CHAPTER IV

SECOND HARMONIC GENERATION AND TANDEL EFFECT

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4.1 Introduction:

The ferroelectric materials whow strong anomalies in dielectric constant and therefore can be used to build the special devices. Second harmonic generation has been previously studied in various ferroelectrics. The phenomenon of second harmonic generation was discovered by Miller (1964) in $BaTiO_3$ Vanderziel (1964) in KDP, Smith (1964) and Suvorov (1968) in TGS. The dielectric nonlinearing of ferroelectric triglycine sulfate (TGS) was studied in a circuit of a ferroelectric frequency multiplier in the radio frequency range by A.M. Vincent (1951). Glanc et al (1963) reported that triglycine sulfate can be used as a thermoautostabilized nonlinear dielectric element (TANDEL). If we increase the magnitude of the a.c. signal applied to the ferroelectric material, the dielectric heating takes place and this raises the temperature of the material to near Curie temperature. In the neighbourhood of Curie temperature the losses begin to fall and as a result the material stabilizes its own temperature. It stabilizes its own temperature. It stablizes at a crystal temperature near Curie temperature where the nonlinearity is usefully high; the signal magnitude can then be lowered below the critical value without loss of that stable state. The device can replace varactors as circuit elements in modulators, frequency multipliers and dielectric amplifiers. It may be used direftly as a thermostat.

The TENDEL effect has been observed in $BaTiO_3$, TGS and KH_2PO_4. This effect can be used in several applications. Blanc et al (1963) had reported that the element has various applications e.g. in frequency multiplier, frequency mixer, frequency modulator, dielectric amplifier, electrometer, electromechanical transducer etc. TANDEL as a new electronic element offers possibilities for microminiaturization and assembling into micro modules and its shock-resistance is outstanding. Other prominent features , in contrast to the semiconductors, are a high d.c. imput resistance insensitivity to power overloading and a simple production technology.

Abe Z, et al (1971) had examined the possibility of using a second harmonic type modulator, made of ferroelectric material as an electrometer. Dolino G. et al (1969) had reported that during second harmonic generation of Ruby laser light in ferroelectric TGS, angular scattering by ferroelectric domains has been found in the plane perpendicular to the polar axis. The influence of an applied d.c. electric field on the generation and the scattering of second harmonic has been measured and it has been indicated that changes in domain structure can be studied by this method.

TANDEL was also studied by Glanc et al (1963,1964a, 1964b), Fousek (1965) and Malek et al (1964). Mansingh and

Eswar Prasad (1977), Chavan and Patil (1980) studied the proportionality of the electrical second harmonic generation in the autostablized state of ferroelectric TGS to the square of the applied a.c. voltage. But no such variation has been observed. The explanation of this comes from the basic TANDEL behaviour. It adjusts its impedance against variations of applied a.c. voltage.

This effect can best be understood with reference to Fig.4.1, which represents the temperature dependence of the dissipation of a ferroelectric crystal switched with an alternating signal. The three curves marked W_2 , (which show a peak around the Curie point T_C) represent the heat produced in the crystal by the alternating field, for three different values of the applied voltage. Part of this heat is due to normal dielectric losses and part to hysteresis losses. The straight line marked W_1 represents the heat lost by the crystal because of conduction and convection losses. Consider the intersections 1, 2 and 3 of the straight line with the middle one of the three lines W_2. These three intersections represent points at which the heat produced is equal to the heat lost, thus representing points of thermal equilibrium for the ferroelectric. It can be shown that 1 and 2 are points of stable and 3 of unstable equilibrium. Because of the steep decrease of the curves W_2 above T_C , the temperature of the crystal (if this is in the state 2) is extremely well stabilized

