Featured Article #2

Source of Light for Backlighting

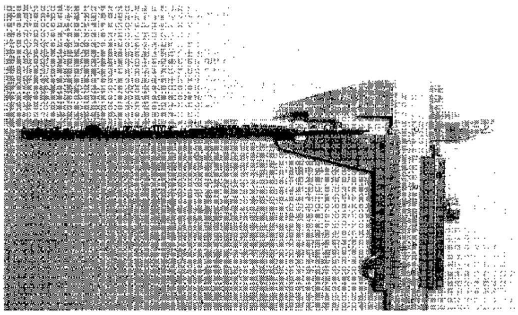
Latest Trend of Inverters for LCD Backlight and Synchronized Phase Coupling Transformer type Inverter

Technolium Co.,Ltd. **Masakazu Ushijima**※

1. Forward

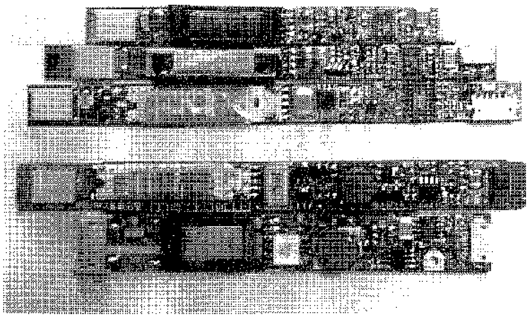
Inverters for CFL used for driving fluorescent lamp of LCD backlight need to be compact with high performance. There are mainly two types of inverters, one is coil type another is piezoelectric type.
Formerly piezoelectric type was focused as more compact, higher performance than coil type, nowadays because of invention of synchronized phase coupling transformer type inverters, the difference between coil type and piezoelectric type have been getting less in comparing their shape and performance. (**Pic.1**)
Additionally, there are other driving methods of excited type and resonance type (For short, we'll call it. New circuit method below) for synchronized phase coupling transformer type inverters.
Excited type originally and resonance type originally were invented as driving method for piezoelectric type. New circuit method uses those techniques for driving coil type synchronized phase coupling transformers, resulting in more compact, high-efficiency inverter of coil type instead of piezoelectric type.
Those excited and resonance types were formerly unpopular because of their complicated circuits. However, coil type inverters with new circuit method are becoming the main current as circuit being simplified by exclusive IC, and for its compactness and high performance.

※ Representative Director of Technolium Co.,Ltd.
〒 Zip Code 107-0062 401,6,2,6 Minami-Aoyama Minato Ku, Tokyo
☎ Tel +81-3-5468-7671



Pic.1 A coil type synchronized phase coupling inverter thinner than connector part.

Inverters of new circuit method don't use choke coil which used to be indispensable. Former circuit method was called collector resonance type, in this circuit the choke coil was vital to generate waveform for primary winding of transformer.
On the other hand, new circuit method eliminates choke coils by utilizing magnetic flux leakage, making the size of inverter more compact.
By the way, the synchronized phase coupling transformer used for it is the transformer of which magnetic flux leakage is strong, secures the coupling of windings with a theory which differs from former close coupling transformers. (The detailed description about a synchronized phase coupling transformer is mentioned at Sec.3.)



Pic.2 Conventional Inverters (below) and New Circuit Method Inverters (above)

2. Collector Resonance Type Inverter and New Circuit Method

2.1 Examples of conventional circuit method (Collector Resonance Type) and New circuit method (Excited/resonance Type)

Pic.2 shows difference between conventional inverters (below) and new circuit type inverters without choke coil (above).To compare with the same power output inverters of two types each other, new circuit type having no choke coil is more compact in shape than piezoelectric type.

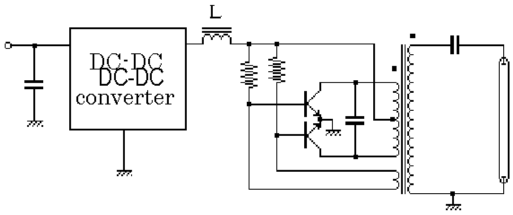


Fig.1 Typical collector resonance type circuit

Collector resonance type is composed by DC-DC converter as primary section and collector resonance type inverter as a secondary section, a sort of two inverter circuit combination.
Therefore conventional collector resonance type inverter converts electric power twice, causing inevitable power loss during conversion.
To the contrary, new circuit method such as an excited type and a resonance type uses mono-inverter structure, with superior features of less power loss as well as simple circuit structure (**Fig.2** ,**Fig.3**).

