SECTION 5

FREQUENCY SYNTHESISER, TYPE XUA: FUNCTIONAL DESCRIPTION

5.1 Introduction

The Type-XUA Frequency Synthesiser is a high-grade commercial equipment (Rohde and Schwarz) designed to generate any single frequency at 1-kc/s intervals from 1 kc/s and 30 Mc/s. The synthesis is based on use of a 100-kc/s crystal oscillator with a high order of frequency stability, referred to subsequently in detailing the various capabilities of the equipment.

The most important application of the synthesiser is in precision frequency measurement, but BBC applications include its use as a drive for high-frequency transmitters. This refers particularly to short-wave transmitters working under the condition of inter-station synchronisation, for which stringent carrier-frequency requirements have to be met. The synthesiser is well suited to this common-wave operation of transmitters at more than onc BBC site, because a range and flexibility of adjustment resembling that of VFO4 variable-frequency equipments is allied to the accuracy and stability of crystal standards. The possible short-term stability is of the order of 1 part in 10^8.

Information given here is intended as a background to practical information in the manufacturer's handbook issued with the equipment. All diagrams accompanying this description are schematics in which, with one minor exception, distinctive shading is used for a four-part classification of individual elements as follows:

(a) The master oscillator (crystal) and those units dealing with frequencies either directly or harmonically related to its output.
(b) A variable-frequency oscillator.
(c) A unit working on frequencies derived by a mixing process.
(d) A fixed oscillator other than item (a).

5.2 Means of Frequency Synthesis

The synthesiser incorporates groups of stages working as triple-mixing combinations, each arranged to cancel frequency drift and providing additive contributions to wanted output frequencies. The principle on which triple-mixers operate is described with reference to Fig. 5, as an essential to understanding how the complete equipment functions.

5.2.1 Basic Triple-mixing Arrangement Fig. 5

Fig. 5 (a) shows the typical configuration of stages for triple mixing, and refers in generalised terms to generated and evolved frequencies.

The crystal oscillator CO is a highly-stable type operating at a relatively low frequency F. It is coupled to both a harmonic-generator HG and a divider DIV to provide harmonics (F1) and subharmonics (F4), respectively, of the crystal frequency. These derived signals are applied to two points in a mixer chain, at MX1 and MX2. Also injected into the mixer chain, but at MX1 and MX3, is the output (F2) of a variable-frequency oscillator VFO.

The last-mentioned item serves only as a selecting device which, by appropriate adjustment of frequency, can be used to beat with a suitable harmonic-generator frequency and enable MX1 to produce an output at difference frequency F3. This signal is fed into a fixed i.f. amplifier IF1, sufficiently sharply tuned to accept only the one resultant of the mixing process.

Additional frequency-changing in MX2 is effected with the F3 signal and the crystal-controlled frequency F4 derived in the divider, and the difference frequency F5 is passed by fixed i.f. amplifier IF2 to MX3. The other input to this mixer is the F2 signal from the variable-frequency oscillator, to evolve a final difference-frequency output F6 that is unaffected by inherent drift in the variable-frequency oscillator.

This independence, and restriction of the variable-frequency oscillator to a selecting function, can be proved as follows:

$$\begin{aligned} F3 &= F2 - F1 \\ F5 &= F3 - F4 \\ &= F2 - F1 - F4 \\ F6 &= F2 - F5 \\ &= F2 - (F2 - F1 - F4) \\ &= F1 + F4 \end{aligned}$$

Thus F2 is absent from the expression for final frequency.

5.2.2 Triple Mixing: Numerical Examples

Fig. 5 (b) has the form of Fig. 5 (a) but with particular frequencies to exemplify the frequency-converting action. Assumptions are:

(a) A crystal-oscillator output at 100 kc/s.

(b) A harmonic-generator multiplication of 5 (to 500 kc/s).
(c) A divider with a factor of 5 (to 20 kc/s).
(d) A required output frequency of 520 kc/s.

In this example the fixed-tuned frequency of the first i.f. amplifier is assumed to be 250 kc/s. To provide the amplifier with an input at that frequency the variable-frequency oscillator is set to give a 750-kc/s signal. This mixes with, and in effect selects, the 5th harmonic of crystal frequency (500 kc/s) because the difference-frequency component of MX1 output is the required 250-kc/s signal.

