REMOTE SENSING OF A CAPACITANCE MANOMETER PRESSURE MEASUREMENT HEAD

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During the active phase of JET, an accurate measurement of absolute pressure in the range 10^{-1} to 10^{3} mbar is needed for tritium gas accounting when the Neutral Injector cryopumps are regenerated. Pirani gauges which cover this pressure range are prone to drift and give an indication of pressure which is gas dependant. Capacitance manometer pressure gauges, a typical example of which is the MKS Baratron©, are well suited to the measurement of absolute pressure in this range. A system has been developed to remotely sense the capacitance of a Baratron head. The Baratron electronics is replaced by a circuit containing only passive, radiation resistant components. Cables up to 100m long connect the measurement head to detection electronics located outside the Torus Hall. Low resolution data at high sample rate is processed to give a reading with 12 bits of resolution at 1 reading per second.

1. OVERVIEW

A capacitance manometer pressure measurement head forms part of a parallel resonant circuit (fig. 1). Two 50 ohm coaxial transmission lines, up to 100m in length, are inductively coupled to the circuit. A pulse generator delivers pulses of 70 nsec duration and 80V amplitude through one of the transmission lines to the head circuit. This causes the circuit to resonate at a frequency of approximately 8.4MHz. The resulting exponentially decaying sinusoidal signal is coupled to the second transmission line and delivered to detection circuits. The signal is filtered to remove interference. A logarithmic amplifier compresses the signal, reducing the amplitude variation while retaining frequency information. A comparator converts the signal to a pulse train at logic levels. The resonant frequency of the head circuit is determined by measuring the duration of a fixed number of cycles of the pulse train. The resulting samples have a resolution of 6 bits at a sample rate of 40000 samples per second. Digital filtering and decimation allows sample rate to be traded for resolution. By reducing the sample rate to 1 sample per second 12 bits of measurement resolution can be achieved.

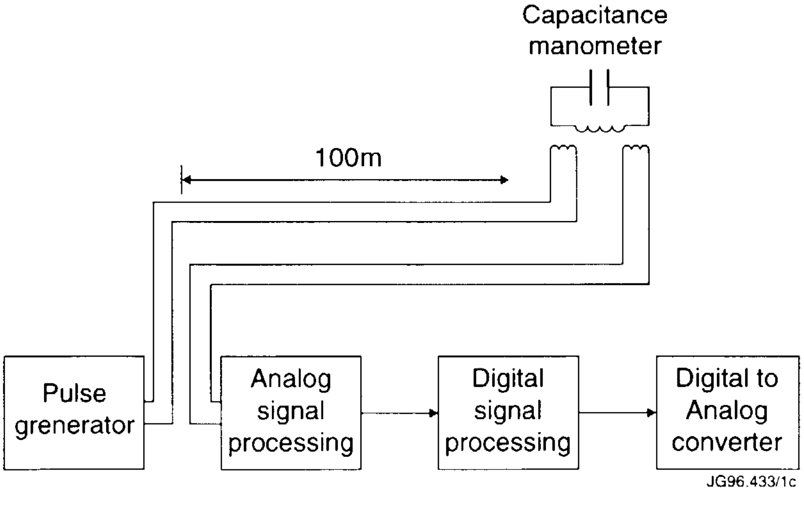

Fig. 1 Overview of capacitance manometer remote sensing system.

2. MEASUREMENT HEAD

The measurement head consists of the diaphragm assembly from a type 122 Baratron mounted in a thick walled aluminium tube with a printed circuit board and connectors (see fig. 2).

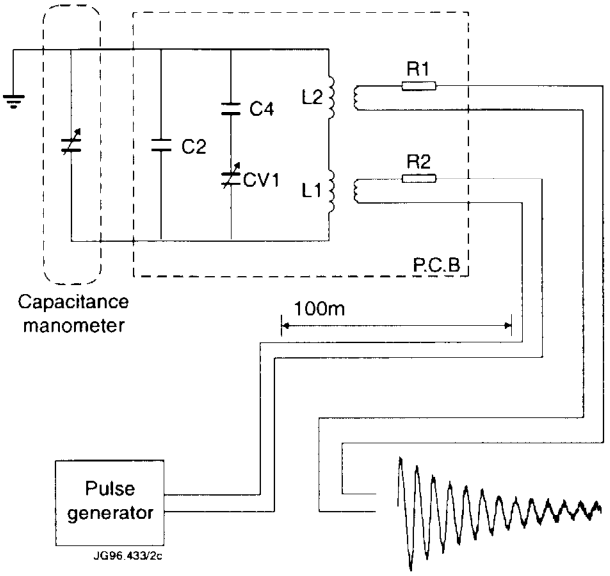

Fig.2 Capacitance manometer measurement head.

