GEORGIA INSTITUTE OF TECHNOLOGY — OFFICE OF CONTRACT ADMINISTRATION

PROJECT ADMINISTRATION DATA SHEET

[X] ORIGINAL [ ] REVISION NO. ______

Project No. E-21-540 (05425-0A0) — XXXX/GIT — **DATE** 11/ 6 /84

Project Director: W. E. Sayle — **School/XXX** Electrical Engr.

Sponsor: Whirlpool Corp., Elisha Gray II Research and Engineering Center

Type Agreement: Whirlpool Letter Authorization dated 8/23/84 for EE Fellowship

Award Period: From 9/1/84 To 8/31/85 (Performance) 8/31/85 (Reports)

Sponsor Amount:

	This Change	Total to Date
Estimated:	$ 2,000	$ 2,000
Funded:	$ 2,000	$ 2,000

Cost Sharing Amount: $ None — **Cost Sharing No:** N/A

Title: Materials Supplement to EE Fellowship

ADMINISTRATIVE DATA

OCA Contact Brian J. Lindberg X4820

1) Sponsor Technical Contact:

Ernest A. Baillif, Senior V.P.
Research and Engineering
Whirlpool Corp., Elisha Gray II
Research and Engineering Center
Monte Road
Benton Harbor, MI 49022

2) Sponsor Admin/Contractual Matters:

Dr. Cutler
Whirlpool Corp., Elisha Gray II
Research and Engineering Center
Monte Road
Benton Harbor, MI 49022
(616) 926-5215

Defense Priority Rating: N/A

Military Security Classification: N/A
(or) **Company/Industrial Proprietary:** N/A

RESTRICTIONS

See Attached N/A Supplemental Information Sheet for Additional Requirements.

Travel: Foreign travel must have prior approval – Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of $500 or 125% of approved proposal budget category.

Equipment: Title vests with All purchases of special items of equipment in excess of $200 each must be approved in writing by Whirlpool and Whirlpool shall have the option to take title to such items of equipment at the end of the Fellowship Program.

NOV 1984 RECEIVED Research Reports Office

COMMENTS:

This authorization for materials, special equipment and services is in support of the area of study selected for the fellowship authorized by the Whirlpool letter referenced above.

COPIES TO:

No Sponsor I.D. #

Project Director (Sayle)	Procurement/EES Supply Services	XXXX GTRC
Research Administrative Network	Research Security Services	Library
Research Property Management	Reports Coordinator (OCA)	Project File
Accounting	Research Communications (2)	Other A. Jones

GEORGIA INSTITUTE OF TECHNOLOGY OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION/CLOSEOUT SHEET

Date 11/21/86

Project No. E-21-540 School/XXX EE

Includes Subproject No.(s) N/A

Project Director(s) W. E. Sayle EXRE / GIT

Sponsor Whirlpool Corp.

Title Materials Supplement to EE Fellowship

Effective Completion Date: 8/31/85 (Performance) (Reports)

Grant/Contract Closeout Actions Remaining:

- [ ] None
- [X] Final Invoice or Final Fiscal Report
- [ ] Closing Documents
- [X] Final Report of Inventions Sent patent Questionnaire to P.I.
- [ ] Govt. Property Inventory & Related Certificate
- [ ] Classified Material Certificate
- [ ] Other

Continues Project No. Continued by Project No. E-21-551

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R. Embry

E-21-540

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF ELECTRICAL ENGINEERING
ATLANTA, GEORGIA 30332

TELEPHONE: (404) 894- 2946

15 December 1985

Dr. W. Gale Cutler
Staff Vice President
University Relations
Whirlpool Corporation
The Elisha Gray II
Research and Engineering Center
Monte Road
Benton Harbor, MI 49022

Dear Dr. Cutler:

I am pleased to enclose copies of the "Whirlpool Fellowship Report" for you and your colleagues at Whirlpool named at the bottom of this letter. This report is for the 1984-85 Fellowship Year and reflects the efforts of Whirlpool Fellows James Powell and Richard Wallace.

As you are already aware, Richard Wallace is continuing on the Whirlpool Fellowship for 1985-86. He is being joined by Edward Randolph (Randy) Collins effective 1 January 1986. Both Richard and Randy will be pursuing doctoral degrees in electrical engineering.

I would suggest that we should plan a visit to your facilities in Benton Harbor in order to introduce Randy Collins to the Elisha Gray II Research and Engineering Center and familiarize him with the varied activities at Whirlpool. Please let me know of dates that would be convenient for you and your colleagues.

