Book

FREQUENCY-STABILIZED OSCILLATOR UNIT
NOTES AND INSTRUCTIONS

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RESEARCH LABORATORY OF ELECTRONICS
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FREQUENCY-STABILIZED OSCILLATOR UNIT

Notes and Instructions

by

R. B. Lawrance

Abstract

Several of R. V. Pound's i-f type frequency-stabilizing units have been built by the Research Laboratory of Electronics. This instruction booklet is intended to include (1) specific instructions for adjusting and operating these units, (2) sufficient information in the form of circuit diagrams, photographs, and reference material to aid others interested in constructing similar units, (3) sufficient technical background material so that a reasonable understanding of the equipment can be gained without extensive reference to more detailed literature. Either an oscilloscope or built-in metering circuits can be used for adjusting the equipment, and procedures for both methods are given.

FREQUENCY-STABILIZED OSCILLATOR UNIT

Notes and Instructions

Contents

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I. INTRODUCTION

The frequency-stabilized oscillator unit is essentially that described by R. V. Pound in RL Report 837, "An Improved Frequency Stabilization System for Microwave Oscillators". Some modifications and additions have been made in the interest of flexibility and ease of adjustment. The present description refers to X-band 2K25 reflex klystron oscillators, but most of the components can be used with other tubes employing the same operating voltages.

Since the equipment is not easily adaptable to audio-frequency amplitude modulation, it should, for standing wave measurements, be used in conjunction with a spectrum analyzer or other indicating device not requiring amplitude modulation.

The oscillator itself and its operating voltages are the same as for normal unstabilized use. The stabilizing method is briefly as follows. The oscillator frequency is compared with the resonant frequency of a cavity and an error-signal is derived which indicates both magnitude and sense of the frequency difference. After amplification (together with incidental modulation and demodulation) the error signal is applied as a d-c signal voltage to the reflector electrode of the oscillator. This causes the oscillator frequency to shift toward the resonant frequency of the cavity; the final frequency difference will be the original frequency difference divided by (loop gain + 1). The amount of usable gain is limited by phase shifts in the error-amplifying circuits and, to a lesser extent, by the characteristics of the r-f plumbing.

A more expanded discussion of the principle of operation is given in Sec. IV and some pertinent elementary background in Sec. V. Sections II and III contain the descriptive and operational information.

II. EQUIPMENT

A. X-band Plumbing.

A block diagram of the stabilized oscillator is given in Fig. 1, and two equally useful plumbing arrangements, differing only in the location of the phase shifter, are shown in Fig. 2. In the latter figure the cavity is shown as connected directly to the phase shifter or the Magic T, but lengths of waveguide up to several feet may be interposed if desired. Ordinary tuning devices are not useful for matching the cavity; its coupling must be adjusted so that at resonance the cavity is approximately matched to the waveguide.

The phase shifter ("line stretcher") and attenuator are standard units, as is the broadband modulator crystal mount. If the cavity is reasonably well matched, the mixer crystal mount can be a fixed-tuned broadband unit similar to

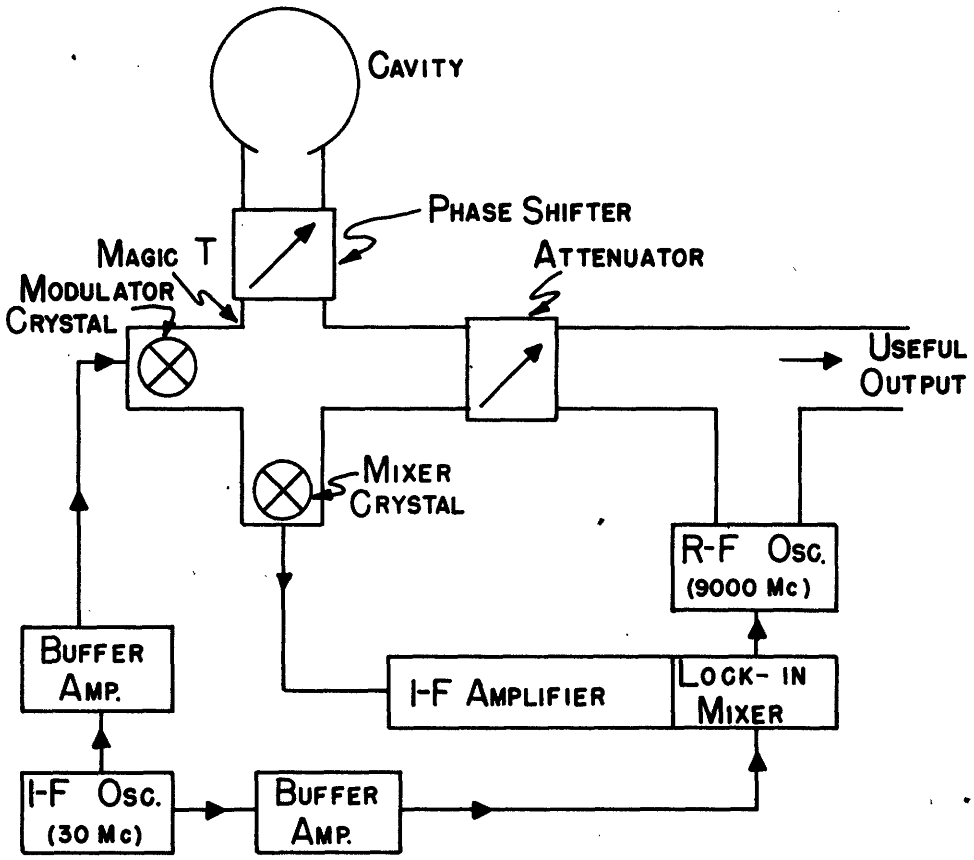

Figure 1. Block diagram of stabilized oscillator.

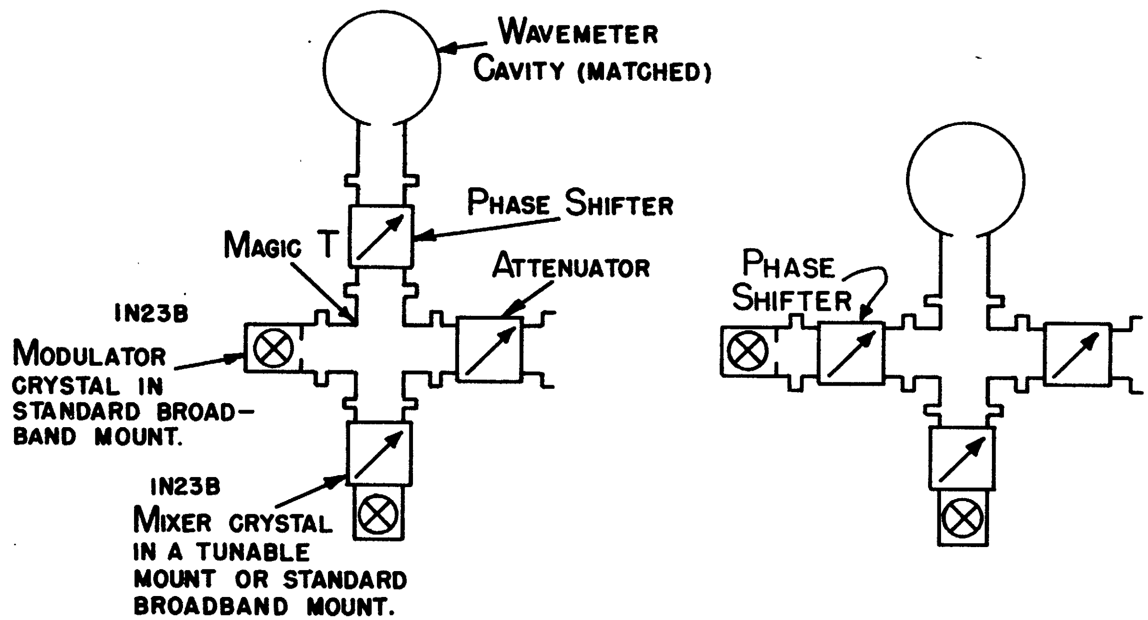

Figure 2. Plumbing for X-band. Two possible positions for phase shifter indicated.

