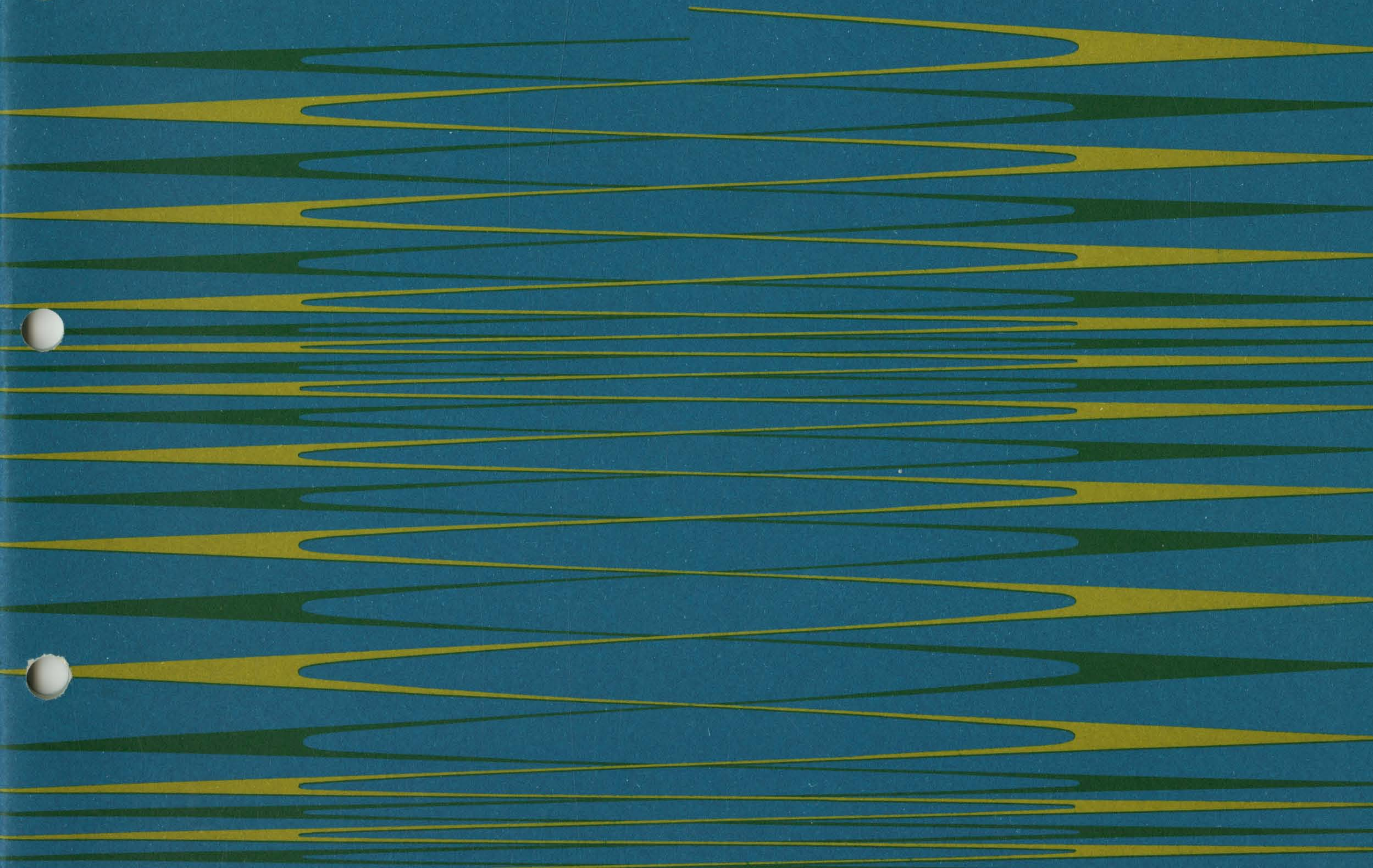
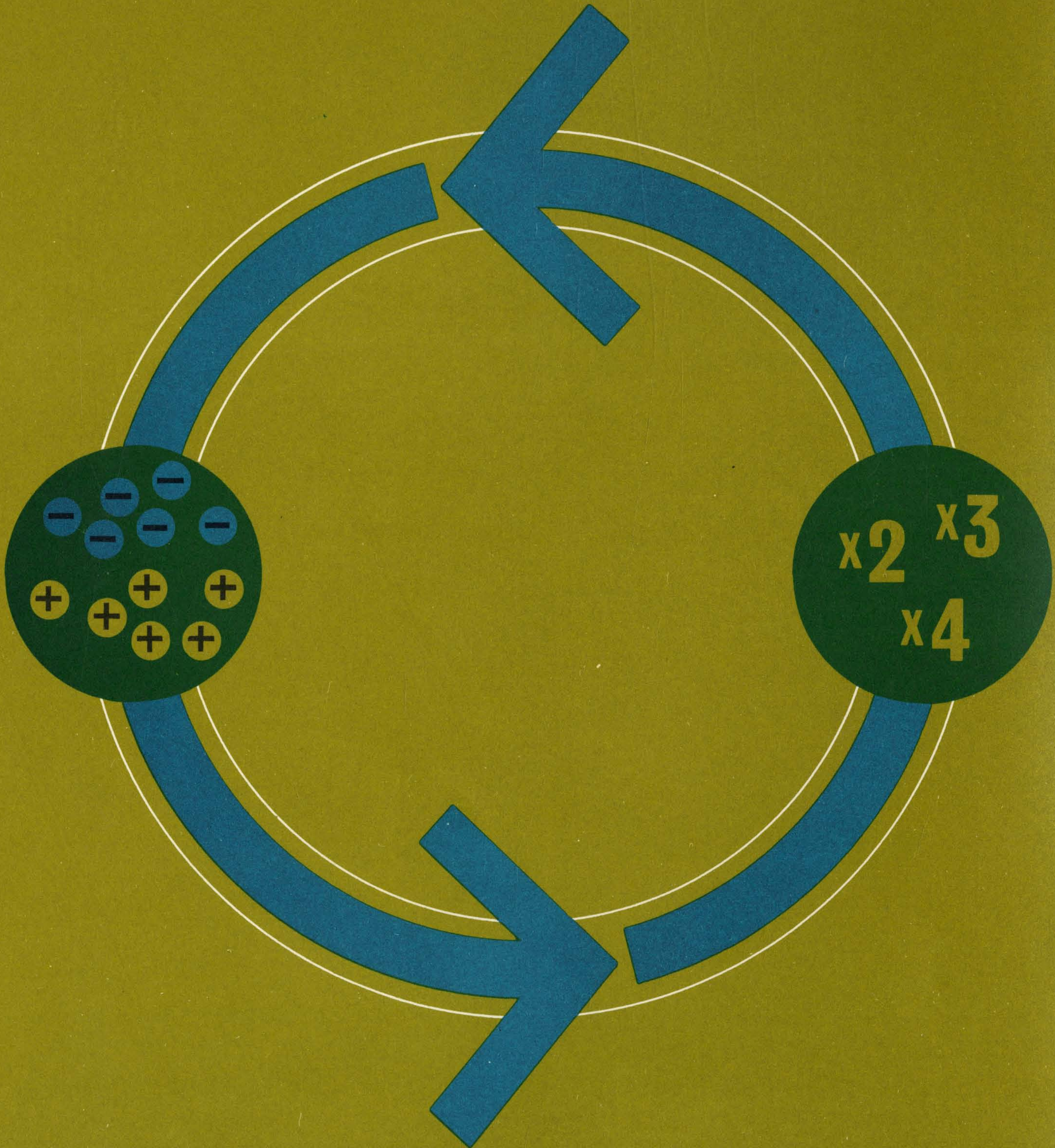
MICROWAVE ASSOCIATES, INC.

VARACTOR HARMONIC GENERATION

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VARACTOR HARMONIC GENERATION