Thank you for your continuing support of graduate education and specifically of Georgia Tech. I hope that the holiday season is a good one for you.

Sincerely Yours

William Sayle II
Professor

copies to Mr. Sam Pearson, Whirlpool
Mr. Don Schnautz, Whirlpool
Dr. Walter Carlson, Georgia Tech
Dr. Dale Ray, Georgia Tech
Ms. Cindy Meyer, Georgia Tech
Dr. Demetrius Paris, Georgia Tech
Ms. Pamela Majors, Georgia Tech
Ms. Jean Wilson, Georgia Tech
Mr. Richard Wallace, Georgia Tech
Mr. James Powell, Georgia Tech
Mr. Randy Collins, Georgia Tech

WHIRLPOOL FELLOWSHIP REPORT

James E. Powell
Richard S. Wallace, Jr.

Power Electronics Laboratory
School of Electrical Engineering
Georgia Institute of Technology

1984-1985

BACKGROUND

Our year began with a visit to Whirlpool Headquarters in Benton Harbor, Michigan, in the Fall of 1984. There we had the opportunity to discuss research topics with several members of the Advanced Development staff. A videotape of the Auburn University research project in carrier current communications was shown; this work was related to work done last year at Georgia Tech by David Jackson. Afterwards we were taken on a tour of the Elisha Gray II Research and Engineering Center.

After reviewing information obtained on the visit, Richard selected Power Electronics in Motor Drive Applications as a research topic, while Jim decided to continue the research begun by David Jackson in the area of Household Carrier Current Communications.

HOUSEHOLD CARRIER CURRENT COMMUNICATIONS

The research project at Auburn had shown that practical carrier current communications systems, capable of transmitting digital data, were possible in the home. There were, however, concerns that control signals from one household might appear in the power bus of adjacent households, creating problems for other users of this form of communication. In addition, the problem of coupling the signals from one phase of a typical household power hookup to another presented difficulties. A related problem was the use of power line filters in the same household to protect computer equipment from line transients, which tended to attenuate the carrier current signals.

After a study of the literature, however, Jim decided to change research topics. It appeared that the some of the problems with carrier current communication could be solved with devices such as line traps, coupling capacitors, and line tuners, as mentioned in the IEEE Guide for Power Line Carrier Applications (1980). The big concerns seemed to be first, if these devices were approved for household use, whether the connection could be made easily, and second, whether a customer would be willing to pay for them to be installed on his/her utility lines. At this point, we consolidated our efforts towards the motor drive applications.

POWER ELECTRONICS IN MOTOR DRIVE APPLICATIONS

Our initial goal in the motor drive applications area was to build a circuit to drive the brushless DC motor in a washing machine. A special washing machine, already fitted with the motor of interest, was at the Whirlpool labs in Benton Harbor. However, since the machine would not be available to us at Georgia Tech for some time, we undertook several smaller projects to familiarize ourselves with the circuit topologies and component types that might be needed later for the brushless DC motor drive. Our main objective in these smaller projects was to gain hands-on experience with power conversion circuits. By designing simple converters for specific purposes (to be described later), we hoped to identify the constraints and trade-offs that would be important in the brushless DC motor drive.

Regulator Control ICs

Monolithic control circuits for power converters have become more readily available in recent years. Since the generation of timing pulses to fire SCRs or switch transistors is the most complex requirement of an electronic power converter design, a good understanding of the capabilities of the various control ICs is important. Our first laboratory experiments were aimed at getting this understanding.

We obtained three types of IC regulators for study: the MC34063, the UA78S40, and the SG1526, all from Motorola. Simple power converter circuits based on each of the control ICs are described in Application Notes provided by the manufacturer. We constructed a few of these circuits, then modified them to test the capabilities of the ICs and to see what range of parameter variations were possible. Such parameters include the range of output voltages and currents, the switching times of diodes and transistors, the sizes of energy-transfer inductors, and the frequency of the on-board oscillator.

The simplest of the regulator ICs, the MC34063, has a single Darlington pair output stage, which can either source or sink current. Such an output stage is not well suited to drive the gate of a power FET, which requires both a current source and a current sink. However, the MC34063 can be used to drive moderately sized power BJTs. The SG1526 features a push-pull output stage and is thus better suited for use with power FETs. The UA78S40 is similar to the MC34063 in its drive capability, but it offers more control functions, a wider range of feedback options, and an on-board op-amp.

