Fundamentals of oscillators for the microwave range (part 2)

Oscillator design

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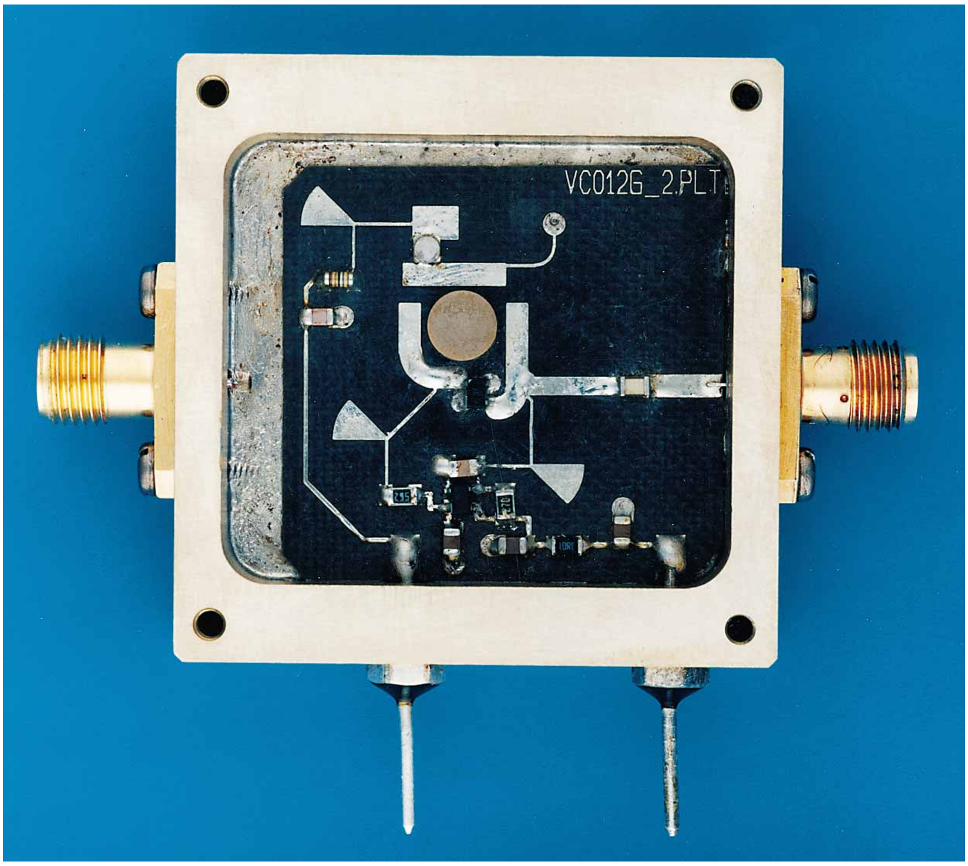
The first part of this article (Components 1/98, pp. 14-16) dealt with the fundamentals of microwave oscillators. This second part concentrates largely on practical applications and examples. As a result of the continuous development of silicon bipolar RF transistors, the latest generation can be used up to very high frequency ranges.



The 12.4-GHz DRO offers the option of a **tuning diode for frequency changing** (package cover removed). The SMA jack on the right is the RF output. (Development and layout: SINTEC GmbH, Böblingen, Germany).

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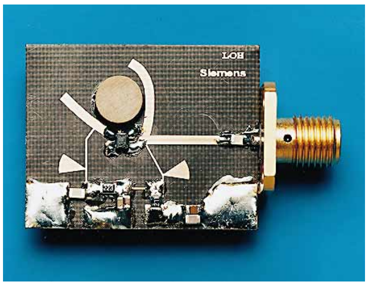
The first and second generations of RF transistors offered transit frequencies f_T of 2.5 and 5 GHz respectively. The third generation raised this to 8 GHz, permitting a wide range of applications to be covered by silicon products. But today's fourth generation holds a special place in the market for discrete semiconductors. This is because its special assembly techniques, similar to those of GaAs FETs, as well as the use of B6HF planar technology, have resulted in transit frequencies of around 25 GHz. The Siemens ground emitter transistors (SIEGET®) BFP 405 and BFP 420 in the SOT-343 package allow oscillators to be implemented with frequencies up to around 12 GHz. What criteria can be used to select the right transistor for a particular application? The relevant data sheets usually indicate the applications for which they are best suited. For oscillators, the following data is important:

- The specified current and voltage ranges of the respective transistor: these determine the oscillator's operating voltage and current and thus its output power.
- The transit frequency f_T for a defined current: silicon bipolar transistors should have a maximum f_T that is twice the operating frequency f_B in view of its effect on the phase noise.
- The S parameters at f_B indicate the small-signal characteristics of the transistor and thus its ability to generate an oscillation at the exciting frequency.
- The compression point P_{-1dB} specifies the approximate value of the maximum possible output power of the oscillator.

The transistor's 1/f noise always represents an important criterion because it is mixed into the carrier by non-linear processes and thus affects the spectral purity of the oscillation. In principle, bipolar silicon transistors have a lower 1/f noise than GaAs MESFETs and HEMTs. The lower the transit frequency, the lower the phase noise of these transistors. The rule of thumb mentioned above should therefore be used to select the transit frequency to be no



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This oscillator **test board** containing the transistor BFP 405 has an output of approximately +3 dBm (2 mW) at 10 GHz.

more than twice the operating frequency while ensuring reliable oscillation.

Dielectric resonators

The use of cylindrical dielectric materials as microwave resonators was described as long ago as 1939, but the implementation had to await the technology of the 1970s. They work by reflecting electromagnetic waves at the boundary layer between the dielectric and the air within the element, producing an energy concentration both inside the resonator and in its immediate proximity. They usually consist of a compound of barium and titanium oxide ($BaTi_4O_9$) with a dielectric constant ε_r of 38. The diameter D of such a resonator can be obtained as a first approximation from the following formula:

$$D = \frac{c}{f_r \sqrt{\varepsilon_r}}$$

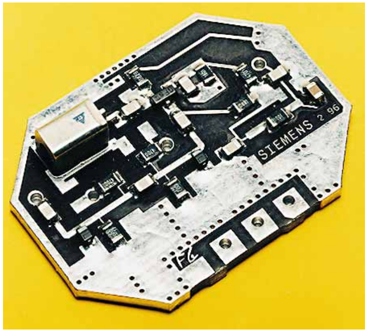
where c is the speed of light, ε_r the dielectric constant and f_r the resonant frequency of the resonator.
The diameter should be selected so that the oscillations are initiated at approximately 200 MHz below the set frequency without a tuning screw or cover. It should be noted that various manufacturers define f_r with the aid of a space configuration (a ceramic cylinder on which the resonator is mounted), so that this value differs from that obtained when the oscillator is coupled to a microstrip line.

Ceramic resonators

Ceramic resonators are of cuboid shape with a coaxial hole and partially metalized surfaces. The connection to the stabilizing oscillator is made via the soldering lug, which is fixed within the hole. As can be seen from its equivalent circuit diagram, this component represents an RF resonant circuit with a typical resistance of 1 to 3 kΩ at the resonant frequency. This frequency is a function of the dielectric constant (typically 21 or 88) and the length of the resonator, the quality term being between 300 and 400. Ceramic resonators up to around 3 GHz are used in real-world applications.

