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DESIGN OF A VERSATILE REMOTE CONTROL SWITCH FOR BROADCAST TRANSMITTERS

Tetsuo Yoshino

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TETSUO YOSHINO

ABSTRACT

A versatile remote control system for the broadcast transmitters, whereby a number of transmitter operations can be commanded directly via the main radio program line, is described. An inexpensive and practical implementation of the system, using IC key-code, audio-tone generators as command-signal generators, and active RC bandpass filters with AC/DC converters connected to logic and memory circuits as decoders, is also given.

To this end, the necessity of installing remote control systems in unattended broadcast transmitter facilities, in compliance with the Broadcast Procedure No.8 ruled on December 1, 1974 by the Department of Communications, Communications Canada, is first examined. The existing remote control systems are also reviewed.

This review leads us directly to the proposed system, whose detailed design is then discussed. The new system can be used as such. However, for the sake of convenience and additional economy, the proposed scheme is integrated into the old remote control switch which, by

itself, has been found by CBC to be unsuitable and hence was abandoned.

Detailed experimental work has also been carried out, which indicates the satisfactory performance of the designed circuits in accordance with theoretical predictions.

The design of the remote control switch presented in this thesis should significantly contribute to the reduction of the cost as well as to the increase in efficiency of operation of broadcast transmitters.

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A	Operational amplifier gain	32
AC	Alternative current	17
AGC	Automatic gain control	11
AM	Amplitude modulation	2
BW	Bandwidth	30
C_j	Capacitor	43
COMP.SIG.	Composite signal	11
dBm	0 dBm = 1 mW into a 600 ohm load	45
DC	Direct current	17
DOC	Department of Communication, Communications Canada	1
D(s)	Denominator of T(s)	30
$D(\omega)$	A network function	36
FM	Frequency modulation	2
F_n	Control function in the remote control system, n = 1,2,3,....,	27
f_o	Center (resonant) frequency	28
f_p	Pole frequency in Hz	31
G	Gate of NAND gate circuit	47
H	Resonant Magnitude of T(s)	30
IC	Integrated circuit	10
mW/ff	Power in mW per flip-flop	54

NAND	Not (A) and (B), where A and B are variables	10
NOR	Not (A) or (B), where A and B are variables	10
N(s)	Numerator of T(s)	30
PCM	Pulse code modulation	13
Q	Quality factor of an inductor	12
Q_p	Pole Q-factor	32
R_i	Resistor	43
RF	Radio frequency	6
r.m.s.	Root-mean-square	45
s	Complex frequency variable	30
S_X^D	Sensitivity of a network function D with respect to a parameter x	36
S/N	Signal to noise ratio	6
SW	Short wave	2
$SW_{1,2}$	Switch #1 or #2	60
T_c	Time of transmitting an audio-tone frequency	60
T_d	Delay time	50
T(s)	Open circuit voltage transfer function	30
TV	Television	4
UHF	Ultra high frequency	2
VHF	Very high frequency	2
VITS	Video interval test signal	8
VSWR	Voltage standing wave ratio	4

x	A parameter in the network function $D(\omega)$	36
ΔC_j	A small variation in C_j due to the ambient temperature	43
ΔQ_p	A small deviation of Q_p	43
ΔR_i	A small variation in R_i due to the ambient temperature	43
$\Delta\omega_p$	A small deviation of ω_p	43
μA	Operational amplifier	25
	A time constant	57
ω_p	Pole resonant frequency in rad/sec	32

CHAPTER 1

INTRODUCTION

1.1 GENERAL

The family of broadcast transmitters employed in the ground stations by CBC can be divided into six categories, as shown in Table 1.1, depending on the purpose of the broadcast and the frequency band used [1 - 5].

In order to establish and operate a broadcast transmitter facility in Canada an applicant must comply with the Canadian broadcast rules [4,6,7]. To this end he must first submit his proposed technical brief to the Department of Communications(DOC), Communications Canada, for technical approval of the facility construction. This brief should basically consist of the following documents [8 - 10]:

(i) Explanation of the complete transmission system to be used for the proposed facility, including an interference analysis.

(ii) Detailed geographical data of the proposed location for the facility, indicating the effective height above average terrain (EHAAT) for the transmitting antenna radiation.

(iii) Description of the proposed models of transmitting equipment to be provided to the system, including antennas, input and output control equipment, and monitoring equipment.

TABLE 1.1 CLASSIFICATIONS OF BROADCAST TRANSMITTERS IN USE IN CBC

FAMILY OF BROADCAST TRANSMITTERS	FREQUENCY BAND	TYPICAL OUTPUT POWER AND REFERENCE PRICES	SOME OF SUPPLIERS	TYPE OF PROGRAM FEED
(1) AM RADIO TRANSMITTERS	550 - 1500 (kHz)	40 W ($5,000) 1 Kw ($13,000) 10 Kw ($50,000)	COLLINS, GATES RADIO, RCA	NETWORK
(2) SW RADIO TRANSMITTERS	15 - 30 (MHz)	250 Kw ($300,000)	COLLINS	NETWORK
(3) VHF TV TRANSMITTERS	54 - 88 (MHz) and 174 - 216 (MHz)	5 W ($6,000) 250 W ($18,000) 3 Kw ($70,000) 15 Kw ($160,000)	ACRODYNE, CGE, GATES, RCA	NETWORK or Off-Air or Microwave
(4) FM RADIO TRANSMITTERS	88 - 108 (MHz)	10 W ($6,000) 100 W ($ 9,000) 2.5Kw ($20,000) 20 Kw ($80,000)	GATES, SPARTA, CSI	NETWORK
(5) UHF TV TRANSMITTERS	470 - 890 (MHz)	100 W ($10,000) 10 Kw ($100,000)	CGE, MSC, NEC	NETWORK or Off-Air or Microwave
(6) MICROWAVE TRANSMITTERS	6590 - 6770 (MHz) and 7000 - 7080 (MHz)	1 W ($20,000) 10 W ($40,000)	FARINON, RAYTHEON	NETWORK or Microwave

(iv) Data of the antenna support structure from the aviation point of view.

(v) Horizontal and/or vertical pattern(s) of the transmitting antenna system.

(vi) If an off-air pick-up or a microwave relay system is proposed, data of the analysis to prove a sufficient quality of the signal at the pick-up point for rebroadcasting.

(vii) A proposed coverage map for the service area indicating field-strength contours in μV/m or mV/m in the case of a radio coverage, or grade A and B contours in the case of a television coverage.

At the same time, the applicant must apply to the Canadian Radio and Television Commission (CRTC) for an operating license, explaining the purpose of his proposed broadcast facility and the total population to be served by the facility with the estimated costs for the facility construction and the annual operation.

It is very important for the licensee to state explicitly in the DOC application form, whether his proposed broadcast facility operates under local control (attended) or under remote control (unattended). It is also important to indicate clearly whether it is in compliance with the minimum requirements for the transmitter facility such as installation of a carrier on-off switch by either local or remote control, selection of day and night power and/or radiation pattern control where applicable, accurate measurement of the carrier frequency and monitoring the output power continuously [6]. The transmitter must also be a DOC approved type and should be protected at least against overload, high temperature and high VSWR.*1

To avoid unnecessary frequency interferences with the other communication and broadcast frequencies, these requirements have recently become stringent for the broadcast transmitter operations in Canada [6].

In addition to these requirements, the reduction of power consumption should be taken into consideration to minimize the operating cost of the transmitter facility.

Let us take one example to illustrate how important this consideration is. A 15 kW VHF-TV transmitter normally consumes 70 kWh approximately and operates continuously for about 17 hours a day. Therefore, unless the high voltage circuit of this transmitter is switched off by either local or remote control switch, the transmitter would waste 70 kWh

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*1. VSWR is a voltage standing wave ratio and defined as

$$\text{VSWR} = \frac{1 + |\rho|}{1 - |\rho|}, \text{ where } \rho \text{ is reflection coefficient.}$$

Usually, VSWRs are between 1.01 and 1.45 in most antenna systems.

for the rest of 7 hour program-off period at the rate of 3 cents per kWh approximately [11]. This would result in loss of $15.00 a day or more than $5,000.00 a year for operating only one high power transmitter. In case of a low power transmitter, the annual loss would vary from $500.00 to $2,000.00, depending on the rate of the power consumption unless a remote control switch is installed in the transmitter.

As of January, 1976, CBC owns 235 television transmitters and 364 radio transmitters officially operating in seven CBC regions in Canada [12]. Approximately 90% of those transmitters should be remote-controlled due to the unattended operations. Hence, considerable benefit could be gained from installation of a remote control switch to command the operation of each of these transmitters.

Recently there has been a strong trend for the reduction of energy consumption in industrial and household equipment [13]. Installing a reliable and inexpensive remote control switch, suitable for each of the broadcast transmitters is also compatible with this trend.

1.2 REMOTE CONTROL SYSTEMS FOR THE BROADCAST TRANSMITTERS

The remote control systems for the broadcast transmitters may be brought under eight main categories depending on the control signals used and/or the available links between a studio and the transmitters.

(I) RF Carrier Link System:

This system is used for TV and Radio rebroadcast transmitters. An RF carrier itself is detected at the receiving terminal where a rebroadcast transmitter is installed. The detected carrier is converted to a suitable signal for control of the transmitter. Since such an RF carrier is normally off-air picked up and has a low S/N ratio, it is impractical to use this system unless a high gain, low noise RF amplifier is provided.

(II) Video-Synchronizing Pulse Link System:

This system is designed for TV transmitters. Only the synchronizing pulse portion of the video signal is detected at the receiving terminal and fed to the memory circuit for the transmitter control. As is well known, the video synchronizing pulse is independent of variations in the picture level and the RF carrier level [14].

(III) Aural Pass-Band Inaudible Frequency Link System:

This system may be used for a radio transmitter and the aural part of a TV transmitter. Spot frequencies (multiple or single), normally in the range of 25 kHz to

40 kHz, inserted into the program as key code signals, are detected by band-pass filters at the receiving terminals and used as coded signals for the transmitter control. These inaudible key-code frequencies may be removed by notch filters [15] after their use to avoid any frequency interferences in the program.

(IV) Continuous Audio-Tone Frequency Link System:

In general, a pair of continuous audio-tone frequencies are transmitted via a second quality line as key-code signals while the program material is delivered through the main program line. As long as these key-tones exist in the system, they are detected at the receiving terminal which is different from the transmitter input terminal, and converted to switching pulses for the transmitter control [16-18].

(V) Digital Pulse Control Link System:

A series of digital pulses could be used instead of audio-tone frequencies in the category (IV) [5]. This concept is useful for a control system between a studio and a transmitter. In the existing system, a telemetry data, modulated on a 39 kHz sub-carrier, is inserted into the aural transmitter along with the normal aural program material (100 Hz to 18 kHz approximately). The data can contain the information on the up-dated status of the transmitter including the whole facility. As soon as the absence of the telemetry information from the transmitter is sensed at the studio, a stop command is sent automatically via the link from the studio to the transmitter.

(VI) Time-Clock Control System:

A time-clock, installed in a transmitter facility, may be used as a primitive tool for the transmitter remote control. This system causes a problem because the operation hour of the transmitter is determined by the time switch set on the clock but not by the daily program schedule.

(VII) Audio Program Frequencies Link System:

A certain portion of program material frequencies, for an example, between 600 Hz and 4 kHz is filtered and converted to a switching signal for the transmitter control [19].

(VIII) VITS Link System:

VITS, that is, a video interval test signal could be used for the remote control of a TV transmitter with an appropriate device [5, 20].

Generally speaking, broadcast transmitters, in which remote control switches are installed, are switched on about 15 minutes before the commencement of the daily program schedule and shut down immediately after the schedule completion.

At present, the video-synchronizing pulse link system in the category (II) prevails over other systems, as the remote control system for the TV transmitters, mainly because of the following reasons:

(i) The TV transmitter can be automatically switched on and off by the direct insertion and removal of the video signal. Thus the desirable schedule of the TV program can be retained by only the application of the video signal [14].

(ii) The existence of the video signal at the receiving terminal will automatically turn on and hold on the transmitter as soon as the main power line is restored after its failure occurs.

(iii) Compared with other systems [5, 14], the cost of this type of control switch (about $500.00 to $1,500.00) is inexpensive.

The system mentioned in category (V) is, on the other hand, very useful if control of both TV and radio transmitters and, at the same time, monitoring the performance at the studio, are required. This is similar to the one in category (III) except for the telemetry data modulated on the subcarrier. The system, however, is costly ($3,000.00 to $7,000.00) [5], for low and medium power transmitters compared with the net price of the transmitter itself (see Table 1.1), and often it is unnecessary to install such an expensive system in many radio rebroadcast transmitters.

As yet (at least up to the time of writing this thesis), CBC has not decided definitely in favour of any particular remote control system. The system that is presently in use for a radio transmitter is the continuous audio-tone frequency link system described in category (IV). However, this is also a costly system because the current purchase price of a second quality line is $15,000.00 approximately, and hence is uneconomical for the usual radio transmitter operation.

Thus, it is desirable to have a reliable and economical way of commanding transmitter operation. Referring to Fig.1.1 [21], one of the ways this can be achieved is to have a system whereby the transmitter operation is effectively controlled via the main program line, which is required for transmitting the program material anyway. In order to accomplish this, it is proposed to design a low-cost remote control switch consisting of voice-band frequency selective filters and switching circuits as basic circuit structures.

Switching circuits can be easily designed using relays in combination with logic and/or memory circuits which frequently consist of NAND and NOR functions, and J-K flip-flops [22, 23]. They are commercially available in the forms of inexpensive integrated circuits (less than $1.50 for both IC quad two input NAND gate, MM5611A, and IC dual J-K flip-flop, SN5473) [24].

A problem, however, arises in the design of voice-band frequency selective filters. As is known, one confronts

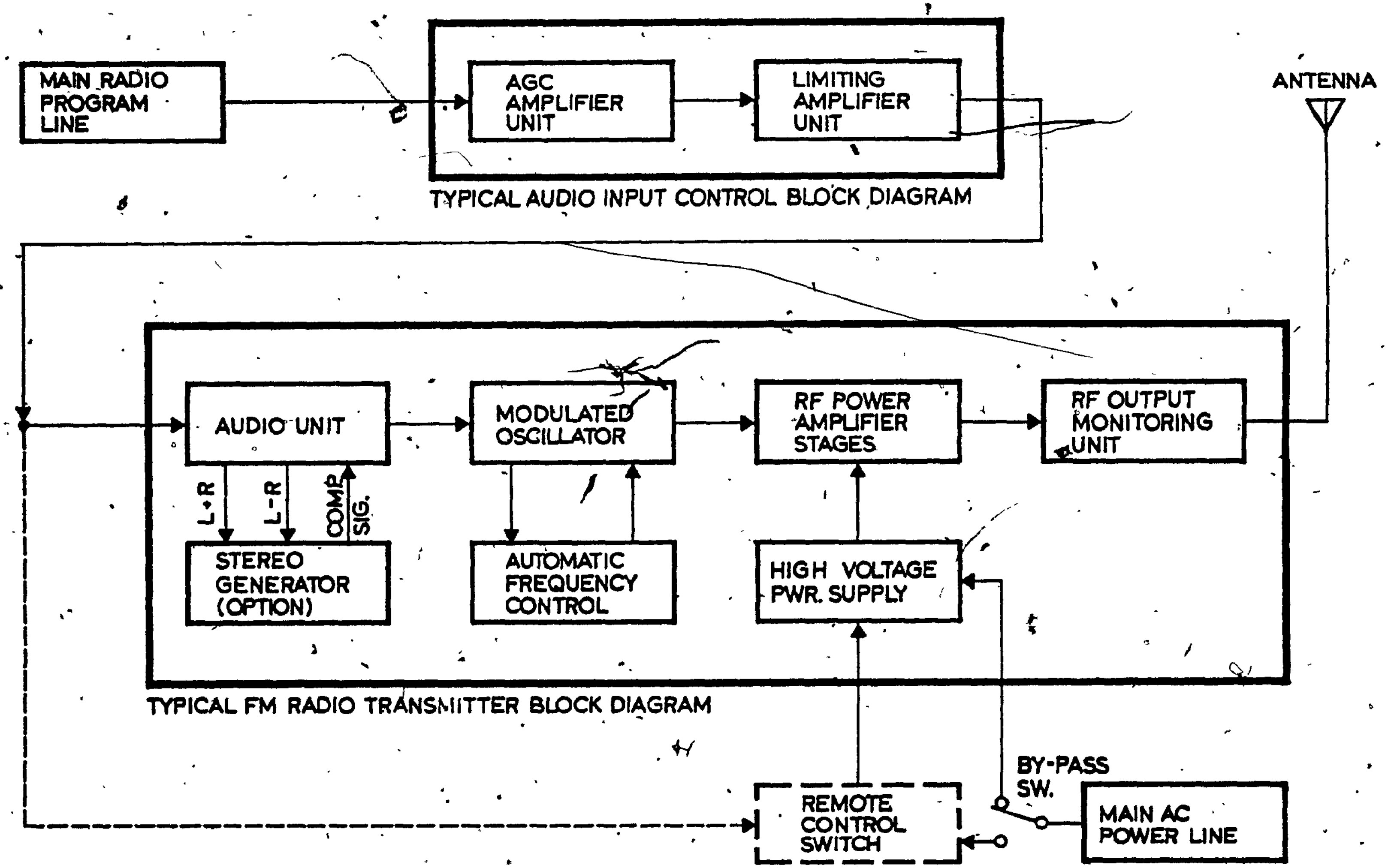


FIGURE 1.1

FUNCTIONAL DIAGRAM OF SIMPLIFIED RADIO TRANSMITTER FACILITY

WITH DESIRABLE REMOTE CONTROL SWITCH

several difficulties in designing them using RLC passive components, mainly because of the following reasons [17, 18, 25]:

(a) Bulky size, heavy weight, large dissipation factor and yet expensive cost of a reasonable Q inductor for the voice-band frequency application.