2.2 Operation theory of an excited type and a resonance type driving method

Those new circuit method inverters such as

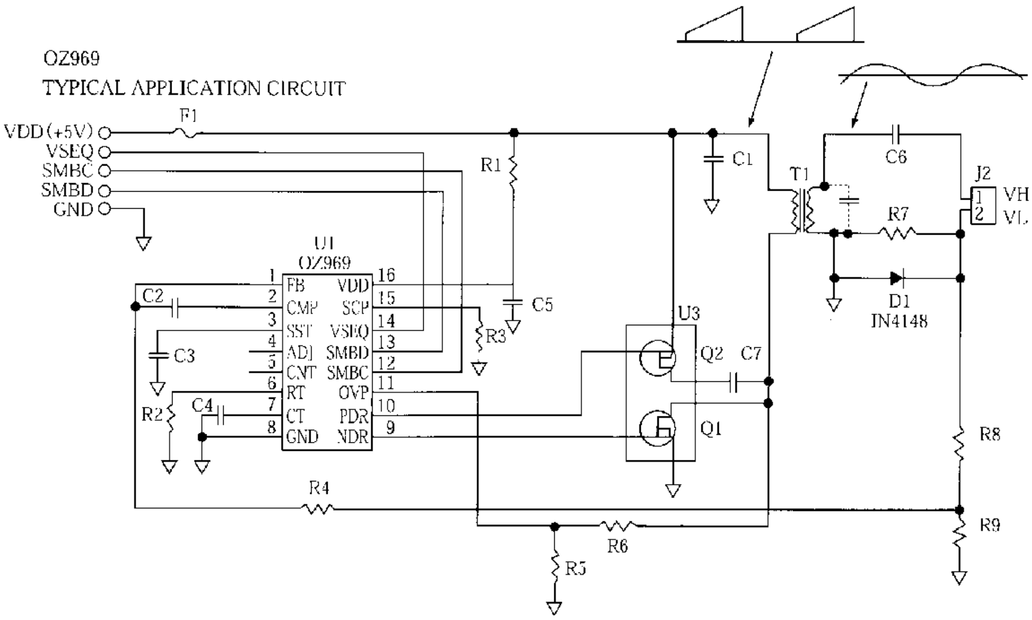


Fig.2 An example of excited type circuit (O_2Micro)

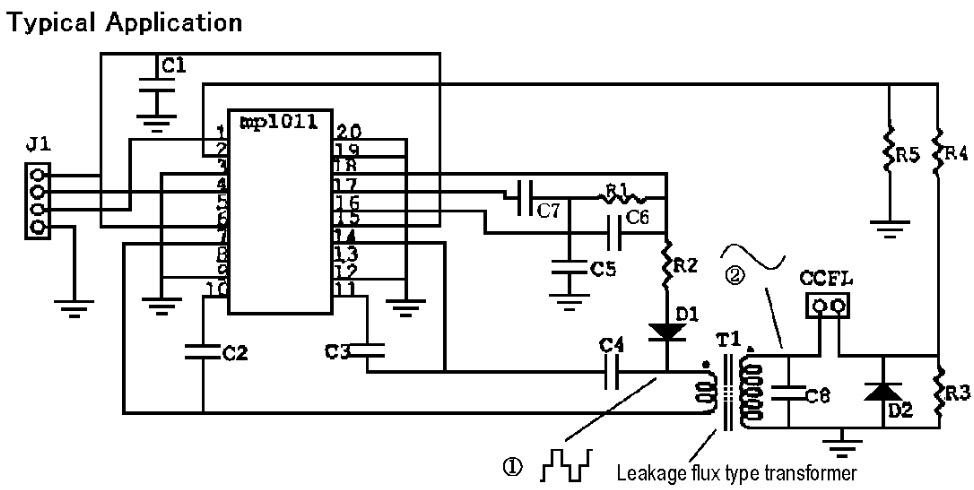


Fig.3 An example of resonance type circuit (MPS)