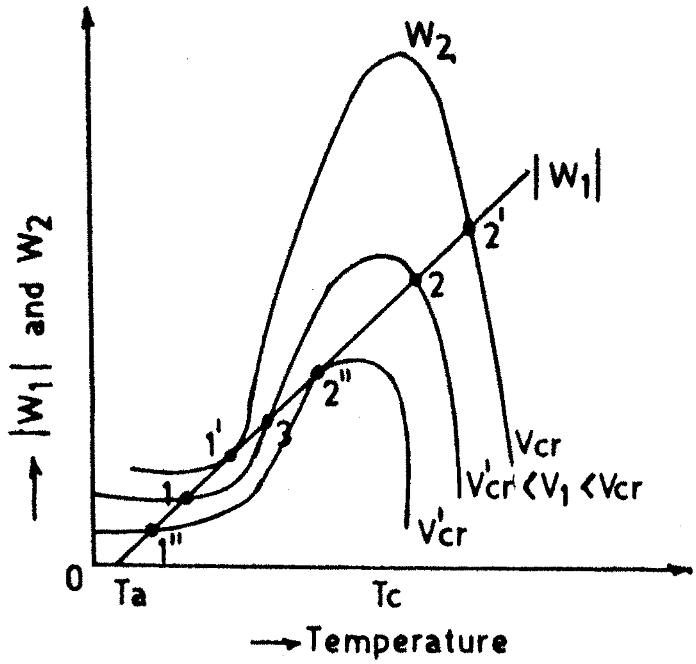

Fig.4·1: The curves W_2 shows the power dissipated in the crystal as a function of temperature, for three different values of the applied voltage. The line $|W_1|$ shows the power lost by the crystal to the surroundings. The curie point is Tc and room temperature Ta.

against fluctuations of the ambient temperature Ta i which tend to shift the straight line parallel to itself. It should be noted, however, that the applied voltage may be so high or so low that the corresponding W_z curve lies above the top curve or below the bottom curve of Fig.4.1. In this case there is only one stable temperature at which the crystal can operate (2 or 1).

4.2 Analysis of Second Harmonic Generation:

Matsuo and Terashima (1956) described the generation of second harmonic in ferroelectrics by approximating the nonlinear relationship between P and E to a hyperbolic function without considering operating temperature. Abe et al (1971) estimated the efficiency of conversion of d.c. imput to second harmonic by taking into consideration the temperature of the ferroelectric. According to Devonshire (1950,1954) the nonlinear relation between P and E of ferroelectrics in the vicinity of the Curie point is expressed as:

$$E = 2A(T - T_c)P + 4BP^3 \qquad ---- \qquad (4.1)$$

Where E is the electric field, P is the induced polarization, T is the temperature of the ferroelectric, Tc is the Curie point temperature and A and B are material specific constants. If constant current having a pure sinusoidal wave with an angular frequency W and small d.c.

voltage are fed to a ferroelectric capacitor in superposition, the polarization of capacitor is given by

$$P = P_o + P_W \, CoS\, \omega t \qquad ---- \qquad (4.2)$$

Electric field across the capacitor is obtained by putting equation (5.2) in equation (5.1),

$$E = \left\{ 2A(T-Tc) \;(Po + P_W\, CoS\,\omega t) + 4B\,(P_O + P_W\, CoS\; 2\omega t)^3 \right\}$$

$$= \left\{ 2A(T-T_C) + 4BP_O^2 + 6\; BP_W^2 \right\} P_o$$

$$+ \left\{ 2A(T-T_C) + 12\; BP_O^2 + 3\; BP_W^2 \right\} P_W \; coswt$$

$$+ 6BP_O \, P_W^2 \; CoS\; 2\; wt + BP_W^2\; CoS\; 3wt \qquad ---- \qquad (4.3)$$

If we connect the TANDEL element having a capacitance C in the series with a small resistance R, so that WCR 1, then the output voltage V_O across the resistor on applying an a.c. voltage V is given by

$$V_O = W\,C\,R\,V$$

$$= W\,C\,R\,E\,d \qquad ---- \qquad (4.4)$$

Where d is the thickness of the crystal. If we assume that the resistance R is so small that the conditions of polarization are not influenced by it, the relation between electric field and polarization is still given by equation (5.1). Then second harmonic voltage V_{2h} across the resistor can be

