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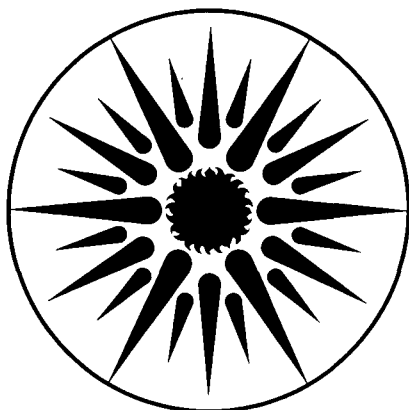
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November 1982

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INTEGRATED CIRCUIT CONTROL
FOR TWO-LAMP ELECTRONIC BALLAST:
FINAL REPORT

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ABSTRACT

This report describes circuitry for a solid-state, high-frequency fluorescent ballast designed to operate two F40 T-12 rapid-start lamps. The circuits are designed to be produced by hybrid integrated circuit (IC) technology. The signal components are produced on a single IC chip; the power transistors are attached to an alumina substrate. The initial IC version reduces the component count by about 50%. The cost of each IC in 500K lots is \$0.70, replacing discrete parts costing \$2.25. Additional savings of more than \$1.00 per unit are realized by the decreased assembly time and improved reliability of the ICs.

The system performance (two-lamp F40) was compared to the discrete version of the ballast and to an efficient core-coil ballast and found to be 6% less and 20% more efficient, respectively. The decrease in efficiency relative to the discrete version of the ballast is due to retaining some power to the filaments during operation in order to maintain normal lamp life.

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1.1 Introduction

The first production of dual 40 ballasts used a discrete design that was configured for later conversion to integrated control. The discrete version was developed first because it was believed that would result in the shortest possible development time. Conversion to IC control was planned as an improvement in cost and producibility that would be necessary as the market matured. About 40,000 were built in the discrete version and the experience gained from these led to some modification of the original circuit plan.

Cherry Semiconductor developed the IC to specifications which were supplied by EETech and consultant John Wu. Two hundred and thirty samples of the integrated circuit were delivered to EETech and thirty of them were tested in ballasts before the program was terminated.

Fifteen ballasts using the integrated control were delivered to Lawrence Berkeley Laboratories in June 1982 as part of their program to promote the development of energy efficient lighting.

This report discusses details of the ballast development and the performance that was measured at EETech before delivery of the samples to LBL.

1.2 Control Theory

There are three modes of operation of the ballast using the integrated circuit control; preheat, ignition, and running. Reference is made to the functional block diagram of figure 1 to better understand the relationships in the control method.

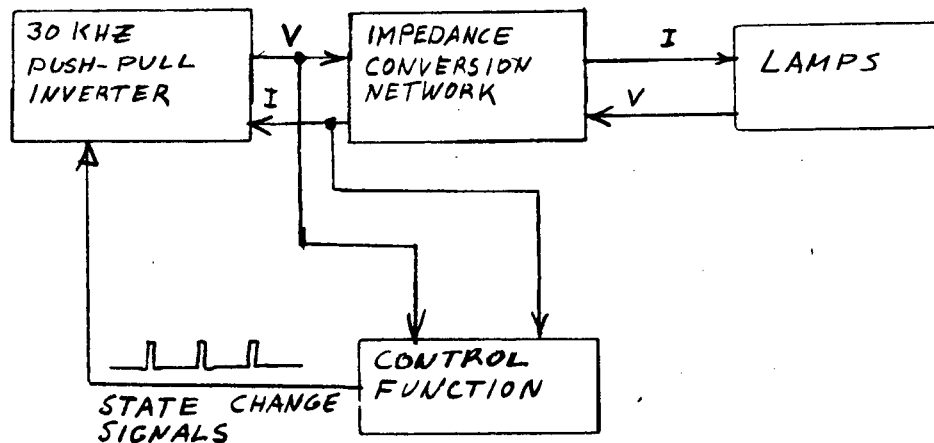


Figure 1. Functional Block Diagram

The impedance conversion network is the "ballast" in a conventional sense. i.e. it converts the constant voltage load of the gaseous discharge lamp into a constant current load for the inverter. All three operating modes make use of the state change signal into the inverter to control inverter current. Increasingly rapid state changes decrease the current of the inverter because the input impedance the inversion network always appears somewhat inductive to the inverter.