The conversion through subsequent mixers and i.f. amplifiers is similarly achieved with difference frequencies. The 250-kc/s signal from IF1 and the 20-kc/s feed from the divider are used to obtain a 230-kc/s output from MX2. In turn this resultant and the 750-kc/s signal from the variable-frequency oscillator are combined in MX3 to produce the wanted output at 520 kc/s.

Proceeding from the above example, suppose drift in the variable-frequency oscillator causes an alteration to 752 kc/s. Owing to the 2-kc/s change the difference frequencies from MX1 and MX2 become 252 kc/s and 232 kc/s respectively. However, in MX3 the combination of the 232-kc/s signal and the 752-kc/s input from the variable-frequency oscillator gives a 520-kc/s output. Thus final frequency is the same as for the original accurate condition. One tangible result of drift is the reduction of triple-mixer output voltage, a consequence of IF1 and IF2 having inputs at frequencies differing slightly from those to which their tuned circuits are peaked.

The effect of readjusting the variable-frequency oscillator for 650 kc/s is a selection of the next lower harmonic-generator frequency, namely the 4th harmonic at 400 kc/s. Difference frequencies from MX1 and MX2 remain at values quoted for the 5th-harmonic condition but, with applied frequencies of 230 kc/s (through IF2) and 650 kc/s, MX3 has a changed resultant of 420 kc/s. Extending this argument shows that each 100-kc/s step-adjustment of variable-oscillator frequency causes the triple-mixer output frequency to change by an identical amount in the same sense. For instance, with the Fig. 1 (b) example the lowest of a series of frequencies at 100-kc/s intervals would be 120 kc/s, with the variable-frequency oscillator at its 350-kc/s setting.

The available output frequencies in a given range can be considerably increased by arranging for smaller incremental changes resulting from 10-kc/s and 1-kc/s step-adjustments. That necessarily involves the ability to alter the frequency applied from the divider to MX2. In effect the synthesiser provides this feature by employing a number of triple-mixer sections which are interconnected and fed at their intermediate mixers with frequencies appropriate to the required range of adjustment.

5.3 Operating Description

5.3.1 General

The Type-XUA synthesiser has a 100-kc/s crystal oscillator housed in a temperature-controlled oven and operated with well-regulated power supplies. The instrument covers different orders of frequency with letter-identified ranges as in Table 1.

Table 1

Range	*Order of Selectable Frequencies*	*Coverage**	*Incremental Change†*
A	Mc/s and tenths of 1 Mc/s	0—30 Mc/s	100 kc/s
B	Hundredths and thousandths of 1 Mc/s	0—100 kc/s	1 kc/s
C	C/s	0—1,000 c/s	1 c/s

*Nominal; for operational convenience the upper limits extend to 30·2 Mc/s, 105 kc/s and 1,050 c/s respectively.

†Per division of dial.

The A and B ranges are based on double triple-mixers, which are expansions of the single form already described. Only these ranges are controlled by the crystal oscillator and therefore wanted output frequencies which are integral multiples of 1 kc/s can be obtained with an accuracy equal to that of the crystal. When output-frequency selection is confined to one or both of these ranges the stability is about 2 parts in 10^8. This favours the drive application mentioned in the introduction, because internationally-agreed frequencies for the short-wave transmitters are nearly all whole multiples of 1 kc/s.

Adjustment of the variable-frequency oscillators for the A and B ranges is facilitated by switched meters. Each can be connected to the appropriate i.f. stage to show by a maximum indication when the variable-frequency oscillator is set correctly.

The non-locked range C enables the equipment to be used as a variable-frequency oscillator with a range of 30 c/s to 30 Mc/s. With this function the frequency accuracy is reduced by ±0·5 c/s and, though short-term stability is very good, slight drift of output frequency is to be expected.

The synthesiser can be used as a frequency meter, providing a signal for the comparative adjustment of other generating sources with the aid of a beat-note detector.

Most of the subsequent description refers to Fig. 6, which is a block schematic of the complete equipment.

