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ANALOG CIRCUITS DIAGNOSIS USING DISCRETE WAVELET TRANSFORM OF SUPPLY CURRENT

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Abstract

A discrete wavelet transform based dynamic supply current analysis technique for detecting the catastrophic faults in analog circuits containing transistor is investigated in the paper. Some considerations due to a problem of fault localization using multiresolution approximation and the illustrative numerical example are presented.

Keywords: fault diagnosis, fault detection and localization, electronic circuits, discrete wavelet transform, multiresolution signal approximation.

1. Introduction

Detection and localization of analog electrical circuit faults is still an important part of modern modeling and designing processes. Despite intensive research activity, convenient, universal, normalized diagnostic procedures enabling precise verification of systems on the industry, service and repair stage have not arisen yet. The main reasons of these difficulties with diagnostic methods for analog systems are large variations of the parameters of such circuits, often hiding the real reason of damage and difficult access to their inside points. This last inconvenience is solved by procedures based on testing of the supply current. The algorithm of monitoring the supply current, although constantly improved [1]-[7], still does not sufficiently solve problems including tolerance of components. Lack of effective algorithms makes identiffication of single and multiple faults and detection of parametric faults very difficult. The paper presents possibilities of using multiresolution representation of signals and discrete wavelet transform for detection of catastrophic faults of analog circuits. The conception outline of use of the discrete wavelet decomposition for detecting of chosen faults is given.

2. Basic time-frequency signal representation

2.1. Continuous and discrete wavelet transformation

The original wavelet (or *mother* wavelet) is a function $\psi(t)$ used to generate a family of wavelets

$$\psi_{ab}(t) = \frac{1}{\sqrt{a}}\psi\left(\frac{t-b}{a}\right), \quad a \in \Re^+, b \in \Re, \tag{1}$$

where parameter a is the scale, parameter b the position (shifting coefficient) and $\psi_{a,b}(t)$ denotes the descending wavelet (belonging to the family of wavelets).

According to the Morlet-Grossman theory [8], continuous wavelet transformation (CWT) of one-dimensional signal $f(t) \in L^2(\Re)$ is defined by the following equation

$$W_{CT} f(a,b) = \int_{-\infty}^{\infty} f(t) \psi_{ab}^{*}(t) dt. \tag{2}$$

This transformation enables full reconstruction of the function $f(t) \in L^2(\Re)$ by means of an appropriately defined reverse transformation.
As the result of a and b parameter discretization we obtain a discrete counterpart of equation (1)

$$\psi_{mn}(t) = a_0^{\left(-\frac{m}{2}\right)} \psi\left(a_0^{-m} t - n b_0\right)_{(m,n) \in Z^2}. \tag{3}$$

Choosing particularly $a_0 = 2$ i $b_0 = 1$ (Z is natural number) we obtain the dyadic orthonormal wavelet basis of the $L^2(\Re)$ space

$$\psi_{mn}(t) = 2^{\left(-\frac{m}{2}\right)} \psi\left(2^{-m} t - n\right)_{(m,n) \in Z^2} = 2^{\left(-\frac{m}{2}\right)} \psi\left(2^{-m}\left(t - 2^m n\right)\right), \tag{4}$$

It means that for a fixed value of m scale is equal to 2^m (a change value of m by adding 1 is adequate to double scale). Distinguishing $\psi_{m0}(t)$ as a basic wavelet for the fixed level of scale m the final formula is obtaine

$$\psi_{mn} = \psi_{m0}\left(t - 2^m n\right), \tag{5}$$

taking step 2^m which is used to shift the basic wavelet in time for scale level m. Discrete wavelet analysis of the signal $f(t)$ is based on determination of its discrete wavelet transforms being the scalar product [9] of a signal f and function $\psi_{mn} = \psi_{m0}\left(t - 2^m n\right)$

$$d_m[n] = \left(f, \psi_{mn}\right), \tag{6}$$

representing common features of the analyzed signal and the series of functions ψ_{mn}. The discrete inverse wavelet transform is defined by the equation

$$f(t) = \sum_{m,n} \left(f, \psi_{mn}\right) \psi_{mn} = \sum_{m} \sum_{n} d_m[n] \psi_{mn}. \tag{7}$$

