Magnetic heading sensor

A compact circuit to provide a 0-5V analogue of heading for telemetry

AJOY RAMAN AND K. RADHAKRISHNA RAO

Central Electronics Centre, Indian Institute of Technology, Madras

The scheme is based on the Humphrey pendulous magnetic flux valve detector type FD 09-0101-1, wound for 1 degree accuracy. The pendulous nature of the sensor avoids errors in measurement due to aircraft attitude within 20 degrees of the vertical, since only the horizontal component of the earth's magnetic field is sensed.

The design of an electronic compass using a Fluxgate sensor described in reference 1 explains in brief the operation of the fluxgate sensor. The circuit used suffers from the limitations that a portion has to be co-located with the sensor coil, operates with a square-wave excitation leading to e.m.i. and is not compact.

The Humphrey flux valve detector is recommended for use with a sine-wave excitation at a nominal frequency of 3kHz. The outputs when filtered show a resolver type of output at double the excitation frequency. When using this sensor with a Type 5 harmonic oscillator resolver to d.c. converter [2], it is necessary first to generate a reference at double the excitation frequency, filter and phase-sensitive-detect the sensor outputs using this reference to obtain direct voltages proportional to the sin and cosine of the heading angle. These voltages are to be set as initial conditions on the two integrators which, along with an inverter, form the harmonic oscillator loop. If the oscillator is now permitted to start, the quadrature outputs begin at the initial conditions set, at a frequency determined independently by the integrator time constants. The time between the start of the oscillations and an event such as the first negative zero crossing of one of the oscillator outputs is a function of heading angle.

The present circuit, while using the Type 5 harmonic oscillator resolver to d.c. converter, employs a triangular-wave excitation which is easier to generate, a novel scheme for deriving the frequency-doubled reference, half-wave phase-sensitive detection on the unfiltered sensor outputs and a method of time-sharing components between the phase-sensitive detector and harmonic oscillator, leading to a compact circuit.

CIRCUIT

The details of the Humphrey sensor and the circuit diagram are shown in Figs 1 and 2. The Burr-Brown universal active filter UAF 41 (IC_1 and IC_3) shown in Fig.3, containing two integrators, an inverter and an uncommitted op-amp, lends itself directly to the implementation of the functions required. IC_1 is used for the generation of the triangu-

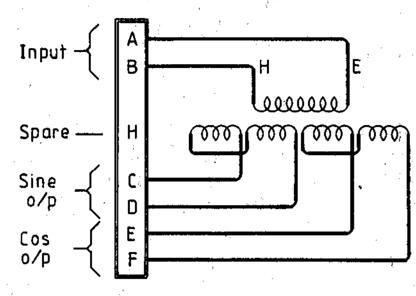
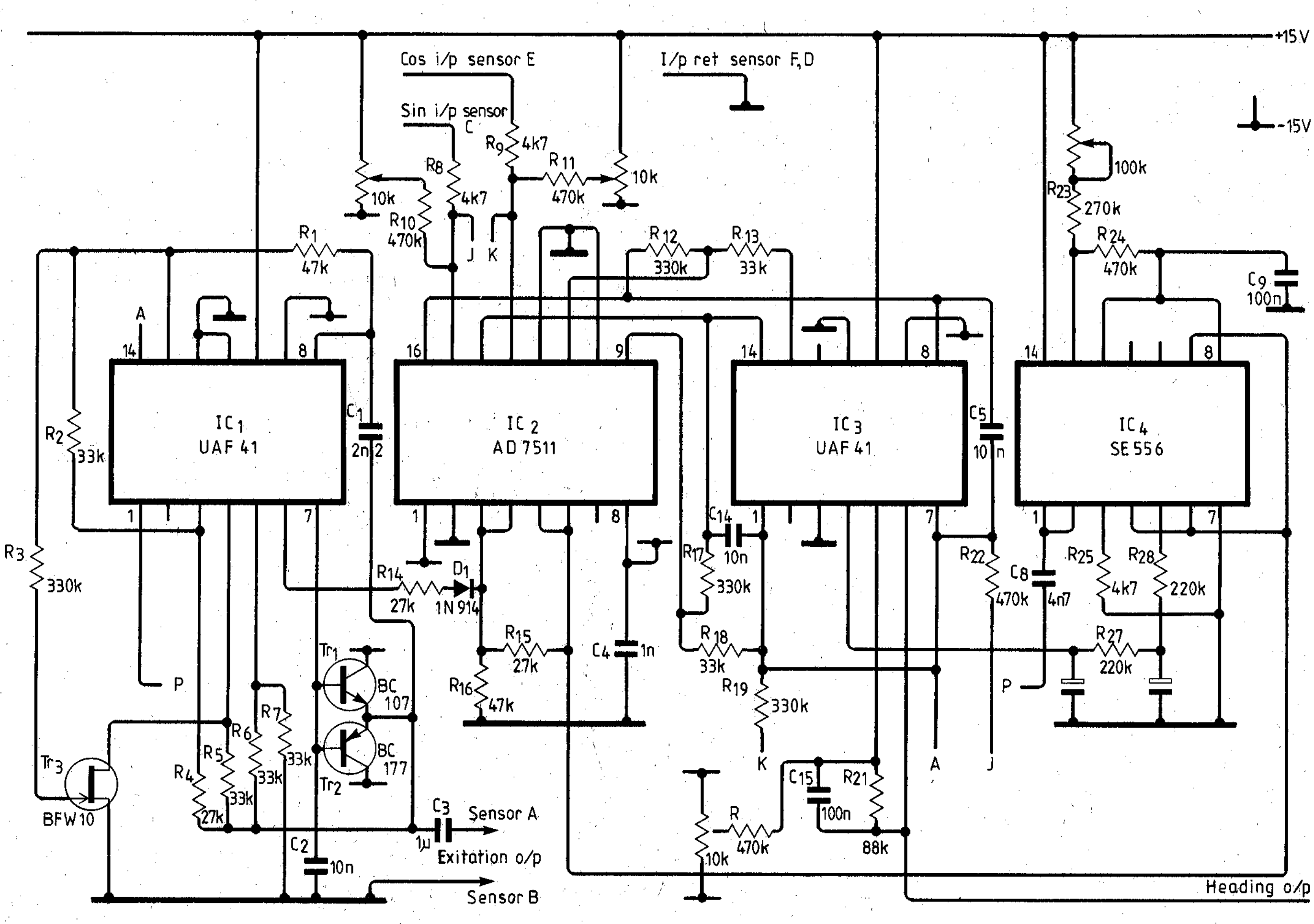


