OPERATIONAL AMPLIFIERS   C PART I COURSE

1. INTRODUCTION

This is the term used for a high-gain, d.c.-coupled amplifier suitable for use with feedback. It is available in cheap i.c. form. Such an amplifier avoids the use of many discrete components. The amplifier performance is determined by the few externally connected components.

The conventional circuit symbol is:

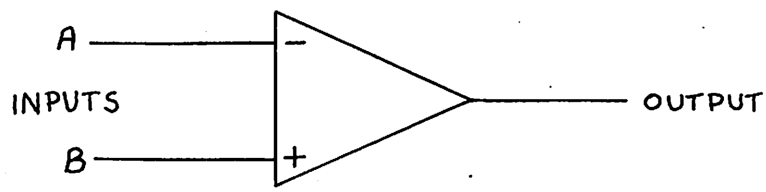

Figure 1: Operational Amplifier Symbol

The - input (A) is known as the inverting input.
The + input (B) is known as the non-inverting input.

The output voltage depends upon the voltage difference at AB. The amplifier may be used in the single-ended input mode by earthing A or B.

The main characteristics of the amplifier are:

- It is internally d.c. coupled.
- The input resistance at AB is very large.
- The output resistance is low (few hundred ohms).
- The voltage gain $\frac{v_{out}}{v_{AB}}$ is very large, typically 100,000.

The amplifier will first be considered as a simple voltage amplifier.

OPERATIONAL AMPLIFIERS

2. USE AS AMPLIFIERS

2.1 As An Inverting Amplifier

The simplified circuit is:

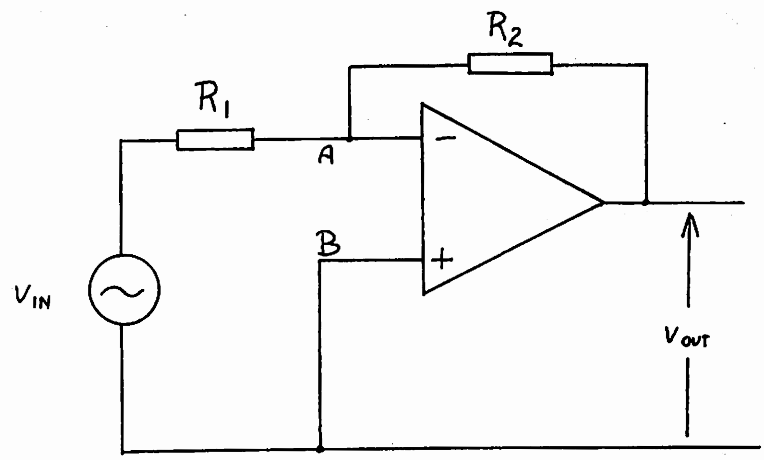

Figure 2: Operational Amplifier as an Inverting Amplifier

2.1.1 Voltage Gain

The circuit of figure 2 can be redrawn as in figure 3.

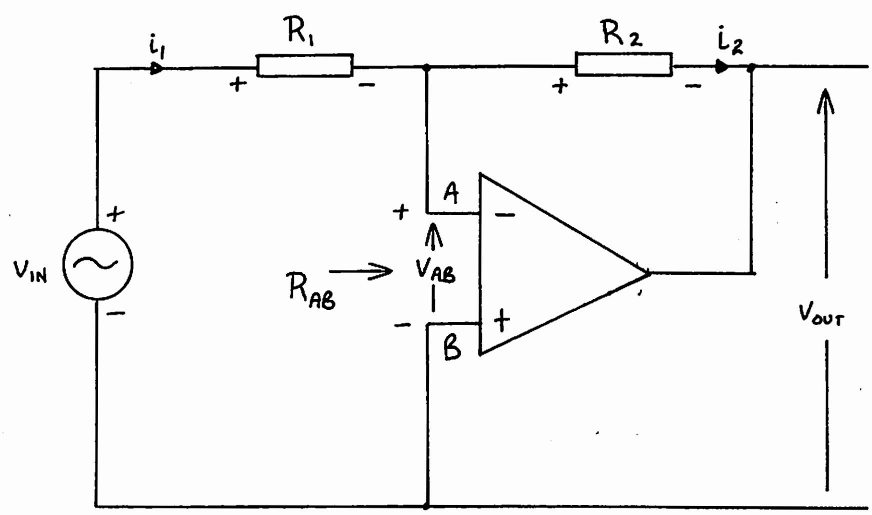

Figure 3: Figure 2 redrawn

The + and − signs represent the instantaneous signal polarity and therefore show the phase inversion.