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THE STATE OF THE ART

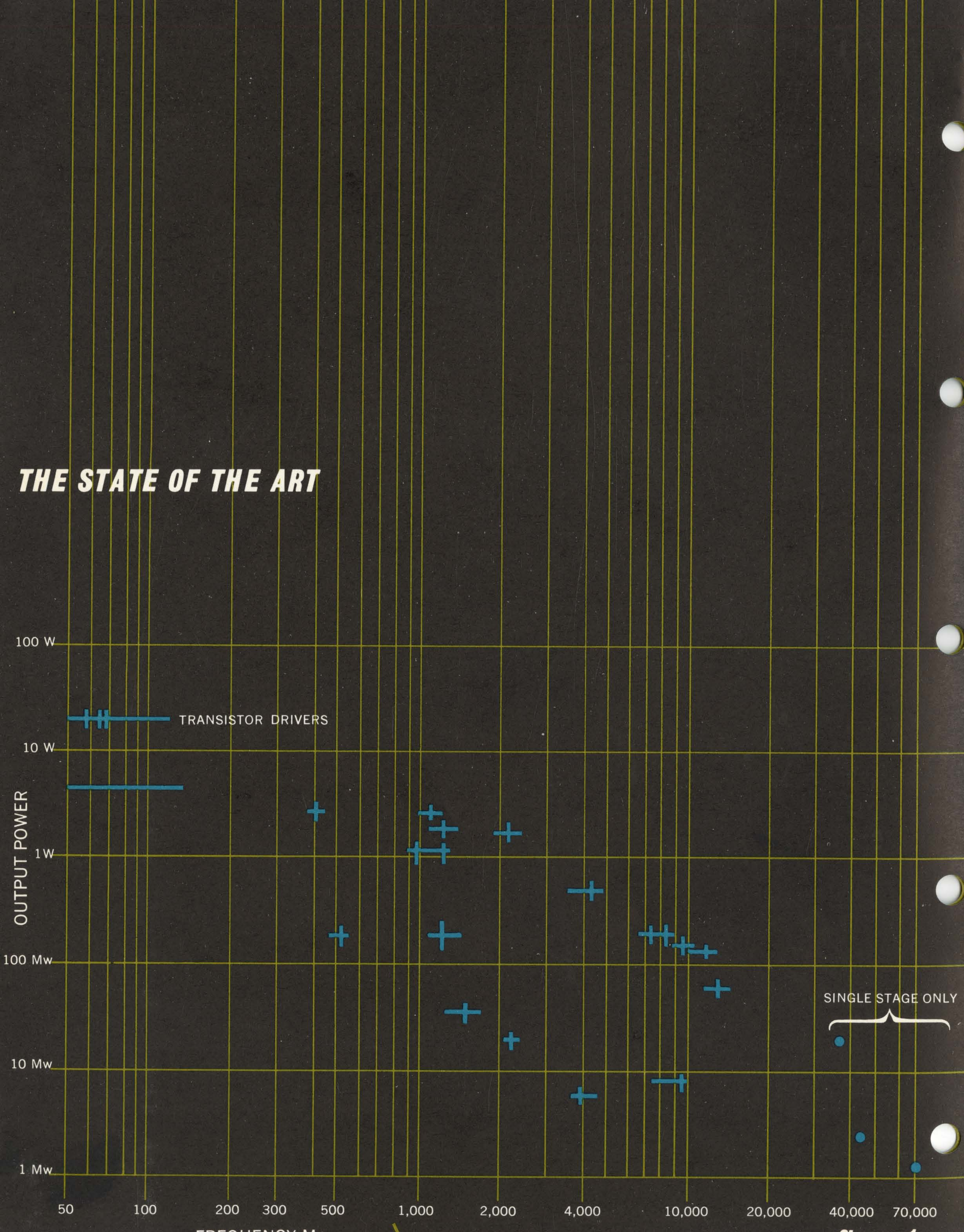
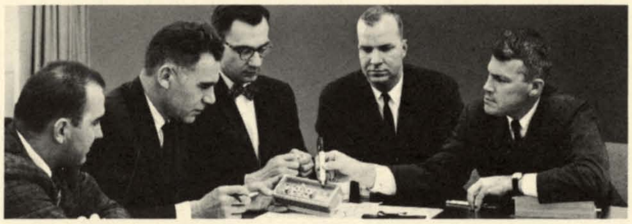


figure 1



As new techniques for power generation have been developed it has been possible to open higher frequency portions of the radio spectrum for practical use. As these higher frequencies become populated, an increasing premium is placed on frequency stability, power capability, and, of course, finally on reliable generation of power at low cost per watt. In the past year semiconductor techniques have advanced to the point where solid-state UHF and microwave generators have become practical and useful devices and should be considered for many systems applications. In addition to eliminating many of the problems associated with microwave thermionic tubes, microwave frequency control of better than 1 part in 10^6 is readily obtainable by either crystal control or stable frequency synthesis at low frequencies and can be multiplied up to microwaves. Local oscillator power can be generated by borrowing a portion of the carrier power and then offsetting it by using a high-level semiconductor mixer driven by a crystal controlled I.F. source. This procedure eliminates the familiar AFC loop normally associated with doppler and other radar receivers. With stability of several cycles per second readily available for the first time at microwaves, extremely narrow band and synchronous circuits provide signal detection capabilities almost unobtainable in the past. Multiple-stage varactor harmonic generators and all solid-state sources are now being incorporated into many systems. The graph in Figure 1 indicates the state-of-the-art of solid-state multipliers at Microwave Associates as of December 1962 and a complete listing of available driver and multiplier chains is shown on the back inside cover of this brochure.

The harmonic generator stages at frequencies above VHF are entirely passive except that RF power is applied at frequencies in the general vicinity of 50-200 Mc. The input frequency may be multiplied by two, three, four, or more in each stage. Outputs in any common microwave band are obtainable in multistage units. The interesting feature of varactor harmonic generators is the high efficiency obtainable in doubling, tripling or quadrupling. Efficiencies from 50 to 90 percent are commonly reported for single-stage devices. Over-all efficiencies of multistate units are, of course, lower, but even when considered with their transistor driver circuits, harmonic generator sources are competitive on a DC vs RF efficiency basis with reflex klystrons. High efficiency is obtained because varactor nonlinearity is reactive rather than resistive. Residual power losses are associated with parasitic series resistance of the varactor diodes and in passive circuit resistance. The purpose of this brochure is to acquaint the reader with the capabilities of Microwave Associates, both as a producer of complete solid-state microwave generators and as a producer of efficient varactors for customer application. We feel we occupy a unique position in this market since we can offer not only the varactors themselves, but further customer assurance that these units will operate because of the interaction between our diode production and solid-state manufacturing groups.

Requirements for diodes which represent continuing advances in characteristics are constantly being funneled to our Semiconductor Division and result in our being able to offer the customer continual improvements in new varactors.

GENERAL PRINCIPLES

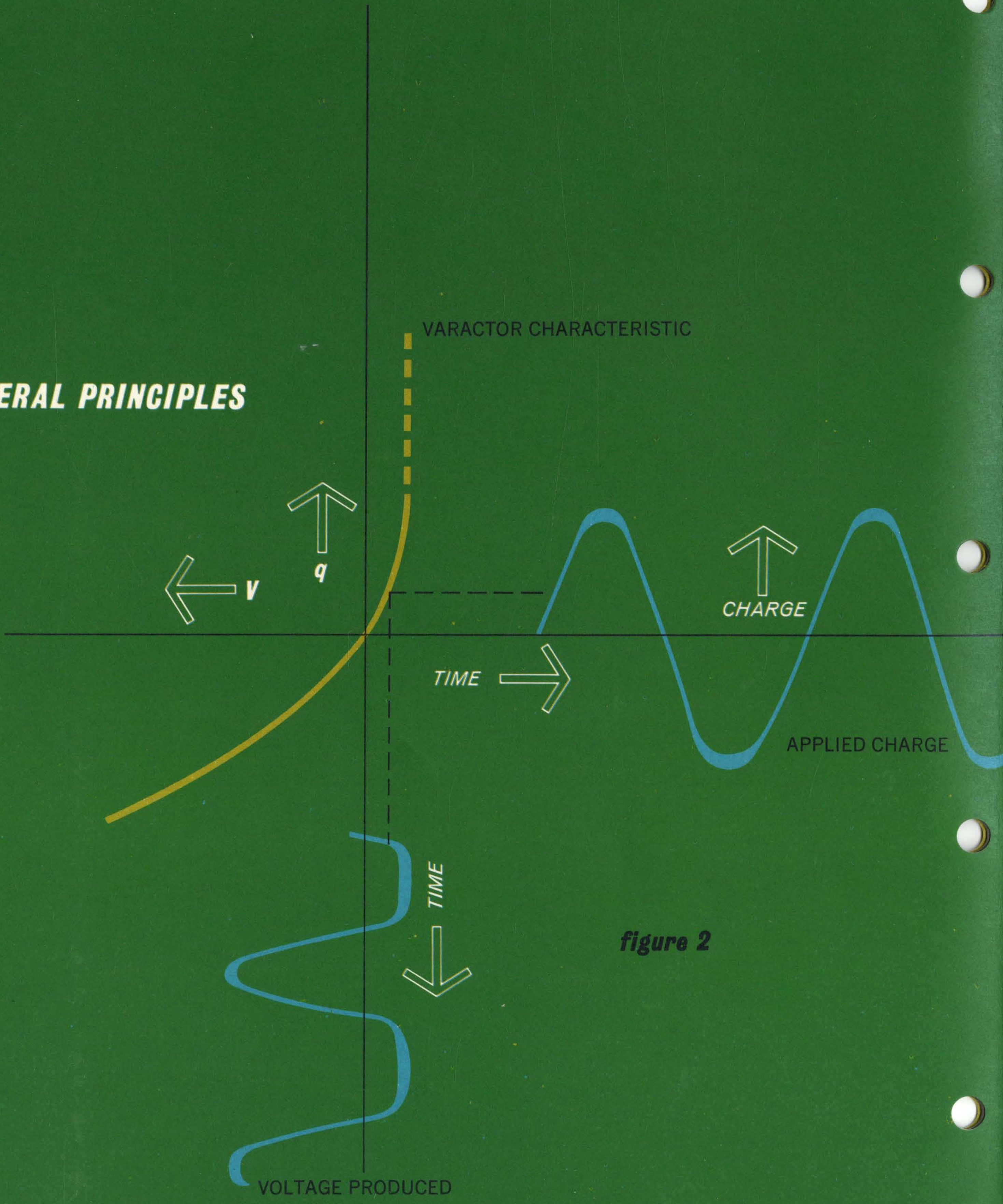


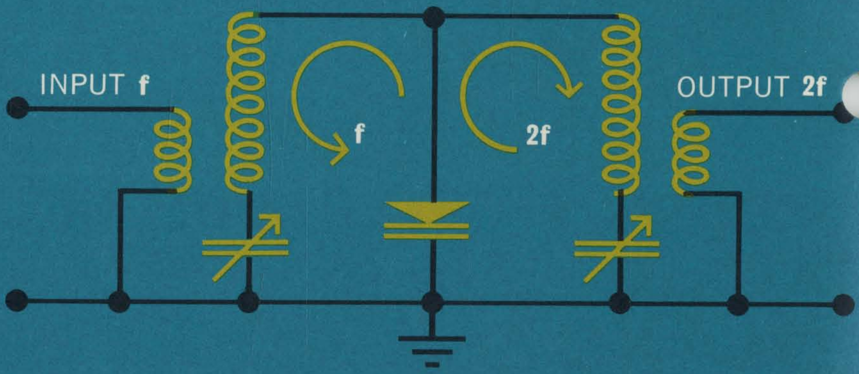
figure 2

MA 8105

The harmonic generators that we shall discuss here use varactor diodes. These are microwave junction diodes designed to make use of the nonlinear charge-vs-voltage characteristic of a PN junction in the reverse bias region and in the positive region close to the origin. Figure 2 shows the basic principle which is commonly used for harmonic generation with these devices. The graph at the upper left of the figure represents schematically a charge-vs-voltage characteristic typical of such a diode. The sine wave to the right represents the input charge variation as a function of time. Below, also as a function of time, is shown the resultant voltage wave which may be deduced from the nonlinear charge-vs-voltage curve. The resultant voltage wave is seen to be strongly distorted and rich in harmonics. This curve, of course, merely represents a schematic concept of the principle used. In actual practice, the charge, voltage, and current waves are all non-sinusoidal and more complex than indicated here.