5.3.2 Crystal-oscillator Dependent System Fig. 6

The output of the 100-kc/s crystal oscillator is distributed to three chains, from which are derived five frequencies for various mixer stages. Arrangements comprise:

(a) HG1 (n × 100 kc/s) and IF1 (low-pass). These feed MX1, the initial stage for range A, to permit stepped selection of frequencies at 100-kc/s intervals between 4·2 and 34·2 Mc/s.

(b) HG3 (n × 100 kc/s) and IF13; HG4 and IF14. These are associated with range B. IF13 is tuned to 700 kc/s, to feed MX7 and provide the input for HG4. IF14 is tuned to the 5th harmonic of HG4 output and this 3·5 Mc/s signal is applied to MX9.

(c) DIV1, DIV2, HG2 and IF7 (low-pass); AMP. Associated with range B. The dividers have factors of 10 and their successive connection produces a 1-kc/s input for HG2. This and IF7 are counterparts of item (a), but to provide for 1-kc/s stepped selection from 10 kc/s to 110 kc/s.* The DIV1 output is applied also to an amplifier (AMP) from which the 10-kc/s signal is injected at MX8.

Note that, despite earlier references to difference frequencies only, a proportion of i.f. stages in the synthesiser are tuned to accept sum-frequency outputs of various mixers.

5.3.3 Ranges of Evolved Frequencies

(a) Range A Figs. 6 and 7.

Fig. 7 is an abstraction from Fig. 6, to show the combination for producing frequencies at the 100-kc/s intervals from 0 to 30 Mc/s. The A group includes two fixed-frequency oscillators, of which FO3 is a crystal type with an accuracy superior to that of FO2. FO3 is not relevant to present description because it is made operative for non-locked working only; see under 5.3.4.

This section of the equipment has zero-output frequency when a 4·2-Mc/s signal is selected at MX1, and therefore that value has to be added to obtain the required final frequency. Table 2 gives the frequency-conversion details to prove the zero condition and to indicate the purpose of FO2; note that for present purposes a 4·2-Mc/s signal from range B is assumed to be applied to MX3.

Table 2

Output		*Mixed with*		*Resultant (Mc/s)*
From	*Frequency (Mc/s)*	*Frequency (Mc/s)*	*From*	
VFO1	97·05	4·2	IF1	92·85
IF2	92·85	88·0	FO2	4·85
IF3	4·85	4·2	IF12	9·05
IF4	9·05	88·0	FO2	97·05
IF5	97·05	97·05	VFO1	0

It follows that IF1 provides a 34·2-Mc/s signal for MX1 when an output at 30 Mc/s is produced.

(b) Range B Fig. 6.

The aggregation for range B, in the upper part of Fig. 6, generally resembles that of range A. Exempted from present consideration is fixed-frequency (crystal) oscillator FO5 which, like FO3 in the A group, is for non-locked operation as described under 5.3.4.

The 4·2-Mc/s signal previously assumed to be applied from the B mixer chain to MX3 (see IF12 in Table 2) is one extreme of the range and the other is 4·1 Mc/s. In this instance the 100-kc/s coverage is with reference to a 10-kc/s datum at which the output frequency is effectively zero, and the wanted frequency is obtained by adding 10 kc/s to the particular frequency required. Conversion details to prove the zero-frequency conditions

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*Nominal, as distinct from actual upper limit of 115 kc/s to provide for overlap mentioned in Table 1 footnote.

are given in Table 3.

Table 3

Output		*Mixed with*		*Resultant (kc/s)*
From	*Frequency (kc/s)*	*Frequency (kc/s)*	*From*	
IF7	10·0	637·5	VFO4	647·5
IF8	647·5	700·0	IF13	52·5
IF9	52·5	10·0	AMP	62·5
IF10	62·5	3,500·0	IF14	3,562·5
IF11	3,562·5	637·5	VFO4	4,200·0
IF12	4,200·0	—	—	—

With an IF7 output of 10 kc/s the B mixer chain makes no contribution to synthesis because, as shown under (a), choice of final frequencies is restricted to the whole Mc/s and tenths of 1 Mc/s available from range A when IF12 feeds a 4·2-Mc/s signal to MX3. Through selection by adjustment of VFO4 the IF12 signal can be altered in 1-kc/s steps to 4·1 Mc/s and in this way it is possible to include multiples of 1 kc/s in the final frequency from IF6.