(b) Non-linear frequency dependence of the quality factor Q of the inductor.

(c) Difficult manufacturability of inductors with equal Q values.

(d) Often, adjustable inductors are required for an LC filter network because of the above reasons (b) and (c). This, however, results in (a).

(e) Consideration of impedance matching and compensation of insertion loss, which are inherent in the design of passive filters.

Let us look into one example of a voice-band LC filter block commercially available as of January, 1976 [18]. This filter has a Q factor of about 40 at the frequency of 1209 Hz, consisting of three adjustable inductors and three fixed precision capacitors which are placed on, approximately 5cm x 9cm, fiberglass board. According to the manufacturer, it is difficult to tune the filter for the specified Q factor and center frequency. The diameter and height of each inductor are 2.5cm and 1.5cm, respectively, and its weight is heavier than the total weight of 15 "quarters". Finally, the total cost of one filter block is about $80.00 including the cost of tuning.

A promising way of overcoming these difficulties is to design and fabricate filter circuits without inductors, that is, active RC filters which require only resistors and capacitors along with active elements. Hence it is worthwhile looking into the recent status and the characteristics of active RC filters briefly.

1.3 ACTIVE RC FILTERS AND THEIR APPLICATIONS

In recent years, the use of the active RC filters for the low frequency applications has rapidly increased in the field of the control and switching systems such as PCM data processing [26], telephone transmission systems [27], analog computers [28].

Active RC filters can be designed to have other advantages over RLC filters [25-29]. Some of them are:

(i) The filter output impedance can be made very low, thereby making the filter response independent of the load impedance. Consequently, the filters can be cascaded without buffer stages.

(ii) The input impedance of the filter is frequently high, compared with the source impedance. This allows a direct connection of the filter to the signal source, drawing little power from the source.

(iii) The filter itself often provides insertion gain, thereby eliminating the need for additional amplifiers.

(iv) The filter can be designed to have Q and the center frequency independently tunable. This allows accurate realization of the filter characteristics.

(v) The filter can be made very compact. Further, it is possible to fabricate the filter by the hybrid integrated technology.

However, an RC active filter, if improperly designed, can be unstable and its characteristics can become highly sensitive to the element variations. On the other hand a passive RLC filter is absolutely stable and its characteristics are relatively insensitive to the element variations.

Since the proposed remote control switch for a radio broadcast transmitter will be operating in the voice-band frequency range, it appears to be of interest to explore the possibility of using such active RC filters in this application.

1.4 SCOPE OF THE THESIS

In this thesis considerations are first given to the improvement of the existing remote control systems for radio broadcast transmitters; this leads to a proposal for a versatile remote control switch which is developed using a unique combination of active RC filters with logic and memory circuits. For this purpose, the thesis is divided into four chapters.

In Chapter 2, two new methods are suggested to improve the existing remote control systems, using directly the main radio program line. For each of these configurations, the technical details are described using block diagrams. These two proposals are then compared to establish their relative merits or demerits.

In Chapter 3, the implementation of one of the proposals, that is "audio key-code frequencies" configuration, which is judged to be the more suitable one for the application at hand, is presented, leading to the design of a versatile remote control switch to be controlled via the usual program line by transmitting simultaneously appropriate combinations of key-code audio-tone frequencies.

The basic circuit structures required are: a key-code generator which has an IC square-wave oscillator using NAND gates, and a decoder consisting of a second-order active RC bandpass filter, an AC/DC converter, a set of logic and memory circuits.

The second-order active RC bandpass filter is synthesized using the direct and coefficient matching method. The sensitivity analysis, the design and tuning procedures are also presented.

At the end of this Chapter, a description is given as to how all these designed circuits have been integrated into the old type of remote control switch which, by itself, has been found to be unsuitable for current systems.

The experimental investigations carried out for this project are described in Chapter 4. These have been conducted utilizing the available test equipment in EHQ, CBC.

The photographs of waveforms from the key-code generators, the second-order active RC bandpass filter are attached, which show close agreement between designed and actual performances.

Finally, Chapter 5 summarizes the results of this investigation and contains the conclusion.

CHAPTER 2

CONSIDERATIONS FOR IMPROVEMENT OF EXISTING REMOTE CONTROL SYSTEMS

2.1. GENERAL

The existing remote control systems have been discussed in Chapter 1 and it is found that it is desirable to develop an inexpensive and reliable remote control switch for usual radio broadcast transmitters to meet the standard DOC requirements for the broadcast facilities [6].

The following two methods are suggested for the improvement of the existing systems, using directly the main program line.

(1) "Selected voice-band frequency switch" approach.

(2) "Audio key-code frequencies switch" approach.

As the basic building blocks of remote control switches in both approaches, active RC filters will be used as frequency selective circuits, followed by suitable AC/DC converters and then logic/memory circuits with relay switches.

2.2 "SELECTED VOICE-BAND FREQUENCY SWITCH" APPROACH

This approach is a modification of the category (VII) in Section 1.2 of Chapter 1 - Audio Program Link System. In this approach the main program line is also the control link for the remote control system. The proposal for this type of switch is described as follows:

A remote control switch is installed in parallel with the input of a transmitter as shown in Fig.2.1. The program material arrives simultaneously at inputs of both the transmitter and the remote control switch through the main program line. A portion of the program frequencies typically above 200 Hz is picked up by an active RC high-pass filter [28, 30, 31] and converted to a DC signal by an AC/DC converter. The DC signal immediately energizes a control switch which is held on as long as the program frequencies appear at the input of the transmitter.

The hum and noise in the program line due to the AC power source are well below the 200 Hz and completely eliminated by the active RC high-pass filter. The DC level to trigger the control switch should be adjusted for an effective level of the program frequency energy. Thus, the undesirable operation of the transmitter due to the system noises can be avoided.

In addition, an adjustable time delay circuit for 5 minutes to 10 minutes is built in so that this delay circuit can be triggered on only by the absence of the program frequencies during the program schedule hour and hold on the relay switch for the adjusted time. Thus, with this time delay circuit, the transmitter can safely remain on for the adjusted time after the loss of the program material occurs

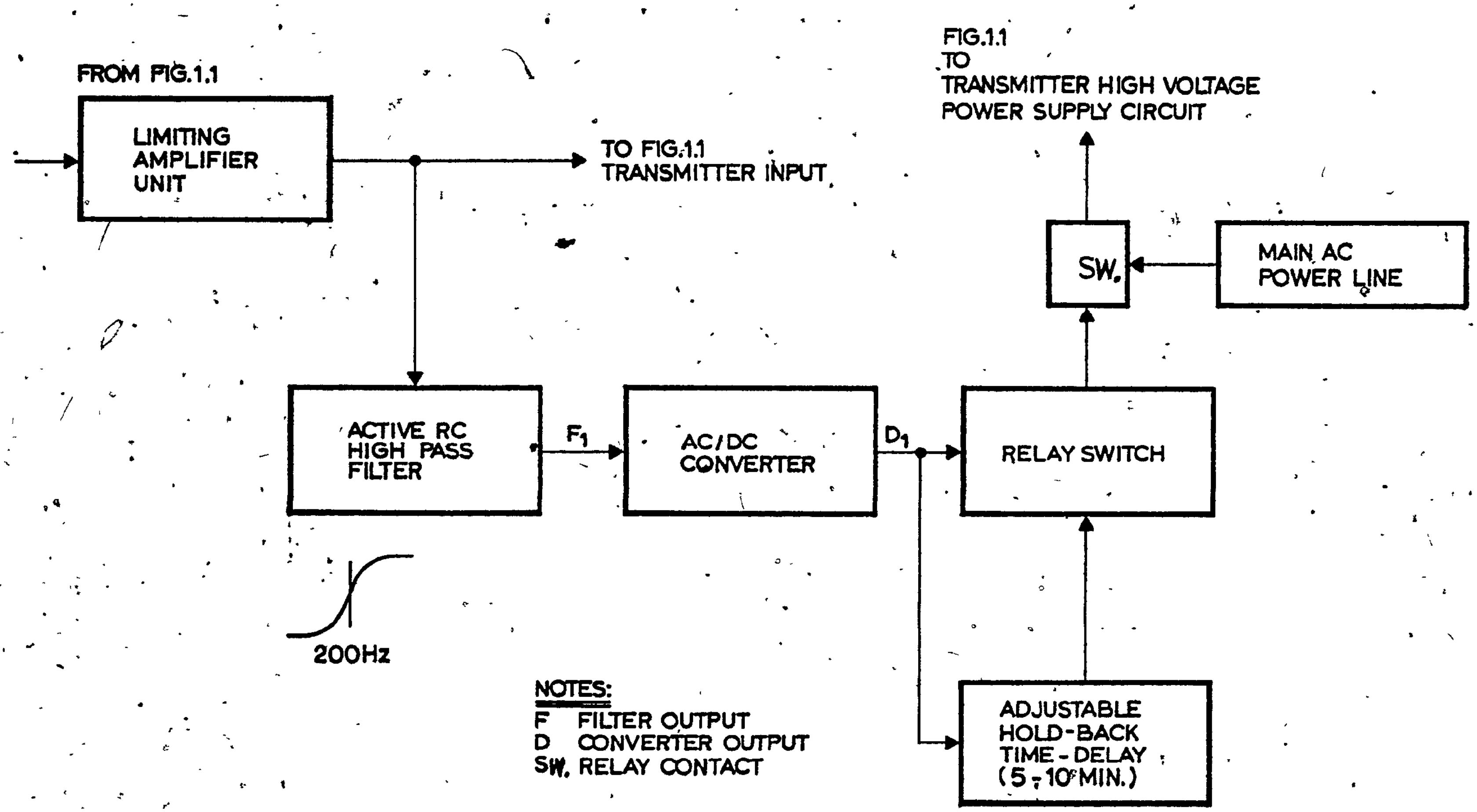


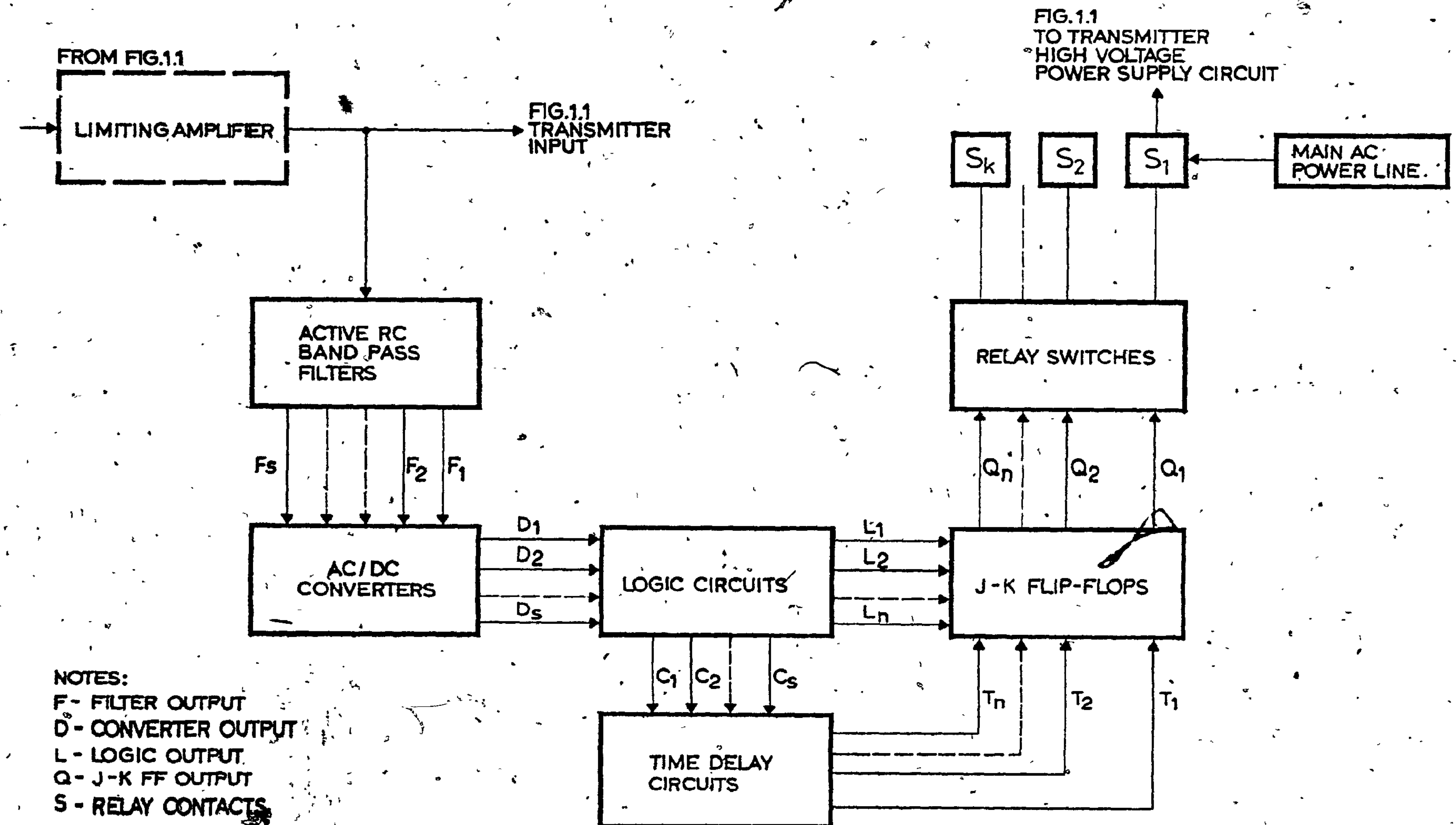
FIGURE 2.1

SELECTED VOICE-BAND FREQUENCY SWITCH CONFIGURATION at the input of the transmitter, in case of either the silent duration or the interruption period of the program material, which is caused normally by studio program change. The continuous absence of the program material frequencies beyond the adjusted time shuts down the transmitter automatically.

2.3 "AUDIO KEY-CODE FREQUENCIES SWITCH" APPROACH

The second approach is a modification of the category (IV) in Section 1.2 of Chapter 1 - Audio-Tone Frequency Link System. Instead of using the second quality line which results in additional expenditure, the direct utilization of the main program line is suggested as the control link between a studio and transmitters, or one transmitter and the other. The details of the proposal are described below.

A remote control switch is connected in parallel with a transmitter input as shown in Fig.2.2. A particular combination of different precision single-tone frequencies is assigned as a key-code to command transmitter operation. For an example, a combination of 851 Hz and 1209 Hz can be assigned as a key-code to switch the transmitter on, and another combination of 851 Hz and 525 Hz as a key-code to switch the transmitter off, etc. There is a large number of combinations of single audio-tone frequencies within the range of audio frequency, large enough to control other functions of the transmitter via the program line.



NOTES:
F - FILTER OUTPUT
D - CONVERTER OUTPUT
L - LOGIC OUTPUT
Q - J-K FF OUTPUT
S - RELAY CONTACTS
T - TIME DELAY COMMAND
C - DELAY COMMAND SOURCE
$s \geq n \geq k$ WHERE s IS A NUMBER OF KEY-CODE FREQUENCIES.

FIGURE 2.2
AUDIO KEY-CODE FREQUENCIES SWITCH CONFIGURATION

These key-code frequencies are simultaneously transmitted through the program line before and after the daily program schedule hours or during program intermissions so that the interference of these frequencies into the program can be avoided. The output level of a key-code generator must be maintained below +10 dBm which is the maximum allowable level into the program line.

When the key-code frequencies reach the input of the remote control switch and are received simultaneously by active RC bandpass filters, they are converted to DC signals by AC/DC converters and fed into logic/memory circuits which control a set of relays, which in turn control the high voltage power supply to the transmitter and other functions of the transmitter, if required.

The program material may contain for a moment these key-code frequencies and cause accidental operations of the transmitter functions. In order to prevent these undesirable operations, a reasonable time delay circuit (0.5 - 1.5 sec.) may be added to an appropriate logic output to control each of the memory circuits.

2.4 COMPARISON OF THE TWO APPROACHES

The use of the approach (1) is limited to only a single control function of the transmitter, because only one relay function can be commanded by an application of the program material frequencies from the studio to the main program line.

The approach (2), on the other hand, while requiring relatively simple building blocks, offers multiple control of the transmitter operation.

Thus, the approach (2) is clearly superior to the approach (1) and only its implementation will now be considered.

CHAPTER 3

IMPLEMENTATION OF PROPOSED REMOTE CONTROL SWITCH

3.1 GENERAL

The purpose of this Chapter is to discuss implementation of the proposed "Audio Key-Code Frequencies" approach. This leads to the design of a versatile remote control switch of broadcast transmitters, which can be operated from the studio, simply by transmitting appropriate combinations of audio-tone frequencies as key-codes for the control switch via the normal radio program line.

