STUDY OF SOLAR FLARES USING COSMIC RADIO NOISE ON 25 Mc./s. AT AHMEDABAD (23°02′ N., 72°38′ E.)

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ABSTRACT

The paper describes observations made at Ahmedabad of sudden cosmic noise absorptions (SCNA's) on 25 Mc./s. associated with solar flares. The frequency distributions of solar flare attenuations, their times of growth and duration, etc., have been determined and the results are compared with similar observations made by other workers. It has been found that SCNA's of 25 Mc./s. recorded at Ahmedabad in 1956–58 have been markedly larger in size and duration than those observed in Australia on 18·3 Mc./s. in 1950–51.

1. INTRODUCTION

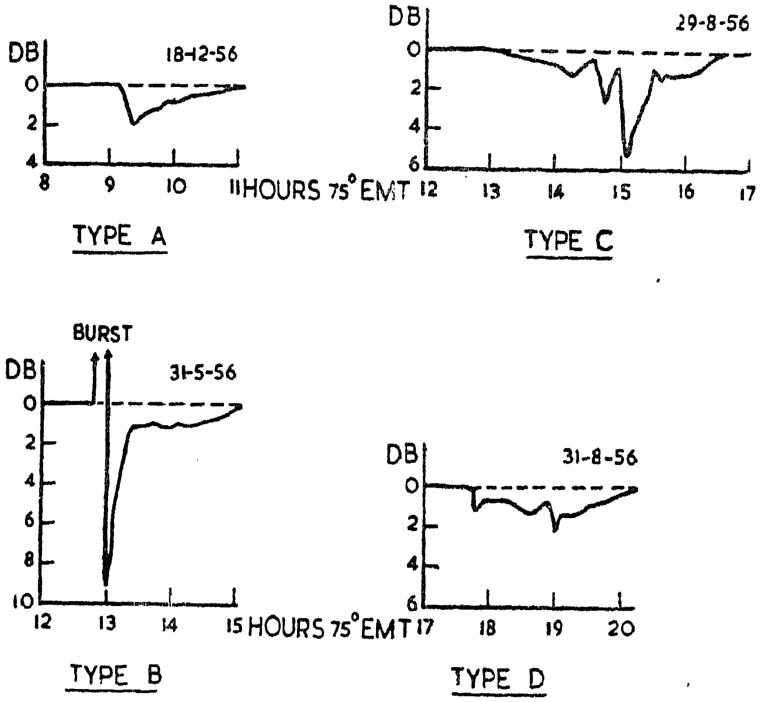
IT is now generally known[1–2] that the measurement of cosmic radio noise provides an effective means of studying the attenuation of radio waves passing through the whole ionosphere. The equipment for measuring the level of cosmic radio noise usually consists of a directional aerial pointed towards the zenith and connected to a stable communications receiver, its output being amplified and recorded on a recording milliammeter. A diode noise generator is used for calibration. The D and F_2-regions are the principal attenuating regions. While the absorption in the D-region is mainly a function of the sun's zenith distance, the attenuation in the F_2-region depends on the value of f_0 F_2, the amount of F-scatter and the electron distribution above the maximum of F_2. Though under normal conditions, the diurnal variation of the total ionospheric attenuation is fairly smooth, sudden and rapid increases in the total attenuation followed by gradual recoveries are sometimes observed. They usually occur during the daytime and are associated with solar flares. The course of a solar flare can be followed by measuring the width of the H_α line in the spectrum of the flare, *i.e.*, the wavelength interval over which the flare appears brighter than the background. The principal effect of the flare-radiations on the ionosphere is to enhance the electron concentration in the D-region. This causes short wave radio fade-outs, sudden cosmic noise absorptions (SCNA) and sudden phase anomalies in low frequency wave propagation (SPA). Shain and Mitra[3] have analysed the SCNA's observed on 18·3 Mc./s. in Australia and compared the results with the observations of SPA's on 16 Kc./s. observed by Bracewell and Straker[4] in England. They showed that an SCNA of maximum intensity of 1 db was equivalent to an SPA of size 200°. Ramanathan *et al.*[5] reported on the characteristics of two SCNA'S which occurred on 23rd February 1956 and 10th March 1956; the former was of exceptional intensity and caused cosmic ray increases near the geomagnetic equator (V. Sarabhai *et al.*[6]). Since then, about 80 SCNA's have been recorded at the Physical Research Laboratory, Ahmedabad (23° 02′ N., 72° 38′ E.), India. The present paper gives an analysis of the results. The list of SCNA'S is given in Table IV.

