CHAPTER - I

INTRODUCTION AND SURVEY

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1.1 INTRODUCTION :- Filter can be considered as a device designed to separate,pass or suppress a group of signals from mixture of signals[1]. So these are considered as frequency selective networks[2]. In such cases the transfer characteristic of the filter is so shaped that the ratio of unwanted to wanted signal at the output of the filter is minimized. The filter specifications are generally given interms of cut-off frequencies or pass band and stop-band edges.

Electrical filters permeate modern technology so much that it is difficult to find any electronic system that does not employ a filter in one form or another. On a larger scale, televisions and radios are typical examples of electrical filters. When television is tuned to a particular channel, it will only pass those signals transmitted on that channel and will block all other signals on a smaller scaler. Filters are basic electronic components used in the design of communication systems such as telephone, television, radio, radar and computer etc.

Before the 1960s, filter for voice and data communication system were designed using passive RLC components. The filters using LCR component were carrying a bulky element " inductor" which is no way can be manufactured using recent IC technology. Where as the component like R, C and active device (e.g. operational amplifier or transistor) circuit could be implemented on the IC'S. So new type of "inductorless" filters active filter has been developed.

Active filters with only resistors called "Active -R filter " have received considerable attention due to their potential advantage in terms of miniaturization, ease of design and extension of response towards high frequency[3].

In this report a new biquadratic active -R filter circuit is proposed which provides all the filter functions at various output terminals. The theory shows that for practical circuit the Q has upper limit which mainly depends on f_o. The circuit was studied for different values of Q, f_o and tapping point. The experimental results show excellent agreement with theoretical results.

1.2 SURVEY OF LITERATURE :- The theory of filters originated with the works of Campbell and Wagner on electric-wave filters in the 1920's. Campbell and Zobel considered design of filters based on 'image parameters' which fundamentally depended on image or iterative impedances[4]. In contrast to the image parameter theory, modern filter design is based on the selection of the filter transfer function to satisfy the specification and then the realization of this function by synthesis techniques.

With the rapid advance in solid-state technology and the wide use of digital computers. The trend is towards shortening the passive filter synthesis and expanding the active design. As a result, modern synthesis techniques lean heavily toward the use of active elements, which, together with resistors and capacitors, virtually eliminate the need to use inductors in many frequency ranges.

The pioneering work was done by SALLEN , KEY and other workers on the synthesis of the second order network using transistor as the active element.

The present trend to microminiaturize the circuit in order to increase the package density and reliability of the circuit has been an important factor. The most convenient form of the microminiaturized techniques has been found to be 'integrated circuits' IC'S. As the integrated circuits op. amp., which were both compact and economical, came into market, a number of new active building blocks and their synthesis techniques were developed by many people. Active filters employing R-C networks in conjunction with active elements such as NIC'S controlled voltage sources, gyrators and F.D.N.R. were proposed by different workers.

Switched capacitor (SC) active filter is the product of fully integrated active filters compatible with MOS technology. Although the idea of using switched capacitor and associated theory was available as early as 1960'S, it was in the decade of 1970's that saw emergence of the SC filter as a very promising method of implementing precision monolithic analog filter in MOS IC's. Latter on Smith and Sedra (1968) gave the concept of current convering. It has been shown by Aronhine, Senani and other workers that the current convers may be used to implement nearly all transfer functions with a high input impedance and independently controllable voltage gain.

The design and analysis of active filters can be more easily solved by using computers. There are so many packages available for analysis of active filters such as DIANA, DINAP, SPICE, ISCAP, SCAR, TCAP etc. Kuo et al have used these computer programs in the analysis of the SC filters. M.A. Soderstrand and K.L. Lee are the pioneers in the computer Aided Design (CAD) and analysis of the active -R filter.

The operational amplifier shows the high frequency roll off due to parasitic capacitances and considerable attention has been given to compensate their effect (Budak & Petrela[5]) This led to the development "Active - R" filters, which makes use of parasitic capacitances in the active device to built the filters without the use of inductors and capacitors at the frequencies higher than possible with active R-C filters.