Fig. 1. Humphrey magnetic flux detector

Fig. 2. Heading sensor circuit diagram



lar wave excitation, using a standard integrator comparator loop, as the frequency-doubled reference and as a comparator for the harmonic oscillator output. The frequency-doubled reference required for the phase-sensitive detectors is derived on the square and triangular-wave outputs of the excitation circuit. Figures 4 and 5 show how the reference, bearing the necessary phase relationship to the excitation, and independent of frequency and component drifts with temperature is derived. This method is superior to frequency doubling by differentiation and rectification of the square wave, or rectification and shift of the triangle wave.

Figure 6 shows how a single op-amp is used for both the functions of a phase-sensitive detector and as an integrator. With S_2 closed and S_1 operated at the reference frequency the circuit acts as a half-wave, phase-sensitive detector, the rectified and filtered signal input being held on capaciter C_5. If both S_1 and S_2 are now opened, the circuit changes to an integrator with the initial condition set on C_5. In IC_3, two such circuit elements are interconnected along with an inverter to form a harmonic oscillator loop. The fourth op-amp is used as an output buffer. IC_4 is a SE 556 used for timing the overall circuit operation, and as a flip-flop to derive a pulse whose width is proportional to heading angle.

Heading angle ψ is evaluated by first obtaining K sin ψ and K cos ψ by half-wave phase-sensitive detecting the sensor outputs, setting these as initial conditions for the two integrators forming part of the harmonic oscillator loop, and initiating the oscillations. The flip-flop is set at the start of the oscillation and reset by the first negative-going zero crossing of the oscillator output. The flip-flop output width, which is proportional to heading, is averaged, offset and buffered to give the d.c. value of heading. Figures 7 and 8 show the typical waveforms.

PERFORMANCE

To calibrate the system, the sensor is placed on a non-magnetic stand capable of being rotated 360 degrees in the horizontal plane and graduated every 1 degree with an accuracy of 0.1 degree. The gain of the phase-sensitive detector has been set to obtain a K value of about 4 volts. R_{28} and R_{29} are used to offset-null K sin ψ and K cos ψ, such that the positive and negative maximum magnitudes obtained by variation of ψ are equal. Adjustments of R_{30} sets the clock frequency and indirectly the gain of the output. With the clock frequency set as one third of the harmonic oscillator frequency, the maximum variation of the final output is 5 volts. R_{31} is used to offset-null the output and, along with R_{30}, to obtain 0 to 5 volts for variation of heading 0 to 358 degrees.

A 2-degree changeover zone of uncertain heading exists. Accuracy depends primarily on the windings within the FD 09-0101-1 flux detector. Overall system accuracy is better than 1 deg. Table 1 shows the typical output variation with heading and change with temperature.

A count obtained by gating a crystal-derived pulse train by the flip-flop output may be used to get a digital indication of heading if desired.

Copies of printed-board layout and component placement diagram may be obtained from this office by sending an A4, addressed and stamped envelope, marked 'HEADING'.

