CHAPTER-I

INTRODUCTION

1.1 MOTIVATION

With the introduction of transistor as a basic active device[1] in the fifties, active circuits have shot into prominence and found wide-scale application in various areas of Instrumentation, Communication and Industrial Control. Previous to this, vacuum triodes and pentodes have often been used but they have certain obvious limitations. Transistor brought the age of the solid state, the technology of which is growing in a pace large enough to push today's marvels into tomorrow's oblivion. However the basic transistor which had been in use as a discrete active block alone till mid-sixties is now being used in the integrated form[2] in a very large scale side by side with its older form. The growth of the integration process for the passive components like resistance and capacitance[3] has extended additional charm to the design of active circuits in miniature and microminiature 'Chips'. Earlier to this, for reasons of cost, size, powerloss and parasitic enhancement it was argued that inductor do not conform to the requirement of an acceptably good passive component particularly if the frequency range is quite low, as required in Instrumentation and Industrial control areas. Attention of the researchers, circuit theorists in particular, turned towards the development of active RC circuits and a bulk of literatures are now available[4-8] to prove that real inductors can be totally dispensed with when proper active insertion is permitted in the design of signal processing networks, signal generators, control circuits and a variety of others where high selectivity or high Q was previously obtained through LC-tuning. The pursuit on this track, for the development of (i) simulated inductance for direct application as a component,(ii) filters of all types or (iii) circuits of autonomous nature, that are economically viable, have superior performance and are amenable to generalization in design procedure and integration more conveniently, should, therefore be more worthwhile than apparently appears.

1.2 ACTIVE NETWORKS

For the Instrumentation, Communication and Industrial Control Systems, the system design is of very basic importance. Particularly in the network front a design, with RC elements and active blocks only, is attractive for its compactness and economy. The characteristic function realized by passive RC network has many restrictions compared to that of LCR networks. To overcome these, active elements have been inserted in the passive structure in a proper manner for the desired purpose[9].

1.3 ACTIVE NETWORK ELEMENTS

Transistor, Transistor Differential Pair : Transistor is the basic solid state active building element which can be used singly or in conglomeration coupled with an appropriate set of connected resistors to form other blocks. Through continued research towards achieving perfection in its performance, it has now been possible to produce transistors of near ideal nature represented by the model shown in figure 1.1. However the limitation in the operating frequency and other imperfections call for

