Total Electric Field due to an Electron Avalanche and its coupling to Transmission Line Conductors

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Introduction

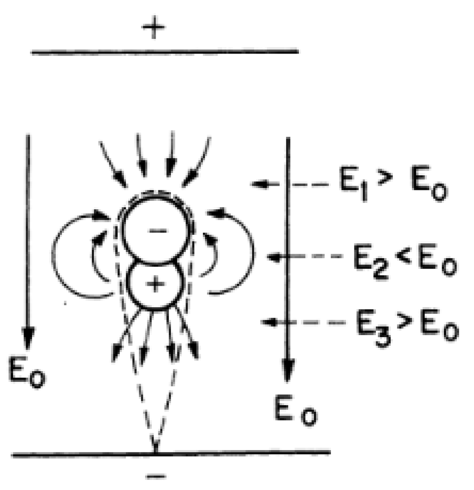
Air is used extensively as an insulating medium in transmission, distribution and electrical substations.At surface irregularities partial breakdown of air can take place → produces violet glow, hissing noise ozone gas.

Corona Discharge :

- Power loss, Audible Noise
- Interference with Radio, TV broadcasting and communication

Extensive work has been carried out → Mostly Experimental resulting in Empirical relationship between measured corona current and RIV

It is necessary to relate the physical phenomena to the electromagnetic field that it produces



- A single electron moving in the direction of the applied electric field results in $e^{y^2/4}$ electrons on travelling a distance z
- The expression for the total electric field is derived for an electron avalanche

Fig.1. Townsend Model for Electron Avalanche

Expression for the Total Electric Field due to an isolated Electron Avalanche

The total electric field due to an electron avalanche comprises of the field due to the moving electron head and the positive space charge left behind. Starting from the retarded scalar and magnetic vector potentials, an expression for the electric field due to a moving point charge of time varying strength is derived. The electric field due to the positive space charge is also evaluated starting from the scalar potential. Addition of the above two electric fields provides the total electric field due to an electron avalanche.

$$\vec{E}(\vec{r},t) = \frac{[q]}{4\pi\varepsilon_0[\kappa^3]}\left[\left[\frac{1}{r^2}\left(\hat{r}-\frac{\vec{v}}{c}\right)\left(1-\frac{v^2}{c^2}\right)+\frac{1}{cr}\left(\hat{r}\times\left(\hat{r}-\frac{\vec{v}}{c}\right)\times\frac{\vec{a}}{c}\right)\right]\right] + \frac{1}{4\pi\epsilon_0}\left[\left[\frac{\partial q}{\partial t}\left(\frac{\hat{r}}{c^2\kappa^2 r}\hat{r}.\vec{v}-\frac{1}{c^2\kappa^2}\left(\frac{\vec{v}}{r}\right)\right)\right]\right] + \frac{1}{4\pi\epsilon_0}\int_0^{[R_r]}\frac{\hat{r}}{r^2}\lambda\,\partial l$$

Validation

Electromagnetic field of an electron avalanche can be evaluated by using the electric field integral equation on thin structures.

