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GROUNDING OF CAPACITORS IN INTEGRATED CIRCUITS*

Fabrication techniques indicate that it is easier to obtain earthed capacitors than unearthed ones in integrated circuits. To take advantage of these techniques, a method to earth all capacitors, by replacing them with earthed gyrator–capacitor combinations, is described here.

Because of the availability of gyrators in integratable circuit form[1,2,3,4,5] and their proven versitility for practical circuit designs,[6,7,8] as well as for modern synthesis methods[9,10], it is apparent that gyrator–resistor–capacitor circuits will form an important part of integrated-circuit technology in the future. However, whereas gyrators and resistors need occupy only a small area when fabricated in quantity, capacitors require a large area and hence are expediently minimised. Likewise, since it appears that extra isolation diffusions[11] for monolithic silicon dioxide capacitors can be dispensed with by incorporating capacitors with one plate common, it is advantageous to develop design techniques which allow all capacitors to share a common earth. A mathematical technique for doing this in lossless structures has previously been presented.[10] In this note we describe a practical and general way of replacing unearthed capacitors by earthed gyrators and capacitors in integrated circuits. Although new gyrators may be inserted, no extra capacitors are required, and, in fact, the capacitors can be normalised to convenient sizes in the process.

Consider an arbitrary capacitor of capacitance c connected between any two points A and B as shown in Fig. 1*a*. The insertion of a (direct-coupled) cascade, earthed, 1 : 1 transformer, as shown in Fig. 1*b*, leaves the circuit operation at points A and B invariant. The 1 : 1 transformer can then be replaced by the cascade of two gyrators of identical gyration resistance γ[12], as shown in Fig. 1*c*. A series capacitor c at point A (Fig. 1*c*) can be easily replaced by a shunt inductor at point A′ (Fig. 1*d*). The equivalence is by standard means (Reference 9, Fig. 2). The resultant inductor can then be replaced by a capacitor-loaded gyrator[13] to obtain Fig. 1*e*. In summary, therefore, a capacitor of capacitance c, connected between any two points in a circuit, can be replaced by three earthed gyrators and one earthed capacitor of capacitance $c_0 = c\gamma^2/\gamma_0^2$, where γ and γ_0 are gyration resistances as shown in Fig. 1. Note that, as a consequence, c can be normalised to any value we wish by adjusting γ and/or γ_0.

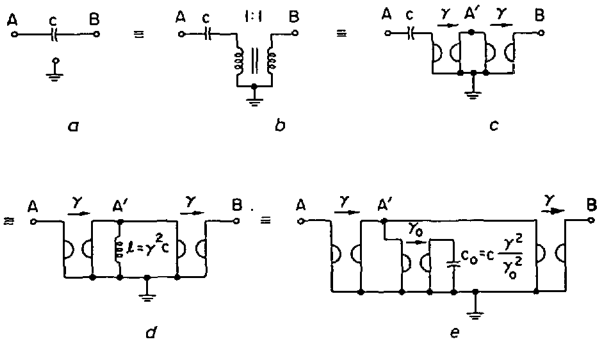

Fig. 1 *Evolution of earthed-capacitor equivalent e of an unearthed capacitor a*

This method could be applied usefully to the Hazony section of Fig. 2A(i), which is the basic section for gyrator–capacitor filter design.[9] Using the result of Fig. 1 gives the earthed-gyrator earthed-capacitor equivalent Hazony section of Fig. 2A(ii). Consequently, the method discussed here should prove of assistance in the design of integrated circuit filters.

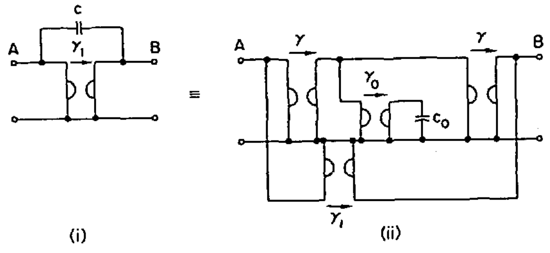

Fig. 2A *Equivalent Hazony sections*

Although the method given has been shown to work in any situation, this should not be taken as a golden rule; in certain cases it may be profitable to resort to other methods which may prove better. For example, in the gyrator–capacitor equivalent of coupled coils of Fig. 2B(ii)[13], the use of Fig. 1 inserts three more gyrators to earth the unearthed capacitor. However, it is simpler to just flip the capacitor through the input gyrator into an inductor (Fig. 2B(iii)), which can then be replaced using only one more gyrator, thus saving two gyrators.