The main components for the audio-tone key-code generators are square wave generators which are obtained by using NAND gates, and a set of switches for selecting audio-tone key-codes. The decoder basically consists of a second-order active RC bandpass filter followed by an AC/DC converter and a set of logic and memory circuits followed by a relay switch. The block diagram of this decoder circuit has been given in Fig.2.2 of Section 2.3.

A versatility of the remote control switch can be increased by adding such a circuit block of the decoder with the corresponding key-code generator. Therefore, the design of one complete set of an audio-tone key-code generator and a decoder is sufficient to demonstrate the technique of implementing the proposed remote control switch.

To design the logic and memory circuits, NAND gates MM 5611A and J-K flip-flops SN 5473 are used. The active RC bandpass filter is constructed, using IC operational amplifiers μA 741C, with precision discrete resistive and capacitive elements.

The synthesis of the active RC bandpass filter is done using the direct and coefficient matching method [25]. The sensitivity analysis of the filter is carried out, and the design procedure of the bandpass filter is given along with the tuning procedure.

As an AC/DC converter, a diode rectifier circuit is employed because of its simplicity.

A given operating mode of the transmitter is effected by an appropriate combination of key-code frequencies. Thus, it is possible for such an operation to take place accidentally if the required combination of frequencies exists in the program line. In order to prevent this situation from occurring, in practice, a time delay unit with a prescribed amount of delay is incorporated in the decoder memory circuit.

For the decoder circuit now to operate, key-code frequencies have to be transmitted for a duration longer than the limit in time delay encountered in the decoder memory circuit. It is highly unlikely that any accidental combination of frequencies in the program line, similar to any combination of key-code frequencies, would last longer than the limit in time delay in the decoder memory circuit.

On the other hand, a timer, installed in the one-touch switch of the key-code generator, would automatically, after releasing the switch, allow the generator to transmit audio-tone frequencies sufficiently longer than the prescribed delay in the decoder circuit. Thus, the transmitter would operate in any given manner only in response to the key-code frequencies.

Finally, it is described as to how all of the designed circuit blocks can be integrated with the half-abandoned remote control switch. This remote control switch is unsuitable to the present CBC systems, since its use, without any modification, would require a costly second quality line.

3.2 DISCUSSION FOR CONTROL CHANNEL FREQUENCIES

As discussed in Chapter 2, there are a large number of combinations of audio-tone frequencies that can be used as key-codes for the proposed remote control switch. A key-code may consist of two different audio-tones which continue for more than 0.5 sec.*1 to avoid any undesirable

*1: In a human voice, it is highly unlikely that a given frequency component will have a continuous duration of more than 0.5 sec.

operations of the transmitter by the program frequencies. These key-code frequencies should be chosen above 100 Hz, taking into consideration the characteristics of the program line frequency response [33].

With the above consideration in mind, the frequency range between 500 Hz and 1000 Hz is chosen for the proposed remote control system. This range is then divided equally into 10 channels having a 50 Hz bandwidth. These channels will be called CONTROL CHANNELS A,B,C,D,E,F,G,H, I,J.

One particular audio-tone frequency is assigned to each control channel which may be located in the center of the channel. Thus, 10 different audio-tone frequencies in total can be assigned in the chosen frequency range.

If two different channels are combined to form one key-coding system for one control function F_n, $(n = 1,2,\ldots)$ as shown in Fig.3.1, we find 45 key-codes*1 in the chosen frequency range, which are quite sufficient to control most of the functions of interest in the transmitter [5].

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*1: The number of different combinations of n different things, k at a time, without repetition, is

$$\binom{n}{k} = \frac{n!}{k!\,(n-k)!}$$

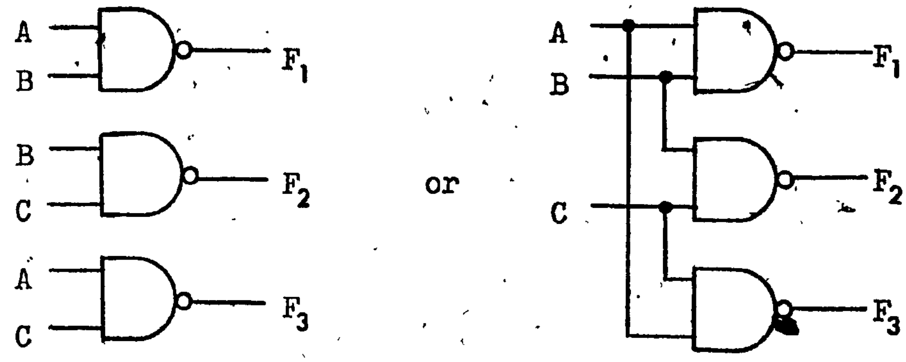


Fig.3.1 Possible combinations of two different channels for one key-code in case of three channels used in the system.

It is possible to have more than 45 control functions by either widening the total frequency range for the same channel bandwidth or narrowing each bandwidth in the same frequency range to allow more control channels.

3.3 DESIGN OF THE SECOND-ORDER ACTIVE RC BANDPASS FILTER

As mentioned in Section 3.1, a second-order active RC bandpass filter is required in the decoder unit. In this section, design of such a filter is considered.

The different channels along with their center frequencies are shown in Table 3.1. The center frequency f_o of the filter should be in the range 525 Hz $\le f_o \le$ 975 Hz as chosen in Section 3.2. Further to ensure minimum interactions between the control frequencies of the adjacent channels, the bandpass filter should be designed with a bandwidth of less

TABLE 3.1

PROPOSED CHANNELS AND THEIR CENTER FREQUENCIES

CHANNEL	FREQUENCY RANGE (Hz)	CENTER FREQUENCY f_0 (Hz)
A	500 - 550	525
B	550 - 600	575
C	600 - 650	625
D	650 - 700	675
E	700 - 750	725
F	750 - 800	775
G	800 - 850	825
H	850 - 900	875
I	900 - 950	925
J	950 - 1000	975

than 50 Hz. Experience indicates that the bandwidth should not be more than 30 Hz. Thus, the minimum Q*1 obtainable from the filter should be in the range $\frac{525}{30} \leq Q \leq \frac{975}{30}$ or $17.5 \leq Q \leq 32.5$, depending on the center frequency of the channel. For this purpose, an infinite-gain multiple feedback configuration with two active elements is used as shown in Fig. 3.2 [28].

The voltage-ratio transfer function T(s) of this filter network may be expressed as:

$$T(s) = \frac{V_o(s)}{V_i(s)} = H\frac{N(s)}{D(s)} \qquad (3.1)$$

where H is a scale factor, and N(s) and D(s) are polynominals in S. In case of the band-pass filter network, they may be expressed as:

$$D(s) = S + S(\omega_p/Q_p) + \omega_p^2 \qquad (3.2)$$

$$N(s) = S(\omega_p/Q_p) \qquad (3.3)$$

and $$\lim_{\omega \to \omega_p} \left|T(s)\right|_{s=j\omega} = H \qquad (3.4)$$

---

*1: The quality factor Q is a measure of the selectivity of the filter and is given as the ratio of the resonant frequency f_o to bandwidth BW; hence

$$Q = \frac{f_o}{BW}$$

where $BW = |f_1 - f_2|$, and f_1, f_2 are half-power point frequencies.

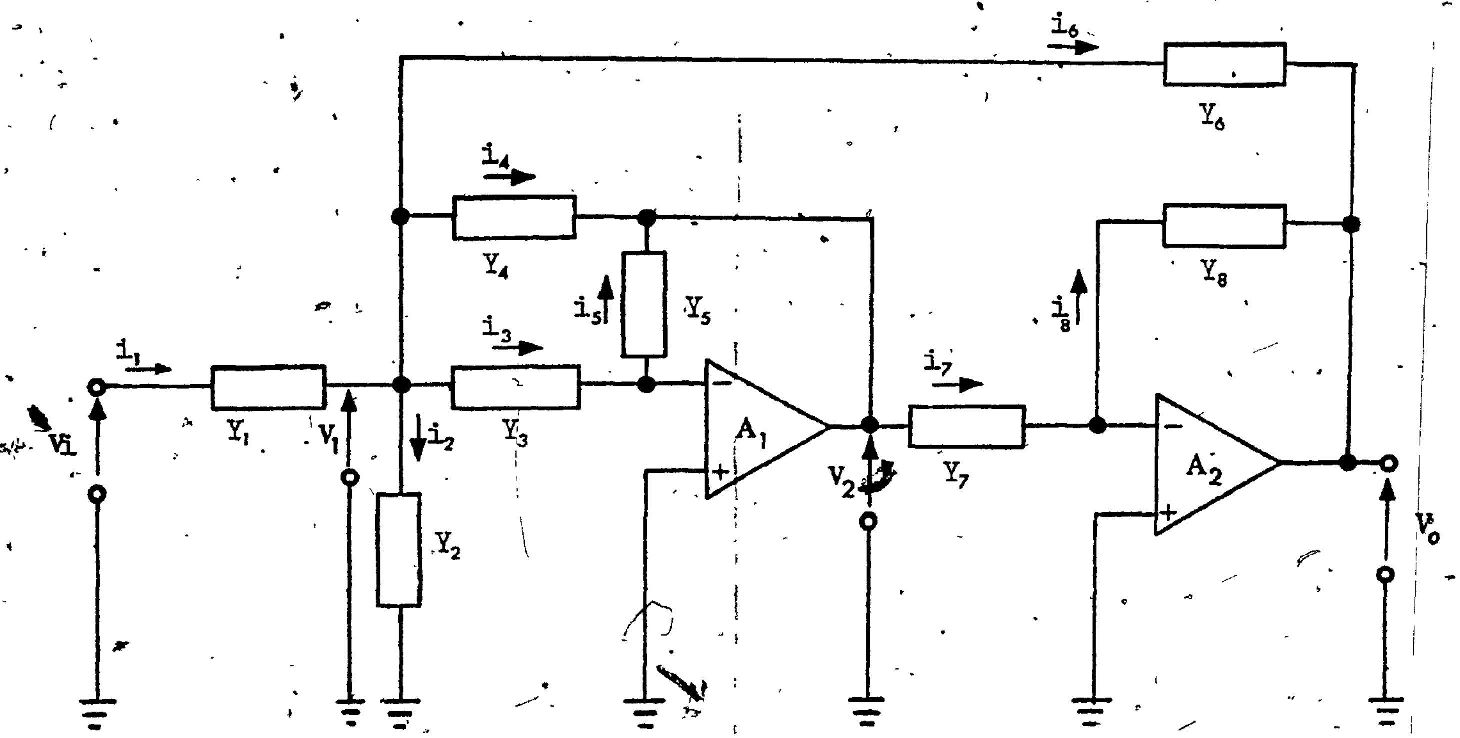


Fig.3.2 Infinite-gain Multiple-feedback Bandpass Filter for a reasonably high Q requirement. A_1 and A_2 are open-loop voltage gains of the operational amplifiers.

where Q_p : pole Q-factor,

ω_p : pole frequency in rad./sec.

$= 2\pi f_p$, where f_p is the pole frequency in Hz.

H : resonant magnitude at f_p.

For a bandpass filter, Q_p is the same as the Q of the filter.

From Fig. 3.2, the following equations can be easily obtained:

$$i_1 = i_2 + i_3 + i_4 + i_6 \quad (3.5)$$

$$i_1 = (V_i - V_1)\, Y_1 \quad (3.6)$$

$$i_2 = V_1 Y_2 \quad (3.7)$$

$$i_3 = \left(V_1 + \frac{V_2}{A_1} \right) Y_3 = -\left(\frac{V_2}{A_1} + V_2 \right) Y_5 \quad (3.8)$$

$$i_4 = (V_1 - V_2)\, Y_4 \quad (3.9)$$

$$i_6 = (V_1 - V_0)\, Y_6 \quad (3.10)$$

$$i_7 = i_3 + i_4 = \left(V_2 + \frac{V_0}{A_2} \right) Y_7 = -\left(\frac{V_0}{A_2} + V_0 \right) Y_8 \quad (3.11)$$

Substituting Eqs. (3.6) to (3.10) into Eq. (3.5), we have

$$V_i Y_1 = V_1 (Y_1 + Y_2 + Y_3 + Y_4 + Y_6) + V_2 (\frac{Y_3}{A_1} - Y_4) - V_0 Y_6 \quad (3.12)$$

To obtain T(s), we express V_1 and V_2 in terms of V_o and solve Eq. (3.12) for V_o/V_i.

Now, Eqs. (3.8) and (3.11) can be rearranged as follows:

$$V_1 = - V_2 (\frac{1}{A_1} + \frac{1}{A_1}\frac{Y_5}{Y_3} + \frac{Y_5}{Y_3}) \quad (3.13)$$

and

$$V_2 = - V_0 (\frac{1}{A_2} + \frac{1}{A_2}\frac{Y_8}{Y_7} + \frac{Y_8}{Y_7}) \quad (3.14)$$

When the operational amplifier is used in the frequency range of less than 10 kHz, its open-loop gain will be at least in the order of 10^5 [32]. Therefore, both $\frac{1}{A_1}$ and $\frac{1}{A_2} \ll 1$, and are negligible in Eqs. (3.13) and (3.14), compared with other element values. Thus, both Eqs. (3.13) and (3.14) can be reduced to

$$V_1 = - V_2 \frac{Y_5}{Y_3} \quad (3.15)$$

$$V_2 = - V_0 \frac{Y_8}{Y_7} \quad (3.16)$$

Further, Eq. (3.15) can be rewritten in the term of V_o as

$$V_1 = V_0 \frac{Y_5}{Y_3}\frac{Y_8}{Y_7} \tag{3.17}$$

Substituting Eqs. (3.16) and (3.17) into Eq. (3.12), we obtain

$$V_i Y_1 = V_0 \frac{Y_5}{Y_3}\frac{Y_8}{Y_7}(Y_1 + Y_2 + Y_3 + Y_4 + Y_6) - V_0 \frac{Y_8}{Y_7}\left(\frac{Y_3}{A_1} - Y_4\right) - V_0 Y_6 \tag{3.18}$$

Again in Eq. (3.18) $\frac{Y_3}{A_1} \ll 1$ and is negligible for our filter design. Rearranging Eq. (3.18), we have

$$T(s) = \frac{V_0}{V_i} = \frac{Y_1 Y_3 Y_7}{-Y_3 Y_4 Y_8 + Y_5 Y_8 (Y_3 + Y_4) - Y_3 Y_6 Y_7 + Y_8 Y_5 (Y_1 + Y_2 + Y_6)} \tag{3.19}$$

For a bandpass filter application of Fig. 3.2, we may select

$$\left.\begin{aligned} Y_1 &= \frac{1}{R_1} & Y_5 &= \frac{1}{R_5} \\ Y_2 &= \frac{1}{R_2} & Y_6 &= \frac{1}{R_6} \\ Y_3 &= sC_3 & Y_7 &= \frac{1}{R_7} \\ Y_4 &= sC_4 & Y_8 &= \frac{1}{R_8} \end{aligned}\right\} \tag{3.20}$$

We substitute Eq. (3.20) into Eq. (3.19) and finally obtain the transfer function T(s) of this bandpass filter network as:

$$T(s) = \frac{S\,[\,R_8/(R_1 R_7 C_4)\,]}{S^2 + S\,[1 + C_4/C_3 - R_5 R_8/(R_6 R_7)]R_5 C_4 + (1/R_1 + 1/R_2 + 1/R_6)/(C_3 C_4 R_5)} \tag{3.21}$$

Comparing Eq. (3.21) with Eq. (3.1), the pole Q-factor Q_p, the undamped frequency of oscillation ω_p and the resonant magnitude H of the network can be easily found as follows:

$$H = \frac{R_5 R_8/R_7}{R_1[(1 + C_4/C_3) - R_5 R_8/(R_6 R_7)]} \tag{3.22}$$

$$\omega_p = [(1/R_1 + 1/R_2 + 1/R_6)/(C_3 C_4 R_5)]^{\frac{1}{2}} \tag{3.23}$$

$$Q_p = [(1/R_1 + 1/R_2 + 1/R_6)R_5 C_4/C_3]^{\frac{1}{2}}/[1 + C_4/C_3 - R_5 R_8/(R_6 R_7)] \tag{3.24}$$

or

$$Q_p = \omega_p R_5 C_4 \frac{1}{[1 + C_4/C_3 - R_5 R_8/(R_6 R_7)]} \tag{3.25}$$

3.3.1 SENSITIVITY ANALYSIS

The sensitivity of a network function $D(\omega)$ with respect to a parameter x is defined [28, 31] by

$$S_X^D = \frac{d\, D(\omega) \,/\, D(\omega)}{d\, X \,/\, X} = \frac{X}{D(\omega)} \frac{d\, D(\omega)}{d\, X} \qquad (3.26)$$

Note that changes in $D(\omega)$ and x have been normalized so that the sensitivity function actually specifies percentage changes from the nominal values of $D(\omega)$ and x.

