DECOUPLING DEVICES

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1 INTRODUCTION

What is POWERFIL that is a product of KRFM? What is great about it? What are they used for?

Before answering the questions above, we would like to bring up these questions:

1. POWERFIL is developed with different view of common sense from the existing usage of passive parts.
2. The power source distribution design of old digital circuits, which has been developed by Electric Circuit Theory of Lumped Elements System, must be improved.

And would like to explain again the terms (words) somehow used until now in this explanation.

2 DECOUPLING DEVICE

KRFM started to use the term DECOUPLING DEVICE for the first time in Japan, when some digital designers began voicing out the necessity to extend the frequency band of EMI (Electro-Magnetic Interference) countermeasure above to 1GHz situation.

KRFM is a company that designs and develops RF & MICROWAVE HYBRID ICs, established by RF engineers. At that time, we were developing micro miniaturized D.C. (Direct Current) CHOOSE COIL, which was made of new idea used in D.C. BIAS unit of RF HYBRID ICs.

We thought that this CHOOSE COIL will certainly be useful for EMI / EMC (Electro Magnetic Compatibility) countermeasure that troubled the digital circuits designers. We firmly believe that in order to have them use, we want the name where effect is recognized. It was the word “DECOUPLING DEVICE”.

The specialty of analog technology designer is circuits design of RF & Microwave that handles wireless equipment. In contrast to that, the specialty of digital semiconductor circuits designers in order to make computers is the digital circuits logic.

Both put importance to different items in need for the electric circuits, thus they have developed independently separate unknown without each interacting deeply about the circuits.

The digital circuits designers noted whether the voltage of logic circuit is High or Low. They pay attention only to the voltage.

The digital circuits designers got concerned with EMI / EMC countermeasure because the device for high-speed switching operation reached the point to be in use. The fluctuation of ground voltage needed to move the digital semiconductor because it couldn't be settled within the permissible range.

The reason is because there was a need to use lots of devices for high-speed switching into digital system.

These digital circuits designers came to pay attention why electromagnetism occurs when the clock signals of the computers exceeded 1GHz. The previous digital designers were not paying attention to wire distribution of D.C. power that provides energy needed for semiconductors to work.

Fig. 1 All Circuit equipments are connected parallel with the power source.

In contrary to this, it became common that the designers of Audio and Microwave circuits paid attention to impedance and electric field while designing. Electrolytic structure and the material of the track were taken into consideration for the simulation and repeated experiments of electromagnetism wherein trial and error designs were naturally performed.

However, a digital circuit and an analog circuit have come to intermingle over the board. For example, a cellular phone has digital and analog dwelling together. It has become such a world. Therefore, even if digital and analog designers believe their designs are perfect, still troubles occur. Those concerned in digital and analog should know each other's fields well. This is where Decoupling Device is needed.

We call our "POWERFIL" as "DECOUPLING DEVICE". Then, what is Decoupling Device?

To explain the functions concretely: It is an electronic circuits part (device), which prevents electromagnetic wave (harmonics) from entering and passing out the Alternating Current (Radio Frequency) domain instead of D.C. for each and every several electronic circuits (devices) passing through the Power Source Circuits (lines).

It is a fact that people may have thought that they are similar with "Decoupling Capacitors".
Fig. 2  Bypass Capacitor (decoupling capacitor) used for semiconductors. It was commonly used for long time amongst the audio amplifiers and analog circuits designers. It is said, “It puts capacitor between the bias circuits that supplies a power and GND (ground) and filtered so that the combination of high frequency signal (loop) cannot be performed”. It crosses over the interstage and does not remain at single amplifier stage.

What or how is it differing from decoupling capacitor?

We think as stated below:

1. It is difficult to actualize decoupling to several 10 GHz by just combining capacitors.
2. It has the function for electromagnetic noise countermeasure and adopted the three-dimensional distributed elements system circuit theory added to the old Lumped Elements System Theory.
3. To actualize the multipurpose D.C. power source isolation, which are to be used for different kinds of digital electric equipments.

We had named it Decoupling Device to these parts, which have all of the above functions.

3 ISOLATION TECHNOLOGY

Specifically “what” and “what” are not combined in “Decoupling”, so that electronic and electromagnetic combination does not happen? Two or more integrate D.C. circuits (ICs) on the narrow range (Printed Circuits Board), for example, an electronic circuit board, do not carry out electromagnetic “combination” in RF field other than direct current via a power source track. How could this be explained?