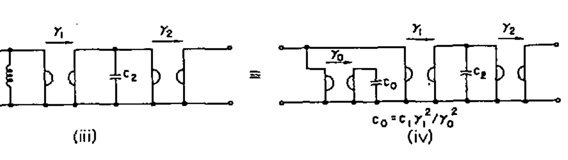

Fig. 2B *Earthed-capacitor coupled-coil equivalent*

As a concluding remark we note that the result of Fig. 1 holds for c, l and c_0 time-variable,[14] and that the same techniques can be employed to earth all other two-terminal elements, for example, resistors, inductors and diodes, in any circuit if so desired.

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FREQUENCY-PULLING PROCESS IN FREQUENCY-SELECTIVE CIRCUIT

Frequency displacement of a reflex klystron oscillator, purposely placed in a frequency-selective circuit in a frequency-pulling process, is not monotonically proportional to the driving-power level. Final frequency separation between the oscillator and the driver, which precedes abrupt phase locking, exceeds initial separation.

It is well known that a well isolated external signal injected into a free-running oscillator of similar frequency will tend to pull the oscillator frequency monotonically toward the driver signal, and, provided the initial oscillator frequency is in the 'locking range' and the output is well matched, will (with increased driver-power level) eventually become phase locked to the driver at the driver frequency.[1,2] When the circuit is frequency selective, the above stated condition is not necessarily obtained. In this test, the oscillator was purposely placed in a frequency-selective impedance-matching circuit. This note reports an interesting behaviour of reflex klystrons under such unusual circuit conditions where the oscillator is generally pulled toward the driver frequency with increased driver level, but only up to a point; if the injected driver power is increased beyond this point, the frequency separation increases again, even to a point exceeding the initial free-running frequency separation. This phenomenon has been observed at both X band and 70 GHz.[3] Continued increase in the injected-driver-power level then abruptly pulls the oscillator into phase lock. To the authors' knowledge this phenomenon observed at X band has not previously been reported. No theoretical analysis of the phenomena is yet available to the authors.

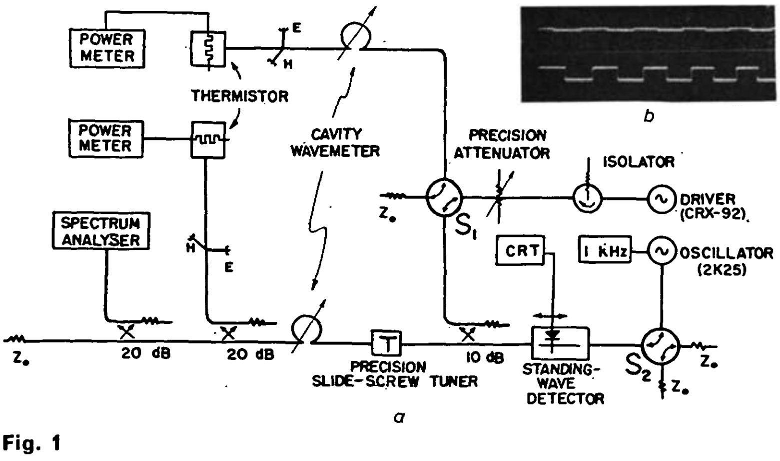

Fig. 1

a Schematic diagram of experimental test setup
b C.R.T. display of oscillator power output (see text)