(c) Range C Fig. 6.

This range is introduced by an h.t. transfer which disconnects the crystal-controlled 10-kc/s signal for MX8 and substitutes the output of VFO6. With a range of 9-10 kc/s this variable-frequency oscillator could be set to simulate the pre-transfer condition, but with inferior stability owing to lack of a triple-mixer arrangement to cancel drift. Subject to acceptability of this limitation, adjustments relative to the 10-kc/s setting enable any fraction of 1 kc/s to be included in final frequencies.

(d) Worked Example

To show frequencies involved in the production of a given final frequency, suppose an output at 17·326 Mc/s is required. To suit the individual ranges the constituents of this are:

17·3	Range A
26	Range B
000	Range C

The 17·3 component is derived with the aid of the HG1 chain and VFO1. Adding this figure to the range-A constant gives the HG1 output frequency, thus:

$$17{\cdot}3 + 4{\cdot}2 = 21{\cdot}5\ \text{Mc/s}$$

Adding this result to the fixed frequency of IF2 gives the VFO1 frequency, thus:

$$21{\cdot}5 + 92{\cdot}85 = 114{\cdot}35\ \text{Mc/s}$$

The 26 component is derived with the aid of the HG2 chain and VFO4. Adding this figure to the range-B constant gives the HG2 output frequency, thus:

$$26 + 10 = 36\ \text{kc/s}$$

The VFO4 frequency is obtained by subtracting this result from the fixed frequency of IF8, thus:

$$647{\cdot}5 - 36 = 611{\cdot}5\ \text{kc/s}$$

MX7 has inputs at 647·5 kc/s (IF8) and 700 kc/s (IF13), so its difference-frequency output is 52·5 kc/s. This is applied to MX8 which, because range C (VFO6) is not required, has a 10-kc/s input from AMP. Therefore IF10 has a sum-frequency output of 62·5 kc/s.

This frequency and the IF14 signal (3,500 kc/s) are inputs for MX9, giving a sum-frequency resultant of 3,562·5 kc/s taken through IF11 to MX10. MX10 has another input at 611·5 kc/s from VFO4, and so a frequency of:

$$3{,}562{\cdot}5 + 611{\cdot}5 = 4{,}174\ \text{kc/s}$$

is passed through IF12 to MX3 in the A mixer chain.

In MX3 there is combination of 4,174 kc/s (IF12) and 4,850 kc/s (IF3), with a resultant of:

$$4{,}174 + 4{,}850\ \text{kc/s} = 9{,}024\ \text{kc/s}$$

applied through IF4 to MX4.

In MX4 there is mixing of this signal with the FO2 feed (88 Mc/s), which provides:

$$9{\cdot}024 + 88{\cdot}0 = 97{\cdot}024\ \text{Mc/s}$$

applied through IF5 to MX5.

Final conversion in MX5 occurs by combination of the VFO1 and IF5 signals to provide a difference-frequency resultant, thus:

$$114{\cdot}35 - 97{\cdot}024 = 17{\cdot}326\ \text{Mc/s}$$

which is the required output frequency.

5.3.4 Oscillators FO3 and FO5

Crystal oscillators FO3 and FO5 are individually associated with the A and B chains respectively, to allow the alternative of their producing frequencies free of the locking normally imposed from oscillator CO.

Non-locked operation can provide a test facility in, for example, checking that the zero positions of the v.f.o. dials correspond to zero output, and might also be required when using the equipment for frequency measurement. It is unsuited to the drive application because oscillators VFO1 and VFO4 no longer exercise a selective function in drift-cancelling arrangements. Consequently output frequencies are influenced by their stability as well as that of FO2 and auxiliary oscillators FO3 and FO5.