Applying Eq. (3.26) to Eqs. (3.22), (3.23) and (3.24), we obtain, letting $K = R8/R7$,

$$S_{R_1}^H = -1 \qquad (3.27)$$

$$S_{R_6}^H = -H \frac{R_1}{R_6} \qquad (3.28)$$

$$S_{C_3}^H = -S_{C_4}^H = \frac{H}{K} \frac{R_1 C_4}{R_5 C_3} \qquad (3.29)$$

$$S_K^H = S_{R_5}^H = \frac{H}{K} \frac{R_1}{R_5}\left(1 + \frac{C_4}{C_3} \right) \qquad (3.30)$$

$$S_{R_1}^{\omega_p} = \frac{-1}{2\, \omega_p^2\, R_1\, R_5\, C_3\, C_4} \qquad (3.31)$$

$$S_{R_2}^{\omega_p} = \frac{-1}{2\, \omega_p^2\, R_2\, R_5 C_3 C_4} \qquad (3.32)$$

$$S^{\omega_p}_{R_6} = \frac{-1}{2\,\omega_p^2\, R_5R_6C_3C_4} \qquad (3.33)$$

$$S^{\omega_p}_{C_3} = S^{\omega_p}_{C_4} = S^{\omega_p}_{R_5} = -\frac{1}{2} \qquad (3.34)$$

$$S^{Q_p}_{R_1} = \frac{-1}{2\,\omega_p^2\, R_1R_5C_3C_4} \qquad (3.35)$$

$$S^{Q_p}_{R_2} = \frac{-1}{2\,\omega_p^2\, R_2R_5C_3C_4} \qquad (3.36)$$

$$S^{Q_p}_{R_6} = \frac{-1}{2(1+R_6/R_1+R_6/R_2)} + \frac{1}{1-(1+C_4/C_3)R_6/(KR_5)} \qquad (3.37)$$

$$S^{Q_p}_{C_3} = -\frac{1}{2} + \frac{C_4}{C_3(1+C_4/C_3-KR_5/R_6)} \qquad (3.38)$$

Since we have from Eq. (3.25)

$$(1+C_4/C_3-KR_5/R_6)^{-1} = \frac{Q_p}{\omega_p R_5 C_4} \qquad (3.39)$$

thus,

$$S^{Q_p}_{C_3} = -\frac{1}{2} + \frac{Q_p}{\omega_p R_5C_3} \qquad (3.40)$$

$$S^{Q_p}_{C_4} = \frac{Q_p}{\omega_p R_5C_3}\left(1-\frac{KR_5}{R_6}\right) - \frac{1}{2} \qquad (3.41)$$

$$S^{Q_p}_{K} = -KQ_p/(\omega_p R_6C_4) \qquad (3.42)$$

$$S^{Q_p}_{R_5} = \frac{Q_p}{\omega_p R_5C_3}\left(1+\frac{C_3}{C_4}\right) - \frac{1}{2} \qquad (3.43)$$

$$S^{K}_{R_8} = -S^{K}_{R_7} = 1 \qquad (3.44)$$

3.3.2 DESIGN PROCEDURE

First of all, to reduce the spread of element values of the bandpass filter in Fig. 3.2 we choose.

$$C = C_3 = C_4 \tag{3.45}$$

$$R = R_1 = R_5 \tag{3.46}$$

When Q_p and $\omega_p = 2\pi f_p$ are given, we find, substituting Eqs. (3.45) and (3.46) into Eqs. (3.24) and (3.25),

$$Q_p = (1 + R/R_6 + R/R_2)^{\frac{1}{2}} / (2 - KR/R_6) \tag{3.47}$$

and

$$Q_p = \omega_p R C / (2 - KR/R_6) \tag{3.48}$$

where

$$R_6 > \frac{1}{2} KR \tag{3.49}$$

If we choose $R_6 = KR$, Eqs. (3.47) and (3.48) can be re-written as

$$\frac{1}{R_2} = (Q_p^2 - 1 - \frac{1}{K}) / R \tag{3.50}$$

and

$$R = \frac{Q_p}{\omega_p C} \tag{3.51}$$

where

$$K = \frac{R_8}{R_7} \geq 1 \tag{3.52}$$

and

$$R_6 = KR \tag{3.53}$$

Since $Q_p \gg 1$, Eq. (3.50) may be reduced to

$$R_2 = \frac{R}{Q_p^2} \qquad (3.54)$$

From Eqs. (3.22),(3.45),(3.46) and (3.53), we have

$$H = K \qquad (3.55)$$

From Eqs. (3.45) to (3.55) the element values of the bandpass filter in Fig. 3.2 may be tabulated as shown in Table 3.2.

TABLE 3.2: DESIGN RELATIONS FOR CIRCUIT ELEMENTS

CIRCUIT ELEMENT	R_1	R_2	C_3	C_4	R_5	R_6	R_7	R_8
DESIGN VALUE	R	R/Q_p^2	C	C	R	KR	R_8/K	R_8

Notes: (1) $K = R_8/R_7 \geq 1$ (2) $R = Q_p/(\omega_p C)$

In Table 3.2, K should be chosen reasonably between 1 and 10.

3.3.3 TUNING PROCEDURE

It is observed from Table 3.2 that the elements R_1, R_5, C_3 and C_4 cannot be used for tuning as the design requires them to be fixed elements in the circuit. On the other hand, $R_2 \ll R_6$ (since $K \geq 1$ and $Q_p^2 \gg 1$), or $1/R_2 \gg$

$1/R_6$. Thus, we note from Eq. (3.23) that ω_p can be adjusted by R_2. An examination of the equations (3.22) and (3.24) now reveals that the following tuning sequence can be conveniently followed.

(1) R_2 can be used to tune $\omega_p = 2\pi f_p$

(2) After tuning ω_p by trimming R_2, Q_p can be tuned by adjusting $K = R_8/R_7$ without influencing ω_p. That is, Q_p can be tuned by trimming R_7 in case R_8 is fixed.

Note that in this tuning sequence, once ω_p is adjusted Q_p can be precisely tuned without affecting ω_p.

3.3.4 VALUES OF PASSIVE ELEMENTS

The purpose of this section is to examine the ranges of the passive element values that will be required for the bandpass filters in the frequency range between 500 Hz and 1000 Hz.

The value of Q_p in the proposed filter can be chosen between 25 and 50. From Eq. (3.51), it is easily seen that, if a passband width is chosen for 20 Hz $\pm$ 10% with the fixed capacitor $C = 0.1\mu F$, then

$$66.9 \text{ Kohms} \geq R \geq 54.5 \text{ Kohms} \quad (3.56)$$

where $29 \geq Q_p \geq 24$ at $f_p = 525$ Hz

and, $$88 \text{ Kohms} \geq R \geq 69.4 \text{ Kohms} \quad (3.57)$$

where $54 \geq Q_p \geq 42.5$ at $f_p = 975$ Hz

Consequently, since $R_2 = R/Q_p^2$ as given in Table 3.1.

$$64.8 \text{ ohms} \leq R_2 \leq 116.1 \text{ ohms at } f_p = 525 \text{ Hz} \quad (3.58)$$

and,

$$23.8 \text{ ohms} \leq R_2 \leq 48.7 \text{ ohms at } f_p = 975 \text{ Hz} \quad (3.59)$$

The tolerances of the passive elements to be used in the filter design should be ± 2% for capacitors and ± 1% for resistors. These tolerances of the capacitors and resistors are commercially available at the prices of less than $1.20 and $0.20 respectively, in Montreal, as of January, 1976 [36, 37].

For the design values of R_6 to R_8, we may choose

$$R_6 = R \quad (3.60)$$

and $$R_7 = R_8 = 10 \text{ Kohms} \quad (3.61)$$

setting K=1 in Table 3.2.

Thus, using element values as given by Eqs. (3.56) to (3.61), the required active RC second-order band-pass filter can be designed for the desired control channel stated in Section 3.2.

3.3.5 SENSITIVITY VALUES FOR PROPOSED DESIGN VALUES OF THE ELEMENTS

We now investigate the sensitivity of the filter circuit by using the analysis of Section 3.3.1 along with the proposed design values of the passive elements as obtained in Section 3.3.4

Substituting Eqs. (3.45), (3.46), (3.52), (3.54) and (3.55) into Eqs. (3.28) to (3.44), we find, setting $K = R_8/R_7 = 1.2$ in this example,

$$S^H_{C_3} = -S^H_{C_4} = -S^H_{R_1} = -S^H_{R_6} = -S^K_{R_7} = S^K_{R_8} = 1 \qquad (3.62a)$$

$$S^H_{R_5} = S^H_K = 2 \qquad (3.62b)$$

$$S^{Q_p}_{R_1} = S^{\omega_p}_{R_1} = S^{\omega_p}_{R_6} \leq -0.001547 \qquad (3.63)$$

$$S^{Q_p}_{R_2} = S^{\omega_p}_{R_2} \leq -1.3010525 \qquad (3.64)$$

$$S^{\omega_p}_{C_3} = S^{\omega_p}_{C_4} = S^{\omega_p}_{R_5} = -0.5 \qquad (3.65)$$

$$S_{R_6}^{Q_p} = -1.000721 \tag{3.66}$$

$$S_{C_3}^{Q_p} = -S_{C_4}^{Q_p} = 0.5 \tag{3.67}$$

$$S_{R_5}^{Q_p} = 2.726208 \tag{3.68}$$

$$S_{K}^{Q_p} = -3.271450 \tag{3.69}$$

Since the filter can be tuned, the variations of and Q_p with respect to temperature are only of interest. Now, we have for $\Delta\omega_p/\omega_p$ and $\Delta Q_p/Q_p$ [25-28],

$$\frac{\Delta\omega_p}{\omega_p} = (\Sigma\, S_{R_i}^{\omega_p})\,\frac{\Delta R_i}{R_i} + (\Sigma\, S_{C_j}^{\omega_p})\,\frac{\Delta C_j}{C_j} \tag{3.70a}$$

$$\frac{\Delta Q_p}{Q_p} = (\Sigma\, S_{R_i}^{Q_p})\,\frac{\Delta R_i}{R_i} + (\Sigma\, S_{C_j}^{Q_p})\,\frac{\Delta C_j}{C_j} \tag{3.70b}$$

Assuming TCR's to be + 100 x 10^{-6}/°C and TCC's to be -150 x 10^{-6}/°C [36, 37], we have

$$\left|\frac{\Delta\omega_p}{\omega_p}\right|_{worst} = (\Sigma\left|S_{R_i}^{\omega_p}\right|)\times 10^{-4} + (\Sigma\left|S_{C_j}^{\omega_p}\right|)\times(-1.5\times 10^{-4}) = 0.304\times 10^{-4}/°C \tag{3.71a}$$

$$\left|\frac{\Delta Q_p}{Q_p}\right|_{worst} = (\Sigma\left|S_{R_i}^{Q_p}\right|)\times 10^{-4} + (\Sigma\left|S_{C_j}^{Q_p}\right|)\times(-1.5\times 10^{-4}) = 3.530\times 10^{-4}/°C \tag{3.71b}$$

Normally, the filters will be installed in the transmitter room where the temperature variation is automatically maintained between 15°C and 25°C. Thus,

$$\left|\frac{\Delta\omega p}{\omega p}\right|_{worst} = 0.0304\ \%\ /\ 10\,°C \qquad (3.72a)$$

$$\left|\frac{\Delta Q_p}{Q_p}\right|_{worst} = 0.3530\ \%\ /\ 10\,°C \qquad (3.72b)$$

Thus, it can be concluded that the sensitivity of the bandpass filter with respect to the values of the passive elements proposed can be kept within acceptable limits.

3.4 DESIGN OF AC/DC CONVERTER

A half-wave, voltage-doubler, capacitor-filtered diode rectifier is proposed for the AC/DC converter as shown in Fig. 3.3. This circuit is chosen because of its simplicity. An a.c. signal from the output of the active RC bandpass filter is converted to a d.c. signal which gives a logic "1" status to the following logic circuit NAND gate MM 5611A. The d.c. input level V_d of this NAND gate should be equal to or greater than + 2.25V [24].

Since a square-wave signal is chosen as an audio key-code frequency, the input signal V_a to the diode rectifier is a square-wave signal. Therefore, referring to Fig. 3.4, the output voltage V_d of this rectifier is

$$V_d = \left[\frac{1}{2\pi} \int_0^{\pi} V_a \, dt \right] \times 2 = V_a \qquad (3.73)$$

Thus, it is easily seen that the a.c. input voltage V_a to this rectifier should be equal to or greater than 2.25 V_{pp}. to give the logic "1" status to the NAND gate MM 5611A. The effective (root-mean-square) value of V_a is

$$V_a \text{ r.m.s.} = \sqrt{\frac{1}{2\pi} \int_0^{\pi} V_a^2 \, dt} = 0.707 \, V_a$$
$$= 1.59 \text{ Volts} \qquad (3.74)$$

If K = H = 1.0 is chosen in Eq. (3.55) for the worst condition, the input voltage to the active RC bandpass filter, that is, the r.m.s. value of the audio-tone signal V_{in} r.m.s. from the program line will be 1.59 V r.m.s. or +6.2 dBm, which is below the maximum permissible limit (=+10 dBm) in the program line.

When K = H = 1.5 is chosen, it is apparent that we may have

$$V_{in} \text{ r.m.s.} = \frac{V_a \text{ r.m.s.}}{1.5} = 1.06 \text{ V r.m.s.} \qquad (3.75)$$

or + 2.7 dBm

for the audio-tone signal from the program line.

The element values of C_r and R_r are not critical and may be 1 μF and 10 Kohms respectively.

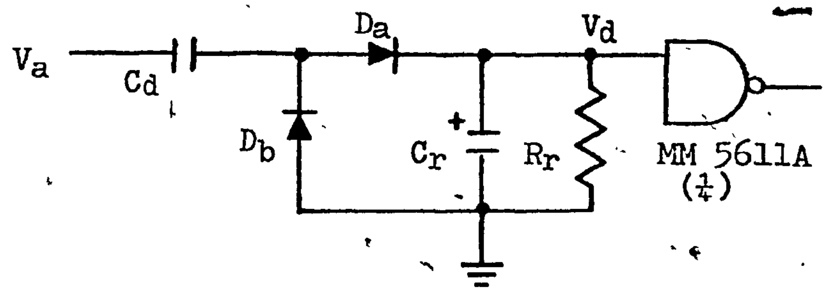


Fig.3.3 The proposed half-wave, voltage-doubler, capacitor-filtered diode rectifier.

Note: C_d - dc cut-off capacitor
C_r - capacitor filter
R_r - discharging circuit for C_r
V_a - ac input voltage to the diode rectifier.

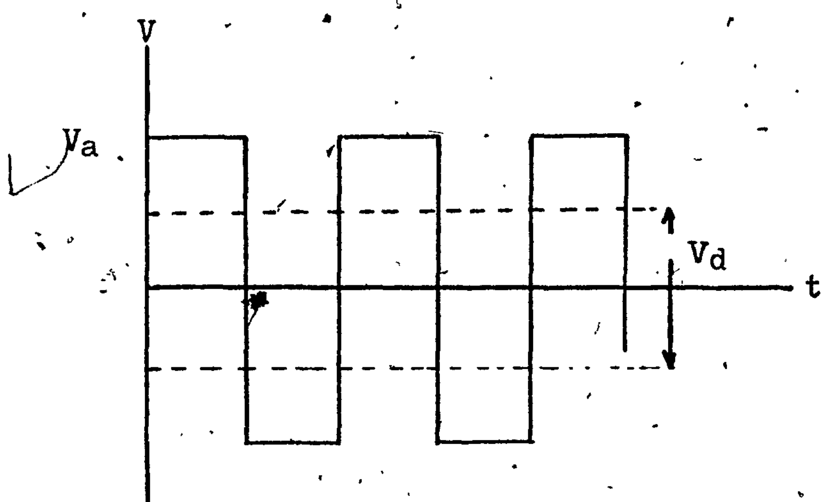


Fig.3.4 Waveforms of the input V_a and output V_d signals of the half-wave, voltage-doubler, capacitor-filtered diode rectifier in Fig.3.3.

3.5 DESIGN OF LOGIC AND MEMORY CIRCUITS

As described in Section 3.2, supposing that one operational function of the transmitter, for an example, its high voltage circuit is to be switched on and off, two independent control functions, say F_1 and F_2 will be required as shown in Fig. 3.5, using three different key-codes to be applied to NAND gates G_a and G_b.

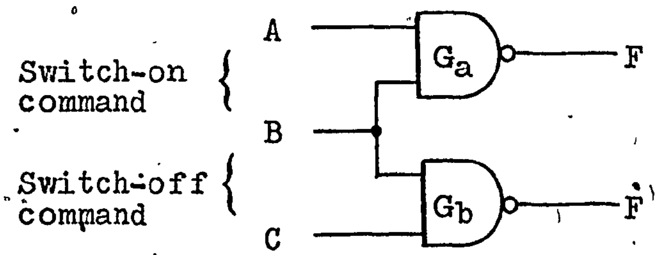


Fig. 3.5 Two independent control functions F_1 and F_2, using three different key-codes.

Figs. 3.6 and 3.7 show two methods to satisfy the required functions, using either only two relay switches or an IC J-K flip-flop with a relay switch. Comparing these two methods, the latter configuration is found to be superior to the other because of the following reasons:

(i) The price of the circuit of Fig. 3.6 is \$12.00 approximately and higher than the price of the circuit of Fig. 3.7 (\$4.00).

(ii) The power consumption of the circuit of Fig. 3.6 is ½ Watt min., while the latter circuit consumes only 150 mW max.