Radhakrishna Rao and Sriniwasan (1973-76) have suggested that the pole of an operational amplifier could be used to design an active-R filter with only one capacitor[6]. Mitra and Aatre (1976), Ho and Chiu (1976), Saliman and Fawzy(1977), Schaumann(1977), Ananda Mohan (1979) have realized the general second order filter circuit using only resistors and operational amplifier while Nandi (1976-78) has contributed towards the realization of the grounded capacitors using op. amp.

Schaumann (1975) has suggested a general second order active-R filter[7]. Soderstrand (1976) has suggested a simplified version of this circuit which realizes all the low pass, high pass and bandpass responses simultaneously at three different nodes[8]. Brand and Schaumann (1975-78) have proposed the design methods for monolithic analog active R filter which is suitable for low pass and band pass functions at two different output terminals. Venkateshwaran (1978), Sowrirajan (1979), Li and Li (1978), Kapvstian and Bhattacharyya (1979), Lakeret et al (1976), Tsukutani et al (1991), Siddique and Ahmed (1991) proposed certain configuration with driving point admittance simulation. R.S. Sharma and U.K. Dullu (1981) have proposed an active -R filter that gives a second order band pass and low pass response simultaneously at two different points but fails to realize the high pass output. H.K. Kim and O.B. Ra (1978-79) have suggested an active R network that realizes all the LP, HP, BP, all pass & notch response.

Mitra and Aatre (1976) have discussed the low sensitivity and high frequency active R filters. Soliman and Fawzy (1978) have suggested a universal active R biquad realizing a general biquadratic, bandpass and low pass response characteristics. When the network is adjusted to realize a high pass characteristics, it becomes a special case of Schumann's active R filter. M.T. Ahmed, M.A. Siddiqui(1978-79) and M.T. Javed (1983) have proposed active R backwards that realize all important types of second order filter functions. A general second order active R network has been presented by J.C.M. Bernudez (1981) and L.P. Coloba (1983) by which two different active R biquads can be realized as the special case. Sun Zhi-Xiao (1980-83) presented a new active R biquad with four output terminals realizing LP, HP, BP, notch and all pass functions, presenting at least two functions each output terminals[9]. A voltage tunable active R filter has been designed by Newcomb and S.T. Lieu (1984) with the different voltage controlled current source (DVCCS) as the basic building block. E.A. Talkhan, M.N. Ibrahim and A.S. Nouh have designed an integratable tunable active R band pass filter. Kapvstian, Bhattacharyya and Swamy (1978-79) have discussed the frequency limitations of the active R. Filters. A fourth order active R ladder has been designed by Soderstrand (1975-78) by using the simulated inductors & capacitors. Soderstrand (1978) has also suggested an active R filters using CMOS transistors. Masaru Ishibla, Yutaka Fukai and

Keisuke Ebisutani (1984) have suggested an active R synthesis of a driving point impedance based on the single pole roll-off characteristics of the op.amp., which simulates inductance, capacitance, F.D.N.R. & F.D.N.C. It is experimentally shown that the inductor simulation presents a reliably high frequency performance.

Shah and Tantary (1987) have proposed an active R version of a voltage controlled oscillator, which utilizes the single pole characteristics of the op. amp. Active R versions of oscillators have been considered by Abuelmaetti and Almansoury (1986) and many other. Mc Ginti (1987) has suggested a design method for the monolithic implementation of a class of active R filters, which provides an alternative to the high speed digital filters. N. Mohan and R. L. Patil (1989) have designed a second order low pass active R filter, which simulates the inductor and capacitors with the synthesis techniques directly derivable from the passive synthesis technique[10].