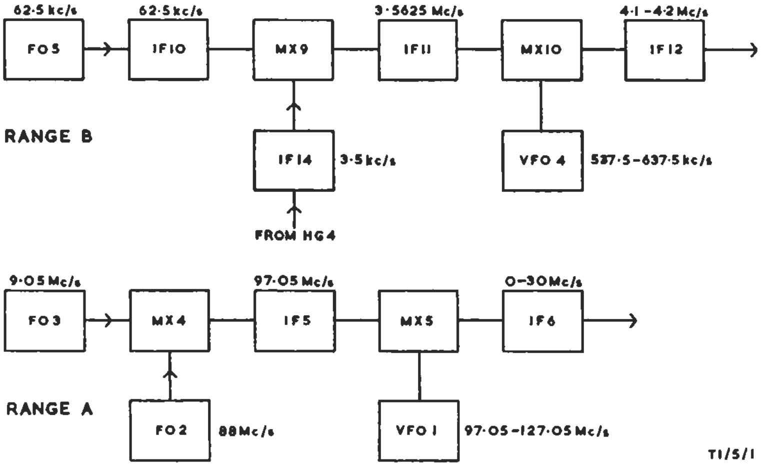


Fig. 5.1 Stage Arrangements for Non-locked Output Frequencies

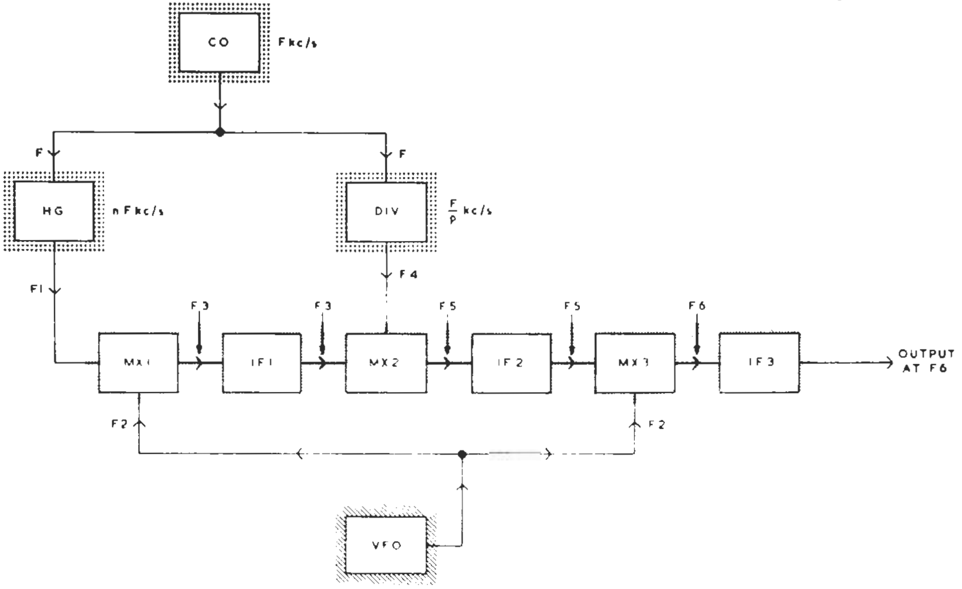
The non-locked condition is obtained by h.t. transfer, with switches shown in Fig. 2, to make the crystal oscillator active and effectively to disconnect stages prior to the point where its output is applied to the particular chain. FO3 and FO5 then become the initial items of modified A and B chains as in Fig. 5.1.

Switching the A chain to non locked-working causes its separation from chain B; see position of MX3 in Fig. 2. FO3 feeds MX4 with a 9·05-Mc/s signal for combination with the 88·0-Mc/s input from FO2. Through IF5 the 97·05-Mc/s resultant is passed to MX5, also fed by VFO1. This oscillator has continuous coverage from 97·05 to 127·05 Mc/s and so, with IF6 accepting difference frequencies, it can be set to obtain an output at any frequency from 0 to 30 Mc/s.