Dielectric resonator oscillator (DRO) with parallel feedback and the BFP 405

In feedback oscillators, the loop gain must be greater than 1 and the phase along the loop in small-signal operation (i.e. at the first moment that the operating voltage is activated) must be an integral multiple of 2π. The feedback is made possible by coupling the dielectric resonator described above to two microstrip lines.
The loop is separated just in front of the transistor base and its ends are reconnected. The reflection factor MAG S11 in small-signal operation is then observed at the oscillator output. It can be optimized by varying the line lengths to size 30, so that the inductive component of the function Z(A0) is zero and the real component 50 Ω. The optimum load impedance Z(ω) is then obtained as an approximation to a purely real 25 Ω. More accurate values can be obtained by means of tuner measurements at the output. This calculation method ensures that the oscillation is reliably excited by the noise signals when the operating voltage is activated, but it provides no information about the large-signal characteristic. The simulation is based on the transistor's measured S parameter in small-signal operation, the microstrip-line models and the resonator model supplied with the program (Harmonica).
If a nonlinear model of the transistor is available (see BFP 405 data sheet), the oscillator's output power



The **multi-layer board** made of epoxy composite accommodates an RF mixer in addition to the 2.45-GHz oscillator.

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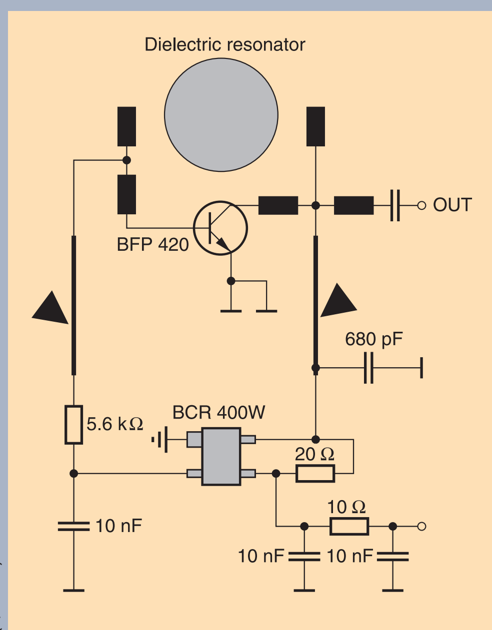
DRO at 12.4 GHz (schematic)



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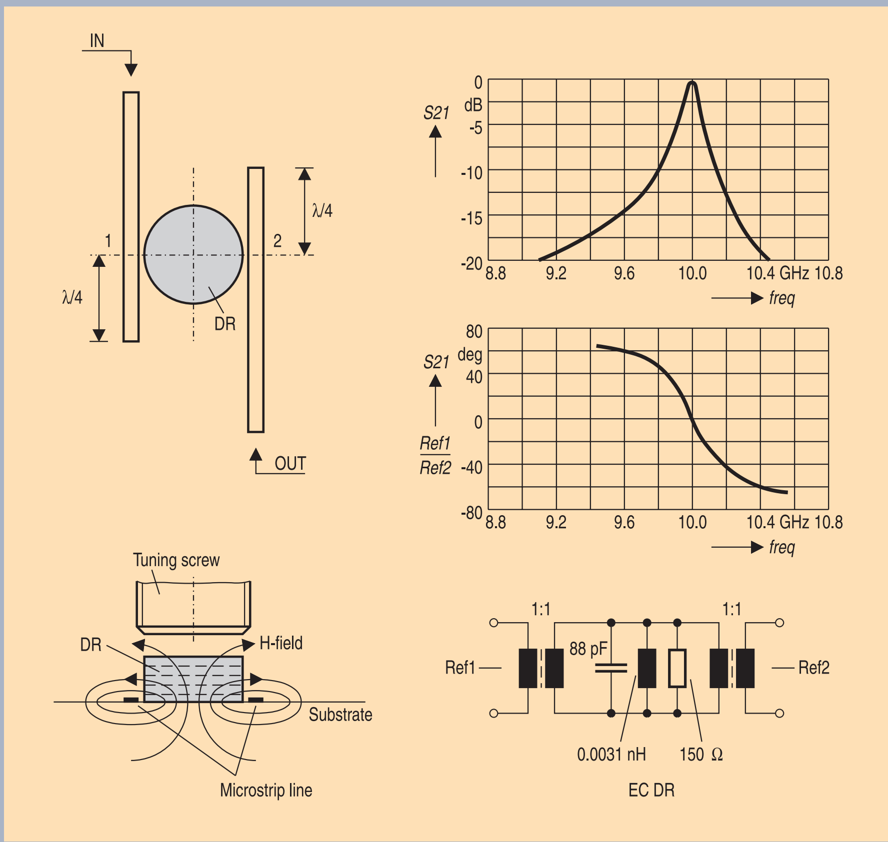
Schematic diagram of the DRO at 12.4 GHz. The BCR 400W bias controller represents a good choice for **stabilizing the transistor** BFP 420.

