Conclusions

Frequency multipliers of the conventional vacuum-tube type are impractical for generating harmonic even of the 5th order. This limitation comes because the driving power becomes prohibitively large for these high order harmonics.

A practical solution to this problem, however, is found in driving the multiplier with preshaped pulses. This has the following advantages over the conventional drive method.

(1) It offers, besides the advantage of higher harmonic output and plate efficiency, the possibility of operation at harmonic number of 10.

(2) Since the pulses are preshaped, the grid bias required to produce a certain angle of plate current flow is very small and remains the same for all angles of current flow. The same is true also of the grid drive voltage.

Convincing proof of the above is provided by the successful design of the multipliers generating as 10th harmonic the frequencies of 2, 20 and 100 Mc/s.

The author made a theoretical study of this system for drive currents of three different waveshapes. The important conclusions reached in this connection are the following :

(1) The optimum amplitude for a given harmonic order 'n' is generated only for a certain critical value of the ratio (d/T)

of the plate current. In the case of currents with Isosceles Triangular and Rectangular waveshapes, the two parameters decrease in inverse proportion to the order of the harmonic. In the case of Fractional sine wave current pulse, this relationship nearly holds good for all harmonics but not for the fundamental.

(2) The efficiency of harmonic conversion from d-c is constant for all harmonics in the optimum condition. Furthermore, its value calculated for currents of three different waveshapes (cf. Table 2.9) do not differ appreciably from one another. This means that one need not worry much about obtaining an exact shape of a particular current pulseform. An over-all shape of the current pulseform (and hence of the driver pulseform) approximating to the one desired will produce essentially the same results.

(3) The amplitude of the fundamental becomes a maximum for a pulse of plate current lasting for half a cycle in the case of Rectangular pulse, as may be expected, but greater than half a cycle in the case of Triangular and Fractional sine wave pulse waveform. This means that the maximum power output in the case of Fractional sine wave and Triangular pulse drives, is not obtained by running the tube in the conventional class-B condition. It occurs at a value of grid bias a few volts smaller than the cut-off bias. The class-B operation ensures the maximum ever attainable power only in the case of Rectangular pulse drive.

The output voltage of the multipliers show fluctuations in amplitude, exponential in time, at the fundamental frequency. This has been confirmed by the theoretical study of the multiplier presented in chapter 3. The fluctuation in amplitude is also found to become increasingly noticeable with the order of the harmonic. This is observed to limit the usefulness of the multipliers at high harmonics. In the multiplying device, where the outputs are developed across a resonant load, these features ought to have figured invariably. Surprisingly, these hardly seem to have been appreciated in literatures.

As stated earlier, with pulse drive, the generation of harmonics of any order is theoretically possible. In the 2 Mc/s multiplier shown, a harmonic of the order of 40 was not found impracticable. Nevertheless, it is found disadvantageous to go for harmonics beyond about the 20th order. This limitation comes in, because the stability question of tuned circuits comesin and one must be sure to tune the desired 20th harmonic correctly and never the 19th or 21st even by accident. Above the 20th harmonic, the last positive half cycle of the multiplier output also failed to drive the limiter tube into saturation.

The variation in the peak amplitude of multiplier output with harmonic frequency has also been computed theoretically. This has been done in both the cases of operation (chapter 4) of this multiplier. The calculation shows that, in the operational mode-1, the peak amplitude of the harmonic voltage decreases by a factor $1/[1-e^{-N\delta}]$ with the order (N) of the harmonic. When operated in mode-2, the variation is not found as straightforward. It turned out to be a function of the frequency dependent variables Z_L, C, t_d and Q. To make ~~the above~~ these calculations possible, a rectangular current drive was assumed through the output circuit of the multiplier. The current waveform actually obtained and used was approximately triangular (cf. Fig.5.3). Nevertheless, the agreement between the calculated and the observed variation is found reasonably good. This further justified the foregoing evidence that, in the case of short duration pulse drive, the shape of the pulse has seemingly unimportant effect on the operation of the multiplier.

The generation of 20 Mc/s harmonic from an input frequency of 2 Mc/s, however, posed practical problems of some difficulty. According to Eq. (3.21), the driver pulses shorter than 0.05 μ sec at 2 Mc/s would be necessary. Here, the use of a condenser-input type rectifier in place of the Schmitt-trigger-differentiator, as pulse shaper, proved advantageous. Besides, because of the reduced tank impedance at 20 Mc/s, the output voltage gets smaller and satisfactory operation of the limiter becomes difficult for harmonics much higher than the 10th order. However, the use of high transconductance E180F tubes in both the harmonic generator and limiter positions gave a thoroughly practical 10th harmonic generator.

The generation of 70, 80, 90 and 100 Mc/s from a fundamental frequency of 10 Mc/s, in satisfactory amplitudes was also accomplished. The amplitude of the pulses from the diode clipper circuit became rather small when pulse duration less than 14 nsec was attempted. Adequate drive for the E180F multiplier was secured however by pressing into service a two-stage wide band transistor pulse amplifier developed by my colleague Dr. S. C. Nath. It is possible that such an amplifier will prove unnecessary for the newly developed high transconductance tube E810F. For very peculiar reasons, this tube remained unavailable to the author till the submission of this thesis.

Lastly, high order harmonic generators show certain features which are never felt in the operation of the more usual second and third harmonic generators. This arises because of the more pronounced exponential decay in the amplitude of the harmonics as primarily generated. While the final output from the limiter, is sinusoidal and unvarying in amplitude, mistuning in the limiter tank circuit shows up this amplitude variation. Accurate tuning of these circuits is therefore important.

In what has been said above, the new findings of this investigation has been summarized. However, this thesis will remain incomplete without a discussion about semiconductor diode varactor frequency multipliers. Present day world attention is strongly focussed on this new device and its possibilities weigh so heavily on the minds of every one concerned that this work may miss the attention it deserves. It is therefore necessary to assert that its findings will be of value in an area which the varactor diode cannot encroach.

Varactor diodes are frequency converters which transform power at a lower frequency to a higher frequency with <u>significant loss</u>. Tube and transistor harmonic generators will convert d-c power into the desired high frequency power and will <u>provide gain</u>

when the low-frequency drive is compared to the high frequency output. This gain is considerable at frequencies below a hundred megacycles. High order harmonic generators are therefore practical in this range, for powers in excess of a few watts. Varactor diodes will surely occupy the field for powers below a watt. It is not expected that a crystal controlled oscillator of good stability will generate more than a watt. If higher powers are needed, tube and transistor amplifiers will be called upon to do that. If the frequency needed is higher than what a stable crystal will produce, the frequency must also be multiplied. This is the area which the varactor diode cannot occupy and power amplifying multipliers will hold their own.

Lastly, the varactor diode is still very costly. It is not yet available to the author who would like to use it, in the later stages of a developmental microwave frequency standard. The basic stable frequency of this standard would come from a 100 Kc/s secondary frequency standard (G.R. 1100 AQ). Multipliers with factors of five will take the frequency to 62.5 Mc/s, and 6AK5 tube multipliers with factors of two will be used to carry the frequency to 250 Mc/s. R.C.A. 5876 pencil triode doublers costing $ 6.04 will carry the frequency to 1000 Mc/s and then the question of varactors (V6000 series) costing in excess of $ 30 comes in !