x3

x2



x4

figure 3 VARACTOR DOUBLER

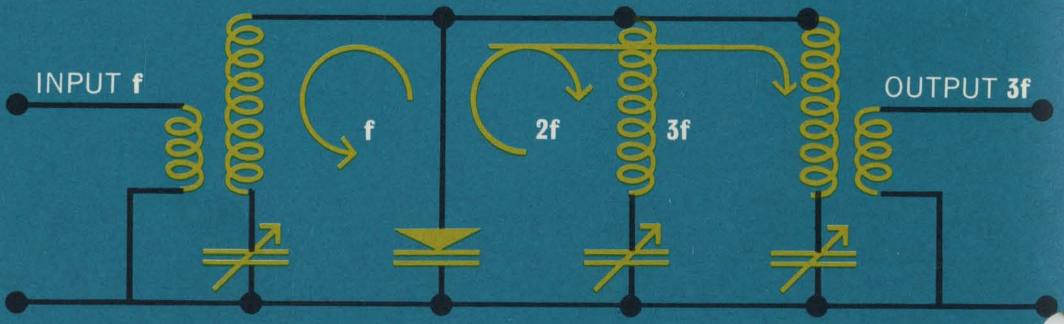


figure 4 VARACTOR TRIPLER

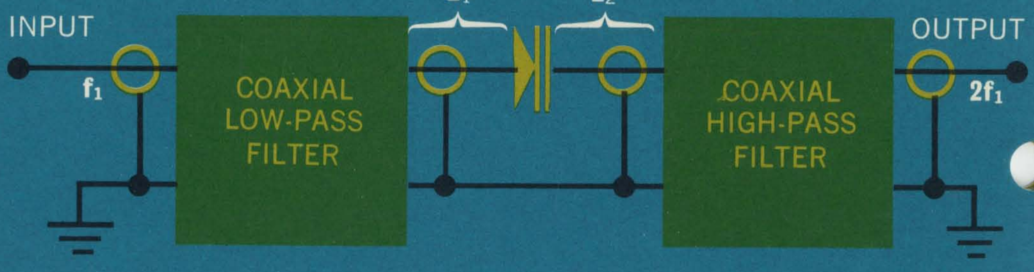
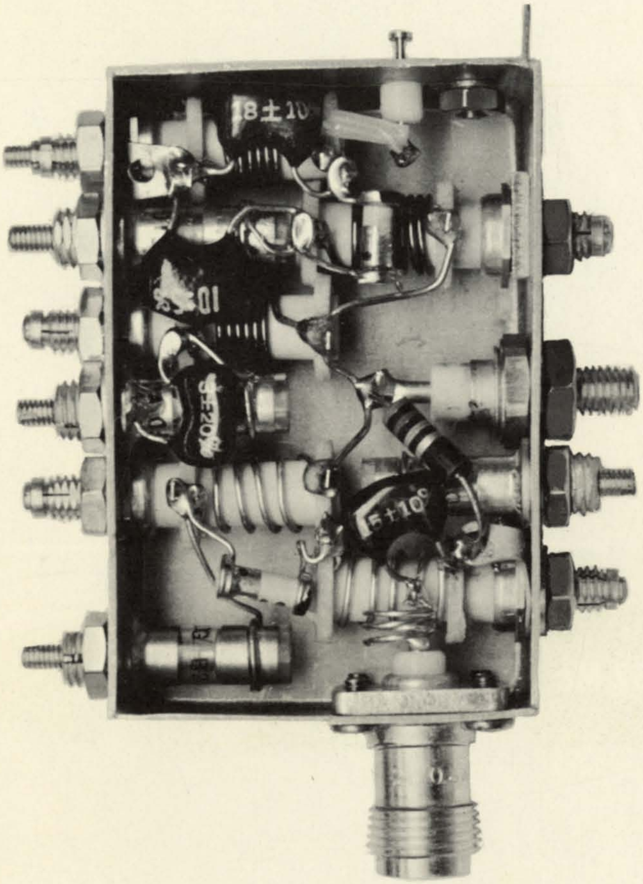


figure 5 COAXIAL DOUBLER



Basic Doubler Circuit

Figure 3 shows a simple type of doubler circuit. This is merely a combination of two resonant circuits coupled together through a common impedance which is the diode itself. Ordinarily the varactor impedance is small compared to the reactances at undesired frequencies in either of the two separate loops, so there is a natural division of current. The major portion of the fundamental current flows in the first loop, and substantially all of the second harmonic current flows in the second loop. Coupling links are added to the two inductances for input and output connections.

Triplers and Quadruplers Utilizing An Idler Circuit

Tripler and quadrupler circuits are somewhat similar to the doubler circuit configuration. A practical 150 Mc to 450 Mc tripler circuit is illustrated in Figure 4. The tuning procedure for this circuit is outlined in a later paragraph.

Three resonant frequencies, again coupled together by the common impedance varactor, form the basic tripler circuit. One loop, resonant with the diode at the fundamental, is coupled to the input. The second loop, resonant with the diode at the second harmonic frequency is added in shunt with the varactor. This is the "idler" frequency which has been shown to be necessary to achieve maximum efficiency by allowing the second harmonic currents to flow. The third loop is resonant with the diode at the third harmonic and is coupled to the output.

For the quadrupler, the basic difference from the tripler description is that the output loop is resonant with the diode at the fourth harmonic, the "idler" frequency remaining at the second harmonic.

Another type of multiplier circuit which has been used at Microwave Associates is the coaxial doubler shown in Figure 5. This circuit utilizes an input low-pass filter followed by an appropriately chosen length of line, a varactor inserted in the coaxial structure, a second suitably chosen line length, and finally an output high-pass filter network. These devices make highly efficient broadband doublers. Circuits of this general type are suitable for frequencies in the 1 — 10 Gc range.

Using the techniques described above, we have been able to obtain doublers, triplers and quadruplers which utilize stub tuning techniques to resonate the various harmonics.

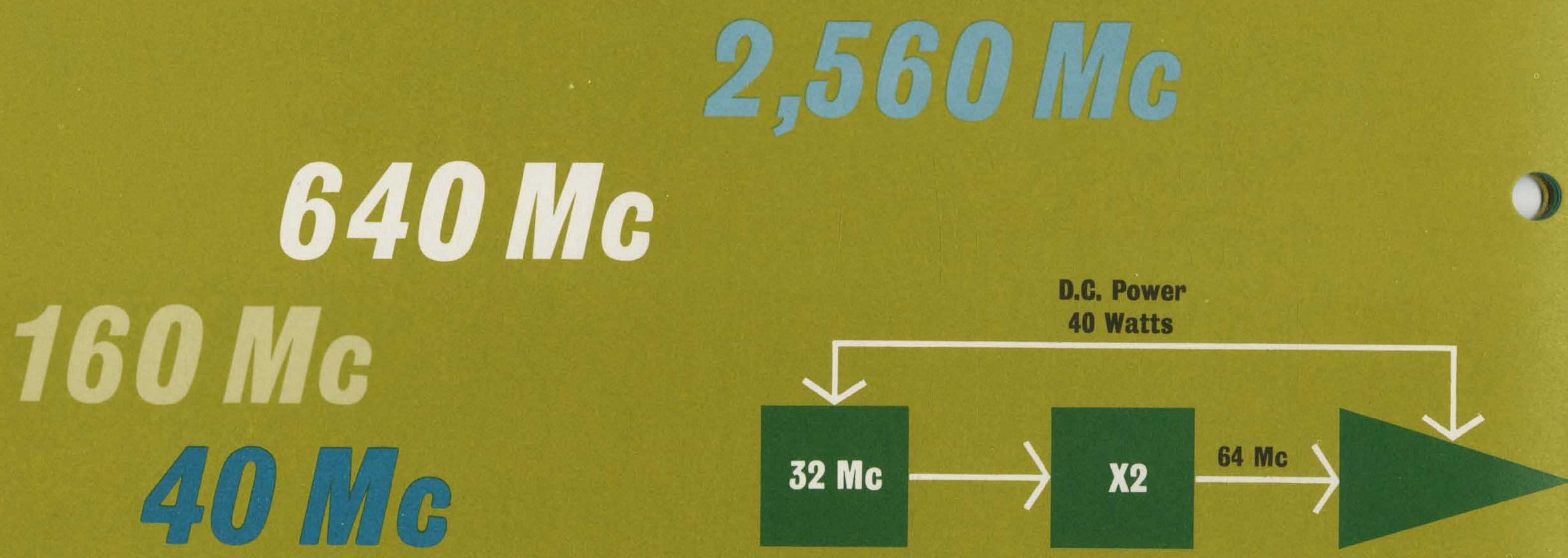
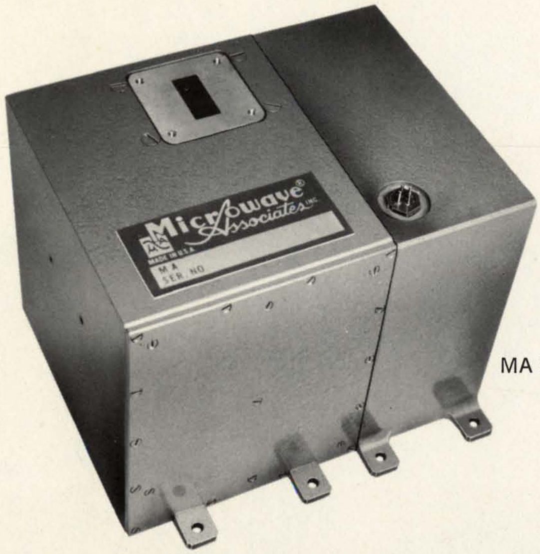