During preheat, the state change signal is controlled in response to the voltage level on the filaments. Increasing voltage results in a higher inverter frequency which in turn tends to keep the voltage from increasing. The result is a stable operating point which is independent of transistor parameters. The operating level is chosen so that the voltage out of the inversion network is not enough to ionize the lamps during preheat mode. The turns ratio on the filament transformer are chosen to give the proper filament current during this mode.

Periodically, at 1 sec intervals the feedback path from the filament voltage is interrupted. This is the ignition mode. State change signals are derived by sensing the times at which instantaneous inverter current exceeds some chosen maximum limit. The limit must satisfy a number of design constraints. First it must be low enough to ensure survival of the inverter switches no matter what output load conditions are present. Second it must be high enough so that ignition of the lamps is ensured. If ignition is not obtained in 20 milliseconds, the ballast reverts to preheat mode and waits another second.

If ignition is obtained during the ignition mode, the state change signals come from a phase detector which compares the phase of the inverter voltage with the phase of the inverter output current. In effect, this causes the inverter to operate at some frequency where the load on the inverter is some chosen power factor. Tight control of the inverter power factor by means of the phase control is important for several reasons:

- 1) The emitter switched inverter, (a form that has minimum switching losses) can only operate properly driving a lagging power factor load.

- 2) Excessively lagging power factor has an efficacy penalty in both the inverter and the impedance inversion network.

- 3) As the resonance of the impedance inversion network moves around, in response to the varying lamps impedance, the frequency of the inverter keeps a proper relation to the impedance inversion network.

1.2.1 Circuit Considerations

Figure 2 is a schematic of the ballast before the integrated circuit replaced the control elements. A comparison with Figure 3 which includes the IC illustrates the part's count advantage of producing the ballast with the IC.

A schematic of the integrated circuit is shown in Figure 4. Transistor N22 performs the function of Q5 in the discrete version. N23 and N24 and the associated diode clamps comprise the phase detector circuit. The components to the right of the dashed line make up the replacement for the NE555 timer, which was an integrated circuit in the original design.

A comparison of the schematics shows that the integrated circuit is almost an element by element copy of the discrete version. It was felt that this was a low risk path to an integrated circuit because the original version is in effect a thoroughly checked out breadboard for the integrated circuit. Not quite.

In some of the samples, the timer would not function in the presence of high signal levels into the inputs of the phase detector. Only one of the inputs exhibited this sensitivity and the samples were screened by Cherry Semiconductor to obtain enough working samples, to fulfill the contract. The coupling appeared to result from a substrate overload. If the integrated circuit version is to become a commercial ballast, a new layout of the IC is probably necessary.

1.2.2 Relative Cost Information

The quoted prices for this IC in semi-custom version was \$1.19 for quantities of 200 thousand. For higher quantities, Cherry Semiconductor recommended a full custom IC with a \$20K tooling charge and a \$.70 piece price in 500K lots. The parts replaced by the IC have a total cost of about \$2.25. More important cost benefits would result from lower assembly time and greater reliability due to an un-cluttered layout.

1.2.3 Performance Comparisons

Table 1 shows the relative light output of the 15 samples which were prepared for LBL. The measurements were made in a surface mounted closed ceiling fixture, suspended 4 feet above the floor, with the photo-cell on the floor. for reference purposes, the same measurements were performed on commercial energy saving magnetic ballasts, on a Thomas electronic ballast, and on a First generation EETech ballast (discrete components and filament heat removed after ignition). The readings were taken over several days, and the magnetic ballast measurements were repeated every day to track any drift in lamp characteristics. The lamps used were GE 34W WATTMIZER II lamps.

Note that if the first reading on the magnetic ballast is taken as the reference, the average increase in efficacy for the EETech IC samples is 20%. If the reference is adjusted for later readings the increased efficacy is 22%.

Sample #12 doesn't seem to be in the "group" but no reason for its low performance was found.

1.3 SUMMARY

The integrated circuit version of the EETech ballast is not simply a repackaging of all the transistors and resistors that are in the SSBl model. The major functional difference is that a maintenance level of filament power is kept on the filaments during the running of the lamp, while in the SSBl model all filament power was removed after lamp ignition.

