Journal of Electronics, Electromedical Engineering, and Medical Informatics
Multidisciplinary : Rapid Review : Open Access Journal eISSN: 2656-8632

RESEARCH ARTICLE OPEN ACCESS

Manuscript received July 31, 2022; revised October 4, 2022; accepted October 6, 2022; date of publication October 30, 2022
Digital Object Identifier (**DOI**): https://doi.org/10.35882/jeeemi.v4i4.253

How to cite: Uma Maheswari Y., Amudha A., and Ashok Kumar L., "A Review on EMI Issues in High speed Designs and Solutions", Journal of Electronics, Electromedical Engineering, and Medical Informatics, vol. 4, no. 4, pp. 191–203, October. 2022

A Review on EMI Issues in High speed Designs and Solutions

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ABSTRACT: As data speed on printed circuit boards have increased, new difficulties have evolved and necessitating the development of new analytical methodologies and solutions. It will be necessary to continue research in order to keep up with the ever-increasing data rates and smaller form factors. The literature and issue pertaining to the EMI/EMC of printed circuit boards are reviewed in detail in this paper for the purpose of providing an overview and to assist people looking for more extensive references related to this area. This review includes EMI issues related to high speed PCB, EMI measurement techniques using software and hardware and solution for the EMI issues. Also reviewed the use of electromagnetic band gap (EBG) technology to minimize electromagnetic interference (EMI). In recent years, there have been a number of articles describing the several uses of EBG for the purpose of blocking undesired radiation at discontinuities. Various EBG structure performances with its applications are analysed and detailed.

INDEX TERMS: EBG, EM simulation, EMI, High Speed PCB, Resonant Cavity, Signal Integrity, SSN.

I. INTRODUCTION

Applications such as mobile phones, mother board, satellites, radar, 5G wireless communications, routers etc., may use technologies like HDMI, SPI, UARTS, I2C, USB, high speed interface which operates in GHz. Major problem in the high frequency operating circuits is a Simultaneous Switching Noise (SSN)also known as ground bounce. This is because of the speed of the edge rate that is switching in the digital circuits between 0 and 1 [15] [35]. This noise is easily propagated between the power and ground plane layers by resonance mode, resulting which signal and power integrity issues in multiple layer high speed Printed Circuit Board (PCB) design. Digital circuits are provided power by different regulated voltages. Power Distribution Networks are in place to distribute the voltage or current needed for the components like controller, processors, BGAs, LGAs, LEDs, USB peripherals, Optical circuits, etc. From the input source, voltage conversion is done to supply these components. Conversion of the voltage should be reliable and efficient. Switched Mode Power Supply is most commonly used for its reliability [46]. SMPS Designer has to optimize the regulation with the minimum switching noise with the change of the load current [73]. Once the circuit is operational, there will be a dynamic change in the load which leads to switching noise; resulting ripple which has to be filtered. Fastswitchingdevices with ON and OFF condition resulting electromagnetic interference issue which isin the form of conduction noise and radiation

noise. Conducted noise is propagated to source and load when there is a mismatch in the impedance. There may be different converters operating with different frequency in the board depending upon the current requirements. With the help of controller input, switching converter converts the input power to the required power. Fig 1 shows the basic block diagram of switching converter. Control section assists the switching unit of the input power for the required output. In Printed Circuit Board, power distribution network (PDN) is established with parallel solid copper plane layers. Power plane layers may be having multiple powers in a single layer which are separated by clearance according to the voltage levels. This parallel plane PDN is the source of the Simultaneous Switching Noise (SSN) as parallel plate waveguide. This noise propagates along the power planes through the dielectric medium and passes to the power source in the case of high frequency operations [24] [72]. Surface mount decoupling capacitors are placed between power and ground to provide the low impedance path. In the high speed digital circuits, there will be trace inductance between power source and IC, which creates transient current loop causing noise between the power and ground, shown in Fig 2(a). Placement of decoupling capacitor proximity to IC, reduces the noise by decreasing the trace inductance. Fig 2(b) shows the capacitor is located to the IC to reduce the loop current. This capacitor acts as source while fast switching and providing low impedance path.

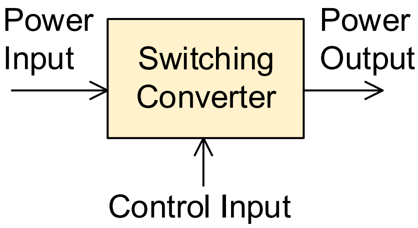

FIGURE 1.Basic block diagram of switching convertor

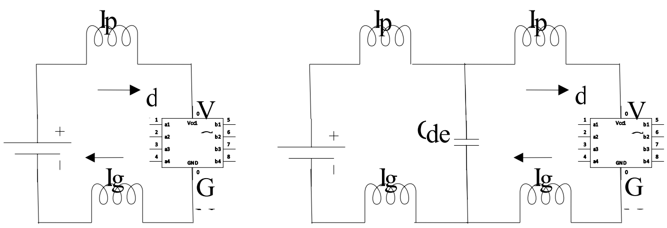

FIGURE 2.Transient current loop and Trace inductance

Parallel power and ground plane layers can be considered as parallel plate structure of the capacitor with the board material being dielectric. Implementation of embedded capacitor with the parallel plate in the printed wiring board instead of actual component helps to reduce the noise. Desired capacitance can be achieved by altering the distance between the parallel plates or with the help of the material of the dielectric medium. The embedded capacitance decouples upto 5GHz.

