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LOW NOISE TUNABLE VHF FREQUENCY CONVERTER DESIGN

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1. PURPOSE

A study is to be conducted, consisting of the following:

1. An analysis of independently-loaded parametric up-converters with the output taken from one sideband, will be undertaken to determine optimum design with regard to: gain-bandwidth product, noise figure, gain sensitivity, and dynamic range. This analysis will be corroborated experimentally and will result in "breadboard" amplifiers in 30-300 Mc, 300-1000 Mc, and the 3 Kc-30 Mc ranges. (The frequency ranges listed here are in order of importance.)

2. At least one "breadboard" amplifier (highest range) with a suitable IF output reflective of the results obtained in the research investigation will be supplied upon completion of the contract.

3. A study will be made of the design and realization of wideband tuning circuits for varactor diodes for application to up-converter design.

4. The relative merits of various down-converters, including tunnel diode mixers, will be considered. However, no development work will be done on down-converters.

5. The effect of tunable electron beam oscillator pump sources on converter noise figure, and methods of reducing this contribution will be studied. The application of available solid state tunable harmonic multipliers will also be considered. Such sources will not be further developed.

6. Methods of achieving pump frequency stability will be studied since the application of tunable up-converters strongly depends upon this stability.

2. ABSTRACT

Studies have been carried out on the design of parametric up-converters tunable over a signal frequency exceeding one octave. Equivalent circuits have been derived for the parametric networks, taking account of simultaneous propagation at the upper and lower sidebands. Circuit designs giving constant transducer gain over the frequency range have been investigated, and wideband pump and signal-frequency coupling networks have been studied.

Experimental studies have been initiated on both lower and upper sideband up-converters tunable over the 30-300 Mc and 300-1000 Mc ranges, having an output frequency approximately ten times the highest signal frequency.

3. PUBLICATIONS, LECTURES, CONFERENCES AND TRAVEL

Publications and Lectures:

None.

Conferences and Travel:

Dr. P. J. Khan conferred with Mr. J. Walsh of USAEL at Fort Monmouth, New Jersey, on July 14, 1965, regarding this contract. Conferences were held at Cooley Electronics Laboratory with Mr. J. Walsh of USAEL on August 26, 1965, and with Mr. S. Stiber of USAEL on August 27, 1965.

4. FACTUAL INFORMATION

4.1 Introduction

Research studies on this contract were initiated during the past quarter. It was decided that these studies should consist of parallel theoretical and experimental investigations. The theoretical studies are directed toward the goal of determining performance limits and design procedures for up-converters tunable over a wide range. Consideration of sideband frequency generation indicates that the design becomes appreciably more difficult when the tuning range exceeds one octave.

The theoretical studies carried out during the past quarter are reported in Section 4.2. The equivalent circuit approach to parametrically-coupled networks has been developed to gain further insight into the operation of a tunable up-converter. These circuits are discussed in Section 4.2.1 and are shown in Figs. 1 and 2. The factors which influence the design of pump and signal coupling networks are examined in Section 4.2.2. The equivalent circuits are modified in Section 4.2.3, to take into account the propagation at the unwanted sideband frequency. The effect of this propagation is assessed.

Experimental studies on both the VHF and the UHF up-converters are reported in Sections 4.3.1 and 4.3.2, respectively. These studies have provided experience in circuit techniques for parametric up-converter operation and have indicated the areas where future research should be directed.

4.2 Theoretical Studies

The theoretical analysis of parametric up-converter circuits has been initiated to derive limits on up-converter performance in regard to gain, tuning range, and noise figure. This analysis also provides design principles for use in the experimental studies.

The analysis is not yet complete, but it does show promise of providing much useful information about this largely unexplored subject. General equations for input and output impedances and transducer gain, when frequency conversion occurs to both the output sideband and the unwanted sideband, have been derived. Study of these equations has indicated the need for further investigation of coupling networks, with unusual impedance characteristics, to obtain constant gain over the tuning range. The effect of unwanted harmonic sideband components also requires further study. The analysis has thus far neglected harmonic elastance coefficients. However, it will be necessary to study the second harmonic pump conponent to obtain an accurate theoretical model of a strongly-pumped up-converter.

4.2.1 Tunable Up-Converter Design Theory. The design of parametric up-converters tunable through variation of the pump frequency has received little attention in the literature. Emphasis has principally been placed on the design of wideband converters through the application of broadband matching theory to the design of coupling networks at signal and sideband frequencies.

Some tunable up-converter studies have been reported by Matthaei (Refs. 1, 2), who developed a unit convering the 760 Mc-1140 Mc band with a pump source mechanically tuned to maintain a constant lower-sideband output frequency of 4037 Mc. However, no limit has been found for the product of gain and tuning range, now has an optimum design theory been developed for the parametric converter.

Consequently, theoretical study of the tunable parametric up-converter circuit has been initiated to investigate the possible performance through optimum circuit design. The analysis of a lower-sideband parametric converter circuit, under the assumptions of fundamental-frequency current pumping and open-circuit terminations at the unwanted side-band frequencies, yields the equivalent circuit shown in Fig. 1. The tuned circuits are assumed to be sufficiently selective to avoid power dissipation at unwanted sideband frequencies. The higher pumped elastance coefficients, S_2, S_3..., are assumed to be zero. A similar analysis for the upper-sideband up-converter results in the equivalent circuit shown in Fig. 2.

In general, a practical parametric up-converter circuit will have significantly greater complexity than the circuits shown in Figs. 1(a) and 2(a). The diode mean elastance, S_0, varies with the pump level and, under large signal conditions, with the signal level. Unwanted sideband components are not completely suppressed by the microwave structure. Because of the parametric mixing process their propagation affects the output

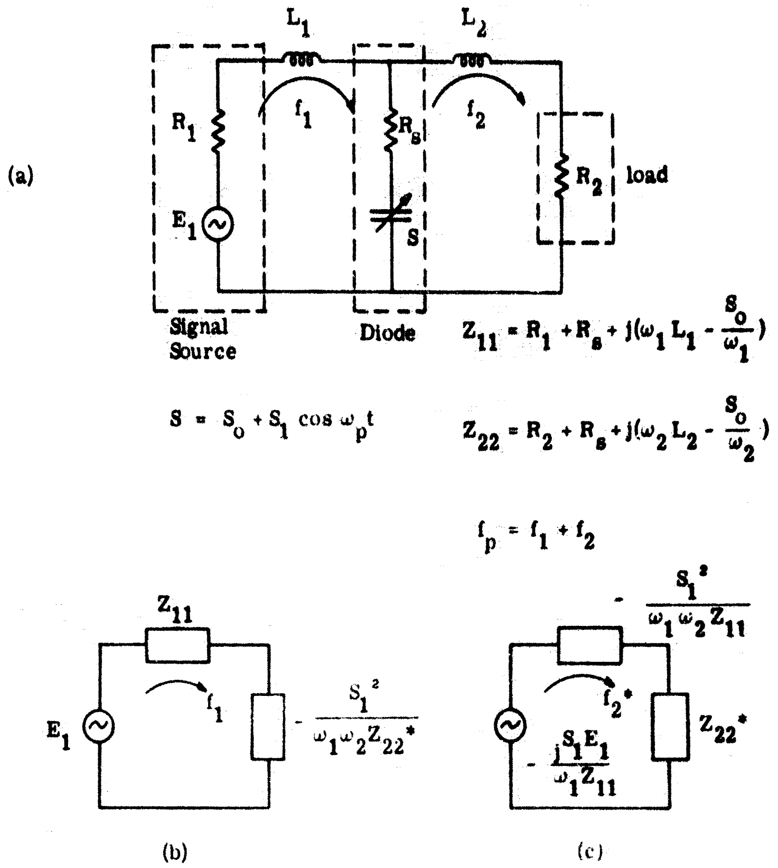


Fig. 1. Equivalent circuit of a lower sideband up-converter: (a) circuit diagram; (b) the signal frequency equivalent circuit; (c) the output frequency equivalent circuit.

at the desired sideband. Because of the parasitic elements associated with the varactor diode mounting and also because the need for broadband matching and impedance transformation in these circuits, the tuning networks at signal and output frequencies are generally more complex than the simple series-tuned circuits shown here. Nevertheless, these circuits provide a useful starting point for the analysis of parametric up-converter circuits.

