Summary  This paper discusses the performance of some recent R. F. power transistors as frequency multipliers and relates this information to their use in solid state V. H. F. and U. H. F. Telemetry Transmitters. The step-recovery diode is similarly discussed. Both devices are shown to have great promise for ultimately lowering the complexity, size, and price of Solid State S Band and L Band Telemetry Transmitters.

Introduction  Galloping solid state technological advances have hastened the development of the S Band Telemetry Transmitter to where it is becoming increasingly competitive with present V. H. F. Transmitters.

Improvements in two areas have been of great significance:

(1)  The Transistor Frequency Multiplier;
(2)  The P-N Junction Charge Storage Diode;

these two phenomena will be shown to be somewhat related.

Transistor Frequency Multipliers  With the arrival of the "overlay" transistor the transistor frequency multiplier may be considered to have come of age.

This device is an epitaxial silicon n-p-n planar transistor employing what the manufacturer terms as the overlay concept in emitter-electrode design. The emitter electrode consists of over a hundred microscopic areas connected together through the use of a diffused grid structure and an overlay of metal which is applied to the silicon die by a photo etching technique. The object of this technique is to obtain a very high emitter periphery to emitter area ratio, in order to obtain high efficiency at high frequency at comparatively high power level. We are speaking of power levels on the order of one to 20 watts.

As important as the excellent performance of this transistor may be, a side effect of this construction is of great significance.

This transistor functions as an extremely efficient frequency multiplier, even at high power levels. As an example, as a frequency multiplier from 125 to 250 MC, the 2N3375
demonstrates a collector efficiency of 50% and a power gain of over 8 db with a power output of 5 watts. This circuit is being used as a standard VHF doubler at Monitor Electronics Company. The 2N3632, containing two devices in parallel, may be picked to furnish 10 watts at 400 MC at 4 db power gain. This transistor used as a tripler may be expected to yield several watts at L Band. This same transistor will furnish over 12 watts at 280 MC at reasonable power gain. Used as a quadruplet approximately 3 watts may be expected at 1120 MC. A single varactor doubler will then yield approximately 1.5 watts at 2240 MC.

The transmitter shown in Figure 1 could be housed in a volume of approximately 30 cubic inches and the price would be moderate.

It is also possible to use the 2N3375 directly as a quadruplet and obtain a very significant power output at 2.25 GC.

Overlay transistors capable of furnishing 20 watts at 400 MC will be released shortly; in fact, two manufacturers are expected to release two similar but not identical devices with the above capability, both of which should open interesting possibilities of obtaining considerable power outputs at L Band and at S Band by means of transistor multiplication.

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Within a year it is expected that transistor devices will be available which will produce from 2 watts to 5 watts at S band. One of these will employ a transistor similar to the overlay type but with a built-in multiplying mode. Another employs a transistor deposited in and integral with cavity.

As to the mechanism by which the overlay transistor is so superior as frequency multiplier, it is almost certainly due to two effects, and we must speculate as to the relative role of each. These are:

1) Variation of collector-base capacity \( C_{OB} \) with collector to base voltage \( V_{CB} \). This results in a “conventional” varactor. See Figure 2

2) The resistivity profile of the collector-base diode is such as to also provide significant charge storage, resulting in a steprecovery effect. This will be discussed in more detail presently.

In addition to these affects, the effective series resistance of the collectorbase diode is comparatively low resulting in a high diode quality factor, necessary for efficient high
power frequency multiplication. Typically, the efficiency of the transistor frequency multiplier may be appreciated from the data given in Figures 3 and 4.

From this data, the transistor as a power amplifier and frequency doubler is 70% as efficient as a transistor power amplifier combined with varactor frequency doubler. Figure 5 is a r-f schematic of the diagram in Figure 4. Figure 6 illustrates a VHF transmitter employing a Transistor Doubler at the output. Efficiency of conversion from D. C. to R. F. approaches 40%.

Figure 7 illustrates a solid state S-Band transmitter employing transistor frequency multiplication.

**Step Recovery Multipliers** The next generation of transmitters may well employ the P-N junction change storage diode, otherwise known as the step recovery diode. Selected devices are now available that can yield one to two watts of R. F. power at S band with multiplication ratios of 5 to 10. Circuitry employing this device has two notable advantages over current techniques. First, reduction in circuit complexity with attendant simplification of component requirements, second, improvement in efficiency. It is possible at this time to achieve efficiencies of the order of 25 to 30 percent with multiplication ratios greater than 5 at 2.2 GC output. The derivative of designs using this device in high ratio multipliers would be ultimate cost and size reduction. It is anticipated that within the next year transmitters will be produced with a total volume of 15 to 20 cubic inches with 1 to 2 watts output at S Band.

These advances in telemetry transmitter design are possible because of the unique characteristics of step recovery diodes. This device is capable of more efficient production of high order harmonics than conventional varactor diodes. The conversion efficiency of the varactor diode is found to fall off at the rate of $1/N^2$ where $N$ is the harmonic number of the output. Because of this relationship it is advantageous to use a varactor diode in doubler or tripler circuits and cascade as many stages as possible. In the case of the step-recovery diode efficiency is proportional to $1/N$. Efficiencies have been demonstrated to follow this relationship in practice for multiplication ratios of 5 to 10.

The step recovery diode is a class of nominally silicon epitaxial diffused passivated devices which have been optimized for controlled storage with a very abrupt transition from reverse storage cutoff. Tens to hundreds of milliamperes can be switched in a nanosecond or less with this device. The optimum device useful to an S Band Transmitter should have a transition time small compared to 450 ns.

$t_i < 1/2T$ or $t_i < 1/2 450$ ns. Where $T$ is the period of the output frequency.
The lower the value of the transition time, the higher the efficiency; manufacturers are delivering selected devices with 150 to 250 ns transition times which yield acceptable efficiencies. A second requirement for efficient operation is that the minority carrier lifetime must exceed the period of input frequency. A recommended ratio of minority carrier lifetime to input periods is a factor of 10.

\[ T \geq 10T_{in} \] Where \( T_{in} \) is the input period.

Again his value will be a compromise by selection. Fifteen to 25 microseconds is an available range at this date and will provide acceptable efficiencies for multiplication ratios of 5 or greater with output at S Band. Assuming the above relationships can be met as well as proper matching to a cavity load the efficiency expected for the X 10 multiplier can be expressed by the following equation:

\[ \text{Efficiency} = \frac{T}{N} \]

The efficiency therefore expected for a X 10 multiplier would be in the order of 30 percent.

Figure 8 shows a schematic and approximate physical drawing of a practical X10 multiplier. A similar device has been constructed and yields efficiencies of 25 to 30 percent.

Fig 1 Transmitter Block Diagram
Fig 2 Varactor Curve

2N3375 transistor in power amplifier varactor diode in doubler

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1 watt
125 MC
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2N3375
Power Amp.

Varactor Diode
Doubler
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10 watts
250 MC

Collector input power = 0.5A x 28V = 14.0W Overall efficiency = 67%

Fig 3 Transmitter Output Stages
2N3375 transistor as power amplifier and frequency doubler

1 watt 2N3375 Power Amp & Doubler 7 watts
125 MC 250 MC

Collector Input power = .5A X 28V = 14W Overall efficiency = 47%

Fig 4 Power Amplifier

USEFUL FREQUENCY DOUBLER;
R. F. CIRCUIT

Fig 5 Frequency Doubler

Fig 6 VHF 3 Watt Transmitter With Transistor Doubler
Fig 7  S-Band 2 Watt Transmitter With Transistor Doubler

Fig 8 Multiplier