Segmentation of the power plane layer otherwise called isolation of the power supply network is another method to reduce the noise level. When there is isolation between the power plane, lengthy return path is established in high speed digital circuit operation. In such case, reference power plane for the signals needed to be routed considering the split lines or discontinuity inorder to avoid signal integrity (SI) problems. This power plane segmentation effectively decouples upto 150 MHz.

Using stitching via prevents the noise propagation between the parallel plates. This parallel plate forms the rectangular wave guide structure with board dielectric material. This wave propagates till the PCB edge and it is partially radiated and partially reflected back and causing electromagnetic interference with the nearby circuit. Implementation of the stitching via to ground layer around the board outline has the greater effect on eliminating noise. Normal spacing between the via are 100 mil and 75 mil from the PCB cutout. This implementation effectively improves the performance.

Electromagnetic Interference issue is analysed in an analog circuit caused by digital data transmission and transmission. PCBs of the same scenario are fabricated with and without design consideration and measured the noise level using TDS 2002 Tekktronics oscilloscope. It is explained well with the application of filter and all the design consideration in the analog design the noise is eliminated in [28].

Radiated EMI in differential mode is controlled by maintaining small loop area in the high speed PCB layout. This is very well proved, experimented and measured using spectrum analyser. The permissible radiated noise level for about 3 meters is given in FCC class B levels. For the frequency 30-88 MHz, 88-216 MHz and 216-1000 MHz, the allowable field strength are 100µV/m, 150µV/m and 200µV/m respectively [61].

However in high speed PCB applications, conducted and radiated emission cannot be avoided. The above discussed techniques works perfectly in the case of lower GHz. Another approach is introducing metameterial which act as filter for switching noise. Research gap in high speed digital designs are design of EMI filter considering the signal and power integrity issues. Electromagnetic band gap structure is proposed to address the EMI issues for higher frequency circuits. This can be integrated in plane layers to perform filtering noise.

The aim of this paper is to review the EMI issues in Printed Circuit Board and necessary action that can be taken to overcome this issue. This paper is shaped by reviewing more than 70 reference articles with the urge of addressing the EMI impact on high speed digital signals. This paper is organized into three major areas. Section II addresses the EMI issues related to high speed PCB.Details such as impedance mismatch, mode conversion of signal, power supply and grounding are discussed. Section III addresses EMI measurement techniques using software and hardware.Section IV addressessolution for the EMI issues. Mitigating procedures, problems in the present mitigation techniques in design strategies, software solutions, hardware solutions and Electromagnetic bandgap (EBG) structure are reviewed. Also the importance of EBG, types and noise reduction upon this implementation and advantages are also detailed.

II. EMI IN HIGH SPEED HIGH SPEED PCB

Interconnect or transmission line of a PCB is a conductor which connects to the components or terminals as per the circuit requirements. There will be a signal path as well as return path to complete the loop.This interconnects produces noise in high frequency signals when the connectivity begins. Due to the noise, loss in signal quality occurs and receiver will not receive the signal as expected. This noise can be reflection and cross talk. In high speed signals, return current follow the least impedance path, whereas in low speed signals, return current follow the least resistance path. If a high speed trace is wired under the plane discontinuity, the return current will not follow underneath the track. Instead, when it meets the discontinuity, it will travel overt the discontinuity and forms a loop as shown in Fig 3. This loop area is creating EMI problems. This return path can be either ground plane or a power plane of a PCB. Changing the track layer through via to immediate layer, may not have this loop area, as the return path follows the same reference plane. Incase if the trace is routed entirely on a different layer as in Fig 4, loop current increased. Bypass capacitors have to be added near to via for providing return path for the signal and thereby reducing the loop area.

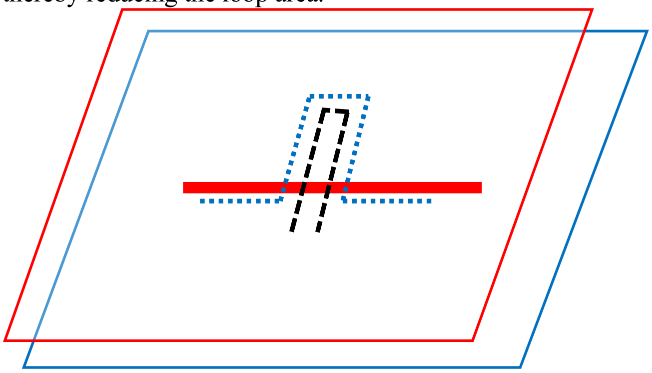

FIGURE 3.Return current path at discontinuous plane

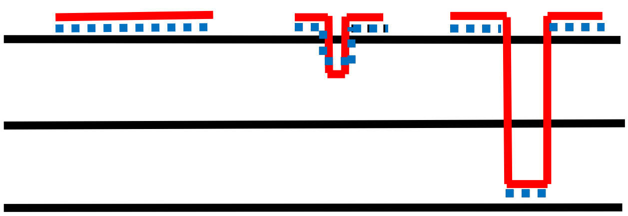

FIGURE 4.Return path of the signal transit from different layer

In the PCB layout, radiated emission was simulated using Power SI from 100 MHz to 0.5 GHz and found high emission level. By increasing the trace width, reflected in emission level up to 40 dB of suppression. By varying width, emission level is compared with FCC standards [54]. By using Taguchi Method in the beginning stage of the design, radiated emission is mitigated. Additional control factors considered are PCB design related parameter and peripheral devices interaction. In this method, orthogonal array, variance method and response diagram are utilized for providing various set of designing parameter. This parametric design helps to mitigate the EMI for meeting the regulation. Analysis of all the factors are tabulated with noise level [16].