The general gain expressions and network properties, such as input impedance and output impedance, are readily derived from these equivalent circuits. For the lower-sideband up-converter, the transducer power gain G_{12} is given by:

$$G_{12} = \frac{4\,Q_{11}^{2}\,R_1 R_2 R_s^{2}}{\left| Z_{11}\,Z_{22}^{*} - Q_{11}\,Q_{21}\,R_s^{2} \right|^{2}} \tag{1}$$

where $Q_{ij} = \dfrac{S_j}{\omega_i R_s}$

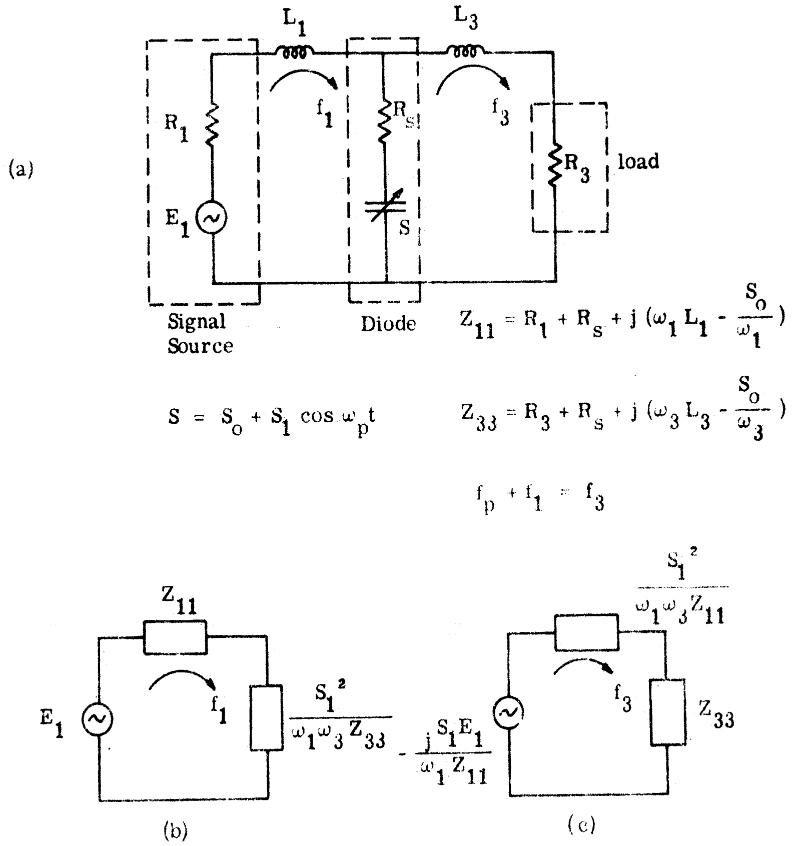


Fig. 2. Equivalent circuit of an upper sideband up-converter: (a) circuit diagram; (b) the signal frequency equivalent circuit; (c) the output frequency equivalent circuit.

The corresponding expression for the upper-sideband up-converter is:

$$G_{13} = \frac{4\,Q_{11}^{2}\,R_1 R_3 R_s^{2}}{\left| Z_{11}\,Z_{33}^{*} + Q_{11}\,Q_{31}\,R_s^{2} \right|^{2}} \tag{2}$$

The input impedance expressions come directly from the equivalent circuits of Figs. 1(b) and 2(b), and are:

$$Z_{in} = Z_{11} - \frac{Q_{11} Q_{21} R_s^2}{Z_{22}^*} \quad \text{for the lower-sideband up-converter} \tag{3a}$$

$$Z_{in} = Z_{11} + \frac{Q_{11} Q_{31} R_s^2}{Z_{33}^*} \quad \text{for the upper-sideband up-converter} \tag{3b}$$

Examination of these expressions immediately indicates some of the problems associated with the design of a tunable up-converter covering a wide tuning range. The output circuit parameters, determined by Z_{22} and Z_{33}, remain constant, since the pump frequency is adjusted to provide constancy of output frequency. However, the parameters Z_{11} and Q_{11} are dependent on the signal frequency. Their variation with frequency introduces a corresponding variation in the gain characteristic. The situation here, where the signal frequency varies in one instance from 30 Mc to 300 Mc, is markedly different from that of the simple up-converter where the bandwidth is typically around 10 percent.

Calculations carried out for the 30 Mc to 300 Mc converter with an output frequency of 3000 Mc show that a typical lower-sideband up-converter adjusted for 15 db gain at 30 Mc, will have a gain of -9 db at 300 Mc, assuming that Z_{11} remains constant as the signal frequency is changed. Likewise, an upper-sideband up-converter adjusted for 15 db at 30 Mc will have a gain of -0.2 db at 300 Mc. These figures indicate the magnitude of the gain variation problem, and also show the comparative sensitivity of the lower-sideband circuit to parameter variations.

It is apparent that wide-range tunable up-converter design requires some form of compensation for the reduction in gain caused by increasing signal frequency. Ideally, this adjustment should also maintain the low noise figure of the up-converter stage as the signal frequency is changed. The solution to this problem is not usually found by the appropriate choice of the impedance levels at signal and output frequencies. Adjustment of the lower-sideband up-converter for about 10 db gain at 300 Mc would result in oscillation as the signal frequency is reduced. When a similar adjustment is made for the upper-sideband up-converter at 300 Mc, the gain rises with decreasing frequency but the up-converter stage noise figure also rises.

Several ways to achieve gain constancy with variation in the signal frequency include: the design of a suitable signal circuit so that Z_{11} decreases with increasing signal frequency; pump circuit design so that the amount of pump voltage applied to the varactor junction and, consequently, S_1, is increased as the pump frequency is varied to accommodate an increasing signal frequency; and, appropriate loading of the unwanted sideband, which varies over a frequency range twice that of the signal frequency. Each of these methods is discussed in some detail in the succeeding sections.

4.2.2 Coupling Network Design for Pump and Signal Circuits. The design of coupling networks for pump and signal circuits requires the application of broadband tuning methods, because of the wide tuning ranges being considered. The design is complicated by the parasitic elements associated with the diode package and mounting, and also by non-linear effects occurring in low-loss networks.