the modulator crystal mount; otherwise it may be preferable to use a tunable mount equipped with a Type N cable fitting. Type numbers and drawing numbers of the various components are listed in the table below as are also the drawing numbers of the circuit diagrams.

Item	Type No.	Dwg. No.	Dwg. Obtainable from
Oscillator Mount	________	B-13242-J	RLE
Accompanying Magic T	________	B-13242-H	RLE
Magic T	________	C-11540-A	RLE
Attenuator	TPX-27GM/25	A-11888-A	RLE
More recent universal design	________	D-65-A	RLE
Phase Shifter	________	A-13368-A	RLE
More recent universal design	________	D-65-A	RLE
Broadband Fixed-tuned Crystal Mount	________	B-85-A	RLE
Tunable Crystal Mount	TPX-36GM	B-7411-A	RLE
Type N Adapter	________	C-62	RLE
Magic T for 3-cm Stabilized Oscillator	________	A-59-A	RLE
Cavity	1511TFX-17GA	(Standard reaction type X-band cavity)	
I-F Amplifier and 30-Mc Circuits	________	D-52-A	RLE
Power Supply Unit	________	A-47-A	RLE

B. The Assembly.

Photographs of the assembled equipment, including X-band plumbing, are shown in Figs. 3 and 4. The power supplies, 30-Mc oscillator and buffer amplifiers, 30-Mc i-f amplifier, and lock-in mixer are contained in a single unit, known collectively as the "stabilizer". This unit may be operated on a workbench or incorporated in a rack-mounted assembly, the over-all panel height being 12 1/4 in.

Power supplies operate at 115 volts 60 cycles, and function satisfactorily from 105 to 120 volts input. Where power-line surges are prevalent, it may be advisable to use an external voltage-regulating transformer.

Three front-of-panel connections are made to the r-f plumbing. The mixer crystal is connected to the input of the i-f amplifier by a standard length cable permanently attached to the amplifier. The length of this cable must not be changed, and the plumbing must be arranged with this in mind. Connection is made to the modulator crystal by an 8-in. cable with male Type N cable plugs. The length of this cable can be varied if necessary, but slight internal retuning is then required. Finally, the cable supplying power to the oscillator tube plugs into an octal socket in the upper right-hand corner of the panel. CAUTION - The oscillator shell is operated at 300 volts above ground. Check that the tube mount does not connect the shell to ground. Check also that cable connections to the oscillator power plug are the same as those on the socket.

C. Controls, Meter Positions, and Connections.[1]

1. The following controls are located on the frontpanel of the stabilizer:

   REFLECTOR SW. -- Toggle switch connecting the reflector electrode to either of two sources of voltage, one for use during preliminary adjustments and the other for use during stabilized operation.

   NON-STABILIZED -- Potentiometer from which reflector voltage(d-c) is derived during lining-up. Range approximately 90 to 155 volts (negative with respect to ground).

   STABILIZED -- Potentiometer from which reflector voltage (d-c plus error-signal) is derived during stabilized operation. Set during line-up. Range same as above.

   I-F GAIN -- Potentiometer controlling amplifier gain. Calibrated dial for ease in setting.

   METER SW. -- Seven-position rotary switch for switching meter postion and range.

   FREQUENCY SWEEP, OFF-ON -- Toggle switch for applying approximately ± 30 Mc frequency sweep, sinusoidally at 60 cps. Used in conjunction with oscilloscope for rapid adjustment to a given frequency and for rapid line-up method.

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1 Names of controls appearing on name plates are fully capitalized in the text; e.g., REFLECTOR SW. The plumbing controls which bear no name plates have only the initial letters capitalized; e.g. Phase Shifter.