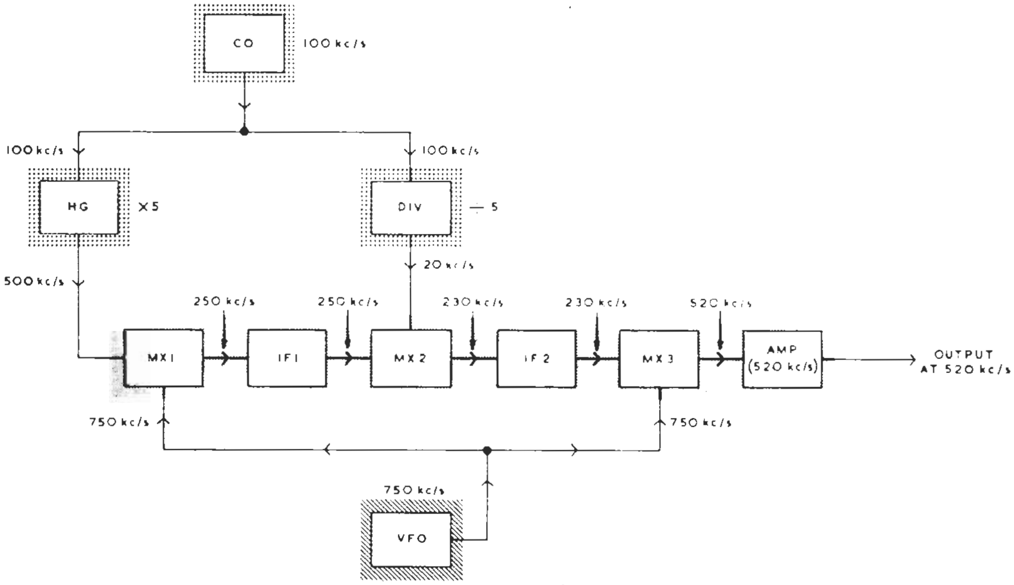
The above-mentioned separation does not occur when chain B is transferred to non-locked operation. The A chain remains in the locked state making it possible to produce frequencies at 100-kc/s intervals throughout its range, but output frequency also depends on the B-chain contribution introduced at MX3 (Fig. 2). Except for the i.f. amplifier between crystal oscillator FO5 and mixer MX9 the non-locked B arrangement is generally similar to its A counterpart, and functionally the only difference is selection of the sum-frequency term in the output of MX10.

MX10 has one input fixed at 3·562 Mc/s and the other variable from 537·5 to 637·5 kc/s, giving a range extending from 4·1 to 4·2 Mc/s. This is as for locked operation, with the difference that VFO4 provides continuous, instead of stepped, change between the 100-kc/s limits. Therefore chain B can fully cover the 100-kc/s gaps between range-A frequencies, by supplying MX3 with a frequency appropriate to the exact increment needed to obtain a particular output frequency at IF6.