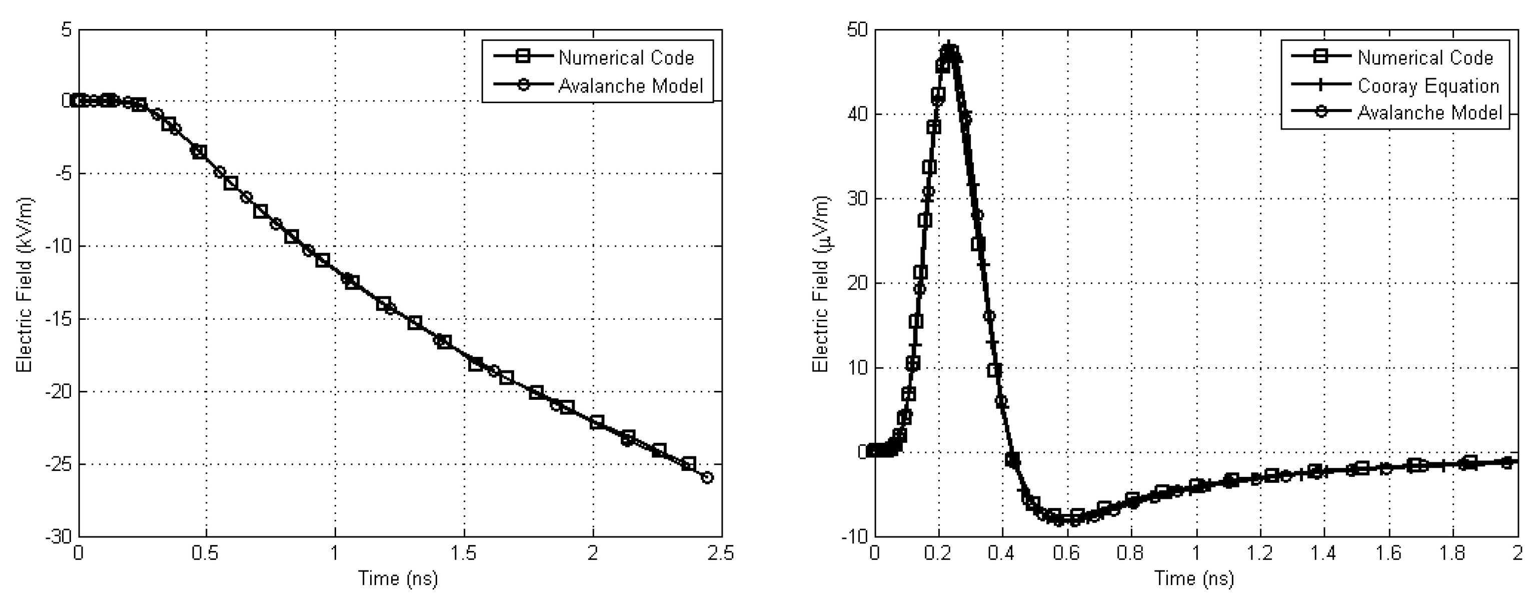


Fig.2. Total electric field at (a) 1.7mm along z-axis and (b) (10m, 0, 17.32m)