Pump circuit network design may be carried out using broadband impedance-matching network theory to derive a network matching the source resistance to the diode series resistance. This design neglects the effect of the power-conversion resistance introduced into the pump circuit by the frequency conversion process, since this resistance is usually small compared to the equivalent series resistance. Assuming that the diode may be represented by a series RC network, it is possible to apply Tchebyscheff matching network design theory (Ref. 3) to the computation of the pump circuit insertion loss associated with a given degree of broadbanding. The computation is carried out in terms of the parameter, δ, defined by $\delta = \frac{1}{2\pi f_b RC}$, where R and C are the values of the equivalent parallel RC network. The diode series RC network, with parameters R_s and C_o, has a value of $\delta = \frac{f_o^2}{f_b f_c}$, where f_o is the center frequency of the pump circuit, and f_c is the diode cutoff frequency defined by $f_c = \frac{1}{2\pi R_s C_o}$.

A pump circuit designed for a 30-300 Mc up-converter with an output frequency of 3000 Mc, using a diode with a 50 Gc cutoff frequency, has an insertion loss of 1.6 db when the network has one tuned circuit, and 0.4 db loss when there are two such circuits. The corresponding figures for a 300-1000 Mc up-converter with a 9000 Mc output, using a 100 Gc varactor, are 0.7 db and 0.15 db.

These calculations neglect the effect of loss in the pump circuit, and also take no account of the parasitic elements characterizing the mounting of a varactor diode in a coaxial or waveguide transmission line. Both of these factors will tend to complicate the matching network design and will increase the pump power requirements.

Nonlinear effects, because of the dependence of the diode mean capacitance on the magnitude of the applied power, are significant principally in the pump circuits, although they have also been experimentally observed under high gain conditions in the signal and output circuits. The principal effect is to make the pump circuit passband asymmetrical, and thus reduce the effective bandwidth. Studies of this phenomenon, documented in another report (Ref. 4) have indicated its dependence upon the circuit, Q. Its effect here is to modify the matching network design and to increase the insertion loss. Further quantitative study of the process is now in progress.

The gain equations set out in the previous section indicated the possibility of achieving some degree of gain constancy with a variation in signal frequency through appropriate control of the manner in which the fundamental pumped elastance coefficient S_1 varies with signal frequency f_1. This method is applicable principally to the lower-sideband up-converter, where adjustment for high gain at the high signal frequencies would lead to oscillation as the signal frequency is reduced, if Z_{11} were constant and S_1 were left unchanged. Analysis of these expressions indicates that the gain constancy requirement may be expressed by: $S_1 = K f_1^n$, where n has a value between 1 and 2, depending upon the gain and the choice of input and output circuit impedance levels. Generally, S_1 for a varactor diode has a maximum value of around 0.28 (Ref. 5). Consequently, the S_1 value at the lowest value of the signal frequency would be small, if this method of gain adjustment were utilized. This would, in turn, degrade the noise figure appreciably. No study has yet been made of the design of a pump network giving this form of power transfer characteristic from the pump source to the diode series resistance. The value of this discussion of S_1 variation with signal frequency is principally as a guide in experimentally adjusting a pump tuning circuit and in accommodating the effects of variation with frequency in the power output of a pump source.

The design of a signal input coupling network is more difficult than that of the pump coupling circuit since here the bandwidth is a greater fraction of the passband center frequency, and the insertion loss in the network contributes directly to the noise figure. The bulk of the studies previously carried out on this subject have been concerned mainly with comparatively narrow band circuits. The choice of input and output network impedance levels to minimize the noise figure has also received little previous attention.

A general input coupling network for a lower-sideband up-converter is shown in Fig. 3(a), which has been derived from the equivalent circuit of Fig. 1(b). A similar circuit for the upper-sideband up-converter is shown in Fig. 3(b). The minimum noise figure of the lower-sideband up-converter has been found to occur when the impedance Z_{12} has a magnitude given by:

$$\left| Z_{12} \right| = \left| (1 + \epsilon) R_s \quad \frac{S_1^{\,2}}{\omega_1 \omega_2 R_s^{\,2}} - 1 \quad + j \frac{S_o}{\omega_1} \right| \tag{4}$$

where ϵ is small compared to one and has a value dependent upon the gain of the up-converter. Under these circumstances the up-converter has a small positive output impedance and optimum performance is obtained when the output termination is chosen for a power match.

The value of Z_{13} giving a minimum noise figure of a system employing an upper-sideband up-converter as the first stage is determined by the noise figure of the succeeding stages. The limits upon Z_{13} are given by:

$$\left| Z_{13} \right| = \left| \frac{S_1^{\,2}}{\omega_1 \omega_3 R_s^{\,2}} + 1 \quad + j \frac{S_o}{\omega_1} \right| \tag{5}$$

when the succeeding stages have a high noise value, and

$$Z_{13} = \left| \frac{S_1^{\,2}}{\omega_1^{\,2} R_s^{\,2}} + 1 \quad + j \frac{S_o}{\omega_1} \right| \tag{6}$$

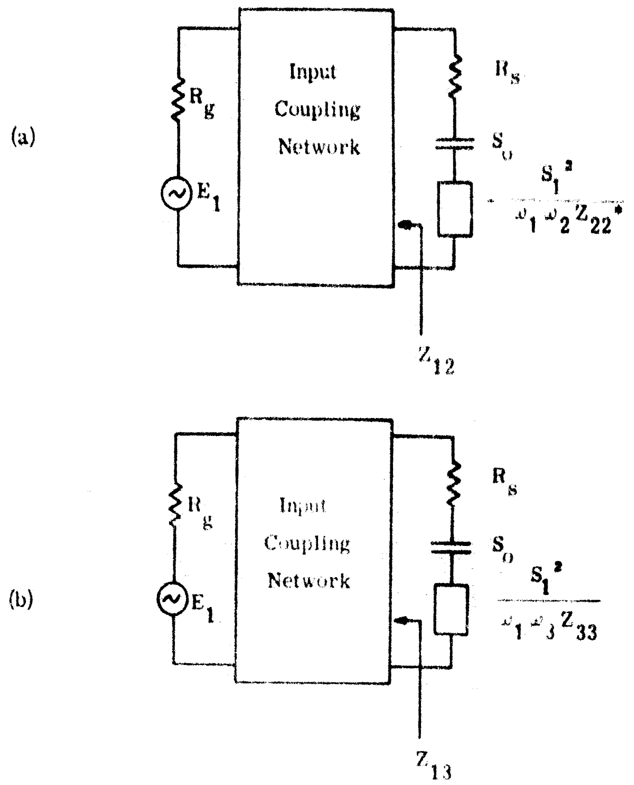
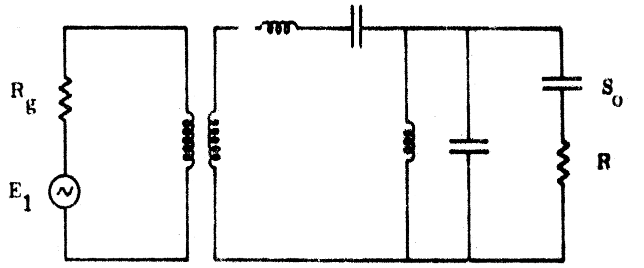


Fig. 3. Signal input coupling networks for parametric up-converters:
(a) the lower-sideband up-converter, and
(b) the upper-sideband up-converter.

when the other stages are noiseless. Optimum performance of the upper-sideband up-converter is obtained when the output termination is chosen for maximum power transfer.