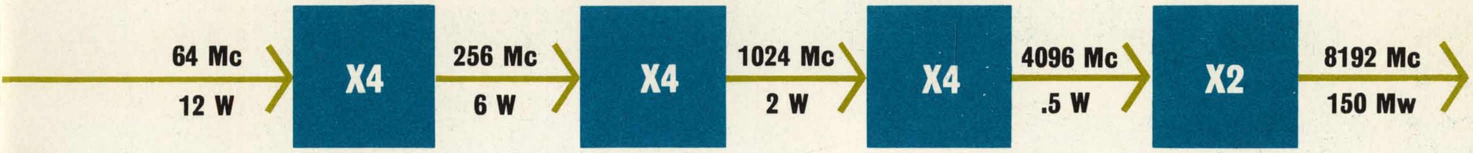
figure 6

SOLID-STATE MULTIPLIER CHAIN / DC TO X-BAND



MA 8106

Tandem Circuits



Once the capability of doubling, tripling, or quadrupling efficiently at many such frequencies is achieved, the next logical step is to connect a number of such devices in tandem such that one will drive another. Starting at a frequency such as 50 Mc, with sufficient drive power, it would be expected that useful power could be achieved at microwave frequencies such as 10 Gc. Figure 6 illustrates such an all-solid-state chain in block diagram form. Beginning at the left we have a crystal-controlled signal oscillator which might be at some convenient frequency, perhaps 5 Mc to 50 Mc. The low-power harmonic generator is used to raise this frequency into a VHF band where a transistor power amplifier may be used. Following this, harmonic generator stages can be placed in tandem to achieve any desired microwave frequency. From a practical point of view, it is desirable to use higher-order multiplication because fewer stages are required and overall simplification is obtained. However, the bandwidth of such circuits is somewhat narrower than that obtained by the tandem circuit arrangement.

Varactor harmonic generators contain many of the required ingredients for parametric amplifiers and oscillators. Circuit design is somewhat critical since an unfortunate choice can lead to instabilities with respect to parametrically excited oscillations. These problems are compounded when many stages are connected in tandem. To minimize the opportunities for oscillations, circuits which have resonances or frequencies well below the drive frequency should be avoided; in particular, one half the drive frequency, or two frequencies whose sum is the drive frequency. Long input lines are particularly hazardous when such lines have a reactive termination at frequencies other than the driving frequency.

It is also important to couple the circuits adequately to both the input and output lines in order to reduce the impedance of the circuits at the various frequencies. This will be helpful at the driving frequency, at subharmonic and other low frequencies, and at the desired output frequency.

Another problem of some importance is that of spurious responses at other harmonics than the one desired. A strongly driven varactor will generate many harmonics simultaneously. A multistage device designed for the n^{th} harmonic will usually include small amounts of the $(n - 1)^{th}$ and the $(n + 1)^{th}$ harmonics, and may contain others as well. To achieve pure signals, filtering is desirable between stages as well as at the output.

Another method of filtering unwanted harmonics is to insert an "idler" circuit tuned to some frequency higher than the output frequency. However, this arrangement is not commonly used.

figure 8 TYPICAL HARMONIC GENERATOR TEST SET UP

A Practical Tripler Circuit

C1, 3, 4, 5, 7	1 — 9 pf
C2, 6	0.4 — 2.0 pf
L1, 2	7T, ¼" dia, #20
L3	5T, ¼" dia, #20
L4, 5	3½T, ¼" dia, #20
R1	33K
V1	MA-4061B

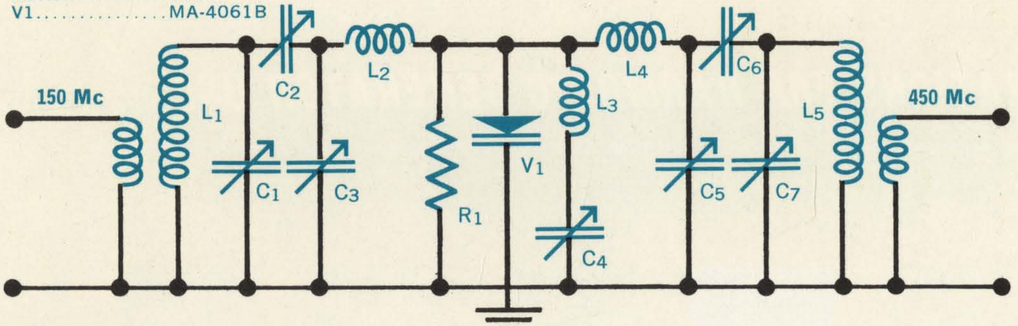


figure 7

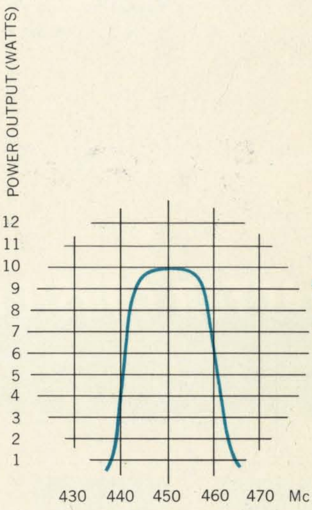


figure 9

The varactor tripler circuit shown in Figure 7 is capable of being driven with 20 watts at 150 Mc, and will deliver 10 watts or more output into a matched load at 450 Mc. The circuit consists basically of a double-tuned band-pass filter tuned to the input frequency ($L_1 C_1$ and $L_2 C_3 V_1$ coupled through C_2); a second band-pass filter tuned to the output frequency ($L_4 C_4 V_1$ and $L_5 C_7$ coupled through C_6); and an idler circuit tuned to the second harmonic, 300 Mc ($L_3 C_4 V_1$). It is important to note that the varactor V_1 is common to all three circuits. The resistor R_1 provides a suitable self-bias to the varactor.

Tuning a circuit which contains 12 variables requires special techniques to provide maximum efficiency, bandwidth, and freedom from spurious responses. The following procedure is recommended:

1 With C_2 and C_6 set for minimum capacitance, resonate L_1 and L_2 by C_1 and C_3 respectively using a grid dip meter to the input frequency of 150 Mc. Similarly, resonate L_3 and C_4 at 300 Mc and L_4C_5 and L_5 and C_7 to 450 Mc.

2 Install the multiplier chain in a test circuit similar to that shown in the block diagram of Figure 8.

3 Using an absorption wave meter, insure that the drive frequency is actually 150 Mc and that the detector is observing 450 Mc. It is very easy to tune up on a higher order harmonic such as the 6th!

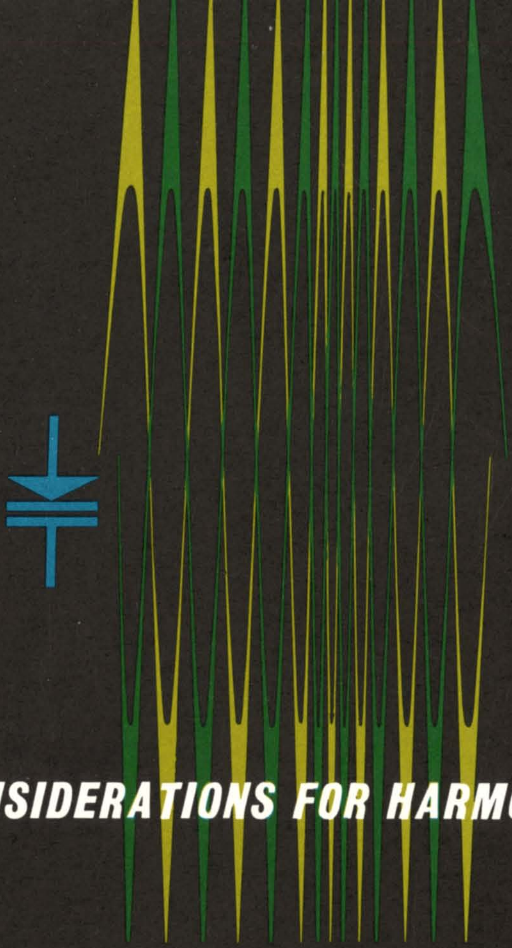
4 With 10 Watts of drive power and maximum sensitivity, there should be some visual indication of the 3rd harmonic on the oscilloscope. Tune for maximum output by peaking C_1, C_3, C_4, C_5, and C_7 in sequence.

5 Stop the sweep oscillator at the band center and using a directional power meter, readjust the input filter, C_1, C_2, C_3, for minimum reflected power. It should be possible to obtain a low input VSWR.

