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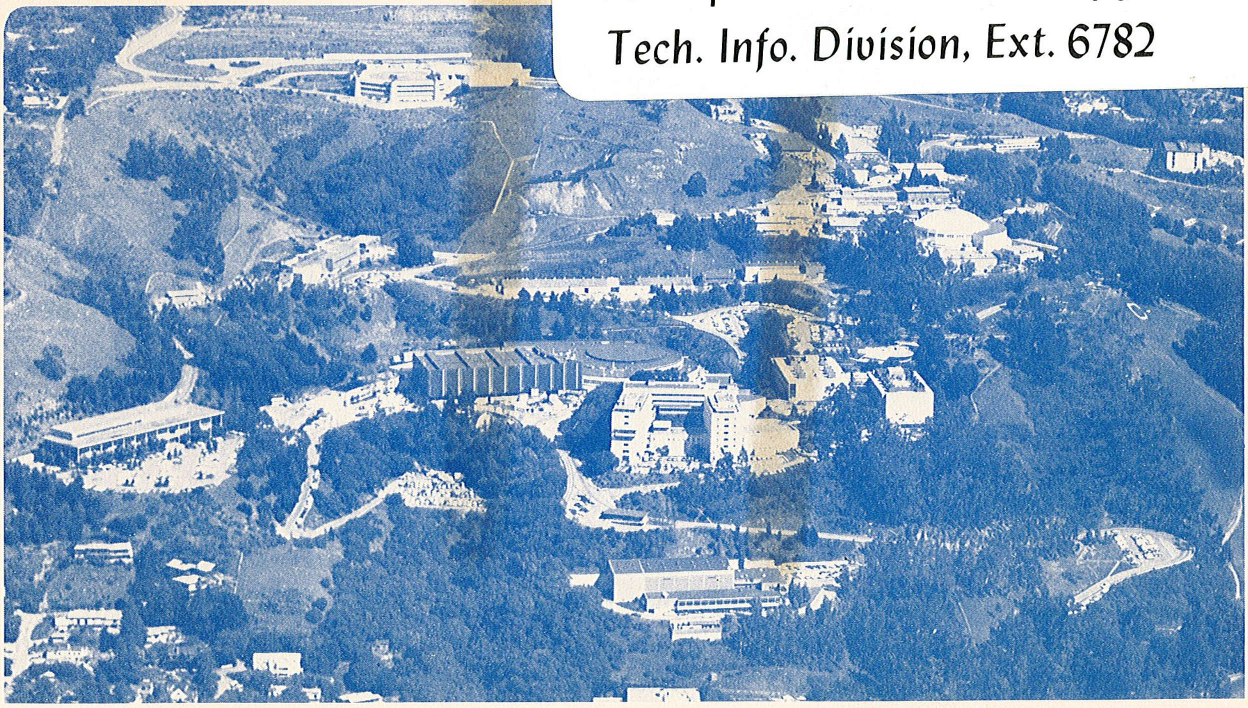

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A PRECISION PROGRAMMABLE BIPOLAR V/f INSTRUMENTATION MODULE*

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Summary

A precision bipolar voltage-to-frequency converter, which is computer-programmable from a digital interface, has been produced at Lawrence Berkeley Laboratory. Utilizing NIM packaging, the 1 MHz V/f has sixteen ranges and may be operated from panel controls as well as remotely programmed. Intended for use in magnetic measurements, good performance and versatility suggest wider application. The instrument is described and the circuit design is discussed in detail. Tests of the first unit are discussed and instrument specifications are given.

Introduction

A new magnet testing system in use at the Lawrence Berkeley Laboratory Magnetic Measurements Group performs digital integration over time on a low-level, slowly-varying analog voltage. An essential part of this system is a precision bipolar V/f converter. This bipolar V/f converter, which has "up" and "down" outputs, must have a maximum input sensitivity of 1 mV full-scale for 1 MHz output. Development of this unit was carried out at LBL. The result of this work is a new instrument with improved specifications which has broad applications in the acquisition and processing of low-level bipolar analog signals.

A most important feature of the instrument is full remote computer programming of all controls. The unit is packaged in a NIM module as shown in Fig. 1. All controls may be operated either locally from the front panel, or from a CAMAC interface (Joerger IR-1). Sixteen full-scale ranges are provided from 100 μV to 10 V. Ranges below 1 mV F.S. all require an external preamplifier.