These equations provide the information required for selection of coupling network impedance levels in the comparatively narrow band case. However, the value of $\frac{S_1^2}{\omega_1 R_s^2}$ varies markedly as the signal frequency changes over the 30-300 Mc and 300-1000 Mc ranges. Consequently, gain constancy over these wide ranges requires that Z_{12} and Z_{13} should vary with signal frequency, if S_1 remains constant. The application of filter techniques to coupling network design is not readily possible in such circumstances and further study of suitable circuit design procedures is now in progress. It appears possible that a circuit of the form shown in Fig. 4 will be suitable for the coupling network. A detailed analysis of this circuit is now being conducted.



$$R = (1+\epsilon)\,R_s\left(\frac{S_1^{2}}{\omega_1\omega_2 R_s^{2}}\right) - 1 \quad \text{for lower-sideband up-converter}$$

$$= 1 + \left[\frac{S_1^{2}}{\omega_1^{2} R_s^{2}}\right]^{\frac{1}{2}} \quad \text{for upper-sideband up-converter with noiseless second stage}$$

$$\left[1 + \frac{S_1^{2}}{\omega_1\omega_3 R_s^{2}}\right]^{\frac{1}{2}} \quad \text{for upper-sideband up-converter with noisy second stage}$$

Fig. 4. Possible circuit design for up-converter signal input coupling network.

4.2.3 Unwanted Sideband Effects. A major consideration in the design of a single-sideband tunable parametric up-converter is the nature of the termination at the other principal sideband frequency. It is clear from elementary considerations that this termination will markedly affect the conversion gain from the signal input to the output at the other sideband. However, quantitative studies of this influence are lacking in the literature.

The provision of a termination at the unwanted sideband frequency is complicated by the wide tuning range of the converter. A lower-sideband up-converter tunable from signal frequency f_{1a} to f_{1b} by a pump variable in frequency from f_{pa} to f_{pb} to provide a constant output frequency f_2, has an upper-sideband output in the frequency range $f_{pa} + f_{1a}$ to $f_{pa} + 2f_{1b} - f_{1a}$. The frequency spectra for these signals are illustrated in Fig. 5(a), and corresponding spectra for the upper-sideband up-converter are shown in Fig. 5(b). The most significant feature indicated by these diagrams is the overlap which occurs between the pump frequency range and the unwanted sideband frequency range. This overlap has a bandwidth of $f_{1b} - 2\,f_{1a}$ and, consequently, occurs whenever the tuning range exceeds one octave.

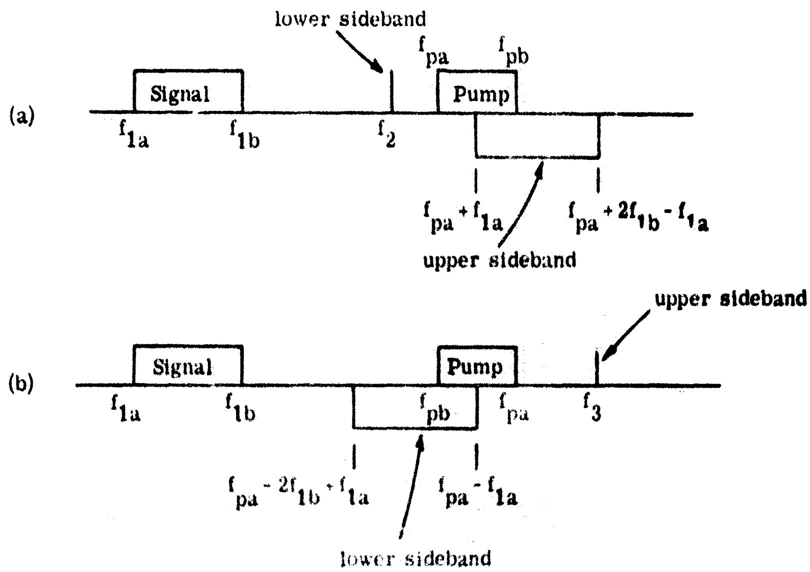


Fig. 5. Frequency spectra of signals present in a tunable parametric up-converter: (a) with a fixed lower-sideband output frequency, and (b) with a fixed upper-sideband output frequency.

The existence of this overlap means that it is not possible to separate the unwanted sideband circuit from the pump circuit through the use of a wideband pump filter. This result has an important bearing upon the theoretical analysis, since it indicates the need for an analysis taking into account the power conversion at unwanted sideband frequencies.

An analysis of general parametric up-converter yields the equivalent circuits shown in Fig. 6. The notation in this figure is that defined in Figs. 1 and 2. A significant assumption in the derivation of the equations yielding these equivalent circuits is that the higher harmonic elastance coefficients $S_2, S_3, \ldots,$ are zero. A more accurate analysis, taking account of these coefficients, will be undertaken later.

The transducer power gain expressions, G_{12} for output at the lower sideband, and G_{13} for output at the upper sideband, come directly from Fig. 6, and are given by:

$$G_{12} = \frac{4\,Q_{11}^{\,2}\,R_1\,R_2\,R_s^{\,2}}{\left| Z_{11}\,Z_{22}^* - Q_{11}\,Q_{21}\,R_s^{\,2} + Q_{11}\,Q_{31}\,R_s^{\,2}\,\dfrac{Z_{22}^*}{Z_{33}} \right|^2} \tag{7}$$

$$G_{13} = \frac{4\, Q_{11}^2\, R_1\, R_3\, R_s^2}{\left| Z_{11}\, Z_{33} - Q_{11}\, Q_{21}\, R_s^2\, \dfrac{Z_{33}}{Z_{22}^*} + Q_{11}\, Q_{31}\, R_s^2 \right|^2} \tag{8}$$