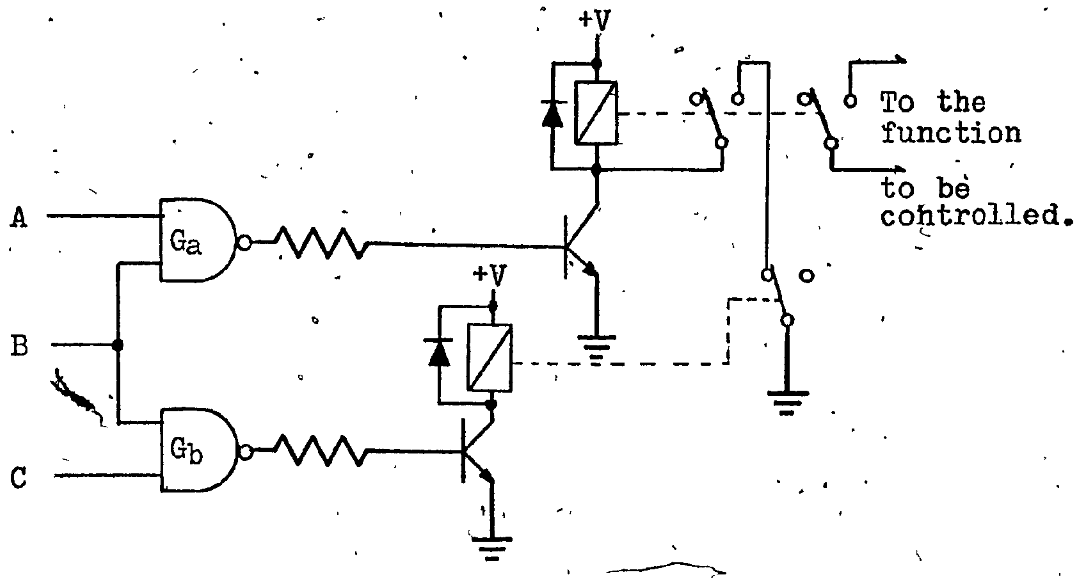


Fig.3.6 " Two-relay switch " configuration.

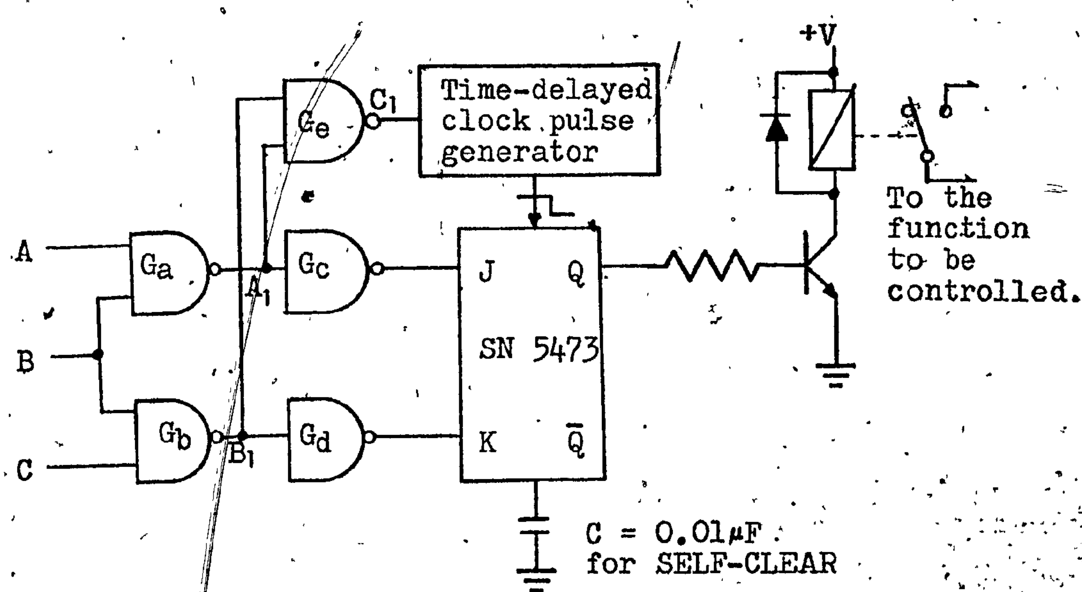


Fig.3.7 " IC J-K flip-flop " configuration. The truth table of this circuit is given in Table 3.3.

TABLE 3.3 TRUTH TABLE OF FIG.3.7

							Each flip-flop		
							t_n		t_{n+1}
	A	B	C	A_1	B_2	C_3	J	K	Q
NO SIGNALS	0	0	0	1	1	0	0	0	Q_n
SWITCH-ON COMMAND	1	1	0	0	1	1	1	0	1
SWITCH-OFF COMMAND	0	1	1	1	0	1	0	1	0
ALL SIGNALS	1	1	1	0	0	1	1	1	$\overline{Q}$

(iii) The command can be memorized in the latter circuit in case of the main power failure, providing that a small external battery is installed to the J-K flip-flop. This will be discussed in Section 3.7.

Hence, we consider only the circuit of Fig. 3.7.

3.6 DESIGN OF THE TIME-DELAYED CLOCK PULSE GENERATOR

It is proposed to design a time-delayed clock pulse generator using a single shot multivibrator as shown in Fig. 3.8. The timing chart of inputs and outputs of NAND gates is given in Fig. 3.9 and Fig. 3.10.

The delay time T_d is determined by [34]:

$$i_2 = \frac{V}{R_2} e^{-T_d/(C_2 R_2)} \tag{3.76}$$

$$T_d = C_2 R_2 \ln \frac{V}{i_2 R_2} \tag{3.77a}$$

$$= \left(C_2 R_2 \log \frac{V}{i_2 R_2} \right) 2.3 \tag{3.77b}$$

Since the required input voltage to the NAND gate MM 5611A (1/4) is + 2.25 Volts [24], we have $V/(R_2 i_2) = 2.25$. Thus,

$$T_d \doteq 0.69\ C_2 R_2 \tag{3.78}$$

We have already proposed in Section 2.3 of Chapter 2, a time delay of the clock pulse to be 0.5 to 1.5 sec. in order to avoid accidental operation by the program frequency.

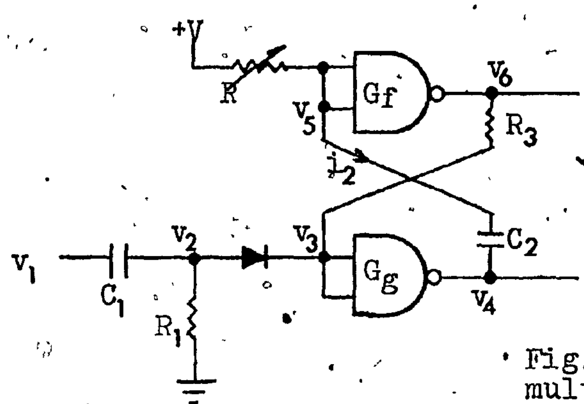


Fig.3.8 A sigle shot multivibrator as the time-delayed clock pulse generator.

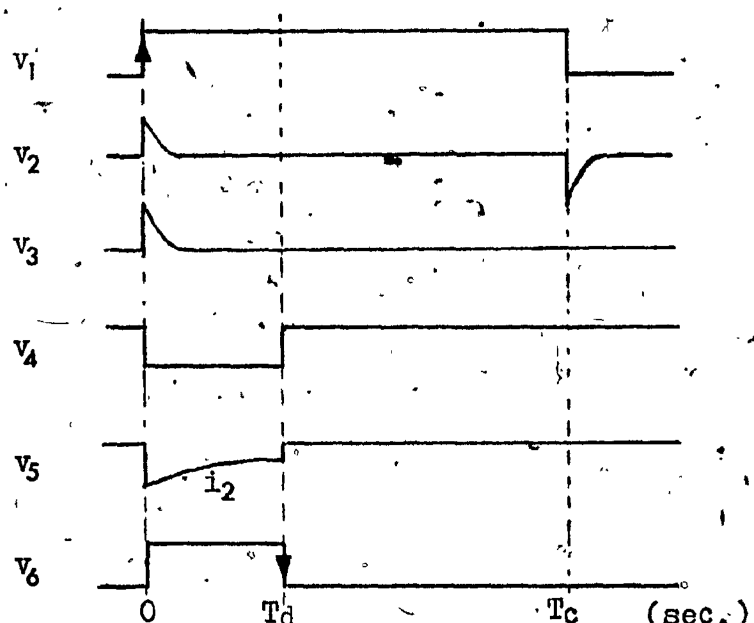


Fig.3.9 Timing chart for the inputs and outputs of the time-delayed clock pulse generator.

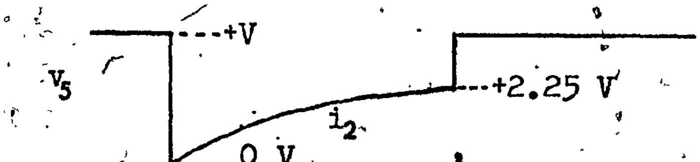


Fig.3.10 Expanded waveform of v_5 with respect to i_2.

When $C_2 = 1\mu F$ is chosen, R_2 will be approximately 15 Kohms for $T_d = 1$ sec. T_d can be adjusted by trimming R_2.

The delayed clock pulse should be a falling edge (negative edge) pulse to drive the J-K flip-flop SN 5473. Therefore, the output of the NAND gate G_f is connected to the clock pulse input of the J-K flip-flop.

To trigger this single shot multivibrator, a rising edge (positive edge) pulse is required as shown in the timing chart. For this purpose an NAND gate G_e is added in the circuit of Fig. 37. From the Table 3.3, it is clearly seen that one of the commands can provide such a rising edge pulse through G_e to the time-delayed clock pulse generator.

Now the J-K flip-flop can memorize the command when the key-code signals come in for a sufficiently longer time than the designed delay time T_d.

3.7 FURTHER DESIGN CONSIDERATIONS

The designs of the different parts of the decoder unit are now available. In order to install the decoder unit in the system, first we have to avoid the d.c. coming into the active RC bandpass filter. For this purpose, two capacitors can be inserted between the system and the decoder input as shown in Fig. 3.11.

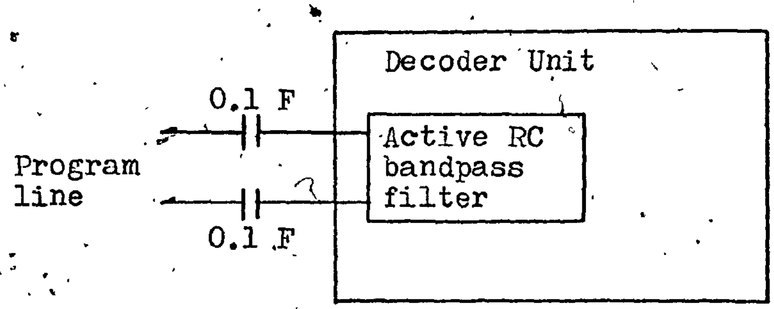


Fig.3.11 D.C. rejection by inserting capacitors in series with the decoder input.

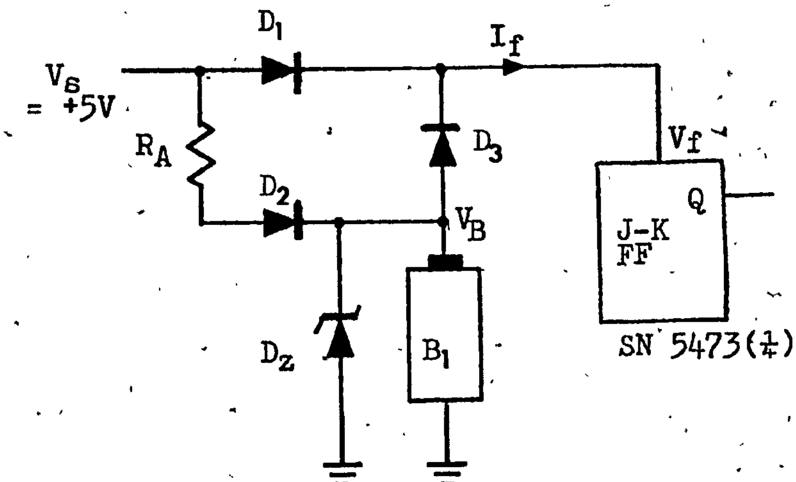
If the remote control switch is to be used for a high power transmitter, an AC relay may have to be incorporated into the switch. One simple way to incorporate the AC relay in the remote control switch, whenever necessary, is to have the AC relay actuated by the DC relay. This is because, for controlling an operation of a high power transmitter, such as switching it on, the relay switch contacts have to carry currents of the order of 100 amps, the corresponding circuit through the relay coil being of the order of 10 amps. Thus, the relay must have high current capacity contacts. Also these contacts should be able to withstand high transient energy of the high voltage circuits.

Rebroadcasting transmitters usually are placed in the remote communities. These communities rely on diesel power generators as their power sources, and frequently suffer from high power-failure rates. For an example, 17 power failures were recorded in December, 1975, only on the Grand

Manan Island, New Brunswick, where a CBC FM transmitter is operating.

In a location, such as the one mentioned above, there is normally an emergency stand-by power supply, which is often shared by the Telephone company, so that radio broadcast service can be maintained even during the black-out. However, there is a transient time lag of about one minute until such a stand-by power generator generates the full power after the main power failure occurs. With or without the stand-by power generator, it is obvious that the operation of the remote control switch is seriously affected by the main power failure. This situation can be avoided by installing a rechargeable battery in the memory circuit (J-K flip-flop) of the decoder unit as shown in Fig. 3.12.

The optimum power dissipation of the IC dual J-K flip-flop SN 5473 is 45 mW/ff [24], that is, this IC requires $I_f = 20$ mA at $V_f = 4.6$ Volts, which can be supplied by the main D.C. source V_s of + 5 Volts. This D.C. source also charges continuously B_1, a re-chargeable cadmium battery [35] via R_A and the diode D_2. The zener diode D_z is provided to protect B_1 from being over-charged. As soon as V_s fails due to the main AC power failure, B_1 will start to supply the energy for the maintenance of the memory status in the decoder unit via D_3 for 400 hours or 16 days at the rate of $I_f = 15$ mA at $V_f = 3.5$ Volts. In order to trigger



Notes: $D_{1\sim3}$ = 1N4148, B_1 = 4V rechargebale cadmium battery ($16.00), R_A = 100 Ω ± 5%, D_z = 3.9V zener diode. (I_f=20 mA and V_f= +4.6 V.)

Fig. 3.12: Proposed memory protection circuit in case of the main power failure, using a rechargeable cadmium battery.

the memory unit, $I_f = 20$ mA at $V_f = 4.6$ Volts are required [24]. However, the above values ($I_f = 15$ mA at $V_f = 3.5$ Volts) are sufficient to maintain the status in the memory unit, once it is triggered.

3.8 DESIGN OF THE AUDIO-TONE KEY-CODE GENERATOR

This section presents a simple design of an audio-tone key-code generator using NAND gates MM 5611A only.

In the proposed remote control system, the performance of the key-code frequency generator is not very critical mainly for the following reasons:

(i) The key-code frequency is used only to control the decoder. The lowest and highest frequencies in the CONTROL CHANNELS proposed in Section 3.2 are 525 Hz and 975 Hz respectively. Therefore, no harmonic frequency interference exists in the proposed system. In other words, a low distortion in the key-code audio-frequency is not strictly required.

(ii) No high frequency stability is required, since the decoder containing a bandpass filter which is designed to have a 3 dB - bandwidth of ± 15 Hz on its center frequency within each of the CONTROL CHANNELS.

However, we must pay close attention to the output level of the generator, which should be more than 2.25 Vr.m.s.

(+ 7 dBm) as already discussed in Section 3.4

3.8.1 DESIGN OF THE AUDIO-TONE FREQUENCY SQUARE WAVE GENERATOR

As shown in Fig. 3.13, the design presents a low-cost audio frequency square wave generator using NAND gats MM 5611A. The generator can be easily tuned for the required frequency between 500 Hz and 1000 Hz.

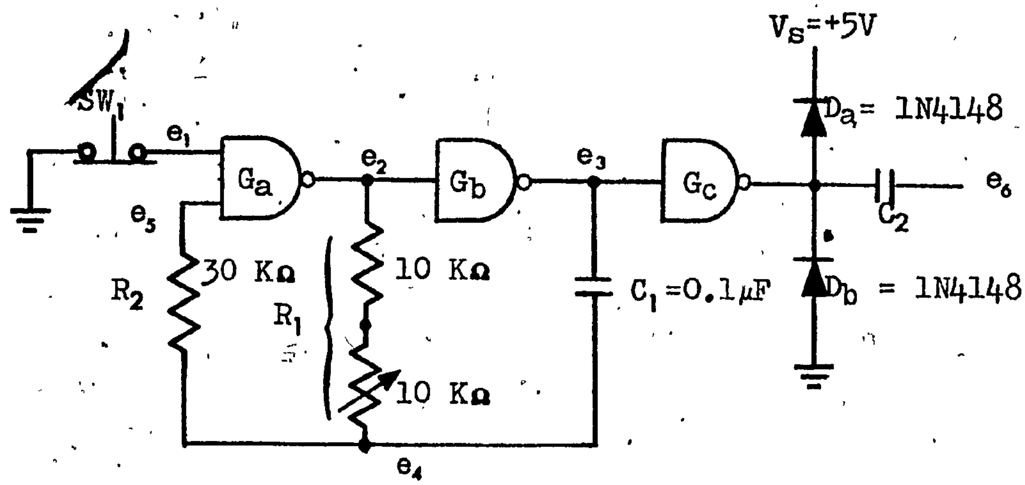


Fig. 3.13: Proposed audio-tone square wave frequency generator circuit.

While e_1 is grounded via a key-coding switch SW_1, this circuit is stable. As soon as the switch SW_1 is released, this circuit starts to oscillate and a 5 Volts peak-to-peak square wave signal will appear at e_6 as shown in the wave-form chart, Fig. 3.14.