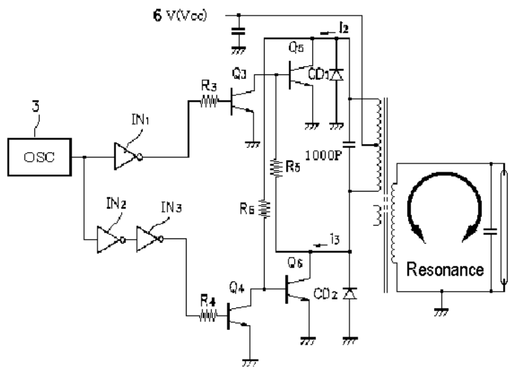


Fig.4 Dual stabilizing snubber circuit

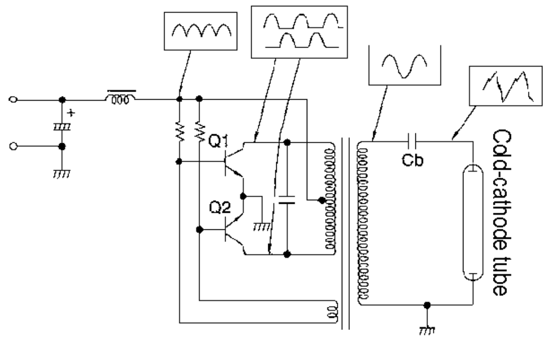


Fig.5 Voltage waves of collector resonance type circuit

excited type and resonance type illustrated as **Fig.4**, feature a resonance circuit at the secondary winding of a transformer.[3)]
This resonance circuit is composed by leakage inductance generated on the secondary winding of synchronized phase coupling transformer and parasitic capacitance (including auxiliary capacitance) by a transformer coil and a LCD back-light.
Therefore, leakage inductance of transformers and parasitic capacitance of a LCD back-light are important parameters for new circuit method.
Fig.5 shows various voltage waves for each part of a conventional collector resonance type circuit. A choke coil supplying sinusoidal waveform input at the primary winding of transformer is vital for a collector resonance type circuit.

To the contrary, on observing voltage waves and current waves at each part of a new type circuit (**Fig.2**,**-3**,**-4**), we find pulse waveform input voltage on the primary winding of transformer is converted into sinusoidal waveform output voltage.
As **Fig.4** shows, an excited type has an oscillating circuit in driving circuit on the primary winding, and its driving frequency is

Table.1 ICs available for new circuit type

O_2 Micro	OZ962, OZ965, OZ969
MPS	MP1010, MP1011
LINFINITY	LX1686
三菱	M62295GP

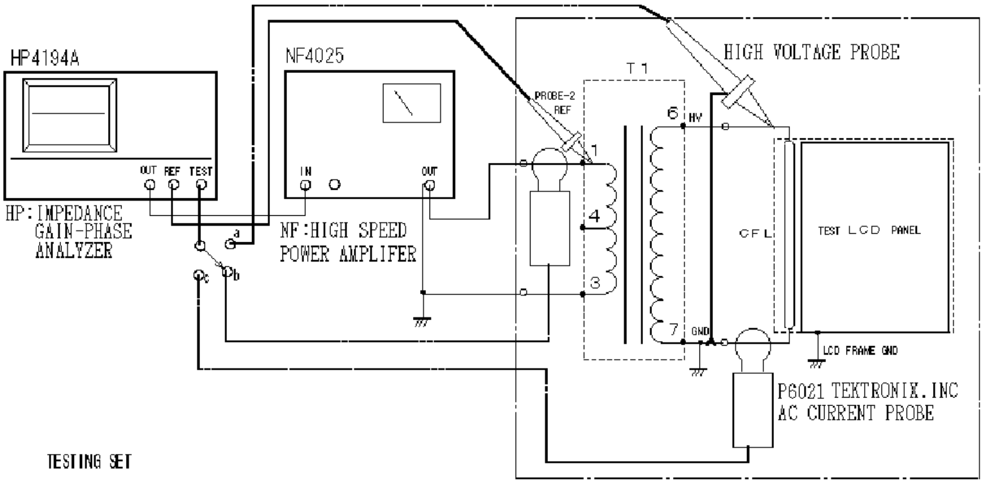


Fig.6 Secondary side resonance point tester

fixed by frequency. In the example shown in **Fig.2**, C4 and R2 define oscillating frequency of driving circuit.

In order to calculate optimum driving frequency in this excited type, it is necessary to measure the resonance frequency at the secondary winding when the LCD backlight is working actually.

By examining GAIN-PHASE characteristic with the tester shown as Fig.6, resonance frequency on the secondary winding can be calculated.

An optimum driving frequency can be calculated easily with this tester, which can visualize the resonance caused by parasitic capacitance of the LCD backlight and leakage inductance at the secondary winding of a synchronized phase coupling transformer when the LCD backlight is working ,that used to be considered difficult to measure.

The transformer T1 used in **Fig.6** is the same transformer used in an excited type inverter circuit. The result of measuring values of the transformer is shown at **Fig.7**.

In the case of an excited type, it is important to calculate an accurate resonance point on the secondary winding and to drive the primary winding circuit with that frequency (In **Fig.7**, the value between core loss minimum point and copper loss minimum point). Mismatching resonance frequency between resonance frequency of the primary winding and between oscillating frequency of the secondary winding may cause bad conversion efficiency of the inverter.

Following is detailed discussion about this matter.