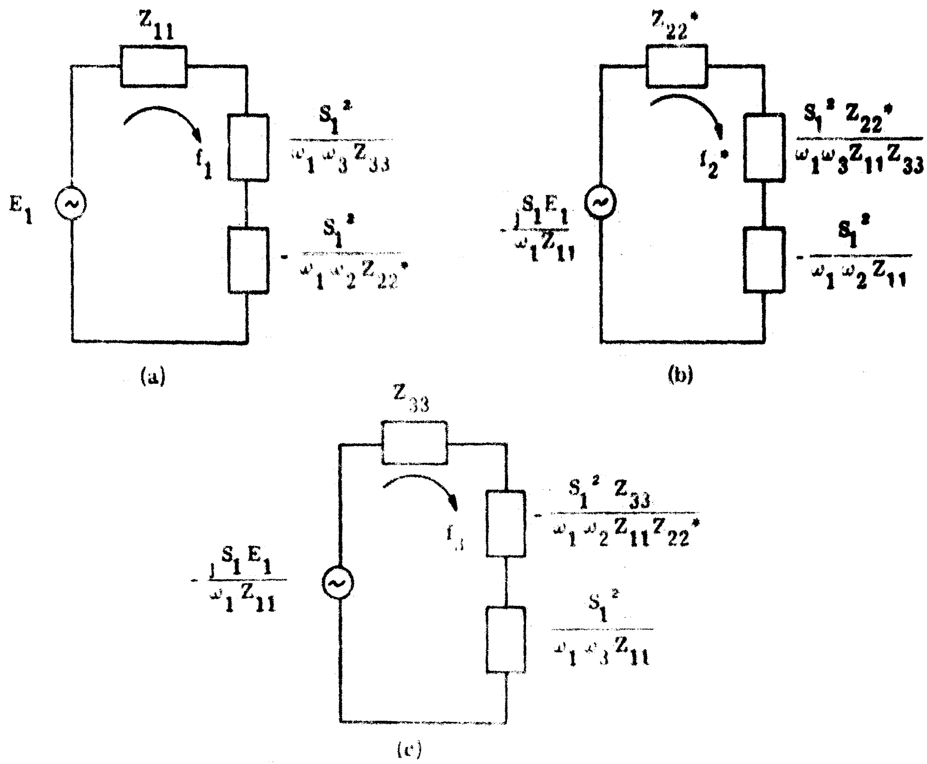


Fig. 6. Equivalent circuit of a general parametric up-converter: (a) single frequency circuit; (b) lower-sideband circuit; (c) upper-sideband circuit.

The design theory for current-pumped parametric up-converters usually assumes that the unwanted sideband is terminated in an open circuit. Because of the parasitic elements associated with a semiconductor diode package, such a termination is difficult to achieve in practical circuit design. The ideal condition is even more difficult to achieve in a wide-range tunable up-converter, because of the periodicity of distributed-network impedances and the overlap in the frequency spectra of the pump and the unwanted sideband. It is apparent from these gain equations that oscillation is possible in an upper-sideband up-converter, because of a small value of Z_{22}. The existence of unwanted sidebands is believed to be the cause of the spurious oscillations and abrupt changes in gain which are often experimentally observed in wideband or tunable up-converters.

The form of the equations above indicates that the gain variation with frequency may be controlled by suitable adjustment of the magnitude of the unwanted termination as a function of frequency. The required frequency variation comes upon solution of the appropriate gain equation for specified input and output impedance levels. In general, the noise figure is degraded by a power conversion to an unwanted sideband because of multiple frequency conversion effects. However, this noise degradation is small for a high-quality diode terminated in a high-Q impedance.

4.3 Experimental Studies

Experimental studies have been initiated on the 30-300 Mc and 300-1000 Mc up-converters to acquire familiarity with the operation of these systems; to identify experimentally the problems in the design of suitable wide-range converters; and, to indicate directions and limitations for the theoretical analysis.

The experimental setups used here were far from optimum, and the experimental results reported bear this out. However, a number of useful results were obtained from the studies, and these have been applied to the development of improved configurations.

The experiments conducted at these two frequency ranges are discussed in detail below. Both series of experiments indicated several fruitful areas for future study. Principal among these areas is the development of suitable low-loss broadband diode mounts in coaxial-line and waveguide. The UHF up-converter required 200 mw of X-band pump power for optimum performance, much more than is usually required for a fixed-pump converter. The reduction of this power requirement through the broadband matching circuit design will require attention. Abrupt gain variations with signal frequency were found, indicating probable interference from unwanted sidebands. The use of tunable band-pass filters in the pump circuits, and perhaps directional filters, is expected to allow future experimental control of these sideband effects.

4.3.1 VHF Up-Converter Experiments. Studies were carried out on lower-sideband and upper-sideband up-converters for the 30-300 Mc signal frequency range, using a pump frequency of around 2000 Mc. Both gain and useful tuning range were small because of the utilization of narrow-band tuning structures, such as double-stub tuners, and also because of unwanted sideband effects.

Measurements were carried out with the varactor diode located in a Microlab broadband coaxial mount, so that the diode is in series with the coaxial line. The tuning range was restricted by the capacitance of the mount, which is large compared to that of the diode junction. The experimental setup is shown in block diagram form in Fig. 7. It is apparent from this diagram that the optimum setting on the double-stub tuners represents a compromise between the usually-conflicting requirements of matching the diode to the coaxial line to provide maximum pump power transfer, and providing the appropriate impedance termination for the output signal and the other sideband. It is possible to separate these tuning requirements by utilizing a more complicated structure. Future studies will be directed toward this end.

An upper-sideband up-converter was constructed with an output frequency of 2100 Mc. The tuners were adjusted for maximum output at 150 Mc, and the gain was measured as a function of signal frequency, for various values of pump power. The results are shown in Fig. 8. The maximum gain values are low, for the reasons discussed above. An interesting feature of these results is that increase in pump power beyond 5 mw has the principal effect of raising the gain at the tuning range extremities rather than at the mid-frequency. Also shown on this graph is a gain curve for a tunable up-converter which is tuned for maximum gain at each signal frequency. This was in contrast to the other curves in Fig. 8, where the tuning was not altered as the signal frequency was changed from 150 Mc.

Gain curves for a lower-sideband up-converter having an output frequency of 1800 Mc are shown in Fig. 9. The converter was tuned for maximum gain at 150 Mc and this tuning was retained as the signal frequency was altered. A simple lower-sideband up-converter is theoretically capable of an arbitrarily high gain, and of oscillation. The effect of upper-sideband propagation is indicated by the maximum gain value of 5 db.

Studies are now being conducted on a General Radio diode mount, where the varactor is mounted in shunt across the coaxial line. This mount has a provision for biasing the diode, and is expected to give improved performance over that achieved with the Microlab mount, because of the reduced mount capacitance. Future experiments will be conducted with an output frequency around 3000 Mc.

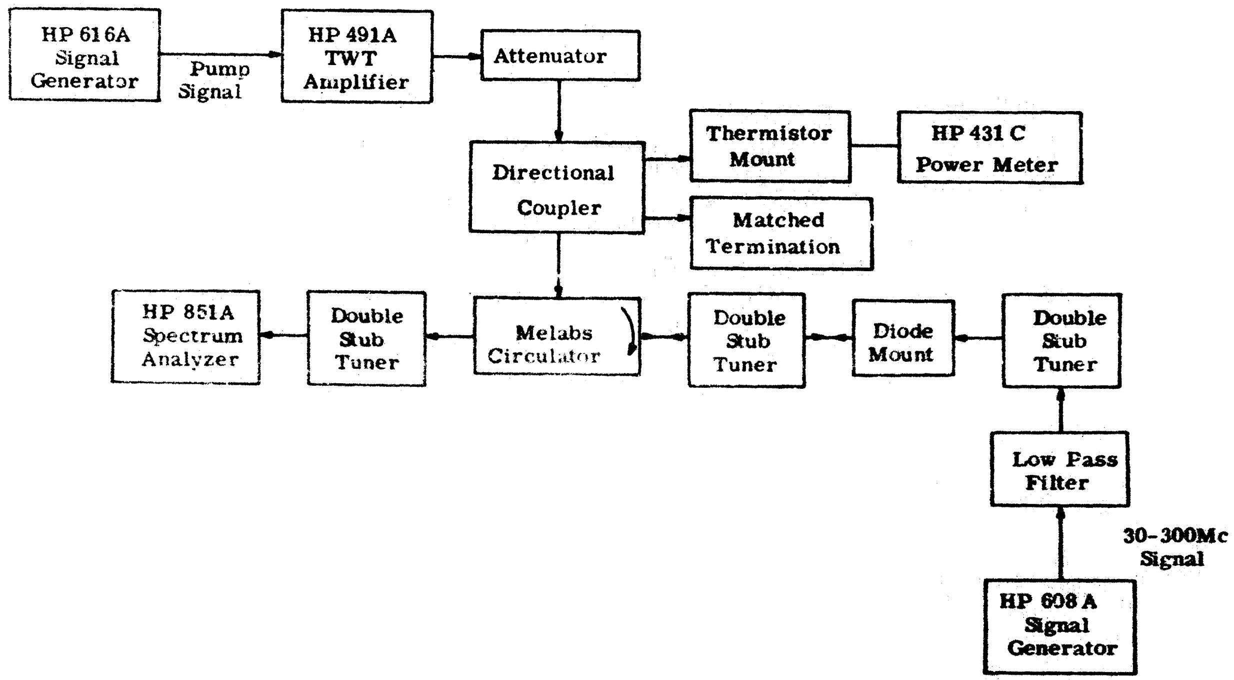


Fig. 7. Block diagram of experimental set-up for VHF up-converter.