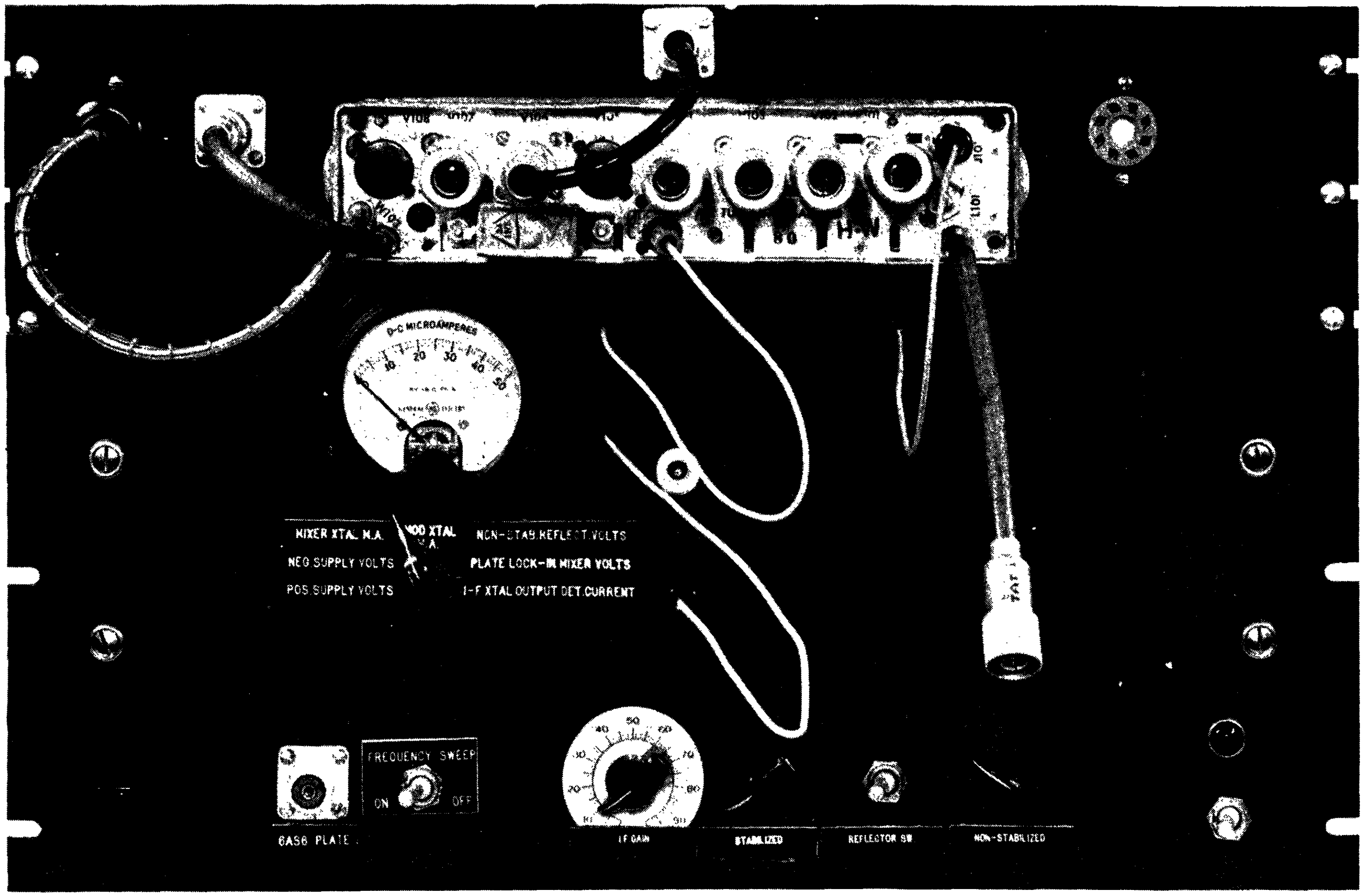


Figure 3. Front panel of stabilizer. Power connections to oscillator tube are made from octal socket at upper right. Cable dangling from right of i-f amplifier goes to mixer crystal. Jack to right of meter is for modulator crystal cable. Other controls are explained in the text.

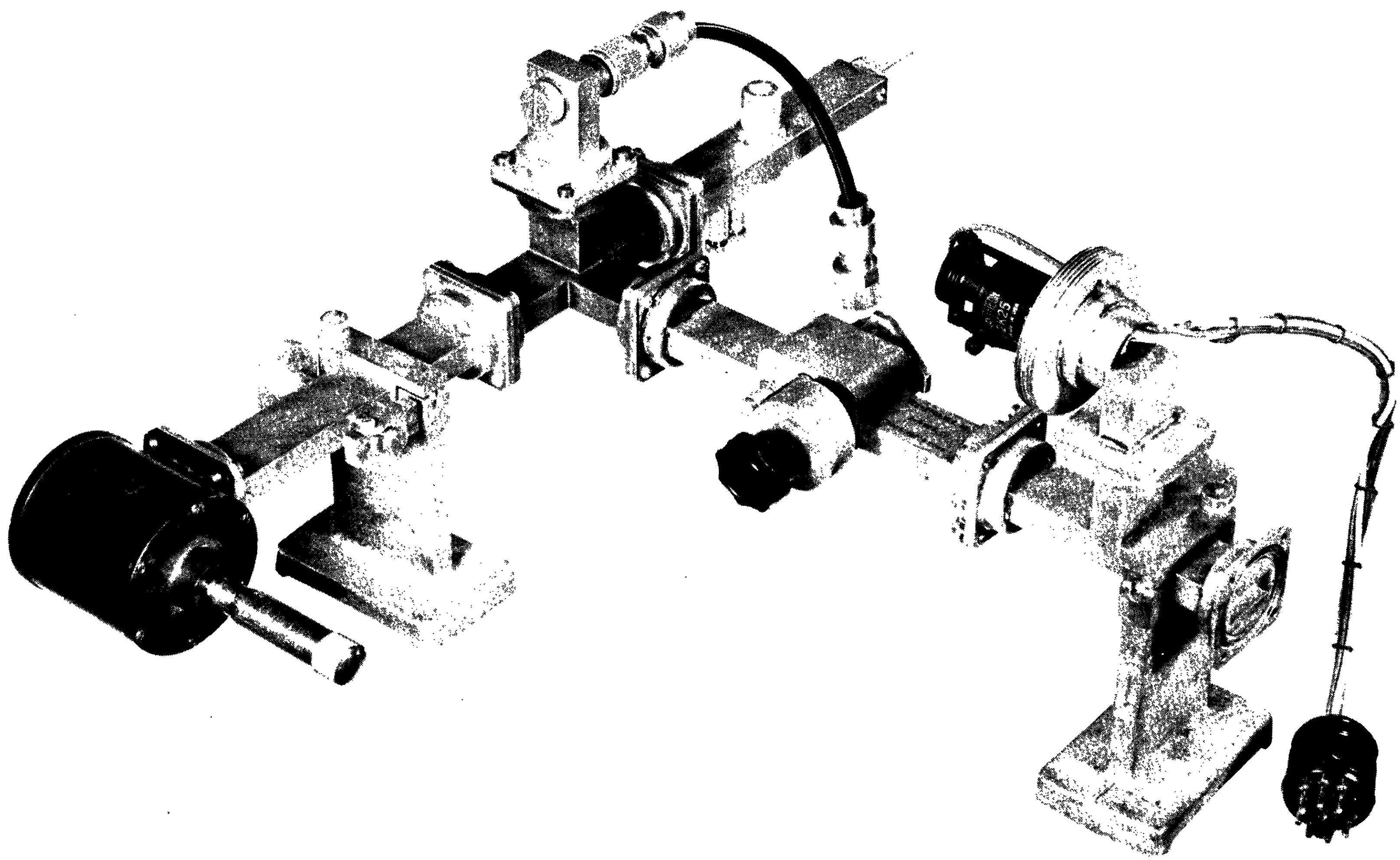


Figure 4. X-band plumbing. Modulator crystal is in untuned crystal mount with cable; tuned mixer crystal mount is behind cable.

2. The following controls are located on the plumbing:

Oscillator Tuning -- Usual mechanical control.

Attenuator -- For isolating stabilization-circuit plumbing from oscillator and for adjusting mixer crystal power level.

Phase Shifter -- For adjusting the phase at which the signal reflected successively from cavity and modulator crystal reaches the mixer crystal; proper adjustment very important.

Cavity Tuning -- Usual wavemeter plunger with frequency or wavelength calibration.

Mixer Crystal Tuning -- Tuner may be used to match mixer crystal. If cavity is well matched, a broadband fixed-tuned crystal mount will ordinarily be used instead of a tunable one.

3. A 50-microampere meter with associated multiplier circuits is used to determine conditions at several important circuit locations. Full-scale deflections on the various ranges are within 20 per cent of the values given below.

The following meter positions are controlled by the METER SWITCH on the stabilizer panel:

POS. SUPPLY VOLTS -- Meter range 0-500 volts. Used for trouble-shooting only. Usual reading 300 volts (meter indication 30 μa).

NEG. SUPPLY VOLTS -- Meter range 0-500 volts (negative). Used for trouble-shooting only. Usual reading 250 volts (meter indication 25 μa).

MIXER XTAL MA. -- Meter range 0-2.5 ma. Used for setting NON-STABILIZED reflector voltage to mode center, also for setting Attenuator and Mixer Crystal Tuning. Normal reading not greater than 0.5 ma (meter indication 10 μa).

MOD. XTAL MA. -- Meter range 0-10 ma. Used principally for trouble-shooting. Usual reading 5 to 7 ma (meter indication 25 to 35 μa).

NON-STAB. REFLECT. VOLTS -- Meter range 0-250 volts (negative). Used for reading mid-mode reflector voltage, as set by NON-STABILIZED potentiometer.