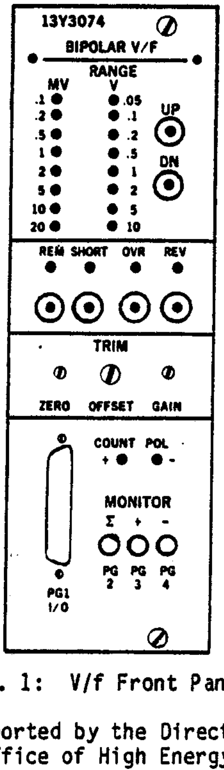

Fig. 1: V/f Front Panel

All indicators are LED's. Pushbuttons are provided for range, local/remote range selection, input shorting, over-range flag reset, and output polarity reversing. A full set of trim adjustments are provided. Remote control and monitoring from CAMAC or other sources is accomplished through a multipin connector. Logic inputs are fully optically isolated, and logic outputs are from differential line drivers.

In this paper, the analog circuit design of the instrument will be discussed. A simple circuit architecture is described which achieves the required precision by eliminating polarity ambiguity and minimizing the number of sources of error. Performance of the instrument is summarized.

Design Objectives

The V/f instrument accepts bipolar analog inputs and generates separate up and down TTL outputs. Outputs are mutually exclusive and are determined by input polarity. As shown in Fig. 2, programming of range and all other functions may be done either locally or remotely. Remote programming is accomplished by eleven latched parallel logic outputs from the Joerger IR-1 CAMAC module. The same module continuously monitors the state of the V/f programming.

In the design of this instrument, important performance objectives were:

1. 1 MHz full-scale frequency range.
2. 10 V full-scale to 1 mV full-scale input ranges.
3. Wide common mode capability (±10 V) and good CMRR (100 db).
4. Resolution better than 5 μV.
5. Accuracy ±.01% on higher ranges to ±0.5% on lowest range.
6. Unambiguous output.

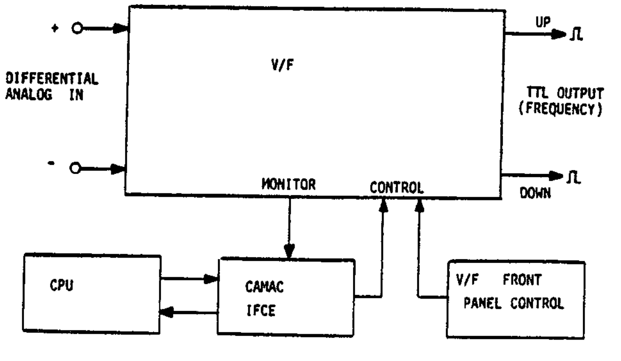

Fig. 2: V/f Monitor and Control

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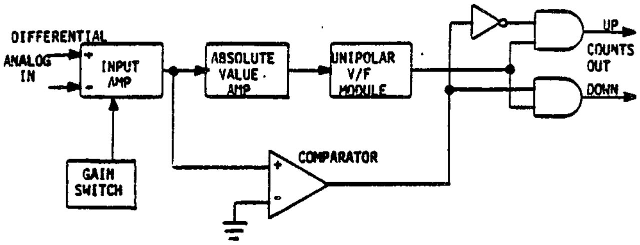

Fig. 3: Basic Bipolar V/f Converter

Circuit Design

The problem of the design of a very accurate and sensitive bipolar V/f converter has proven to be slightly tricky to designers in the past. The requirements of up/down outputs, microvolt resolution, and low drift, when taken together, can lead to surprisingly complex and often unsatisfactory circuits having such problems as directional ambiguity and differing positive and negative scale factors. More than one engineer, for instance, has resorted to the use of dual unipolar V/f modules, with all the attendant calibration problems, to achieve results. Most often, however, a bipolar V/f design takes the basic approach shown in Fig. 3.

The arrangement of Fig. 3 appears to be straightforward, and has the advantage of using a single unipolar V/f module. These modules have been developed to a high level of performance and are available from many vendors. The difficulty which arises with this circuit in practice is that of multiple sources of error. There are at least four differential amplifiers before the V/f module in most practical realizations of this circuit, each contributing error and drift. Also, the problem of designing a V-in, V-out absolute value amplifier having .01% accuracy, as required here, is not trivial. Because of the problems inherent in a literal realization of the block diagram of Fig. 3, simplification of the circuit design was sought.