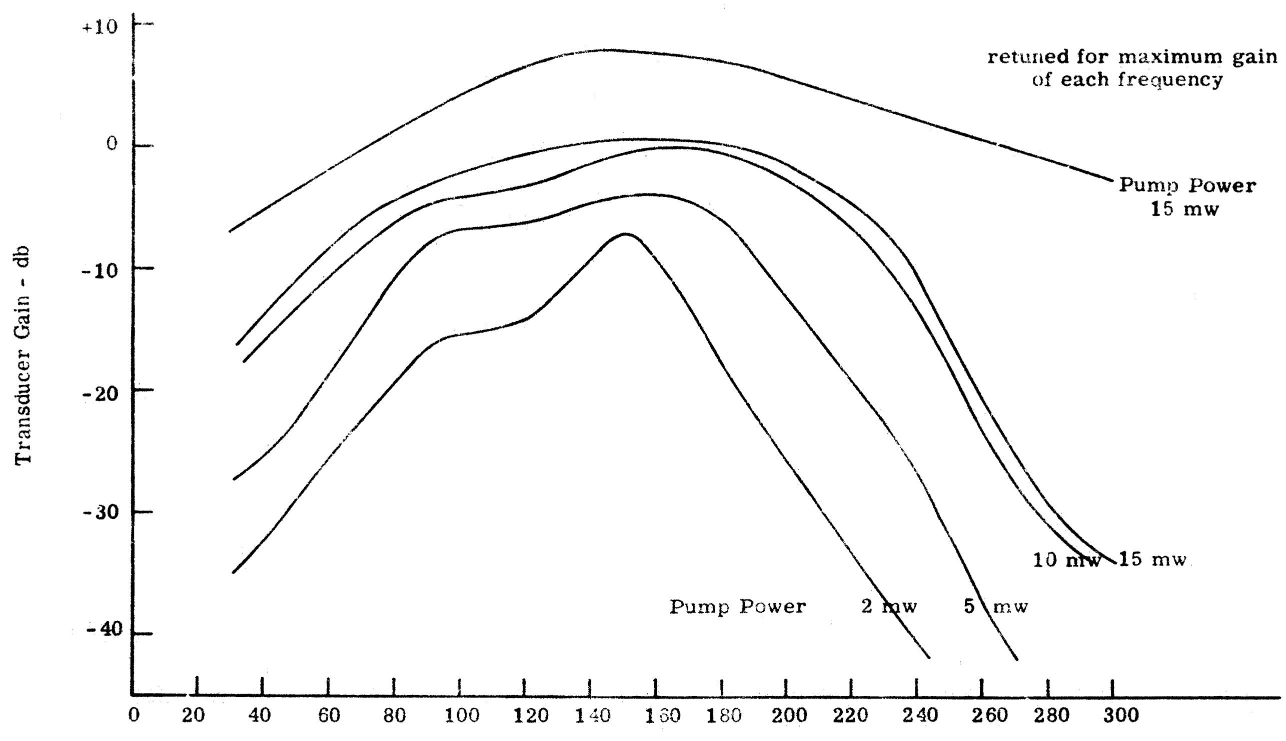


Fig. 8. VHF tunable upper-sideband up-converter transducer gain as a function of signal frequency.

4.3.2 UHF Up-Converter Experiments. The 300-1000 Mc up-converter was studied, using an X-band pump source. As in the case of the VHF up-converter, the experimental setup utilized here was not optimum, but was used to obtain further insight into practical up-converter design.

The setup used for the experiments is shown in Fig. 10. The diode holder consisted of a coaxial line intersecting an X-band waveguide section in the broad-face wall, with the result that the diode is mounted in shunt across the waveguide and in series with the coaxial line. No tuning was used in the signal circuit. The X-band tuning adjustments required the same degree of compromise as was necessary with the VHF up-converter setup shown in Fig. 7.

Measurements were carried out with the upper-sideband output frequency constant at 9280 Mc, the center frequency of the 20 Mc wide 2-cavity direct-coupled narrow-band filter in the output line. The up-converter was tuned for maximum output at 650 Mc signal frequency, and the gain was measured as a function of signal frequency. It was found that a wide variety of gain responses were possible, since the gain is a multipeaked function of the E-H tuner setting and the gain value achieved by iterative tuning techniques depends upon the initial tuner setting. One representative set of gain curves are shown in Fig. 11, and another in Fig. 12. A set of gain curves for a tunable lower-sideband up-converter having an output frequency of 9280 Mc, and adjusted for maximum gain at 650 Mc is also shown in Fig. 12. The curves indicate the variety of gain responses possible with this experimental setup, and also the effect of upper-sideband propagation in limiting the maximum gain attainable with the lower-sideband up-converter.

Several modifications have been made to the original setup. Studies were carried out on waveguide diode mount in which the tuning was carried out with a sliding short-circuit termination to the waveguide and a sliding coaxial short-circuit in series with the diode. It was found that this method gave much greater bandwidth than tuning with an E-H tuner. The diode mount has also been modified to provide for fixed-bias operation. A 5-stage direct-coupled waveguide band-pass filter with a 0.1 db ripple Tchebyscheff response over 8100-9100 Mc was designed and constructed, providing a broadband filter for the pump circuit in an upper-sideband up-converter. Future studies will be with a