Mobile electronics is investigated with a prototype for emission and immunity with experimental setup with conducted and radiated mode [34]. Author touched upon the different PWM architecture, EM interaction in high speed applications, methodologies. Also reviewed the complementary functional blocks on the electronic products and sequential testing approach for the EMI events.

A. IMPEDANCE MISMATCH

The transmission line characteristic can be measured using time domain reflectometer (TDR). With the help of TDR, it is possible to inject the fast rising edge signal on the transmission line and it's corresponding reflection can be measured. Transmission line is considered as shown in Fig 5 as lumped model. The same layer trace represent inductance throughout the trace length and between the parallel layers capacitance is formed as shown in the Fig 5 parallel plate parasitic equivalent. These inductance and capacitance is maintained along the traces.

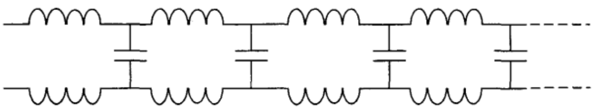

FIGURE 5.Equivalent circuit of transmission line

If there is a change in the impedance, there will be a reflection. Common reference impedance is 50 Ω. It is common practice to refer to the characteristic impedance of uniform transmission lines when describing the instantaneous impedance measurement results. In terms of electrical properties, this is the most important one. The switching noise and reflection noise produced by interconnects with increasing rise times are the two main of noise that interconnects create. Crosstalk between an aggressor's and victim's signal causes return route loop inductances that causes switching noise. Because of the aggressor's di/dt, the victim's magnetic field is constantly changing, that creates a voltage Noise. Switching noise is the name given to this noise since it occurs only when the current changes or switches. Interconnect noise may develop at signal bandwidths as wide as 10 MHz and as wide as 50 MHz. Reflection noise may occur in this frequency range, based on the length of the interconnects. It's created by the transmission line resonating between the high impedance receiver and the low impedance driver, causing the signal to propagate down the line.

Any time a signal is sent across an electrical transmission line, it signifies that there has been a rise in voltage between the signal and return wires. There will be an electric field formed between the signal and the return line if the voltage difference between the two rises. If the voltage changes, electric field also changes. This will increase the change in magnetic field.

The signal's instantaneous impedance is defined as the impedance it encounters at each point along its path. There is no distortion in the signal while the instantaneous impedance is constant, but the signal will reflect if the impedance varies. This is the primary reason for instantaneous impedance is significant.The typical impedance is the one value of instantaneous impedance that characterizes a transmission line. Hence, the transmission line's entire instantaneous impedance is constant.

In a non-uniform interconnect, the instantaneous impedance is not really a constant. Impedance in the interconnect does not really have a constant instantaneous impedance. Discontinuity of the impedance occurs with the change in impedance, also called as non-uniform transmission line.

B. COMMON MODE AND DIFFERENTIAL MODE SIGNALING

In the common mode, both signal and the return follow in the same direction. In PCB, this trace is called as single ended or individual trace. The challenge with the common mode signal is to predict the path. If this can pass through larger loop, significant EMI issues occur. By following high speed design rules, maintaining solid reference plane, minimizing the stubs and having stripline traces, reduce the common mode issue.

In the differential mode, signal takes the defined return path in the opposite direction. Pair of traces is routed between driver and receiver. One trace carries positive signal and the other carries negative signal. As the signals are opposite and equal, there is no return current through ground as the return path is well defined as in Fig 6. This type of routing has more advantages but requires more board area as two traces for a same signal. Designer need to follow tight design rules such as exact equal trace length andspacing within and between the pair traces thereby maintaining the differential impedance, failing which coupling noise will occur [30].

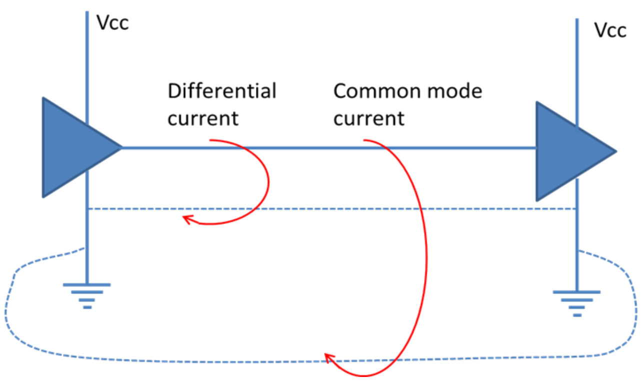

FIGURE 6.Common mode and Differential mode

III. COMPONENTS

The low-frequency behavior of an electrical component is distinct from that of a high-frequency component. Resistor behaves like a resistor, when operated at a low frequency. However, when operating at high frequencies, the analogous circuit is not only a resistor; it also includes an inductance effect and capacitance effect. However, parasitic capacitance restricts impedance in resistors at higher frequencies. Capacitors operate like inductors above their resonance frequency, rising in impedance with frequency as in Fig 7. Leadless components play a major role on signal quality.