1.3 BASIC FILTER CIRCUITS AND CLASSIFICATION.:-

The general area of electrical engineering which has to do with selective processing of signal information, commonly referred to as filtering. The filter is a network used to shape the frequency spectrum of an electrical signal. So the filters may be classified in number of ways. An 'analog filter' is a filter to process analog or continuous time signals, whereas a digital filter is used to process discrete time or digital signals. Analog filters may further

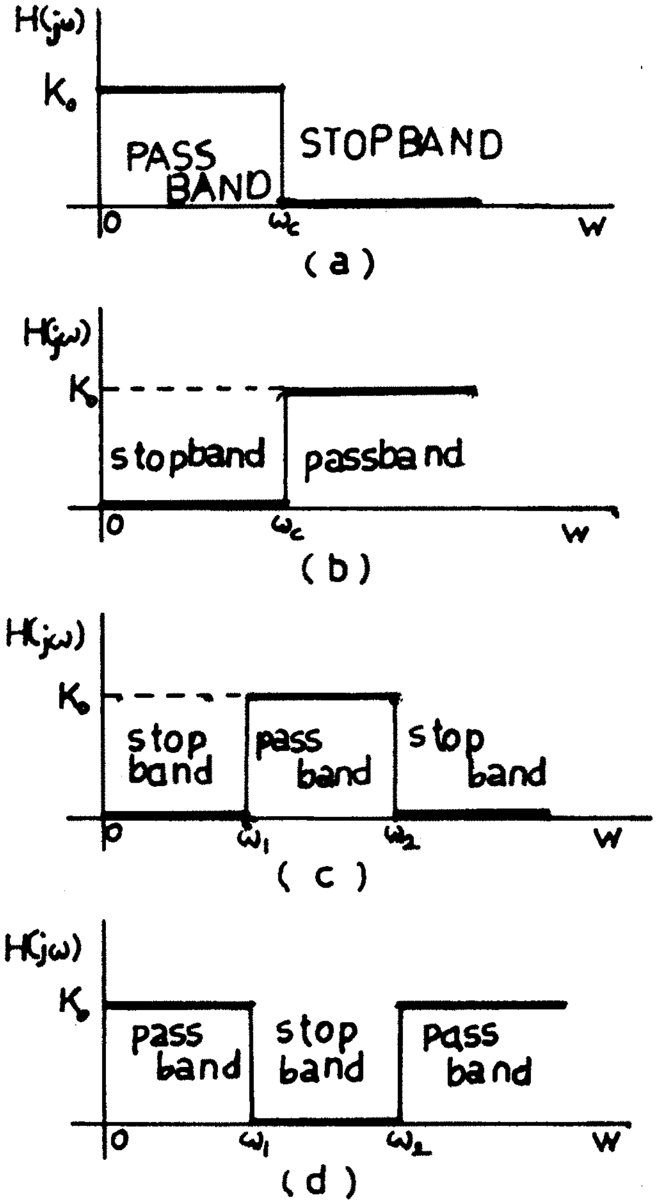

Fig.1.1. Ideal Characteristics Of,
(a) Low Pass (b) High Pass
(c) Band Pass (d) Band Stop Filter.

be divided into " Passive or active filters" depending on the type of elements.used in their realization.

Filters are also classified according to the functions they perform, as low-pass, high pass, band-pass, band reject, amplitude equalizers and delay equalizers. A passband is frequency band in which the attenuation of the filter transmission characteristic is small, whereas in stopband the opposite is true. The patterns of passband and stopband give rise to the four most common filter names whose ideal characteristics are shown in fig. 1.1.

An ideal low-pass characteristic is shown in fig. 1.1 (a) with pass band extending from $w = o$ to $w = w_c$ and stopband from w_c to infinity, where w_c is called the angular or radian cut off frequency or simply cut off frequency. Fig. 1.2 shows the passive one pole low pass filter section with its response characteristics. The passive lowpass filter passes input signals from dc ($jw = 0$) to some cut off frequency where the output amplitude has reduced to 0.707 (-3db) of that of dc amplitude. The transfer function equation is

$$\frac{V_o}{V_{IN}} = \frac{1/RC}{S + 1/RC} \qquad \ldots\ldots \quad (1.1)$$

A zero of transmission exists at infinity, as the capacitive reactance is zero at $f = \infty$. It is apparent that

