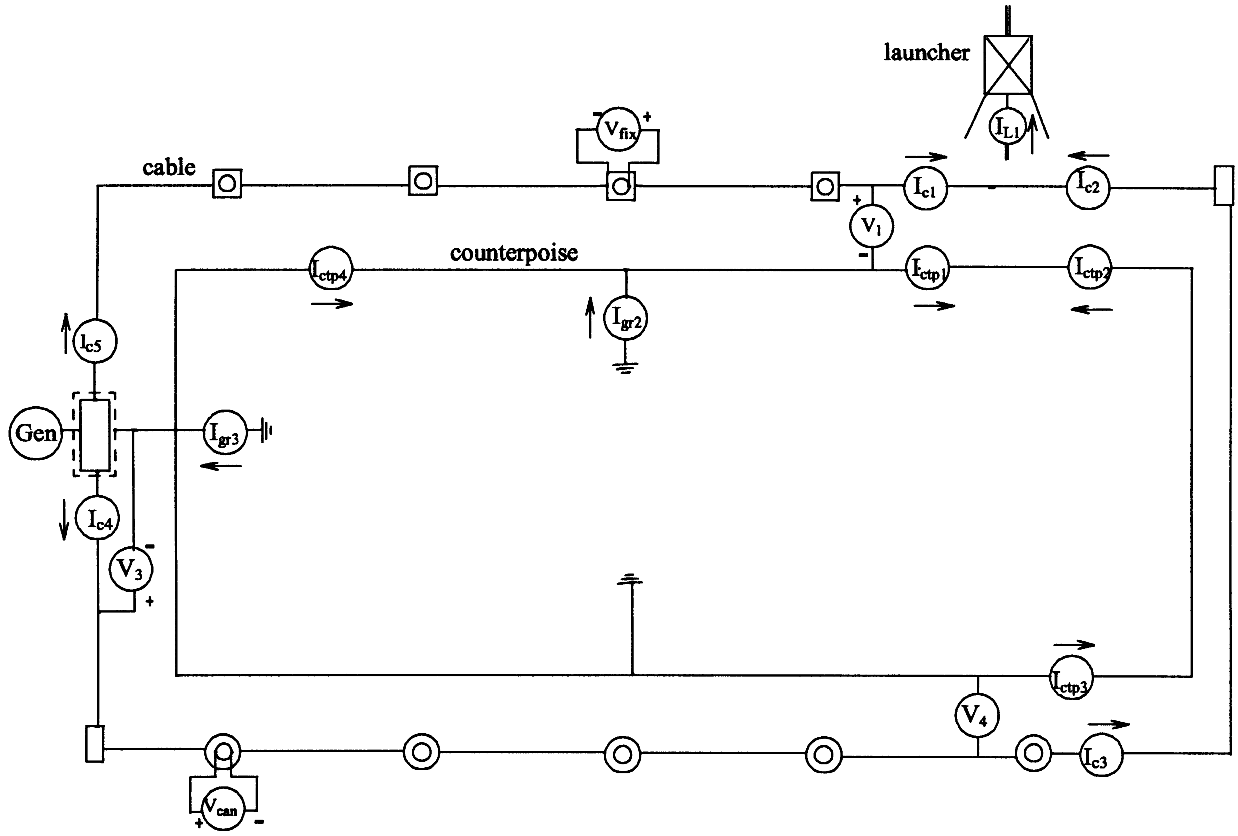

Figure 2. Current and voltage measurement locations for configuration #4.

3. DATA PRESENTATION

We first present in Section 3.1, as an example, data for the first return stroke of Flash U9841 triggered on September 16, 1998, that are representative of all data for configuration #4. Then, in Section 3.2, we present a summary of all the findings from the 1997-1998 experiments. Additional data are found in Bejleri (1999)[3].

3.1 Case Study: Flash U9841, 1st Return Stroke

Data for negative flash U9841 presented here were obtained under test system configuration #4 (see Table 1 and Fig. 2). Flash U9841, produced four return strokes with peak currents of 15, 7.2, 3.8, and 11 kA. After the storm, the part of the system under the launcher was excavated and no damage to the cable was found. The counterpoise was melted at the point where the lightning attached to the system, and only two of the seven strands comprising the counterpoise remained continuous. The current transformer at the stake-mounted light close to the ground rod on the south side of the runway was found not to work properly after this flash and was replaced with a new one. The secondary cables of the damaged current transformer exhibited two pinholes and many burn marks on their surface. Selected current and voltage waveforms are shown in Fig. 3 and discussed below.