Induced Current for Negative Avalanche away from the Conductor

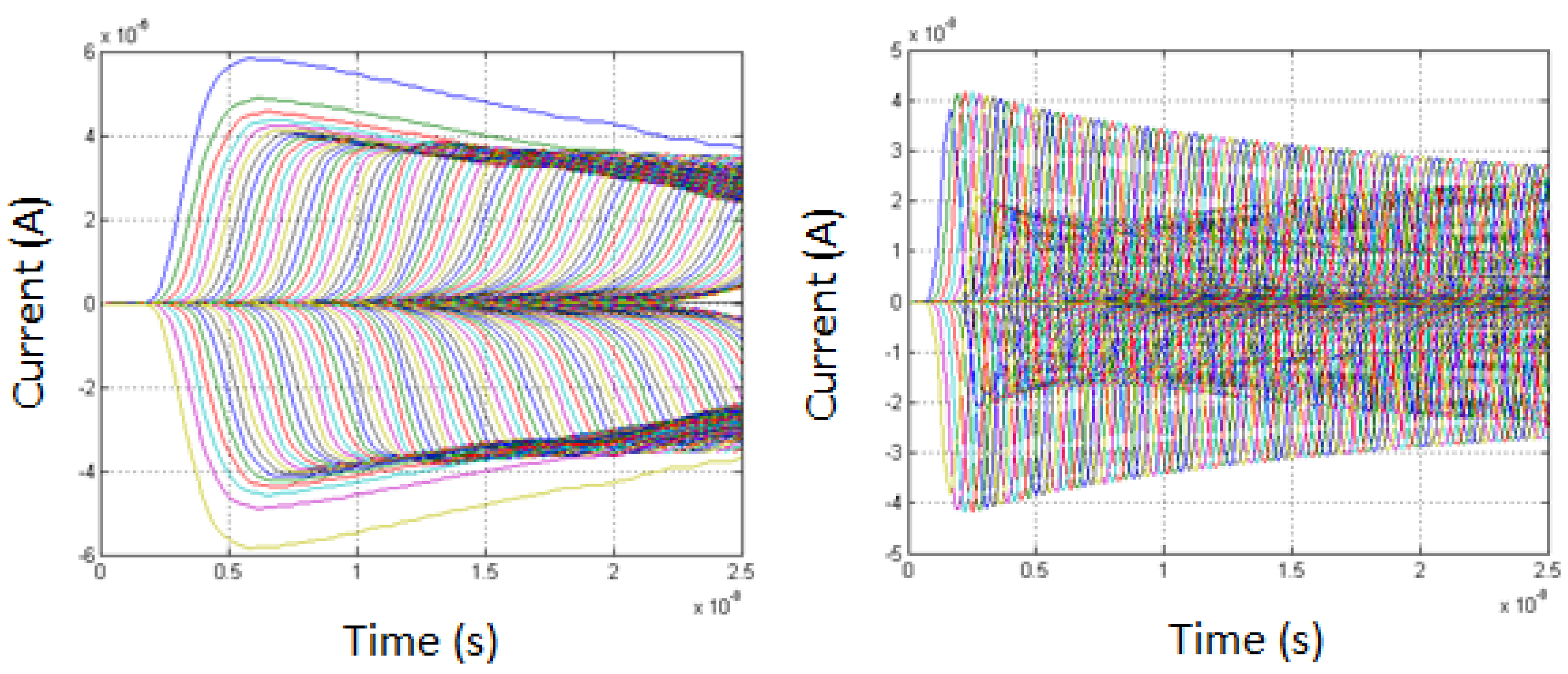


Fig.3. Induced Current due to Near Field and Far Field component of the Total Electric Field

It is Observed that the Induced current is completely dominated by the Near Field component of the Total Electric Field