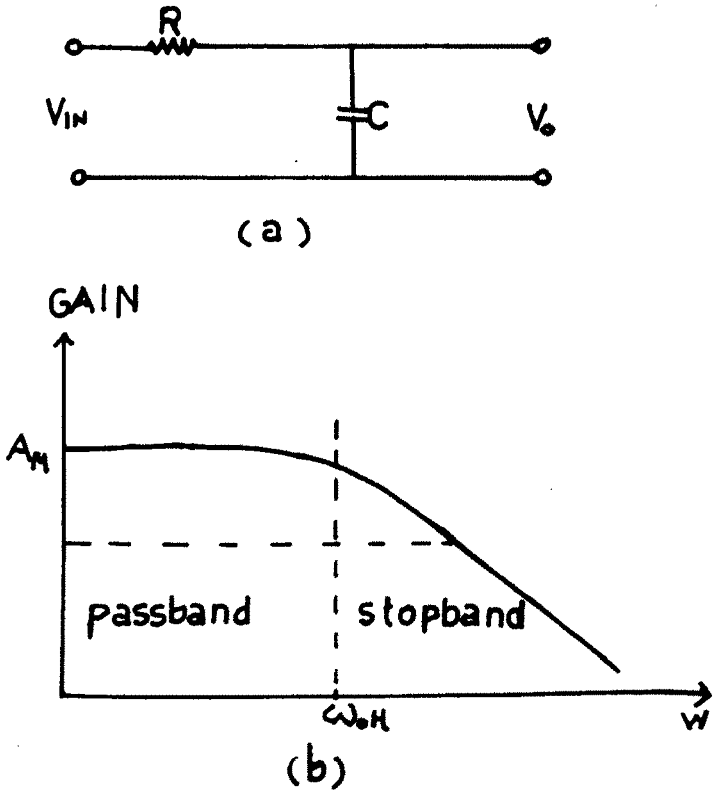

Fig.1.2: Passive One Pole Low Pass Filter
(a) Circuit Diagram (b) Frequency Response

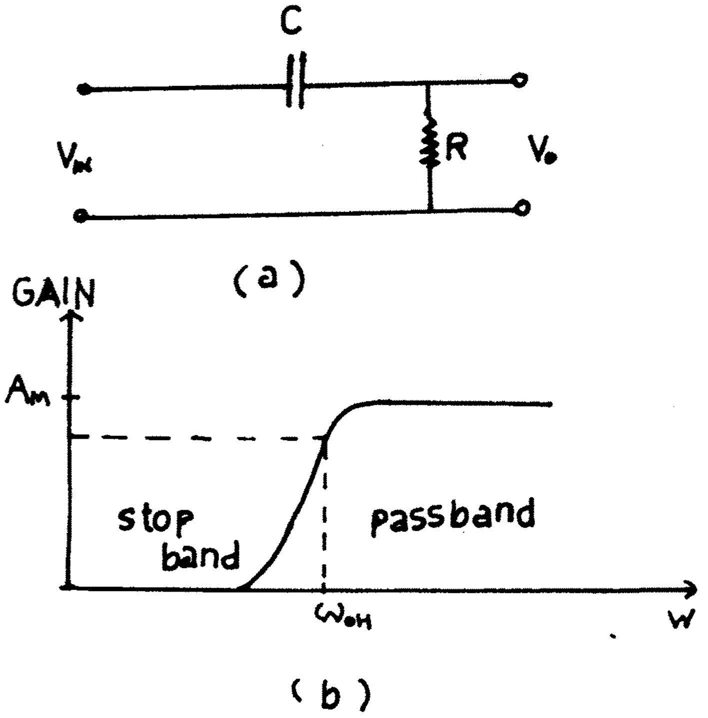

Fig.1.3: Passive One Pole High Pass Filter
(a) Circuit Diagram (b) Frequency Response.

the transfer function has a lower power of S in the numerator than in the denominator and it tends to zero as S becomes infinity[11].

A second order gain function that realizes low pass characteristic is

$$\frac{V_o}{V_{IN}} = \frac{b}{S^2+aS+b} = \frac{W_P^2}{S^2 + (W_p/Q_p)\,S + W_P^2} \qquad \ldots.(1.2)$$

An ideal high pass characteristic is shown in fig. 1.1(b) with pass band extending from W_c to infinity and stopband from 0 to W_c.