As shown in Fig. 1, all the ICs are hanging down, like the ladder thrown over the power source of plus and minus tracks. We can say that they are electrically connected to each other. At this time, they are connected by direct level; and to disconnect at the exchange level means “isolation”. “Decoupling Device” is the functional part in order to achieve this isolation. When talking about Decoupling Device, what comes up is Decoupling Capacitor.

Fig. 3 Is the ideal broadband decoupling capacitor really working?

Fig. 2 shows as combined, detours (bypass) only exchange signals and it only allows passage direct current ingredient into C. It is also called bypass capacitor. Does it really conveniently bypass the exchange signals?

Fig. 3 is a formal plot when using several capacitors. But the ideal state, which is the non-existence of resistance or inductance, does not exist in the line, which from the power source line extends to IC side.

In addition, the “electromagnetic noise” that is called exchange ingredients and harmonics ingredients, enters into power supply side or gets out form IC side differs in thinking of bypass. When one thinks of bypass of electromagnetic noise high-speed digital signals, one question, up to what frequency range to do isolation? This is another big problem.

Rectangular wave that is digital signal waveform has to have base clock frequency 5 -10 times that of harmonics wave ingredient in order to transmit correctly.

2GHz-4GHz electromagnetic noises occurs in IC that operates at 400MHz, therefore bypass range must cross more than 4GHz regions to bypass. This is tremendous frequency. If decoupling capacitor used in audio amplifier is seen, you have to call it extremely high frequency. Even though LTCC (Low Temperature Co-fired Ceramic) technology, a miniaturization technology that Japan leads, is used to assemble the multiplayer ceramic capacitor, this
frequency region is difficult to achieve.

4 DECOUPLING CAPACITOR

When considering decoupling using the passive elements, the greatest reason why the recent semiconductors are becoming difficult in expanding to about 4GHz, is because there are almost no discrete passive parts. In deciding the calculated value of decoupling capacitor made to bypass, there were many who calculated by saying alternating current impedance should be lowered with formula:

\[ Z_0 = \frac{1}{\omega \cdot C} \quad (\omega = 2\pi f) \]

But for example, it is easy to calculate 1GHz signal of decoupling of 1GHz. There are not much capacitor that would remain as 100pF against the frequency of 1GHz.

There is no ideal capacitor, which continues to rise from direct level high frequency of 1GHz by 100pF but if used for decoupling alternating current wave the expression is simple.

Here is the trap in expression of Lumped Elements System. A commercial capacitor is not an ideal capacitor, the characteristic changes according to frequency. It cannot get same capacity value in any frequency. And the inductance capacitor contents become more remarkable in frequency band beyond the resonating point.

There is a decoupling capacitor that is often seen as bypass capacitor of digital circuits and many of which is arranged to use as shown in Fig 3 form low frequency to high frequency. It is regrettable that from the point of decoupling, no flat bandwidth could be actualized.

Not only that, the more the capacitor are put in parallel with a power source, the more digital circuits designers have experienced that relevantly hot electromagnetic noise countermeasure called EMC countermeasure will backfire. Since the existing capacitor is not an ideal capacitor, its remains of inductance contents will cause L (Inductor), C (Capacitor) resonance of new frequency.

Electromagnetic noise countermeasure caused by decoupling capacitor, which depends on concentrated constant system formula, is like “mole striking”.

The electromagnetic countermeasure by decoupling capacitors is to calculate the frequency to be bypassed by Lumped Elements System Theory wherein signal occurs on the other part. And another signal will occur if capacitor is placed on other part to stop the signal. This will be continued and continued.

How will decoupling of broadband be possible? The answer is, no need of an exaggerated simulation, but proven by a simple experiment. Just put inductor into the series.

However, many designers of high-speed electronic circuits are opposed to this. They say that putting L (Inductor) into electronic circuit to semiconductor, consumed at high-speed may cause the ground bounce; this high frequency noise increases instead.

5 GROUND BOUNCE

Those who designs the circuit may know very well why ground bounce occurs, as shown in Fig 5 what comes in mind first is common impedance combination.

As if to attach, it is mentioned that high-accumulated semiconductor is CMOS (Complimentary Metal Oxide Semiconductor).

