1949

Microwave mixers

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http://hdl.handle.net/10945/31638

MICROWAVE MIXER

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Submitted in partial fulfillment
of the requirements
for the degree of
MASTER OF SCIENCE

United States Naval Postgraduate School
Annapolis, Maryland
1949

PREFACE

Because of the lack of facilities for original design, building and testing of various types of microwave mixers, this paper is a compilation of the various reports in the literature on design considerations of microwave mixers.

Acknowledgement is made to Mr. Oscar Lundstrom of Sperry Gyroscope Company, under whom the author worked for eleven weeks, for his assistance and advice on the design of microwave crystal mixers.

TABLE OF CONTENTS

Chapter I -- TYPES OF MICROWAVE MIXERS ------------ 1

Introduction ------------------------------- 1

Triode Mexer ------------------------------- 3

Diode Mixer -------------------------------- 5

Crystal Mixer ------------------------------ 6

Chapter II -- DESIGN PARAMETERS OF MICROWAVE CRYSTAL MIXERS ---------------------------- 9

Crystal Mounts ----------------------------- 9

Signal Input Circuit ----------------------- 12

Local Oscillator Coupling Circuit ---------- 13

In coaxial line mixers ---------------- 16

In wave guide mixers ------------------ 18

R-F Bypass for Output Circuit -------------- 19

LIST OF ILLUSTRATIONS

Fig. 1 Sketch of Lighthouse tube mixer

Fig. 2 Equivalent circuit of a crystal mixer

CHAPTER I

TYPES OF MICROWAVE MIXERS

1. Introduction.

In the design of receivers for microwave frequencies, experience has proven that the superheterodyne type is superior to any other. The fact that the i-f amplifier is operated at a fixed frequency allows the receiver to be designed with practically any shape of bandpass characteristic desired. The r-f selectivity, except for image frequency effects, is completely determined by the selectivity of the i-f amplifier. Another property of this receiver is that the signal level at the second detector is high enough to make the noise contribution from this part of the system completely negligible. Under this condition, the detector may be chosen on the basis of its fidelity in reproducing modulation, rather than on the basis of its noise figure.

Another important property of the superheterodyne receiver for use at microwave frequencies is the fact that the radio frequency is converted to a relatively low intermediate frequency. Therefore, conventional lumped-constant circuits and ordinary pentode and triode vacuum tubes may be used in the i-f amplifier. In most microwave receivers, the intermediate frequency is less than one per cent of the signal frequency, consequently, the effect of time and temperature drifts in the highly selective circuits upon the receiver frequency setting is smaller by a factor of 100 than it would be if the selectivity were accomplished at the signal frequency.

Because of these advantages, the superheterodyne receiver has been used in practically all microwave receivers. In the design of such a receiver, the first problem is to procure a mixer or converter which will convert the signal frequencies into the intermediate frequency. At the lower conventional frequencies, vacuum tubes were used as mixers or converters. Mixer tubes and the mixer sections of the converter tubes accomplish the mixing in the electron stream flowing to the plate of the tube. All of these electronic mixer tubes require that the drift time of the electrons through their many elements be short, compared with the period of the r-f waves which they mix. Their performance, consequently, falls off at rather low frequencies. At moderately high frequencies, it has been found necessary to return to the older technique of accomplishing the superposition of the waves in circuits external to the tube, and use the tube as a simple detector. At microwave frequencies, there is no other recourse and even then tubes are effective only in the low frequency part of the microwave region. The use of crystals in mixers at the microwave frequencies was found to be the only solution. In circuit use, the crystal is employed as a diode type of converter. The signal and local oscillator powers are fed in on a pair of microwave terminals, the rectifying action in the crystal produces the usual set of sum and difference frequencies and the appropriate difference frequency energy is taken out at a pair of intermediate frequency terminals.