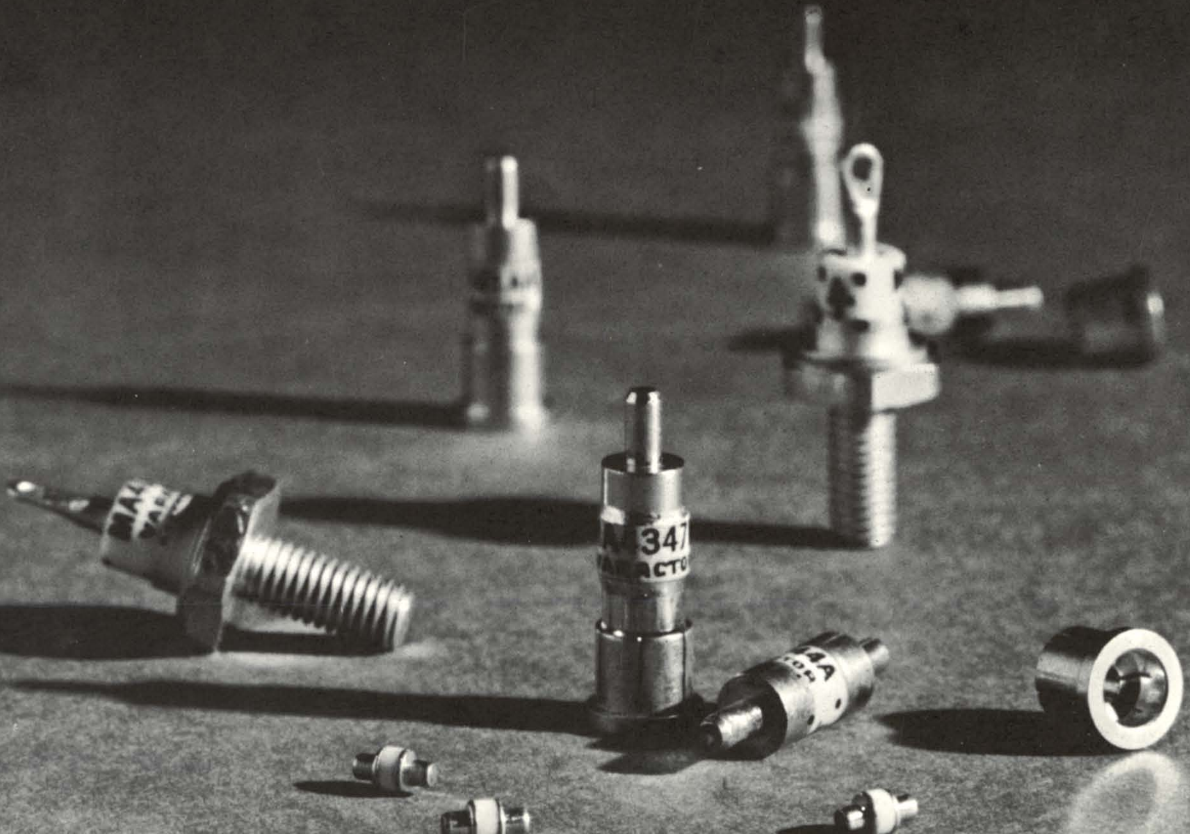
6 Restart the sweeper and observing the output trace, make small adjustments of the C_5, C_6, C_7 combination to optimize the output trace over the broadest bandwidth. A typical clean output trace is shown in Figure 9.

7 As a final precaution, both the efficiency and output frequency should be checked. If the efficiency is low it may be an indication that the circuit has been tuned to the wrong harmonic. Since the tuning adjustments are somewhat drive sensitive, final adjustments should be made with the driver actually planned for the system.

For convenience of those circuit designers who would like to use the above circuit to gain familiarity with harmonic generator techniques before embarking on more sophisticated projects, the MA-8130 tripler is available at a very nominal cost.



VARACTOR CONSIDERATIONS FOR HARMONIC GENERATOR USE



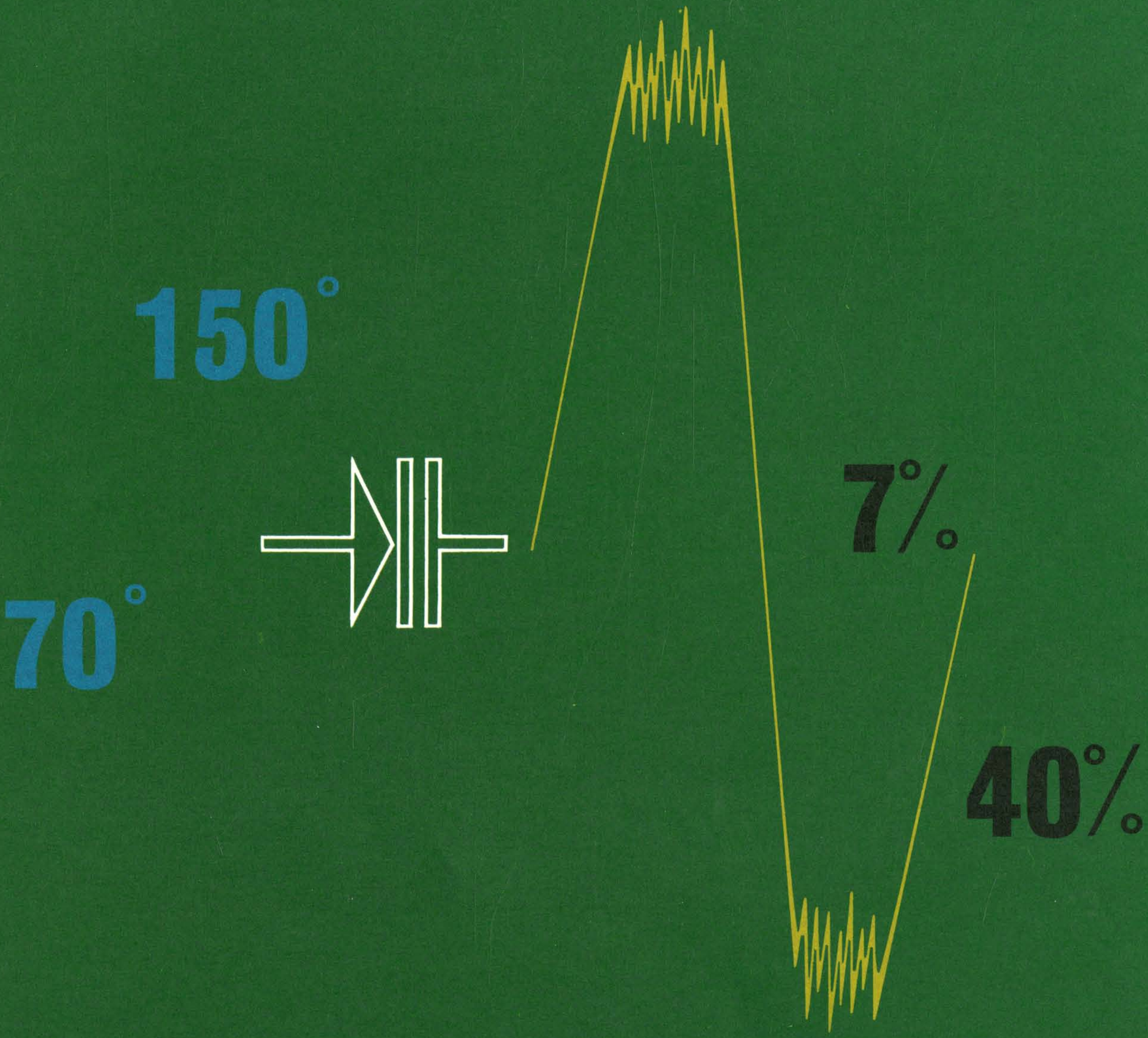
As the state-of-the-art of varactor development progresses, it has become increasingly necessary to design, characterize, and produce varactors especially for the end use intended. The close working relationship between the varactor design and harmonic multiplier groups at Microwave Associates has increased our overall knowledge of large signal varactor characterization to the point where we have now evolved a family of varactors especially produced for harmonic generation. The harmonic generator varactor must be designed to handle safely and efficiently the applied drive power. This requires high reverse breakdown voltages, low RF losses, and excellent thermal transfer capabilities. The harmonic generator makes use of time-dependent capacitances not only at the fundamental frequency but at the harmonics of the drive frequency as well. The entire voltage characteristic of the diode including the forward conduction region must be used when large input powers are applied.

The ideal varactor diode would have infinite capacitance with large charge-storage capacity in the forward direction, small capacitance in the reverse direction, a high breakdown voltage, no series resistance, and no delay in extracting stored charge. Our research programs for varactor improvement are aimed at this ideal, and newer models are now in sight which approach it more closely than any now on the market.

Varactor selection for harmonic multipliers can be accomplished by using the Preferred Junction Diode List described on the inside back cover of this brochure. Also shown is a list of Microwave Associates Solid-State Power Sources and Harmonic Multipliers.

Much information has been written on the importance of the particular laws of behavior of the capacitance-vs-voltage characteristic in the reverse direction while very little attention has been focused on the important phenomenon that occurs in the forward direction. Microwave Associates' multiplier varactors can be successfully driven into the forward region to a value approaching the contact potential, ϕ, without degrading performance by the addition of noise contributions. This has been possible due to carefully controlled manufacturing processes on the silicon material. The value of ϕ for these varactors is approximately +0.6 volt. When a varactor is driven positive, carriers are actually driven across the junction and can be removed on the next cycle provided that the "lifetime" of the material is such that they do not recombine. This effect, called "injection capacitance" occurs very abruptly between 0 and approximately +0.6 volt and gives an appreciable capacitance bonus when compared with operation in the negative bias region alone. In all Microwave Associates' silicon power varactors, use can be made of the injection capacity up to frequencies at least as high as X-Band.

At present, the "lifetime" of gallium arsenide varactors is not sufficiently long to provide useful "injection capacitance."



150°
70°
7%
40%

Bias

Self-bias is recommended with most practical multiplier circuits. As noted in Figure 7, it is usually desirable to shunt the varactor with a carbon resistor in order to provide a controlled DC path across which the bias voltage is developed. Such a self-bias circuit tends to accommodate wide variations in applied power and the slight change in DC characteristics as one varactor of the same catalog type is substituted for another. If possible, a bias resistor should be selected that allows the varactor to be fully driven and to take advantage of the tremendous charge storage capabilities of the region from 0 to +0.6 Volt.

Efficiency, Temperature and Noise

As previously mentioned, solid-state multiplier chains produce overall efficiencies that compare with reflex klystrons. The main advantages of solid-state chains include reliability, longer operating life, elimination of expensive high voltage power supplies and extremely stable operation.