Switching Element Comparison

The applications for these power converters are limited to the voltage and current ratings of the internal switching transistors on the chip. One of our major design efforts has been to find external switching elements which allow higher voltage and current applications, but that can be driven by the integrated circuit regulator. We are investigating power bipolar junction transistors and power field effect transistors at present. Two circuits are being developed to meet the same requirement: provide a variable 0-120 volt, 2 ampere power source to an separately excited DC motor field winding. The topology selected is a standard step-down (buck) DC-to-DC converter, but one is being designed with a power BJT as its main switching element, while the other uses a power FET. A schematic for a step-down converter using a power BJT is shown in Figure 1. We expect the results of this comparison to help in selection of the right power switch for the brushless DC motor project.

Motor Speed Controls

Our first motor drive circuit project was a speed control for a small trolling motor. The motor runs on a 12 volt battery and draws a maximum current of about 8 amperes. The speed of the motor varies with the applied voltage level, so the control circuit would ideally provide a DC output at any level between zero and 12 volts. The required output voltage range for actual trolling, however, is more like 6-10 volts. For this range of voltages, the feedback control of the step-down converter works very well. The design was demonstrated for Gale Cutler and Don Schnautz while they were at Georgia Tech in the Spring of 1985. Subsequently, the trolling motor control was put on a PC board and mounted in a small cabinet for use at the lake. The schematic for the trolling motor drive circuit is shown in Figure 2.

Our next motor drive application has been the 0-120 volt variable converter mentioned earlier. In addition to the power BJT and power FET approaches currently under way, a third approach, using SCR-baseds, has been developed. The SCR circuit consists of a bridge rectifier in which two of the diodes have been replaced by

SCRs to allow control of the output RMS voltage by varying the firing angle. The desired firing angle is set by comparison of the line voltage waveform with an external reference level. The schematics for this design are shown in Figures 3 and 4. The design also features isolation of the control pulse generation circuit from the power switches by means of optically gated pilot SCRs. This design has been tested in the laboratory at the full range of firing angles (0-180 degrees) and at load currents up to 8 amperes. Tests using the separately excited DC motor have just begun, and will continue during the Winter quarter of 1986 in support of a newly offered course in variable speed motor drives.

SUMMARY

At the beginning of the year, there were no Power Electronics projects in work. As a result of goals established for the Whirlpool Fellows, several projects, at the graduate and undergraduate levels, have been completed or are in progress. With the brushless DC motor drive circuit as our long-range goal, and building on the experiences of this year, we expect the pace of our efforts to increase in the coming quarters. Several projects in the area of power conversion, including two in variable speed motor drives, are on the calendar for 1986.

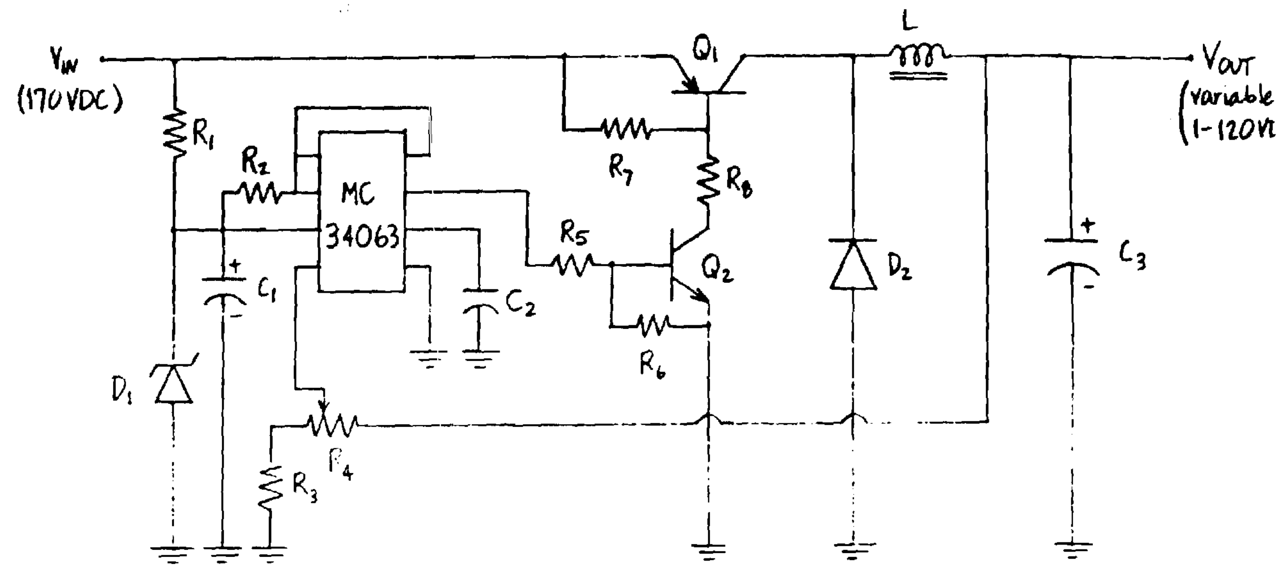

Figure 1.