In the design of mixers, the three important factors are coupling of signal power and local oscillator power into the unit and the isolation of the radio frequency power from the intermediate frequency circuit. In this paper is set forth the factors effecting the accomplishment of these three functions and a consideration of the design parameters used to obtain the necessary objectives. In the following discussion, most emphasis will be placed on crystal mixers, as the present trend in microwaves is to higher frequency bands.

2. Triode Mixer.

The effective noise figure of two cascaded networks depends inversely upon the gain of the first network and directly upon the noise power available from it. If a triode tube is used as a mixer, the gain that can be realized falls off with increasing frequency because of the time required for the electrons to cross the interelectrode spaces. One phenomenon caused by the transit time is an apparent grid-to-cathode conductance which increases as the frequency increases. This conductance limits the grid-to-cathode voltage that can be developed from a given signal power, with the result that the gain decreases as frequency increases. The manufacturing tolerances which must be maintained to minimize this effect have prevented the development of conventional tubes for microwave frequencies.

The development of tubes of the lighthouse type has enabled the use of tubes as mixers up to 3000 or 4000 Mc/sec. The noise figure of a mixer using such a tube has never been made so small as the noise figure for crystal mixers. The tube is self-biased near cutoff by a cathode resistor and then driven hard by the L.O. voltage. Consequently, on the negative half-cycle, very little change in plate current occurs, whereas on the positive half-cycle considerable plate current flows. The average plate current, therefore, depends upon the magnitude of the voltage at the grid, and since this voltage is composed of the L.O. voltage, plus a small signal voltage, the beat frequency will exist as a component of the plate current. As long as the signal voltage is small, compared with the L.O. voltage at the grid, the beat frequency current flowing in the plate circuit is directly proportional to the signal amplitude. Because the tuned circuit must be resonant for the signal frequency, the efficiency of transfer of the L.O. signal to the grid is relatively low. Hence, considerable L.O. power must be available. The loss of signal power into the L.O. circuit must be kept small. This latter requirement is one that has an important influence upon the design of all mixers, for it must be met if the minimum noise figure possible with a given type of mixer element is to be achieved.

A sketch of the basic parts of a microwave mixer designed for operation near 3300Mc/sec is shown in Fig. 1. The resonant grid-to-cathode circuit is made up on the radial cavity. The signal voltage is coupled in by means of the coaxial line, the center conductor of which crosses to the opposite wall of the resonator. The signal power may be matched into the cavity by proper choice of the distance from the center of the cavity to the point at which the coaxial line enters the cavity. The greater this distance, the larger the voltage step-up from the coaxial line to the grid. Since the signal line affects the resonant frequency of the cavity, the cavity diameter is dependent upon its position. To achieve the small coupling between the grid-to-cathode region and the L.O. input line, the distance from the outside edge of the resonator to the L.O. input line is made considerably shorter than the distance to the signal line. A matched termination on the L.O. line then contributes only a small admittance at the grid of the tube. Consequently, little signal power is lost in this conductance, compared with that delivered to the grid-to-cathode conductance of the tube. To ensure that the L.O. line is matched, a cable with a distributed loss of several decibels between the L.O. and the mixer is used. In addition, the cable serves to minimize the effects on the L.O. of the large reflections at the mixer of L.O. signals. These reflections exist because the L.O. line is not terminated in the characteristic admittance of the line. In this way, the behavior of the L.O. is less affected by the mixer circuit but the available L.O. power required is increased. This typical circuit had a noise figure of about 20 db.

3. Diode Mixer.

A plane-parallel electrode diode, similar in construction to the lighthouse type triode, has been developed for use in mixers. The diode plate current contains the beat frequency component, in addition to a d-c component, because the diode passes a current only during the positive half-cycles of the input voltage, which consists of the superposition of the small signal on a relatively large L.O. voltage. As is true for the triode, the magnitude of this voltage is proportional to the amplitude of the signal voltage, if the signal voltage is very small compared with the L.O. voltage.

With diodes of this type used as mixers, the minimum noise figure is about 18 db at 3000 Mc/sec. At higher frequencies, poorer noise figures are found. As a consequence ot its relatively poor noise figure, the diode mixer is not widely used.