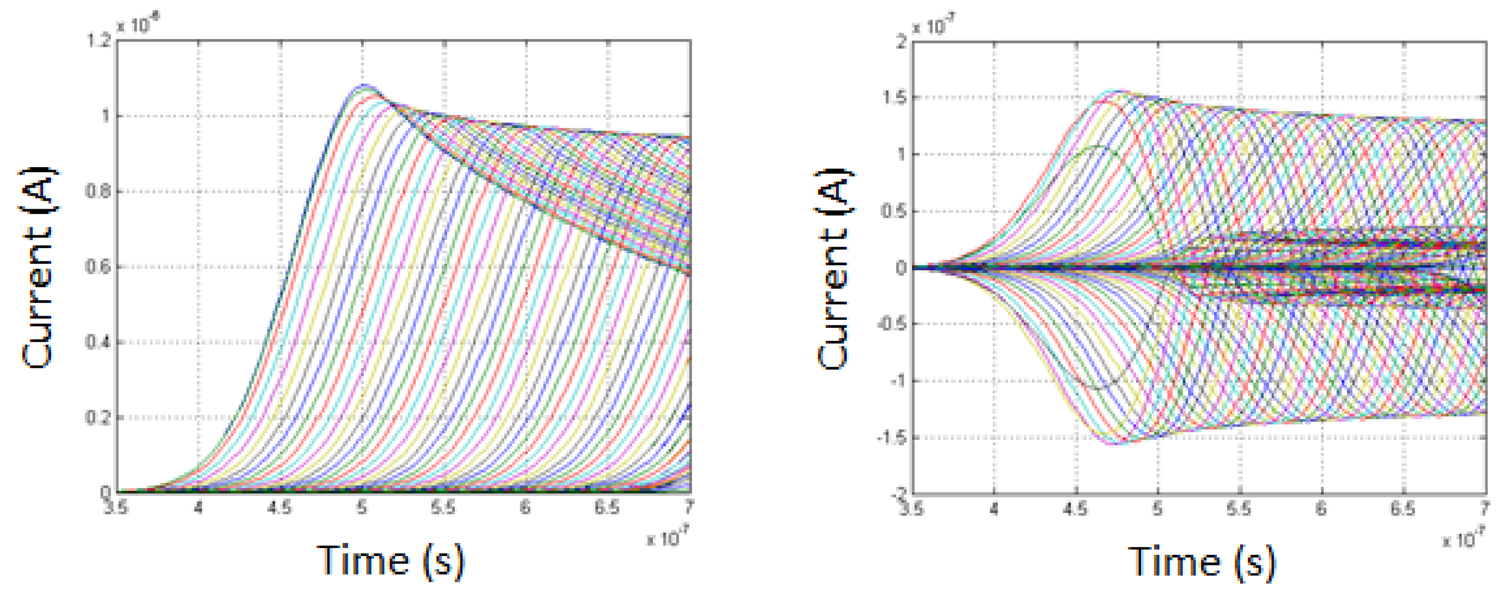
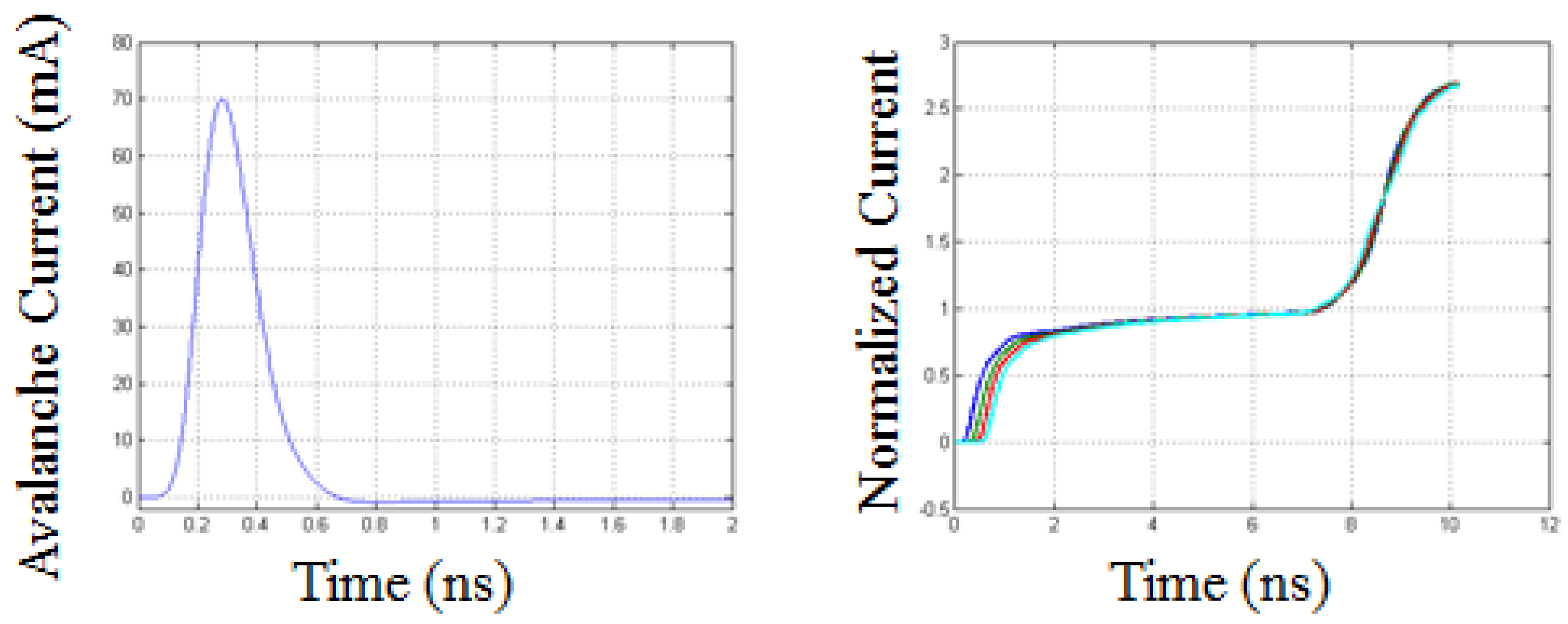


