all the components of F_{ij} vanish except F_{23}. Because of the axial symmetry A_σ is independent of ϕ and Z and then from (8) follows $F_{23} = 0$. Hence the contribution of F_{ij} to T_{ij} is nil.

In the above case the axially symmetric field solutions of Rosen's theory turn out to be vacuum solutions. This is a remarkable result. In general relativity only the mass parameter of the complex scalar field vanishes (see Rao *et al.*[3]), but in bimetric relativity distribution corresponding to complex field as well as electromagnetic field yields only an empty space-time. Then follows a theorem:

'In Rosen's bimetric relativity the only possible solution of the axially symmetric fields—complex massive scalar field, Maxwell electromagnetic field is a vacuum solution.' The word axial symmetry is, however, related to E–R metric (3) and not to the most general cylindrically symmetric Marder's metric which involves three parameters.

The theorem established by us in our previous work[4] follows from the above theorem as expected.

Department of Mathematics, Nagpur University, Nagpur 440 010, T. M. KARADE. Y. S. DHOBLE.

May 24, 1979.

* In bimetric theory ordinary differentiation of general relativity is replaced by γ-differentiation.

1. Rosen, N., "Bimetric theory of gravitation," *Topics in Theoretical and Experimental Gravitation Physics*, Edited by V. De Sabbata and J. Weber, Plenum Press, New York, 1975, p. 273.
2. Karade, T. M., *Rev. Roum. Phys.* (*Rumania*), 1978, 23, 425. Reprinted: POST–RAAG Reports No. 79 (Japan), 1978.
3. Rao, J. R., Panda, H. S. and Nayak, B. K., *Aust. J. Phys.*, 1975, 28, 353.
4. Karade, T. M. and Dhoble, Y. S., *Non Existence of the Axially Symmetric Massive Scalar Fields in Rosen's Bimetric Theory of Relativity*, Communicated for publication, 1979.

A METHOD OF DETERMINING THE SOURCE SPECTRUM OF THE RETURN STROKE OF ATMOSPHERICS

THE return stroke of a lightning discharge emits electromagnetic signals, called atmospherics that usually attain a spectral peak within the V.L.F. region, *i.e.*, 3 to 30 KHz. Source spectrum of lightning discharge has been determined by many workers using different techniques. Chapman and Mathews[1] showed that the radiant energy from the return stroke has the spectral peak around 5 KHz which has been verified by Taylor[2]. From the whistler studies, Helliwell, *et al.*[3] have obtained a spectral peak around 5 KHz. Many workers[1–8] have given different expression for the current waveforms of the return stroke which gave spectra having peak in the range of 2·5 to 11 KHz. In the present communication, a method is suggested for evaluating the source spectrum of the return stroke of the lightning discharge.

The waveforms of the atmospherics were photographed at Waltair using the atmospheric waveform recorder at night during the period March, 1976 to March, 1977 using a wide-band technique along with the direction of arrival of atmospherics by Radio Goniometer. The recorded waveforms after necessary enlargement are subjected to Fourier analysis at the intervals of 1 KHz using IBM 1130 digital computer to yield the amplitude in the frequency range 1–30 KHz. The source distance of atmospherics is evaluated following the methods given by Caton and Pierce[9] and Hepburn[10].

Assuming that only single dominant mode essentially contributes to the received field (Frisius and Heydt)[11], the amplitude, $F(f,\rho)$, is given by

$$F(f,\rho) = g(f) \times \frac{600}{h} \sqrt{\frac{\lambda}{r_t \sin \frac{\rho}{r_t}}} \times |\Lambda_1(f)| 10^{\frac{-A_1(f)}{20}\cdot\rho} \quad (1)$$

where $g(f)$ = source spectrum, h = ionospheric height, λ = wave-length, r_t = terrestrial radius, $|\Lambda_1(f)|$ = excitation factor of the dominant mode, ρ = distance and $A_1(f)$ is the attenuation factor at frequency f.

