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DESIGN NOTE

An improved MOSFET-based Robinson oscillator for NMR detection

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Abstract. The design and performance of a modified version of the Robinson oscillator using MOSFETs are described. The NMR detector, which offers excellent sensitivity, is capable of operating at very low RF levels (down to 1 mV) and permits satisfactory recording of weak NMR signals even at room temperatures. The circuit is very simple to implement and requires no critical components or layout.

1. Introduction

Earlier forms of NMR spectrometers employed either Q-meter circuits or radio frequency bridges for detecting resonant absorption. Normally these circuits possess several disadvantages, for example their response to the unwanted dispersion component along with the absorption signal and susceptibility to microphonics (Deschamps *et al* 1977).

For simplicity and ease of operation it is often convenient to use a self-oscillating detector. Two types of such oscillators are commonly used: the marginal oscillator, a well known version being the Pound–Knight–Watkins spectrometer (Pound and Knight 1950, Watkins and Pound 1951); and the Robinson oscillator (Robinson 1959, 1965, 1982, 1987, Faulkner and Holman 1967). In these oscillators susceptibility to microphonics can be reduced by typically an order of magnitude compared with a similar *Q*-meter circuit.

Since the operation of marginal oscillators depends on the non-linear characteristics of the device used (Sullivan 1971), their sensitivity tends to be less than that of *Q*-meter circuits, and further they are difficult to operate at low RF levels. These drawbacks of the marginal oscillators can be overcome to a good extent by the use of a Robinson oscillator, where the RF feedback needed to sustain oscillations is derived from a limiter stage. This circuit is particularly useful for measurements where low RF levels are required. Robinson oscillators are also considerably less sensitive to the unwanted dispersion component. Robinson oscillators have recently gained much popularity as an efficient NMR detector because of these features.

Several versions of Robinson oscillators, including those employing integrated circuits (Deschamps *et al* 1977) have been published. The latter versions using integrated circuits however suffer from reduced sensitivity resulting from the relatively low input impedance and the poor noise characteristics of the integrated circuits used.

We describe below a much simpler version of a Robinson oscillator based on MOSFETs, which can be operated at RF levels down to 1 mV. The high transconductance, superior noise characteristics and better high-frequency performance of the MOSFETs have been fully exploited here to achieve the adequate signal-to-noise (SN) ratio required for recording weak NMR signals even at room temperatures.

2. Description of the circuit

The circuit, shown in figure 1, comprises three stages: (i) a RF level limited oscillator; (ii) a detector; and (iii) a low-noise amplifier.

Proper design of the oscillator stage is of much importance as it determines the minimum RF level at which the circuit can be operated and the maximum sensitivity that can be achieved. The active devices used for the oscillator should have an input impedance that is much higher than the shunt impedance of the nuclear resonance circuit, which in practical circuits is typically a few thousand ohms. Later versions of Robinson oscillators have been using JFETs as the active devices. However, their input impedance is not high enough to prevent the *Q*-value of the tank circuit being slightly affected. Operation at very low RF levels using such circuits is also very difficult, mainly due to poor transconductance of conventional JFETs.

To overcome some of these disadvantages we have adopted MOSFETS (3N 200) as the active device. MOSFETS have a much higher transconductance value than JFETS

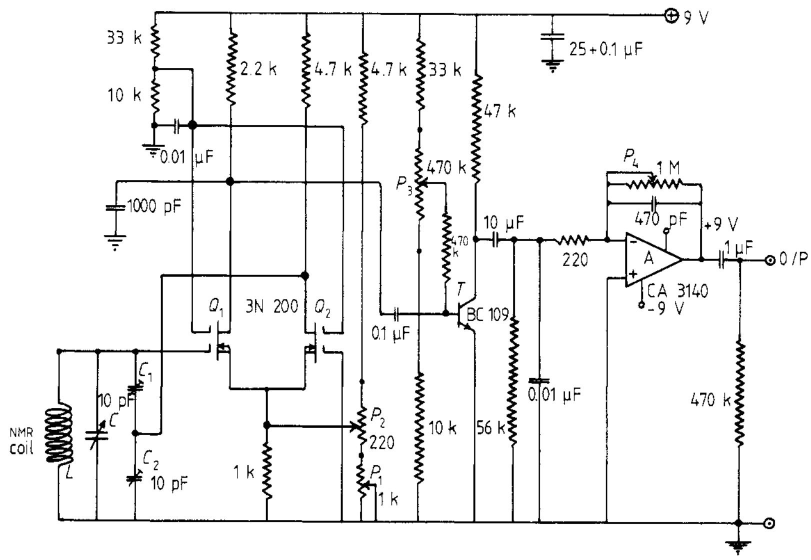

Figure 1. A schematic circuit of the MOSFET-based Robinson oscillator.

and they provide excellent high-frequency characteristics as well as very low $1/f$ noise; these factors make them a good choice for the long-tailed pair used in a Robinson oscillator. The better noise characteristics of MOSFETs and their tolerance to microphonics are also added benefits.