2.2. Multiresolution signal representation

For the defined value of m the equation (7) can be written as

$$f = \sum_{m=-\infty}^{J} P_{W_m} f + \sum_{m=J+1}^{\infty} P_{W_m} f = \sum_{m=-\infty}^{J} P_{W_m} f + P_{V_J} f, \tag{8}$$

where $P_{W_m} f$ denotes the orthogonal projection of the signal f into subspace $W_m \subset L^2(\Re)$ and every subspace $V_{j+1} \subset L^2(\Re)$ is an orthonormal enclosure of $W_{j+1} \subset L^2(\Re)$ in the space V_j. Defining the set $\{\varphi(t-n); n \in Z\}$ being the orthonormal basis in V_0 (scaling function), the orthonormal dyadic basis is defined

$$\psi_{jn} = 2^{-j/2}\left(2^{-j}t - n\right), \quad n \in Z , \tag{9}$$

what enables to write the equation (8) as

$$f(t) = \sum_{j=-\infty}^{J}\sum_{n\in Z} d_j[n] + \sum_{n\in Z} a_J[n]\varphi_{Jn} , \tag{10}$$

where $a_J[n] = (f, \varphi_{Jn})$. Formula (10) is a multiresolution representation of the signal f, which gives an opportunity to generate various approximations of the signal and enables choosing coefficients which can be or have to be omitted.

One of possible realizations of such representation is the Mallat algorithm [9] realizing discrete wavelet decomposition of the signal using filter banks (highpass and lowpass filters). As a result of each iteration, the high-frequency term D_j (detail term) and low-frequency A_j (approximation) of the investigated signal S are determined. A graphical interpretation of such decomposition is shown in Fig.1. At every j-th level of algorithm, full information about the signal is included in the set of all details and approximation of the j-th level of resolution [10].

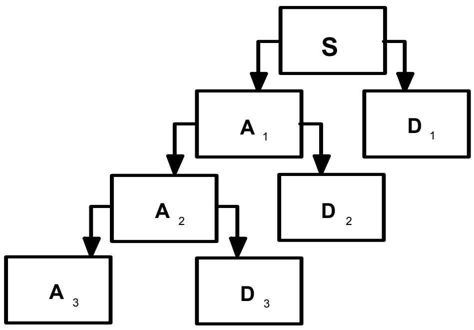

Fig.1 An exemplary wavelet decomposition tree for level j=3.

3. Calculation procedures

3.1.Methods of diagnosis

The concept of fault detection using the multiresolution signal decomposition described above is based, like for CWT analysis, on the comparison of chosen features of the transient response (supply current, load current, input current) of a faulty circuit with the transient response of golden one (nonfaulty). Multiresolution waveform transformation gives much greater possibilities of choosing specific features of the damage. Time - variable supply current is being analyzed as a response to a step change of the supply voltage, or properly selected input signal. Application of a filter system (Mallat algorithm [9],[10]), associated with appropriate basic waveform divides the supply current on range of components. Operation of division we make for time variable supply current of the tested device (FA_j, FD_j) and model device (GA_j, GD_j). Additionally, in a similar way, the supply current of circuit with tolerance unsettled parameters of components (the worst example is tested) is divided (TA_j, TD_j). Measure of difference between discrete time functions following from multiresolution wavelet decomposition are calculated from the formulas

$$k_{Aj} = \frac{\sqrt{\frac{1}{M}\sum_{i=1}^{M}\left(A\hat{F}_j[i] - A\hat{G}_j[i]\right)^2}}{\sqrt{\frac{1}{M}\sum_{i=1}^{M}\left(A\hat{T}_j[i] - A\hat{G}_j[i]\right)^2}}, \quad k_{Dj} = \frac{\sqrt{\frac{1}{M}\sum_{i=1}^{M}\left(D\hat{F}_j[i] - D\hat{G}_j[i]\right)^2}}{\sqrt{\frac{1}{M}\sum_{i=1}^{M}\left(D\hat{T}_j[i] - D\hat{G}_j[i]\right)^2}}, \tag{11}$$