2. AN EXAMPLE OF AN SCNA AND ASSOCIATED IONOSPHERIC FADE-OUT

Figure 1 (*a*) shows the record of an SCNA which occurred on the 27th January 1957 at 1245 hr. 75° EMT. It was characterised by a sudden reduction in the intensity of cosmic radio noise on 25 Mc./s. at the time of a solar flare. The intensity of cosmic radio noise continuously decreased till a minimum was recorded at 1250 hr. The maximum absorption was about 6·5 db. Thereafter, a gradual recovery started and the noise level was normal by about 1330 hr. This is the usual pattern of SCNA's, but the rates of growth and decay vary widely from one SCNA to another. In general, the growth of an SCNA is rapid and the recovery slow. Figure 1 (*b*) shows a sequence of three records of ionospheric pulse reflections taken before, during and after the solar flare associated with the SCNA described above. The first record at 12 hr. shows that the reflections were normal. The second at 13 hr. shows an absence of reflections up to 14 Mc./s. This represents a partial ionospheric fade-out caused by the solar flare. The third record at 14 hr. shows that normal ionospheric reflections had again been established. Intense solar flares usually produce complete radio fade-outs which disrupt wireless communication on short waves for sometime. Cosmic noise-fade-out on 25 Mc./s. is usually of a partial nature and during most solar flares, measurable intensity of cosmic noise can be observed. There have been a few instances when there was almost complete fade-out on 25 Mc./s., but such occasions are rare. Since cosmic noise records are continuous, it is possible to study the progress of solar flares even when the sun is obscured owing to cloud.

3. CLASSIFICATION OF SCNA'S

As seen from the cosmic noise records at Ahmedabad, it has been found to be convenient to classify SCNA's into four types; examples of them are shown in Fig. 2, where the excess absorption due to flare expressed in db is plotted against time. An SCNA of type A is characterised by a sudden increase in absorption, an SCNA of type B is accompanied by bursts of solar radio noise, type C is associated with multiple or extended solar flares, and an SCNA is said to be of type D when it is observable at a time when the sun is low in the sky. The SCNA's were classified on this broad qualitative basis, irrespective of the maximum intensity, or in other words, of the maximum absorption produced by the ionosphere. SCNA's of type B are the most common. For a quantitative study of SCNA's, one has to examine the records in detail by noting the times of start, and growth, their duration and "size". The maximum absorption during an SCNA expressed in db is termed the "size" of an SCNA. Absorption at a given time during an SCNA is the ratio, expressed in db, of the observed power to the power that would have been received at that time, had there been no SCNA. While the times of start and growth of SCNA's can be read with an accuracy of ± 1 min., the duration cannot be estimated with equal precision. The slow rate of recovery towards the end of an SCNA is mainly responsible for this. However the time taken by an SCNA to recover to half the size can be measured with fair accuracy.



TYPE A

TYPE C

TYPE B

TYPE D

FIG. 2. Four types of SCNA's. Type A, Type B, Type C and Type D.

4. INTENSITY OF SOLAR FLARE AND SIZE OF SCNA

Bracewell and Straker[4], and Shain and Mitra[3] from their studies of SPA's of 16 Kc./s. and SCNA's of 18·3 Mc./s., conclude that in general, solar flares of classes 3, 2 and 1 were associated with intense, moderate and small SPA's and SCNA's. It has been observed from our studies of SCNA's of 25 Mc./s. that solar flares of class 3 or 3+ are usually associated with SCNA's of large size but since the size of an SCNA depends not only on the intensity of the flare as determined optically but also on the sun's zenith distance at the time of the flare, a solar flare of class 1 may cause an SCNA of size greater than that caused by a class 2 solar flare.