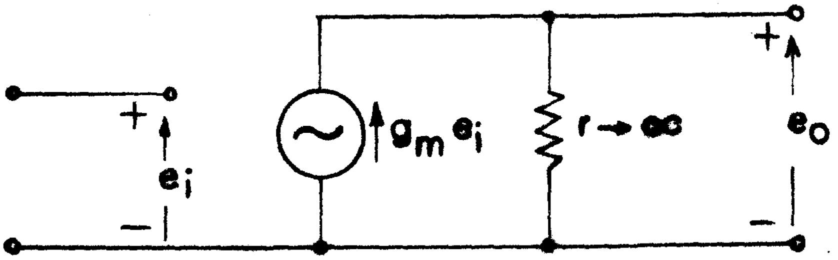


Fig.1.1 Transistor Model

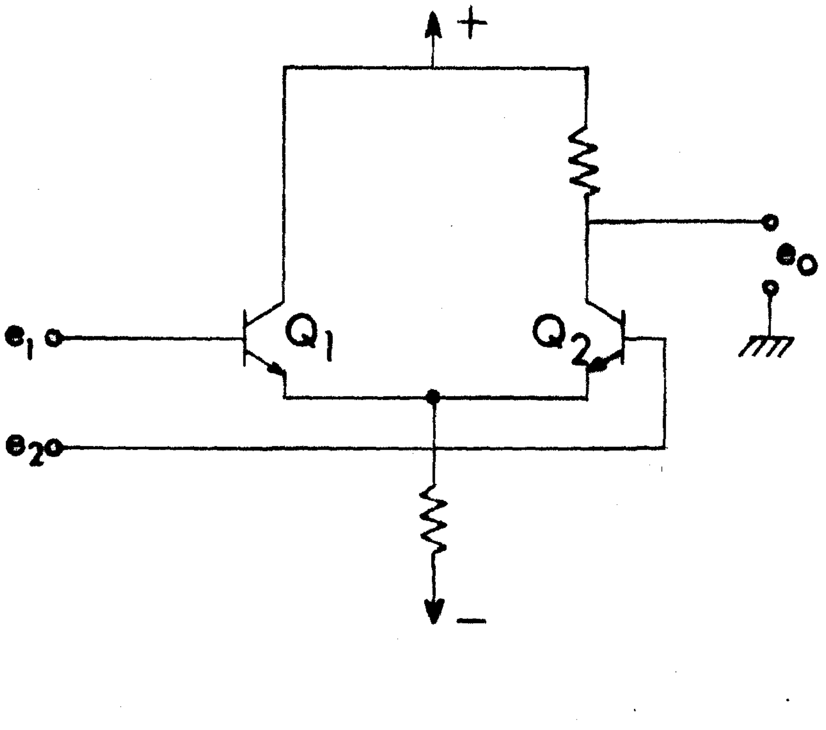
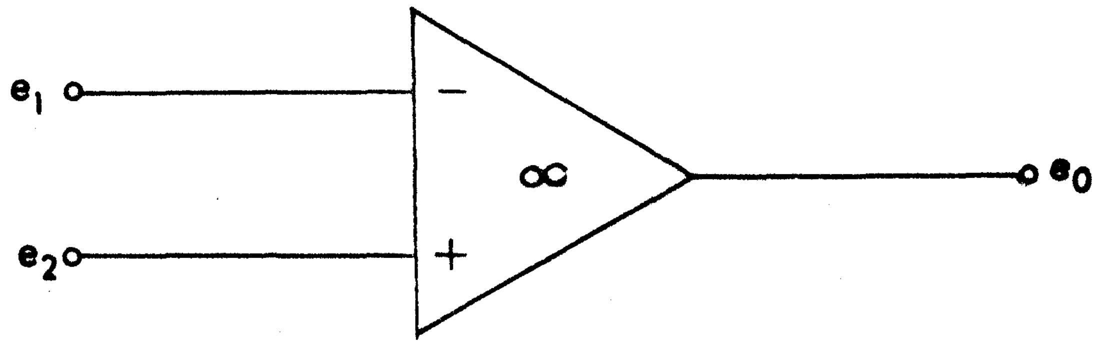


Fig.1.2 Emitter coupled differential pair(ECDP)

a more complex model for circuit synthesis purpose. Transistor being the basic active element, any kind of active circuit can be generated by the use of it.

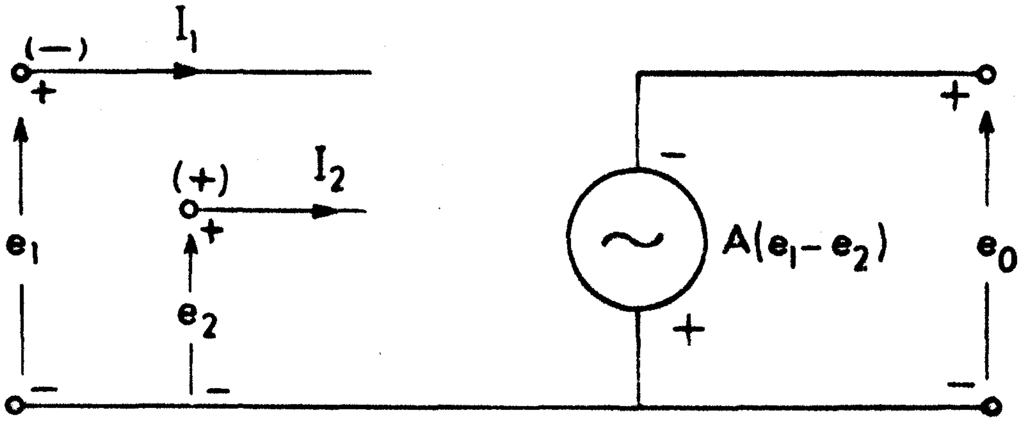
A very important active building block that is obtained through a pair of transistors is the Emitter Coupled Differential Pair[10] (ECDP) shown in figure 1.2. It can be used with both e_1 and e_2 effective or with e_1 effective and e_2 at a.c. ground potential or vice-versa. The common emitter coupling provides a degenerative feedback in the individual transistors due to which the effect of the changes in the transistor parameter is minimized, the current variation due to supply potential or temperature change in individual transistor tends to cancel, distortion is reduced, input impedance is increased, flow of base current is restricted, bandwidth is increased and the overall stability improves. This, thus provides an overall improvement in performance in the realization of active building block. It has naturally been accepted as the starting phase of what is known as the operational amplifier.