The aluminium provides good shielding to Radio Frequency interference. The capacitance manometer is part of a high Q parallel resonant circuit. The inductors L1 and L2 are connected in series electrically but sited physically in anti-parallel resulting in an inductance with high immunity to external magnetic fields. The circuit capacitance is made up of the manometer capacitance in parallel with C2, which determines the centre frequency, and C4 in series with CV1 which allow the centre frequency to be adjusted. The inductors are loosely coupled to the transmission lines by a single turn loop. A resistor matches the impedance of the circuit to the transmission line. Coupling between the transmission lines and the head circuit is predominantly resistive (i.e. non-reactive) ensuring a minimal effect on resonant frequency. The electrical components are chosen for their very low temperature coefficients and all head materials are radiation resistant.

The centre frequency of the head circuit is 8.4MHz. The frequency varies from approximately 8.0MHz to 8.8 MHz over the range of the input signal. The choice of centre frequency was a compromise between the loss characteristics of the transmission cables, the size of the inductors, stray capacitance effects and the need to maintain a high Q to maximise the available signal.

3. ANALOG SIGNAL PROCESSING

A pulse generator delivers pulses of 80V amplitude and 70ns duration at a rate of 40kHz to the measurement head through one of the transmission lines. An exponentially decaying sinusoidal signal at the head resonant frequency is coupled to the second transmission line and delivered to detection circuits (see Fig. 3).

3.1 Bandpass filter

The signal from the transmission line passes through a 12th order, low Q, bandpass filter which removes interference. The filter passband extends from 4MHz to 12MHz. The attenuation is 60dB at 28MHz which is at the low end of the frequency range used by the JET ICRF heating system. The filter has low phase distortion around 8MHz and the low Q design ensures that the filter transient response does not distort the input signal. The filter also incorporates a diode limiter to protect the subsequent amplifier stage.

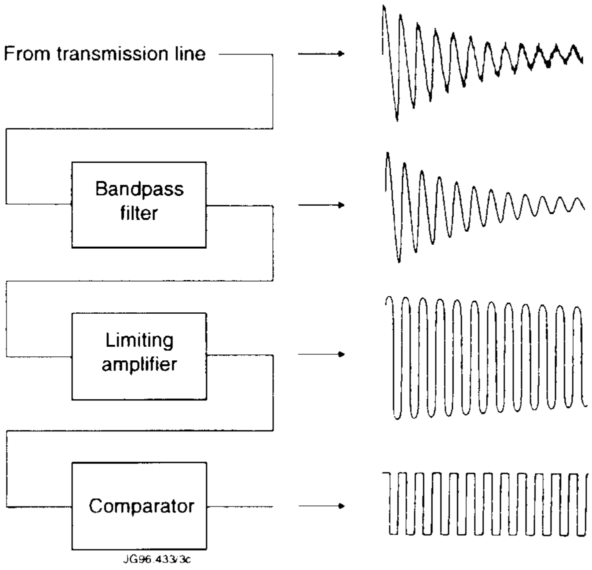

Fig. 3 Analog signal processing chain

3.2 Limiting amplifier

The bandpass filter is followed by a limiting amplifier. A 5 stage design, based on logrithmic function blocks, compresses the exponentially decaying sinusoid reducing amplitude variation while retaining frequency information. The output is a nominally constant 0dBm into 50 ohms for an input signal range of -60dBm to +10dBm.

3.3 Comparator

A comparator circuit converts the limiting amplifier output to a pulse train at logic levels. The comparator output consists of bursts of approximately 100 cycles at the resonant frequency of the head. The repetition rate of the burst signal is 40KHz.