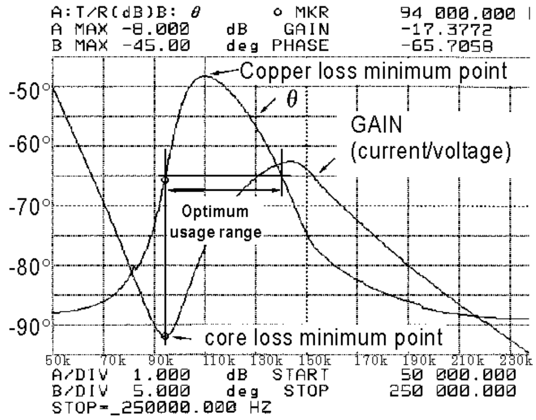


Fig.7 Primary winding side characteristic around resonance point at the secondary winding

2.2.1 Stimulating types have less copper-loss

In **Fig.7**, focusing on Phase characteristic gives **Fig.8**, focusing on GAIN characteristic gives **Fig.9**. **Fig.8** shows the phase of voltage and current given at the primary winding when the inverter is connected to LCD backlight, which is working actually.

It indicates the closer to 0 degree of phase difference between voltage and current, the less amount of loss current on the primary winding. Therefore, the peak of the Phase curve points

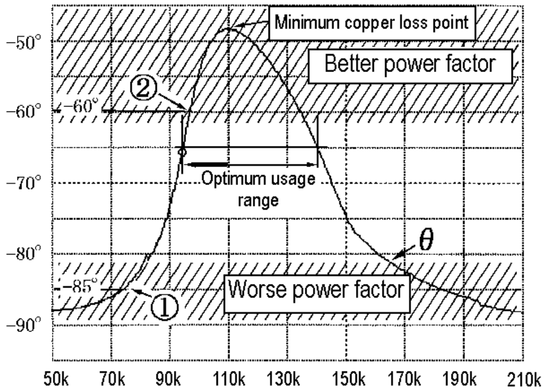


Fig.8 Current phase around the resonance point (from Fig.7)

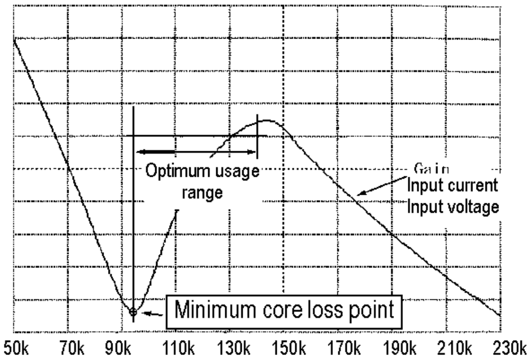


Fig.9 Minimum core loss point

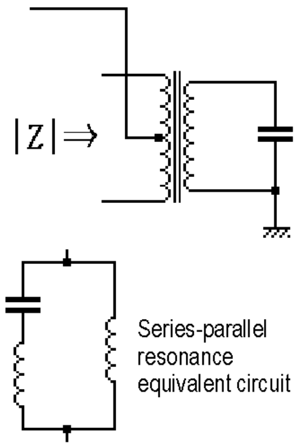


Fig.10 Equivalent circuit viewing from primary side

out the minimum current loss and minimum copper loss.

An actual calculation of current loss from power factor is as follows:

Power factor is indicated by COS θ .If the value is closer to 1, less current loss is occurred at the primary winding.

For example, to calculate the power factor at the frequency on the point in **Fig.8**, the result is;

COS-85° = 0.0872

This means only 8.7% of the primary winding current is used for supplying power to a cold-cathode tube of the backlight, and the rest of current is used for exciting the core of the transformer.

There is much primary current, as if it is used for heating up copper winding.

Next, a calculation for the power factor at the frequency of point gives;

COS -60° = 0.500

It means 50% of primary current of transformer is used for making backlight working.

2.2.2 Excited types also have less core loss

Now we consider the GAIN curve of **Fig.9**.

Current in comparing to input voltage at the prime winding.

The reason why the current is little on minimum core loss point is as follows:

When there is a resonance circuit on the secondary side, observing impedance of the

Secondary side around the resonance frequency from the primary side gives an equivalent circuit with series circuit and parallel circuit (**Fig.10**). At the parallel resonance point the impedance viewed from primary side increases much. Measuring the prime side impedance by attaching an auxiliary capacitance on the secondary side for adjusting resonance frequency gives the result shown in **Fig.11.**

Right-below is the impedance calculated from primary winding inductance as a comparison.

It shows the existence of resonance circuit on secondary side makes the impedance on primary winding increasing much.