In this chart, the time constant τ is determined by

$$\tau = C_1 R_1 \tag{3.79}$$

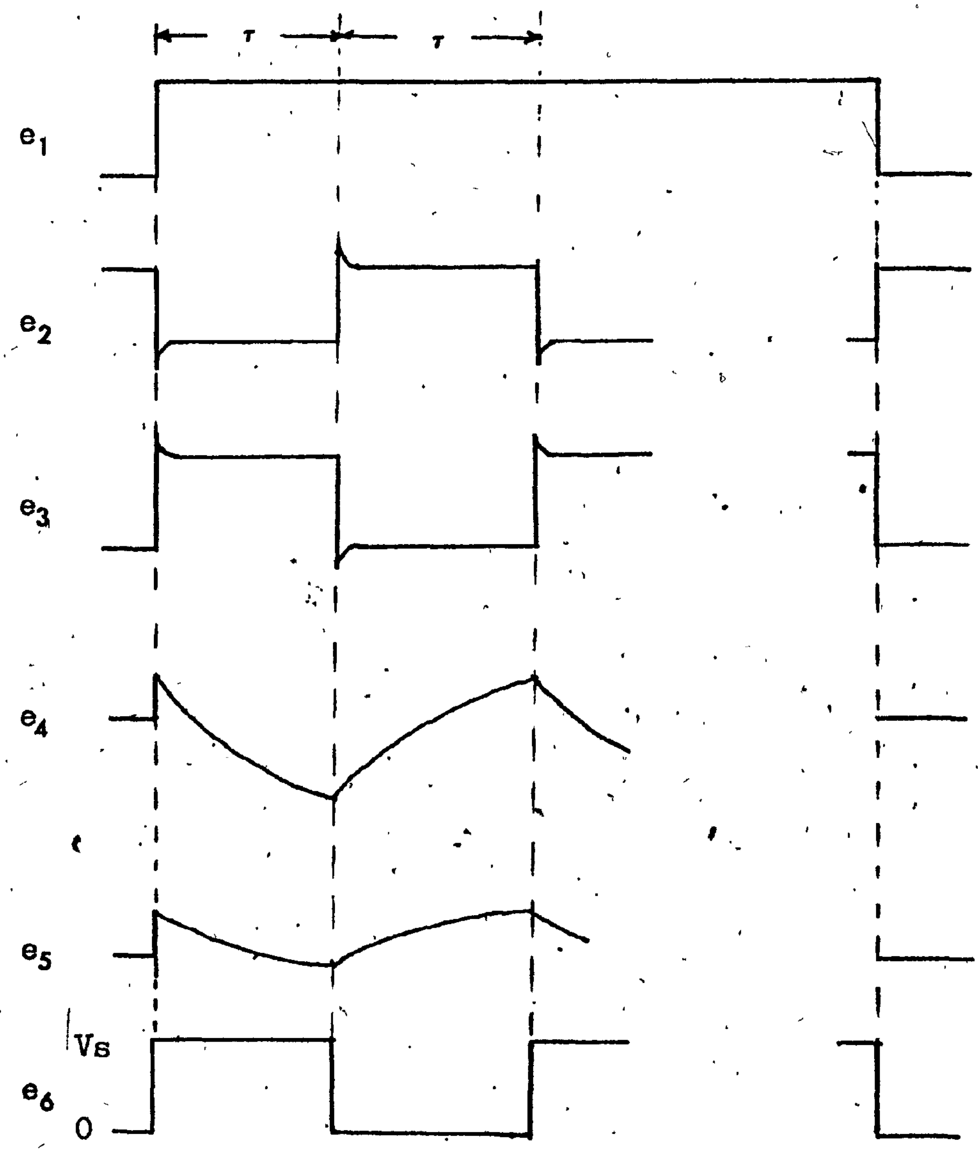


Fig.3.14 Waveform chart of the square wave generator shown in Fig. 3.13.

Thus, the period T of the square waveform is

$$T = 2\ C_1 R_1 \qquad (3.80)$$

that is, the required frequency is

$$f = \frac{1}{T} = \frac{1}{2\ C_1 R_1} \quad (\text{ Hz }) \qquad (3.81)$$

By fixing the capacitor C_1 at 0.1 uF, we can easily obtain the desirable frequency between 500 Hz to 1000 Hz by adjusting R_1 from 10 Kohms to 20 Kohms.

A resistor R_2 is provided to prevent a high current injection into the gate G_a due to the transient pulse of e_4 as shown in Fig. 3.14. Two diodes D_a and D_b are added to the output of the gate G_c in order to remove the spikes at both edges of the waveform e_3.

As a result of this design, it is clearly seen that the generator circuit can be fabricated in the form of a circuit block module as shown in Fig. 3.1 for all required audio-tone frequency generators in the proposed remote control system. The specific control frequency can be obtained by adjusting only R_1.

3.8.2 DESIGN OF KEY-CODE SWITCHING CIRCUIT FOR THE AUDIO-TONE GENERATOR

As discussed in Section 3.6, the memory circuit of the decoder should be designed to have a time delay of more than 0.5 sec. to prevent accidental operation of the transmitter due to program frequencies.

Therefore, the time T_c of transmitting an audio-tone frequency must be sufficiently longer than the prescribed time delay in the memory circuit.

Thus, from Eq. (3.78), we may have

$$T_c = 2T_d \qquad (3.82)$$

It is possible to use a mechanical switch for setting this time. However, a simple design is described for an electronic time switch which will determine the transmitting time T_c automatically once it is triggered on.

From Fig. 3.14, the pulse e_1 must be a positive pulse whose duration is to be 2 T_d. To obtain this pulse, NAND gates MM 5611A may be used again as shown in Fig. 3.15.

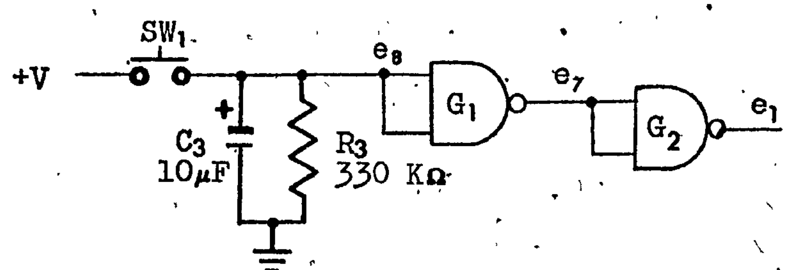


Fig. 3.15: Proposed electronic time switch

When the switch SW_1 is pressed on, the d.c. power supply charges C_3 almost instantly. This forces e_7 down to the ground and consequently e_1 rises to the positive voltage. After releasing the switch SW_1, the charge in C_3 will start to discharge at the rate of $T_c \doteq 0.69\ C_3R_3$. Taking C_3 to be 10 μF, R_3 may be chosen to be 330 Kohms to yield $T_c \doteq 2.0$ sec.

3.8.3 OTHER DESIGN CONSIDERATIONS FOR THE KEY-CODE AUDIO-TONE GENERATOR

In order to integrate the key-code audio-tone generator and its time switch into the complete remote control switch system, some additional factors should be taken into consideration. They are as follows:

(i) It should be ensured that the proper combination of the audio-tone frequencies are entering the program line. For this purpose, an indicator circuit, as shown in Fig. 3.16, is connected to the output of the NAND gate G_c. This circuit mainly consists of two NAND gates, one transistor and one LED. The square wave outputs of the oscillators A and B, in this case, provide a logic "O" status to the NAND gate G_5. This results in a logic "1" status at the output of the NAND gate G_6, which turns the LED, LD_1, on.

(ii) Since the program line impedance is not very large (600 ohms), to avoid an insertion loss, a reasonably high impedance circuit such as a transistor emitter follower as shown in Fig. 3.16, should be inserted between the output of a generator and the program line.

(iii) The positive power supplies + 5 Vdc, 2 Amps, and + 12 Vdc, 1 Amp. are required to operate the generator and the decoder circuits of the remote control switch.

In recent years, d.c. power supply modules have become commercially available [38]. For an example, a 5 Vdc power supply module of LAMBDA, LAS 2005 costs U.S. $25.00/15 watts or U.S. $1.70/watt, offering the attractive specifications [38] such as load and line regulations within ± 0.2%, ripple less than 2 mV r.m.s. at the maximum output of 3 Amps/5 Volts with the a.c. input of 115V ± 10%.

Thus, a commercial power supply is quite satisfactory for our remote control switch with respect to the cost and quality.

3.9 THE COMPLETE REMOTE CONTROL SWITCH

The complete remote control switch system has two parts:

(a) The transmitter unit, installed in the studio, transmitting the command instructions via the program line

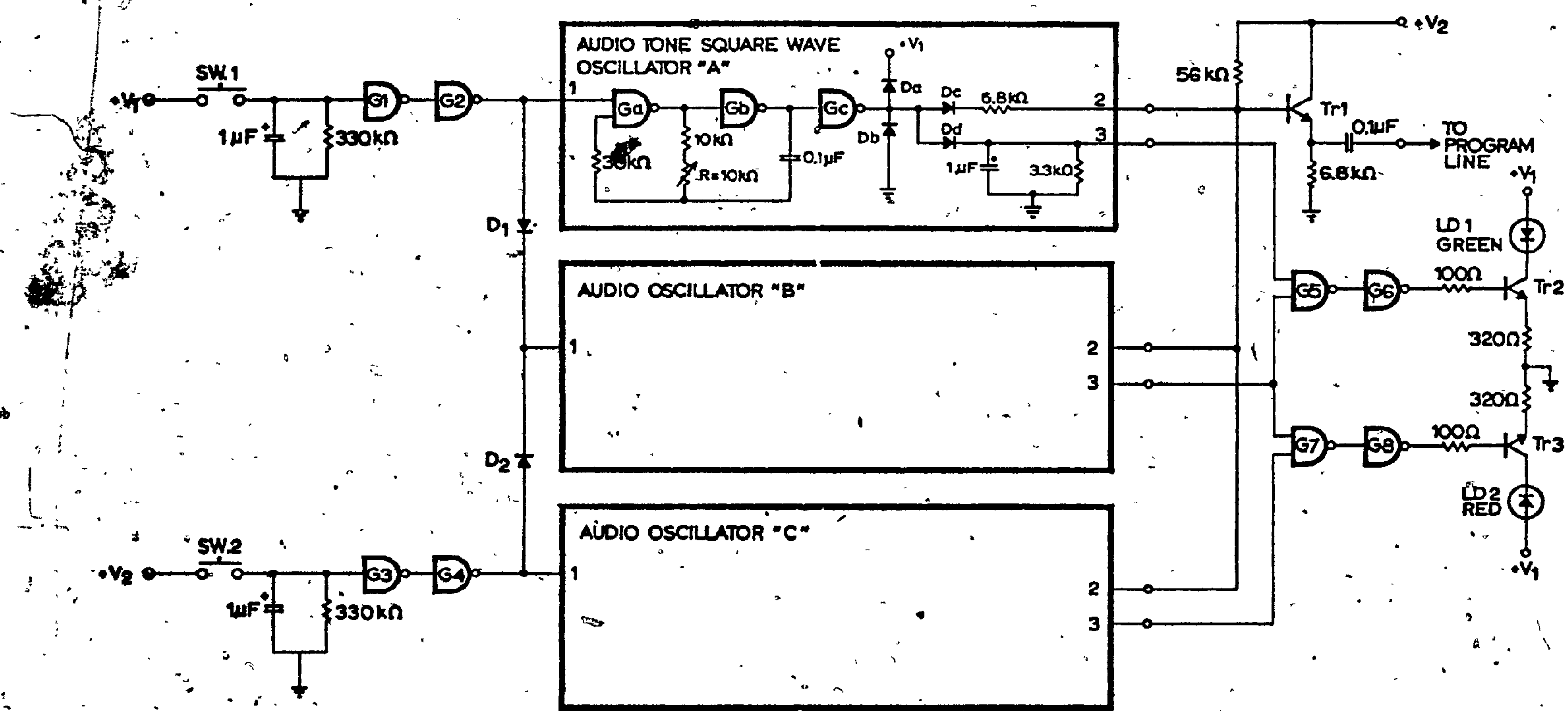
and

(b) The decoder unit, installed in the transmitter site, receiving the command instructions.

The complete circuit diagrams of these two parts shown in Fig. 3.16 and Fig. 3.17. It should be noted that the element values of the active RC bandpass filter are not given. However, the actual values, for a given CONTROL CHANNEL frequency, can be determined by using Table 3.2. It should also be noted that the required channel frequency can be easily obtained by simply adjusting the 10 Kohm potentiometer of the audio-tone square-wave oscillator in Fig. 3.16.

The diodes D_1 and D_2 act as key-coding circuits. By pressing the switch SW_1 or SW_2, for this example, two audio-tone frequencies "A+B" or "B+C" can be made to appear at the emitter of T_{r1}. The LED, LD_1 or LD_2 will be correspondingly lit indicating the operation commanded.

The switches SW_1 and SW_2 can either be manual or time-clocked.



NOTES: (1) CIRCUITS OF AUDIO TONE OSCILLATORS "B" & "C" ARE IDENTICAL TO "A", BUT TUNED FOR DIFFERENT FREQUENCIES BY TRIMMING R.

(2) G1-8 AND Ga-c = MM5611A (1/4)

(3) D1,2 AND Da-d = 1N4148

(4) LD1,2 = LED 10mA, 1.6Vdc

(5) Tr1-3 = 2N2222

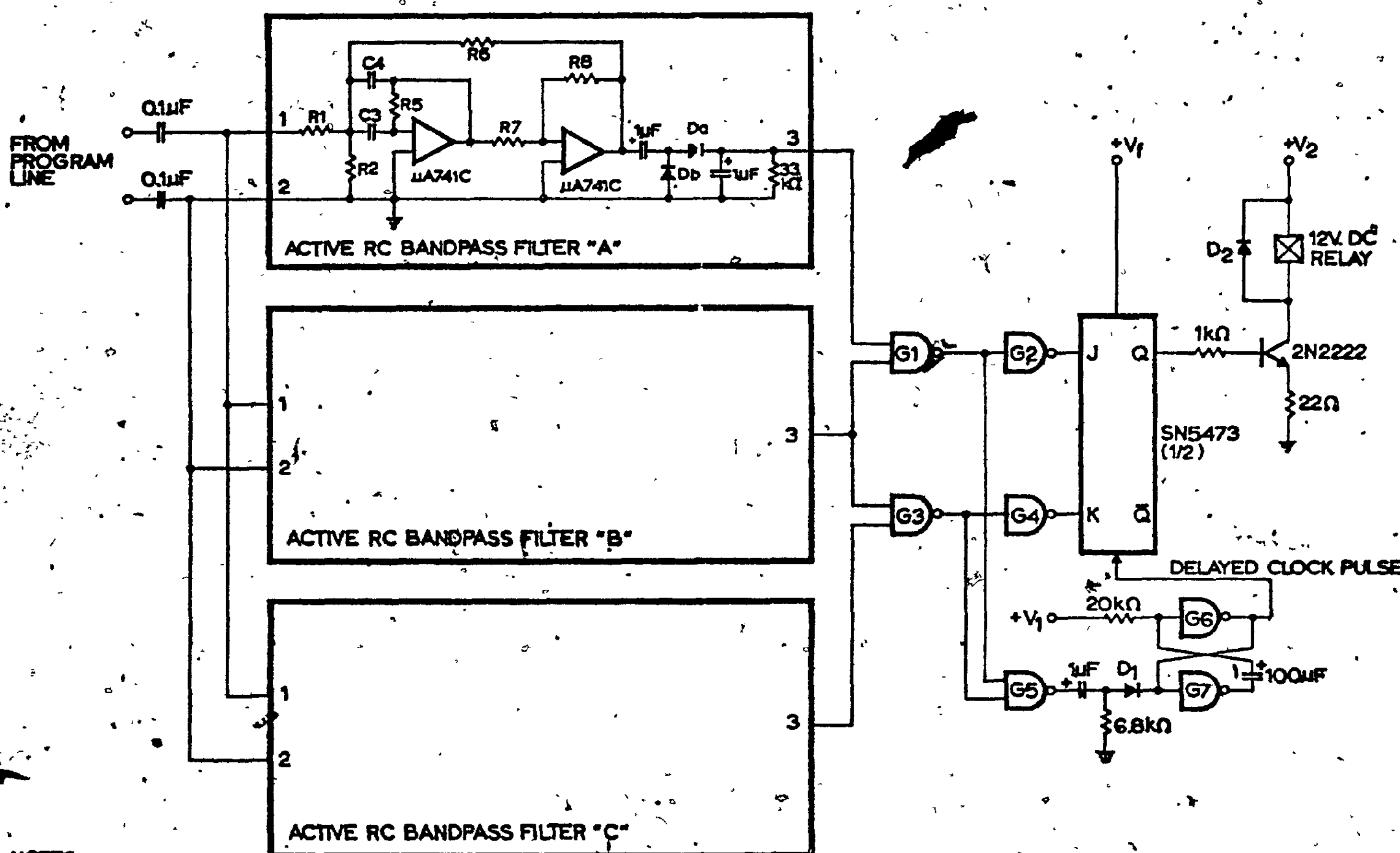
(6) V1 = +5Vdc

(7) V2 = +12Vdc

(8) SW.1,2 = PUSH-ON MOMENTARY SWITCH.

