



# **Characterisation and simulation of digital device electromagnetic noise under non-ambient temperature conditions**

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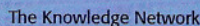
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Characterisation and simulation of digital device electromagnetic noise under non-ambient temperature conditions

J.-M. Dienot

Presented is a new approach to the evaluation of electromagnetic emissions of electronics circuits under thermal stress. Near-field radiations, of essentially magnetic-type owing to the current switching of CMOS chips, have been measured in different external temperature conditions. Electrical equivalent models are proposed to investigate thermal influences on the electromagnetic compatibility characteristics of a printed circuit board excited by digital sources.

**Introduction:** The sources of electromagnetic emissions with digital components on a printed circuit board (PCB) are due mainly to the DC supply network, input-output network, and the device packaging pins, which act as parasitic elementary antennas excited by fast voltages or current transitions of the integrated chips [1]. With the realisation of an epoxy layer test board including elementary digital components (buffers/inverters), we have developed a wideband magnetic (H) near-field test setup for digital circuits with their environment (Fig. 1). H-field measurements with a 1 cm diameter probe are made over different areas of the PCB test boards with CMOS family circuits in dual inline (DIL) packaging. The probe, connected to a 50 Ω spectrum analyser, gives a view of switching noise and current variation, as an H-field image, over the ground trace, the supply lines, input and output lines. This initial test bench is completed with a warming plate, over which the PCB test board (10 × 10 cm) is placed. A localised warming area of the plate allows the heating of specific surfaces of the PCB: supply line zone, digital circuit only, ground traces. The board is about 1.5 cm over the plate, to avoid direct heat contact. Thermal probes on body parts of the circuits give a realistic value of the average temperature of each device (Fig. 1). We describe the measurements achieved in these conditions and the results of electrical simulations to reproduce and explain the phenomena.

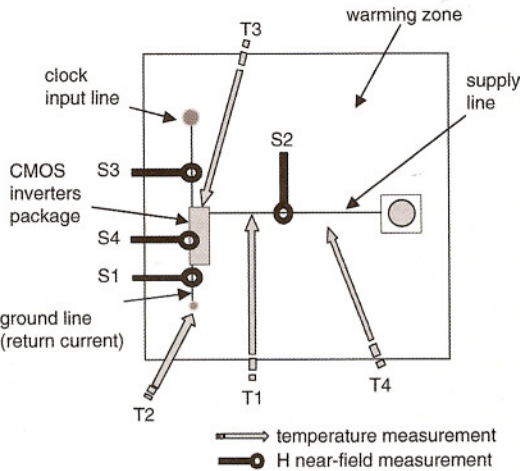


Fig. 1 Temperature and H-field measurements points on CMOS test board

**Electrical modelling method:** The EMC behaviour of the test board can be simulated with electrical equivalent models dedicated with H near-field level calculations due to switching and supply noise [2]. Each part of the circuit, the active component, PCB tracks, coupling measurement sub-system, is identified as an elementary block in an electromagnetic compatibility (EMC) strategy of modelling, as strong or weak contributors of the switching noise phenomena, and modelled with an electrical equivalent model, initially thermally static (24°C by default) (Fig. 2)

(a) **Contribution of active circuit:** High modelling level issues from the physical and behavioural variation of temperature are reported on SPICE CMOS and DIODE models. In MOS level3 and BSIM4, the main parameters sensitive to the temperature are threshold voltage  $V_{TH}$ , carrier mobility  $\mu_0$ , and the slope in subthreshold mode dependent on  $kT/q$  [3]. Calculation of the reduction of levels and slopes of internal current of the MOS device during switching, owing to temperature effect, can be realised with these parameters.

(b) **Contribution of PCB copper track network:** PCB tracks are modelled as elementary cells of transmission line theory (TLT) models. R, L and C values of the matrix cell are calculated with numerical software, with the 3D FEM (finite element) method. The impact of the temperature shift on the equivalent model of the conductive connection network is realised with a modified copper conductivity variation, in respect of temperature test (60–150°C) and the thermo-physical properties of the electronics and microelectronics materials [4]. The initial copper conductivity of 1.7  $\mu\Omega/\text{cm}$  is modified by temperature with the use of a thermal expansion coefficient of  $16.6 \times 10^{-6}/^\circ\text{C}$ . In the final extraction of the equivalent RLC parameters of the supply line (the most electrical long line of our PCB test board), variations of initial (ambient) RLC values are obtained and reported on simulation schematics.