Further the spectral amplitude ratio, SAR, between two frequencies f_1 and f_2 is given by

$$20 \log \frac{F(f_1,\rho)}{F(f_2,\rho)} = 20 \log \frac{g(f_1)\, h(f_2) \sqrt{\lambda_1}\, |\Lambda_1(f_1)|}{g(f_2)\, h(f_1) \sqrt{\lambda_2}\, |\Lambda_1(f_2)|} - [A_1(f_1) - A_1(f_2)]\cdot\rho \quad (2)$$

where suffixes 1 and 2 represent the parameters for frequencies f_1 and f_2. Hence for a particular atmospheric

$$SAR = \text{constant} - [A_1(f_1) - A_1(f_2)]\cdot\rho. \quad (3)$$

The above equation shows that the SAR is a linear function of distance of travel and the constant is equal to the first term on the right hand side of equation 2. It has been proved[12] that the reflection heights $h(f_2)$ and $h(f_1)$ do not vary much in the frequency range (1 to 15 KHz). The excitation factor $|\Lambda_1(f)|$ at different frequencies is taken from the data of Wait and Spies[13].

The ratio of the amplitudes at two different frequencies of an atmospheric f_1 and f_2 is evaluated using the first term on the right hand side of equation (3) by plotting SAR *versus* distance of 400 atmospherics. The mean value of the spectral amplitude ratio of atmospherics received in all directions for a pair of frequencies is taken as the source spectrum and is assumed to be statistically constant. Table I shows the frequency of maximum component, the bandwidth obtained by different investigators. It can be seen that the authors' value for the peak frequency of maximum component agrees well with that of the results of Florman[14] and Croom and the value of bandwidth with that of Norinder and Florman. The results justify the method adopted by the authors for evaluating the relative amplitude source spectrum of the return stroke. The source spectrum after normalizing to 7 KHz is shown in Fig. 1. It is observed that the normalised amplitude, above the peak frequency, varies as $1/f$ as observed by Watt and Maxwell[15].

TABLE I

Characteristics of various source-types

Source	Frequency of Maximum Component (KHz)	Width at half maximum (KHz)	Derivation
Norinder	2·3	9	Current wave form
Florman	4	9	Spectra of close discharges
Croom	4	15	Spectra of Distant discharges
Authors	5	10	Spectra of Distant discharges