Because of the high voltage gain, v_{AB} is very small and may be considered as zero volts. R_{AB} is very high so no current flows into the amplifier at A.

$\therefore$ $i_1 = i_2$. Call this i.

Hence, $v_{in} - iR_1 = 0$

and $v_{out} - iR_2 = 0$

$\therefore$ $v_{in} = iR_1$

$v_{out} = iR_2$

$$\text{Circuit voltage gain} = \frac{v_{out}}{v_{in}} = \frac{iR_2}{iR_1} = \frac{R_2}{R_1}$$

The circuit of figure 2 may therefore be considered as an example of parallel-applied negative feedback (by R_2) and R_1 is the added "source" resistance to give the required overall voltage gain. (R_1 is sometimes referred to as R_s and R_2 as R_f).

2.1.2. Input and Output resistance

An important result of the negative-feedback treatment of the circuit is that the input resistance may be found easily.

Figure 2 is redrawn below in figure 4 together with its equivalent circuit.

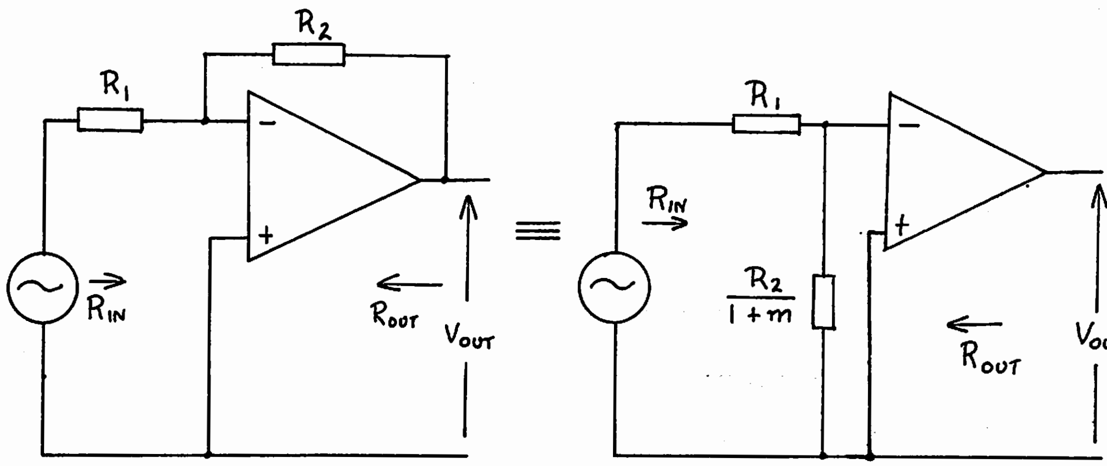

Figure 4: Effect of R_2 on the input impedance

Because the voltage gain, m, of the operational amplifier is very high, $\frac{R_2}{1 + m}$ is very small, therefore R_{in} is approximately equal to R_1.

Because the circuit has parallel-derived n.f.b., R_{out} is very small

(<1 ohm).

Therefore we have a circuit where the voltage gain, the input resistance and the output resistance are almost independent of the amplifier voltage gain m.

2.2 As a non-inverting amplifier

The simplified circuit is:

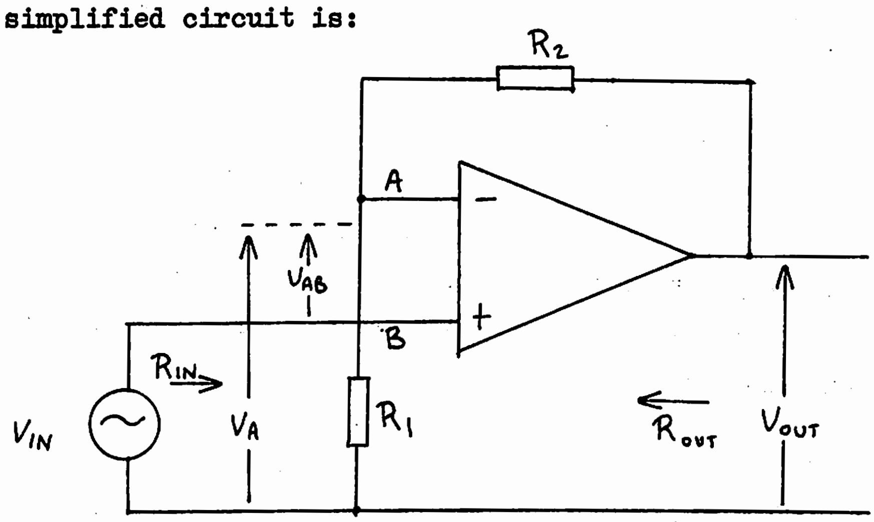

Figure 5: Non Inverting Amplifier

2.2.1. Voltage Gain

As v_{AB} is almost zero, $v_A \simeq v_{in}$.

$$v_A = \beta v_{out} \text{ Where } \beta = \frac{R_1}{R_1 + R_2}.$$

$$\therefore \text{ the voltage gain } \frac{v_{out}}{v_{in}} = \frac{v_{out}}{v_A} = \frac{v_{out}}{\beta v_{out}} = \frac{1}{\beta}$$

$$\therefore \frac{v_{out}}{v_{in}} = \frac{R_1 + R_2}{R_1}$$

(Compare this with the expression for the voltage gain for the inverting amplifier)

This circuit is also as example of negative feedback with the condition $\beta m \gg 1$, which gives a circuit voltage gain of $\frac{1}{\beta}$.

2.2.2 Input and output Resistances

R_{in} is very high (MΩs).

R_{out} is very low because of the parallel-derived negative feedback.

2.3 Voltage Follower

This is the name given to the circuit where the voltage gain is unity and v_{out} is in phase with v_{in}.

To obtain this condition from the circuit of figure 5, R_1 is omitted and R_2 is made a short-circuit. The new circuit is shown in figure 6.

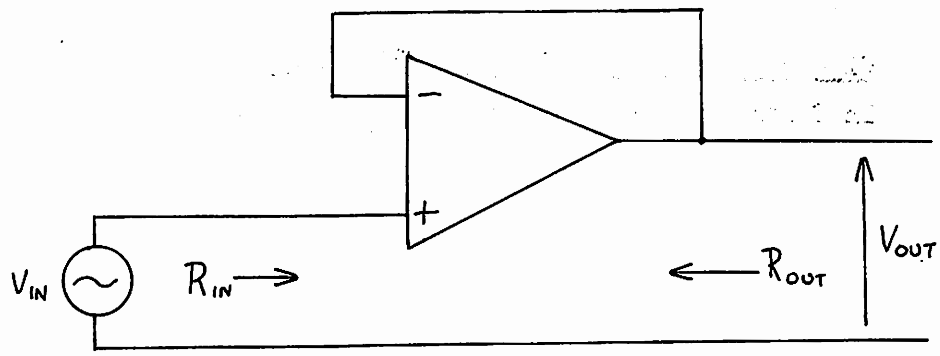

Figure 6: Voltage Follower

2.4 Operational Amplifier as a Summing Amplifier

A number of separate signals may be added, without undesirable loading of the signal sources, by using the amplifier in the inverting mode as shown in figure 7.

