LIGHTNING DETECTION

In this article I hope to provide you some additional background into what type of signal characteristics a lightning sensor looks for, how it may want to processes and then validate the signal once it is detected. Since working for 3M Stormscope as a Field Service Technician in the late 1980's my interest in the subject has remained. The Stormscope was introduced in 1976 and evolved from the WX7A up through the WX-11, later known as Series I. The WX-1000 System (Series II) when it arrived in the late 1980's was a much improved, menu driven and an expandable system. While developing the WX-1000 System a ground based triangulating sensor system was set up in Florida and monitored while flight-testing was in progress. This allowed us to quickly fly to areas of interest and also to better analyze and validate the flight results. The University of Florida has performed many studies in this area and is a good source for information.

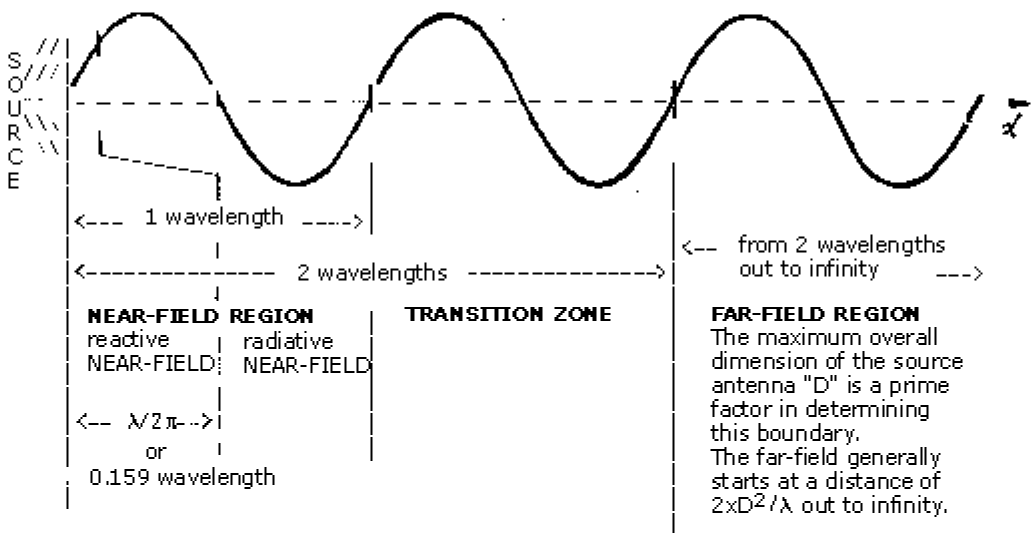
This weather mapping system is used to detect lightning discharges and display them graphically to the pilot. Lightning produces an electromagnetic (EM) field by stripping electrons from atoms in the air. This process emits a broad spectrum of electromagnetic energy as well as a great deal of light and sound. The process starts with transient collisions of ice crystals with riming graupel pellets thus transferring charges within the maturing cloud as the heavier (more negative) particles fall and resulting in a vertical electric field. The net effect of this self-propagating lightning is the transfer of a negative charge from the atmosphere to the earth (Cloud to Ground). When the stepped leader hits the ground, the return stroke is triggered, producing a sharp voltage rise. This specific signature distinguishes a cloud-to-ground stroke from other electromagnetic noise. The radiated field of this lightning stroke will induce current in the crossed loop portion of the antenna (H-Field) and the sense antenna will recognize the generated vertical field (E-Field). It's important to keep in mind that all lightning strikes are unique and therefore the question arises, How do we plot these unique events? Studies have been conducted to help quantify the characteristics of this electromagnetic pulse and help form statistical "Model Signatures". Once a typical or acceptable model is realized then we can use it to design and calibrate our receiver/processor.

The Signal Spectrum

As mentioned above the spectrum that is a result of the lightning strike contains a broad range of frequencies with very fast rise times. Evaluating these ranges selectivity is important. It is impractical to attempt to observe the broad spectrum in one channel. The bandwidths must be narrow enough to minimize the effects of interfering signals and yet must be wide enough to preserve the amplitude and duration of the wanted signals. There are several frequency groups we want to specifically look at here. The first group is centered around 50Khz and then a wider band of 1-250Khz, which dictates why skinmapping is so very important when installing these systems. Finally the third group might be from 1 to 15Mhz although it seems to be the least important. Some have defined a lightning strike as a series of low frequency (1 to 100Khz) strokes super-imposed with high frequency component (100Khz to 5Mhz) sub-pulses and this being preceded by the leader discharge of 5 to 15Mhz. The rise times of a typical strike are less then five microseconds with a zero crossing occurrence in the range of 50 microseconds. The system must be able to recognize and capture these frequencies as they are induced into the antenna system. The amplitudes will of course bear significant weight in determining the range along with the waveshape and the duration of the strike. All the above parameters can then be compared to a statistical model to further calibrate the plotting of the strike.