3.1.1 Total lightning current and counterpoise currents

The total lightning current [I_{L1}] for the first return stroke has a peak values of 15 kA (see Fig. 3). The currents in the counterpoise at the east of launcher location [I_{ctp1}], with a peak value of 8.8 kA, and west of launcher location [I_{ctp2}], with a peak value of 6.0 kA, show characteristics similar to those of the lightning channel current. In particular, the risetimes are of the order of 1 μs or less.

Current at the NW location, [I_{ctp3}], increases to its negative peak value with a rise time similar to the total lightning current rise time. Then the current exhibits a plateau, which lasts approximately 12 μs, and rapidly decays to zero with the pulse duration being 40 μs.

Current waveform at the south of the runway location, [I_{ctp4}], initially exhibits an increase to its negative peak value of 2.6 kA with a rise time similar to the lightning current risetime and decays similar to the current measured at the east of launcher location. Current

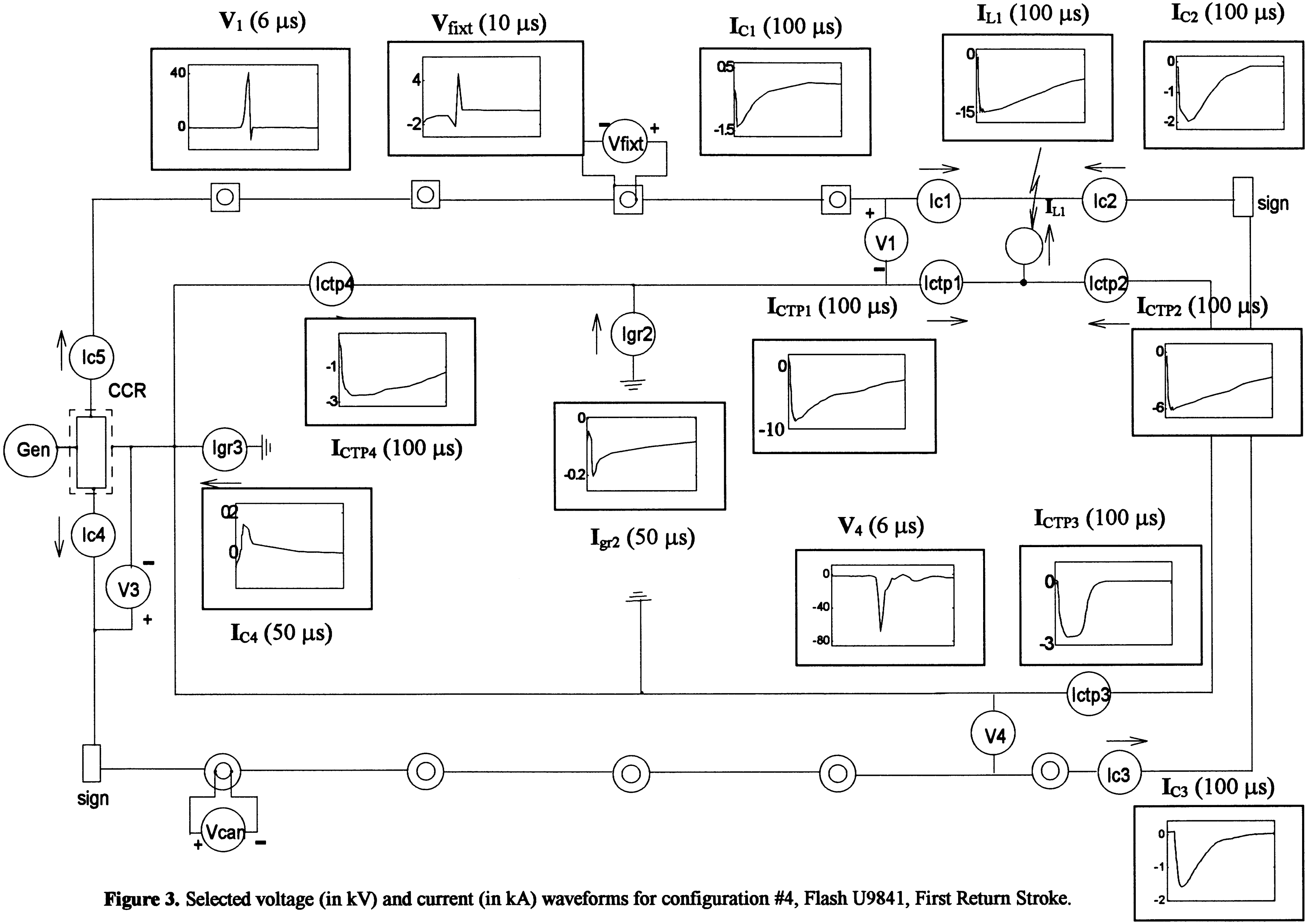

Figure 3. Selected voltage (in kV) and current (in kA) waveforms for configuration #4, Flash U9841, First Return Stroke.

in ground rod $[I_{gr2}]$ at the south location has a negative peak of 200 A, rise time of 0.6 μs, and accounts for only 1.3% of the total lightning current.

