RF CIRCUIT DESIGN

This month we commence a short series of articles on the design of RF circuits. Each of the articles will merely provide a framework and not necessarily a complete design of the relevant circuit.

Test oscillator

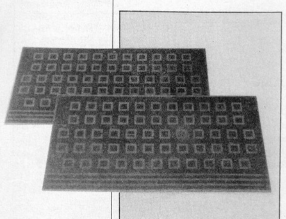

Fig. 1. The copper-clad universal RF board Type 85000 has fifty-seven islands and three isolated tracks for supply voltage or control voltage — such as AGC — lines.

This first article deals with a virtually indispensable unit in RF design: a simple signal generator. This unit provides a signal at a certain frequency and amplitude, and may be frequency- or amplitude-modulated. It is intended to cover a frequency range of 2 — 150 MHz in a number of bands.

Universal RF board

The Type 85000 is an unpierced copper-clad board with fifty-seven isolated islands and three isolated tracks. It is particularly suited to RF circuits because of the large earth plane, and enables the connections of all components to be kept really short — a prerequisite in RF design. Examples of the board proper and of a voltage-controlled oscillator constructed on a copper-clad board are shown in the photographs in Figures 1 and 2 respectively.

Block diagram

The block diagram in Fig. 3 shows that the test oscillator consists of three separate sections: the oscillator; amplitude control; and output buffer. The oscillator is based on a MOSFET, whose mutual conductance, g_m, and consequently the amplitude of its output signal, is controlled by a direct voltage on gate 2.

The amplitude control section monitors the oscillator output and controls gate 2 of the MOSFET accordingly, so that a reasonably constant-level oscillator signal is obtained. This arrangement has the advantage that it enables the oscillator to work over a fairly wide frequency range.

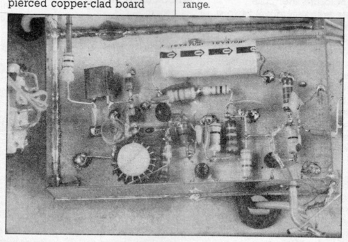

Fig. 2. Example of a voltage-controlled oscillator constructed on a copper-clad board.

The buffer section provides an output impedance of 50 ohms.

Circuit description

The oscillator — see Fig. 2 — is designed around T_1: its frequency-determining components are L_1 and varactors D_1 and D_2. These variable-capacitance diodes are controlled by P_1: a high voltage across them causes a small capacitance, and vice versa. The frequency of an *LC* oscillator is given by

$$f = 1/2\pi\sqrt{LC}\ [\text{Hz}] \qquad (1)$$

where f is the frequency of the oscillator, L is the inductance in henries (H), and C is the total capacitance of the two varactors in series in farads (F).

The ratio between the lowest and the highest oscillator frequency, f_1 and f_2 respectively, depends on the square root of the ratio between the maximum and minimum capacitance, C_2 and C_1 respectively, of the varactors:

$$f_1{:}f_2 = \sqrt{C_2{:}C_1} \qquad (2)$$

The maximum capacitance of the Type BB106 varactor is about five times the minimum capacitance for a reverse bias voltage of 3 of 25 V, so that the frequency ratio is roughly 2.236, or rather more than an octave. The highest attainable frequency is around 300 MHz, but this depends, of course, also on the value of L_1.

The series combination L_2-L_3-L_4 is intended as a sort of wide-band choke. The inductance of L_4 (100 mH) is rather too large for high frequencies, because the reactance at those frequencies amounts to a few kiloohms owing to parasitic capacitances. Lower inductances are, therefore, used for the higher frequencies: L_3 and L_2. Inductor L_2 is only of use at frequencies above 50 MHz: if the oscillator is not required to work on these frequencies, this coil may be omitted and replaced by a wire link.

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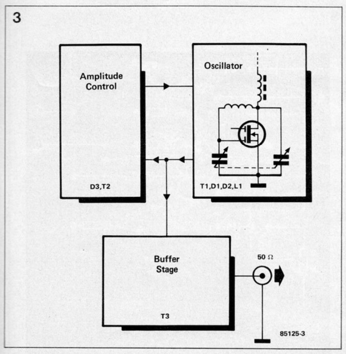

Fig. 3. Block diagram of the RF test oscillator.

The signal at gate 1 of the oscillator is rectified by D_1 and smoothed by R_2-C_3. As soon as the resulting direct voltage rises above 600 mV, the transistor tends to conduct harder, which causes the potential at gate 2, and therefore the oscillator output, to drop. This regulation is necessary if the oscillator is to work over a relatively wide frequency range. Also, without regulation, the output level would vary greatly with tuning: in the present circuit, the output level variation is held within 10 dB, i.e., a ratio of about 1:3.

The oscillator signal is applied via capacitive divider C_7-C_8 to transistor T_3, which is connected as a source follower. The mutual conductance, g_m, of this FET is about 20 mS, so that, since

$$Z_o = 1/g_m \quad [\Omega] \qquad (3)$$

the output impedance, Z_o, is 50 ohms.

Mutual conductance is the ratio of the change in output current to the change in input voltage when the output voltage is held constant. It is measured in siemens (S), which replaced the mho (reciprocal of ohm) some time ago.