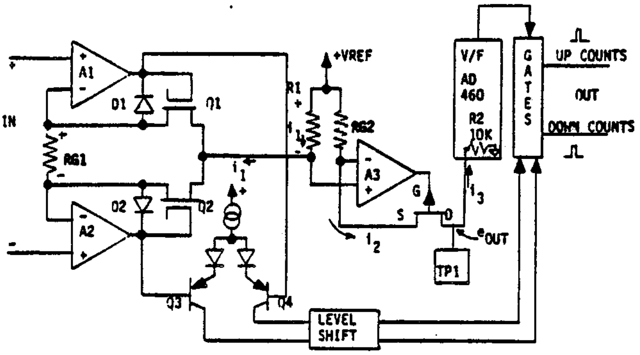

Fig. 4: Simplified Bipolar V/f Schematic

The circuit of Fig. 4 is a realization which combines the input amplifier, absolute value amplifier, and comparator in a way which reduces error and minimizes parts. In this circuit, the first stage (A_1, A_2, Q_1, Q_2) is an absolute value transconductance amplifier. The output current of this stage is unipolar and precisely proportional to the absolute value of the input voltage. The operation of this rectifying precision amplifier is as follows: if the input offset voltages and the input currents of A_1 and A_2 are neglected, and the gains of A_1 and A_2 are considered very large, it is seen that for a positive input voltage, the feedback action will force sufficient current through Q_1, R_{G1}, D_2 into the output of A_2 to establish a voltage equal to the input voltage across the gain setting resistor R_{G1} (Q_1 and Q_2 are enhancement mode V-mos FETS, and D_1 and D_2 are hot carrier diodes). For a negative input voltage, the same action occurs with Q_2, D_1, R_{G1}, and A_1 to establish a voltage of the opposite polarity across R_{G1}. In each case, a unipolar output signal current, i_1, is produced. The transconductance gain of the first stage can be written as:

$$gm_1 = \frac{i_1}{|e_{in}|} = \frac{1}{R_{G1}} . \tag{1}$$

Because the output current i_1 flows through the load resistor R_1, the voltage gain of the first stage is seen to be:

$$G_1 = gm_1 \cdot R_1 = \frac{i_1}{|e_{in}|} \cdot R_1 = \frac{R_1}{R_{G1}} \text{ v/v} \tag{2}$$

The second stage, a precision "current mirror," can also be analyzed as a transconductance amplifier with a resistor output load. A_3 and its associated P channel J-Fet Q_3 establish, by feedback action, a voltage across the second stage gain setting resistor R_{G2} equal to the input voltage developed across R_1. Because all the resulting current through R_{G2} flows into the V/f module input ($i_2 = i_3$), with input resistance R_2, the gain of the second stage can be written as

$$G_2 = gm_2 \cdot R_2 = \frac{1}{R_{G2}} \cdot R_2 = \frac{R_2}{R_{G2}} \text{ v/v} \tag{3}$$

and the overall gain is

$$G \equiv \frac{e_0}{|e_{in}|} = G_1 \cdot G_2 = \frac{R_1}{R_{G1}} \cdot \frac{R_2}{R_{G2}} \text{ v/v} . \tag{4}$$

Note that the AD460 (or DM8417) V/f module is current driven at its voltage input. This both eliminates one stage in the overall design and provides a convenient test point, TP_1.

In the practical circuit, the overall gain of the bipolar V/f front end consisting of A_1, A_2, A_3, etc., is easily adjusted over a range of 10^4:1 by switching different values of R_{G1} and R_{G2}. R_{G1} values are switched in decades, and R_{G2} values are used to establish the X1, X2, X5 sequence. Because both the positive and negative gains of the input absolute value amplifier are set with the same resistor, these gains will be nearly identical.

Parameter	Specification	Units
Scale Factor:		
minimum	0.001	V/MHz
maximum	10.0 (13 ranges)*	
Accuracy:		
10 V range	±0.01	% of F.S.
1 V range	±0.015	
0.1 V range	±0.02	
0.01 V range	±0.05	
0.001 V range	±0.5	
Common Mode Rejection Ratio:		
DC--60 Hz	>100	db
Common Mode Input Range	$\pm 10 \mp 0.5\, e_{in}$	volts
Input Impedance	10^8	ohms
Average Temperature Coefficient of Scale Factor 20°C > 30°C:		
10 V range	±0.001	% per °C
1 V range	±0.002	
0.1 V range	±0.002	
0.01 V range	±0.002	
0.001 V range	±0.01	
Operating Temperature Range (Ambient)	10 > 40	°C

*16 ranges with external preamp.