4. Crystal Mixer.

The crystal rectifier has been developed to the extent that it is the most effective mixer element for the superheterodyne receiver at microwave frequencies. The qualitative description of the operation of a crystal as a mixer is similar to that of the diode and, as in the case of the diode, the i-f voltage is linearly dependent upon the signal amplitude for signals small compared with the L.O. power. Because the part of the crystal in which rectification takes place is physically very small, transit time effects are minimized and may be neglected even in the microwave region. The improvement in crystals during the war has been so great that rugged receivers using crystal units as mixers have been made with noise figures as low as 7 db at frequencies up to about 25,000 Mc/sec.

One of the simplest possible circuits that a mixer can have is shown in Fig. 2. The signal generator (antenna) and

L.O. are connected in parallel through the crystal unit to the i-f output terminals. The functions of the various parts of the circuit are the following. The magnitude of the L.O. current, in conjunction with the i-f load admittance, establishes the input admittances of the mixer to the small signal. The r-f choke on one side of the crystal unit and the i-f choke on the other provide a low resistance path to the rectified current. Therefore, the crystal does not become appreciably biased by the rectification of the L.O. signal. In order that the r-f voltages of both the signal and the local oscillator may be impressed primarily across the crystal unit, an r-f bypass condenser is provided across the i-f output terminals.

The i-f load circuit influences the r-f conditions only insofar as, in combination with the r-f bypass circuit, it develops an r-f drop. Similarly, the r-f circuit influences the i-f admittance only insofar as, in combination with the i-f bypass circuit, it produces an i-f voltage drop. The best performance of a mixer of this kind as a frequency converter is obtained when the signal power is caused to develop the maximum possible voltage across the crystal unit. This condition is satisfied if the signal generator admittance is made equal to the complex conjugate of the input admittance of the mixer, and if no r-f signal power is dissapated in the admittance of the L.O. on the i-f load. This requires only that the L.O. admittance is so small and the admittance of the r-f bypass circuit is so large, compared with the signal admittance of the crystal, that the amount of signal power dissapated in them is a negligible fraction of the available signal power.

CHAPTER II

DESIGN PARAMETERS OF MICROWAVE CRYSTAL MIXERS

The design of the r-f portion of a mixer reduces to these three parts:

a. Design of a signal coupling mechanism to match all available signal power into the crystal units.

b. Design of a L.O. coupling mechanism that has negligible effect on the signal admittance.

c. Design of an r-f bypass circuit for the i-f output terminals that will not allow the r-f power to couple to the i-f load circuit.

1. Crystal Mounts

Crystals for use in mixers have been manufactured in the form of a cartridge. It is possible, therefore, to design the crystal mount to fit into either coaxial cable or waveguide. If the mismatch is not large, tuning elements such as sliding screw tuners, stub tuners, plungers and sliding quarter-wave-length transformers may be added to cause the crystal to match the line.

In the coaxial line mount, it is necessary to have a path of low d-c resistance to and of low i-f impedance between the center and o ter conductors of the coaxial line. In some mixers, the return path is provided by a loop that excites the coaxial line. If there is no such loop, a quarter-wave length side stub, which is also useful for supporting the center conductor can provide this d-c return. In the 10 cm band, the coaxial line fits over the crystal mount and the crystal admittance is not greatly different from the line admittance.

In a waveguide mount, there are several parameters which can be chosen to make the average representative crystal unit terminate the line in its characteristic admittance. The position of the crystal unit, both relative to the center of the broad dimension of the waveguide, and axially along the narrow dimension, may be adjusted to control the resultant admittance. The distance along the waveguide from the axis of the crystal cartridge to the short circuit at the back end of the unit is also such a parameter. None of these parameters are strictly independent. It is found, however, that if the admittance determined from the measurement of the V.S.W.R. in the waveguide, leading to the crystal is referred to the plane of the axis of the crystal cartridge, the adjustment of the length of waveguide beyond the crystal unit results essentially in variation of the susceptance component of the crystal admittance. At a length about equal to one-half of the wavelength in the waveguide, the crystal unit is completely short circuited by the reflected short circuit at the end of the waveguide, and the reflection co-efficient of the mount is unity.