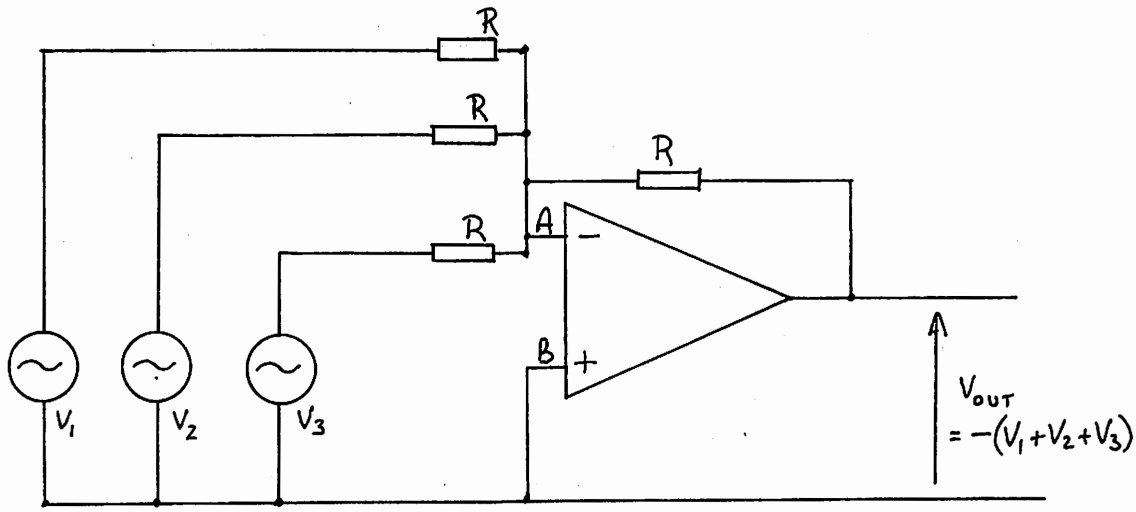

Figure 7: Summing Amplifier

At A the voltage is almost zero (thus it is commonly called a "virtual earth") and each input, v_1 v_2 and v_3 has a load = R. By making the feedback resistor also equal to R, the voltage gain from each input to the output is unity.

2.5 Amplifiers in cascade

If positive and negative d.c. supplies are used for the operational amplifier, the input and output terminals are at earth potential and interconnection between amplifiers may be made directly (i.e. without using coupling capacitors) thus preserving the d.c. response of the complete amplifier.

3. WITH REACTIVE COMPONENTS IN THE FEEDBACK

In figure 8 Z_1 and Z_2 replace R_1 and R_2.

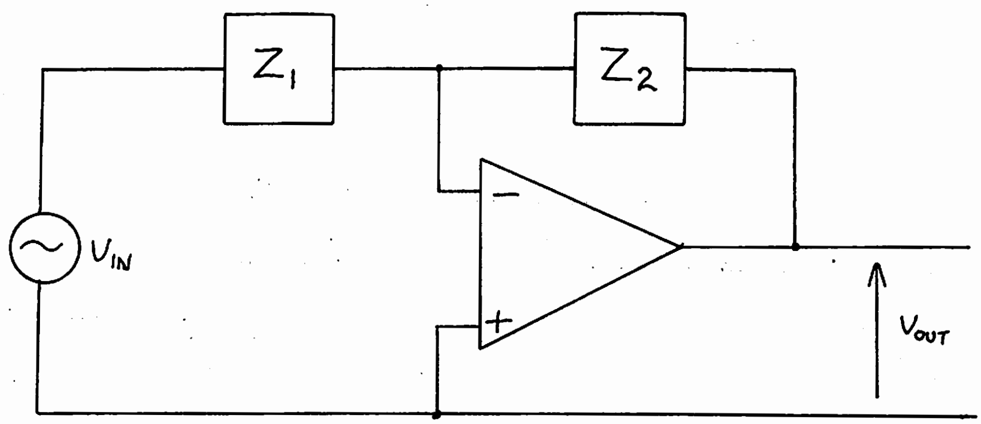

Figure 8: General form of inverting amplifiers

Z may consist of resistance and reactance, therefore simple equaliser or tone control circuits can be made because $\frac{v_{out}}{v_{in}} = \frac{Z_2}{Z_1}$.

This ratio of two impedances makes design simpler than using a potentiometer to obtain the same response. An example will illustrate the application. See figure 9.