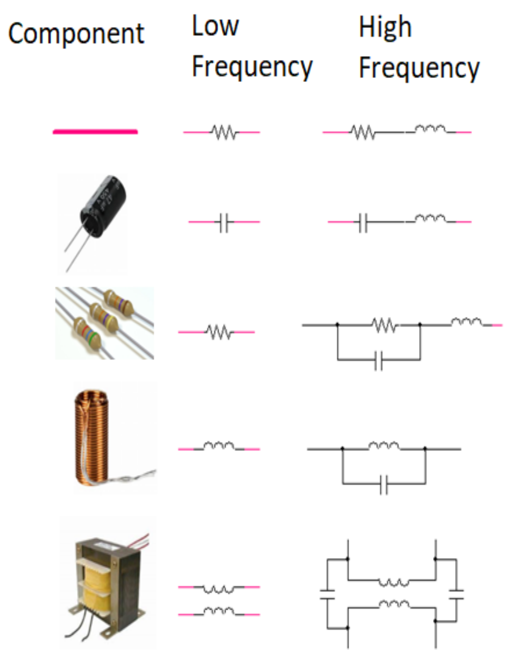

FIGURE 7.Equivalent circuit of component with operation frequency

Many integrated circuits produce EMI that is harmful to human health. Die (silicon) and package-level methods might be explored by the designer in order to limit EMI at the chip level. Die and pin connections in the package create "noise" on the integrated circuit, and this noise is related to the heat sink, which functions as an antenna to further radiate EMI [63]. It is coupled to the heat sink through the die lid. Integrating EMI shield or filter with semiconductor package is essential in high speed PCB design. Because of this, PCB side designing made simple and reduction in board size. Physical vapour deposition (PVD) and spraying an organic coating directly on the semiconductor package are the two most effective methods for creating an integrated EMI shield. When it comes to the stack-up of components in a package, it is quite similar to the stack-up of PCBs. In the package level improvements such as unified ground planes for I/O and Core, stitching of the GND planes, dedicated power bus structures for Core & I/O and stripline routing for all critical signalscan be done.The EMI may be strongly affected by voltage and temperature fluctuations up to a maximum of 6 dB.

A. CROSSTALK

When the two traces routed close by and if the current pass through, coupling will happen from the aggressor to the victim. There will be two noises will get generated. Forward noise which flow in the victim trace with the direction same as aggressor. This is called capacitively coupled crosstalk. Backward noise which flow in the victim trace with the direction opposite to aggressor. This is called inductively coupled crosstalk. These noises will be created only when the change in the current in aggressor. In case of high speed switching with fasted rise time, the coupling becomes stronger. Noise can be reduced by separating the traces apart and having proper reference plane. Signal Integrity tools can be used for cross talk analysis.

B. SIGNAL INTEGRITY

Signal integrity issue occurs with the faster rise time and affects the reliability of the digital products. PCB material also plays the major part in this issue. Relative Dielectric constant of a board material is related to the signal integrity issue. At clock frequencies over approximately 100 MHz or rise times shorter than around 1 nsec, signal-integrity effects become significant. In its largest definition, signal integrity refers to all the issues that develop in high-speed goods as a result of interconnects. Electrical characteristics of interconnects interact with voltage and current waveforms in digital signals to impact performance.To understand the lossy transmission line, eye diagram is the effective way. When there is loss, the amplitude gets reduced. Eye opening will be small [21][25][45][58][59][67][70].

C. POWER INTEGRITY

In high frequency digital designs, power distribution network (PDN) design is very important. To lower the power impedance, decoupling capacitors are added. Analysis on PCB-PDN is done in [21]by quantifying the contribution of inductance from various geometrical part and current path. Noise generated from the signal line gets coupled to power supply. Power integrity is making sure that the required current and voltage are received from supply to load. In order to achieve this PDN analysis is perform for determining the possibility of placing the decoupling capacitor thereby reducing the impedance on the power line [71].

IV. EMI MEASUREMENT TECHNIQUES

From the Maxwell's equations, one can get to know how the electric and magnetic field changes with conductor and dielectrics. Maxwell's Equations describe the interaction between magnetic and electric fields. With the given point in space at any time instant, the both electric and magnetic field have to satisfy the differential equation, with the help of this it is possible to know the fields with respect t time and location.

Analyzing EMI may be done in two distinct ways. The time and frequency domains are usually referred to here as. Signals are examined as they change through time in the time domain. Signals are evaluated in the frequency domain with regard to a predetermined range of frequencies.

A. USING SOFTWARE TOOLS

Variety of numerical modeling methods are available in EM tools. They are Finite Difference Time Domain, Finite Element Method, Boundary integral formulation and Method of Moment. The EBG geometry is meshed into small area with nodes and with the help of system equations voltage and current are known in the each nodes. Various methods are used to investigate the characteristics EBG structures which are dispersion diagram, scattering parameter and in-phase reflection. These bandgap investigations can be done in EM simulators. In the case of dispersion diagram, boundary condition of the structure is considered. This diagram is plotted with transverse wave number as horizontal axis and frequency as vertical axis. Bandgap can be easily identified with this diagram. In scattering parameter method , it is possible to find the stop band frequency, much faster and more realistic results. In-phase reflection method describes the reflection property. It is the ratio of the reflected wave to the incident wave.