CMOS circuit hardly flows electronic current when the incoming signal has no change, but when signal changes there will be lot of flows. The potential of bounce becomes as the lead wire becomes bigger. Naturally, it is integrated and put in big package; the inside lead wire is long and straight and the
internal lead wire also becomes long and stays hanging. Out of this experience, the designers who handles the inductance of high-speed an digital circuits, are hesitant to use inductor of semiconductor broadband decoupling device.

Since the ground bounce is a common mode noise, decoupling capacitor is said a measure for reduction of ground bounce. Actually, when capacitor bypasses, it softens the voltage decent of active element (such as IC). Even though how effective the mounting may be with the distance shortened and near ideal, this reason is not realized in clock frequency that has digital circuits exceeding GHz.

![Diagram](image)

\[ V_1 = (i_1 + i_2 + i_s) Z_1 \]
\[ V_2 = (i_1 + i_2 + i_s) Z_1 + (i_1 + i_s) Z_2 \]
\[ V_5 = (i_1 + i_2 + i_s) Z_1 + (i_1 + i_s) Z_2 + i_s Z_3 \]

**Fig.5** Change in voltage happens with same reason to the plus side. It is called VccSag and distinguished from Ground Bounce.

It is correct to that bypass capacitor is effective only to a specific band; unless the ideal ground and power source are brought in, decoupling can be done of combination of common impedance. It is a mistake to demand a measure like a black magic. Then, we can search for the due to what kind of minus problem there are.

Elimination of the ground bounce and decoupling of power source have different purpose. Bypass capacitor that prevents ground bounce is a measure to erase the incorrect operation of digital circuits acting on low frequency. On the other hand, decoupling device is a measure for power source isolation. And these two have trade off relationship. If many capacitors are used in order to eliminate ground bounce, many noise countermeasure engineers have experienced that phenomenon that electromagnetic noise increase on the contrary.

### 6 Electromagnetic Noise Countermeasure Technology

From this point, would like to focus on electromagnetic noise countermeasure, which is one of the feature effects of Decoupling Device.

Historically, in the beginning, electromagnetic noise abundantly forcing the filtering part where countermeasure of the digital signal transmission lines the passive device L (Inductor), C (Capacitor), R (Resistor), the majority of the signal in the transmission line which electric current was done, the EMI countermeasure for filtering was the main.

The EMI issue was not expanded to GHz band during the stage when clock speed of digital signal was slow thinking that it was not necessary. It is known that this method had delayed the rise time of square wave signal and shaved off important frequency components because filter was directly inserted to the transmission line.

Because of this, recently, ferrite beads came to be used frequently because it was thought that impedance increases when signal band exceeds and resistance value is zero. But this ferrite beads has no effect to the signals exceeding several 100MHz because it does not consist of only pure resistance.

The more the digital signal GHz band becomes high-speed, the more it becomes impossible to arrange the parts in the transmission waves. It is a fact that the transmission line is made short as possible in order to make and transmission line design is simulated in order to avoid miss match of impedance which may cause the signals from spreading out.

**1. No Such An Ideal Capacitor**

The high the frequency increases the more it loses its' ideal isolation because capacitors have remained Inductance equivalent series (ESL).

\[ f_c = \frac{1}{2\pi \sqrt{ESL \cdot C}} \]

Resonance's happens, and the characteristics of isolation is greatly made to deteriorate by the oppression of remaining inductance which went into the shunt and as indicated in Fig 4 represented by multilayer ceramic capacitor becomes a V shaped frequency characteristics.

**2. No Such An Ideal Inductor**
To achieve an ideal filtration as frequency rises is same with inductors and capacitors but with the influence of parasitic capacity ($C_0$)

$$f_L = \frac{1}{2\pi \sqrt{L \cdot C_0}}$$

resonance's happens and indicates immediate wedged shaped resonance frequency characteristics than the capacitor.

**Fig.6** Filtering Frequency Characteristic Comparison of COILFIL bandwidth A vs Chip Inductor bandwidth B

3. **L C Filter**

As per above reason, L, C has insufficient pass band quality. In order to actualize the filtering of GHz band, these are to be combined to multiple stages. But the numbers of L, C elements increase as the electromagnet noise countermeasure RF circuit use he mainstream because as a single unit from only several GHz is available. The power source element of digital semiconductor being mounted abundantly SMT parts for the purpose of wideband decoupling are not found.

4. **Common Mode Choke**

Common Mode Choke Coil strengthens the current and it creates magnetic field for the differential mode current by mutually negating magnetic flux. It has been widely used to suppress common mode noise. Choke coils are bulky and are used only up to several 100MHz where ferite effect is eliminated. Therefore, it is too narrow band to be used as decoupling device. However, its electromagnetic theory leads to explanation of COILFIL that follows.