(c) **Coupling factor of measurement probe:** The influence of the EMC electrical coefficients of couplings between the tracks and the H-field probe are also considered to be affected by temperature difference. As internal probe impedance is not affected by forced warming, because of the distance of its location (1.5 mm), the inductive part of the copper tape over which is placed the H probe modifies the ambient (24°C) coupling factor and measurement probe resonance frequencies.

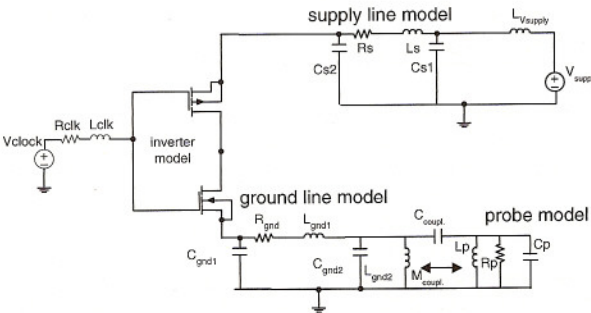


Fig. 2 Complete SPICE electrical model of test PCB with CMOS device and H probe

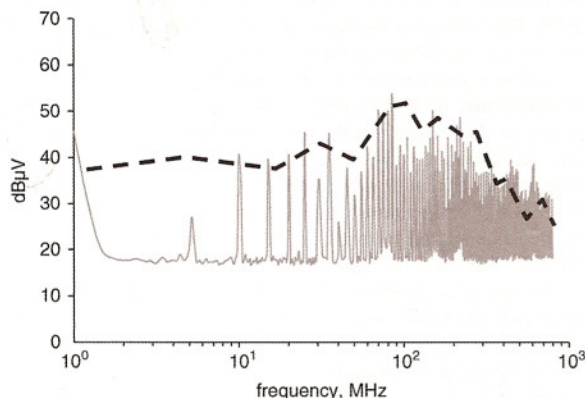
**Measurements and simulation results:** Characterisations of EMC emissions over the PCB have been realised with a CMOS ACT/HCT04 discrete device. A maximum level, considered as test board resonance excited by switching times of the circuit, is around 88 MHz, and about 57 dB  $\mu\text{V}$  at ambient temperature. Among many thermal (24 to 150°C) and spatial parametric characterisations, the main observation is the shift of radiated energy level to high frequency with increasing temperature. At 82°C, a higher emission peak appears at 200 MHz (twice than initial main resonance frequency). For high stress temperature (110–130°), a global reduction of the spectrum levels is observed, which indicates the start of loss of the switching quality of the circuit. The main impact of H-field spectrum variation owing to thermal stress is due to voltage and current transition waveforms modified by temperature. Switching times, high and low, generate wideband frequency responses, with the first-order approximation:

$$f_{\text{MAX}} = 0.35/(t_{\text{switching}})$$

With this information, modelling and measurement fitting efforts have been realised to obtain good correlations between measured and



simulated spectrum waveforms. In Fig. 3, for the case of thermal-EMC behaviour at 58°C, the maximum error between the experimental and simulated spectrum is about 5 dB over a wide frequency range (1 GHz). Discrepancies at low frequency are due to measurement accuracy limits. At higher frequency range, near 1 GHz, high-order modelling of lines have to be refined to fit new frequency peaks activated by temperature effect. Table 1 summarises the sensitivity of the 'block' models to obtain pertinent simulation response. Two main sets of parameters seem to be very sensible for simulation against temperature: attending main internal SPICE transistor coefficient  $V_{TH}$ , and  $\mu_0$ , which are very temperature dependent, but also the parameter involved in the coupling model of the GND line with the probe:  $M_{coupl}$  and  $L_{gnd2}$ .



**Fig. 3** Spectrum measurement and simulation (dashed line) of switching noise for PCB temperature of 58°C

**Table 1:** Model parameter sensitivity for thermal-EMC simulation correlations

Model parameter	27°C	58°C	97°C
Supply line	10%	5%	1%
Inverter	60%	70%	75%
GND line	15%	10%	4%
Probe/GND coupling	15%	15%	20%

**Conclusions:** The work presented in this Letter, on a canonical PCB case with elementary electronic digital gates, has shown the experimental behaviour of temperature on the EMC characteristics of circuits, and has demonstrated the first modelling approaches with the use of phenomenological models. Electromagnetic noise is temperature-sensitive, and the active part has a large effect on global emission spectrum and frequency repartition. Coupling effects with PCB wires also have a non-negligible role in realising a performance modelling and simulation result. Ambient temperature conditions, e.g. in electronics embedded systems, should be considered with EMC constraints and multi-domain modelling in the future.