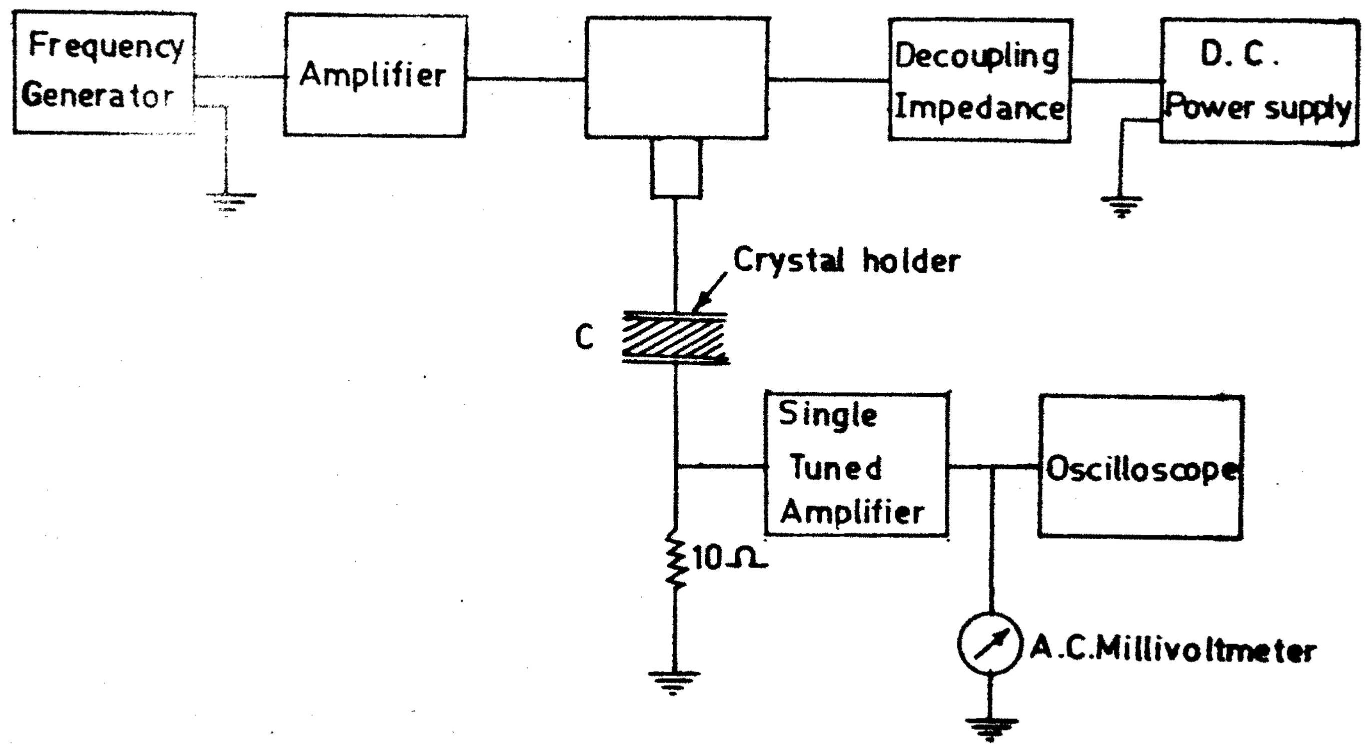

Fig. 4·2 : Experimental set up for Tandel.

obtained by replacing E in equation (5.4) Wt in equation (5.3) and is given by

$$V_{2h} = 6\ W\ C\ R\ d\ B\ P_o\ P_W^2\ \text{CoS}\ (2\ Wt) \quad ---- \quad (4.5)$$

It can be seen from equation (5.5) that the generated second harmonic is proportional to P_o (which is proportional to the applied d.c. bias) and to P_W^2 (proportional to the square of the applied a.c. voltage). The result of the equation (5.5) has been successfully used only for a qualitative explanation of the experimental results.

4.3 Experimental:

In the present problem, we have studied the voltage response of the TANDEL elements $NaVo_3$, KVo_3 connected in series with a pure resistor of 10 ohms. The block diagram of the experimental set up is as shown in Fig.(4.2). The pellets of above materials having thickness 1 mm. were placed in the crystal-holder. The electrodes of the crystal-holder were made conducting by using coating of silver-paste. A frequency of 10 Khz was used in the entire course of investigations and a single tuned amplifier was adjusted at 10 KHz. The frequency generator used was Philips GM 2308 type whose maximum a.c. output is 90 volts. The filter circuit consisting of inductance in series and capacitance in shunts was used as decoupling impedance. The a.c. millivoltmeter (Philips-pp90(was used for the measurement of voltages across the resistor.