5. CHARACTERISTICS OF SCNA'S

(*a*) *Size.*—Figure 3 represents the frequency distribution of the sizes of SCNA's of 25 Mc./s. at Ahmedabad. It is clearly seen that the mode of the distribution lies between 1 and 2 db and that the number of SCNA's falls off rapidly with increasing size. Actually what one might expect is that the number of SCNA's of the smallest size would be the largest. But in practice, this has not been found to be so. It is possible that a few SCNA's of size smaller than 1 db have been missed owing to natural or artificial interference. Besides, it has been observed that all small flares are not capable of causing SCNA's or it may be that, an SCNA once started, always grows to a certain minimum size. A similar type of distribution, in the case of SPA's, was observed by Bracewell and Straker. Shain and Mitra succeeded in showing that the cumulative frequency distribution of SCNA's obeys the following relation,

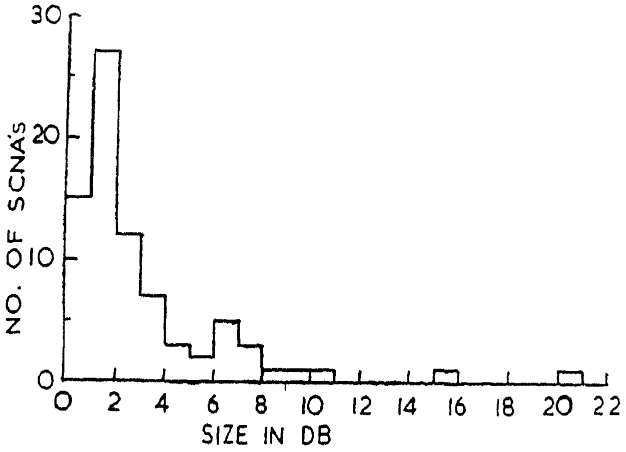


FIG. 3. Frequencies of SCNA's of different intensities.

$$dn = ks^{-p}\ ds \tag{1}$$

where n is the number of SCNA's in a small range 'ds' of s, where s is the size and k is a constant. They found that a value of p near about 2 gives the best fit. Figure 4 shows the cumulative frequency distribution of the SCNA's of different sizes observed at Ahmedabad on 25 Mc./s., that is, the percentage of the total number of SCNA's having a size equal to or greater than a defined amount. Even though the sizes of SCNA's observed at Ahmedabad are larger than those observed in Australia by a factor of about 3, the above relation (1) with p near about 2 still holds.

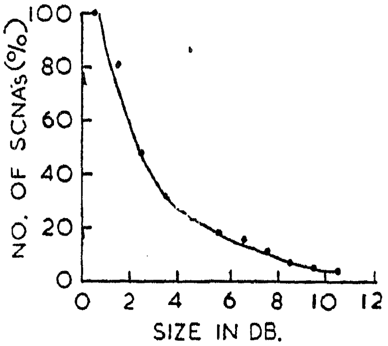


FIG. 4. Cumulative frequencies of SCNA's.

(*b*) *Time of growth.*—In Table I, the mode, median and quartile values of the times of growth of SCNA's and SPA's are compared. It is evident that the frequency distribution of the times of growth measured at Ahmedabad agree well with those observed elsewhere. Helen W. Dodson *et al.*[7] attempt to distinguish between sudden short wave fade-outs and gradual short wave fade-outs. According to them, gradual and sudden SID's represent two quite different phenomena. It is possible that the SCNA's of short and long times of growth are associated with sudden and gradual short wave fade-outs respectively.

TABLE I

Times of growth of SCNA's and SPA's in minutes

Method	Authors	Mode	Median	Quartiles	
				Q_1	Q_3
SCNA 18·3 Mc./s.	Shain and Mitra	. .	5	4	9
SPA 16 Kc./s.	Bracewell and Straker	6	7·5	5·5	10·5
SCNA 25 Mc./s.	Bhonsle	5	7	4·7	11·0

(*c*) *Duration.*—Table II gives durations of SCNA's and SPA's and summarizes the observations of the other workers. The median and quartile values of duration differ widely at different places. The median value of duration obtained from the observations at Ahmedabad is much larger than those obtained from SCNA's at 18·3 Mc./s. and SPA's at 16 Kc./s. It is interesting that while the times of growth of SCNA's and SPA's are in good agreement, their durations differ. By duration we mean the interval of time between the earliest indication of an SCNA and its end as determined from the appearance of the record. Figure 5 represents a scatter diagram of size against duration of SCNA's at Ahmedabad. SCNA's of type C, *i.e.*, multiple or extended ones, are not included in this diagram. There is an obvious tendency for the duration to increase with increasing size of SCNA. In general the SCNA's observed at Ahmedabad take a much longer time to recover than those observed in Australia, and this is probably connected with the difference in the phases of solar activity in which the observations were made.