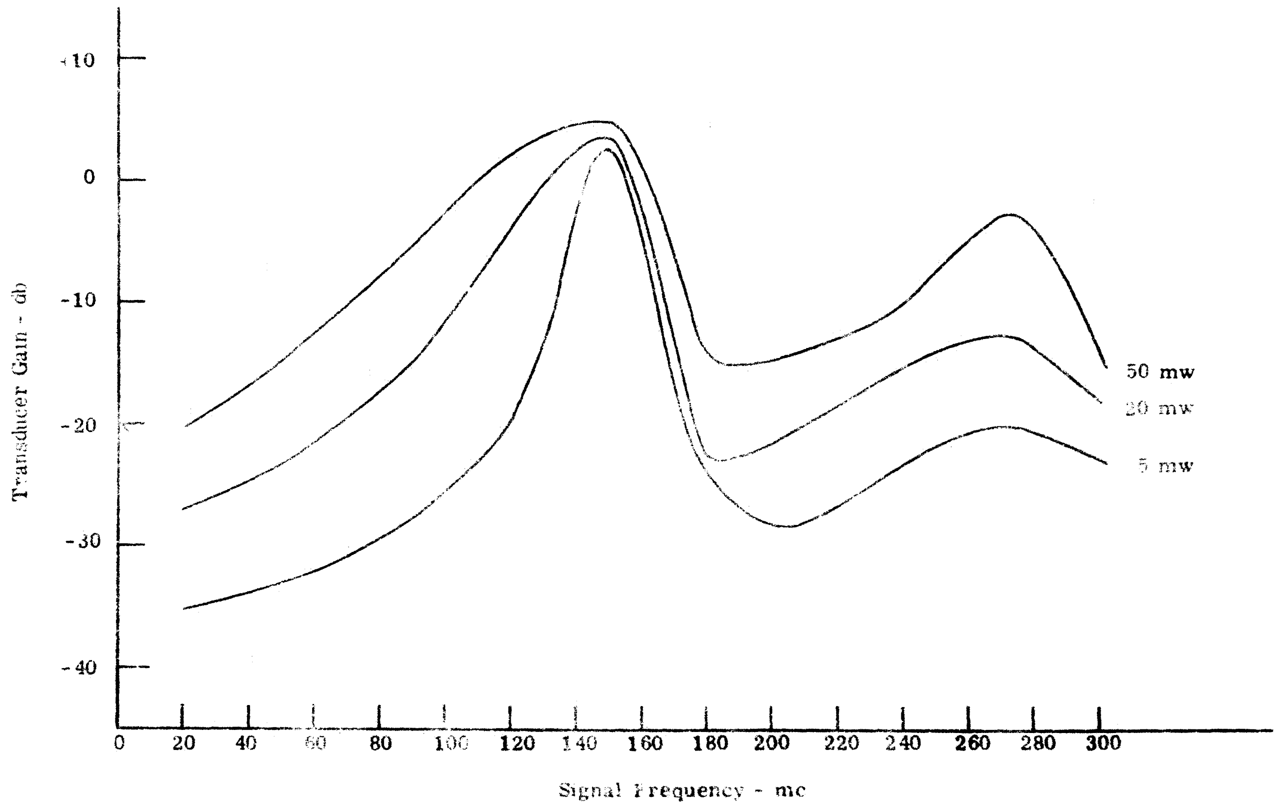


Fig. 9. VHF tunable lower-sideband up-converter transducer gain as a function of signal frequency.

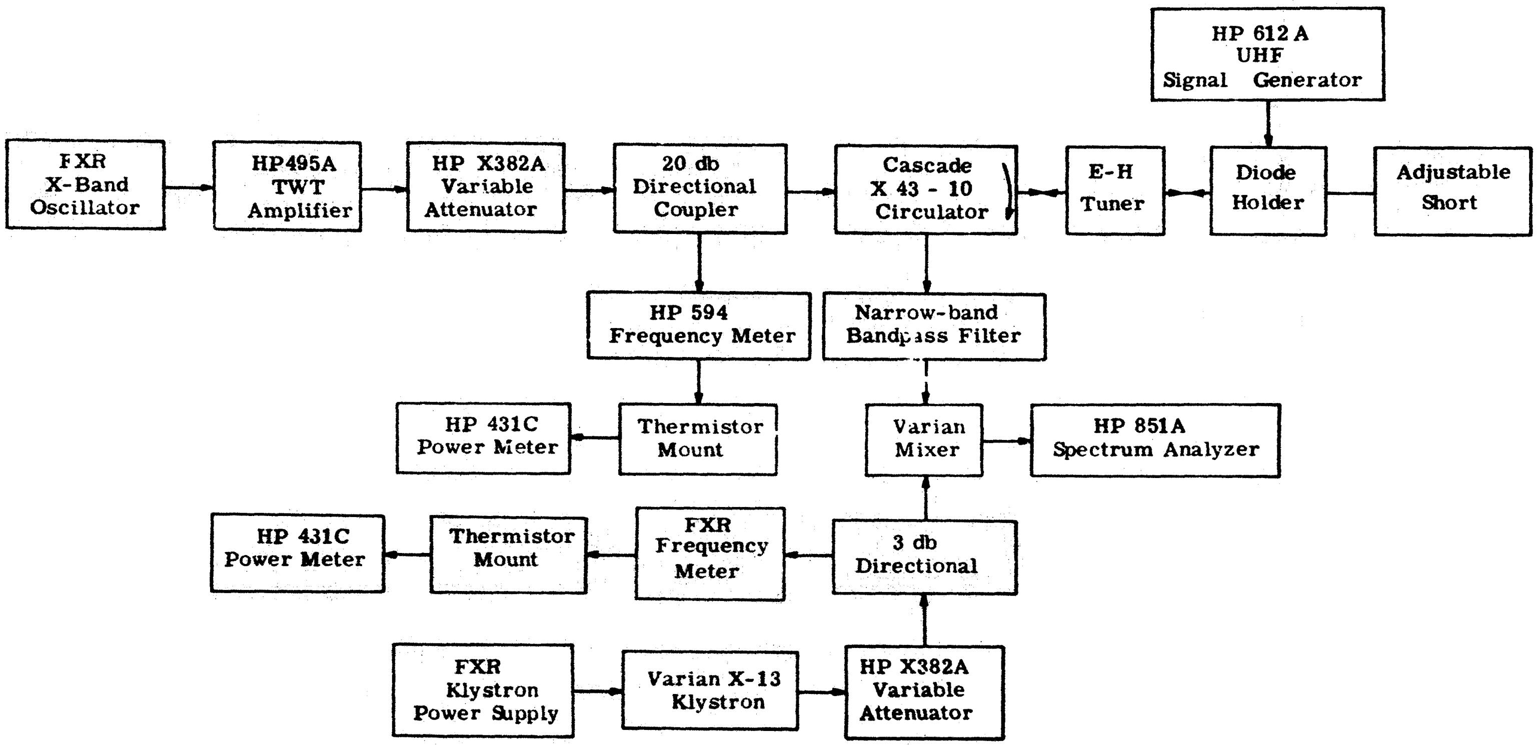


Fig. 10. Block diagram of experimental set-up for UHF up-converter.