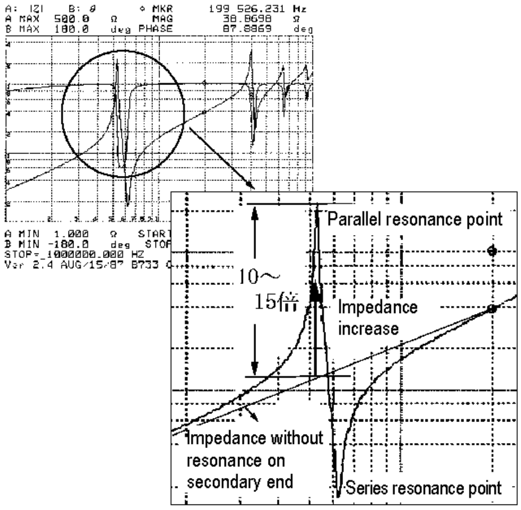


Fig.11 Impedance increase around resonance point

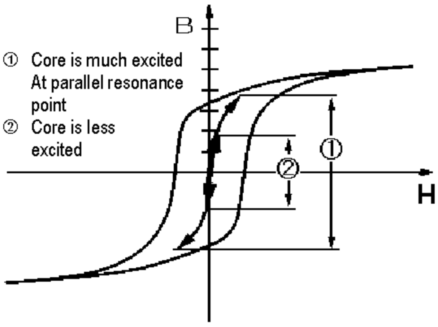


Fig.12 Excitation of a core

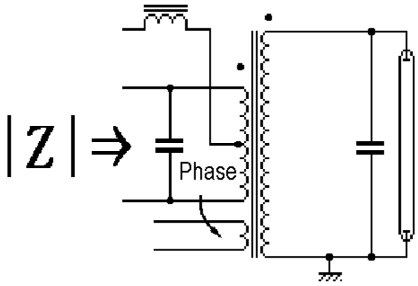


Fig.13 Two resonance circuits

This phenomenon used be considered as negative characteristic of transformers caused by flux leakage, has not been utilized before. This kind of changing impedance is most prominent for the synchronized phase coupling transformer, utilized positively.

The range of impedance change is much wide more than our expectation. **Fig.11** shows the actual impedance is 10~15 times as much as calculated value from impedance of primary winding. This is very important, means that the exciting current in the primary winding is remarkably decreasing at the parallel resonance point (**Fig.12**).

Therefore, extremely little excitation of the primary winding's core results in much decreasing core loss.

Excited driving type can select driving frequency arbitrarily. Thus driving frequency is pin-pointed so that heat generation of core and winding can be eliminated drastically, causing a leap in improvement of inverter's conversion efficiency.

On the other hand, for excited type, the fact that secondary resonance frequency is greatly affected by parasitic Not at parallel resonance point capacity of a LCD backlight which has not been standardized before, brings need of precise management of a LCD module inch size and various parasitic capacitance of products made by various manufacturers.

2.3 Driving with collector resonance circuit

By the way, can we use a collector resonance circuit for driving with an optimum frequency?

The answer is "No". The reason is as follows: **Fig.13**,**-14** shows Impedance characteristics of a transformer using collector resonance circuit viewed from the primary side. (Note:Frequency axis differs from **Fig.7** because of different samples.)

For a collector resonance circuit, impedance characteristics is complicated because of a resonance capaciter on primary side as well as a resonance circuit on secondary side made of transformer's leakage inductance and parasitic capacitance (**Fig.14**).

To define the resonance frequency of collector resonance circuit, the point of phase 0 degree in this fig. gives the oscillating frequency.

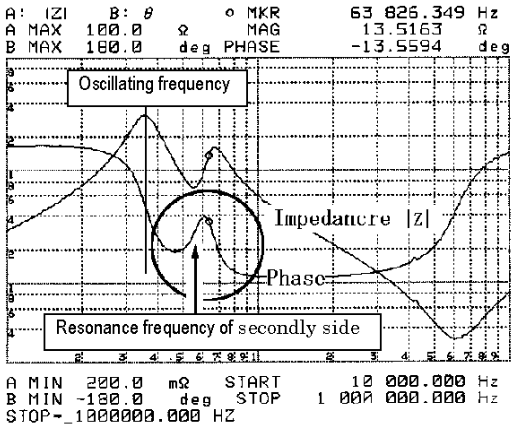


Fig.14 An example of impedance of collector resonance circuit viewed from primary side

On examining phases around this point, we found its form downward-sloping curve. On higher oscillating frequency for some reason, the phase returning to base winding will delay, causing a lower frequency. Reversely, on lower oscillating frequency for some reason, phase will fall forward, causing higher frequency.
In this way oscillating frequency of collector resonance circuit will try to stay at the 0 point of the phase.
Now we consider the possibility of oscillation with a secondary resonance frequency as calculated in **Fig.7**, by adjusting a resonance capacitance in collector resonance circuit.
To examine the phase characteristics around that point closely, finds upward-sloping curve like **Fig.15** .Suppose we had adjusted collector resonance capacitance so that we could just meet the frequency. If some cause makes oscillating frequency higher than that point, forwarding phase will make frequency higher. Reversely if some cause makes oscillating frequency lower