Near-Field vs. Far-Field

We know that certain behavior characteristics of the EM fields dominate at one distance from the radiation source while different behavior can dominate at another. Engineers have defined boundary regions in order to categorize the different characteristics of the electromagnetic fields as a function of distance from the radiating source. These boundaries are determined by wavelength and they are: the “Near-Field”, “Transition Zone”(Mid-Field) and “Far-Field”. Far-Field is explained as the region extending farther then two wavelengths away from the radiating source. The Near-Field is defined as the region located less then one wavelength from the source and is said to contain a more complex relationship between the “E” and “H” fields. The Mid-Field is the region that exists between the Near-Field and Far-Field and it may contain some characteristics of both the Near-Field and Far-Field. Shown below is a diagram that depicts these field relationships.



Strength of Signal

It is said that all waves can be described in reference to their amplitude or strength as they propagate away from the source. We should keep in mind that the total energy radiated remains a constant but the strength of the wave decreases the further out from the source it gets. This EM wave and its energy is spread out over larger areas as the radius increases from the source and so you have decreased signal strength at any one point. We look at space as a three dimensional medium and so this energy spreads out in a spherical manner. With this in mind and knowing the surface area of a sphere is “ 4¶r^2 ” then we can say that the area will increase in proportion to “ r^2 ”, and energy if equally spread out is inversely proportional to “ r^2 ” $(1/R^2)$. This is known as the inverse-square law. Simply stated it means that signal strength decreases as the square of the distance from the source. Using the above as a basis one could derive specific formulas that would better represent the near-field, mid-field and far-fields and allow a better calibration of the lightning strike.

Cloud to Ground vs. Intra-Cloud

It is said that intra-cloud lightning discharges exhibit a rapid succession of narrow pulses in a period of approximately 10 microseconds. The cloud to ground discharge generates fewer pulses but a longer period in the 20 to 50 microsecond timeframe (Zero Crossing Point). A cloud to ground strike is also more vertically polarized which is why the sense portion of the antenna is vertically polarized. This information helps us to determine what type of strike “Model” or signature we are concerned with.

Signal Processing

When a strike occurs the sense portion of the antenna receives the “E” field while the loop portion senses the bi-directional “H” field. As mentioned above several frequency ranges need to be captured and this can be done through selective filtering within the receiver. While we look for these frequencies from say 1 to 250Khz they must be sampled over a period of time reflective of our typical lightning model. The models I have seen reflect a time period of around 50 to 100 microseconds and this may vary depending on the type signal field that is received. The sampling time of either field should therefore be compatible, perhaps double in order to capture adequate signal. Now that we have qualified the frequency, the rate and the duration of this signal, what does this mean? The far-field being more influential over time but further from the source could be sent through a narrow bandpass filter while the mid-field could be evaluated in a wide bandpass filter (remember it has characteristics found in both the near-field and far-field). Lightning detection for aircraft is mostly concerned with cloud-to–ground strikes and not intra-cloud, therefore the sense portion of the antenna is vertically polarized. Synchronous detection of the crossed loop signals are critical and so the sense channel signal can be filtered and shaped to allow coincident processing and integration of the magnetic signal. The processed loop signals must then be level compared with a reference voltage that is representative of what a maximum range strike would be. If the signal exceeds this threshold then it is considered within the systems 200nm listening area. Quadrant placement in relation to the aircraft’s nose must also be determined. The direction and distance of the strike is determined from the relative amplitudes of the Hx and Hy loop signals. Here some vector analysis and trigonometry will initially solve location. Synchronous detection again is used to resolve 180° ambiguity. The above mentioned filtering process generates two component values. If a specific range equation is assigned to each based on the inverse-square law then we can refine the unit’s accuracy and determine distance. The software now becomes the main player as we have processed the analog signals and presented them to an A/D converter. The digital portion of the processor and its software can further evaluate and manipulate these signal magnitudes to properly place the strike based on a specific strike “Model” contained in memory. Once this process is completed then the strike results can be placed into video memory for further handling by the video logic and finally transmitted up to a display for presentation to the pilot. A lightning detection system just like weather radar has proven to be a very useful tool in providing situational awareness to the pilots and help them to circumnavigate these hazards .

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