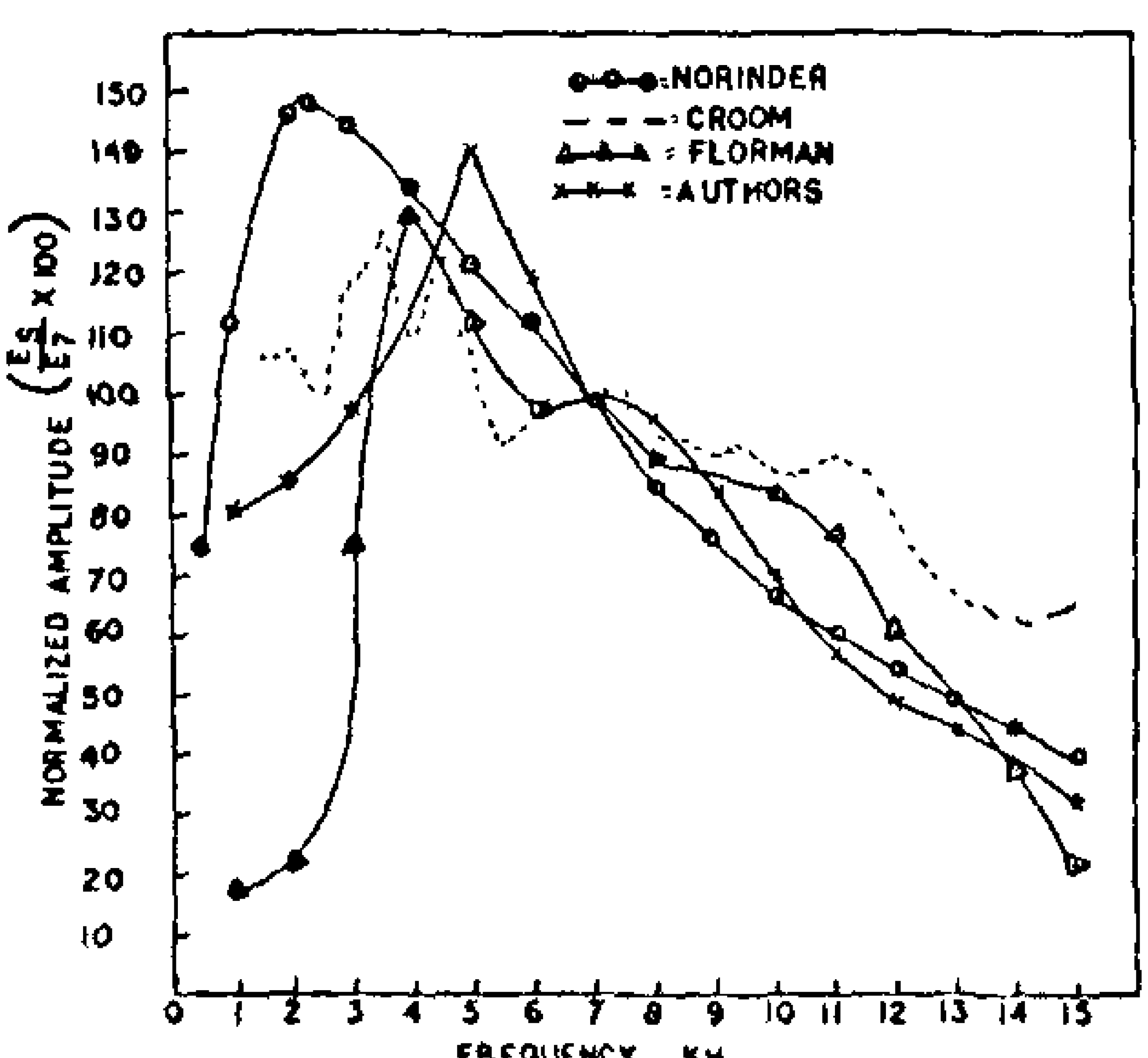

FIG. 1. Source spectra (normalized to 7 KHz component) due to various authors.

The method adopted by the authors has the following advantages.

1. It is essentially a single station method of observation whereas Croom has followed two station method. Croom has assumed the excitation factor with frequency to be constant and using relative attenuation, he evaluated the source spectrum.
2. The observations of the discharge at close distances to evaluate the source spectrum needs correction due to the presence of the near fields whereas the method adopted by the authors is free from the near field effects due to observations made at large distances.
3. At the same time the method used by the authors also gives the relative attenuation of the pair of frequencies as can be seen from equation (3).
4. The method suggested by the authors is most useful at places where thunderstorms are rare and close discharge method cannot be successfully used.

From the observed values of the frequency of maximum amplitude and bandwidth, the constants, a, β, in the current discharge of the return stroke assumed to have an equation as

$$I = I_0 (e^{-at} - e^{-\beta t}),$$

$I_{max} = 20$ Ka and the constants, a, b, of the velocity of the return stroke assumed to have an equation as $V = V_0 (e^{-at} - e^{-\beta t})$ are evaluated by trial and error. The values of the constants so obtained are given in Table II along with that of other workers for comparison.

TABLE II

Values of constants employed by different workers

Workers	a 10^4 sec^{-1}	β 10^4 sec^{-1}	I_0 K amp.
Bruce and Golde	4·4	46	28
Norinder	0·7	40	20
Kimpara	4·0	20	37
Croom	1·0	50	22
Srivastave and Tantry	1·4	50	22
Authors*	1·0	30	23·3

* Values of the constants a, b and V_0 are $a = 6 \times 10^4$ sec^{-1}, $b = 7 \times 10^5$ sec^{-1} and $V_0 = 3 \times 10^8$ m/sec.

Department of Applied Physics,
Andhra University,
Waltair 530 003,
April 2, 1979.