PLATE LOCK-IN MIXER VOLTS -- Meter range 0-250 volts (negative). Used for getting STABILIZED reflector voltage potentiometer (with I-F GAIN at zero) to same voltage as NON-STAB. REFLECT. VOLTS. Also used to check setting of Phase Shifter (with I-F GAIN turned up) and check discriminator curve. With proper stabilized operation this reading is a function of cavity tuning, over a total range of 15 to 25 volts.

I-F XTAL OUTPUT DET. CURRENT -- Meter range 0-1 volts (approximate only). Used to check setting of Phase Shifter. Can also be used (in conjunction with matched load on cavity position) to set mixer crystal tuning accurately, if tuned crystal mount is used.

4. The following connection points appear on the stabilizer front panel:

I-F input cable from mixer crystal on plumbing (type N).

Modulator drive from 30-Mc buffer to modulator crystal on plumbing (type N).

Power to oscillator tube (octal socket).

6AS6 PLATE -- UHF socket connection to oscilloscope, for observation of discriminator characteristic with FREQUENCY SWEEP in ON position and REFLECTOR SW. in NON-STABILIZED position.

III. METHODS OF ADJUSTMENT

A. General.

In lining up the stabilizer it is desirable for the oscillator to work into an approximately matched load. Usually an attenuator is used between the oscillator and the slotted section or other apparatus being used; this attenuator should be set for maximum isolation during oscillator adjustment.

For the first step the REFLECTOR SW. is set on NON-STABILIZED, and the reflector voltage and oscillator mechanical tuning are adjusted so that the desired operating frequency falls in the middle of a mode. The STABILIZED reflector voltage and Phase Shifter are next adjusted, after which the REFLECTOR SW. is changed to STABILIZED and the correct setting for I-F GAIN established.

The complete sequence of adjustments may be carried out by use of the various meter positions; under these circumstances the FREQUENCY SWEEP is not used and remains in the OFF position. Alternatively, an auxiliary oscilloscope may be used in conjunction with the FREQUENCY SWEEP, the meter being used principally in the final adjustments. Use of the oscilloscope makes setting to a given frequency faster and simpler. Complete sequences of adjustments are given in the following sections.

B. Meter-only Adjustment Sequence.

1. Initial adjustment for oscillation

   REFLECTOR SW. -- NON-STABILIZED.

   I-F GAIN -- Minimum (fully counter-clockwise).

   METER SW. -- MIXER XTAL MA.

   FREQUENCY SWEEP -- OFF.

   Attenuator -- Intermediate position.

   Other adjustments -- Setting immaterial.

   Adjust NON-STABILIZED potentiometer for maximum meter reading (if more than one maximum setting is found, use the more clockwise setting, for greater output).

2. Frequency Check

   I-F GAIN -- Change to normal setting (approximately 45-55 divisions).

   METER SW. -- Change to PLATE LOCK-IN MIXER VOLTS.

   Tune cavity slowly over range until a single very pronounced sharp back-and-forth flick of the meter is observed. (There may be one or two spurious ones, but the real one will be unmistakable.) The cavity is now set to oscillator frequency. If this is the desired frequency, proceed with Step 4; if not, continue with Step 3.

3. Frequency Shifting

Settings as in Step 2.

Rotate oscillator mechanical tuning adjustment slightly; then find new frequency with cavity as before. Continue adjustment until oscillator is tuned to nearly the desired frequency (if frequency change is large, NON-STABILIZED reflector voltage may require readjustment to maintain oscillation). Then repeat Step 1 (adjustment of NON-STABILIZED reflector voltage for maximum reading on MIXER XTAL MA.) and make fine adjustment of mechanical tuning for exact frequency. Adjustment of NON-STABILIZED reflector voltage should now show peak output on MIXER XTAL MA. at desired frequency, within 10 Mc on frequency scale or .003 divisions on wavemeter.

4. Setting Attenuator

REFLECTOR SW. -- NON-STABILIZED.

I-F GAIN -- Minimum.

METER SW. -- MIXER XTAL MA.

Cavity Tuning -- Detuned at least 2 turns.

Adjust NON-STABILIZED potentiometer for maximum meter reading, as before. Set Attenuator for reading of approximately 0.5 ma (10 μa). (If attenuation must be reduced below half maximum, either the crystal is insensitive or the oscillator output is low. Operation with low crystal current is permissible; do not reduce attenuation below about 10 db.) If tuned crystal mount is used, tune for maximum crystal current. (This latter adjustment is approximate but generally adequate; more accurate adjustment is discussed later.)

5. Measuring mid-mode reflector voltage

METER SW. -- Change to NON-STAB. REFLECT. VOLTS

Note reading.

6. Adjusting STABILIZED reflector voltage

METER SW. -- Change to PLATE LOCK-IN MIXER VOLTS.

Adjust STABILIZED potentiometer for same reading as in Step 5.

7. Adjusting Phase Shifter

Cavity Tuning -- Detuned at least 2 turns.

I-F GAIN -- Increase to normal (45-55 divisions).

Meter reading will change. Adjust Phase Shifter to restore meter to same reading as above. This should be a fairly sensitive adjustment; it can be checked by observing a near-zero minimum in I-F XTAL OUTPUT DET. CURRENT. Another check is that meter reading should not change as I-F GAIN is changed between minimum and more-than-normal gain.

There are two settings of the Phase Shifter which can restore meter reading, but only one is correct. (It gives pull-in stabilizing action, while the other pushes oscillator frequency away from that of cavity.)

8. Checking Phase Shifter Adjustment

METER SW. -- PLATE LOCK-IN MIXER VOLTS.

I-F GAIN — Normal.

Observe meter as cavity is tuned slowly through oscillator frequency. With right-hand rotation (cavity volume decreasing, wavelength decreasing, frequency increasing) the correct sequence of back-and-forth flick is first down, then up. (Be sure not to use spurious responses for this test; they will be 30 Mc, or .01 wavemeter divisions, from correct setting and will be considerably smaller.)

If necessary, repeat Step 7 to locate the other correct setting of the Phase Shifter.

9. Preliminary Setting of I-F GAIN

Adjust I-F GAIN so that tuning cavity slowly through oscillator frequency causes meter (still on PLATE LOCK-IN MIXER VOLTS) to deflect by approximately 20 volts in each direction.

10. Stabilized Operation

REFLECTOR SW. — Change to STABILIZED.

Tune cavity back and forth through oscillator frequency. Meter reading (still on PLATE LOCK-IN MIXER VOLTS) should be a smooth function of cavity tuning over middle of range.

11. Final Setting of I-F GAIN

METER SW. — Change to MIXER XTAL MA.

Tune cavity back and forth through oscillator frequency as before. Increase I-F GAIN until with cavity detuned reading is from one-fifth to one third maximum; as cavity is tuned through mode, current should increase smoothly to nearly normal reading and then decrease smoothly to former value. This indicates cavity is controlling oscillator over the whole mode. A check with METER SW. on PLATE LOCK-IN MIXER VOLTS will show two stable values of voltage, corresponding to high and low detuning. These values will be 10 or 15 volts on either side of the normal mid-mode reflector voltage, and the transition between these should be a smooth function of cavity tuning. (Unstable flicks or jumps may appear, however, if the cavity is detuned by more than 30 Mc; these are due to spurious sidebands.)