Fig.4. Injected Current Models (series current sources) used in literature versus Actual polarity of the Induced current due to Electron Avalanche

The Actual Induced Current due to Electron Avalanche is observed to be Bipolar in Nature i.e. flowing away in opposite direction from the point of initiation of the Electron Avalanche. In Literature, injected currents are assumed in the form of series connected current sources, thus resulting in unipolar current

Induced Current for Negative Avalanche - Point Plane Geometry



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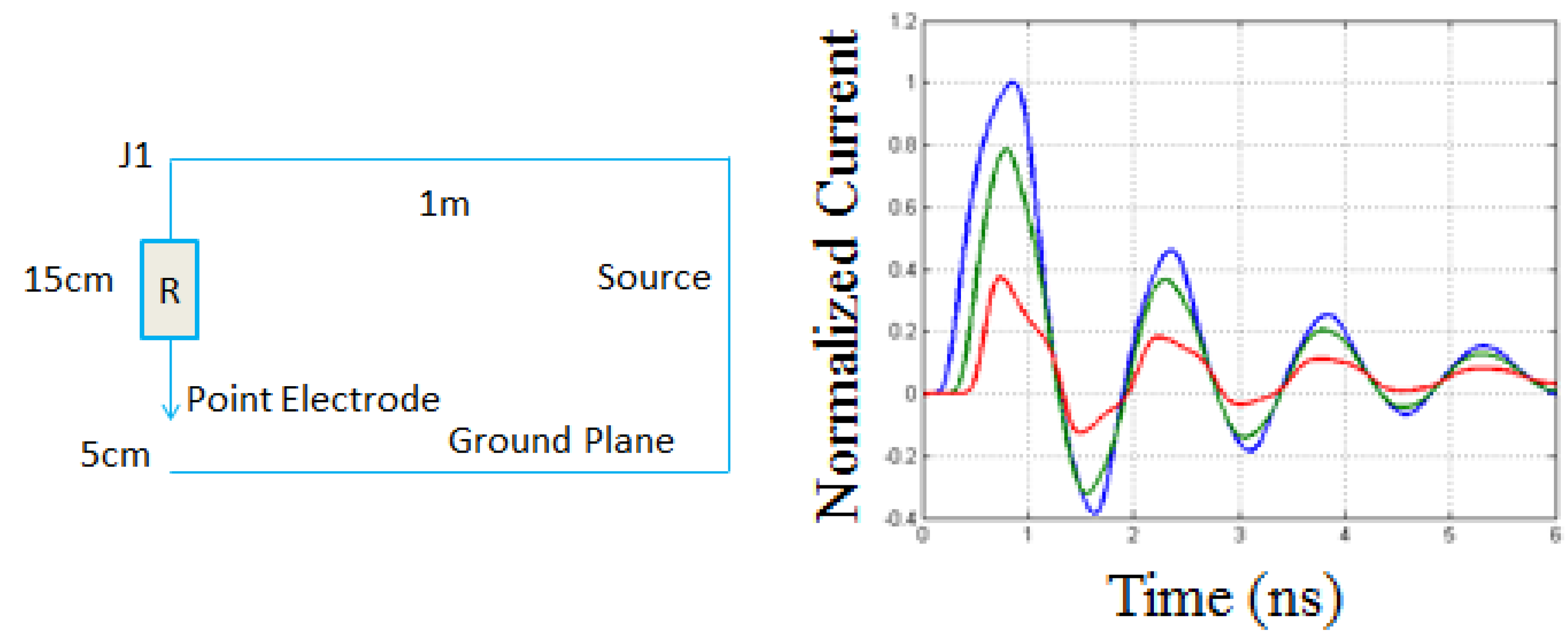

Fig.5. Normalized Current with zero resistance and 10k inserted at J1

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Conclusions

- Analytical expression for the total electromagnetic field produced by an isolated electron avalanche has been derived for the first time
- Validated using the EFIE based modeling
- The current induced in the conductor is practically determined by the near field component of the total electric field
- It is shown that it is impossible to measure the actual current in the electron avalanche