TABLE II

Durations of SCNA's and SPA's in minutes

Method	Authors	Mode	Median	Quartiles	
				Q_1	Q_3
SCNA 18·3 Mc./s.	Shain and Mitra	..	21	15	34
SPA 16 Kc./s.	Bracewell and Straker	30	33	26	48
SCNA 25 Mc./s.	Bhonsle	55	47	27	62

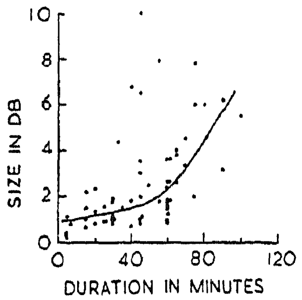


FIG. 5. Scatter-diagram of size and duration of SCNA's.

(*d*) *Ratio* (*Duration/Time of Growth.*)—Waldmeir[8] gave the ratio of the duration of the flare to its time of growth as 5. In Table III a comparison is made between our observations of SCNA's with those of SPA's. There is good agreement in the values of this ratio. This means that, on an average, an SCNA lasts for a period which is about five times the period which it takes to grow to its full size.

TABLE III

Ratio (*Duration/Time of growth*) *of SCNA's and SPA's*

Method	Authors	Mode	Median	Quartiles Q_1	Quartiles Q_3
SPA 16 Kc./s.	Bracewell and Straker	4	..	3·5	6·5
SCNA 25 Mc./s.	Bhonsle	4·5	4·7	3·5	7·5

6. CHANGES IN ATMOSPHERIC IONIZATION ASSOCIATED WITH SOLAR FLARES

Nicolet[10] suggested that the formation of the normal D-region could be explained by the photo-ionization by L_α, and Mitra[9] extended this idea by suggesting that the enhancement of L_α radiation during solar flares was responsible for the increased D-region ionization. He assumed that the flare-time enhancement of ionization occurred uniformly throughout the D-region. In the light of later work on low frequency reflections from the lower ionosphere (Gardner[13]) and rocket observation on solar spectra (Friedman *et al.*[12]), flares do not seem to have any perceptible influence on the E and F layers, but the D-layer is very much affected. Observations of SPA's show that the reflecting ceiling for long waves is lowered by about 15 km. during 3^+ flares. The ionization of a substance like NO by L_α seems insufficient to produce such a large lowering of the base of the D-layer. According to Friedman and Chubb, if the lowering of the D region were due to L_α, its intensity in large flares should increase by a factor 10^5. This is highly improbable. The alternative view which is now generally accepted is that, the solar flares emit X-rays and with increase in the size of the flare, increasing amounts of X-rays of the shortest wavelengths (λλ 8Å–2Å) are emitted. These rays penetrate the atmosphere down to 70 km. causing ionization of all components of atmospheric air. Gardner and Pawsey's[11] studies of the partial reflections of long waves from the lower ionosphere confirm the

TABLE IV

Solar flare absorptions tabulated from the recordings of cosmic radio noise on 25 Mc./s. at the Physical Research Laboratory, Ahmedabad, India

23rd Feb. 1956 to 14th Sep. 1958

Date	Class of flare according to CRPL	Type of SCNA observed in Ahmedabad	Time of beginning UT	Duration in min.	Time for half-recovery in min.	Maximum absorption in db
1956 February 23	3+	B	0331	90	22	6·2
March 10	2	B	0450	100	25	5·5
May 30	2+	C, D	0240	180	20	2·1
30	2+	B, C	0940	160	13	8·1
31	3	B, C	0749	50	8	9·2
July 24	..	B	0920	70	5	4·5
25	..	C	0530	20	4	2·0
25	..	C	0550	20	8	0·8
27	..	A	0540	25	7	1·5
27	..	C	0920	50	7	2·3
August 27	1	C	0949	15	7	1·5
27	1	C	1002	60	10	1·2
28	1+	A	0805	80	17	6·0
29	2	A, C	0955	150	20	5·3
September 9	..	A	0745	45	12	6·5

TABLE IV (*Contd.*)