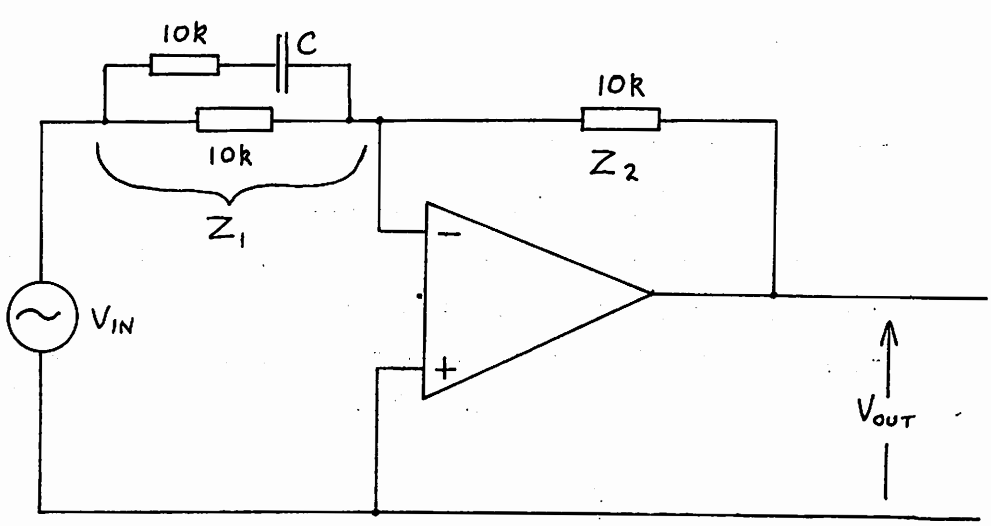

Figure 9: With complex Z_1

At low frequencies, Z_1 = 10k and $\frac{v_{out}}{v_{in}} = \frac{Z_2}{Z_1} = \frac{10k}{10k} = 1$

with phase inversion.

At high frequencies, when C tends to zero reactance, Z_1 = 5k

and $\frac{v_{out}}{v_{in}} = \frac{Z_2}{Z_1} = \frac{10k}{5k} = 2$

The response is shown in figure 10.

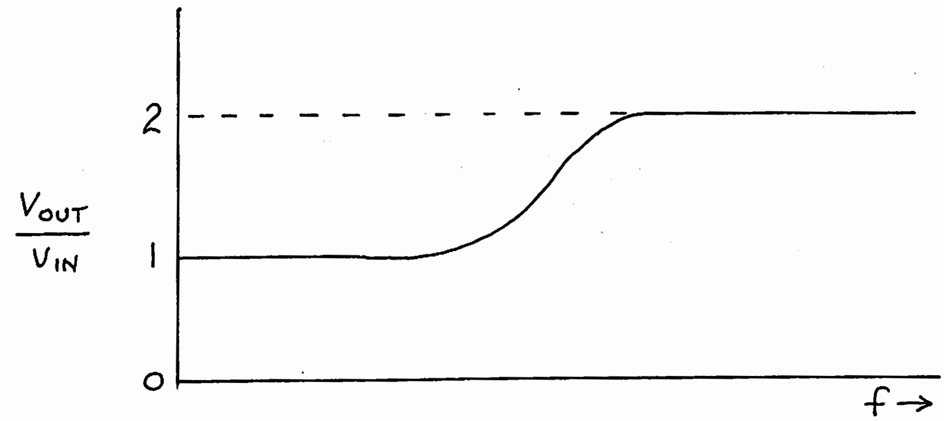

Figure 10: Response of the circuit of figure 9

Note that the low-frequency response is 1. With the potentiometer method for obtaining the same response, a voltage loss at low frequencies is inevitable.

4. WITH NON-LINEAR FEEDBACK

By using diodes or other non-linear devices in the feedback path the operational amplifier may be given a non-linear transfer characteristic. One particular circuit which is often encountered in BBC equipment is the 'precision rectifier'. (See figure 11)