In Fig. 3, a comparator was used to determine the sign of the bipolar input signal. This function is very simply handled here by the PNP differential switch Q_3, Q_4. Because the outputs of of A_1 and A_2 switch through a dead zone of over one volt when the input polarity changes, Q_3 and Q_4 need not be matched to provide unambiguous sign information to the output gating. Level shift circuitry is conventional.

A practical realization of the circuitry of Fig. 4 requires relatively few parts, and its performance depends principally on the specifications of a few devices. The V/f module was chosen for its excellent performance and its availability. Pin-compatible units are made both by Analog Devices and Digital Measurements Corporation (DMC). Although the particular design task here required a 1 MHz full scale range, a pin-compatible 100 kHz unit is available from Analog Devices with even better specifications (AD458), and pin-compatible 5 and 10 MHz modules (8610, etc., 8710) are offered by DMC.

In the input circuitry, the performance of operational amplifiers A_1, A_2, and A_3 is critical. Microvolt offsets, picoamp input currents, low drift, high gain, low noise and good A.C. response are all required. The amplifier chosen was the Intersil ICL 7650 Chopper Stabilized Operational Amplifier. This inexpensive monolithic device has a combined input offset voltage and temperature drift which approaches ±1 microvolt over the 10°C to 50°C range, and it meets most of the other requirements of the circuit. A limitation of the 7650 is that it operates on power supplies of ±5 volts and thus cannot accommodate the wide range of differential and common mode input levels required by the circuit of Fig. 4. This problem was easily solved by the circuit of Fig. 5 in which the power supply pins of A_1 and A_2 are "bootstrapped" by the monolithic J-FET AD503 operational amplifiers A_4 and A_5. In addition to this function, these voltage followers provide a convenient bias point for a network of leakage guard rings on the circuit board while increasing the effective common mode rejection ratio of the input stage greatly.

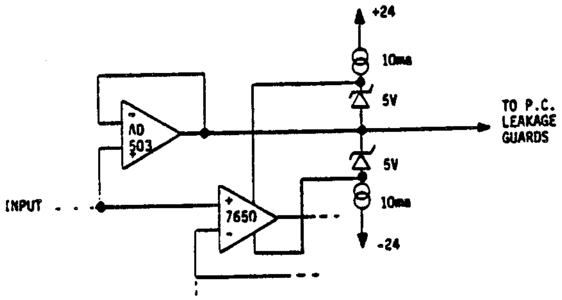

Fig. 5: Power Supply Bootstrapping

Circuit Performance

The general purpose precision bipolar V/f converter described was built and tested under both laboratory and field conditions. Tested in the laboratory under temperature cycling, it was found that the performance objectives were substantially satisfied*. In the field, used in a computer-controlled quadrupole magnet testing application, the new V/f instrument produced results which were substantially identical to those obtained from a previously used standard instrument (VIDAR), and which were a factor of two to five times more consistent. Significantly, the peak level of input signal in these tests was under 200 microvolts.

Table I is a list of specifications for the Precision Bipolar V/f Converter. All units will meet or exceed these specifications.

As expected, the tests showed that determining factors of instrument performance were the specifications of the input amplifiers and of the V/f module. The use of the Intersil 7650 involves a small compromise because of its input noise specification (2 μV at 10 Hz B.W.). The V/f modules performed within specifications. To obtain good performance on the lower ranges and meet the design goal of resolving input signals below 5 microvolts, special relays designed for low thermoelectric potentials were used for gain switching. The relays chosen were COTO No. 3402-5-51 (Coto Coil, Providence, RI). These relays have thermoelectric potentials below one microvolt.

Conclusions

The general purpose bipolar V/f converter described here is a high resolution instrument packaged in a NIM module. It is externally computer-programmable from a CAMAC interface as well as having a full set of panel controls. Good sensitivity and resolution are achieved by a high-performance, cost-effective design which utilizes a standard unipolar V/f module and which minimizes complexity and sources of error. The module should be of use in applications requiring the digitizing of signals having bandwidths not exceeding of 500 Hz, and particularly where the time integral of the input variable is of interest. Because of the wide possible applicability of this instrument, the packaging is designed to facilitate moderate quantity production, if required.

Acknowledgement

The authors wish to acknowledge the kind assistance of Robert Main of LBL in the testing of this design.

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*Results of these tests are discussed in Ref. 1.