Operational Amplifiers (OA) : The operational amplifier is the most popular active network element now-a-days and is extensively used in active network synthesis. The OA is a direct coupled high gain amplifier, and with applied feedback its performance characteristic is controllable. It is capable of amplifying, controlling or generating any waveform of frequencies from d.c. to several megahertz. All the classical computation functions are easily performed by this. The output of an OA is controlled by its two inputs, inverting and non-inverting. An input to the inverting



(a)

Operatianal amplifier representation



(b)

Fig.1·3 Controlled-source model of Fig. 1·3 (a) input terminal gives phase-reversed output whereas an input to the non-inverting terminal gives in-phase output.

The OA can be represented by a voltage source which is controlled by two floating terminals as shown in figure 1.3. The OA has high voltage gain for differential signals effective between two inputs and has very low gain for the same signal applied to both the inputs simultaneously. These are called differential mode and common-mode input signals respectively. The synthesis techniques with OA already galore in literature out of which a few are exemplary[11-14]. However its applicability remains to be exploited fully as yet. Operational Amplifier can be considered to be an idealized version of a transistor with very high gain and is thus useful in obtaining many other active elements such as

i) Generalized Immitance Converter (GIC)[15].
ii) Controlled Sources[16]
    a) Voltage Controlled Voltage Source (VCVS).
    b) Current Controlled Current Source (CCCS).
    c) Voltage Controlled Current Source (VCCS).
    d) Current Controlled Voltage Source (CCVS).
iii) Gyrator[17].
iv) Frequency Dependent Negative Resistance[18].

1.4 INDUCTOR REALIZATION

Active RC networks have to be basically active because the replacement of real inductor is to be done with a simulated one. The simulation is in terms of R, C and one or more active blocks.

There has been a considerable effort in recent years for an appropriate simulation of an inductor. Depending on the types of realization such as linear, bilinear, ideal etc., on the port orientation such as grounded or floating or on the use of type of the active blocks different categorization of the realization technique is possible. The basic aim remains, however, to realize an ideal grounded or floating inductor with (i) low parameter sensitivity, (ii) the use of acceptable active blocks and (iii) low count components. Further, grounded capacitor realization adds to the convenience of micro-circuit adaptability[19] of the design. Realized inductors have also been successfully tried in the design of signal processing networks[20], oscillators[21], and various other areas of interest.

1.5 FILTERS

Although simulated inductor can be well adopted for circuit realization of a desired system such as a filter, direct realization of it appears to be more convenient and rather straightforward[22]. This is commonly known in the literature as inductorless filter. The essence of such a scheme lies in the inherent elimination of any real inductor through active RC synthesis. Although literature abounds in such realization techniques[23-29], the final word about it is still to be told. Here again insertion of an acceptable active block in low count with versatility in easy convertibility of the filter for the desired response characteristics receives major attention. Superior performance and high selectivity are other features to consider.

For active blocks, one major aspect to look upon is the dependence of the realization on the gain bandwidth product which affects the operational frequency range as also the Q-factor. Compensation techniques are lately being investigated to increase the gain bandwidth to improve the performance, but very often these increase the complexity in the realization[30,31]. The limited range with uncompensated schemes is, however, sufficient for application in Instrumentation and Industrial Control systems. In any case, this is an inherent limitation of the device and it creeps in during the integration stage of the solid state block. Further development towards its improvement is likely to compensate for this deficiency in a simpler manner.

1.6 OSCILLATORS

Inductor simulation or inductorless filter realization are realization of functions of nonautonomous nature. Often in the application areas mentioned, conservative autonomous functions are of great importance. All practical oscillators come under this category. The autonomous conservative networks are basically regenerative in nature. In quite a few such cases, multifrequency oscillations are generated. It is however possible to design an electrical network to obtain single frequency oscillation. The analytical representation of such a system is quite simple and is given as

$$\ddot{x}^2 + \omega_o^2 x = 0 \qquad (1.1)$$

The quantities characterising such oscillations are (1) amplitude, (2) frequency and (3) phase. The frequency is determined by the system parameters only. In classical mechanics, analyses of all the nature of a linear system have been made and successfully applied to mechanical, electrical and other types of oscillatory systems. The energy relation in such a system determines its period of oscillation. In electrical types evidently the system should have an inductance and capacitance in the ciruit. The oscillation condition has been enunciated from the principle of feedback and is given as

$$\bar{A}.\bar{B} = 1 \qquad (1.2)$$

where $\bar{A}$ = gain of the active block in the circuit
and $\bar{B}$ = amount of back coupling.