FIGURE 3.16

PROPOSED REMOTE CONTROL SWITCH, AUDIO-TONE SQUARE WAVE OSCILLATORS AND THEIR KEY-CODING CIRCUITS IN THE GENERATOR CIRCUIT OFFERING THREE CONTROL CHANNELS.



NOTES:

(1) CIRCUITS OF ACTIVE RC BANDPASS FILTERS "B" & "C" ARE IDENTICAL TO "A" EXCEPT THEIR CENTER FREQUENCIES.

(2) G1-6 = MM5611A (1/4)

(3) D1-2 AND Da-b = 1N4148

(4) V1 = +5Vdc

(5) V2 = +12Vdc

(6) V1 = +4Vdc (SEE FIG.3.14)

FIGURE 3.17

PROPOSED REMOTE CONTROL SWITCH DECODER CIRCUITS OFFERING THREE CONTROL CHANNELS

3.10 INTEGRATION OF THE PROPOSED REMOTE CONTROL SCHEME WITH THE ABANDONED CBC REMOTE CONTROL SWITCH

The proposed remote control switch can be directly used. However, it was found that a remote control switch was available. This was abandoned by CBC, excepting for very important locations. The reason for this is that the switch requires a costly second quality line and hence is not economically suitable. It is desirable, both for convenience and additional economy, to be able to use parts of the old switch without the second quality line. For this purpose, the old scheme has to be modified.

In this section, the modification of the old switch is considered allowing the proposed remote control configuration to be integrated into it. The modified version is shown in Fig. 3.18.

The existing remote control switch (shown outside a dotted line in Fig. 3.18) consists of two different audio-tone collector-tuned oscillators 851 Hz and 1209 Hz in the key-code generator unit and the corresponding frequency-seleotive LC filters in the decoder unit [17, 18].

The additional NAND gate oscillator is set to be a frequency of 525 Hz. This frequency is chosen to minimize interference with the other existing channels. Using Table 3.2, the elements of the corresponding bandpass filter can

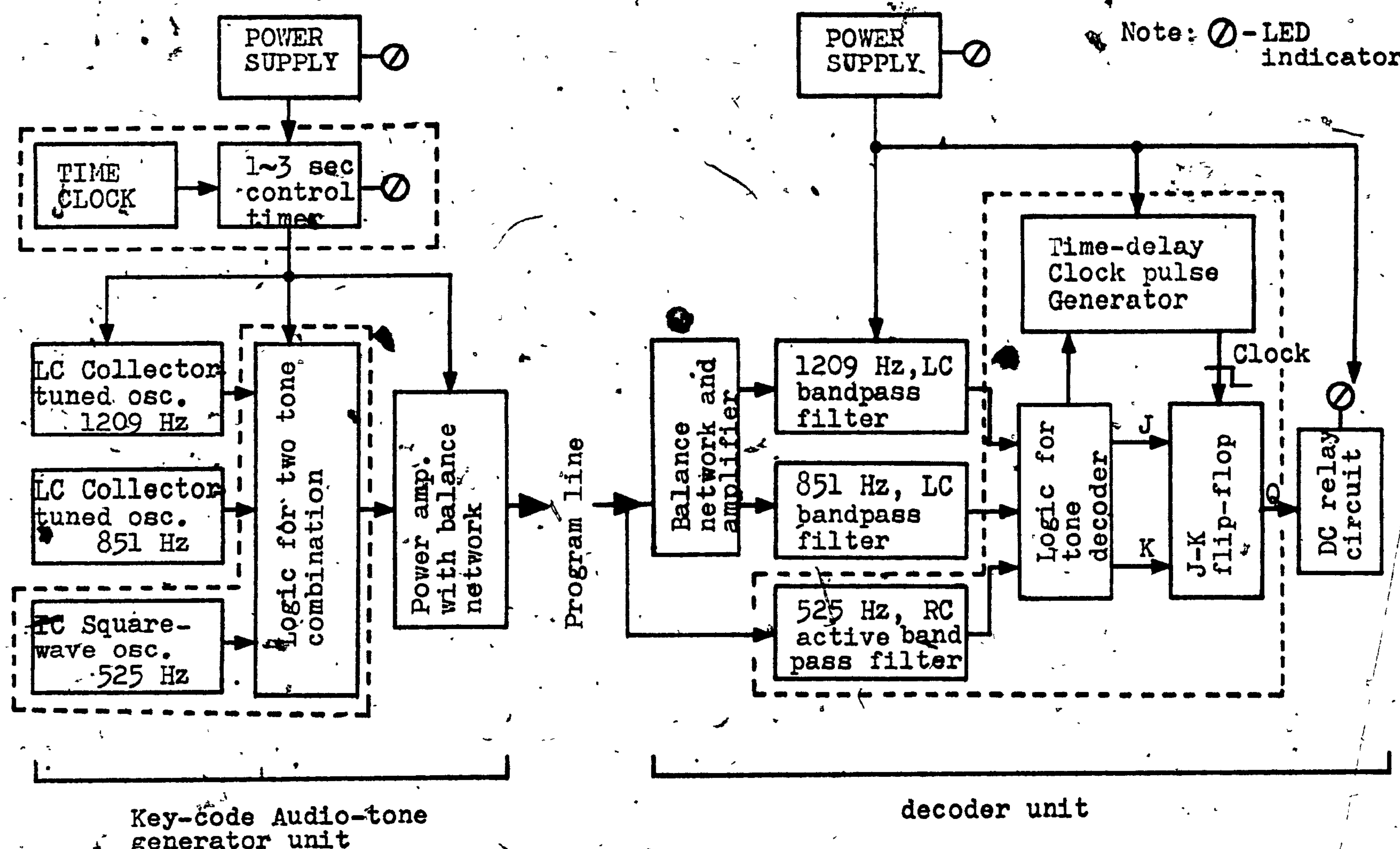


Fig. 3.18 BLOCK DIAGRAM AFTER INTEGRATION OF THE PROPOSED SCHEME WITH THE ABANDONED CBC REMOTE CONTROL SWITCH
(THE PROPOSED SCHEME IS ENCIRCLED BY DOTTED LINE)

be easily found.

In this case, $Q_p = 30$ and $\omega_p = 2\pi f_p$ (f_p = 525 Hz) are chosen. Setting K = 1.2 and using the values of available passive components, we have in Fig. 3.17:

$$C = C_3 = C_4 = 0.1\ \mu F \pm 2\% \tag{3.83}$$

$$R = R_1 = R_5 = 60.1\ \text{Kohms} \pm 1\% \tag{3.84}$$

$$R_8 = 10.0\ \text{Kohms} \pm 1\% \tag{3.85}$$

$$R_6 = 72.2\ \text{Kohms} \pm 1\% \tag{3.86}$$

$$R_7 = 8.34\ \text{Kohms} \pm 1\% \tag{3.87}$$

and $$R_2 = 68\ \text{ohms (adjustable)} \tag{3.88}$$

The corresponding key-code audio-tone frequency of the oscillator in Fig. 3.16 can be obtained by trimming R_1, a 10 Kohm potentiometer.

The photographs of the complete modified remote control switch is shown in Fig. 3.19 and Fig. 3.20.

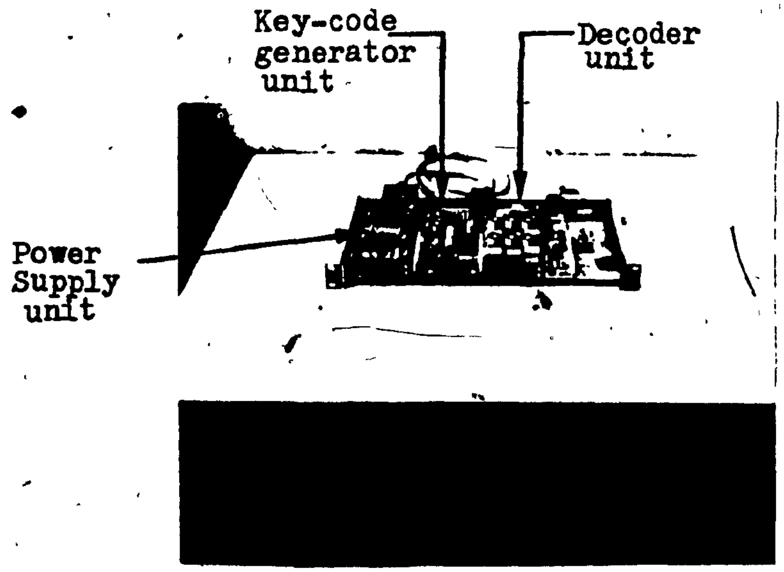


Fig. 3.19 The whole view of the modified remote control switch for Grand Manan FM, N.B.

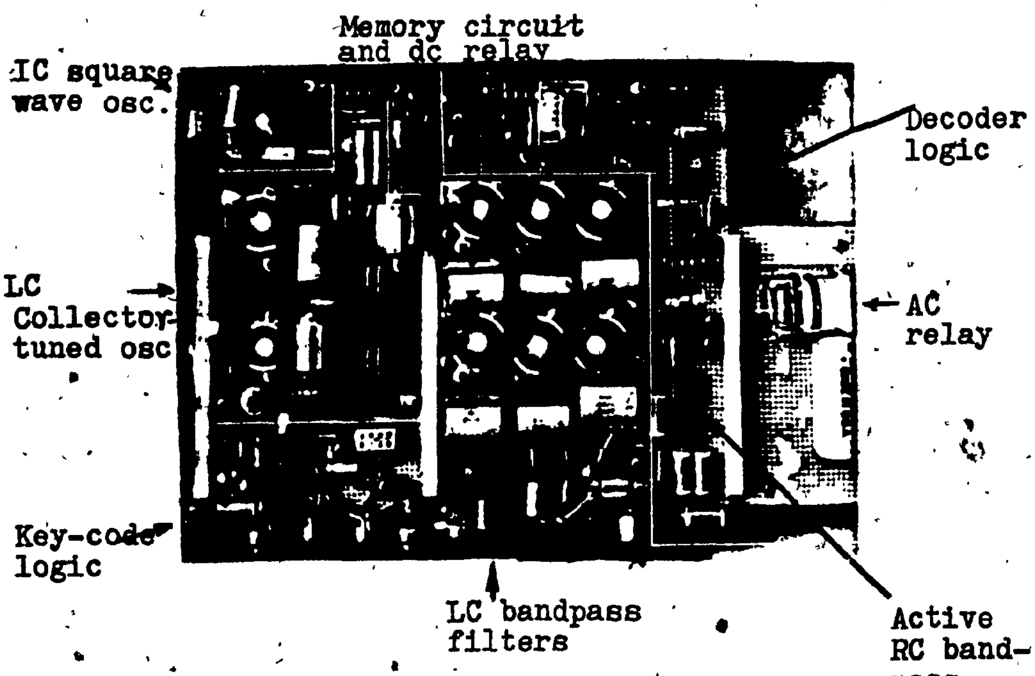


Fig. 3.20 The top view of the modified remote control unit in Fig.3.19.

CHAPTER 4

EXPERIMENTAL RESULTS

4.1 GENERAL

In this Chapter, detailed experimental results of the modified remote control switch as shown in Fig. 3.20, along with the photographs of the wave-forms of outputs of the key-code audio-tone frequency generator, the responses of the bandpass filters, the outputs of both the key-code logic circuit and the delayed clock pulse generator are given.

The modified remote control switch has been found to be suitable for controlling the high voltage circuit of the transmitter via the program line. The test has also confirmed that the proposed key-code audio-tone generator unit and its decoder unit which were integrated into the old remote control switch satisfy the theoretical predictions.

The results are presented after a brief description of the test equipment used.

4.2 TEST EQUIPMENT

The test equipment which was used for this experimental work are listed as follows:

(i) Audio Frequency Generator, Brüel Kejoer, Model 1014.

(ii) Audio Sweep Generator, R-O-R, Model 302B.

(iii) Frequency Counter, EiP, Model 350D.

(iv) Oscilloscope, Tektronix, Model 7613. with Plug-in 7A15 and 7B53A.

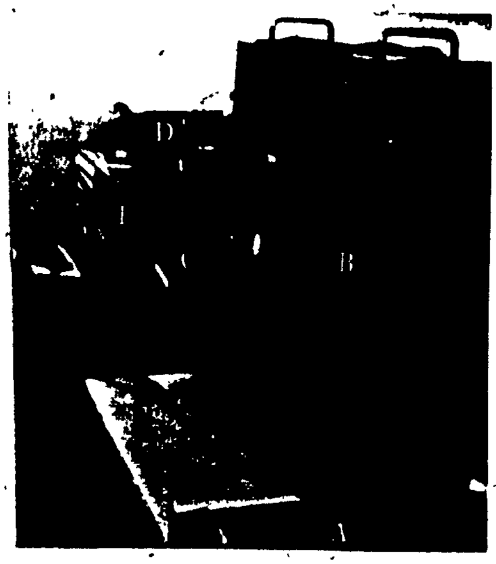


Fig. 4.1: View of the test set-up.

A- Remote Control Switch

B- Audio Frequency Oscillator

C- Audio Sweep Generator

D- Frequency Counter

E- Oscilloscope with Plug-ins

4.3 EXPERIMENTAL RESULTS

Using the test equipment listed in Section 4.2, the test was carried out at the room temperature (between 20°C and 25°C).

4.3.1 WAVEFORMS FROM THE KEY-CODE AUDIO-TONE FREQUENCY GENERATOR

These show the waveforms of frequency assignments for the control commands, namely, the combination of the audio-tones 851 Hz and 1209 Hz for the "switch-on" command and the combination of the audio-tones 851 Hz and 525 Hz for the "switch-off" command.

As described in Section 3.8.1 and 3.10, both audio-tones 851 Hz and 1209 Hz are sinusoidal and the third audio-tone is a square wave signal.

The direct amplitudes of the generator outputs without the 600 ohm load are 11 and 13 Volts peak-to-peak as indicated in Fig. 4.2 and Fig. 4.2a respectively, along with the transmitting time of 2 sec. approximately.

The different amplitudes of the waveforms of the two command signals are due to the different configuration of the oscillator circuits supplying the audio-tone frequencies. The oscillators for 851 Hz and 1209 Hz are collector-tuned sinusoidal oscillators which is followed by a buffer amplifier

[17]. However, the oscillator for the 525 Hz is a square wave generator which consists only of NAND gates without a buffer amplifier.

The amplitudes of the command signals, 11 and 13 Volts peak-to-peak are very high for the program line. Hence, the resistor 6.8 Kohms has been connected to the emitter side of the transistor T_{r1} as shown in Fig. 3.16, so that the overall amplitude entering the program line can be reduced to the permissible level of + 10 dBm, when the key-code audio-tone frequency generator unit is connected to the program line.

The difference in transmission times between the "switch-on and -off" commands is caused by the use of larger tolerance capacitors (± 10%) and resistors (± 5%).

Fig. 4.3 and Fig. 4.4 show the activation periods of the "switch-on" and "switch-off" commands respectively.

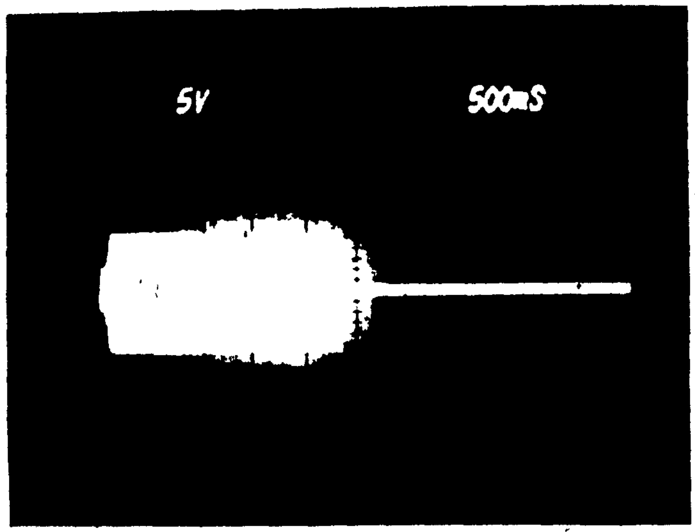


Fig. 4.2 Output waveforms of the combined two audio-tones 851 Hz and 1209 Hz assigned for the "switch-on" command.

Maximum amplitude ≐ 11 Volts peak-to-peak.
Transmitting time ≐ 2.3 sec.

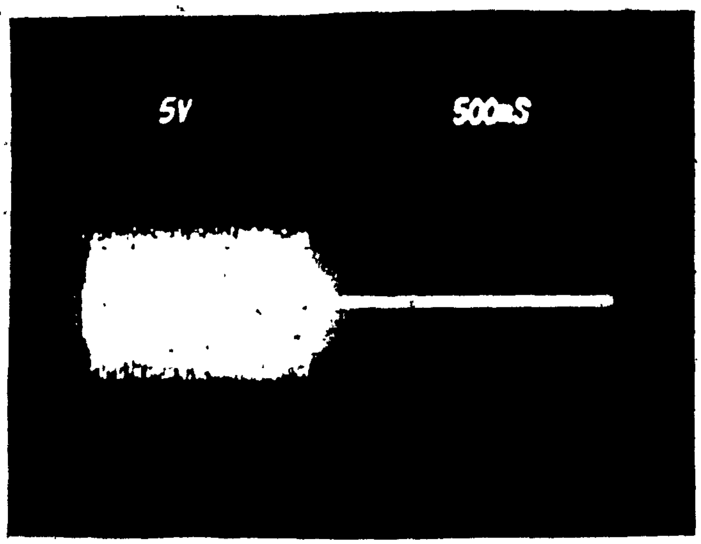


Fig. 4.2a Output waveforms of the two combined audio-tones 851 Hz and 510 Hz assigned for the "switch-off" command.