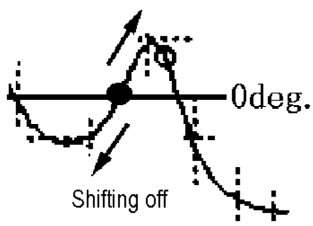


Fig.15 Phase characteristic around the resonance point

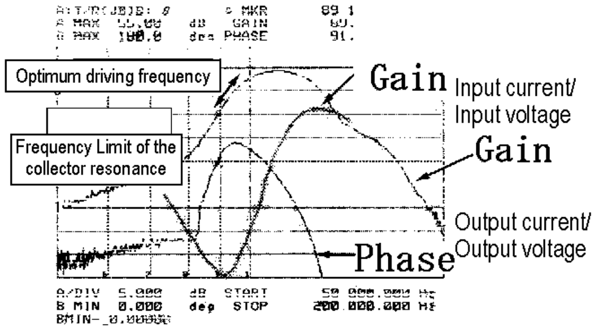


Fig.16 Input voltage and Tube current

than that point, backward phase will make frequency lower.
Those mechanisms shows the fatal problem of collector resonance circuit, that is; it's impossible to fix the circuit oscillation at the ideal frequency, oscillation will be performed only at some lower frequency or higher frequency. Therefore excited type is more handy for its forcing oscillating frequency pin-point at the ideal point of optimum efficiency.

2.4 Excited type can output much power

Fig.6 is the reference of cold-cathode tube current of LCD panel on the secondary side and input voltage at the primary winding, tested by the resonance point tester shown in **Fig.16**.
For reference, gain of input voltage and current are added to the same fig.
Fig.16 shows the mount of tube current to compare with transformer input voltage. At the optimum driving frequency, tube current is twice as much as collector resonance circuit against the same input voltage.
This proves that an excited type can gain power twice as much as a collector resonance type with using same type of transformers.

3. About Synchronized Phase Coupling Transformers

Next, we discuss the synchronized phase coupling transformer (**Pic.3**), which has made coil type inverters drastically compact.

Pic.3 Comparison of a synchronized phase coupling transformer and a conventional transformer (realized compactness less than one third by transformer ratio)

3.1 What is a Synchronized Phase Coupling Transformer?

"A Synchronized Phase coupling Transformer" might be an unfamiliar term, which was named by an technical official of MITI, when the intensive research, that was based on the new theory of transformer's operation found by our company in 1992, was made as MITI auxiliary research project in Heisei Year 8 (1996).[6)]
Through that research it was recognized that there had been a long-term-overlooked phenomenon about the combination theory which differs from the one for a closed flux path type, and it could be also applied for power conversion.
Furthermore, those inverters based on the new theory using this synchronized phase coupling transformers have obtained patents in various countries, and have been manufactured worldwide. [3)]

3.2 Operation theory of synchronized phase coupling transformer

Conventional transformers tried to increase coupling coefficient of the primary winding and the secondary winding by closing flux path.
However, there is another way to get high coupling coefficient, that is to have a capacitance load on the secondary side and a leakage inductance component generated from the secondary winding of the transformer which has strong flux leakage resonate.
This is called "Flux Inductive Effect", it means that an extremely strange-shaped transformer which has open flux path like **Fig.17** can also obtain the coupling coefficient as much as that of a closed flux path transformer.
Following is the explanation of theory why a synchronized phase coupling transformer can gain a practically useful coupling coefficient.

