White Paper:-
Subject: **The Operation of Electrical Transmission Lines at High Frequency.**

A *transmission line* is the material medium or structure that forms all or part of a path from one place to another for directing the transmission of energy in the form of electromagnetic waves.
Components of transmission lines include : -

- wires,
- connectors,
- coaxial cables,
- dielectric slabs,
- PCB striplines and
- waveguides.

If the transmission line is uniform along its length, then its behavior is largely described by a single parameter called the *characteristic impedance*, symbol Z_0.
A *high-frequency* transmission line can be defined as one which is designed to carry electromagnetic waves whose wavelengths are shorter than or comparable to the length of the line. Under these conditions, the approximations useful for calculations at lower frequencies are no longer accurate. This often occurs with radio, microwave and with the signals found in high-speed digital circuits such as HD/SDI systems. In such applications, it is critical that all of the components employed in the transmission line are impedance matched. (N.B. the employment of real 75 ohm connectors will not "convert" existing non impedance matched systems).

Characteristics of transmission lines.
The following gives an insight into parameters that must be considered when designing systems to operate at high frequency in an HD/SDI environment.

Impedance is the resistance to the propagation of an alternating signal and is defined as the ratio of the complex voltage of a given wave to the complex current of the same wave at any point on the transmission line - typical values for TV broadcast are 75 ohms.

Return Loss is measured at the junction of a transmission line and a terminating impedance or other discontinuity, and is the ratio of the amplitude of the reflected wave to the amplitude of the incident wave. The return loss value describes the reduction in the amplitude of the reflected energy, as compared to the forward energy, and is normally expressed -dB. For example, if a device has -10dB of return loss, the reflected energy from that device is always 10dB lower than the energy presented. For all devices that are not perfect transmission lines, or purely resistive loads (perfect black-bodies), the return loss value varies with frequency.

Insertion Loss is the decrease in transmitted signal power resulting from the insertion of a device in a transmission line. It is usually expressed relative to the signal power delivered to that same part before insertion. Insertion loss is usually expressed in decibels (dB). The insertion loss of a device may also be referred to as *attenuation*.

Voltage standing wave ratio (VSWR) is the ratio of the voltage amplitude of a partial standing wave at an anti-node (max) to the voltage amplitude at an adjacent node (min) in an electrical transmission line. For example, the *VSWR* value 1.2:1 (often quoted as just 1.2) denotes maximum standing wave amplitude that is 1.2 times greater than the minimum standing wave value.

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Reducing Negative Properties

Every *discontinuity* in the transmission line can have a negative effect on the integrity and final energy of the transmitted signal. It is therefore essential to ensure changes in impedance and geometry are reduced to a minimum. The following safeguards should be considered.

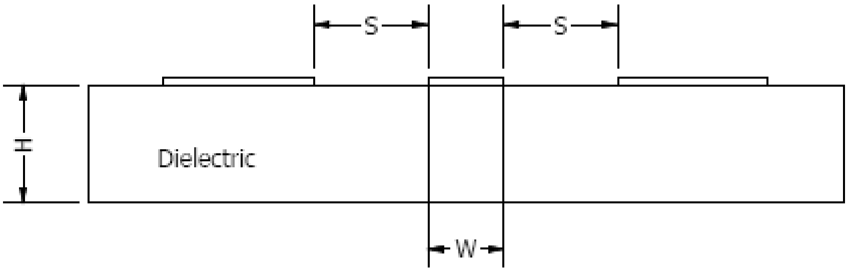
- I/O connectors must be selected with consideration to the PCB termination method and the connector impedance.
- Select connectors with a suitable maximum VSWR across the working frequency range.
- PCB track impedances must be assessed.
- Track shape must be carefully designed to minimize discontinuities.
- Avoid sudden changes in track direction and width.
- Ensure adequate grounding between transmission lines.

Connectors must be selected with consideration to

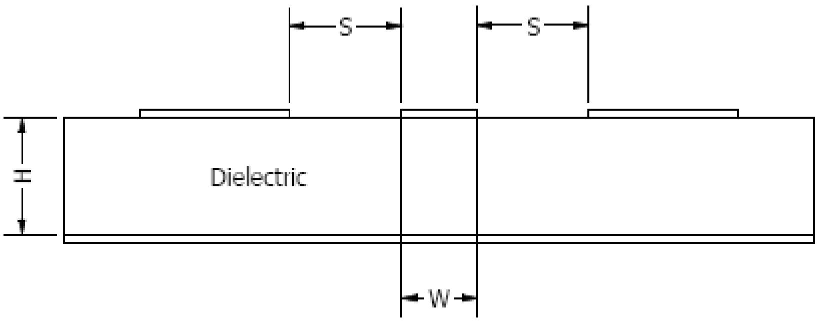
- The real connector impedance
- The PCB termination method to avoid significant discontinuities.
- Connectors should have the same characteristic impedance as the system transmission line and have a VSWR as near to 1 as possible (or a return loss better than -20db) across the required frequency of operation.
- They should provide the necessary physical interface to the real world and should terminate to the PCB in a way that least disrupts the transmission path, (for instance PCB edge mounting connectors ensure the connector signal path is in the same plane as the PCB stripline).

PCB Construction needs to take into consideration the following

- Copper plate thickness and dielectric substrate materials should be carefully chosen to best suit the requirements of the transmission system.
- Simply changing the sub-straight material and/or its thickness can change the characteristic impedance dramatically.
- The use of multiple layers within PCBs may also provide ways of managing impedance by allowing internal combinations of ground planes and track geometries.
- Track geometries
  - A <u>microstrip</u> circuit uses a thin flat conductor that is parallel to a ground plane. A microstrip can be made by having a strip of copper on one side of a printed circuit board (PCB) or dielectric substrate while the other side is a continuous ground plane. The width of the strip, the thickness of the insulating layer (PCB) and the dielectric constant of the insulating layer determine the characteristic impedance.
  - A <u>stripline</u> circuit uses a flat strip of metal which is sandwiched between two parallel ground planes. The insulating material of the substrate forms a dielectric. The width of the strip, the thickness of the substrate and the dielectric constant of the substrate determine the characteristic impedance of the strip.
  - A <u>Coplanar</u> waveguide (CPW) is formed from a microstrip separated from a pair of ground planes either side of it, all on the same plane. In the ideal case, the thickness of the dielectric (PCB substrate) is infinite; in practice, it is thick enough so that EM fields die out before they get out of the substrate. The characteristic impedance of the CPW is easily modified by changing the ratio between the microstrip width (W) and the width of the gap to the adjacent ground planes (S).



- A variant of coplanar waveguide is formed when a ground plane is provided on the opposite side of the dielectric, which is called *finite ground-plane coplanar* waveguide.



One of the advantages of a coplanar waveguide is the ability to change the width of the microstrip whilst maintaining the characteristic impedance of the transmission line.

In summary, the characteristics of transmission lines at frequencies in excess of 3GHz are quite different from those at lower speeds. These conditions are found in high-speed digital circuits such as HD/SDI systems; in such applications it is essential that that all of the components employed in the transmission line are impedance matched. Whilst attention must be paid to the material, design and geometry of PCBs, a critical contribution to impedance matching is made by the use of Real 75 ohm connectors such as those made by Cambridge Connectors which have been engineered specifically for these applications.

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