4. DIGITAL SIGNAL PROCESSING

The pulse train from the comparator is processed by a MACH 445 complex programmable logic device (CPLD). The functional requirements of the CPLD are described using Boolean logic statements and programmed into the device.

4.1 Mode of operation

The system uses two clocks CLK1, a 14.31818MHz quartz oscillator, generates TRIG (see Fig. 4). One clock pulse is gated to the TRIG output every 358 clock cycles giving a pulse repitition rate of 40KHz. This signal feeds a pulse amplifier which in turn drives the head circuit. CLK0 is a 50MHz quartz oscillator and is used for all other timing and control functions including frequency measurement, digital filtering, sample rate decimation, signal scaling and D/A interface. By using separate clocks for generating TRIG and measuring frequecny the phase of the input signal WRT CLK0 changes from sample to sample. This causes a one bit jitter on the measured input signal. The jitter on a sequence of readings contains information about quantisation noise. A low pass digital filter removes the quantisation noise, increasing the signal resolution in the process. The signal, which is now oversampled, is decimated producing an output signal which is still Nyquist sampled. A D/A converter produces a 0-10V output covering the measurement range of the head.

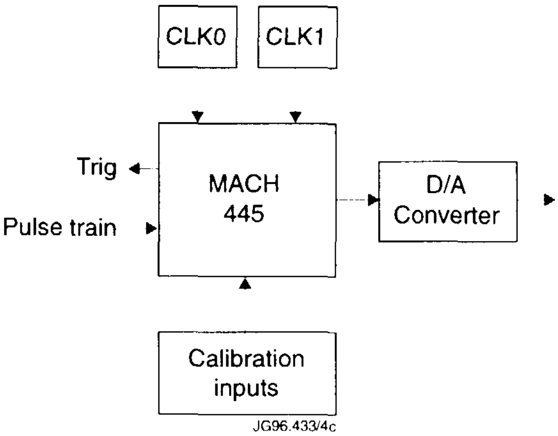

Fig. 4 Digital processing and analog interface.

4.2 Frequency measurement

The frequency of the input signal is measured by counting cycles of CLK0 (50MHz) for a predetermined number of cycles, typically 100, of the input signal. The resulting sample is inversely proportional to the resonant frequency of the head circuit. The resolution of the sample is 6 bits.

4.3 Filtering and sample rate decimation

The readings from a number of samples are accumulated in a binary counter. The high order bits of the counter give a block average of 2,4,8 or more samples. Averaging is a low pass filtering process with a magnitude characteristic which tends to SIN(x)/x. Averaging up to 40,000 samples increases the resolution of the signal to 12 bits with a reduction in the sample rate to 1 reading per second. The variation of vacuum pressure during regeneration is relatively slow is is well covered by this sample rate. Other applications, for example vacuum interlock, require higher sample rates which can be achieved but at lower resolution.

4.4 Scaling and calibration.

The signal is scaled to give a 0-10V output over the input pressure range of the head. Inputs to the MACH445 allow the following to be set.

1. The number of cycles of the input signal per sample.
2. The number of samples to accumulate. (gain control)
3. The number of bits in the accumulator. (resolution and sample rate control)
4. An accumulator pre-load value. (zero offset)

5. RESULTS.

Laboratory tests were carried out on the design and the system output plotted with the output from a standard Baratron as a vacuum vessel was vented from <1mbar to atmosphere. Fig. 5 shows a graph of the two signals.

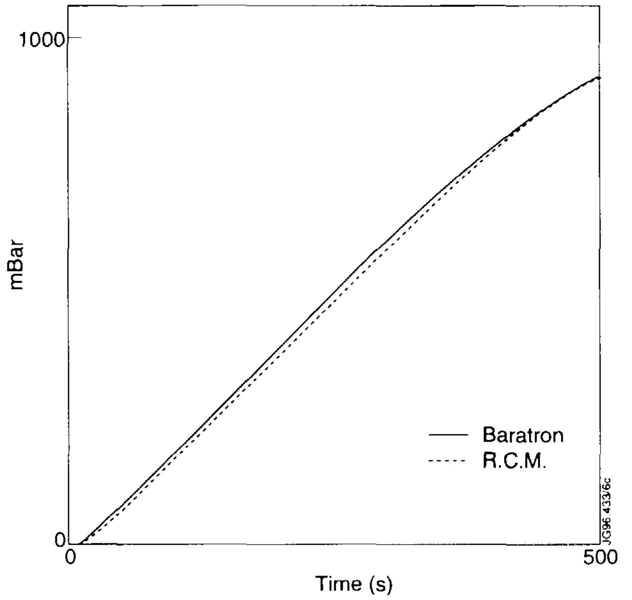

Fig. 5 Comparison between a Baratron and the Remote Capacitance Manometer (R.C.M.).