If a spectrum analyzer is used, the I-F GAIN setting may be increased nearly to the point of oscillation, which will be evidenced by the appearance of symmetrical audio side frequencies. Such audio oscillation is also easily seen on an oscilloscope connected to 6AS6 PLATE.

C. Oscilloscope-plus-meter Adjustment Sequence.

1. Initial adjustment for oscillation

REFLECTOR SW. — NON-STABILIZED.

I-F GAIN — Minimum (fully counter-clockwise).

METER SW. — MIXER XTAL MA.

FREQUENCY SWEEP — OFF.

Attenuator — Intermediate position.

Other adjustments — Setting immaterial.

Adjust NON-STABILIZED potentiometer for maximum meter reading. (If more than one maximum setting is found, use the more clockwise setting, for greater output.)

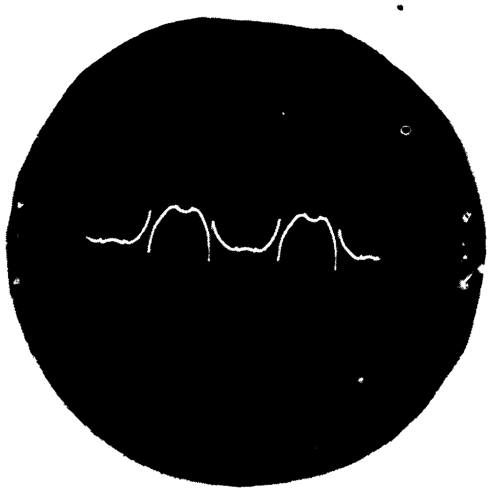


Figure 5. Discriminator pattern at 6AS6 PLATE, with 20-cycle linear horizontal sweep.

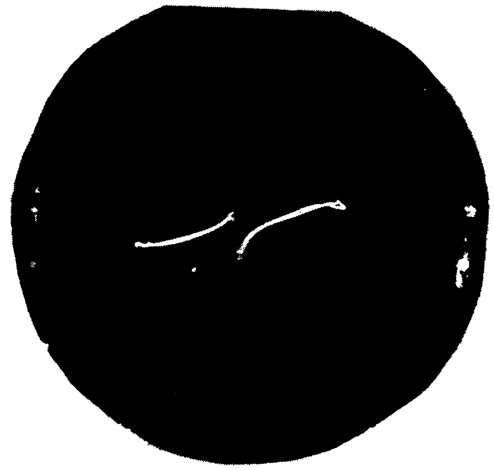


Figure 6. Discriminator pattern at 6AS6 PLATE, with 60-cycle sinusoidal horizontal sweep.

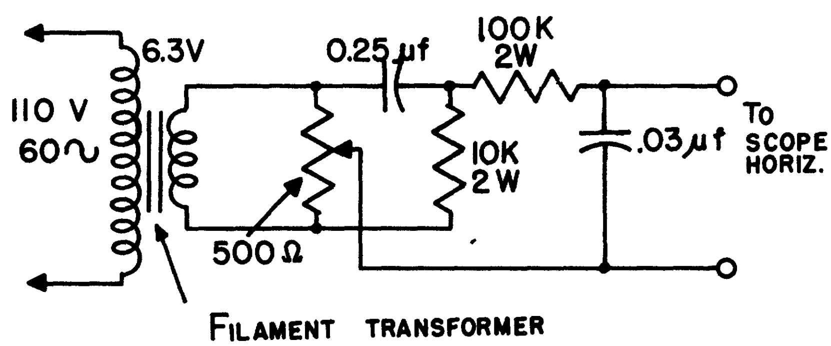


Figure 7. Typical 60-cycle phase shift network.

2. Frequency Check

I-F GAIN — Change to normal setting (approximately 45-55 divisions).

FREQUENCY SWEEP — Change to ON.

6AS6 PLATE — Connected to vertical amplifier of oscilloscope.

CAUTION: Lead carries -150 volts d-c.

Oscilloscope Horizontal Sweep — Synchronize at 20, 30, or 60 cycles.

Wavy oscilloscope trace will appear, probably very distorted. Tune cavity until several identical sharp up-and-down signals appear on trace (number depends on horizontal sweep frequency). Set cavity so that these discriminator curves are evenly spaced across the sweep at which time trace will bear some resemblence to Fig. 5. Read oscillator frequency from cavity calibration. If this is the desired frequency, proceed with Step 4; if not, continue with Step 3.

3. Frequency Shifting

Settings as in Step 2.

Rotate oscillator mechanical tuning adjustment slightly, then find new frequency with cavity as before. Continue adjustment until oscillator is tuned to nearly the desired frequency. (If frequency change is large, NON-STABILIZED reflector voltage may require readjustment to maintain oscillation.) Then repeat Step 1 (adjustment of NON-STABILIZED reflector voltage for maximum reading on MIXER XTAL MA.) and make fine adjustment of mechanical tuning for exact frequency. Adjustment of NON-STABILIZED reflector voltage should now show peak output on MIXER XTAL MA. at desired frequency, within 10 Mc on frequency scale or .003 divisions on wavemeter.

Steps 4, 5, and 6 (setting Attenuator, measuring mid-mode reflector voltage, adjusting STABILIZED reflector voltage) are done exactly as before, with I-F GAIN at minimum and FREQUENCY SWEEP off.

Step 7 (adjusting Phase Shifter) can be done as before or as follows:

FREQUENCY SWEEP — Change to ON.

I-F GAIN — Change to normal.

Adjust Phase Shifter for pattern similar to Fig. 5: a not-too-distorted sine wave with the wavemeter discriminator curves symmetrically located. The general picture may be thought of as a series of crescents, concave alternately up and down. Again, two settings of the Phase Shifter will give similar pictures, one the inverted image of the other, and steps 8 through 11 of the previous schedule must be followed to assure proper pull-in stabilized operation.

Alternatively, a 60-cycle sinusoidal horizontal sweep can be used, giving a picture similar to Fig. 6. In this case the ambiguity of Phase Shifter setting is immediately resolved by noting the general slope of the pattern, which will be inverted for the improper adjustment. An audio phase adjustment to the scope horizontal signal will generally be necessary; a typical network is shown in Fig. 7.