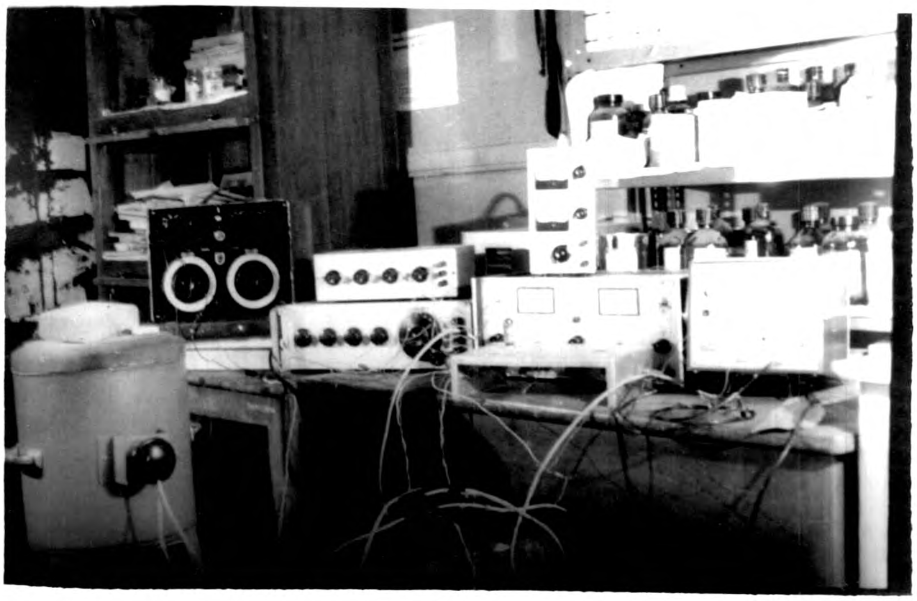

Fig: 4·3

The temperature controller arrangement was used to maintain the exact temperature in the neighbourhood of Curie point. This experimental arrangement is as shown in the Fig.4.3.

4.4 TANDEL of $NaVo_3$:

For $NaVo_3$ - TANDEL , the minimum peak voltage for autostabilization was found to be 25 volts. Hence three amplitude levels 30, 35 and 40 volts peak were selected for the present studies. The ambient temperature was 378 $^{\circ}$C. The variation of the second harmonic voltage with d.c. bias for various peak voltages is shown in Fig.4.4.

4.5 TANDEL of KVO_3 :

In order to study KVo_3 -TANDEL, the minimum peak voltage for autostabilization was found to be 20 volts. That is why we selected three amplitude levels at 25, 30, 35 volts. The ambient temperature was maintained at 310 $^{\circ}$C by using temperature controller arrangement. The variation of the second harmonic voltage with d.c. bias for various peak voltages is as whon in Fig.4.5