Analysis of the linear systems of oscillations can be made with the help of conventional linear techniques. The added advantage is that many nonlinear techniques can be applied with appropriate limiting conditions to derive the solutions.

1.6.1 THE SINEWAVE GENERATORS

Active devices coupled with passive networks are capable of generating sinewave oscillations with the appropriate conditions specified. The passive circuit parameters are generally the determining factors of the system frequency.

Low frequency sinewave generation is inconvenient with an LC network because of their large values. RC networks are more advantageous in that respect. An oscillator with a 3-section CR phase shifting network and a vacuum tube was described by Ginzton and Hollingsworth[32]. The transistorised version of this circuit is due to Nichols[33]. Continued efforts in this line have produced different RC oscillators with special types of networks like Wienbridge, Bridge-T, Twin-T etc.[34-38].

The main consideration in sinewave generation is to obtain oscillations of good frequency and amplitude stability and also frequency variability. All the requirements are rarely met by any individual circuit suggested so far.

Active RC filter may be convenient in so far as the choice of the frequency selective networks are considered. The basic limitations are conceivable in terms of the drifts in the active parts. But now it is known that the drifts with time and temperature in active devices which are amenable to compensation (compensated active devices) are no worse than that of passive elements. Variation of the function of an active element such as the gain of a closed loop operational amplifier, may be used with advantage in a variable frequency oscillator. With special active blocks such as the differential transistor pair with a high CMRR the drift problem can be reduced as well.

Irrespective of the types of the circuits used, the derivation of the equation, pertinent to the analysis of harmonic oscillations is made, following a suitable technique dependent on the system alone. Usually the frequency and the starting conditions are determined from the conventional loop or nodal analysis of the circuit.

1.6.2 NON-LINEAR SYSTEMS

Majority of the problems relating to real physical systems are possibly investigated mathematically involving solution of differention equations - ordinary linear, nonlinear and partial.

For the solution of the nonlinear problems the mathematics involved is, in the present day state-of-the-art, referred to as nonlinear mathematics. The analytical treatment of the nonlinear problems are hindered due to insufficient mathematical development in this area. The engineers however have the complementing tools in computer for the analysis of the dynamic behaviour of the physical system. In fact, the highly nonlinear problems which occur in practice, have been successfully solved when the analytical approach is coupled with the aid of computers.

1.6.3 THE PERIODIC SOLUTION

Attempting to solve the autonomous and nonautonomous oscillatory system, the primary interest grows around the steady state oscillations i.e., existence of a periodic solution, ensuring the stability. Ponicaré[39] was the first to present a suitable analytical approach for obtaining the periodic solution. The basic principle is the parameter (μ, say) dependence of certain term of the nonautonomous differential equation. The major difficulty in Ponicaré method is in finding the characteristic exponents required for the solution. Minorsky's strobscopic method[40,41] solves this difficulty by replacing the original nonautonomous differential equation by another autonomous one, such that the existence and the stability of its singular points is a criterion of the existence and stability of the periodic solution of the original problem.

The classical van der Pol[42] equation describes many of the operating features of the oscillator. The equation is quite simple but the small parameter approximation method is not applicable for a large value of the parameter (μ or ϵ) associated with the first derivative term. A study of van der Pol equation for both small and large value of ϵ has led to the appropriate understanding of the operation of self-oscillations. Van der Pol's original method of solution was graphical and was presented in the form of an integral curve in the phase plane. The latter efforts for an analytical solution[43,44] of the equation acquired little significance although it was demonstrated that for larger and larger values of ϵ the system tends to oscillate in relaxation mode.

1.6.4 RELAXATION OSCILLATION

Relaxation oscillations differ considerably from sinusoidal or quasi-sinusoidal oscillations. Relaxation oscillations are rich in harmonics which can attain very high order.

In practical relaxation oscillations, pulse generation for example, effectively there is a single reactive element capable of storing energy. The energy can be stored only in one part of the period. In the other part this energy is dissipated in a resistance. Naturally the exciting device should supply an amount of energy equal to that stored or dissipated in the period. In an autonomous system, the exciting device is formed in the system which is required to supply the energy and this often is a negative resistance device or a generator[40-42]. The presence of the negative resistance in the circuit of the oscillatory system may be considered in two general ways. First an actual negative resistance is used for circuit synthesis; secondly a feedback is applied in such a way as to produce an effective negative resistance in the system during the part energy is supplied.