There are two advantages to this approach:

- 1) It eliminates the need for the power transistor which switched the filament power in or out.
- 2) It holds the promise of longer lamp life by keeping the lamp cathodes at a higher temperature.

The disadvantage is that it decreases the efficacy of the system because filament watts don't contribute to any light output.

The integrated circuit replaces 6 resistors, 7 transistors, 14 diodes, and an NE555 timer. The board area that is saved by the integration can be used to spread out the remaining parts, making manufacture somewhat easier.

1.3.1 The LBL Samples

The 15 samples that are delivered to LBL have the following physical and functional characteristics.

The samples were built by removing parts from an SSBl board and attaching the integrated circuit. Connections were made to the circuit board by soldering in the necessary jumper leads. Therefore, these samples don't exhibit the layout advantages that will result from integration.

With energy saving lamps the maintenance voltage on the filaments is from 2.3 to 2.5 volts. Using about 2.5 to 3 watts in the filament. With standard 40W lamps the filament voltage will increase to 3.5 volts, using about 5 to 6 watts in the filaments. This is a significant handicap in the efficacy "race". Although sales literature will steer the user toward energy-saving lamps, data should also be taken on F40 lamps.

Preheat voltage on the filaments is around 4.5 volts. This occurs with energy-saving lamps and standard F40 lamps.

The open lamp ignition voltage was inadvertently decreased about 15%, in the LBL samples. Because of this, some difficulty may be experienced in starting lamps below room temperature. However, it should not interfere with the LBL data gathering.

Refinements for Production Ballasts

The decrease in open lamp ignition voltage experienced in the LBL samples is not intrinsic to the integrated version and it would be restored to the levels present in the SSB1 model.

The selection of a proper filament maintenance voltage cannot be made based on presently available data. The factors involved are as follows:

- 1) The purpose of leaving filament power on is to avoid lamp life penalties.

- 2) It has been determined that lamp life without any filament power after ignition is approximately 10,000 to 12,000 hours.

- 3) Some ballasts are on life test with filament maintenance at same level as the LBL samples. Only 4,000 hours have been logged in this test, so no conclusions can be drawn about the adequacy of this filament maintenance level.

If it is determined that 2.5 watts of filament power isn't enough to make a significant difference in the lamp life, someone will have to decide whether the most appealing product would result from decreasing the filament power to the lowest possible level (consistent with the integrated configuration) and accept the life penalty or raise the filament power to some higher level and accept an efficacy penalty.

Table 1. Relative Light Output

<u>Ballast</u>	<u>Line Watts</u>	<u>L.U.</u>	<u>Efficacy</u>	<u>Relat. Efficacy</u>	<u>Relat. Adj. Efficacy</u>	<u>Temp.</u>
Advance	72.3	407	5.629	1		78 Deg F
EETech Sample #1	57.0	395	6.930	1.23		78 Deg F
EETech SSB-1	57.5	422	7.189	1.27		73 Deg
EETech Sample #2	56.2	385	6.851	1.22		74 Deg
EETech Sample #3	58.4	399	6.832	1.21		74 Deg
GE Maximiser	78.3	450	5.747	1.02		75 Deg
Advance	71.8	398	5.543	.985	1	75 Deg
EETech Sample #4	56.3	380	6.750	1.20	1.22	
EETech Sample #5	56.4	387	6.862	1.22	1.24	75 Deg
EETech Sample #6	58.5	399	6.820	1.21	1.23	75 Deg
EETech Sample #7	56.3	383	6.803	1.21	1.23	75 Deg
EETech Sample #8	56.3	381	6.767	1.20	1.22	74 Deg
EETech Sample #9	56.7	378	6.666	1.18	1.20	74 Deg
EETech Sample #10	54.7	363	6.636	1.18	1.20	71 Deg
Advance	72.3	397	5.491	.98	1	71 Deg
Thomas	61.5	390	6.341	1.13	1.15	73 Deg
EETech Sample #11	58.9	399	6.95	1.23	1.27	