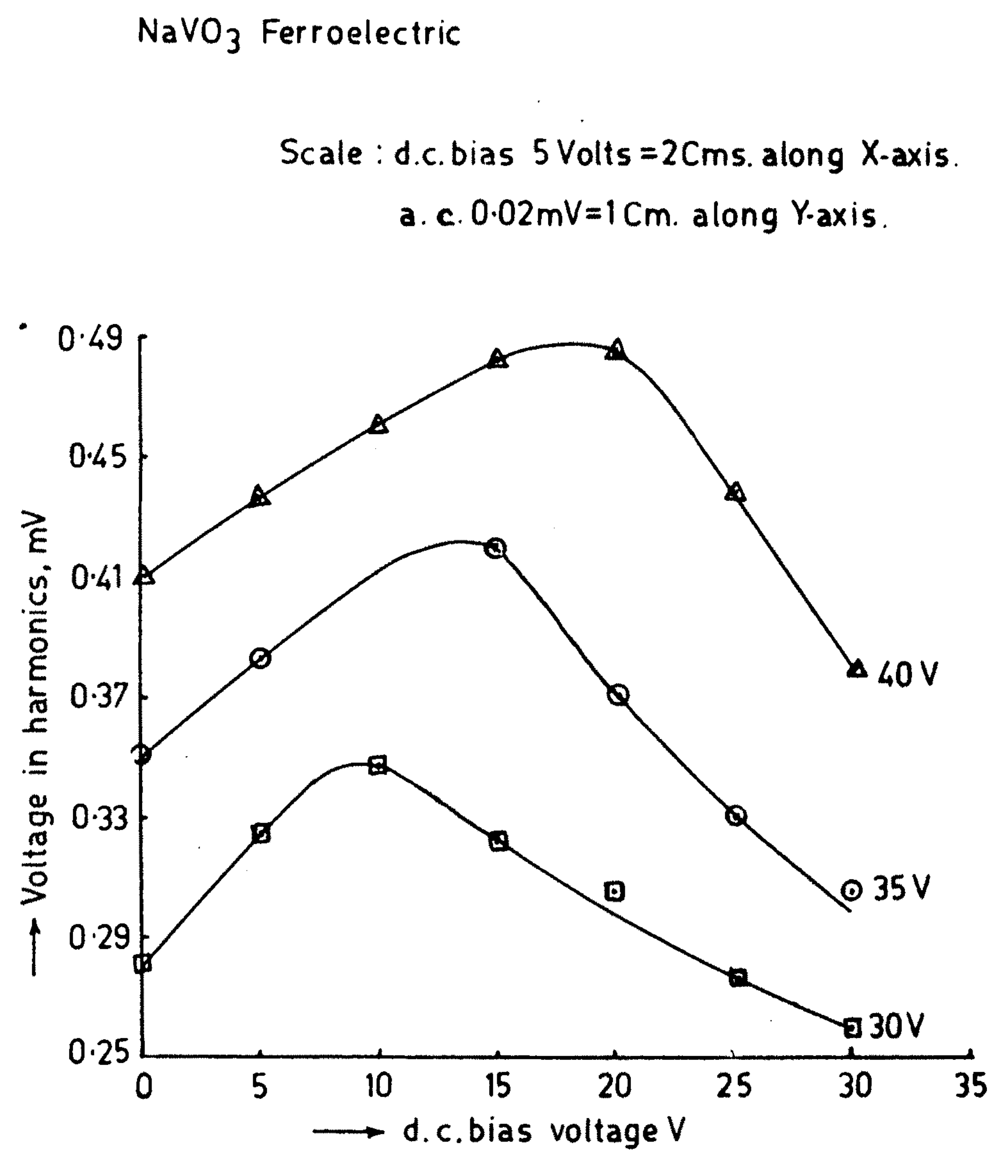

Fig 4·4: The variation of second harmonic voltage with d.c. bias for different a c voltage (Volts Peak) ⊡30 V, ⊙35V, △40V.