3.1.2 Cable currents

Cable currents were measured at four different locations for flash U9841. Currents $[I_{c1}]$ and $[I_{c2}]$, with peak values of 1.4 and 2.0 kA, respectively, have the same direction and rise time as $[I_{ctp1}]$ and $[I_{ctp2}]$. Current at the NW location $[I_{c3}]$, has a peak value of 1.6 kA. Current at the Electrical Vault location $[I_{c4}]$ has much smaller peak value than $[I_{c1}]$, $[I_{c2}]$, and $[I_{c3}]$.

3.1.3 Voltages

Voltage waveforms measured for the first return stroke of Flash U9841 include voltages measured between the cable and the counterpoise at the east of the launcher location $[V_1]$, NW location $[V_4]$, voltage between the light fixture and the light bulb filament at one of the stake-mounted lights $[V_{fixt}]$.

The voltage between the cable and the counterpoise 3 m east of the launcher, $[V_1]$, is recorded with a sampling interval of 50 ns. The voltage has a positive peak of 40 kV and a negative peak of 9 kV. Voltage reaches a positive peak in 150 ns (the cable has a higher potential than the counterpoise) and then a negative peak (the counterpoise has a higher potential than the cable). The time interval between the positive and negative peaks is 50 ns. The voltage waveform has a duration of only 200 ns. Voltage between the cable and the counterpoise at the NW location $[V_4]$, has a negative peak of 68 kV. The voltage waveform reaches its negative peak in 200 ns (the counterpoise has a higher potential than the cable) and has a duration of only about 3-4 μs.

3.2 Overall Results, 1997-1998

3.2.1 Current decay along the counterpoise

When lightning struck a stake-mounted light or directly struck the counterpoise, 10 to 30% of the total lightning current was dissipated locally, within 3 m of the strike point, while 70 to 90% was carried by the counterpoise further away from the strike point. Measuring the counterpoise current at four different locations (two on each side of the strike point) made it possible to estimate that about 63% of the current detected 3 m from the strike point was dissipated in the ground after propagating along 50 m of the counterpoise, and about 73 % of the current detected 3 m on the other side from the strike point was dissipated in the ground after propagating along 67 m of the counterpoise. A strong linear correlation exists between the decay rate of the counterpoise current with distance (in amperes per meter) and the current peak near the strike point: the higher the peak value of current entering the counterpoise, the higher the decay rate. If peak current in the counterpoise is assumed to decay linearly with distance, the percent decay rate is 1 % per meter, independent of the peak current amplitude, as illustrated in Fig. 4. The current waveshape changes as the current wave propagates along the counterpoise: while the rise time remains more or less the same, a plateau or a broad maximum, not seen in the total lightning current

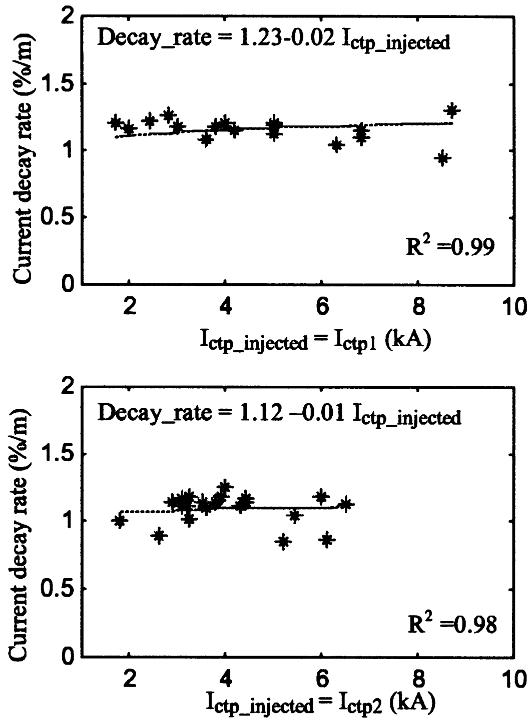

Figure 4. Decay rate of current per meter length of the counterpoise.

waveform, is observed at distances of 50 and 67 m. The plateau duration is approximately between 10 and 50 μs. In some cases, when the lightning current is smaller than 10 kA, current waveforms do not exhibit the plateau.