Efficiency as a function of temperature is surprisingly stable. Tests have indicated that the tripler circuit described in Figure 7 decreased in overall efficiency by only 7 percent when the temperature was varied over a range of 150°C. The circuit was not retuned as the temperature was increased. If retuning is convenient, experiments have shown that less than a 1 percent change in efficiency can be accomplished when operating in the above temperature range.

When considering a complete multiplier chain, an overall decrease in efficiency of approximately 15 to 20 percent can be expected (without retuning) over a change in temperature of 70°C. This is somewhat remarkable when considering the number of stages involved. Another point to remember is that when comparing the efficiency of a doubler circuit in the UHF region to that of a C to X Band doubler, the difference may be as much as 40 percent. The lower efficiency of the microwave circuit is due to several reasons which include the usual microwave parasitic elements such as diode case capacitance, lead inductance and a lower cut-off frequency to signal frequency ratio.

An approximate theoretical rule for efficiency can be given which has good experimental support. This rule states that the conversion loss in db is approximately equal to the frequency change in percent of the cut-off frequency of the varactor. This relation applies to all orders of multiplication and can be applied also to entire multiplier chains if the varactors all exhibit the same cut-off frequency, although this is usually not the practical situation since higher cut-off frequency varactors are used in the high frequency stages. As an example of this rule, assume a quadrupler operating from 1 to 4 Gc with a 150 Gc varactor. This involves a frequency change of 3 Gc, or 2 percent. Accordingly, the varactor will be responsible for about 2 db loss and an additional 0.5 to 1 db loss can be expected due to miscellaneous reasons.

Recent noise studies were conducted in the S- and X-band regions with regard to a-m and f-m noise contributions in a specified bandwidth from the carrier. When compared to data taken from reflex klystrons in the same bandwidth, it was encouraging to note that the varactor solid-state power source noise contributions were lower. This fact is of prime importance for CW doppler and other radar systems where high signal to noise ratios are required.

Noise can be added due to low-frequency pickup which is up-converted (and usually amplified) as sidebands of the harmonics. Therefore, if fixed-bias is used, the leads must be carefully shielded. This is another reason why self-bias is usually preferred.

Power Handling Capability

Varactor frequency multipliers differ from tube or transistor multipliers in one major respect in that all the power in the output stage must be supplied by the driver whereas in the latter case some of the output power is supplied by the DC power supplies to the intervening stages. Such being the case (assuming no interstage amplifiers) the earlier (lower) frequency multiplier varactors are usually subjected to considerably more power than those used in the latter stages. Thus, power at the highest frequencies may be limited by the available capacity of the lower frequency stages, including the transistor drivers. As transistors and varactors further improve or where cost considerations dictate the use of hybrid tube/semiconductor systems the power handling capabilities of the varactors for all stages of multiplication must and will be increased.

The instantaneous reactive power handling capability is limited by breakdown voltage. Nominal reactive power is a useful term in estimating the power that can be transformed in frequency by a varactor.

$$\text{Nominal reactive power} = \frac{k}{2} F_{in} C_{min} V_B^2$$

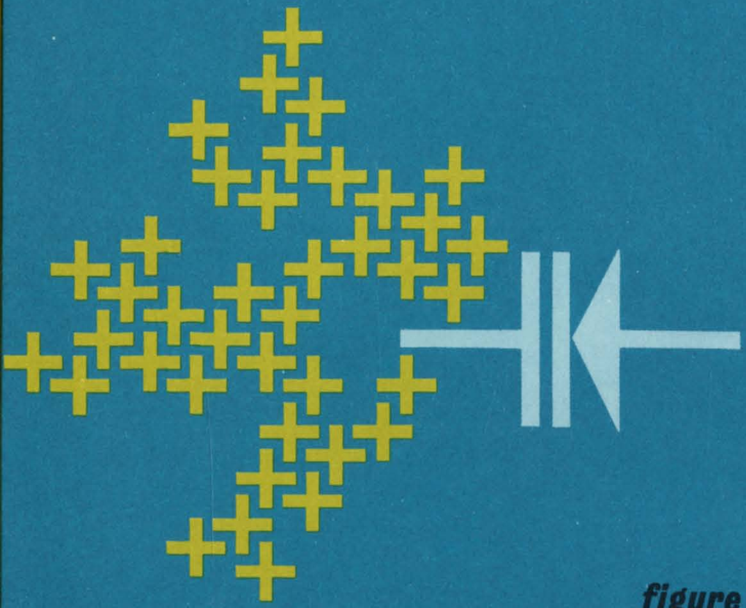
The value of k varies from 10 or more at VHF to 0.2 in the X-Band region.

In the VHF region, it can be expected that the "normalization power"

$$P_{norm} = \frac{(V_B + \phi)^2}{R_s} \approx \frac{V_B^2}{R_s}$$

will be a valuable rating.

In most multiplier circuits, the varactor is used in a configuration that involves an impedance of from 10 to 100 ohms with the majority of the cases favoring the lower end of the scale. Assuming no transformation, one can make some simple assumptions concerning the range of peak voltages to be encountered. It can



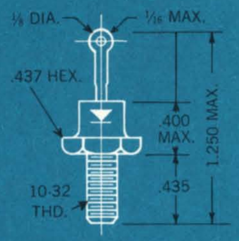
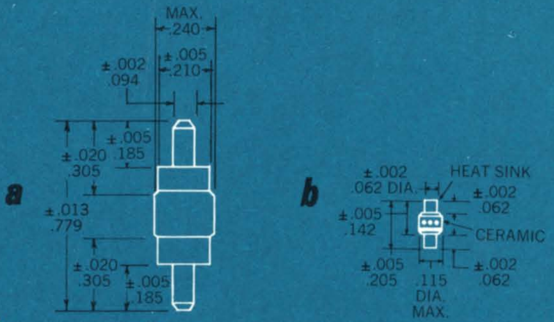


figure 10



STYLE C

STYLE D

figure 11

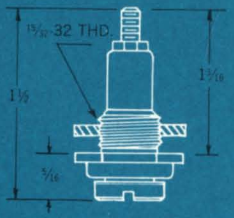
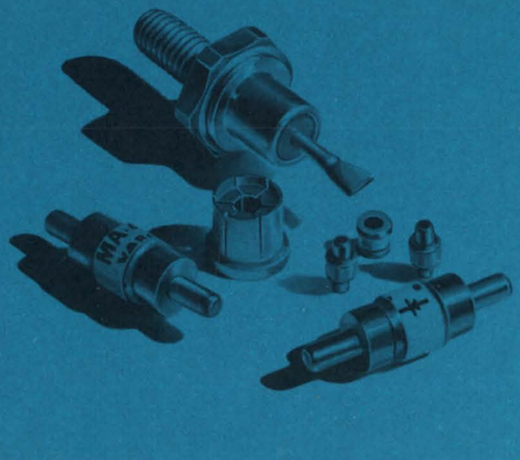


figure 12



easily be seen that 150 volts peak inverse will satisfy almost all applied voltages to be encountered in the practical case in the near future. Since increasing the voltage handling capability of a diode usually means increasing its series resistance (R_s) and RF losses, it is desirable to choose the lowest voltage diode compatible with the voltages to be encountered. Larger junction areas have the advantage of lower R_s and better thermal dissipation so that average power capability is approximately proportional to junction area. Charge storage or injection capacitance previously described also greatly increases the power handling capability of a varactor. Hence, in semiconductor processing for power varactors, particular attention must be paid to preserving the carrier lifetime characteristics of the completed diode in order to allow the injection capacitance phenomenon to occur without recombination effects dominating. The ultimate reactive power capability is so enhanced by the injection capacitance that the $i^2 R_s$ internal limitation is usually the controlling factor in determining the maximum CW power.

At Microwave Associates every effort has been made to reduce the losses in our power varactors, and, further, to use construction practices that combine high-temperature technology with excellent thermal paths for heat dissipation. For high power use in the region from 30 to 1500 Mc we have designed the MA-4060 and MA-4061 series of power varactors as shown in Figure 10. These are available in zero bias capacitance ranges from 5 to 80 pf. The diode utilizes a silicon wafer with excellent thermal, RF, and reliable characteristics. The contact is thermally bonded to the wafer and the case construction combines ceramic, for low RF loss, copper for its excellent thermal properties, and is hermetically sealed. The stud provides ease of mounting with excellent RF and thermal paths to ground along with providing the heat sink. This new varactor has met with great success because of its high performance, simplicity, and low cost. The MA-4060 and MA-4061 series are **all dynamically tested in actual power multiplier circuits before shipment** as part of Microwave Associates continuing effort to insure efficient frequency multiplication.

For lower powers the lower voltage style C cartridge, Figure 11a, is recommended with the higher capacitances used at UHF and the lower capacitance versions up to 4 Gc. As the capacitance of a varactor is lowered the thermal resistance of the path from the "top" of the diode generally increases. Our "High Q" series of cartridge diodes provides hermetic sealing, stable geometry, excellent heat paths, and low RF losses. This series can be mounted in waveguide, in series with the center conductor of a coaxial line, or in the MA-785 varactor mount as shown in Figure 12. This mount is designed for chassis use and provides excellent heat transfer and simple diode insertion. This holder is especially useful at frequencies up to 1500 Mc.

At frequencies over 4 Gc we recommend low voltage varactors in the Style D pill-prong package which exhibits low-loss distributed circuitry to take advantage of high cut-off frequency. This tiny package, shown in Figure 11b, is suitable for direct mounting into waveguide or for series or shunt use with coaxial or strip guide lines.

It is important to realize that at all frequencies the varactor art is rapidly improving. Hence, before selecting a varactor it is always advisable to review our latest "Recommended Junction Diode List" which is issued quarterly.