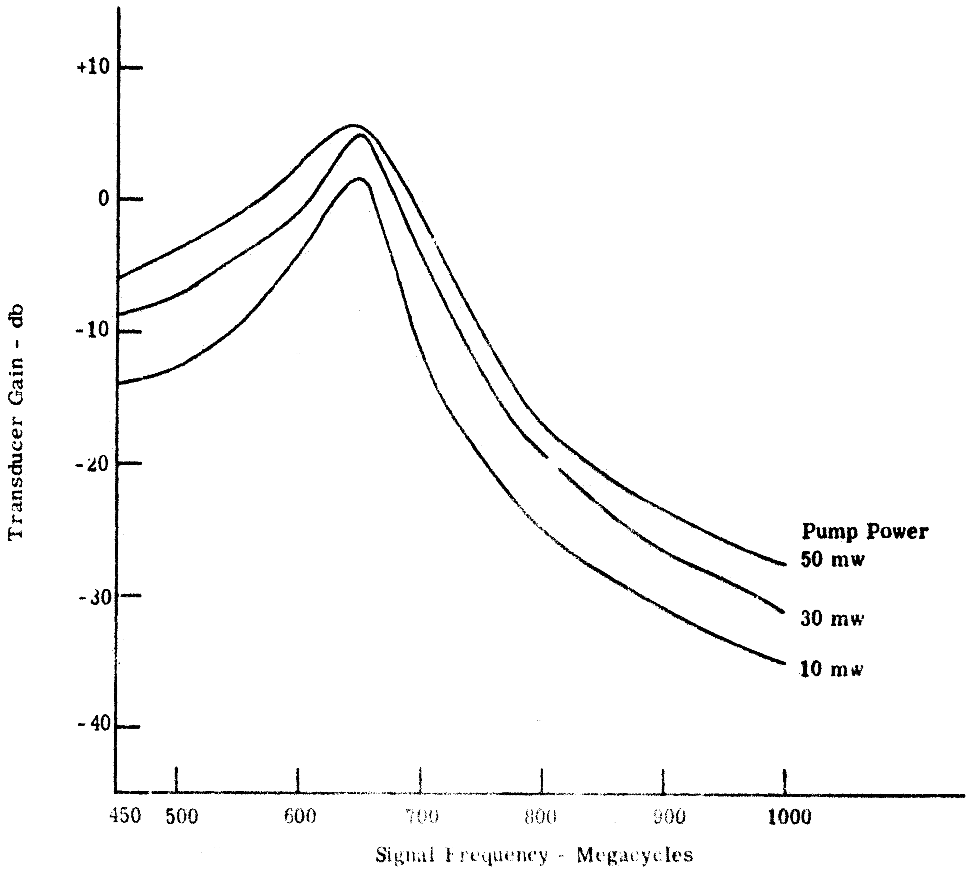


Fig. 11. UHF tunable upper-sideband up-converter transducer gain as a function of signal frequency.

setup providing separation between the input pump and output sideband signals to provide some measure of independence in the tuning of these circuits. Some study of tunable filters will probably also be initiated, as a possible solution to the frequency overlap problem indicated in Fig. 5.

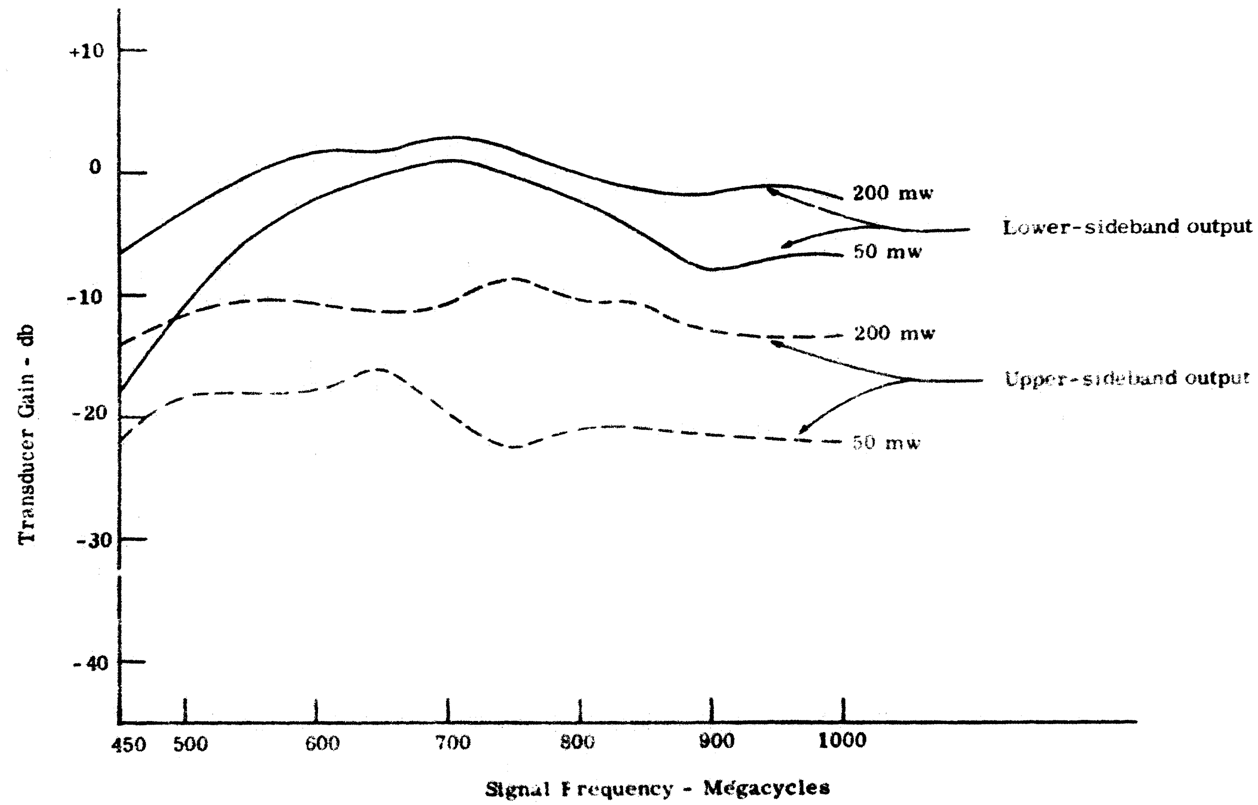


Fig. 12. Transducer gain of UHF upper-sideband and lower-sideband up-converters as a function of signal frequency.

4.4 Conclusions

The studies of tunable parametric up-converters initiated during the past quarter have served to indicate the major problem areas where research is required, and have provided some insights into possible solutions to these problems.

The principal problems concern the achievement of gain constancy over the wide signal ranges and the control of the unwanted sideband, which is propagated back from the varactor into the pump circuitry if a broadband pump filter is used. A considerable amount of study will be required to develop broadband signal and pump coupling networks which will provide constant gain as the parametric coupling impedance

$\frac{S_1^2}{\omega_1 \omega_2 Z_{22}^*}$ or $\frac{S_1^2}{\omega_1 \omega_2 Z_{33}}$ varies over the signal frequency range. A combination of a directional filter and a tunable pump filter appears necessary to permit independent control of the unwanted sideband.

5. PROGRAM FOR THE NEXT INTERVAL

During the next quarter, attention will be directed to the following:

1. Theoretical study of broadband coupling networks for pump and signal circuits.

2. Investigation of the effect of higher harmonic sideband components on tunable up-converter performance.

3. Study of methods of achieving constant gain as the signal frequency is varied over a wide range.

4. Further development of the experimental configurations for the 30-300 Mc and 300-1000 Mc up-converters, using the conclusions of the theoretical studies.

5. Derivation of an optimum tunable up-converter design theory, having regard to gain, noise figure, tuning range, and dynamic range.

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13. ABSTRACT

Studies have been carried out on the design of parametric up-converters tunable over a signal frequency exceeding one octave. Equivalent circuits have been derived for the parametric networks, taking account of simultaneous propagation at the upper and lower sidebands. Circuit designs giving constant transducer gain over the frequency range have been investigated, and wide-band pump and signal frequency coupling networks studies.

Experimental studies have been initiated on both lower and upper side-band up-converters tunable over the 30-300 Mc and 300-1000 Mc ranges having an output frequency approximately ten times the highest signal frequency.

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