It is not advisable to achieve a match with the waveguide crystal mount by using a length, between the short circuit and the crystal, near to a half-wavelength since the susceptance introduced by the waveguide is then large. The susceptance varies very rapidly with frequency and, hence, the mount is sensitive to frequency. The adjustment of the length of the waveguide beyond the crystal is the design parameter most easily determined because a sliding short-circuiting plunger in the waveguide can be used. If the susceptance component of the crystal admittance can be tuned out only with a length nearly equal to the length for which the crystal is short circuited, it is preferable to change the mount in some way to allow the use of a length more nearly equal to one-quarter wavelength in the guide. It has been found that a change of the position of the crystal along the line through its axis also causes a change primarily in the susceptance component of the crystal admittance. The position may be so chosen that the crystal mount has only a small susceptance with a short circuit a quarter-wavelength beyond the crystal. The effect of moving the crystal cartridge across the waveguide in the plane perpendicular to the waveguide axis is primarily to vary the conductance component of the admittance. This variation occurs because the voltage (integrated field intensity) between the top and bottom of the waveguide is a sinusoidal function of the crosswise position, with a maximum at the center and zeros at each side. The presence of the crystal unit has the greatest effect on the electric field when the crystal is at the center, and has less influence when the crystal is moved toward the side of the waveguide. The conductance of the crystal mount thus falls from a maximum value with the crystal at the center to a minimum with the crystal at either side. In this way, it has been found possible to make a crystal mount for the 9000 Mc/sec frequency region which has an admittance, with a crystal representing an average with respect to admittance scatter of all units, equal to the characteristic admittance of the waveguide at the level of signal equal to the optimum L.O. drive.

It is more difficult to make the desired adjustments of admittance in the coaxial line mount than in the waveguide mount. Although the wavelengths for which the coaxial line mount is used are longer compared with the dimensions of the crystal, the crystal cannot be treated as a lumped-circuit element because it appears as part of the center conductor of the coaxial line.

The method used by Sperry Gyroscope Company for the design of a coaxial line crystal mount in the 2600-4000 Mc/sec band follows. A crystal holder was made to fit on a standard 5/8" coaxial line fitting and the crystal inserted. Measurements at the crystal input admittance referred to the forward face of the crystal were then made on about forty crystals at frequencies of 2500, 2700,3000, 3500, 4000, 4500, and 5000 Mc/sec. The mean value at each of these frequencies was then plotted. The V.S.W.R. at 2 to 1 was set as a limiting parameter. To meet this requirement, the V.S.W.R. was referred to a point toward the generator which would rotate the plotted curve clockwise. A fixed shorted stub was then added at this point to bring the V.S.W.R. at 2700 Mc/sec closer to unity. The resultant had a V.S.W.R. below 1.6 over the desired range.

2. Signal Input Circuit.

The signal input design problem is that of transferring the incoming signal power from the circuit connected to the antenna into the crystal mount. If the line to the antenna is similar to the line in which the mixer is built, the mixer may simply be connected to the antenna line. The mixer tuning should be such that, with the L.O. operating at the proper level and frequency and with a matched i-f load in place, the admittance of the mixer for small signals with all crystals is as near the characteristic admittance of the line to the antenna as possible. Measurements may show a small correction from the tuning arrived at with signals at the L.O. level to be desirable. For most mixers, it has been found that the small signal admittances do not differ sufficiently from those measured at L.O. level to warrant changing the mount.

When the mixer signal comes from a TR cavity, the mixer circuit must be made to load the TR cavity properly. With TR tubes having integral cavities designed to operate between matched waveguides, the design procedure is not greatly influenced by the cavity, but with loop-coupled cavities or those designed to operate between coaxial lines, a coupling circuit must be a part of the mixer. Coaxial line mixers are designed for operation with definite TR cavities, and the measurement of the matching conditions is carried out on the input side of the TR cavity. If the effects on the conversion loss and i-f admittance of the crystal, of the line length between the crystal and the TR cavity are neglected, the matching conditions can be completely determined by measurements at the input admittance to the TR cavity.