<u>Ballast</u>	<u>Line Watts</u>	<u>L.U.</u>	<u>Relat. Efficacy</u>	<u>Efficacy</u>	<u>Relat. Adj. Efficacy</u>	<u>Temp.</u>
EETech Sample #12	57.4	385	6.438	1.14	1.17	73 Deg
EETech Sample #13	59.8	401	6.705	1.19	1.22	73 Deg
EE Tech Sample #14	57.1	390	6.83	1.21	1.24	73 Deg
EETech	58.6	399	6.808	1.21	1.24	73 Deg

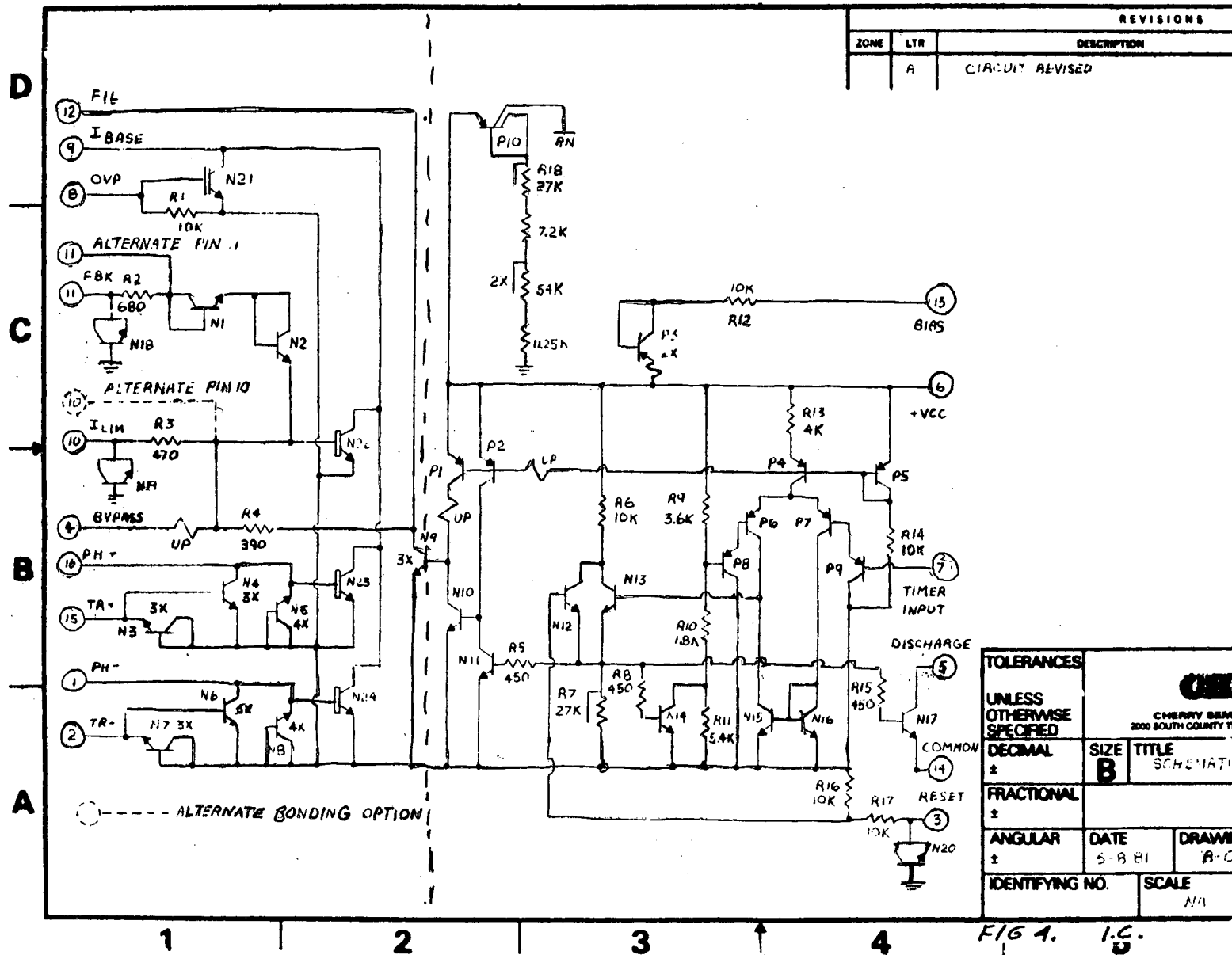


Figure 4.

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