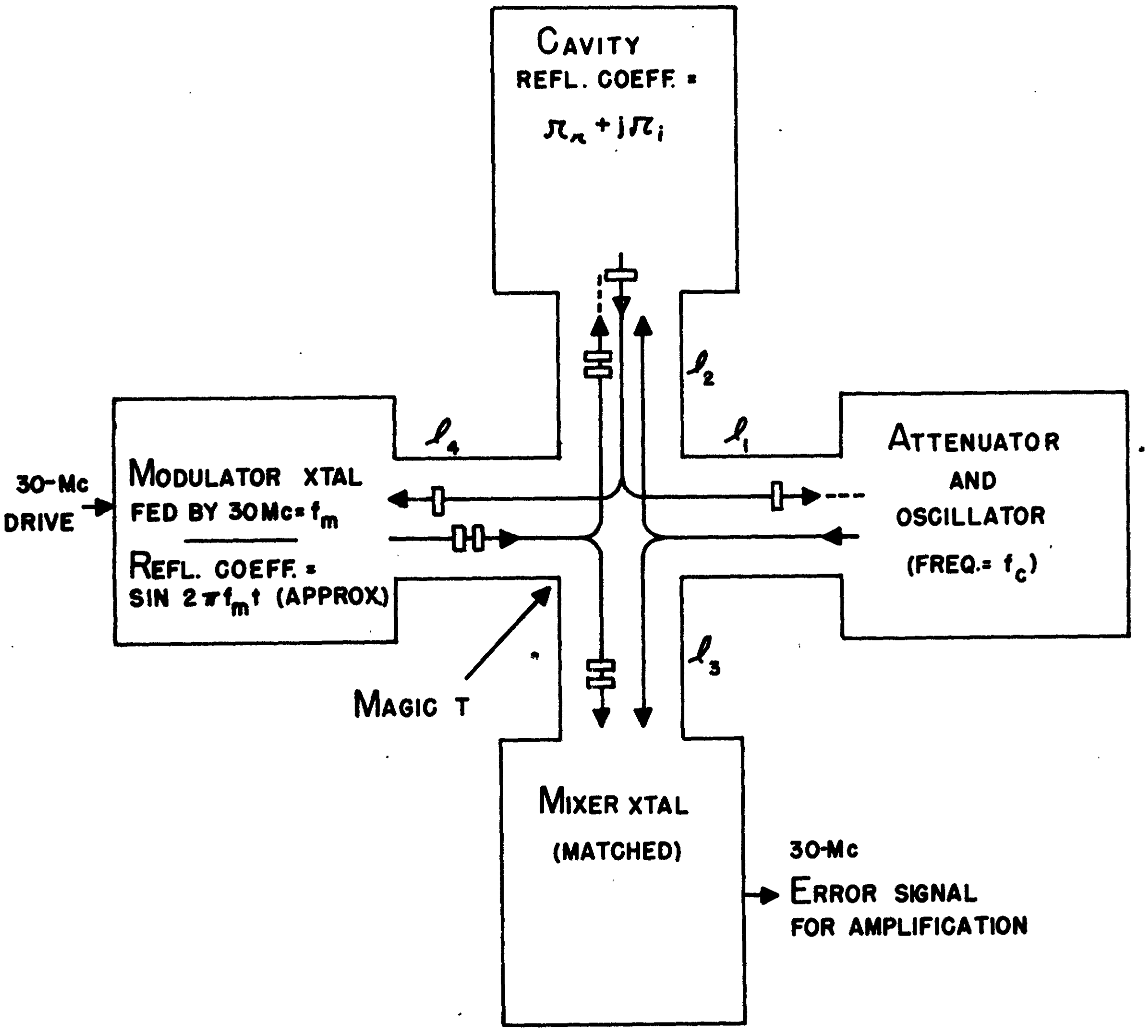
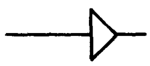
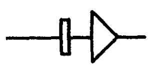
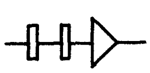
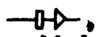


Figure 8. Paths of various signals in Magic T.

Symbol	Nature of Signal	Information	To	and To
	Carrier (unmodulated)	Oscillator frequency, reference phase	Mixer Xtal	Cavity (reflected)
	Carrier, amplitude and phase altered by cavity	Difference between cavity frequency and oscillator frequency	Modulator Xtal (reflected as sidebands)	Attenuator (gets lost)
	Sidebands: oscillator frequency ± 30 mc	Same as , but modulation added	Mixer Xtal combines with  and is rectified to give error signal	Cavity (gets lost)

General Note: When some familiarity with the above adjustment sequences has been acquired, several shortcuts will become evident, considerably decreasing the time required.

IV. DISCUSSION

A. Principle of Operation.

Figure 8 shows schematically the paths of the various signals in the Magic T represented as traveling waves. The output wave of the oscillator is unmodulated, and is referred to as the "carrier wave," or simply "carrier". The 30-Mc error signal is built up from a portion of the carrier by four successive processes: reflection from the cavity, reflection from the modulator, recombination with another portion of the carrier, and rectification of the envelope of the resulting modulated wave.

The carrier initially incident on the Magic T splits into two equal portions (see Sec. VA); one of these waves is sent down one arm to the mixer crystal and the other travels towards the cavity. After traversing a length $2\ell_2 + 2\ell_4$ some of this latter portion is also sent down the mixer arm, where it may be thought of as recombined with the signal originally diverted down that arm. The error signal is derived from the envelope of this resultant modulated signal and hence depends drastically upon the relative phase of the two components, that is, upon the number of guide-wavelengths contained in $2\ell_2 + 2\ell_4$. It turns out that this should be an odd multiple of one-fourth, and the Phase Shifter allows exact adjustment of the effective length to the correct value. Obviously the Phase Shifter can be placed in either the cavity arm or the modulator arm, whichever is convenient.

In the next section it will be shown that when a sine wave is incident on a nearly resonant cavity, both a sine wave and a cosine wave are reflected, the amplitudes of these components being different functions of frequency. Only the cosine-wave portion is used in constructing the error signal, and the 90° phase difference is utilized in preventing the sine-wave portion from having any effect. The cosine-wave component, after reflection from the modulator crystal, is combined with carrier signal in such a way as to produce 30-Mc amplitude modulation, which will be detected by the crystal rectifier and amplified by the i-f amplifier. The sine-wave component, however, produces nearly pure phase modulation, which contributes no 30-Mc signal to the rectified crystal output.

B. Reflections from the Cavity.

The way in which the reflection coefficient of the cavity varies with frequency provides the basis for the stabilization method. As usual, the reflection coefficient is the quantity by which the incident voltage amplitude is multiplied to get the amplitude and phase of the reflected voltage wave; it is a complex number whose magnitude can never exceed unity. Being a complex number, the reflection coefficient can be considered as split up into real and imaginary components; the real component reflects a wave in phase with the incident wave, while the imaginary component reflects a wave shifted 90 degrees. These are, respectively, the sine-wave and cosine-wave reflected components referred to in the preceding section. If the