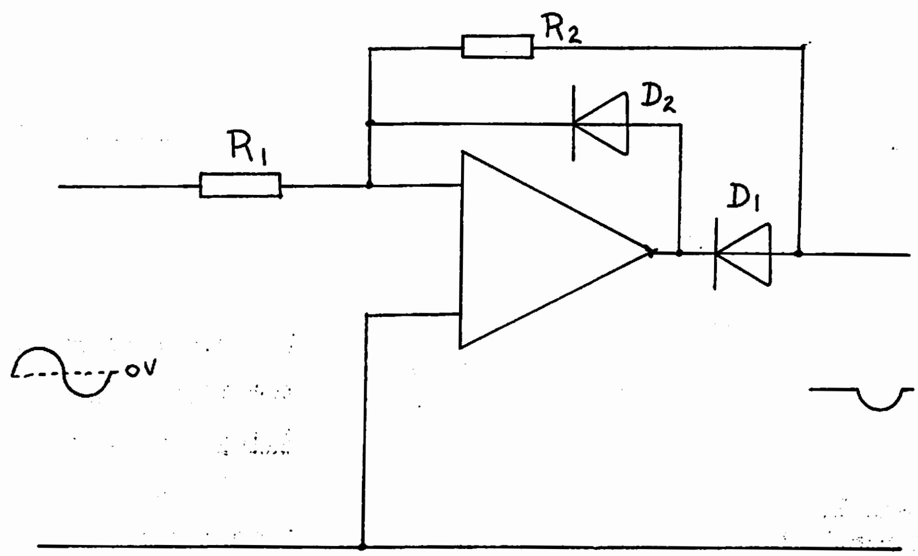

Figure 11: Precision Half-Wave Rectifier

On +ve half cycles of the input the inverted output is passed through D_1. Feedback is applied by R_2. As D_1 is within the feedback loop its forward conduction offset is reduced by the gain of the operational amplifier.
On -ve half cycles of the input D_2 conducts and no voltage appears on the output.
This circuit forms an almost perfect half wave detector circuit, non-linear errors due to the diode being eliminated.
A full wave version is shown in figure 12. Where the inverted half wave rectified signal is added to the input in a summing amplifier.

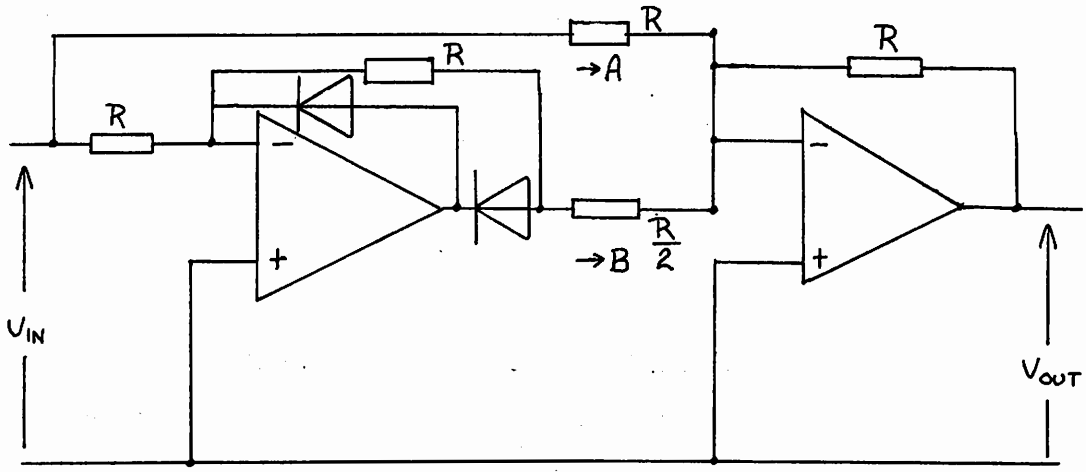

Figure 12(a): Precision Full-Wave Rectifier

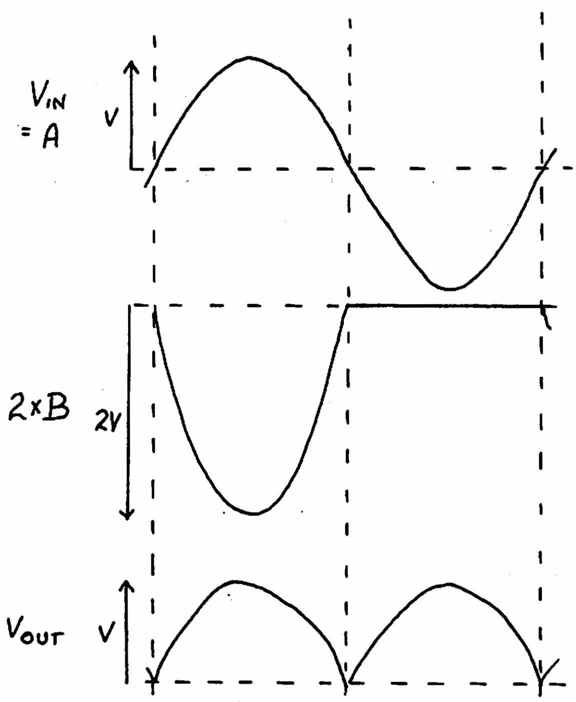

Figure 12(b) Waveforms for (a)

By selecting suitable resistors the input signal is added to twice the inverted half wave rectified signal. The output is then the full wave rectified signal.

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23rd March 1978