The output is linear with pressure over most of the signal range with some lack of sensitivity at the low end of the scale and too much sensitivity at the top end.

During the active phase of JET it will be neccessary to have an absolute pressure measurement in the range 0.1 mbar to 1 bar to perform accurate accounting of tritium released from the Neutral Injection cryopumps. Fig 6 is the output from the Remote Capacitance Manometer during a regeneration of one of the Neutral Injector cryopumps, Fig.7 is the output from a pirani auge recorded at the same time. The innacuracy in the reading from the gas dependant pirani gauge is clearly seen.

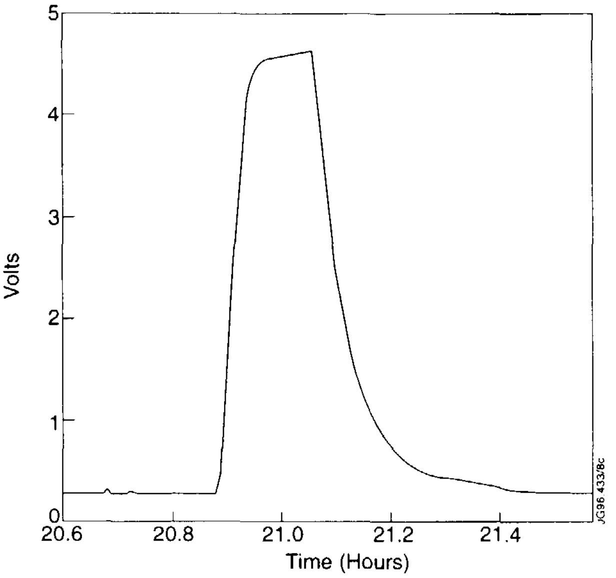

Fig. 6 Remote capacitance manometer output signal during regeneration

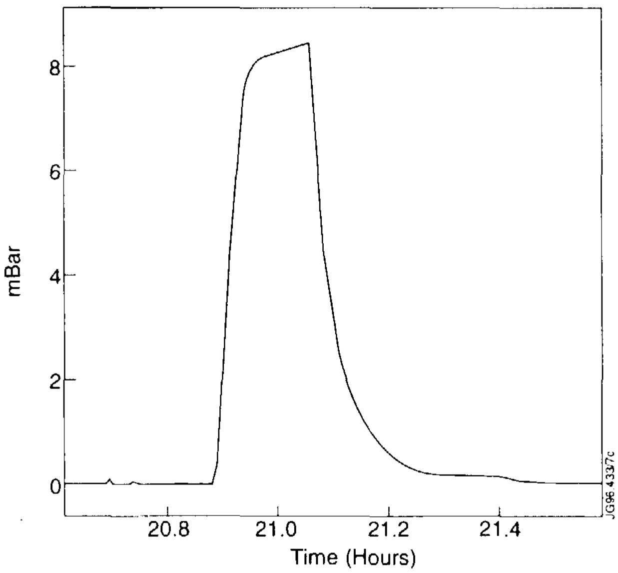

Fig. 7 Pirani gauge output during regeneration

6. FUTURE DEVELOPMENTS

The resolution/sample rate trade off is affected by the cutoff characteristic of the digital decimating filter. Block average filtering is easily achieved with binary counters and acts as a useful but non ideal filter. A dedicated DSP device would allow a better filter to be defined at the cost of a more complex system. The logic device would still be required but a smaller, faster device could be used resulting in an improved measurement of the head resonant frequency. A modification to the system to linearise the D/A output by using a table lookup EPROM between the CPLD and the D/A is currently being pursued.