As in many versions of Robinson oscillator (Faulkner and Holman 1967, Deschamps *et al* 1977), in the present design the operating conditions are chosen to give nearly perfect limiting, independent of the oscillation level. As a result the absorption signal does not appear as a component of the drain current and hence a separate demodulator is used. Conventional circuits have employed highly specialised diodes, capable of working at low levels, as a rectifier (Faulkner and Holman 1967, Deschamps *et al* 1977). To avoid the requirement of critical components, and also to use components commonly available, we have utilised a base emitter junction of a silicon transistor (BC 109), properly biased to act as an efficient detector. This arrangement can perform well at levels much lower than those the diode rectifier can respond to. Besides, at the collector of the transistor, a stage of AF amplification is also obtained as a bonus.

The SN ratio of the final output signal is affected considerably by the noise contributed from the AF stage. In order to minimise this noise we used a single low-noise op-amp (CA 3140) for the final AF amplification, instead of several transistor amplifier stages as in some earlier circuits (Robinson 1982, 1987). The op-amp gain can be adjusted conveniently either for boosting weak NMR signals or for preventing saturation of the amplifier in the presence of strong signals.

Since the DC power requirement for the present design is rather low, it enables standard 9 V cells to be used to power the complete circuit. As a result the interference due to additional noise generated by power supply stabilisers, present in some earlier circuits (e.g. Robinson 1982), is eliminated totally in the present design.

3. Operation and performance

For convenience the values of the components in the tank circuit were so chosen to yield an oscillation frequency near 12 MHz.

Keeping a reference sample in the NMR coil, initially the presets P_1 and P_2 (figure 1) are adjusted to select the required RF level. The biasing of the detecting transistor T is then adjusted, using the preset P_3, such that T is made slightly conducting. Then, viewing the absorption signal pattern on an oscilloscope, P_3 (as well as the preset P_4 controlling the gain of the op-amp A) are properly adjusted to get a signal having the best SN ratio. Under this condition the circuit will yield optimum SN for any other signal at the particular RF level. For recording a signal at a different RF level one may re-optimise the SN by adjusting the presets P_3 and P_4.

The circuit shown in figure 1 has been operated at RF levels ranging from 150 mV down to 1 mV. The silicon transistor rectifier arrangement has been observed to work excellently even when the RF level at its base is less than 20 mV. This is a real advantage compared with the

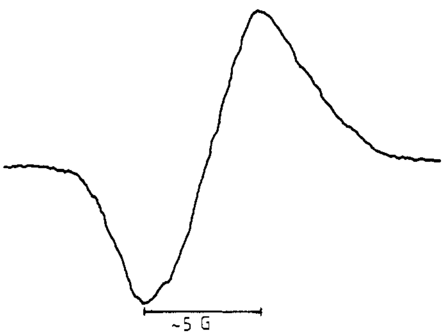

Figure 2. Tracing of the derivative curve of proton resonance in polycrystalline NH_4Cl at 30 °C (resonance frequency ~12 MHz; RF level ~20 mV)

diode rectifier set-up in some earlier circuits. Besides, the noise interference in the detected signal output of this rectifier is found to be considerably less than that originating from a diode rectifier arrangement. This in turn serves to enhance the overall SN ratio of the output signal compared with some earlier circuits.

The performance of the complete circuit was tested by recording weak NMR signals, especially from solids, at room temperature. The recordings of the signals were entirely satisfactory. Figure 2 shows a typical tracing of the derivative curve of proton resonance in polycrystalline NH_4Cl recorded at room temperature (30 °C).

4. Conclusion

The MOSFET-based Robinson oscillator circuit, which uses only commonly available components, gives a much improved performance compared with conventional NMR detector circuits, even for room-temperature operation. The simple nature of the present circuit enables a compact printed circuit layout (~4 cm × 6 cm) without necessitating any complex interstage shielding or any critical layout of components. The enhanced sensitivity allows it to operate at very low RF fields and the overall simplicity of the circuit makes it an excellent NMR detector, especially useful for probing weak signals.

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