3. Local Oscillator Coupling Circuit.

The prime requirement of the method of coupling the L.O. power to the crystal is that it does not cause a significant loss of received signal power. This requires that the shunt admittance of the L.O. circuit measured in the mixer be small compared with the signal-generator and crystal admittances. For this to be possible, the power available from the local oscillator must be much larger than that which is actually transmitted to the crystal, because a large mismatch exists between the local oscillator and the mixer circuit.

An additional complication to the problem of the design of an L.O. coupling circuit is that the power output available from different oscillator tubes of the same type can differ by large factors. When this variation is added to the variation encountered as the tube is tuned through a wide band and to the variation in the amount of coupling with crystal admittance, the total variation of L.O. power delivered to the crystal under all conditions of operation is more than can be tolerated if the mixer is to operate within a few tenths of a decibel of optimum noise figure. It has, therefore, been considered necessary to have an adjustable L.O. coupling in order that the optimum L.O. power at the mixer crystal may always be obtained. In so-called fixed-tuned mixers, this adjustment is retained and is the only adjustment required for operation with any crystal of the proper type and with any L .O. tube in the specified band of frequencies. A practical L.O. coupling circuit must be adjustable, and the connection in the tubing of the crystal mount cannot be made. The signal loss, therefore, is increased because of reflection.

Most of the mixer circuits that have been designed for radar service have been operated with a TR cavity preceding the mixer in the signal line. The most commonly used TR cavities are highly resonant, and the circuit representing the L.O. coupling is not the same as that for the signal. Most TR cavities have sufficiently high Q's to be treated as completely reflecting circuits at the L.O. frequency, when resonant at the signal frequency. If such a TR cavity is used, the L.O . injection can be made at a point in the mixer line, between the cavity and the mixer, where the admittance of the line terminated by the cavity is almost zero. In a waveguide, for instance, the TR cavity appears as though it were a short circuit at frequencies sufficiently removed from resonance and, therefore, the admittance of the line terminated by the cavity is very small at a point a quarter of a waveguide wavelength toward the crystal.

If the L.O. signal is injected at such a point, as a signal from a generator having a small admittance, the effective coupling is greater by a factor of about four than the coupling obtained without the cavity. This can be explained qualitatively by supposing the L.O. to excite a wave that travels in both directions from the injection point in the mixer line. Without the TR cavity, the wave that travels toward the signal input end of the line is lost, but with the TR cavity present, it is reflected. The choice of the injection point at a quarter of a wavelength from the position of the short circuit that is equivalent to the TR cavity at the L.O. frequency corresponds to a position such that the reflected wave has the same phase as that traveling toward the crystal. Hence, the total amplitude of the wave traveling toward the crystal is twice as great as it would be without the cavity. Therefore, four times as much L.O. power arrives at the crystal.

3a. L.O. Coupling in Coaxial-line Mixers.

In the frequency band where a small coaxial-line crystal mount is used, the most common L.O. coupling circuit is a small capacitive probe, terminating a coaxial line that is coupled to the L.O. and projecting into the main coaxial line of the crystal mount. In such a circuit, the center conductor of the side arm, ending in the probe, makes a sliding contact with the center conductor of the L.O. input line. This device allows adjustment of the probe insertion without movement of the L.O. line. The length of the sub line supporting the center conductor changes with adjustment of the probe insertion, but since the probe represents a severe mismatch at the end of the line, the small reflection due to this stub is not serious.