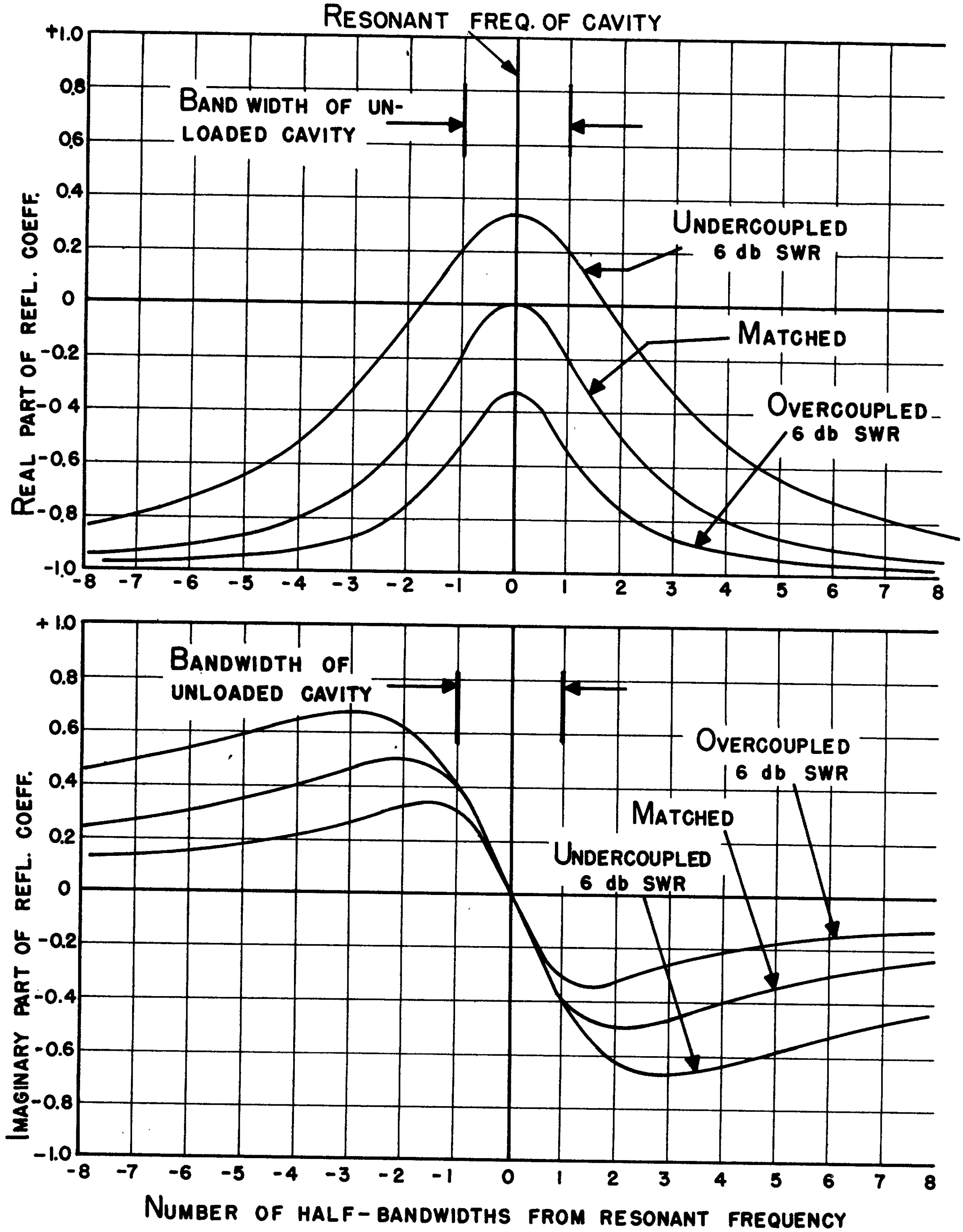


Figure 9. Real and imaginary parts of reflection coefficient of cavity near resonance. Abscissas are essentially frequencies in terms of unloaded Q of cavity.

magnitude of either coefficient goes through zero, it suffers a change in sign, which corresponds to a 180° shift in phase but does not disturb the in-phase and quadrature relationship.

Figure 9 shows curves of the real and imaginary reflection coefficients of a cavity, in the vicinity of resonance. At frequencies far above and far below its resonant frequency the cavity evidently absorbs no power and reflects like a short circuit; the real coefficient approaches -1, and the imaginary coefficient approaches zero. At resonance the cavity appears purely resistive; the imaginary coefficient is zero and the real coefficient may be positive, negative, or zero, depending on the match between cavity and waveguide. For frequencies slightly different from resonant the real component is an even function and the imaginary component a linear odd function of the deviations. The effect of the real reflected wave can be made zero by proper adjustment of the Phase Shifter.

It will be seen from the curves of Fig. 9 that for a matched resonant cavity the imaginary coefficient varies more rapidly with frequency than for any degree of mismatch. A matched cavity is therfore the most desirable, but it is evident that a small mismatch is not fatal. In general it is desirable for the mismatch not to exceed 3 or 4 db and for the cavity to be undercoupled rather than overcoupled. A cavity intended for stabilizer use should first be tested on a standing-wave machine, and if necessary, the coupling should be altered by changing the size of the coupling hole. Evidently tuning screws and similar matching devices would distort the reflection at off-resonance frequencies and are hence useless, although a quarter-wave matching section could be used.

C. Reflections from the Mixer Crystal.

It has been tacitly assumed that the only signal reflected from the modulator crystal (and hence the only signal capable of giving 30-Mc rectified output) is that which has previously been reflected from the cavity. If the mixer crystal is exactly matched, no signal will be reflected from it, and the assumption will be justified. The mixer crystal can, if desired, be matched with great accuracy by the following procedure:

1. Remove the cavity and use a matched termination at the cavity position.
2. REFLECTOR SW. -- NON-STABILIZED.
   FREQUENCY SWEEP -- OFF.
   METER SW. -- I-F XTAL OUTPUT DET. CURRENT.
   I-F GAIN -- Normal.

   Tune mixer crystal mount for minimum meter reading, increasing I-F GAIN after each adjustment. It should be possible to get a nearly perfect null even with full gain.

V. ELEMENTARY BACKGROUND

A. Magic T.

The characteristics of an idealized Magic T may be stated as follows: (1) Power may be fed into it from any one of four arms. (2) When matched loads

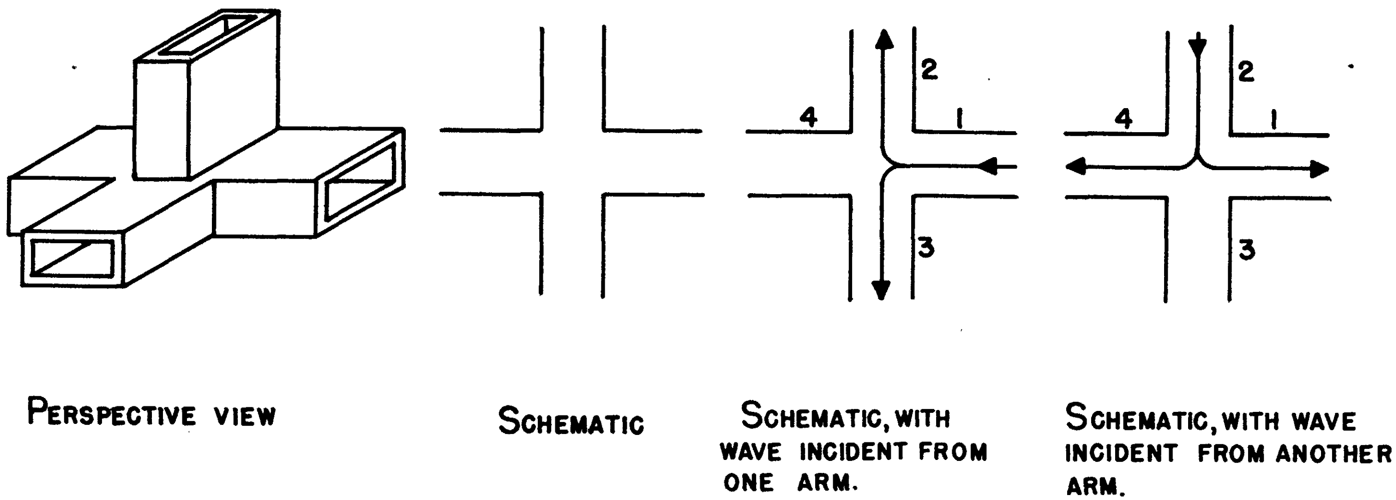


Figure 10. Magic T

are used, power fed into one arm is divided equally between two of the three other arms, the other receiving no power. The power-receiving arms are called "adjacent" to the first arm, while the other arm is called "opposite". The voltage amplitude in each adjacent arm is evidently .707 of the voltage amplitude in the input arm. The schematic diagram of a Magic T is shown in Fig. 10.