where M denotes the number of signal samples and j stands for the level of signal decomposition. By analyzing many real circuits, the assumption was made that if only one coefficient k_{Aj} , $j=1...J$, is greater than one, then the circuit is treated as damaged. However, if all coefficients k_{Aj} ($j=1...J$), and almost all coefficients k_{Dj} ($j=1...J$) are smaller than one, then the circuit is undamaged (for some constituents, small transgression of the value of one is allowed, J is assumed to be the maximal resolution level of the signal decomposition process).

A trial study of application of the high resolution analysis for identification of false components was made. Before tests, we identify the ranges of changes of different components of supply current of faulty circuit, for all tested components. These ranges of changes result from tolerance of parameters. Especially, we are looking for such which stay separate (in part of run though) for different components. During the test we determine appropriate components of ICC current of damaged circuit and check in which area they are fully located. The type of this area identifies the damaged component.

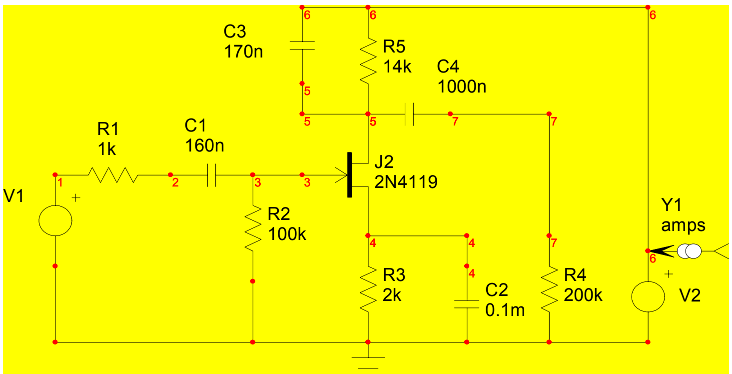

Fig.2 Diagram of the circuit under test

3.2. Calculation example

We made an analysis of the supply current for many different analog circuits. An exemplary circuit submitted to damage tests is presented in Fig.2. Response of the supply current for a step change of input voltage Vcc from 24V to 1V was analyzed. Detection coefficients of the damage, calculated according to formula (11), are given in Tables 1 and 2.

At the first stage of analysis, using the suggested method of detection of a catastrophic fault, copmponents: R1, R2, R3, C2, R4, R5 and C6 were checked. Detection of catastrophic short capacitors C3 and C4 needed additional test with step input signal. Both damages were detected.

The experiments showed that application of information given in multi-distributive approximation of supply current of the circuits under test for localization of the fault, taking tolerance into account, is not easy. The described procedure allowed to identify faults in some components of circuits under test. Numerical experiments showed that for most of circuits we can choose such damages which can be localized by comparison of a circuits under test ICC component (most frequently approximation) with the range of the same component of faulty circuit supply current calculated, taking the tolerance of the components into account. An example of unquestionable localization of shorted resistor R2 in the circuit shown in Fig. 2 is given in Fig. 3.

Table 1. Detection coefficients for short components R1, R2, R3 (or C2), R4.