FIG 5



(a) GENERAL



(b) PARTICULAR

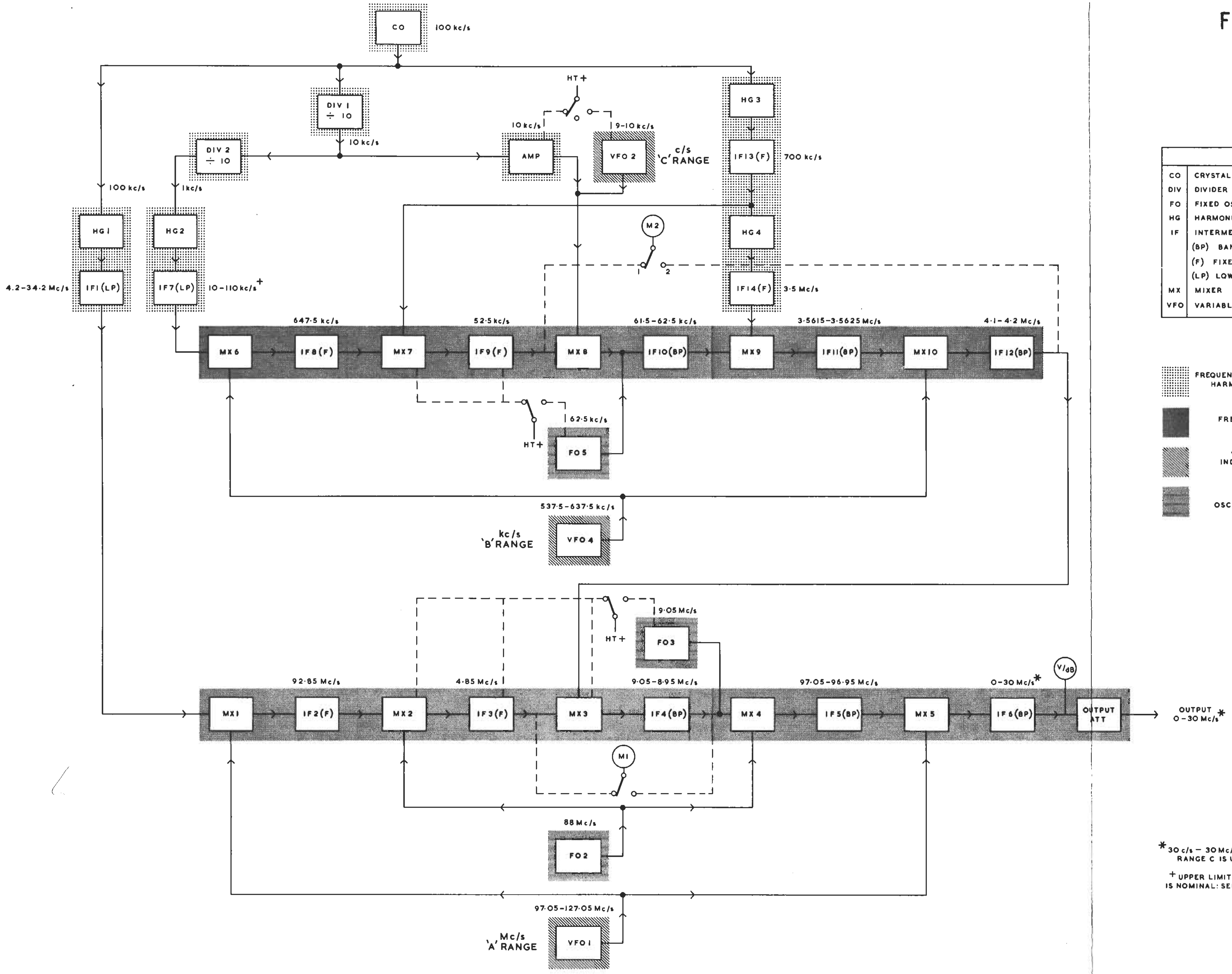
KEY

░	FREQUENCIES EITHER DIRECTLY OR HARMONICALLY RELATED TO 100 kc/s CRYSTAL
▓	FREQUENCIES PRODUCED BY MIXING
▨	VFO FREQUENCIES INDEPENDENT OF FINAL FREQUENCY

CODE	
CO	CRYSTAL OSCILLATOR
DIV	DIVIDER
HG	HARMONIC GENERATOR
IF	INTERMEDIATE FREQUENCY
MX	MIXER
VFO	VARIABLE FREQUENCY OSCILLATOR

ROHDE & SCHWARZ FREQUENCY SYNTHESISER: BASIC TRIPLE MIXING

FIG 6



ROHDE & SCHWARZ FREQUENCY SYNTHESISER: BLOCK SCHEMATIC

CODE	
CO	CRYSTAL OSCILLATOR
DIV	DIVIDER
FO	FIXED OSCILLATOR
HG	HARMONIC GENERATOR
IF	INTERMEDIATE FREQUENCY
	(BP) BAND PASS
	(F) FIXED
	(LP) LOW PASS
MX	MIXER
VFO	VARIABLE FREQUENCY OSCILLATOR

KEY

▒	FREQUENCIES EITHER DIRECTLY OR HARMONICALLY RELATED TO 100 kc/s CRYSTAL
■	FREQUENCIES PRODUCED BY MIXING
▨	VFO FREQUENCIES INDEPENDENT OF FINAL FREQUENCY
▤	FIXED AND TEST OSCILLATOR FREQUENCIES