In order that the L.O. tube will, oscillate with this probe as its load, it is necessary to arrange that the actual load admittance presented to the oscillator is compatible with the characteristics at the oscillator. One way in which this can be assured is to use such a length of line, between the oscillator and the probe, that the admittance presented to the oscillator at the other end of the line, lightly loads the oscillator. If this is done, and if the system is to be continuously tuneable, the line must be so short that the phase length of the line does not change appreciably in the required tuning range. Another way of avoiding load admittances, which upset the operation of the oscillator tube, is to use lossy cable to couple the oscillator to the mixer circuit, to attenuate the wave reflected from the probe. In view of the difficulty in getting sufficient L.O. drive without suffering from signal loss, however, this can be done only if a large excess of power is available from the tube.

A third way in which the load admittance of the L.O. can be maintained at a reasonable value over a wide frequency range is by use of a "resistor disk" in the coupling line. The "resistor disk" is a disk of Bakelite, coated with a carbon resistance material, and having silvered inside and outside rings for contacts. The resistance between the contact rings of the disk is made equal to the characteristic impedance of the coaxial line. The disk would be a reflectionless termination for the line if its r-f characteristics were such that it loaded the line with a resistance alone, and if the admittance of the remainder of the line beyond the disk were zero. In practice, there is a capacitive susceptance due to the large dielectric constant of the Bakelite base. The line may still be terminated by the disk, however, it is placed in a position where the admittance of the line beyond it contains an inductive susceptance of the same magnitude as the capacitive susceptance of the disk. Thus, the susceptance is resonated out and the load terminating the L.O. line has the conductance of the disk plus a small conductance caused by the small power transfer from the probe to the crystal mixer line. This circuit is less wasteful of L.O. power than that using attenuating cable.

3b. L.O. Coupling in Waveguide Mixers.

A simple mixer for use in the frequency band where waveguides are used can be coupled to the L.O. in a variety of ways. Since it is best that the L.O. operate into a special load circuit, it is advisable that two separate waveguides be used, one for the mixer proper and one for the L.O. and load circuit. Hence, a directional coupler would be an ideal arrangement to use. The big disadvantage of the directional coupler in this application is that it is very difficult to provide an adjustable coupling. Directional couplers have not been used extensively in microwave mixer circuits, chiefly because it is difficult to make them adjustable and because they have not been mechanically convenient for most applications.

A simple non-directional circuit for coupling the L.O. to a waveguide mixer, which is similar to the directional coupler, but contains only one coupling channel, can be used. The amount of coupling for the single channel can be made variable by the addition of an adjustable susceptance element in the channel.

For operation with a resonant TR cavity, because of the more efficient coupling resulting, a simpler type of circuit can be used. This coupling device consists of a simple inductive window between two adjacent parallel waveguides with a common wall on their narrow side. The aperture in the wall may be either circular or rectangular, although rectangular apertures running the full height of the common wall have usually been used. These apertures are made less than a half-wavelength in width and to a fair approximation, the circuit may be considered as a lumped inductive susceptance in the plane of the window. The simple aperture coupling is less efficient than the channel coupling in the sense that the reflection due to the aperture is larger than that due to the channel for a given coupling factor. Because the space available for a radar mixer is usally limited, the applications of this L.O. coupling circuit have mostly been a variation of this scheme.

4. R-f Bypass Circuit for i-f Output Lead.

The r-f bypass of the i-f output terminals cannot be com pletely accomplished through the use of a simple lumped capacitance. The function of this circuit may be consid ered as two fold: (1) It provides a path of high r-f admittance, compared with that of the crystal, with the result that the loading of the transmission line is the same as if the crystal were short circuited to the line at this point; (2) It prevents leakage of any appreciable amount of r-f power, primarily L.O. power since its level is so much higher than that of the signal, into the input circuit of the i-f amplifier. Since the r-f admittance of the input circuit of the i-f amplifier to which the mixer is connected is arbitrary, the effectiveness of the filter circuit could be reduced considerable if a resonance were to occur when the two were connected together.

Consuquently, to avoid such effects, a large capacitance or a more complex filter is required. It is felt that the circuit of the filter type is more effective than the lumped capacitance in a restricted band of radio frequencies. Since most applications of microwave mixers have been in receivers having wide i-f pass bands, the i-f capacitance of the mixer is important in determining the maximum pass band of the input circuit of the amplifier. The lower this capacitance, the wider the input circuit can be made.