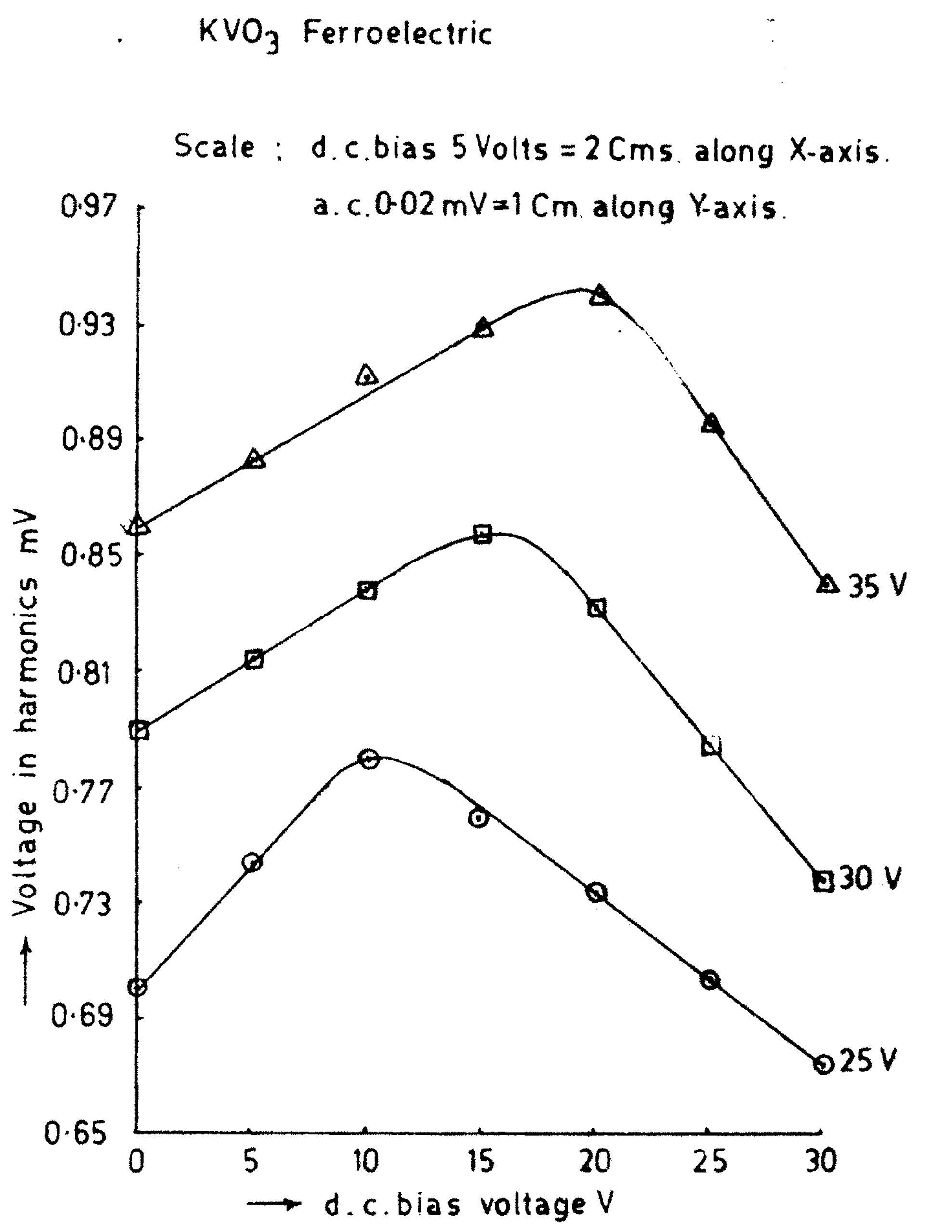

Fig.4·5: The variation of second harmonic voltage with d.c.bias for different a.c.Voltges (Volts Peak) ⊙25V, ⊡30V, △35V.

The list of experiments conducted on $NaVo_3$ and KVo_3 TANDELS is given in Table 4.1 in order to get a comprehensive view of various TANDEL experiments.

TABLE 4.1

Variation of Second Harmonic Voltage with d.c.bias

Substance	Threshold peak voltage for autostabilization (Volts)	Peak a.c. voltages (Volts)	Magnitude of second harmonic at zero bias in (millivolts)	Magnitude of d.c. bias for going out of autostabilization (Volts)
		30	0.28	11
$NaVo_3$	25	35	0.35	16
		40	0.41	21
		25	0.70	10.5
KVo_3	20	30	0.79	17
		35	0.86	21.5

4.6 Results and Discussion:

If we observe the figures 4.4 and 4.5 of the second harmonic voltage response for $NaVo_3$ and KVo_3 TENDEL elements then we see that the second harmonics generated are linear with the applied d.c. voltage as predicated by the equation 4.5 for low biasing fields. Similar results were reported by

Malek et al(1964), Mansingh and Eswar Prasad (1977) and Chavan and Patil (1980). But this does not hold good at higher biasing voltages; the results deviate from that of linear second harmonic. The amplitudes of the second harmonics get decreased at higher biasing voltages.

Every second harmonic curve has a linear region and this linearity is increased by increasing the values of heating a.c. voltages. This fact can be explained as follows:

At low biasing fields the P_W polarization is counteracted by d.c. bias field so that the second harmonic is generated. At high biasing fields also the polarization is counteracted till the material does not fall out of the state of autostabilization. But as a.c. voltage is increased, higher d.c. bias voltage should be required for driving the material out of state of autostabilization. This was explained by Malek Z. et al. (1964).

From equation (4.5), it can be revealed that generated second harmonic should be proportional to the square of the applied a.c. voltage; but in the present investigations such variations were not observed. The basic TANDEL behaviour provides an explaination for such results. The TANDEL adjusts its impedance against variations of applied a.c. voltage, so that product CP_W^2 in equation (4.5) remains constant and this is consistent with the theory of TANDEL outlined by

Dvorak et al (1964). It can be very easily observed from the figures 4.4 and 4.5 that when d. c. bias voltage is zero, there is still some second harmonic output. This is in agreement with the result of Abe Z. et al (1971), Mansingh and Eswar Prasad (1977) and Chavan and Patil (1980). They have attributed this off-set to the presence of defects, giving rise to an internal bias which in turn generates a second harmonic.

Our results establish that $NaVo_3$ and KVo_3 can be used as TANDEL elements which provide the autostabilization state.

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