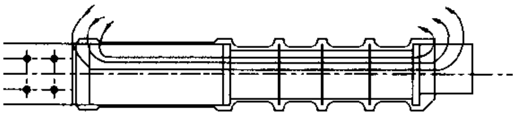


Fig.17 Drawing in Flux Effect

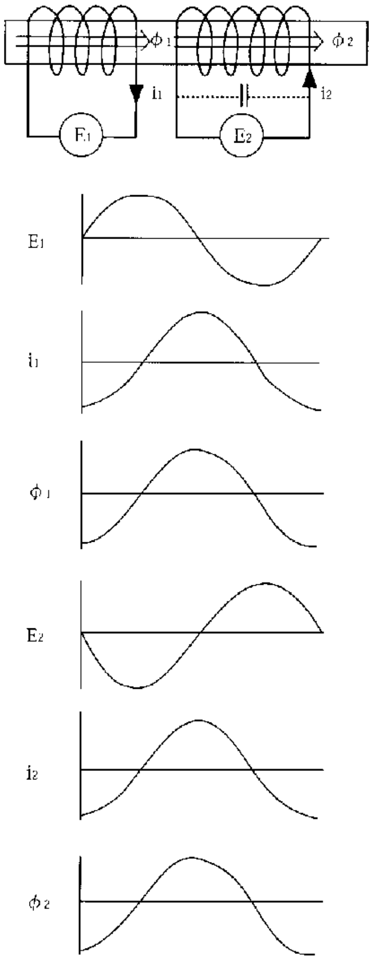


Fig.18 Magnetic Flux and Current Phase

① E1 is the voltage added at the primary winding of the synchronized phase coupling transformer; ϕ 1 is the flux generated right under the primary winding (**Fig.18**).
② Similarly, E2 is the induced voltage at the secondary winding and I2 is the current flowing into an connected load on secondary side. ϕ 2 is the flux generated right under the secondary winding by I2.

③ Because of the primary winding having inductive component, the phase of I1 is delayed 90° than that of E1.
④ The flux ϕ 1 generated by I1 is directly proportional to I1, thus the phase of ϕ 1 and I1 are identical.
⑤ The voltage E2 induced by ϕ 1 is delayed 90° than that of ϕ 1. Thus E1 and E2 have reversed phase with each other.
⑥ Herein the secondary winding has a capacitive component, I2 flowing in the secondary winding is advanced 90° in phase than E2.
⑦ Because the flux ϕ 2 generated by I2 have the same phase with each other, the phase of ϕ 2 also is advanced 90° than E2.
⑧ Thus we found the phase of ϕ 1 and that of ϕ 2 are identical. In this case it also means that the flux generated at the primary winding is totally induced into the secondary winding through the series of cores.
It is also important for improving the performance of a synchronized phase coupling transformer to have a consecutive core between the primary winding and the secondary winding, for the flux preferring passage through a core with higher μ to leakage through the gap between the primary winding and the secondary winding. As a result, the flux of the primary winding and the flux of the secondary winding become almost identical, that means the coupling coefficient between the primary winding and the secondary winding is extremely high.

In this way, the principle of the synchronized phase coupling transformer is that a high coupling coefficient is achieved by synchronization of the flux phase ϕ 1 of the primary winding and the flux phase ϕ 2 of the secondary winding (**Fig.19**).
To add some words, someone may consider the possibility of broken balance of synchronized phase when some resistant load is connected to the secondary winding. But it will not occur because the phase of current flowing in a capacitance is 90° different from that of current flowing in a resistance, which will not cause any interference.

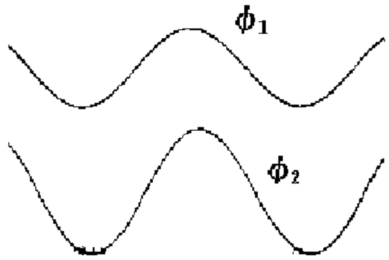
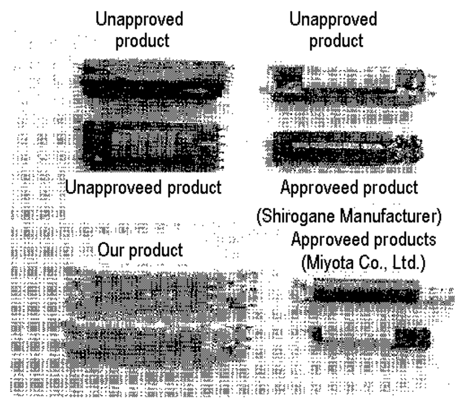


Fig.19 Synchronized ϕ 1, ϕ 2

Also, the excitation current needed for keeping a coupling coefficient of synchronized phase coupling is so little, one fifteenth as much as conventional excitation current. Therefore a little capacitive component on the secondary winding can achieve a coupling coefficient better than closed flux path type.
In the case of a synchronized phase coupling transformer, the needed capacitive component on the secondary winding is obtained tactfully by parasitic capacitance of secondary winding and stray capacitance of LCD backlight.
Moreover, in the case of unachieved condition for resonance frequency, adding adjusting capaciter to a LCD backlight in parallel/series can adjust resonance frequency.

3.3 Variation of Synchronized Phase Coupling Transformers

Pic.4 shows various examples of synchronized phase coupling transformers. For those for LCD backlighting is required to be thin-shape, there are many modified-shaped types comparing with conventional transformers, such as long and slender type, extremely thin type,etc (**Fig.20**).