* 30 c/s – 30 Mc/s WHEN RANGE C IS USED

\+ UPPER LIMIT IS NOMINAL: SEE TEXT

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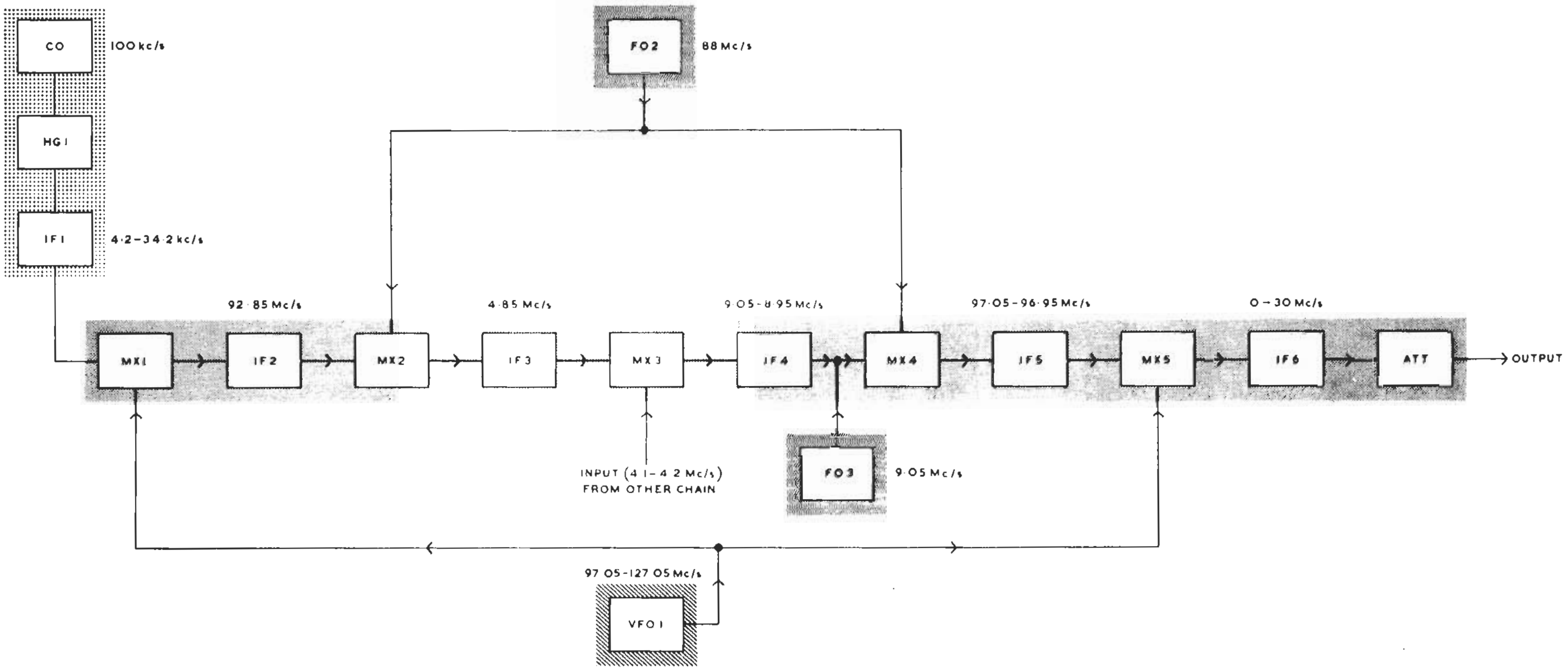

KEY

░	FREQUENCIES EITHER DIRECTLY OR HARMONICALLY RELATED TO 100 kc/s CRYSTAL
▩	FREQUENCIES PRODUCED BY MIXING
▨	VFO FREQUENCIES INDEPENDENT OF FINAL FREQUENCY
▤	FIXED AND TEST OSCILLATOR FREQUENCIES

CODE	
CO	CRYSTAL OSCILLATOR
FO	FIXED OSCILLATOR
HG	HARMONIC GENERATOR
IF	INTERMEDIATE FREQUENCY
MX	MIXER
VFO	VARIABLE FREQUENCY OSCILLATOR

FIG 7

ROHDE & SCHWARZ FREQUENCY SYNTHESISER: TYPICAL DOUBLE TRIPLE-MIXING ARRANGEMENT

T1
SECTION 5