Step-Down Converter w/External Power BJT

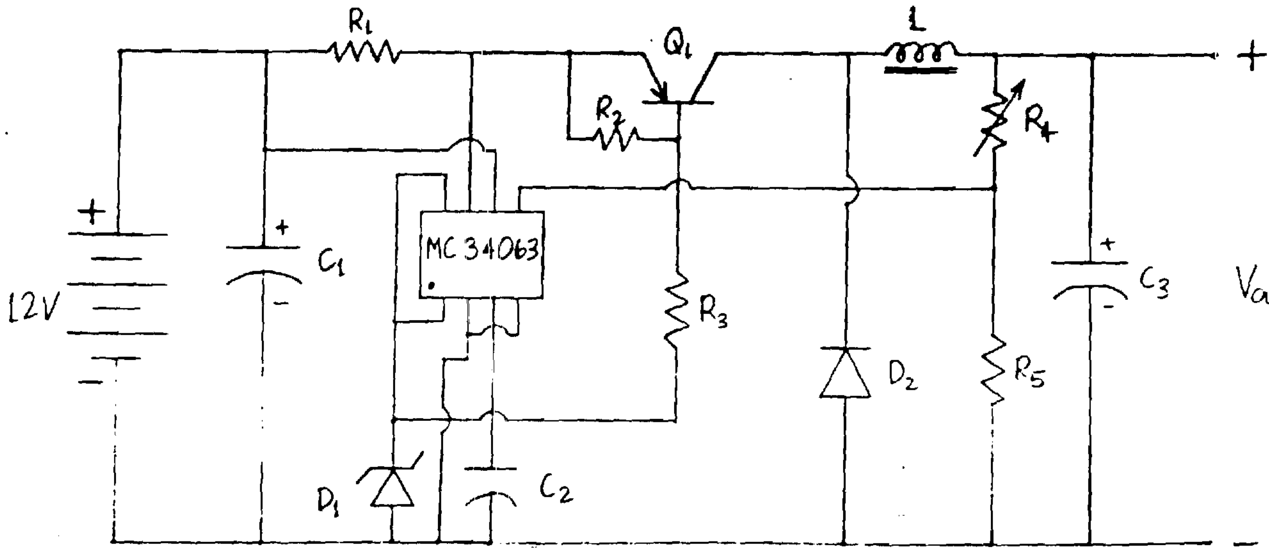

Figure 2.