The passive highpass filter passes input signals with unity gain from infinity (very high) to cut off frequency, where the output amplitude has reduced to 0.707 (-3 dB) of the high frequencies amplitude .

The transfer function equation is

$$\frac{V_o}{V_{IN}} = \frac{S^2}{S + 1/RC} \qquad \ldots..\ (1.3)$$

The second order gain function for high pass characteristic is

$$\frac{V_o}{V_{IN}} = \frac{S^2}{S^2 + aS + b} = \frac{S^2}{S^2 + (W_p/Q_p)S + W_p^2} \qquad \ldots.\ (1.4)$$

This gain function has a pair of complex poles and a

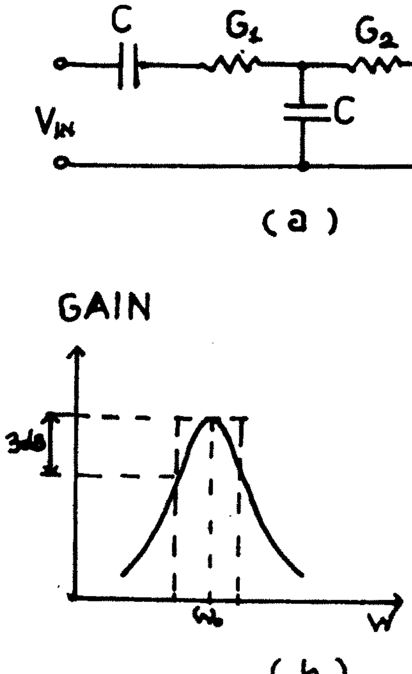

Fig.1.4: Passive Band Pass Filter
(a) Circuit Diagram (b) Frequency Response.

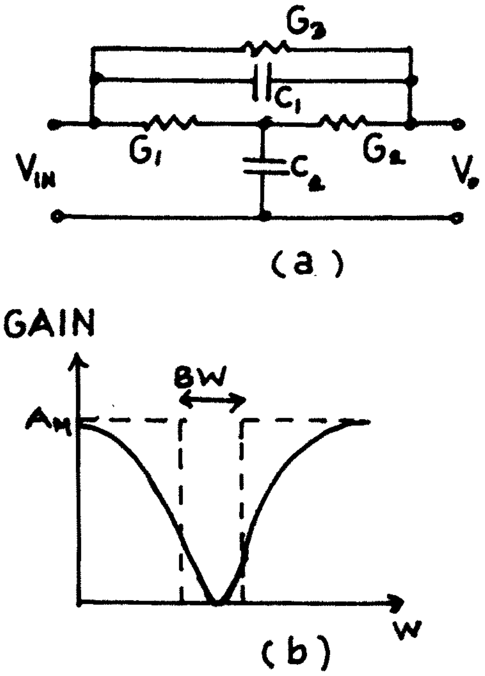

Fig.1.5: Passive Band Stop Filter
(a) Circuit Diagram (b) Frequency Response.

double zero at the origin. Fig. 1.1(c) is the characteristics for an ideal band pass filter, in which radian frequencies extending from W_1 to W_2 are passed. While all other frequencies are stopped. Band pass filters were classified in two categories either narrow band or wide band. Unlike the low pass and high-pass filters which passed frequencies in the passband with unity gain the band pass filter has a gain in the pass band. The shape of the frequency response of a band-pass filter is identical to the tree-image and reflected image low-pass filter considered as one continuous shape.

The second order transfer function is given by

$$\frac{V_O}{V_{in}} = \frac{aS}{S^2+aS+b} = \frac{(W_p/Q_p)\, S}{S^2 + (Wp/Qp)S+W_P^2} \quad \ldots\ldots (1.5)$$

This function has a pair of complex poles in the left half S plane and a zero at the origin. At low frequencies and at high frequencies, the loss increases as S, that is, at 20 dB/decade. The frequency response rises from zero at the origin to peak near the pole frequency; then a zero of transmission (S in numerator, S^2 in denominator) at infinity, draws the response back down to zero as the frequency becomes higher. The bandwidth is between the lower and upper -3dB (0.707) points.