B. USING HARDWARE METHODS

Power cables, wires, resistors, capacitors, opamps, etc., may emit undesirable emissions up to the GHz range, which can be transmitted by ac power systems via conducted emission or radiated through antennas. Emission testing is required for all electronic instruments in order to maintain a clean electromagnetic environment [46]. In these kinds of testing, the emitter is EUT being tested. Emission testing may be performed on radiated and conducted emissions [41].

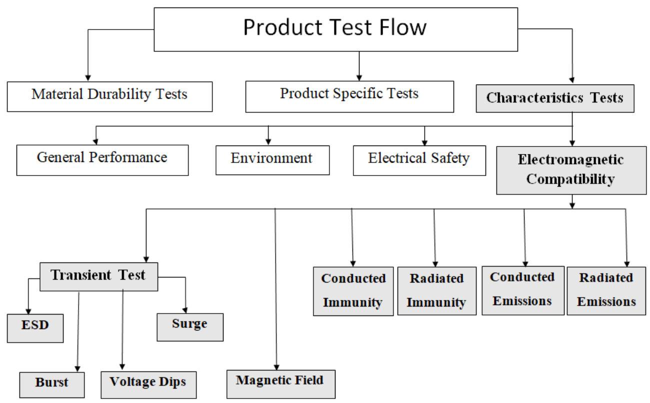

FIGURE 8.Product Test flow in a Product Life cycle management

Open area testing is one of the most effective ways to conduct radiated emission testing on big devices (OATS). A metallic ground plane, an EMI receiver or spectrum analyzer, and the EUT, which is normally maintained at a distance of 3 m or 10 m (unless stated otherwise) from the receiver, are typical components of this sort of setup. Specific chambers like anechoic or reverberation chamber or in a Gigahertz Transverse ElectroMagnetic cell for smaller prototypes (GTEM cell) are used for testing radiated emission. Typical test flow for any electronic product is given is Fig 8. Characteristic test is important for applying regulation of product before introducing to market.

Standards are available for emission and immunity levels that are defined by various regularity bodies. These standards are classified into basic, generic and product specific standards. Major standard organizations are IEC-International Electrotechnical Commission, CISPR-International Special Committee on Radio Interference, IEEE - Institute of

Electrical and Electronics Engineers, ISO - International Organization for Standardization, BIS - Bureau of Indian Standards, JAS - Japanese Standards Association etc,. Once the measurement result is within the limit defined by the standard, product can be applied for required regulations such as FCC, CE, and CCC etc.

V. SOLUTIONS FOR EMI PROBLEMS

A. SOFTWARE SOLUTIONS

Attention should be paid on the software functionalities of the controller, mainly on phase locked loop (PLL) and watchdog timer.For the same functionality with different software program implementations are analysed [65] for EMI measurement. It is to be noted that there are about 10 dB noise level is observed. PIC18F4550 and LPC1114FN28 were considered for analysis in different types of program considering loop and interrupt along with different clock rate, clock source and PLL set up.

B. HARDWARE SOLUTIONS

Electromagnetic shielding is one of the most common approaches for reducing EMI and its influence on an electronic system. Metal, conductive polymers, metamaterials, and ferrites are all examples of conductive materials used to construct enclosures for electronic components. Shield can be adopted for a whole or a part of the system based on the need. This prevents the radiation between two regions. Enclosures can be shielded using copper foil. Teflon twisted cable minimizes the EMI noise level. Termination of the shield wire is very essential in order to avoid loop current.

SSN noise reduction is proposed by adopting magnetic material ferrite flim deposition with the help of RF-sputter. Over 20 dB of noise reduction is achieved with the material thickness of 3 um for totally 16 GHz. Also compared to nickel material 90% reduction is proved and it does introduce resonance in lower frequencies. Waste biomass corn stover was converted into absorbing materials of electromagnetic wave which solve environmental pollution caused by burning. This results a reflection loss of -51.7 dB noise level with the thickness of 3.25 mm and an absorption bandwidth as 13.5 GHz (4.5-18 GHz) [17][18][47][66][69].

C. SOLUTION USING DESIGN STRATEGIES

Practicing good design practice saves greater than 22 dB noise level which reduces emission easily. This is experimentally verified with good and bad PCBs considering stackup, crossing in split planes, decoupling network, series termination, ground plane arrangements and offset in power plane [4].

D. EMI FILTERS

Common mode (CM) and differential mode (DM) are the most common noise components in the conducted emission noise (CM). Noise from CM and DM sources might be eliminated using the filter in the circuits with interference sources. Filter can be applied in power lines as well as signal IO lines. RFI filters with X and Y capacitors having perfect ground schemes mitigates the emission level.

E. GROUNDING:

A low-inductance ground system is the most critical feature when designing a PCB for decreasing EMI. Dedicated and Continuous ground plane is required to provide perfect return path to source. Instead of connecting all the individual ground and then to ground plane, direct individual ground connection is recommended as there will not be any current loop and ground bounce. Ground connection should be done for the signal layer as shown in Fig 9 to avoid the noise coupling.