Maximum amplitude ≐ 13 Volts peak-to-peak.
Transmitting time ≐ 2.2 sec.

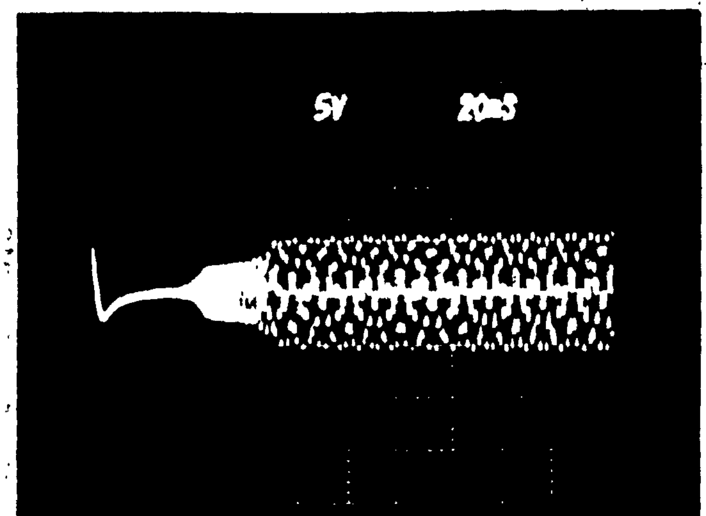


Fig. 4.3 Activation of the "switch-on" command consisting of the two combined audio-tones 851 Hz and 1209 Hz.

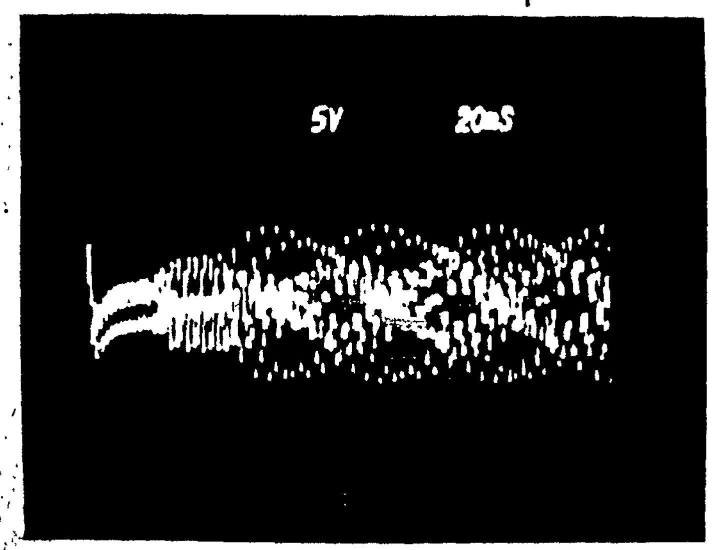


Fig. 4.4 Activation of the "switch-off" command consisting of the other two combined audio-tones 851 Hz and 525 Hz.

4.3.2 FREQUENCY RESPONSES OF BANDPASS FILTERS IN THE DECODER UNIT

As mentioned in Section 3.10, two existing but abandoned LC bandpass filters are re-used in the modified decoder unit of the remote control switch along with the new second-order RC active bandpass filter designed according to the proposed procedure.

Frequency responses of these bandpass filters are shown in Figs. 4.5, 4.6 and 4.7. It was found that the active RC bandpass filter was easily tunable for both the center frequency and the pole Q-factor, while the response of the LC filters were found to be difficult to adjust.

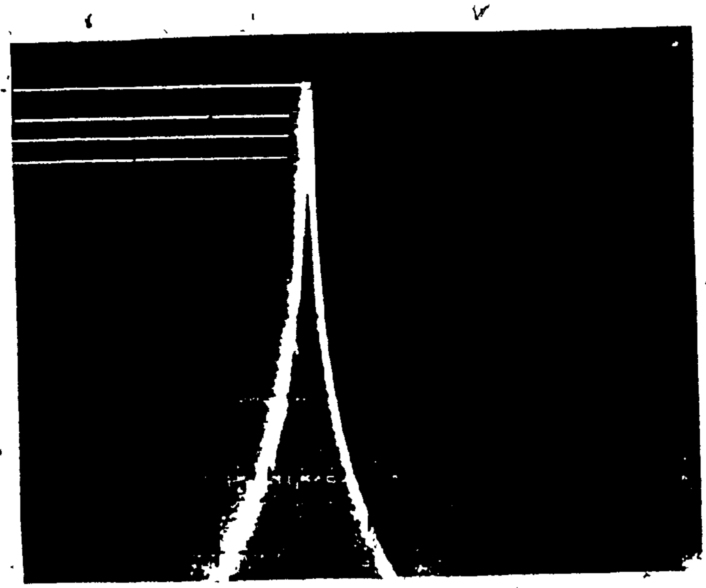


Fig. 4.5 Frequency response of the second-order active RC bandpass filter designed for f_p = 525 Hz and Q_p = 30.

TEST DATA:

f_p = 525 Hz, tuned.

3dB bandwidth = 18 Hz

Q_p = 29

H = 1.1

Attack Time ≐ 100 nsec.

Recovery Time from the overdrive ≐ 1 msec. (+ 10 dBm input)

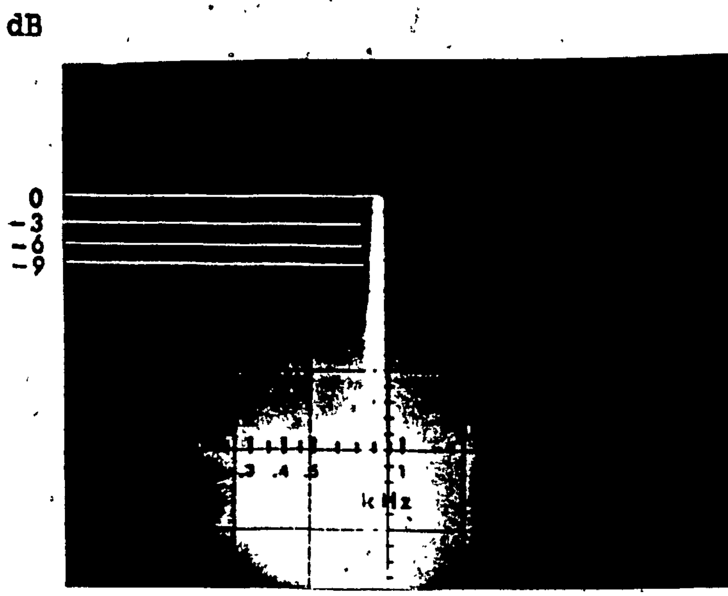


Fig. 4.6 Frequency response of the LC bandpass filter for $f_p = 851$ Hz.

TEST DATA:

Attack Time ≐ 500 nsec.

Recovery Time from the overdrive (+ 10 dBM input) ≐ 1 msec.

3dB bandwidth = 27.5 Hz

$Q_p = 31$

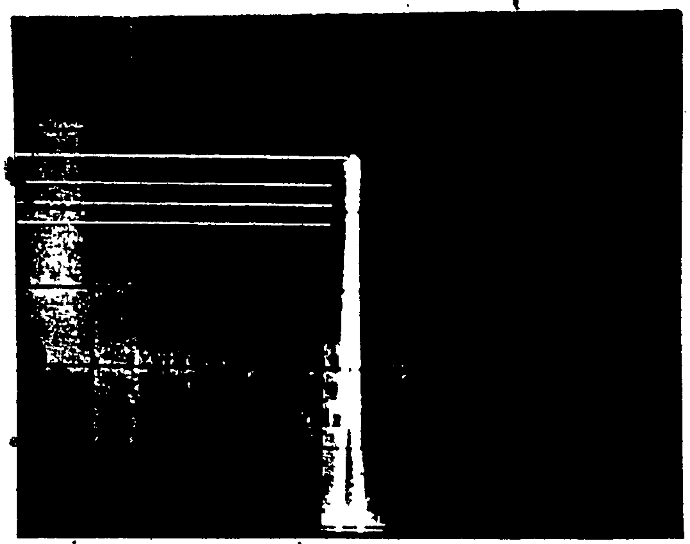


Fig. 4.7 Frequency response of the LC bandpass filter for f_p = 1209 Hz.

TEST DATA:

Attack Time ≐ 500 nsec.

Recovery Time from the overdrive ≐ 1 msec.

3dB bandwidth = 34.5 Hz

Q_p = 35

4.3.3 RESPONSE TEST AT THE LOGIC INPUT IN THE DECODER UNIT

The responses at the logic inputs at G_1 and G_3 in the decoder unit as shown in Fig. 3.17 were observed for each command frequency and are shown in Figs. 4.8 and 4.9.

The delay encountered by the 525 Hz command frequency is longer by 10 msec than the delay encountered by the other two command frequencies. This is caused by the capacitor-filtered diode rectifier after the RC active band-pass filter as shown in Fig. 3.17. However, this additional delay does not affect any other circuits, because the delayed clock pulse itself may have the delay tolerance of $\pm$ 0.2 sec.

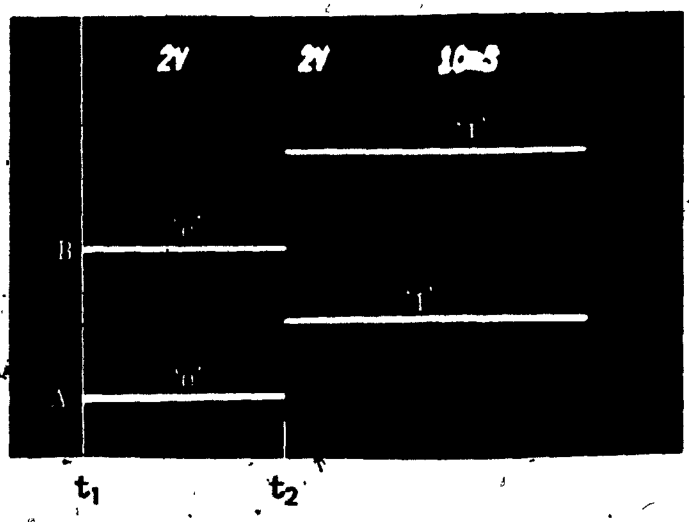


Fig. 4.8 Responses at the logic inputs of the decoder unit for the "switch-on" command.
The waveform B (for 1209 Hz) was triggered by A (for 851 Hz).

t_1 = 0 msec. and t_2 = 40 msec.

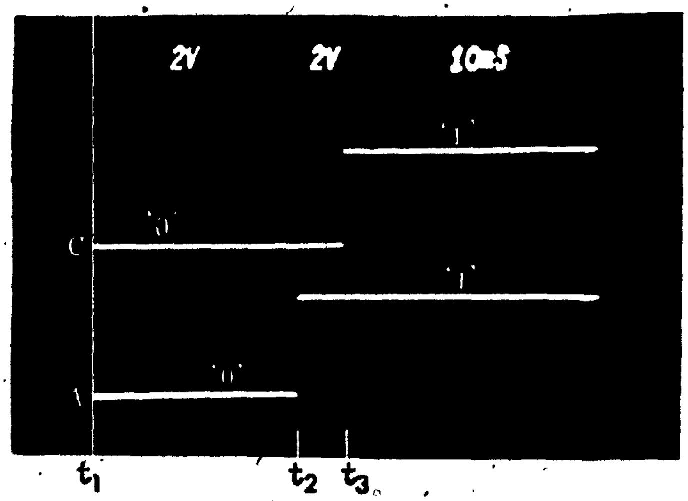


Fig. 4.9 Responses at the logic inputs of the decoder unit for the "switch-off" command.
The waveform C (for 525 Hz) was triggered by A (for 851 Hz)

t_1 = 0 msec., t_2 = 40 msec. and t_3 = 50 msec.

4.3.4 RESPONSE TEST OF THE DELAYED CLOCK PULSE GENERATOR

As shown in Figs. 4.10 and 4.11, the response of the delayed clock pulse generator was checked and has been found to satisfy the theoretical estimate, which is 0.8 sec. as designed.

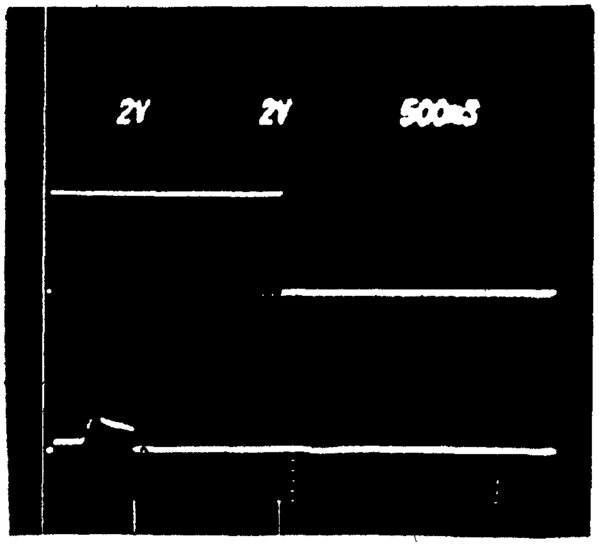


Fig. 10 Overall response of the decoder switching circuit.

t_1 = 0 msec. and t_3 = 2300 msec.

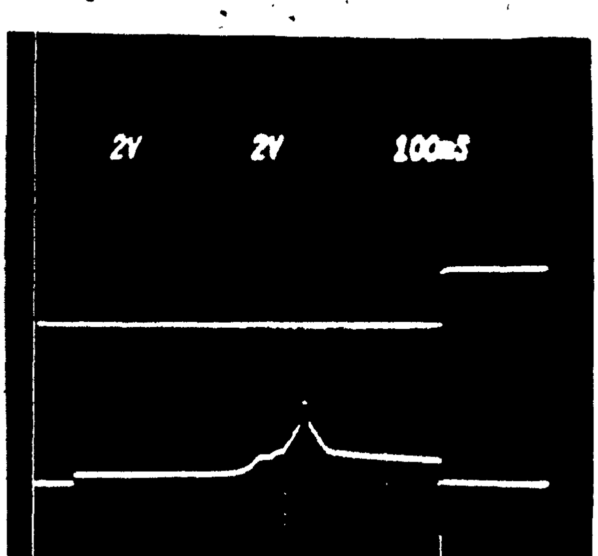


Fig. 11 Expanded delay response of the delayed clock pulse generator between t_1 and t_2.

t_1 = 0 msec. and t_2 = 800 msec.

CHAPTER 5

CONCLUSION

A new remote control system for broadcast transmitters has been described. The system is versatile and yet inexpensive. The new switch allows control of a number of transmitter operations via the main program lines and can be implemented using IC key-code audio-tone generators as command signal generators, and active RC bandpass filters with AC/DC converters connected to logic and memory circuits as decoders.

As can be seen from the experimental results, as well as the relevant photographs, the overall performance of the modified remote control switch is quite satisfactory and quite close to the theoretical design. The functions of the transmitter facility that can be controlled by this switch include not only the high voltage circuit of the transmitter, but also monitoring functions for operational parameters, such as output power and frequency, modulation, ambient temperature of the transmitter room, etc., and the control of the radiation patterns for the day-time and night-time operations, if required.

The remote control switch described is attractive because of the following reasons:

(i) The low-cost ($5. approx.) and integrable active RC second-order bandpass filter replaces the bulky, heavy and costly ($80.00 approximately as of January, 1976) LC bandpass filter as a voice-band frequency selective filter.

(ii) The switch can be directly inserted in the program line in parallel with the radio transmitter since the switch input impedance is that of the active RC bandpass filter and can be designed to be very high (more than 10 Kohms), compared with the input impedance of the transmitter (600 ohms nominal).

(iii) The audio-tone key-code frequency selective circuit along with the delayed clock-pulse generator for the memory circuit ensures proper operation of the switch only by the commanded key-code frequencies, not by the program frequencies which may contain instantaneously frequencies identical to those key-code frequencies.

(iv) The decoder of the remote control switch can be easily manufactured in the form of a building block module.

(v) The number of the transmitter operations that can be controlled depends on the combination of these modules.

(vi) The key-code frequency generator can be fabricated in the form of a building block module as well.

(vii) The memory circuit is protected from the main power failure by means of a rechargeable cadmium battery. Thus, once the command is memorized in this circuit, this switch is able to retain the same status (the mode of the transmitter operation) as commanded, till the power is restored. This is very useful for the transmitters which are to be installed in remote communities, which rely on Diesel power generators as their power sources and suffer from high power failure rates.

(viii) Careful consideration has been given to use minimal kinds as well as a number of ICs and semiconductors. A total cost of manufacturing the remote control switch is $70.00 approximately, including ICs, transistors, diodes, discrete precision passive elements, relay switches and fibre-glass board.

While the proposed system can be used as such, for the sake of convenience and economy, the old, but abandoned CBC remote control switch was modified to incorporate the described features of the new technique.

Extensive experimental tests on the hybrid system has indicated satisfactory agreement with theoretical predictions.

Even though the proposed switch has not been tested in its entirety, the author feels confident (since the proposed system is expected to be more efficient than the hybrid system) that the use of the proposed design of the remote control switch would significantly contribute to the reduction of the operational cost, as well as the operational efficiency of CBC broadcast transmitters.

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