Finally, the ideal band-elimination or band stop characteristic is shown in fig. 1.1(d), where the radian frequencies from W_1 to W_2 are stopped and all others are passed.

The second order transfer function with band reject characteristic is

$$\frac{V_O}{V_{in}} = \frac{S^2 + d}{S^2 + aS + b} = \frac{S^2 + W_z^2}{S^2 + (W_P/Q_P)S + W_P^2} \qquad \ldots\ldots (1.6)$$

This function has complex poles in the left half S plane and complex zeros on the jw axis. Also the pole frequency is equal to the zero frequency. The loss at low frequencies and at high frequencies approach unity, while the loss at the zero frequency is infinity.

1.4 BASIC ACTIVE FILTERS AND ADVANTAGES :- Now a days trend is towards shortening the passive filter synthesis and expanding the active design. This is to recognize the tremendous advances made in integrated-circuit processing techniques, which frequently render active elements much cheaper to produce than some of the passive one. Some of the limitations of the passive filters, viz., the size of the inductors at low frequencies, the necessity of buffer or isolation amplifiers to prevent loading while cascading sections of filters and the need for an external amplifier to adjust the required gain have led to intensive research and development in the field of active filters. Unfortunately, it has not been possible to integrate inductors with practical value of inductances and reasonable Q factors. As a result, modern synthesis techniques lean heavily towards the use of active elements, which, together with resistors and capacitors, virtually eliminate the need to use inductors in many frequency ranges.

Most of the active filter structures are realized by embedding an operational amplifier in RC network in a feedback configuration, providing high Q networks. These give very sharp filtering action and are light, compact and economical. They covers a wide frequency range, offer high input impedance and low output impedance value and hence minimize the effect of loading on the filter characteristics. The general configuration is shown in fig. 1.6. Here N is a three port RC network and μ is the finite gain amplifier.

The active element is an operational amplifier connected as a voltage-controlled voltage source (VCVS). The VCVS will be assumed to have ideal characteristics, that is, infinite input impedance, zero output impedance, zero reverse transmission and ideal phase shift (either zero or 180 degree)[12]. The voltage gain required will generally be low and will be determined by the synthesis method used in the various cases.

1.4.1 ADVANTAGES OF ACTIVE FILTER :-

A] SIZE CONSIDERATION :- Active filters are generally smaller than their LC counterparts, since inductors are not required. Further reduction in size is possible with micro

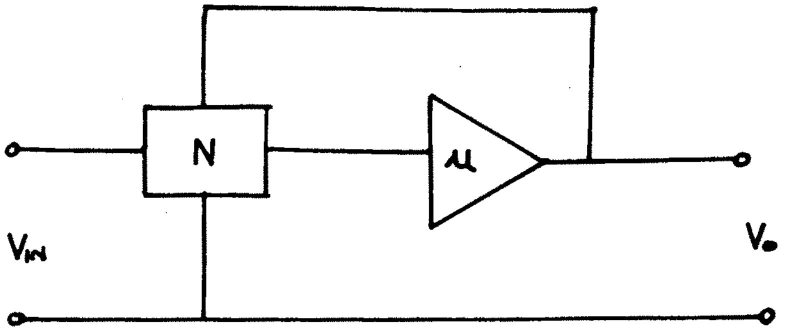

Fig.1.6: General Configuration Of Active Filter.

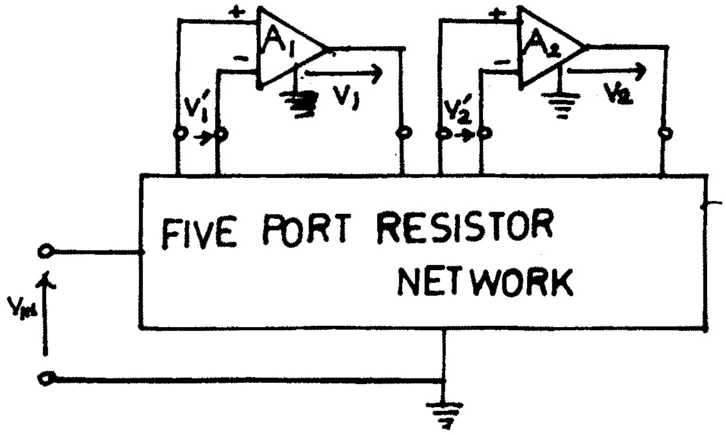

Fig.1.7: General Circuit Diagram Of Second Order Active-R Filter.