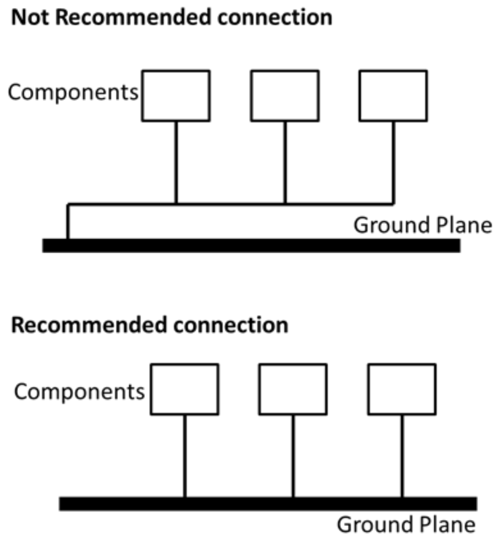

FIGURE 9.Grounding Method

F. CIRCUIT TOPOLOGY MODIFICATION

The values of Loop inductances and parasitic capacitances are increased when the components are not arranged properly and this leads to noise. It is also essential to pay attention in deciding PCB stackup. By adopting simple methods noise can be mitigated such as having ground layer next to high speed signal layer, routing of critical signals as short as possible without vias, attention to oscillator and crystal traces, differential signaling routing implementation for cancelling coupling noise, effective termination technique, decoupling capacitor placement proximity to power pins to ground, reducing crosstalk by spatial placement of the traces etc,. Modulation of clock signal is also one of the strategies for reducing the EMI. Adopting staggered data transmission where the data transmission in each line is paused at fixed interval of time and performed by decomposing binary details in coded blocks. Repeated combination of those blocks will be used to transfer all the data. Since there is transmission cut, decrease in current transitions happen along the lines which are responsible for radiated noise [35].

G. SPREAD SPECTRUM

Identification of the critical noise source is very essential. Using frequency modulation, the energy collected in a narrowband is dispersed over a larger bandwidth in the spread spectrum. As a result, the value of peak energy decreases, resulting a lower chance of EMI. Another way is, based on the speed of operations, components can be laid out such as digital, analog, interfaces, power module etc. Traces for the corresponding signals should also be in their corresponding area. Filter can be provided for the traces going to another sub module.

VI. ELECTROMAGNETIC BAND GAP (EBG) SOLUTION FOR EMI

Introducing the decoupling capacitors, tracing topology, addition of stitching vias can be followed to suppress the SSN noise. These methods are not a suitable for the suppression of the noise effectively with the high frequency operations. Earlier, to mitigate the noise levels multiple ground layers are integrated in PCB layer stackup. Also ground shielding of each signal layers are were used. For controlling the SSN and introducing the EBG is one among them. EBG structures suppress the SSN noise in such applications. Metamaterial otherwise called as artificial material arranged as structure with lesser wavelength can act as electromagnetic material. Recently there are many metamaterials are proposed as it possess unique properties [38]. These structures are having periodic pattern which is also called as Artificial Impedance Surfaces (AIS). With the conventional material of the plane layers, electromagnetic waves are blocked with the structure shape, geometrical parameter, symmetrical arrangement and its size. There structure can be classified as mushroom and planar type based on the position of the pattern [5][12][19][32][42][49][56]. EBG structures were proposed over the recent years and discussed the effectiveness in the suppression of noise. Initially it was used for suppressing the coupling of antennas and then it extends in Printed Circuit Board as an inexpensive method to suppress the propagation of wave within the plane layers and the parallel plates in the frequency range of GHz.

The symmetrically structured pattern is embedded in the dielectric of the PCB as shown in Fig 10. Mushroom like structure creates capacitance and inductance properties made as filter since this structure is embedded with dielectric. The EBG pattern is connected to the plane layer with via. Fabrication of this type is complex as pattern need to be implemented in the dielectric.

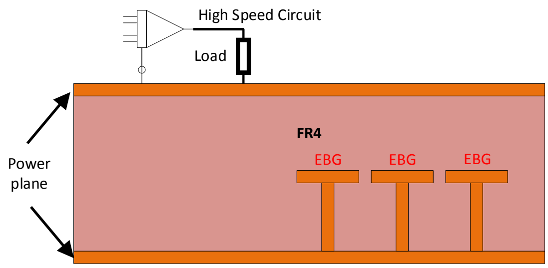

FIGURE 10.Mushroom Type EBG

EBG structure is used for obtaining narrow band notch for minimizing noise in WLAN system. Author introduces mushroom type EBG and achieved rejection at 5.2 / 5.8 GHz instead of the bandgap range. With the parameter adjustment in the structure, intended notch frequency is achieved. Frequency range considered here is 3 GHz to 11 GHz.

A. PLANAR

Planar EBG structure represents the plane layer where the part of the layer can be etched with EBG pattern as shown in Fig11. In this type of structure, there exists parallel plate capacitance between EBG layer with ground layer and within the gap between the patterns. Also Inductance is formed with serial EBG connections. Various researches are going on planar EBG for noise mitigation.