Date	Class of flare according to CRPL	Type of SCNA observed in Ahmedabad	Time of beginning UT	Duration in min.	Time for half-recovery in min.	Maximum absorption in db
November 15	1	B, C	0810	85	8	1·3
18	1	B	0838	55	15	1·8
22	1	A	0855	60	20	1·0
December 17	2	A	1010	30	15	0·8
18	1	A	0405	60	25	1·9
19	..	A, C	0605	95	7	7·6
19	1	A, C	0845	50	17	2·7
20	2	A	0450	55	8	7·9
20	1	A	0635	65	5	3·8
26	2	A	0535	60	5	1·2
27	1	A	0625	30	15	1·9
1957 January 27	..	A	0745	40	10	6·7
February 14	1	B	0422	45	35	1·1
19	..	B, D	0250	5	2	1·1
March 12	..	A	0548	15	5	2·2
April 14	..	A	0536	60	20	1·5
16	3	A	1040	75	30	7·8
20	..	D	0200	15	5	0·7

TABLE IV (*Contd.*)

Date	Class of flare according to CRPL	Type of SCNA observed in Ahmedabad	Time of beginning UT	Duration in min.	Time for half-recovery in min.	Maximum absorption in db
June						
4	..	B	0857	70	25	3·4
10	1	B	1048	60	30	2·6
July						
1	1+	B	0345	40	8	0·7
4	..	B	0435	60	30	0·9
8	2	B	0538	30	8	1·0
12	..	B	0436	25	15	3·9
16	2	B	0737	45	15	3·5
21	2	D	0135	5	2	0·2
21	..	C	0333	5	2	0·4
21	..	C	0416	5	2	0·3
21	..	B	0704	65	30	2·6
22	..	B	0630	45	20	1·0
29	2	C	0456	50	7	1·1
August						
8	2+	B	1122	45	15	1·1
September						
1	1	D	0204	20	10	0·7
3	..	B	1024	45	7	2·0
7	2	B	0815	35	7	15·0
15	1	C	0333	75	30	0·9
18	1	C	0630	60	15	0·8

TABLE IV (*Contd.*)

Date	Class of flare according to CRPL	Type of SCNA observed in Ahmedabad	Time of beginning UT	Duration in min-	Time for half-recovery in min.	Maximum absorption in db
19	2^+	B	0803	65	22	4·0
21	1^+	C	0415	75	20	1·2
October						
1	1	B	0653	35	8	1·5
19	2	B, C	0632	90	30	1·4
November						
10	2	B	0658	45	15	3·0
17	1^+	B	0530	60	15	1·8
23	2	B	0735	60	17	3·6
December						
10	..	A	0435	75	27	2·0
15	..	B	0537	7	3	3·8
17	..	B	0737	90	35	3·2
18	..	B	0625	60	22	1·6
19	2	B	0753	60	17	2·4
20	1	A	0545	?	15	1·1
26	1^+	B	0917	45	8	0·8
1958 March						
11	..	B	0614	15	10	1·0
11	..	B	0717	30	15	1·8
23	3^+	B	0955	150	10	20·0
April						
2	2	B	0500	20	5	2·3

TABLE IV (*Contd.*)

Date	Class of flare according to CRPL	Type of SCNA observed in Ahmedabad	Time of beginning UT	Duration in min.	Time for half-recovery in min.	Maximum absorption in db
7	..	B	0652	30	7	1·1
May 5	1+	B	0415	33	7	4·3
June 2	..	B	0700	20	7	1·2
3	..	C	0240	25	7	1·2
6	2	B	0437	40	12	1·8
July 29	3	B	0300	45	17	10·0
August 28	2+	B	1022	75	30	6·0
September 14	2+	B	0853	60	25	2·6

Type A .. Sudden increase in absorption.
B .. Sudden burst of intensity followed by absorption.
C .. Absorption due to multiple or extended flares.
D .. Flare at the time of low sun.
Local Mean Time = UT + 4^h 50^m

existence of two reflecting regions, one near 70 km. and another near 90 km. Gardner[13] showed that even during SID's, this grouping of echo-heights is maintained. He concluded that during an SID, most absorption of E-echo takes place between 85 km. and E-reflection level. The course of an SPA and SCNA during a solar flare need not be the same. SPA's depend mainly on the ionization of the lower D-region but SCNA's are affected by the total absorption which is proportional to $\int N \nu \, dh$, through the ionosphere where N is the number of electrons per unit volume and ν is its collision frequency. Hence, it is to be expected that SCNA's will take more time to disappear than SPA's.