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## Absolute value coding for robust and scalable video coding

D.W. Redmill, D.R. Bull and C.N. Canagarajah

Absolute value coding is introduced as a method for significantly reducing temporal drift within a motion compensated predictive video codec in the presence of loss. Drift reduction both improves error resilience and enables scalability by omission of parts of the bit-stream. In conjunction with matching pursuits, the system can be used to provide a displaced frame difference codec using fixed length codewords, which further improves error resilience and facilitates simple bit-stream editing.

**Introduction:** There is increasing demand for video coding systems which offer good resilience to channel errors and are scalable to different bit rates. Many standard video compression systems [1] use motion compensated prediction (MCP) and displaced frame difference (DFD) coding techniques to reduce temporal redundancy. MCP is sensitive to temporal error propagation or drift between the encoder and decoder. In this Letter we present a novel method known as absolute value coding (AVC) for reducing this drift. The technique is well suited for use with matching pursuits (MP) to generate a DFD codec using fixed length codewords (FLC). The use of FLC both improves error resilience and facilitates simple bit-stream editing. The proposed techniques provide a low delay alternative to temporal filtering techniques used in H.264/MPEG-4 SVC [2].

**Algorithms:** Matching pursuits (MP) [3] is a method for approximating a signal  $\mathbf{f}$  with a linear sum of weighted basis functions from an over-complete dictionary  $D$ . Basis functions  $\mathbf{g}_k$  and weights  $\gamma_k$  are chosen to recursively minimise the residual error:

$$k_m = \max_k |(\mathbf{f} - \hat{\mathbf{f}}_{m-1}) \cdot \mathbf{g}_k^T| \quad \forall \mathbf{g}_k \in D \quad \gamma_m = (\mathbf{f} - \hat{\mathbf{f}}_{m-1}) \cdot \mathbf{g}_{k_m}^T \quad (1)$$

The decoded signal  $\hat{\mathbf{f}}_m$  is then recovered using the initial prediction  $\hat{\mathbf{f}}_0$  and the iterative equation:

$$\hat{\mathbf{f}}_m = \gamma_m \mathbf{g}_{k_m} + \hat{\mathbf{f}}_{m-1} \quad (2)$$

The recursive approximation makes MP well suited to scalable coding. With well designed dictionaries, MP gives approximately equi-probable codewords which can be efficiently coded using FLC.

Absolute value coding codes the 'absolute value' of each basis function. Equations (1) and (2) become:

$$k_m = \max_k |(\mathbf{f} - \hat{\mathbf{f}}_{m-1}) \cdot \mathbf{g}_k^T| \quad \forall \mathbf{g}_k \in D \quad \alpha_m = \mathbf{f} \cdot \mathbf{g}_{k_m}^T \quad (3)$$

$$\hat{\mathbf{f}}_m = (\alpha_m - \hat{\mathbf{f}}_{m-1} \cdot \mathbf{g}_{k_m}^T) \mathbf{g}_{k_m} + \hat{\mathbf{f}}_{m-1} \quad (4)$$

The key advantage of AVC is that the correlation  $\hat{\mathbf{f}}_m \cdot \mathbf{g}_{k_m}^T = \alpha_m$  will be correct irrespective of any errors in  $\hat{\mathbf{f}}_{m-1}$ , thus eliminating temporal error propagation which is correlated with selected basis functions. The main disadvantage of AVC is a slight increase in bit rate associated with the magnitude values  $\alpha_m$  having a larger variance than differential values  $\gamma_m$ . AVC is well suited for use with MP which has a high ratio between positional and magnitude information making the overhead less significant. Note that with non-orthogonal basis functions it is possible to find a more optimal reconstruction. However, there is little gain, since the basis functions selected by MP are close to orthogonal.

**Results:** To demonstrate the potential of the proposed system, a simple video codec has been simulated using a simple fixed size MCP strategy, and a block based MP. To support scalability, basis functions are selected according to several DFDs reconstructed assuming bit rates of 12.5, 25, 50 and 100 kbit/s. Fig. 1 shows scalability results for the proposed system both with and without AVC. Also shown are non-scalable results and those for a two-layer system with prediction from the base-layer only. AVC gives results much closer to the non-scalable system, while not using AVC causes significant loss owing to temporal error propagation. The two-layer system gives poor results owing to the failure to fully exploit temporal correlations. The use of FLC also facilitates the use of low complexity adaptive scaling strategies that select which basis functions to retain based on a combination of initial ordering, luminance/chrominance,