The experimental setup is shown in Fig. 1*a*. The oscillator is 1 kHz square-wave modulated for identification purposes as needed; the driver is c.w. operated. Fig. 2 shows the results obtained. A precision slide-screw tuner is used to produce a frequency-selective impedance adjustment to investigate the pulling process in the frequency-selective circuit. Fig. 2 (i) shows a Polarad SA84WA spectrum-analyser display of the driver output at the right, the driven-oscillator output in the middle (and one of the sidebands[4,5] on the far left). As driver power is continuously increased, we note the oscillator free running (*a*), partially pulled (*b*), minimum frequency separation between oscillator and driver *c*, increased frequency separation *d* and oscillator level just prior to disappearing in the noise level *e*. In the case of *a*, the position of the driver frequency is indicated by a small signal which is not large enough to exhibit any noticeable pulling, as can also be seen in Fig. 2 (iii). It is interesting to note that the frequency separation of *e* is actually greater than the separation between the free-running oscillator and the driver. This, as well as the monotonical decrease of the oscillator power level during the pulling process, is clearly seen in Fig. 2 (ii), which is a time exposure of the spectrum-analyser display representing the oscillator as the injected-driver-power level (driver is off the screen to the right in Fig. 2 (i)) is gradually and continuously increased from zero. This interesting behaviour of the oscillator frequency has previously been observed by the authors with millimetre-wave reflex klystrons at 70 GHz.[3]

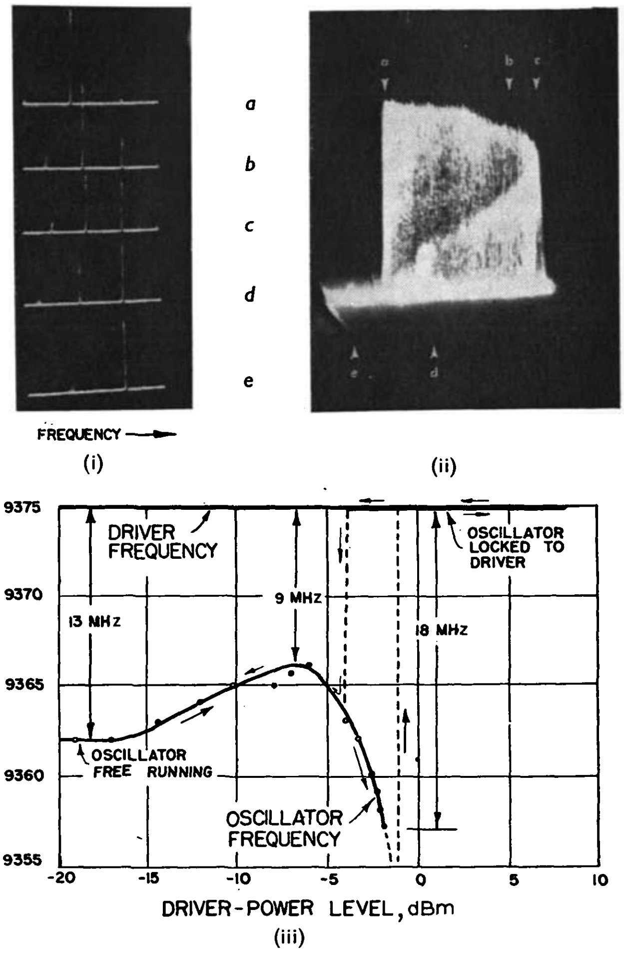

Fig. 2 *Observed pulling process*

(i) Driver (right), oscillator (middle). Driver power increased from *a* to *e*
(ii) Time exposure of oscillator frequency corresponding to part *a* to *e* of *a*
(iii) Oscillator pulling as a function of driver-power level

The complete X band pulling process observed is shown in Fig. 2(iii); initially the free-running oscillator (a 2K25 tube with a power output of 10 dBm) and the driver (a CRX-92 reflex klystron) are adjusted approximately 13 MHz apart. Increased injected-driver-power level pulls the oscillator to within 9 MHz of the driver frequency; increasing driver power above −6 dBm causes the oscillator frequency to recede, while the oscillator power continues to decrease monotonically until at a driver level of −2 dBm it is almost lost in the noise level. At this point, the frequency separation has reached approximately 18 MHz. Now an increase in driver power of about −1 dBm abruptly pulls the oscillator