S. GOPALAKRISHNA,
P. SITARAMASWAMY.

1. Chapman, F. W. and Methews, W. D., *Nature, Lond.*, 1953, **172**, 495.
2. Taylor, W. L., *J. Res. Bur. Stand, Wash.*, 1963, **67D**, 539.
3. Helliwell, R. A., Hean, A. G. and Taylor, W. L., *Proc. Inst. Radio Engrs. N.Y.*, 1958, **46**, 1760.
4. Srivastava, K. M. L. and Tantry, B. A. P., *Indian J. Pure Appl. Phys.*, 1966, **4**, 272.
5. Croom, D. L., *J. Atmos. Terr. Phys.*, 1964, **26**, 1015.
6. Bruce, C. E. R. and Golde, R. H., *J. Inst. Elect. Engrs.*, 1941, **88**, 487.
7. Norinder, H., *Proc. Inst. Council of Scientific Unions*, Second Meeting, Brussels, 1951.
8. Kimpara, A., *Proc. Res. Inst. Atmos.*, Nagoya University, 1961, **8A**, 148.
9. Caton, P. G. F. and Pierce, E. T., *Phil. Mag.*, 1951, **43**, 393.
10. Hepburn, F., *J. Atmos. Terr. Phys.*, 1960, **19**, 53.
11. Frisius, J. and Heydt, G., *Radio Science (New Series)*, 1968, **3**, 1004.
12. Wait, J. R., *Electromagnetic Waves in Stratified Media*, Pergamon, 1970.
13. — and Spies, K. P., *J. Res. Bur. Stand, Wash.*, 1963, **67D**, 183.
14. Florman, E. F., *N.B.S. Rep. No.* 3558, November 10, 1955.
15. Watt, A. D. and Maxwell, E. L., *Proc. Inst. Radio Engrs. N.Y.*, 1957, **45**, 787.

QUALITATIVE CHECK OF PHOSPHORUS DISTRIBUTION IN NEUTRON IRRADIATED SILICON CRYSTALS USING AUTO-RADIOGRAPHY

THE nuclear transmutation of silicon[1,2] has been recognised as the best method of doping silicon homogeneously with phosphorus, and is based on the following reaction.

$$^{30}\mathrm{Si}\,(n,\gamma)^{31}\,\mathrm{Si} \xrightarrow{T_{\frac{1}{2}} = 2.6\ \mathrm{hr}} {}^{31}\mathrm{P} + \beta^-$$

The extent of doping in a Si single crystal, having high initial resistivity, depends mainly on the total time of its irradiation with thermal neutrons and the flux density. The stable phosphorus atoms produced during the above reaction, further capture neutrons and give rise to radioactive ^{32}P isotope, which is a beta emitter with a half-life of 14·2 days. It has been found that with higher doses of the neutron flux, the beta (volume) activity, produced in the crystal due to ^{32}P atoms, takes about 2–3 months to decay completely[3].

In this paper, a simple and an effective method of checking the qualitative distribution of phosphorus atoms in irradiated silicon samples, employing autoradiography has been discussed. The method is based on determining the variation in density of the unstable ^{32}P atoms in the irradiated silicon crystal, in terms of measuring the amount of blackening produced on a photographic film, which in turn would reveal the actual distribution of the stable phosphorus (^{31}P) atoms throughout the volume of the crystal.

This can be accomplished by preparing autoradiographs, by keeping irradiated silicon samples in close contact with X-ray film, for a short period (2-3 days), before the activity in the samples (due to ^{32}P isotope reduces to negligible proportions.

In the present case, several slices (0·4 to 0·8 mm thick) and a cylindrical ingot (2 cm long) cut from a float zoned silicon single crystal (15 mm dia.) irradiated with a thermal neutron flux (3×10^{13} n/cm²/sec), were kept in close contact with fast dental X-ray films for a period of 48–96 hrs. The autoradiographs, *i.e.* the X-ray films containing typical blackened circular and longitudinal patterns, thus prepared, were used for the density measurements on a densitometer (rapid photometer, model GII of M/s Carl Zeiss 'Jena' Germany) using half millimeter wide slit. The photometric sensitivity of the equipment is of the order 100,000 scale divisions for an area of 1 mm². In Fig. 1, a typical cross-sectional densitometer trace (obtained graphically by automatic slow movement