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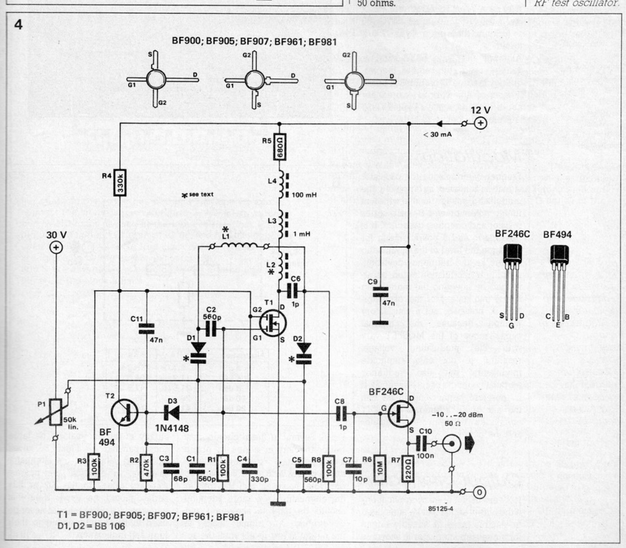

Fig. 4. Circuit diagram of the RF test oscillator.

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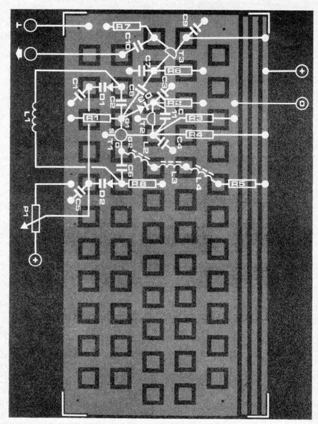

Fig. 5. Suggested component layout of the RF test oscillator.

Parts list

Resistors:
R_1;R_3;R_8 = 100k
R_2 = 470k
R_4 = 330k
R_5 = 680Ω
R_6 = 10M
R_7 = 220Ω
P_1 = 50k linear preset

Capacitors:
C_1;C_2;C_5 = 560p
C_3 = 68p
C_4 = 330p
C_6;C_8 = 1p
C_7 = 10p
C_9;C_{11} = 47n
C_{10} = 100n

Inductors:
L_1 = 0.1 . . . 10mH (see text)
L_2 = 5 turns 0.3 mm dia. (30 SWG) enamelled copper wire on ferrite bead 3×3 mm.
L_3 = 1mH choke
L_4 = 100mH choke

Semiconductors:
T_1 = BF900 or BF905 or BF907 or BF961 or BF981
T_2 = BF494
T_3 = BF246C
D_1;D_2 = BB106 (see text)
D_3 = 1N4148

Universal RF board Type 85000

Frequency range

If varactors Type BB106 are used, the oscillator can be tuned over a frequency range of one octave, i.e., the maximum frequency is about twice the minimum frequency. To cover a frequency range of, say, 2 MHz to 32 MHz (four octaves) four different coils are required for the L_1 position. Since it is not really possible to use a large tapped coil and a range switch — because the resulting stray capacitances would cause unreliable and unstable operation — separate plug-in coils must be used for L_1. At the highest frequencies — above about 150 MHz — the coil should be air-cored; below 150 MHz, it needs to be wound on a dust-iron toroid. Some examples of suitable coils for frequency ranges as stated are:

- 150-300 MHz: 50 mm enamelled copper wire, SWG20 (1 mm dia.), one turn;
- 75-150 MHz: 9 turns 24 SWG (0.6 mm dia.) enamelled copper wire on a Type T50/12 toroid;
- 7.5-15.0 MHz: 70 turns SWG 30 (0.3 mm dia.) on a Type T50/2 toroid.

Although the Type BB106 varactor can be used right across the frequency range, a Type BB105 is better if most of the work is carried out above 100 MHz, while a Type KV1226 is preferable below 20 MHz.

Modulation

Frequency-modulating the oscillator signal is achieved by applying the modulating voltage to the wiper of tuning potentiometer P_1 via a series resistor and coupling capacitor. It is possible to add a potentiometer for adjusting the level of the modulating voltage, i.e. the frequency deviation. Amplitude modulation could be arranged by injecting the modulating signal into gate 2 of the oscillator. This is, however, not a satisfactory method because the internal capacitances of the MOSFET vary with the modulating voltage, resulting in not only amplitude modulation, but also frequency modulation, of the oscillator signal. It is, therefore, better to modulate with the aid of an additional MOSFET connected between the oscillator and the buffer.

Output attenuator

It is very useful in many applications if the output signal can be attenuated in suitable steps. A suitable circuit for a one-step attenuator is shown in

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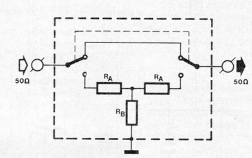

Attenuation	R_A	R_B
2 dB	5,7 Ω	215,2 Ω
4 dB	11,3 Ω	104,8 Ω
8 dB	21,5 Ω	47,3 Ω
10 dB	26 Ω	35 Ω
20 dB	41 Ω	10 Ω

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Fig. 6. Circuit of a possible 50-ohm one-step attenuator. The resistor values in the accompanying table are calculated: in a practical circuit, the nearest standard values should be used.

Fig. 6. Several of these circuits may be connected in series to obtain switch-selected stepped attenuations of, say, 2 dB, 4 dB, 8 dB, and so on. Note, however, that the greater the attenuation, the more attention should be paid to screening and decoupling. Any signal "leaks" at the output at low levels spoil the accuracy of the attenuator. The table accompanying Fig. 6 gives calculated values for the attenuator resistors; in practice, the nearest standard values in the E12 or E24 series should be used. Note that wirewound resistors should never be used in RF circuits owing to their high self-inductance.

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