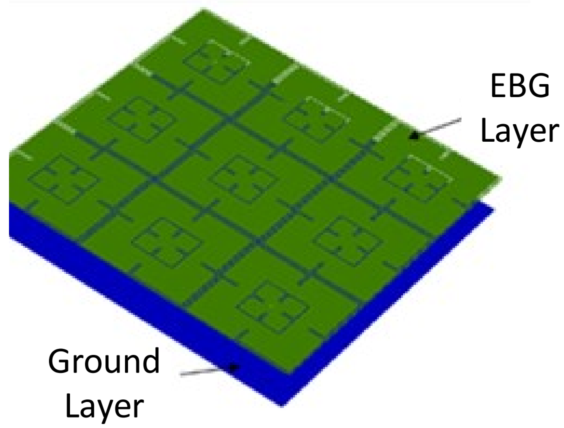

FIGURE 11.Planar EGB Structure

Dual band EBG structure was designed and simulated in CST microwave tool and measured 1 to 5 GHz for microwave and wireless applications. This EBG structure has dual bandgap for suppressing the noise at 1.8 GHz and 4.3 GHz [43][44][55]. For wearable and medical applications, compact miniaturized EBG structure is experimented and proved that the enhancement in the radiated energy and important thing is, it provide isolation between antenna and human body [2][7][8][9][13][51]. This is compared with the literature and claimed this is the best suit. About 95% reduction in the Specific Absorption Rate (SAR) because of this structure. EMC risk analysis is important for the applications link vehicle engineering and medical appliances. In wearable medical devices, implementation of miniature EBG reduces the noise level and satisfy the limit of FCC and CNIRP regulations [6][10][22][27][36][48][52][53].

There are various literatures that are discussed about the planar EBG and noise suppression. Coplanar EBG structure with novel L bridge was explained for SSN suppression in high speed circuits for the frequency range from 210 MHz to 20 GHz at a bandgap depth of -30 dB. The comparison of suppression behavior between port locations for L-bridge, Meander-L EBG and novel L EBG were tabulated with frequency and band width details. This novel meander-L bridge acquires wider band width as 19.79 GHz. Cutoff frequency is theoretically calculate and measured in simulation tool as well in VNA and all these are compared. Signal integrity requirements are also experimented in time domain [57]. Symmetrical H-shaped slot fractal uniplanar electromagnetic bandgap structure is arranged alternately and analysed the characteristic. Dual bandgap is achieved at 3.32 GHz and 3.53 GHz. Ansoft HFSS and network analyser are used for simulation and measurement [33][68].With the help of ultra-wideband planar bandpass filter, triple notched band filtering effects were achieved. This is achieved by introducing open circuit stub and asymmetric dual feed line for rejecting undesired RF signal. Double sided, swap EBG structure for UWB is discussed to suppress SSN for the frequency range 600 MHz to 6.7 GHz and the results are compare with traditional structure and proved that this structure obtain good suppression. From this literature it is concluded that the extended metal between the unit cell helps to improve the inductance and to very good lower cutoff frequency [14][37][62].

Two different performances are achieved due to the reconfiguration of the EGB structure and results are validated. Author used HFSS for simulating the structure for predicting the behavior with dispersion diagram and Anritsu 37369C VNA (Vector Network Analyser) for measurement. Author also wish to introduce plama modeling and to reduce the reflection angle to minimize coupling [31].Two different matamaterials such as complementary split ring resonator (CSRR) and EBG structure are introduced in plane layer for filtering action and analysed the frequency response and signal integrity. This is a new idea done by the author and no previous work were reported. EBG performs significantly for noise reduction around 15 dB than CSRR. Authors used method of moments in Agilent Momentum software (2.5D solver) and the finite-difference time-domain method by means of the SEMCAD X platform and VNA for measurement [29].

Novel planar EBG structure acting as low pass filter where ground plane is etched with the structure with various configuration are examined. The same is compared with conventional filter and claimed that the performance and control of resonant frequency is good. For the numerical results, method of moment (MOM) is used in simulation tool [23].New UC-EBG structure based on the conventional structure with the modification in metal patches and proved the suppression level in SSN. At -40 dB depth, it is achieved stop band from 0.18 GHz to 4.53 GHz which is 45% wider than the conventional one [64]. Physical behavior of the planar EBG structure is studied along the resonant properties. With the additional inductance in the plane, EBG resonant mode is getting affected. This is experimentally validated by building three EBG boards with different parameter. Analytical and measured (Anritsu MS4624B VNA) values of frequencies are calculated and compared. Based on this study, partial layout option can be achieved in noise reduction and keeping the continuous solid plane around the structure [20].

Alternative small EBG planar structure is designed and proposed to place it near the noise devices as a fence for noise reduction. The issues such as IR drop on plane layer and signal integrity for the traces that are affected by this discontinuity are analyzed with the implementation of this structure using CST EM studio [26].Wideband planar EBG structure is designed for the applications such as WiMax, UMTS, WiFi, PCS, GSM and Bluetooth and more. Maximum bandgap is achieved here is between 1.75 GHz to 4.85 GHz which is achieved by the dimensional modification which is around 32 % improvement compared to previous shape JC-EBG. With the addition of meander line bridges compared to straight line improved the EBG performance in bandgap and transmission coefficient. From this literature it is proved that required lower band can be achieved with turning the structure. HFSS with Finite Element Method and CST with Finite Difference Time Domain (FDTD) are used for simulation [3].