Also, there have been a few situations where a customer has incorporated experimental varactors on a production drawing and discovered that later diodes performed differently and are no longer compatible with the circuit. This probably resulted from improving the diode parameters such that the impedance characteristic shifted slightly. This can especially be a problem in narrow-band circuits. It is therefore most urgent that the factory be contacted before a final decision is made on a production drawing.

MODULATION OF HARMONIC GENERATOR SIGNAL SOURCES

Harmonic generator sources can be modulated in a variety of ways. These include frequency modulation, phase modulation, pulse modulation and amplitude modulation. Since a harmonic generator is inherently a nonlinear device, certain modifications and distortions may occur when a modulated signal is applied at the input. We will discuss the various classes of modulation in turn.

1. Frequency Modulation and Phase Modulation

Within the normal bandwidth limitations of the multiplier, frequency or phase modulation is always acceptable. It should be recognized that the deviation in frequency is multiplied along with the frequency itself. For example, a 100 Mc input signal which is deviated plus or minus 1 Mc might be multiplied by 96 to give 9600 Mc ±96 Mc. The modulation index is also multiplied by 96 when this occurs. Suppose this modulation were done at a 100 Kc rate. This rate is *not* multiplied. The output continues to be frequency modulated at a 100 Kc rate but with a much higher frequency deviation and modulation index.

For such modulation the bandwidth of *each stage* of multiplication must be sufficient, otherwise distortions will occur which may include simultaneous amplitude and frequency modulation of the output.

Phase modulation gives similar effects. If the phase of the input is shifted, the phase of the output will shift also, and the output shift will be greater by a factor equal to the total multiplication ratio.

2. Amplitude Modulation

Harmonic generators are inherently nonlinear. The output power is normally *not* proportional to the input power, and faithful reproduction of complex A-M waveforms from input to output must not be expected. Various harmonic generators differ widely in this regard. Some are capable of reproducing deeply modulated signals with acceptable "linearity" for passing intelligible voice frequencies, while others give drastic distortions of various kinds.

All such circuits show a "threshold" effect in that weak signals are passed with very poor efficiency. All show saturation effects at excessive drive levels. Some show sharp amplitude jumps as the driving level is smoothly increased. The tendency to exhibit discontinuities and strong distortion effects is more common in multi-stage devices than in single-stage units. Such effects are minimized by optimum coupling at input and output. In general, harmonic generators are capable of being modulated to a moderate degree by varying the input level so that amplitude-modulated waves can be multiplied provided the depth of modulation is suitably limited. With careful design, the range of proportional control can be extended considerably.

At our suggestion, a major manufacturer of microwave relay equipment applied a modulating signal directly to the multiplying varactor producing completely acceptable amplitude modulation. This practice is only recommended for the final stage of multiplier chains.

3. Pulse Modulation

Pulse modulation is a special case of amplitude modulation. Simple on-off pulses present no problems except that the transient conditions during rise and fall may distort the leading and trailing edges of pulses.

4. Frequency Shift Modulation

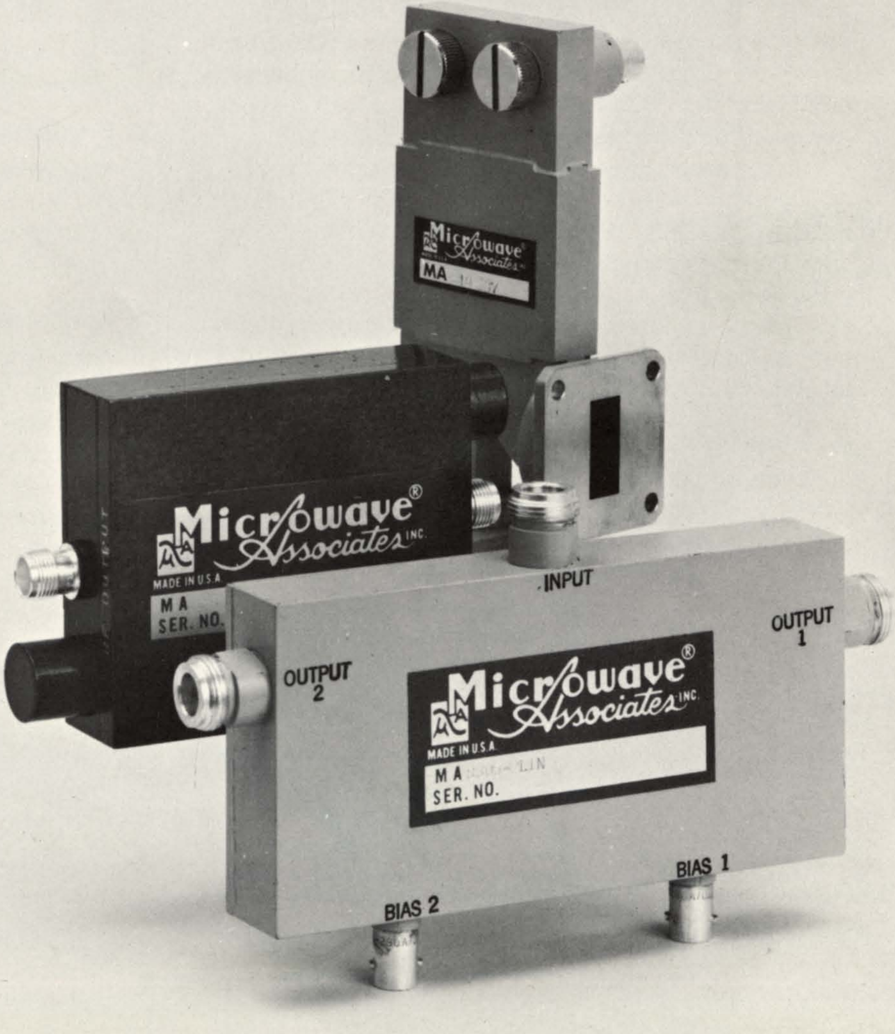
No problems are to be expected with frequency-shift keying provided the bandwidths of the various circuits are sufficient to handle the spectrum. This may be analyzed as a special case of frequency-modulation.

5. Single-Sideband Audio or Video Modulation

This case has not been fully analyzed but it is evident that drastic distortion is to be expected. Consider the hypothetical case of a single audio tone which is allowed to vary slowly in pitch from 1000 to 2000 cycles. With a standard single-sideband transmitter, the output would be a sine wave which would vary from 1 Kc above the carrier to 2 Kc above the carrier. If such a wave were multiplied in frequency, the output frequency would vary by a much greater amount, giving an unacceptable distortion of the audio wave. If a more complex single-sideband signal were applied, distortion products of various kinds can be expected as discussed below.

6. Phase-Reversal Modulation

A form of pulse modulation now becoming popular involves reversal of signal phase to distinguish between the two binary states. This system is advantageous in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MA
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OUTPUT 2
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MA
SER. NO.
BIAS 1
BIAS 2

that it makes better use of the peak power capabilities of the multiplier giving a signal which is on essentially 100% of the time, much as in FM. If the two signal phases are on an equal fraction of the time, all of the energy is in the information-carrying sidebands and the carrier is suppressed. Thus, the signal-to-noise ratio will be 6 db greater than an on-off pulse system. This system requires less bandwidth than FM or frequency shift keying techniques and therefore has a signal-to-noise ratio advantage over such systems.

Phase-reversal modulation can be applied at the input or at the output of a harmonic generator chain. It should be noted, however, that phase-reversal of the input will cause phase reversal at the output only if the total multiplication ratio is an odd number.

Detection of phase reversal pulse signals in a receiver requires special techniques to identify polarities and establish a proper time reference.

7. Other Modulation Effects

When the input wave contains two or more frequencies, the output wave may contain many extra frequency components because of nonlinear mixing effects. If the multiplication ratio is n and frequencies f_1 and f_2 are applied, the output will contain such products as nf_1, nf_2, $nf_1 \pm 2f_2$, $nf_2 \pm f_1$, etc. If a pure signal is desired, the input signal must be pure. In a multistage device, interstage filtering is recommended to prevent the transmission of undesired harmonic signals between stages. Unless this is done, the output will contain many harmonic components. Suppose that we use two quadrupler stages in tandem. If the second stage receives a signal which includes small amounts of the third and fifth harmonics as well as the fourth, these will mix in the second stage to produce an output containing the desired 16th harmonic plus small amounts of the 15th and 17th harmonics. These may be so close to the desired frequency that they can be filtered out of the wave only with some difficulty.

8. Modulation Methods

The discussions above apply to the case of harmonic generation when the input wave has already been modulated. As indicated, FM is acceptable in the input wave with no loss in efficiency, provided we do not exceed the bandwidths* of the various harmonic generator circuits. AM and pulse modulation can also be applied in certain cases although nonlinear distortions may be expected in the modulation envelope for high percentage modulation. We also indicated that a harmonic generator will give very serious distortions if the input is a single-sideband wave modulated by audio or video signals. If the signal is amplitude modulated in the output, the usual reduction in efficiency will apply.

It is possible to modulate the output wave of a harmonic generator signal source with an external semiconductor device. Such modulators have been built for a wide variety of applications of Microwave Associates. They include silicon junction diode phase shifters for phase modulation, "switches" for amplitude and pulse modulation and double-balanced modulators for generation of single-sideband signals. These devices are transmission networks in which a varactor diode acts as a variable capacitance or variable resistance element. By varying the bias on the diode, the capacitance can be changed at the modulating rate, generating variable phase shifts or variable transmission loss by detuning the network. When driven from a back-biased to a forward-biased condition, the diode changes from a small capacitance to a near short-circuit, causing a variable degree of wave reflection or absorption.

Single-sideband signals can be generated at the output of the harmonic generator by using a pair of balanced modulators in parallel such that they are driven 90° out of phase by both the drive and the modulating signal. The sum output in this case will give cancellation of one sideband and the carrier.