electronic technology. By using deposited RC networks and monolithic operational amplifier chips or with hybrid technology, active filters can be reduced to microscopic propositions.So the weight is also reduced.

B] CIRCUIT RELIABILITY :- It is because of the smaller size and automation, active RC filters have reduced parasitic effect and increased circuit reliability and performance.

C] ECONOMICS AND EASE OF MANUFACTURE :- Since it is not yet possible to integrate an inductor, passive circuits using inductors can only be produced using discrete components which is usually far more expensive. On the other hand active filters have the distinct advantage that they can be easily assembled using standard off the shelf components and they can be fabricated in microminiature form using integrated circuit technology. So in large quantities the cost of an integrated circuit can be much lower than its equivalent passive counterpart.

D] EASE OF ADJUSTMENT :- In critical passive filter, tuned circuits require adjestment to specific responce. Capacitors can not be made variable unless they are below a few hundred picofarads. Inductors, however, can easily be adjusted, since most coil structures provide a means for tuning such as an adjustment slug. Many active filter circuits are not easily adjustable. They may contain RC section where two or more resistors in each section have to be varied in order to control resonances. These circuits have been avoided.

Other advantages of active RC realizations independent of the physical implementation are given below[13].

1. The design process is simpler than that for passive filter.
2. Active filters can realize a wider class of functions.
3. Active realization can provide voltage gain whereas, passive filters often exhibit a significant voltage loss.

1.4.2. DRAWBACKS OF ACTIVE RC REALIZATION :- Among the drawbacks of active RC filters is the finite bandwidth of the active devices , which places limit on the high frequency performance. Most of the active RC filters are used up to approximately 30 Khz. This is quite adequate for the use in voice and data communication system. However, amplifiers are available with extended bandwidth at increased cost so that active filters at frequencies up to 500 Khz are possible.

The maximum pole frequency limit decreases with the pole Q, which defines the sharpness of the filter characteristic. The outputs of active filters built with operational amplifier have a dc voltage offset which drifts with ambient temperature changes.

On the other hand, passive filters do not have such a limitation and they can be employed up to approximately 500

Mhz, the limitation being the parasitic capacitance associated with the passive elements. Another important criterion for comparing filters is sensitivity due to variation in the element values. It will be shown that the sensitivity of passive filters is much less than that for active filters. Finally, active filters need power supplies while passive filters do not. Nevertheless, the economic and performance advantages of active RC filters far outweight the disadvantages. The trend is to use active RC filters in most voice and data communication systems. The passive filters are used as the basis for active simulation. In fact some of the active realizations are just active RC equivalents of the corresponding passive filters.

1.4.3 APPLICATIONS OF ACTIVE FILTERS :- Active filters arises from adverse publicity given to the problem of sensitivity associated with component variations. However,these problems are only significant when attempting to realize the strict specifications required for some communications applications and not, say, when designing a simple instrumentation filter.

Perhaps the most important use is in conjunction with PCM-CODEC (pulse code modulation coder/ decoder) chip for the digitization of telephones[14]. Further applications in communications include de-emphasis and pre-emphasis, equalization, active impedance-matching networks for repeaters and teleprinter low pass filters to suppress harmonics.

An interesting example of communications applications is in dial-tone multi frequency (DTMF) signaling as developed by Bell Telephone Laboratories for the use in Touch Tone Dialing. It is also used in associated system such as the radio telephone link for railway operating system.

The other major application of active filters lies in instrumentation, examples of which are : noise rejection in digital voltmeters, harmonic filtering in transforms, vibration and shock studies. They also find increasing use in the field of medical electronics where they have a distinct advantage over passive filters in the low and sub-audio range. Many physiological signals fall within the three-decade band below 20 Hz., for example : heart monitoring by electrocardiograph (ECG) and brain-wave recording by electroencephalograph (EEG).