It was due to the study of van der Pol[45] that a method obtaining a continuous transition from the sinusoidal to relaxation oscillation is known. Physically this is interpreted as in an LRC circuit one of the reactive elements is gradually reduced to zero and the system being beyond the 'limit' state, the oscillation that occurs may be considered as a kind of jumping from one state of equilibrium to another. The period of oscillation in such circuits is generally controlled by the alteration of the passive elements which simultaneously affect the performance of the multivibrator or pulse generator. Synthesis of multivibrator circuit whose time period can be linearly altered by varying a single circuit parameter other than the formal frequency determining network element without affecting the operating characteristics of the generator can be a welcome addition to the list of the range of the multivibrators.

1.7 SCOPE OF THE WORK

Of late nonautonomous and autonomous function realization have gained tremendous importance in the areas of Communication, Instrumentation and Industrial Control. Active RC filters have consequently been receiving attention in a generalized way[46-48] or in a discreet manner[49]. The generalized studies have been directed to evaluate the realizability criteria such that the filters received adequate mathematical description. Individual design has to have more of down to earth and practical approach. Since the recent approach based on various counts of superior performance requirements; convenience in tuning, I.C. implementation; sensitivity minimization and others is to develop second order building blocks, at the most, for the system design, major attention has been given to the design of such blocks with more versatility. These blocks themselves may be developed through an integrated approach or through the replacement of the inductors in the existing models by these active RC simulations.

The present study begins with the simulation of inductors of different types with RC and a very general active block i.e. the operational amplifier. The grounded inductor realization is presented in Chapter-II. The method is a little deviated from the now conventional approach of using a single capacitor. However the method presented shows that in it a number of type of inductors can be realized including an ideal one having very large inductance values. The application of the inductor in obtaining a variable frequency sinewave oscillator has also been demonstrated.

Not all filters are realizable with a grounded inductor. In modern practice filters with floating inductors are modelled with different types of simulated elements[50-51]. The direct approach, however is to simulate floating inductors and use them in such a realization. The scheme of a floating ideal inductor with three operational amplifiers and a grounded capacitor has been presented in Chapter-III and a filter realization scheme has also been given with experimental results.

Chapter-IV presents a generalized approach of active RC filter realization with a single operational amplifier. The presentation has been motivated to obtain the important communication filter, the all pass filter, through a generalized approach. Subsequently through various examples realizability of all other types of filters has also been demonstrated.

Single resistive element control sinewave generators have acquired importance in data telemetering and other industrial control. Such types have been produced of late through individual trials[52-56] and with some constraints. In Chapter-V a systematic development of systems to provide the desired facility has been presented. The waiver of some critical restrictions has even allowed the system to be adopted as a voltage controlled oscillator.

Single stage emitter coupled transistor differential pair has been exploited here as a very convenient active block. As mentioned, it is a highly stable controlled source and can be made effective in a wide variety of purpose. A very stable sinewave generator has been produced through it which is minimally sensitive to temperature and supply voltage as well. The system has been presented in Chapter-VI.

Interestingly, the basic scheme with the emitter coupled transistor differential pair presented in Chapter-VI turns out to be a van der Pol generator whose operation may be continuously controlled from single frequency harmonic to relaxation mode by simple parameter control. Chapter-VII presents this van der Pol generator and shows that the long standing discrepancy between the practically obtained waveform and the theoretical one, either through graphical or approximated analytical approach[57,58], exists only because of inaccurate modelling of the active block. The antisymmetric transfer characteristics of the differential pair has been suggested to be of hyperbolic tangent type and the transcendental characteristic equation has been solved in the computer for various timing ranges. The results have been compared to show that the suggestion is apt. This system can be seen to be a very convenient waveform generator. The system can be adapted quite easily as a voltage controlled oscillator. This adaptation has also been included in this chapter with sufficient details.

Specifically the relaxation mode oscillation deserves special mention because of its versatile utility. It has further been improved to suit wide scale practical applications. This has been presented in Chapter-VIII by adapting the scheme as a single resistive element controlled linear pulse generator which has been simultaneously made minimally sensitive to variable operating conditions. The emitter coupling helps to attain this insensitivity to a great extent. The extent of coupling is important for this purpose.

Finally in Chapter-IX concluding remarks with necessary critical discussions are made.

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