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A simple linear magnetic field sweep generator for magnetic resonance experiments

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Abstract. A simple and inexpensive linear magnetic field sweep generating system suitable for magnetic resonance experiments is described. The circuit, utilising a modified IC bootstrap configuration, generates field sweep over a wide range of sweep durations with excellent sweep linearity.

1. Introduction

In the earlier broadline NMR spectrometers, the linear magnetic field sweep required to record the NMR spectra was obtained using mechanical arrangements (e.g. Sthanapathi *et al* 1977). In those set-ups the reference voltage of the control unit of the magnet current stabiliser was varied within a prescribed range by mechanical arrangements such as a clockwork mechanism or motor drive in conjunction with a helical potentiometer. However, these systems possess several inherent drawbacks including electrical noise produced by the movement of the slider on the potentiometer, the eventual degeneration of the potentiometer through wear, etc. With prolonged use these potentiometers will become excessively noisy and the sweep will no longer be steady.

Electronically controlled field sweeps have been employed recently, and these can be made highly flexible as well as reliable. In one such system (Vander Ven 1968) an op-amp integrator circuit generates a sweep voltage which is used to vary the magnet current to effect the field sweep. However, it has been observed that the sweep generated by the integrator circuit becomes increasingly non-linear with increasing sweep time. Improved circuits to provide sweeps of better linearity have been proposed recently. However, one such circuit (Khandozhko *et al* 1980), which claims a far better sweep linearity than earlier ones, employs rather complex circuitry with associated difficulties for implementation.

The main features of the field sweep unit presented in this note are its simplicity and excellent sweep linearity. Here, for generating the sweep, a conventional IC bootstrap ramp generator has been modified so that for any desired sweep speed the field can be varied in an almost perfectly linear manner with respect to time by appropriately presetting the circuit parameters.

2. Description of the field sweep unit

The circuit of the field sweep unit, which is shown in figure 1, consists of three main sections: (i) a generator of linear sweep voltage, (ii) DC amplifier stages for enhancing the sweep signal to the required output power level and (iii) the magnetic field sweep generator coils.

A conventional IC bootstrap ramp generator consists of an op-amp functioning as a voltage follower. It has, however, been observed that the unity gain voltage follower cannot maintain good sweep linearity for different sweep durations. An analysis of the typical bootstrap ramp circuit, as given below, shows that a modified IC bootstrap ramp generator can provide a very much improved sweep linearity.

The slope error of a bootstrap ramp circuit is known to be proportional to $(1-A+R/R_i)$, A being the amplifier gain, R_i the input impedance of the amplifier and R the charging resistance (Millman and Taub 1965). This indicates that if a unity gain voltage follower employing a commonly available op-amp is adopted as a bootstrap long-duration ramp generator, then R/R_i cannot be kept small enough to minimise the slope error. However, if FET input op-amps are used, then in principle one should get perfectly linear sweeps since $R/R_i \simeq 0$. Though this is true to some extent, in practice it has been observed that such perfect linear sweeps are never generated in the case of circuits employing FET input op-amps like CA 3140 or OPA 121 with unity gain. The reason evidently is due to the non-ideal performance of the remaining