The operation of the filter is similar to that of many filters used as joints for r-f lines. In the filter used in the 10 cm mount, a spring metal contact is used to make connection to the large end of the crystal cartridge. The spring contact is mounted by a rivet on the base of a cylindrical metal cup that has an open end toward the i-f outlet. The center conductor of the i-f line extends into this cup and terminates at the solid end of it. The inside of the cup, which is filled with a polystyrene dielectric, is thus a concentric line short-circuited at one end and a quarter wavelength long in the dielectric. The open end, therefore, has a vanishingly small admittance. A wave progressing along the coaxial line formed by the outside conductor, and the outer part of this cup induces currents in the outer wall of the cup, and, in order for the wave to travel out the i-f line beyond the open end of the cup, the current of the inner conductor must pass through the small admittance of the cup. Thus, unless the r-f admittance of the i-f output line seen at the open end of the cup is also very small, the major part of the voltage drop at this point appears across the end of the cup or choke. The r-f current in the i-f output line is kept small because of the small admittance of the choke and, therefore, the r-f power getting into the i-f circuit is kept small. In order that the choke system be equivalent to an r-f bypass at the base of the crystal, the length of the coaxial line formed by the outer conductor, and the outside surface of the cup or choke is made equivalent to a quarter wavelength. Because this line is terminated in an admittance at least as small as the admittance of the choke, a large r-f admittance results between the base of the crystal and the outer conductor of the crystal mount.

In the waveguide crystal mount used in the 3 cm band, the r-f filter on the i-f output lead operates in much the same way, except that the addition of a small lumped capacitance just beyond the quarter wavelength choke gives further assurance that the r-f admittance of the i-f output line is large at this point. The choke occurs, for mechanical reasons, in the outer conductor of the coaxial i-f output line. The point at which the choke appears in series with the output line, however, is a quarter wavelength along the line from the point at which the large bypass admittance is desired, in this case between the pin end of the crystal cartridge and the bottom wall of the waveguide. The reasons governing the choice of a circuit containing both a distributed parameter filter and a lumped capacitance are largely mechanical since the center conductor of the output line must be supported. The capacitance of the lumped capacitor is not large compared with the distributed capacitance of the output lead. The total i-f capacitance and its inclusion makes the tolerances on the dimensions of the choke filter less rigid. The filter action is also less frequency sensitive than it would be without the capacitor.

A choke joint or a filter of this kind is most effective over a wade frequency range, if the characteristic impedance of the coaxial line forming the choke is as high as possible, and if that at the line forming the quarter wave transformer is as low as possible. At the frequency for which the effective lengths of the choke and of the transformer are exactly one quarter wavelength, the filter is perfect, since the impedance at the open end of the choke is infinite. The impedance between the crystal and outer conductor of the mount is, therefore, zero if dissipation in the filter itself is neglected. At a frequency differing from this by a small amount, however, the impedance at the open end of the choke is a large reactance. The larger this reactance is, compared with the characteristic impedance of the transformer section, and compared with the r-f impedance of the i-f line, the smaller are the leakage of r-f power into the i-f circuit and the impedance between the end of the crystal and the outer conductor of the mount. The reactance of the choke is proportional to the characteristic impedance of the line forming the choke.

In the coaxial line mount, therefore, the ratio of the diameters of the outer and inner conductors of the line forming the choke is made relatively large and the ratio of the diameters of the outer and inner conductors of the line forming the quarter wavelength transformer is made small. The maximum usable line size in the 3 cm band mount is one in which the mean circumference of the outer and inner conductors is nearly 3 cm, for modes other than the principal mode may be propagated in a larger line. The characteristic impedance of the choke, therefore, cannot be made very high and, consequently, the addition of the capacitor across the i-f line helps to reduce the leakage of r-f power in a wide band of frequencies.

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