Further areas of application are comingup and include control (e.g. servo system design and process control equipment), entertainment electronics(e.g. stereo amplifiers and musical synthesis) and pulse shaping (e.g. to avoid crosstalk in color TV broadcasting equipment). That is without mentioning sonar systems, telemetry, phase- locked loops, oscillators, hum suppressions, per-filtering of analog to digital convertors, spectrum analysis and seismological research. Nor is this list comprehensive and areas of applications not yet visualized will emerge as the twin effects of lower cost and greater production volumes create an increased awareness of active filters among engineers and other potential users.

1.5 ACTIVE- R FILTER :- Four basic building blocks of passive filter are resistance, capacitance, self inductance and mutual inductance. In addition, with the development of inexpensive operational amplifier, the use of active filters built with resistors, capacitors and operational amplifiers has been extensive. So the tremendous size reduction of electronic systems using integrated circuits has motivated the elimination of inductors from active filter design. In more recent years, there has been a drive to utilize inherent circuit capacitances, thereby eliminating the use of external capacitor also. Active filters with only resistors, that is without external capacitor, is called "Active -R filter".

Originally the parasitic capacitances associated with operational amplifiers were considered undesirable and much attention was given to compensate for their effect. Now many research workers have made use of these parasitic capacitances in the design of active filters. The gain of many commercial operational amplifiers is usually internally compensated to have a 6 dB/octave roll off. This pole is useful in designing filters in that resistors are the only additional elements needed to construct general second order filter circuits. The procedure is given by Schaumann. In these, the filter characteristics, that is, the cut off frequency, center frequency, Q, bandwidth etc, are directly related to the pole location and the d.c. gain of the operational amplifier. More generally, they depend on the gain-bandwidth product of the amplifier.

The advantages of an all-resistive passive section in circuit integration are obvious and at the same time extension of frequency range, miniaturization in size and ease of design and tunability are the additional advantages. From sensitivity consideration analysis, it is seen that the circuit has low sensitivities as compared to active RC and passive filters.

The realization of a second order filter requires the use of two op. amp. in a five port passive R network as in fig. 1.7.

By suitable choosing the transfer function of the op.amp. block, we can systematically simulate the various types of impedance such as an inductance (L), a capacitance (c), a frequency-dependent negative conductance (FDNC). Further, we can derive a simulator of a frequency-dependent negative- inductance (FDNL)and frequency-dependent negative capacitance(FDNCA) which are extensions of Bruton's (1969) concept[15].

1.5.1 ACTIVE -R FILTER DESIGN PROCEDURE :- The active R design technique is based on use of the 'integrator model' for the compensated operational amplifier. Using this model, the operational amplifier may be treated either as an inverting or non-inverting grounded integrator, depending on how it is connected. This allows for a much more simplified design and analysis procedure, yet does not represent a significant loss of accuracy except at very low frequencies. Furthermore, the effect at low frequencies is simply to provide a 'floor' such that for high - pass and band pass realizations there is a maximum attenuation at low frequencies and this floor will be at an optimum value if the active R design is used[8].

1.6 CONCLUDING REMARKS :- A filter is a network used to shape the frequency spectrum of electrical signal. Filters are classified according to the functions they perform, as low-pass, high pass, band pass, band reject amplitude equalizers and delay equalizers. Filters using L,C,R components, called passive filters, were using a bulky element inductor which in no way can be manufactured using recent IC technology, where as the component like R,C and active element circuit could be implemented on the IC'S. So a new type of inductorless filter has been developed called "active filter". This has various advantages over passive filter.

In more recent years, active filter with only resistors is developed and is called "active -R filter". The parasitic capacitances associated with op.amp. were considered undesirable and much attention was given to compensate for their effect. The advantages of an all resistive filter are extended frequency response, miniaturizing size, ease of design, tunability and low sensitivity. These filters are applicable in communication application as well as in instrumentation.

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