The base for digital circuits is on the switching movement. Therefore those high-speed integrated circuits are said to be combined of complex switching circuits. For this reason, during the condition when LSI logic switches simultaneously, it is known that bouncing has occurred in the LSI. This electromagnetic noise is called SSN (Simultaneous Switching Noise). Till now, it was thought that electromagnetic noise countermeasure could not be done without stopping those.

However, the electromagnetic and harmonic waves have both exceeded 1GHz and about to be 10GHz for super broadband. Is not that time has come to change our way of looking at conventional passive elements filtering? This is another reason why the term decoupling device is being used.

**Fig.7** Single and Series Connection of Wounded Coil

7 **WIDEBAND DECOUPLING DEVICE**

Ever since established, KRFM being a team, had been handling development of wideband decoupling devices for D.C. Power Source Isolation Technology.

Our basic circuits is structured with the combinations with the passive elements of inductors and capacitors, but it is designed with the Distributed Elements System Theory Circuit and those passive elements being used are developed with our new thoughts. It is different from conventional discrete passive elements.

1. **COILFIL**

An isolation characteristic of conventional inductors, multilayer type and wounded type, as shown in Fig.6 and Fig.8, indicates wedged type spike shaped. Whereas, inductors, which we have developed, so
called "COILFIL" has NO spikes. Frequency characteristics form is the opened U shaped. The filtering band frequency is spreading wideband as indicated in A of Fig.6. And it has the useful point, which couldn't be realized in other inductors.

Fig.8-1 Conventional 33nH Air Core Coil
Fig.8-2 Multiplayer 10nH Chip Inductor

Fig.8-3 Measured in series, Air Core Coil and Multilayer Chip Inductor (0603 size).

Declined characteristics can be increased when two COILFILs with same inductance value is mounted near and when they are converted with series on parallel line. Isolations spread out in broadband for series connections that indication value is different.

Fig.7 shows that even if conventional inductors crossed in series, the declined characteristic doesn’t significantly improve. Malfunctioning of magnetism and resonance point will transfer to low frequency if wounded type will be mounted to circuit board by connecting.

2. POWERFIL

Usually, conventional inductors when inductors for low and high frequency connected parallel, spike shaped characteristic only piles up with it. Fig.8-3 shows the frequency band characteristic when two are mounted in series to DUT (Device Under Test) Fig.9-3 indicates the Isolation Characteristics when KF1 COILFIL (0603 size) of Fig 9-1 and KF2 COILFIL (0805 size) on Fig 9-1 is mounted on DUT with same condition.

Fig.9-1 KF2 type COILFIL
Fig.9-2 KF1 type COILFIL
Fig.93 Series connection of KF1 and KF2 COILFIL
Fig. 91 KF2 COILFIL (0805 size) Fig.9-2 in DUT of the same condition drawn in series when mounting. It is understood that there is no spike shaped resonance and becomes a gentle broadband.

We had been able to continue this development of Decoupling Device “POWERFIL” through the subsidy from TAO (Telecommunication Association Organization), sector of Ministry of Public Management, Home Affairs, Posts and Telecommunications. With this was able to actualize the form 4.4 mm(W) × 4.4 mm(L) × 2.5mm(H), maximum band of 30 kHz × 12.5 GHz( at -20dB).
This was not possible when COILFIL was connected in arrangement.

Power source using designs of Digital Semiconductors which are carried out as Large Scale Integration by active semiconductors high-speed, should be designed as Distributed Elements System Theory as various views other than this process.

Therefore, we have the solution for immediate use,

1. It realizes the decoupling of broadband by the combination of parts that makes up IC.
2. Parts attached to outside of package
3. Parts put into a power supply (bias) circuit.

The introduction of “COILFIL” and “POWERFIL” now, are still a transitional product as DECOUPLING DEVICES.

Since our US patent (Pat 6,504,464) was issued, and with the assist of JETRO (Japan External Trade Organization) we had established locations here in the US in order to penetrate our technology as well as continue further research and development together with American engineers.

Ultimately, we foresee an opportunity for our company to grow as productivity increase, however, at this early stage, where we are introducing our name and product, and with our limited resources, we would be more than open to invite any objections and at the same time searching for any companies who would like to collaborate for future research and development.

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