Table 1, showing output variation with heading and change with temperature

Angle in degrees	Heading output in volts as a function of temperature 25°C	0°C	60°C
000	0.008	0.004	0.004
030	0.443	0.426	0.428
060	0.840	0.835	0.836
090	1.242	1.237	1.237
120	1.649	1.644	1.644
150	2.075	2.071	2.069
180	2.508	2.506	2.503
210	2.930	2.930	2.925
240	3.338	3.341	3.336
270	3.740	3.744	3.737
300	4.147	4.159	4.147
330	4.573	4.588	4.570
358	4.988	5.009	4.999

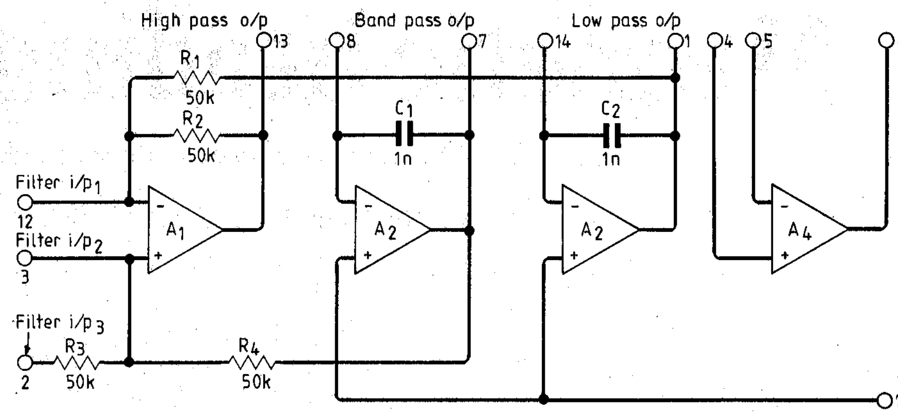


Fig. 3. Burr-Brown UAF 41 schematic

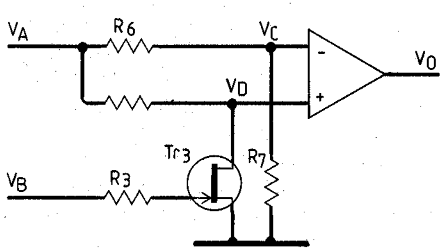


Fig. 4. Frequency-doubled reference circuit schematic

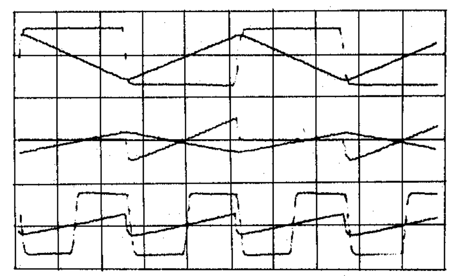


Fig. 5. Upper trace: triangle wave and square wave at frequency f. Middle trace: triangle and fet drain wave-form. Lower trace: sawtooth and comparator output at 2f. (All traces vertical scale 20V/div. and horizontal scale 0.1ms/div.)

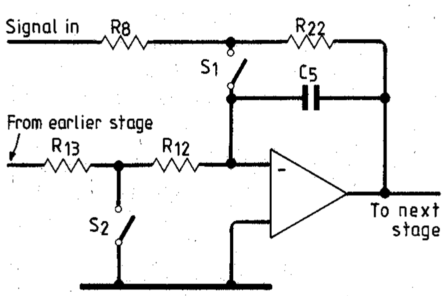


Fig. 6. Op-amp time shared between phase-sensitive detector and integrator schematic.

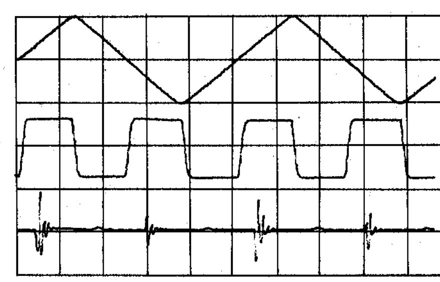


Fig. 7. Upper trace: sensor excitation (Tr_1, Tr_2 emmitters, 10V/div.) Middle trace: phase-sensitive detector reference (IC_1, Pin6, 20V/div.) Lower trace: typical sensor output (500 mV/div.) (Horizontal scale 0.1ms/div.)

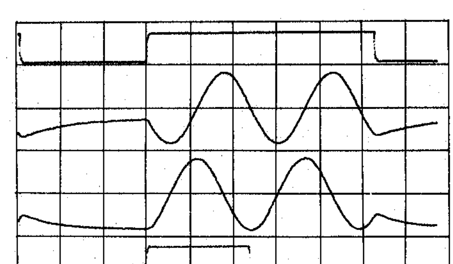


Fig. 8. Upper trace: clock output (IC_4, Pin 9, 20V/div.) Second trace: phase-sensitive detector (sin)/harmonic oscillator output (IC_3, Pin 7, 5V/div.) Third trace: phase-sensitive detector (cos)/quadrature output (IC_3, Pin 1, 5V/div.) Lower trace: flip-flop output (IC_4, Pin 5, 20V/div.) (Horizontal scale 10ms/div.)

References

1. Neil Pollock. Electronic compass using a fluxgate sensor. *Wireless World*, October, 1982.
2. Electronic Design – practical guide for synchro to digital converters. *Electronic Design* 9 April, 1970.