Configuration of the microstrip lines



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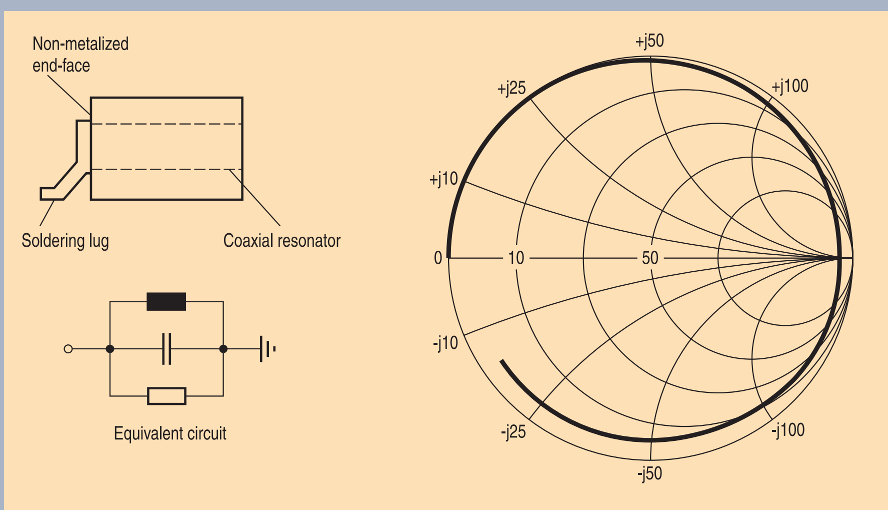
Magnetic coupling of the resonator to two microstrip lines with S parameters and an equivalent circuit (EC) for the resonator. The phase angle with respect to the reference level 1/2 is 0° in the resonance condition.

Ceramic resonators – Smith chart



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Side view and equivalent circuit of a **coaxial resonator**. The measured parameter S11 in the Smith chart is shown on the right up to 3 GHz. The resonant frequency is approximately 2.4 GHz.

as well as its harmonics and optimum load impedance can be calculated. The latest developments even allow the oscillator's phase noise to be simulated.

DRO with parallel feedback and a SIEGET BFP 420

The relationships underlying the operation of a BFP 420 are similar to those of the other DRO. However, the BFP 420's output power increases to typical values of 10 dBm (10 mW) with a current consumption of around 30 mA at a collector-emitter voltage of 3.5 V.
Thanks to its higher reverse transfer capacitance C_{cb} of 170 fF, the BFP 420 has a considerably lower risk of destruction due to electrostatic discharge, whereas the BFP 405 requires a suitable protection circuit. On the other hand, it has a lower gain at high frequencies, so that the design of the oscillator package becomes more important. Thus an RF oscillation can be generated at 12.4 GHz only when the losses due to the resonator coupling are reduced with the aid of a suitable package cover.
The side view of a coaxial resonator shows its cuboid shape and coaxial cavity. As the equivalent circuit diagram shows, this is a high-frequency resonant circuit. The Smith chart shown on the left is obtained when the parameter S11 is measured up to 3 GHz at a resonant frequency of around 2.4 GHz. Both ceramic and dielectric resonators are available from Siemens Matsushita Components.

SUMMARY

Today's fourth generation of silicon products for microwave oscillators – the SIEGET BFP 405 and BFP 420 in the SOT-343 package – allow the implementation of oscillators with frequencies up to about 12 GHz.

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