Step-Down Converter for Trolling Motor

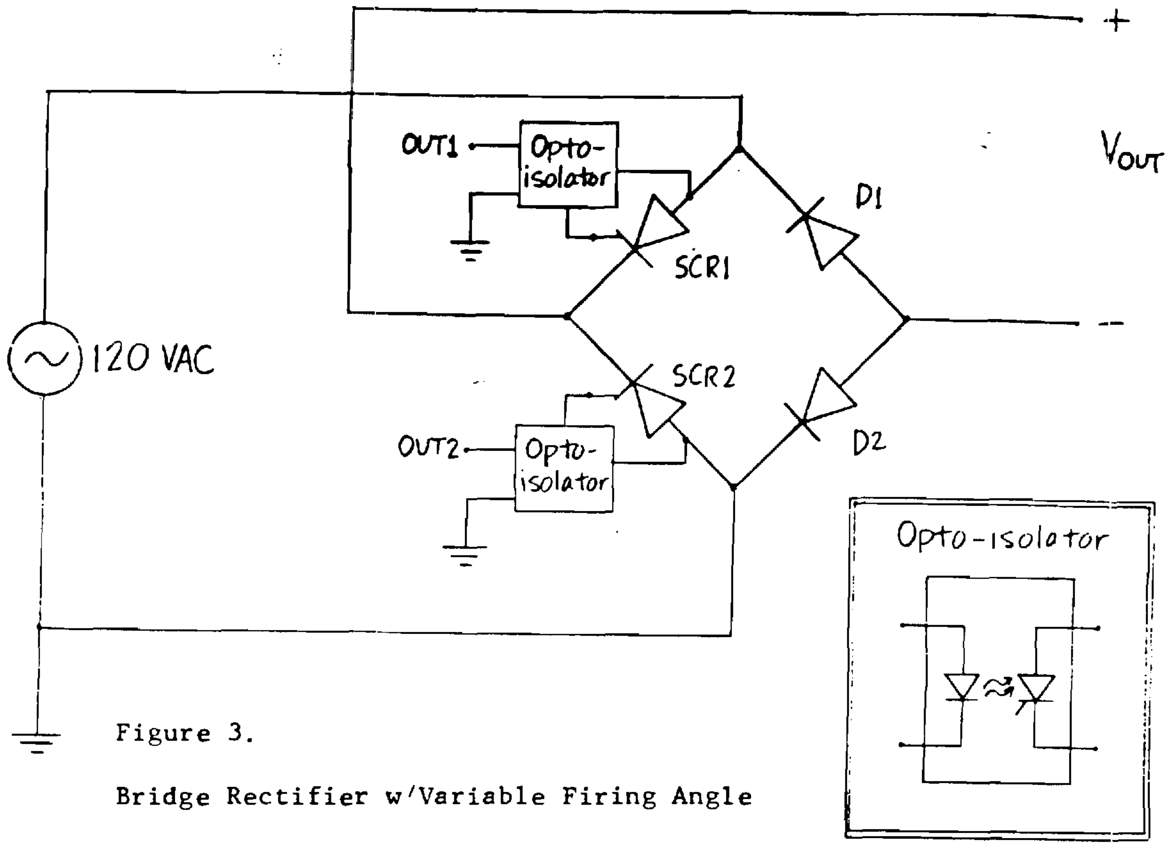

Figure 3.

Bridge Rectifier w/Variable Firing Angle

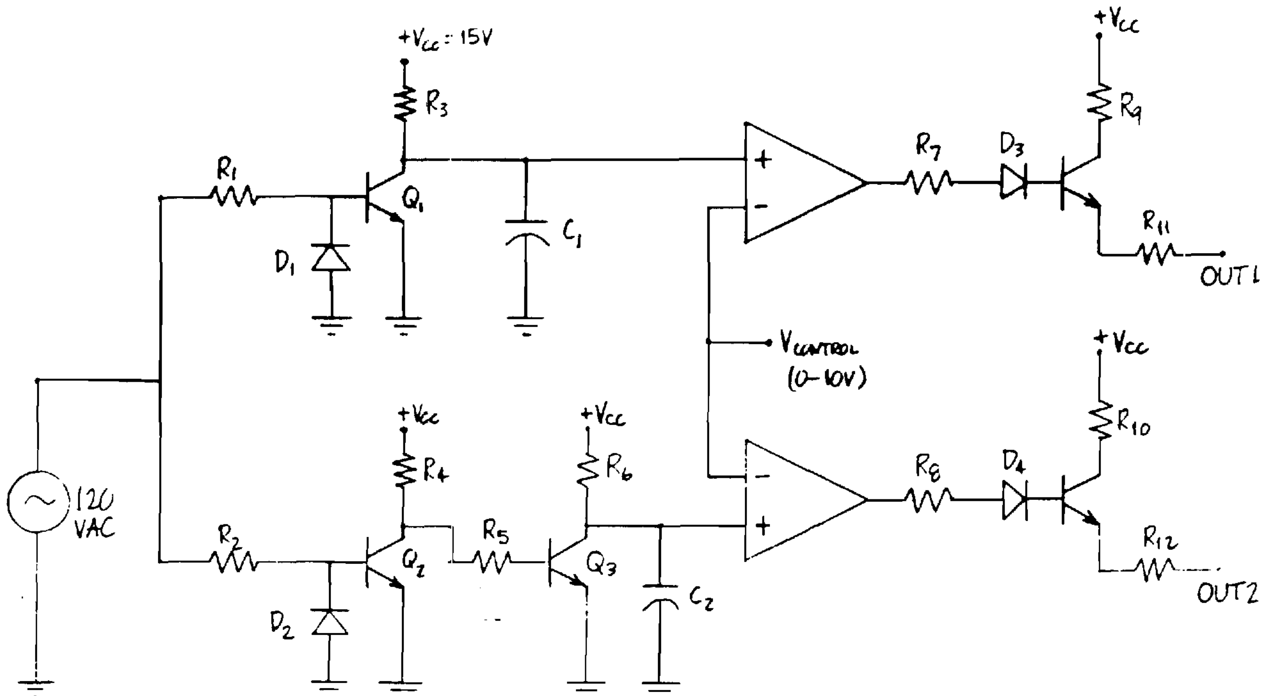

Figure 4.

Firing Pulse Generation Circuit