For wide bandwidth applications, single and dual band EBG structure are proposed with the increase of inductance and capacitance of the patch for getting extra lower cut-off frequency with wider bandwidth. Various single band EBG structures such as mushroom, cross hair, swastika and hexagonal patch with different patch size are simulated and tabulated the bandwidth. Similarly, dual band width structure is considered and tabulated. Hence proved when the size increase in the EBG structure, band in shifting towards lower cut-off frequency due to the increased capacitance. This structure can be applied in enhancement of antenna gain and bandwidth, signal integrity, noise reduction for filters, reduction of mutual coupling for antenna arrays and in high speed switching circuits[40].

T-Shaped EBG structure is analysed for three different configurations such as 2X2 (60X60 mm), 3X3 (90X90 mm), 3X3 (90X90 mm) scaled down to 50 % with thin substrate and combination of these structure layout (60X60 mm). As the combination structure is not a periodic structure, the bandgap depends upon the location of the noise source input port and output port. Effect of substrate is also studied by varying the dielectric thickness and proved that the bandgap is improved because of the increase in the overall capacitance [39].

TABLE 1. COMPARISON OF VARIOUS EBG STRUCTURE

EBG structure	Total area in mm^2	Unit cell area in mm^2	Suppression level (dB)	Bandgap (GHz)	Reference
Al EBG with Slit	30.4 X 30.4	15.2 X 15.2	-40	0.9 – 3.5 GHz	[50]
CSSR	70 X 60	20.8 X 20.8	-30	1 – 12 GHz	[11]
Selectively embedded EBG	120 X 90	30 X 30	-30	0.49 – 16 GHz	[72]
T-EBG	60 X 60	30 X 30, 15 X 15	-40	2.02 – 18.84 GHz	[39]
miniaturi	46 ×	46 × 46	-15.5	2.4 GHz	[8]

zed EBG structure	46				
monopole antenna	-	50.7 × 25.7	-6.76	2.4 GHz	[22]
Fabric CPW antenna	-	60 × 60	-6.55	2.4 GHz	[9]
Antenna With EBG-DGS	-	20 X 30	-6.45	2.4 GHz	[7]
Periodic coplanar EBG	90 X 120	30 X 30	-30	0.4 – 16 GHz	[56]
Novel Meander-L structure	153 X 91.8	30.6 X 30.6	-30	0.2 – 20 GHz	[57]

Extensive comparison of various structure of EBG with their dimension is done with the existing literatures for the frequency bandgap and the noise suppression level and tabulated in Table 1. This will be helpful for the reader for better understanding. According to the application's signal speed, corresponding filter can be chosen for the plane layer. Also practical application of the specific EBG structure is extracted from the literature along with the software tool used and measurement instrument used and listed in Table 2. This will more useful for the relevant industry.

TABLE 2. APPLICATION OF EBG STRUCTURE WITH SOFTWARE AND INSTRUMENT USED DETAILS

EBG structure	Application	Software	Instrument used	Reference
Pinwheel Meander-Perforated Plane Structure (PMPP)	SiP	ANSYS HFSS	-	[63]
MTM (Metamaterial)	Wearable devices	CST Microwave Studio	-	[5]
Monopole UWB	WLAN	ANSYS HFSS	-	[12]
compact UWB BPF using DGS [9] and HMSIW	WiMAX and WLAN	ANSYS HFSS	Agilent E8363B network analyzer	[42]
New small-size topology for populated power plane with CSRRs	Ultra Wide Band applications	CST micowave studio Ansys HFSS	-	[43]
Star Patch structure	Wearable devices	CST micowave studio	Rohde & Schwarz ZVB14 vector network analyzer	[55]
Compact fabric antenna structure	Medical Body-Area Networks (MBANs)	CST micowave studio	-	[6]
E-shaped miniaturized EBG	biomedical technology	CST micowave studio	Anechoic chamber	[8]
compact AMLA	wrist-wearable applications	CST micowave studio	Rohde & Schwarz ZVB20 VNA	[22]
Endfire radiation wearable planar antenna with the AMC surface	ISM band	CST micowave studio	R&S ZVL13	[2]
Symmetrical e-slots structure	Wearable Medical Device Applications	CST micowave studio, ADS	-	[3]
MSF-UC-EBG	Microwave Application	Ansys HFSS	Agilent E5071C PNA series network analyzer	[37]

VII. CONCLUSION

EMI issues related to high speed PCB, EMI measurement techniques using software and hardware and solution for the EMI issues are reviewed in this work. Mitigating procedures, problems in the present mitigation techniques in design strategies, software solutions, hardware solutions and Electromagnetic bandgap (EBG) structure are also reviewed. Importance of EBG structure types, measurement methods and applications have been presented and reviewed. Also analysed the capability of noise suppression in PCB. The presented literatures have proved that the introduction of the EBG structure, suppresses the electromagnetic noise. Planar type EBG is used as it eliminates via connectivity and made easy for the designers as well as the fabricators. Based on the analysis, applications having more than 10 GHz L-type structure can be suitable for noise filtering. Attempted with passive components for altering the high frequency behavior and this does not have any impact. Proved that integration of EBG and high speed PCB reduces the EMI noise. The greater demand in protection from electromagnetic noise provides us the need for effective EBG structure for a specific application. Hence more research work has to be performed on this area.

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