Single-sideband modulation can also be performed with ordinary modulators that include sharp band-pass filters which reject the carrier and one sideband.

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*Here, of course, we realize that the term "bandwidth" may not mean the same thing it normally represents in linear systems. There may be little or no connection between the "steady-state" measured bandwidth and the impulse response of such a nonlinear system.

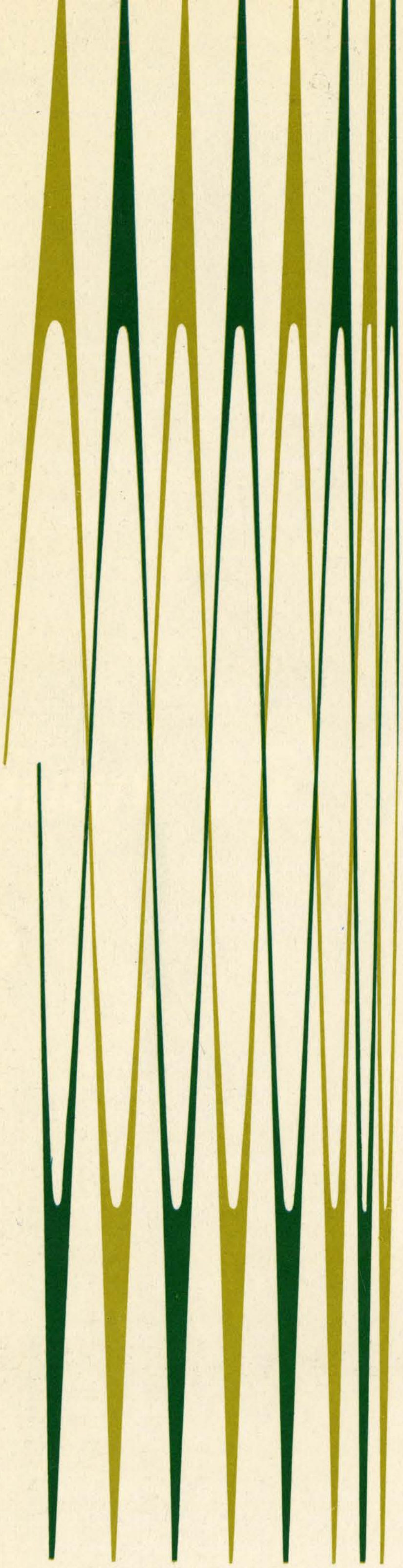
RELIABILITY

Varactor multipliers with their attractive small size and weight characteristics are particularly suitable for missile and satellite systems and have found wide usage in these applications. The reliability requirements of these systems have focused great attention on the varactor reliability even at this relatively early stage in its development. As a result, the assessment of the reliability characteristics of existing types and the improvement of these characteristics are of paramount importance.

A great deal of work is being done at Microwave Associates at the present time in both of these areas. The step-stress technique developed by Dodson and Howard of Bell Telephone Laboratories is being used extensively for our reliability assessment work. The method has the advantage that it requires a relatively small number of samples and provides information in fairly short times. It involves the exposure of samples to increasing stress levels to the point at which all samples have been destroyed. Extrapolation of this data to system stress levels provides estimates of failure rates at these levels. We are presently involved in a program sponsored by the Signal Corps evaluating a number of varactor types.

Improved packaging techniques appeared to represent the area in which significant reliability improvements can be affected. Data from the step-stress tests already completed have led to a number of package design improvements. The effects of these design changes are currently being evaluated.

The major importance of diode reliability and its effect on over-all multiplier reliability is clearly recognized. Active programs to improve diode design and construction on both a short-range and a long-range basis are in progress. It is expected that these programs will improve varactor reliability by orders of magnitude within the next year or two. For existing programs requiring high-reliability, pre-selected varactors which are submitted to environmental screening tests are available. Consult your nearest Microwave Associates' representative or the factory for information regarding these units.



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SUMMARY

Solid-state systems are relatively new and are becoming increasingly popular. This popularity has increased the demand for higher power transistors and varactors especially within the past year.

Remembering that Microwave Associates has the capability of producing complete solid-state multiplier chains along with refined varactor techniques, this combination results in improved customer service. Our circuit engineers are constantly investigating the quality of our varactors, resulting in improved circuits and better diodes. Also, having the capability of the circuits group, we can recommend basic design techniques to enhance your application requirements.

Recent improvements in varactor technology include higher power handling capability, improved efficiency and high reliability. These improvements result in higher power outputs in the microwave region, seriously competing with reflex klystrons, with an added improvement in stability.

It is apparent that the dual capability of Microwave Associates should be an incentive for design engineers to investigate the use of varactors or complete packaged varactor multiplier circuits in their systems. Our application groups are constantly available, and will be most happy to discuss your solid-state requirements.

Acknowledgements

We wish to acknowledge the assistance of the following government laboratories in sponsoring advances in the state-of-the-art of varactor and solid-state multiplier development: The Electronic Technology Laboratory of the Aeronautical Systems Command; Code 681 of the Navy Department, Bureau of Ships; and the Signal Corps Engineering Laboratories.

For the engineer who wishes to study varactor circuit technology in detail, we recommend the text Varactor Applications by Paul Pennfield and Robert Rafuse, M.I.T. Press, 1962.

VARACTORS FOR HARMONIC GENERATION

(Doubling, Tripling, Quadrupling)

VHF-UHF

Drive Frequency (Mc)	Drive Power (Watts) 25	20	10	5	2.5	1
30-60	MA-4061A	MA-4060A	MA-4060A	MA-4060A MA-4347G	MA-4060B MA-4347F	MA-4346F
60-120	MA-4061A	MA-4060A	MA-4060A	MA-4060B MA-4347F	MA-4347E	MA-4346E
120-240	MA-4061B	MA-4061B	MA-4060C MA-4347F	MA-4060C MA-4347E	MA-4347D	MA-4346E
240-480	—	MA-4061C	MA-4060D MA-4346F	MA-4060D MA-4347D	MA-4347C	MA-4346D
480-960	—	—	MA-4346E	MA-4346D	MA-4346C	MA-4346C

MICROWAVE

Drive Frequency (Mc)	Drive Power (Watts) 2	1	0.5	0.2	Case Style
1000-2000	MA-4355B1	MA-4355A1	MA-4354B1	MA-4353A1	D
2000-4000	MA-4355A1	MA-4354B1	MA-4354A1	MA-4352A1	D
4000-8000	MA-4354B1	MA-4354A1	MA-4352A1	MA-4351A1	D
8000-12000	—	—	MA-4352AA1	MA-4351AA1	D

All of the above power levels are practical, provided that adequate heat sinking is available to prevent exceeding the dissipation rating of the diode.

SOLID STATE MICROWAVE POWER SOURCES

PART NO.	DESCRIPTION	INPUT	OUTPUT
MA 8117	L-Band Crystal Controlled Source	28 V @ 500 ma	1.2-1.3 Gc* 1 Watt
MA 8118	S-Band Crystal Controlled Source	28 V @ 500 ma	2.5-2.7 Gc* @ 500 mw
MA 8103	C-Band Crystal Controlled Source	40 V @ 500 ma and 28 V @ 250 ma	3.7-4.2 Gc* @ 500 mw
MA 8106	X-Band Crystal Controlled Source	48 V @ 600 ma and 28 V @ 200 ma	8.2-9.6 Gc* @ 150 mw
MA 8109	X-Band Crystal Controlled Source	48 V @ 600 ma and 28 V @ 200 ma	7.6-8.2 Gc* @ 150 mw
MA 8110	X-Band Crystal Controlled Source	48 V @ 600 ma and 28 V @ 200 ma	9.6-11.5 Gc* @ 100 mw
MA 8101	X-Band Crystal Controlled Source	28 V @ 250 ma	8.5-9.6 Gc* @ 10 mw
MA 8113	VHF Quadrupler Multiplier	60 Mc @ 6 Watts	240 Mc @ 2 Watts min.
MA 8116	L-Band Multiplier X 16	75-82 Mc @ 6 Watts	1.2-1.3 Gc* @ 1 Watt
MA 8105	L-Band Multiplier X 18 (Broadband)	66-72 Mc @ 15 Watts	1.2-1.3 Gc† @ 2 Watts
MA 8122	Ke Band Multiplier X 144	~93 Mc @ 6 Watts	13.4 Gc @ 50 mw
MA 8119	S-Band Multiplier X 9	250 Mc @ 10 Watts	2.1-2.3 Gc* @ 2 Watts
MA 8120	S-Band Multiplier X 16	~140 Mc @ 3 Watts	2.1-2.3 Gc* @ 100 mw
MA 8121	C-Band Multiplier X 64	~64 Mc @ 10 Watts	3.9-4.2 Gc* @ 500 mw
MA 8108	X-Band Multiplier X 128	~60 Mc @ 12 Watts	7.6-8.2 Gc* @ 150 mw
MA 8104	X-Band Multiplier X 128	~67 Mc @ 12 Watts	8.2-9.6 Gc* @ 150 mw
MA 8107	X-Band Multiplier X 192	~55 Mc @ 15 Watts	9.6-11.5 Gc* @ 100 mw
MA 8102	X-Band Multiplier X 96 with Input Amplifier	~94 Mc @ 50 mw and 28 V @ 250 ma	8.5-9.6 Gc* @ 10 mw
MA 8112	L-Band Multiplier X 16 with Input Amplifier	~80 Mc @ 200 mw 28 V @ 500 ma	1.2-1.3 Gc* @ 1 Watt
MA 8114	VHF Crystal Controlled Transistor Driver	48 V @ 600 ma 28 V @ 300 ma	55-65 Mc* @ 14 Watts
MA 8115	VHF Crystal Controlled Transistor Driver	28 V @ 500 ma	90-100 Mc* @ 6 Watts

*Fixed Frequency Specified by Customer †Broadband Unit

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Studio IV

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