j	R1		R2		R3,C2		R4	
	k_{Aj}	k_{Dj}	k_{Aj}	k_{Dj}	k_{Aj}	k_{Dj}	k_{Aj} (*1e7)	k_{Dj} (*1e9)
1	9.8706	46.7310	3.2403	0.0954	3.2403	0.0954	5.9902	3.4922
2	9.8125	44.4552	3.2413	0.2667	3.2413	0.2667	4.3716	1.4918
3	9.7757	32.3417	3.2415	0.9667	3.2415	0.9667	3.1777	1.1356
4	9.6831	33.8739	3.2357	9.2756	3.2357	9.2756	2.1875	0.8880
5	9.6520	21.7973	3.2105	8.4385	3.2105	8.4385	2.0299	0.3984
6	9.5044	13.9562	3.2151	4.6122	3.2151	4.6122	1.7952	0.1475
7	11.2094	11.3238	3.2685	3.0342	3.2685	3.0342	1.9815	0.0962
8	12.9274	8.8199	2.9674	6.6561	2.9674	6.6561	2.6464	0.0991
9	13.8026	10.1286	2.8975	6.0837	2.8975	6.0837	3.1314	0.1157
10	14.3913	8.1570	2.8116	6.5622	2.8116	6.5622	3.4252	0.0937
11	14.7976	7.9291	2.7417	6.6675	2.7417	6.6675	3.6468	0.0931
12	15.0950	7.7951	2.6865	6.9038	2.6865	6.9038	3.8129	0.0915

Table 2 Detection coefficients for short components R5 (or C3), C1, C4.

j	R5,C3		C1		C4	
	k_{Aj}	k_{Dj}	k_{Aj} (*1e-4)	k_{Dj} (*1e-4)	k_{Aj}	k_{Dj}
1	8.0213	0.2062	0.1528	0.8067	0.5977	0.0393
2	8.0239	0.7505	0.1528	0.5503	0.5980	0.1406
3	8.0260	2.9515	0.1523	0.4739	0.5974	0.3508
4	8.0240	11.5850	0.1518	0.4059	0.5964	1.5899
5	8.0258	6.2323	0.1544	0.2748	0.5990	1.4120
6	8.0214	8.0862	0.1517	0.0971	0.6004	1.2129
7	7.6606	12.1614	0.1765	0.1839	0.6114	0.5657
8	7.1727	13.2281	0.1627	0.3731	0.5434	1.3509
9	7.0176	12.9666	0.1664	0.3409	0.5262	1.2045
10	6.8494	13.7699	0.1632	0.3716	0.5074	1.2947
11	6.7197	13.9367	0.1594	0.3782	0.4927	1.3122
12	6.6212	14.1512	0.1561	0.4065	0.4813	1.3547

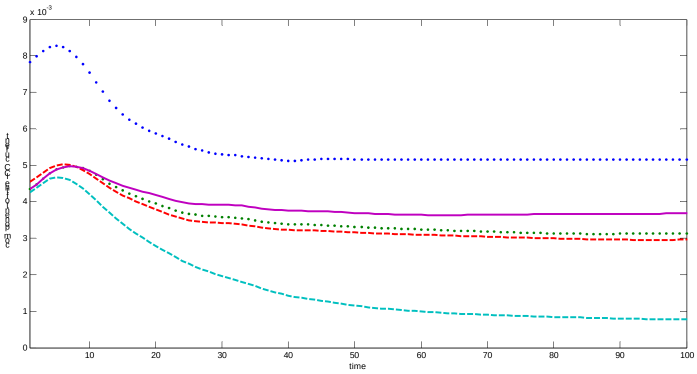

Fig. 3. Illustration of the defect localization process. Dotted lines denote the range of change of coarse component (A_3) of supplying current, at shorted R2 , caused by considered tolerance, the continuous line (second from top) – change of component A_3 of supplynig current with shorted R2, the dashed lines (bottom) denote the range of changes of component A_3, at shorted R5, caused by the considered tolerance of components.

4. Conclusions

Multi-distributive approximation of supply current with the use of the discrete wavelet transform appeared to be an efficient and comfortable tool in detection of catastrophic defects. The described conception does not require access to inside nodes of the circuits, also does not require complicated software, as it may be based on standard accessable procedures, project programme (ICAP4) and mathematical calculation (Matlab). It also seems much more effective than suggested the method suggested in [7] using genetic optimization of constant wavelet transform.

Defect localization procedures shown in the paper proved correct only for part of copmponents and require further study. Nevertheless, basing on trials done, the authors are convinced of the possibility of identification of all faults, considering additional comparable factors.

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