From the diagram it is evident that power from arm 1 splits between arms 2 and 3. If reflection takes place in arm 2, this reflected power splits between arms 1 and 4, and similarly for reflection in arm 3. The only way power can get from arm 1 to arm 4 is by reflection either from arm 2 or from arm 3. Power can get from arm 1 to arm 3 directly and also by successive reflections from arms 2 and 4.

B. Crystal Modulator.

A crystal mounted near the end of a waveguide can be matched so that it absorbs all the power incident upon it. If a direct or alternating voltage is applied to the crystal, its effective impedance can be changed and it will reflect. The amplitude of the reflected wave will depend on the percentage change of crystal impedance and the phase will depend on whether this impedance is higher or lower than the guide impedance. The wave reflected by a driven crystal is amplitude modulated, with typical envelopes and power spectra shown in Figs. 11 and 12. If the crystal is matched, the carrier can be made to disappear but the sidebands will remain.

A perfect modulator is one in which the crystal impedance varies symmetrically between zero and infinity. For a perfect modulator of this type half of the incident power is absorbed and half is reflected, one-fourth in each sideband. (Each sideband is thus at a level 6 db below the incident carrier. In practice nearly perfect operation is obtained, with the principal sidebands approximately 8 db below the incident carrier and the distortion sidebands at least 10 db lower.) If the sidebands are re-combined with a sufficiently large carrier either amplitude modulation, phase modulation, or a mixture of both will be produced.

A simple way of representing the modulator action is to write the reflection coefficient as a Fourier series:

$$\text{Driving voltage} = E \sin \omega_m t$$
$$\text{Refl. coeff.} = a_o + a_1 \sin \omega_m t + a_2 \sin 2\omega_m t + \ldots.$$

where a_o corresponds to the carrier reflection coefficient, a_1 corresponds to the first order sideband reflections, a_2 to the second order, etc. In practise a_o may be 0.1 or 0.2 and a_1 may be as much as 0.8; a_2, a_3, etc. are much smaller than a_1 and can be neglected.

C. Lock-in Mixer.

An ordinary heterodyne mixer, as found in most broadcast radios, uses a multi-grid mixer tube with one frequency f_1 fed into one control grid and another frequency f_2 fed into the other control grid (or suppressor grid). The plate current contains components of the sum and difference frequencies $f_1 \pm f_2$. A lock-in mixer is merely a heterodyne mixer with f_1 and f_2 equal, so that the difference frequency component is direct current. (The sum frequency component is filtered

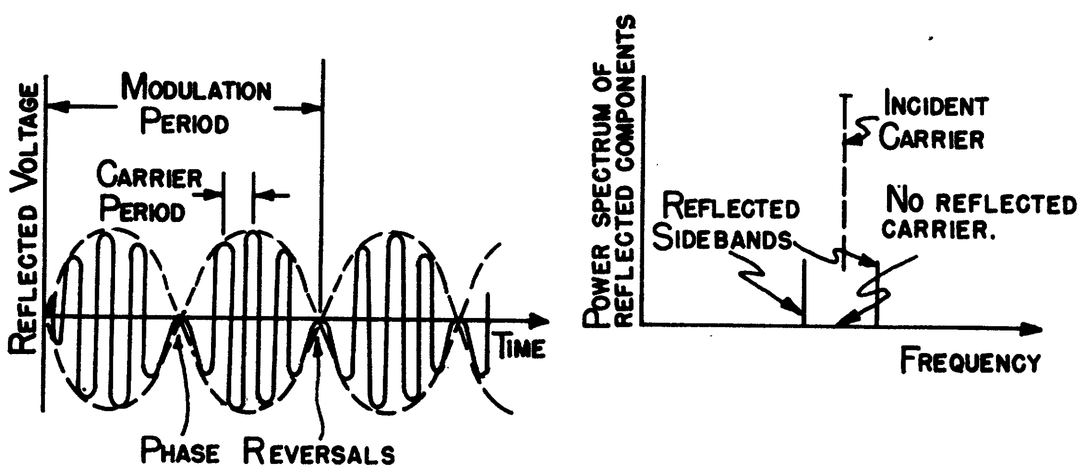


Figure 11. Operation of ideal, perfectly matched, reflection modulator.

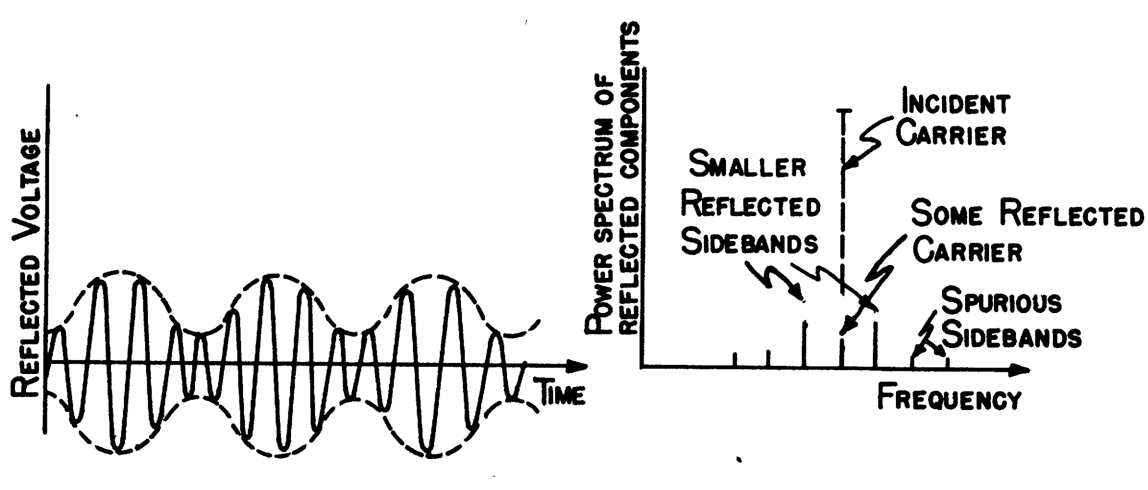


Figure 12. Operation of practical reflection modulator, not perfectly matched.

out with a bypass capacitor.) The direct current "signal component" either adds to, or subtracts from, the normal steady plate current, depending on the relative phase of the two grid-driving voltages. The amplitude of the signal component, and hence the change in plate voltage, depends on the product of the two voltage amplitudes. In the lock-in mixer one driving voltage is a constant-amplitude 30-Mc signal fed to the suppressor grid; the control grid is fed with the 30-Mc error signal. The amplitude of the error signal is proportional to the frequency error and the phase is 0 or 180° depending on the sign, or sense, of the error.

Thus, the lock-in mixer plate voltage changes by an <u>amount</u> which depends on the frequency difference (of the oscillator and the cavity), and in a <u>direction</u> which depends on the sense of the difference. The lock-in mixer plate voltage is coupled to the oscillator reflector electrode, and since the oscillator frequency is sensitive to changes in reflector voltage, this is exactly what is needed for translating the error signal into a frequency correction.

VI. BIBLIOGRAPHY

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