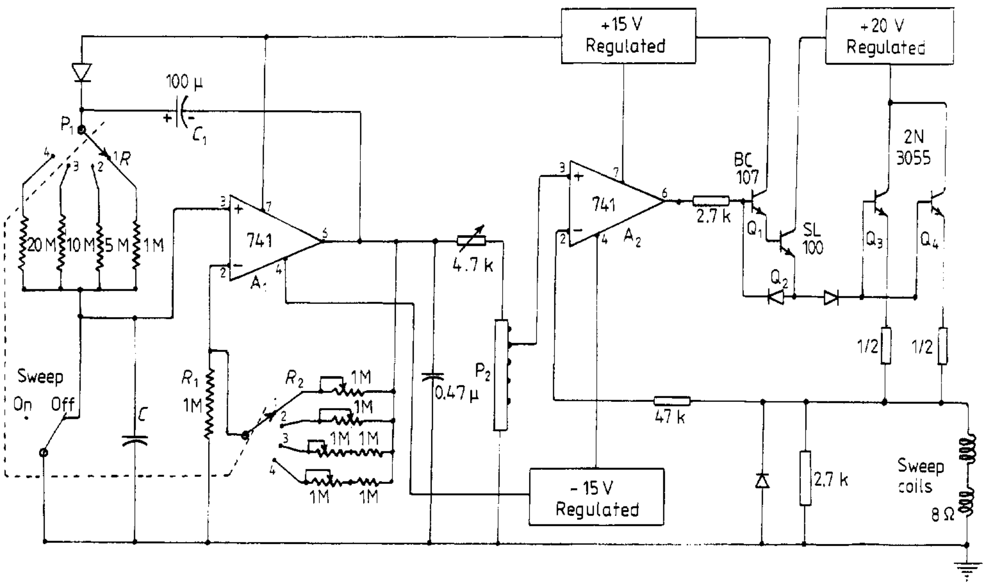

Figure 1. Schematic circuit of the field sweep generator.

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components such as the charging capacitor, bootstrapping capacitor etc, which contribute to the slope error. The slope error for the bootstrap ramp circuit can then be taken as proportional to $(1-A+R/R_i+k)$, where k stands for the contribution to the slope error by components other than the op-amp. Thus one finds that even an FET input op-amp under unity gain conditions cannot generate perfectly linear sweeps. If, instead, the op-amp gain is chosen to be greater than unity, as $A'=1+R/R_i+k$, we see that the slope error will reduce to zero, thus eliminating any non-linearity. This was indeed observed by us and we have seen that by carefully setting the op-amp gain the utmost in sweep linearity can be obtained for the desired sweep durations. It appears that an op-amp gain greater than unity serves the dual purpose of keeping the sweep time much less than the RC time constant as well as providing the excess gain required to stretch out the non-linearity of a unity gain bootstrap sweep. Both these factors help to obtain excellent sweep linearity.

The modified bootstrap ramp generator forms the first part of figure 1. The op-amp A_1 acts as the bootstrapping amplifier while R and C constitute the charging circuit. In this set-up the sweep speed at the output will be $A'V/RC$, V being the voltage across the bootstrapping capacitor C_1. The maximum sweep output voltage will then be $V_0=A'Vt_s/RC$ so that the sweep time $t_s=V_0RC/A'V$. Provided that C has a low leakage but high charge capacity, then V_0 will approach a saturated value V in a time $t_s=RC/A'$. The sweep duration can thus be varied by changing R or C.

We have designed the circuit to give sweep durations of $\frac{1}{2}$, $\frac{5}{2}$, 4 and 8 min by choosing a constant value for C and varying R. A low leakage tantalum capacitor was chosen for C while an ordinary electrolytic capacitor was chosen for C_1, which should have a value much greater than C. R_2 together with R_1 set the op-amp gain required to obtain the utmost in sweep linearity. By trial R_2 is adjusted to obtain the best linearity for each sweep duration setting.

The linear ramp voltage is then subjected to proper current boosting by the DC amplifying section which consists of an op-amp buffer A_2 followed by the current boosting transistors Q_1–Q_4. On passing this sweep current through a pair of separate field sweep coils the required linear variation in magnetic field is obtained. Variation of the strength of the sweep field can be conveniently done by varying the amplitude of the ramp voltage input to the DC amplifiers. In our case the potential divider P_2 provides a magnetic field sweep range from 0.5 to 8 mT (5 to 80 G) by a factor of two in successive steps.

3. Operation and performance of the field sweep unit

The recordings of the sweep voltages for different sweep durations have shown that the output linearity over the entire range is much better than 0.1%. The linearity of the corresponding magnetic field sweep was also found to be very good. The performance of the complete sweep unit was then tested by recording the proton resonance signal in polycrystalline NH_4Cl. The recording of the signal was entirely satisfactory.

4. Conclusion

The linear magnetic field sweep unit, which uses only commonly available components, gives a much improved performance in comparison with conventional sweep circuits. The modified sweep generator circuit adopted here has a notable advantage in that the amplifier gain can be conveniently manipulated to obtain the utmost in sweep linearity for any desired sweep duration. Besides, unlike the earlier circuits (e.g. Khandozhko *et al* 1980), a separate DC input is not required here to initiate and maintain the sweep. These advantages make the field sweep generator presented here a simple but effective one, as required for the recording of wideline NMR spectra.

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