3.2.2 Currents in ground rods

During experiments with configurations #1 and #2 the entry point of current in the counterpoise was about 12 m from the north ground rod. In this case, the current through the ground rod was as high as 1 to 2 kA, accounting for 10 to 15% of the total lightning current.

During experiments with configurations #3 and #4 the entry point of current in the counterpoise was about 36 m from the south ground rod. Shown in Fig. 5 are the waveforms of the lightning channel current and the current through the ground rod for the first return stroke

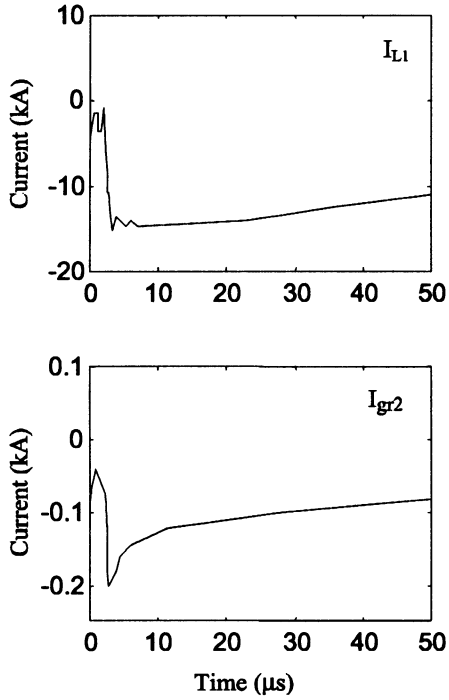

Figure 5. Lightning channel current [I_{L1}] and ground rod current [I_{gr2}] for Flash U9841, first return stroke.

of Flash U9841. In this particular case the current through the ground rod accounts for approximately 1.3% of the lightning channel current (peak values). For all the lightning strikes 36 m from the south ground rod, the maximum value of current leaving the system through this ground rod was about 300 A, which was less than 5% of the total lightning current. The ground rod current waveform has approximately the same risetime as the lightning current but it has shorter duration. This suggests that the ground rod is a better path than the counterpoise for the higher frequency components in the current.

3.2.3 Cable currents

From the data recorded, it appears that the current flowing in the counterpoise induces current in the cable. Coupling between the counterpoise and the cable appears to be strongest near the strike point.

3.2.4 Lightning damage to the system

Several elements of the test airport runway lighting system sustained damages caused by one or more lightning strikes. The damages include (1) failure of one of the electronic boards of CCR, (2) minor damage to the light fixture and to the glass cover of the light bulb of the stake-mounted light under the launcher, (3) multiple burn marks on the surface of the secondary cable of the current transformers (at the strike point and at distance of 36 m from it), (4) pinholes on the secondary cable of the current transformer, (5) melting of the counterpoise conductor at the point where the lightning attached to the system. No evidence of direct lightning current injection into the cable or flashover to the cable from the counterpoise was found.

4. CONCLUSIONS

When lightning strikes a stake-mounted light or directly strikes the counterpoise, the counterpoise carries the bulk of the total lightning current away from the strike point. Current flowing in the counterpoise decays at a rate of about 1% per meter. Vertical ground rods connected beyond several meters from the strike point dissipate a relatively small fraction of the total lightning current.

REFERENCES

[1] Uman, M.A., V.A. Rakov, K.J. Rambo, T.W. Vaught, M.I Fernandez, D. J. Cordier, R.M. Chandler, R. Bernstein, and C. Golden, "Triggered-lightning experiments at Camp Blanding, Florida (1993-1995) " Trans. IEE Japan, Vol. 117-B, no. 4, pp. 446-452, 1997.

[2] Rakov, V.A., M.A. Uman, K.J. Rambo, M.I. Fernandez, R.J. Fisher, G.H. Schnetzer, R. Thottappillil, A. Eybert-Berard, J.P. Berlandis, P. Lalande, A. Bonamy, P. Laroche, and A. Bondiou-Clergerie, "New insights into lightning processes gained from triggered lightning experiments in Florida and Alabama", J. Geophys. Res., Vol. 103, No. D12, pp. 14117-14130, 1998.

[3] Bejleri, M., "Triggered-lightning testing of an airport runway lighting system" Master's thesis, University of Florida, Gainesville, 1999.