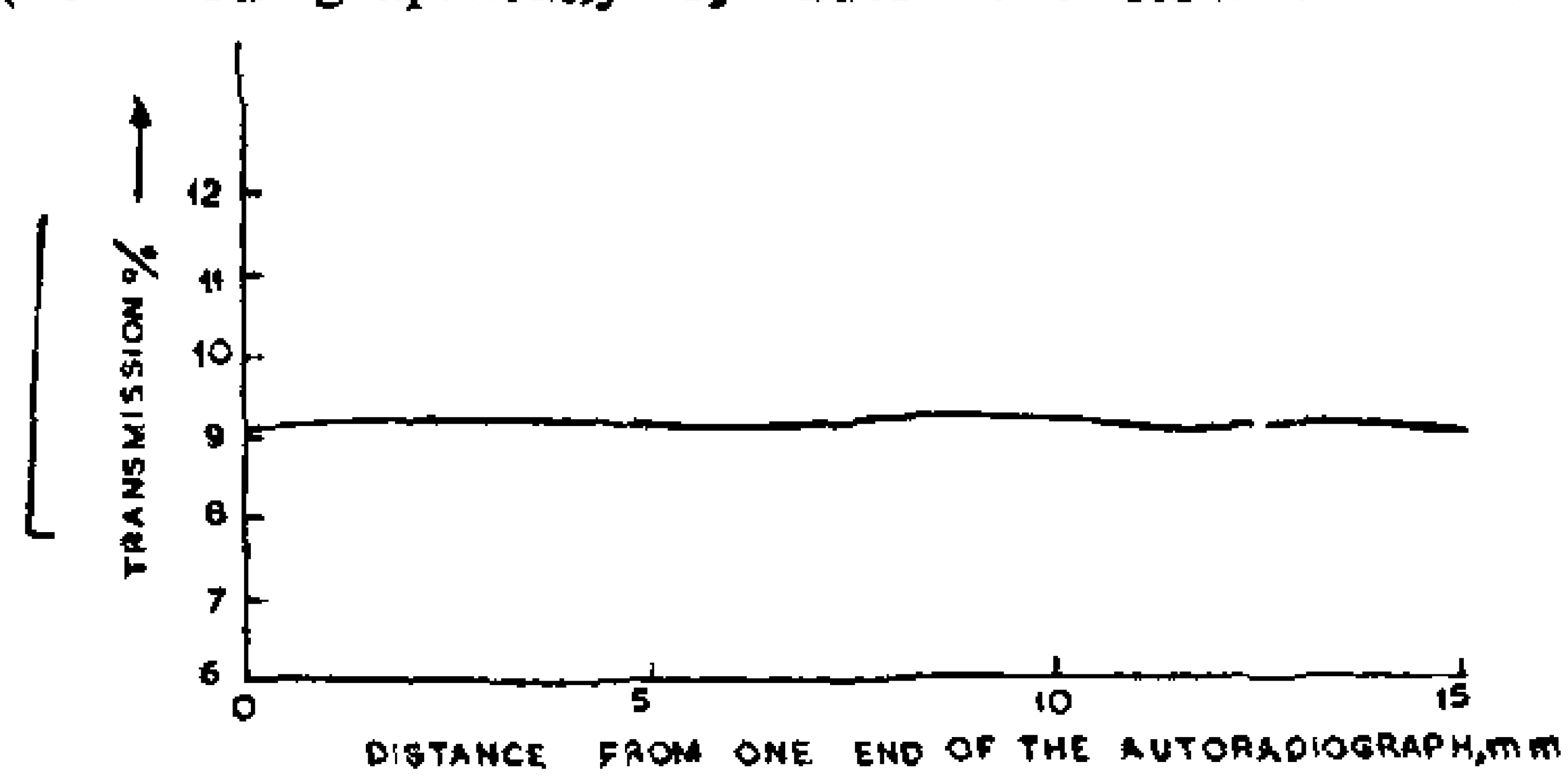

FIG. 1. Densitometer trace showing variation in the intensity transmitted through a typical cross-section of the autoradiograph pattern

of the film), shows a variation of about 2% in the intensity transmitted. In the other radiographs also, the variation in the density of the blackened portions was found to be of the same order. This very well suggests that an almost uniform distribution of ^{32}P atoms exists throughout the irradiated silicon crystal. Since the radioactive ^{32}P isotope is a product of the stable ^{31}P isotope (through neutron capture), thus it can safely be assumed that the ^{31}P, (phosphorus) dopant atoms are also distributed homogeneously across the whole crystal.

As a further check, the electrical resistivity measurements were made across the same samples after annealing them at 750° C. The radial resistivity variation in different samples was found to be of the order of 2 to 3%, as shown in Fig. 2, for a typical sample. These