Pic.4 Variation of Synchronized Phase Coupling Transformers

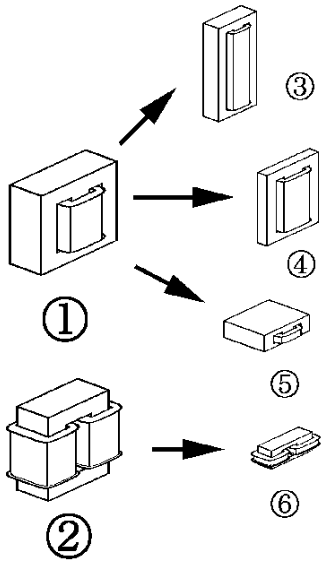


Fig.20 Conventional Transformers (①~②) and Synchronized Phase Coupling Transformers (③~⑥)

Closed flux path type transformers need to be shaped like and in **Fig.20** ①~②, in order to obtain sufficient coupling coefficient for actual use.
Modified transformers like ③~⑥ seem to be maintaining the original shape of closed flux path type. However, actual products have much flux leakage, resulting in large leakage inductance. Those types cannot obtain practical coupling coefficient by using conventional closed flux path.
Therefore adjusting secondary winding for making appropriate leakage inductance, then generating synchronized phase coupling by resonating the inductance and parasitic capacitance of a LCD backlight can achieve practical coupling coefficient.
In this way, practical inverters have become possible even with transformers of extremely opened flux path type and of very long and slender type.

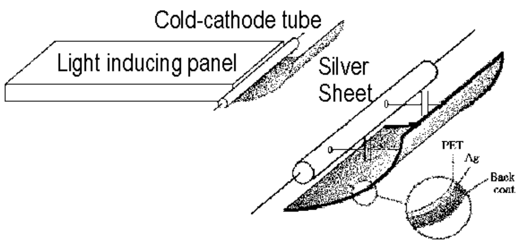


Fig.21 Generating Parasitic Capacitance [7]

4. Conclusion

We have understood that the combination of stimulating drive method and synchronized phase coupling transformers is very applicable, making most of the features of synchronized phase coupling transformers.
Because the epoch-making inverters have been realized by combining those technologies, it will be possible that this technology will be applied for other types of inverters, the range of application will be widened more than ever.
This time there is no enough room for discussing parasitic capacitance of LCD backlight, which has important significance during new circuit method's operation. I'd like to introduce this mater for next time.
(http://www.tim.co.jp/)

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The Inverter Set-up Transformer for LCD backlighting

The Bobbin transformer So Thin, So Powerful !

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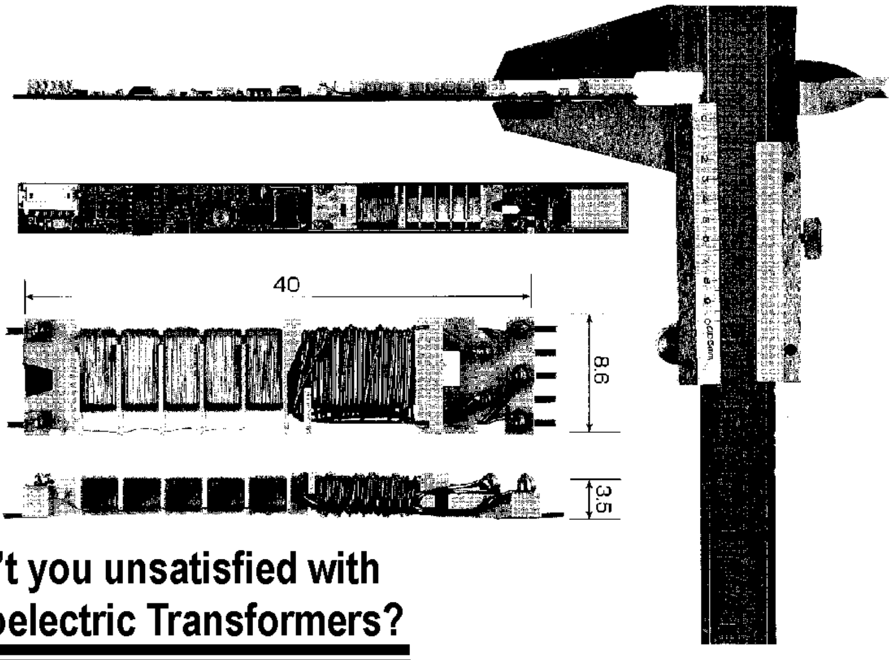

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It cost much.
Unstable Performance
Congenial Problem with Panel
Power is not enough.

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	S.P.C.Type	Piezo.type
Cost	Low	High
Performance	High Efficiency	High Efficiency
Power	Sufficient	Insufficient
Thinness	Thin	Thin
Congeniality w/ LCD panel	Stable	Unstable

Technolium Co. Ltd.

〒 Zip Code 107-0062 401,6,2,6 Minami-Aoyama, Minato Ku, Tokyo Tel. 03-5468-7671 (Key No.) Fax. 03-5468-7673

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