Proposed Adjustable Tuned Circuits for Microelectronic Structures

The use of integrated circuits has led to a re-evaluation of the methods of circuit design. While active elements are very cheap, inductors are very expensive since they can be incorporated only with difficulty as actual elements in an integrated circuit[1] and then only as fixed components. Since it is often of interest to have variable inductances available for tuning purposes, we here investigate one method of obtaining electronically adjustable single or coupled coils.

Recently a proposed gyrator type circuit, suitable for microelectronic structures, has been suggested.[2] Treated as a two-port, the device is described by

$$v_1 = -R_b i_2 \tag{1a}$$

$$v_2 = R_a i_1 \tag{1b}$$

where R_a and R_b can assume reasonable time variations via electronic (voltage) control. It is convenient to designate this two-port by the dashed portion of Fig. 1. If one loads this device with a capacitor, as also shown in Fig. 1, then, since $i_2 = -d(cv_2)/dt$, one sees at the input

$$v_1 = R_b \frac{dR_a c i_1}{dt}. \tag{2}$$

If one makes R_a or R_b adjustable (as previously described[2]) but then fixed once adjusted, one obtains a variable inductor of inductance $l = R_a R_b c$. By then shunting the input port with another capacitor a voltage controlled variable frequency resonator is obtained.

To realize this last described tuned circuit, two capacitors are required, namely the one at the "gyrator" output and one at the "gyrator" input to resonate with the simulated inductor. In the original circuit,[2] two coupling capacitors at the input and output were envisaged. It appears that by the use of more refined circuitry it is possible to eliminate these; in any case, that at the output, for example, serves no purpose if the output itself is terminated in a capacitor and is not connected to any other circuit element. Consequently, for present purposes the only parts which have to be realized are resistors, transistors, and the two capacitors (which in fact have a common terminal) required for the tuned circuit; the circuit does, therefore, seem natural for integration.

Once the above principle is understood, it is an easy step to obtaining electronically adjustable coupled coils. For this, consider the circuit of Fig. 2(a) which on analysis yields

$$v_1 = R_{b_1} \frac{dR_{a_1} c_1 i_1}{dt} + R_{b_1} \frac{dR_{b_2} c_1 i_2}{dt} \tag{3a}$$

$$v_2 = R_{a_2} \frac{dR_{a_1} c_1 i_1}{dt} + R_{a_2} \frac{dR_{b_2}[c_1 + c_2] i_2}{dt}. \tag{3b}$$

If all parameters are chosen constant, as well as

$$R_{a_1} R_{a_2} = R_{b_1} R_{b_2}, \tag{4}$$

then the two-port of Fig. 2(a) is equivalent to the coupled coils of Fig. 2(b) having the inductance matrix

$$L = \begin{bmatrix} R_{a_1} R_{b_1} c_1 & R_{a_1} R_{a_2} c_1 \\ R_{a_1} R_{a_2} c_1 & \frac{R_{a_1}}{R_{b_1}} R_{a_2}^2 (c_1 + c_2) \end{bmatrix}. \tag{5}$$

We again note that this can be made adjustable by varying R_{a_1}, say, which, if we desire to retain reciprocity in the network, now requires that R_{b_1}, say, have similar variation, by (4). We also note that $l_{12} \geq 0$, but that $l_{12} < 0$ can be obtained by reversing one of the gyrators. By shunting the input and output with capacitors, a mutually coupled adjustable tuned circuit results, again in a form suitable for microelectronic structures where the common capacitor junction is a useful feature.

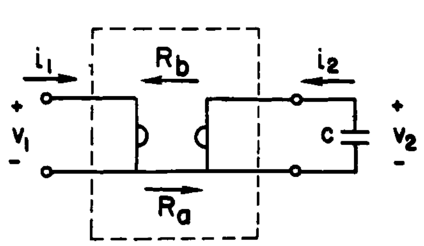

Fig. 1. Variable inductor simulation.

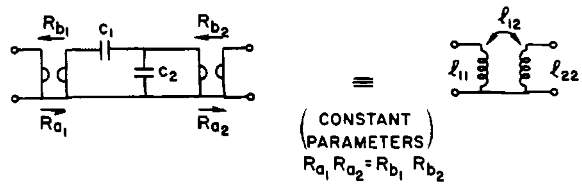

Fig. 2. Coupled coil simulation.

Often it is sufficient to consider (3) with constant parameters but without the reciprocity restriction of (4). By relaxing the constraint of (4) one can still obtain pole-zero patterns similar to those of tuned circuits, but the tuning adjustments via R_a's or R_b's are simplified over those described above for the coupled coils.

It is also worth pointing out that mutually coupled capacitors can be obtained by using Fig. 2(a) with the capacitors placed on the outside, instead of the inside, of the gyrators.

In summary, the use of a previous variable gyrator circuit has led to electronically tunable circuits which appear suitable for integrated circuitry. From these basic principles one can continue further to obtain and investigate other useful devices, as voltage controlled oscillators and amplitude and frequency modulators. Present experimental and theoretical investigations are aimed at improving the existing gyrator circuit and examining its applications. It is hoped to report on these at a future date.

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[1] S. N. Levine, *Principles of Solid-State Microelectronics*. New York: Holt, Rinehart and Winston, 1963, p. 163.

[2] W. New and R. Newcomb, "An integratable time-variable gyrator," *Proc. IEEE (Correspondence)*, vol. 53, pp. 2161–2162, December 1965.

The Cutoff Frequency Falloff in UHF Transistors at High Currents

It is well known that the cutoff frequency f_T in UHF transistors shows an appreciable falloff at high collector currents. Kirk[1] has attributed this to the fact that the transition region boundary adjacent to the neutral base layer is displaced toward the collector metal contact with increasing collector current. The attending widening of the neutral base layer results in the observed falloff. We propose here an alternate theory where the falloff results from a saturation effect in the collector transition region.[2]

Most UHF transistors have a structure in which a relatively small section of the collector region is weakly p-type (p^- region), whereas the remainder of the collector region is very strongly p-type.

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[1] C. T. Kirk, Jr., "A theory of transistor cutoff frequency (f_T) falloff at high current densities," *IRE Trans. on Electron Devices*, vol. ED-9, pp. 164–174, March 1962.

[2] D. A. Agouridis has studied the effect with the help of noise measurements and intends to report on it later.