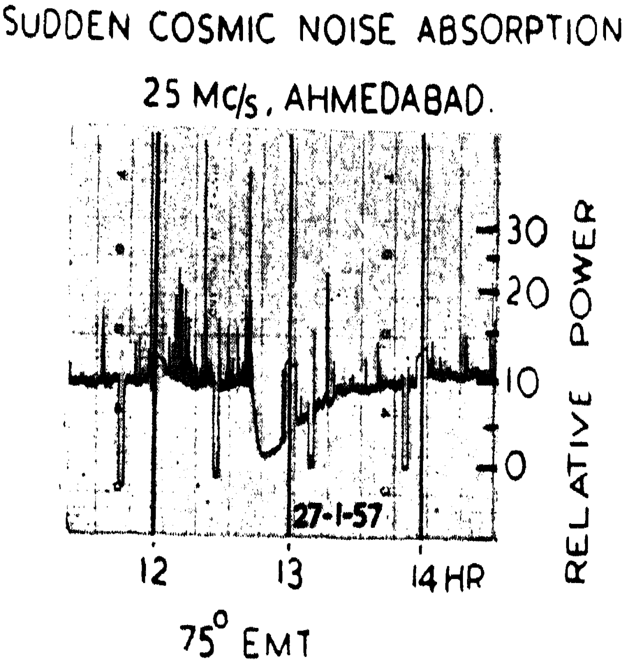

SUDDEN COSMIC NOISE ABSORPTION
25 Mc/s, AHMEDABAD.
30
20
10
0
RELATIVE POWER
27-1-57
12
13
14 HR
75° EMT

FIG. 1 *(a)*

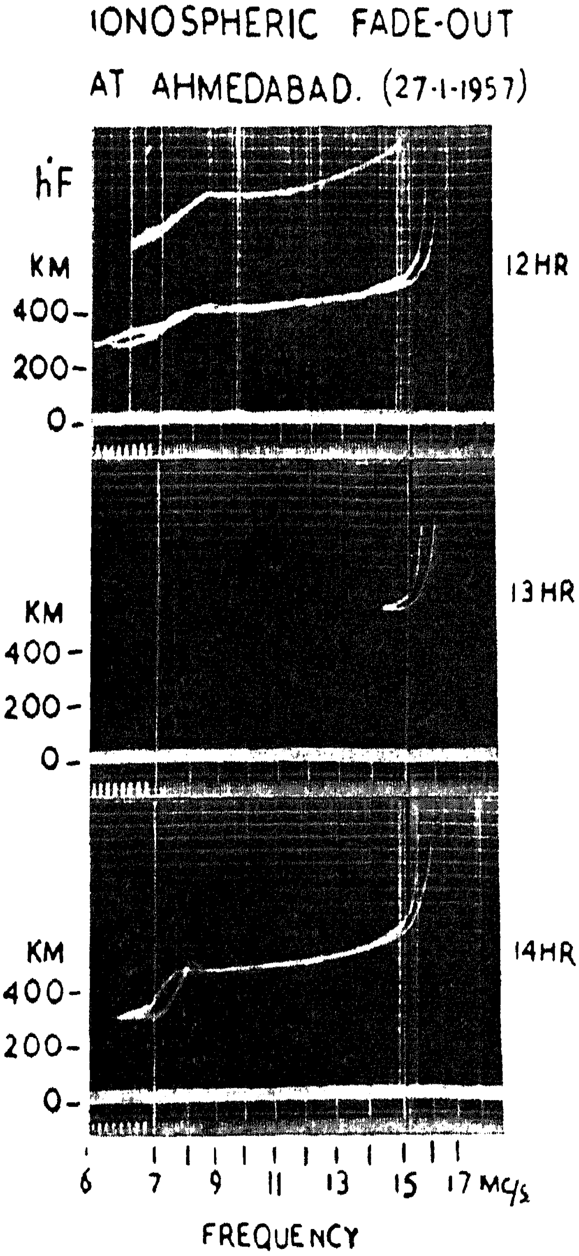

IONOSPHERIC FADE-OUT
AT AHMEDABAD. (27-1-1957)
h'F
KM
400-
200-
0-
12 HR
KM
400-
200-
0-
13 HR
KM
400-
200-
0-
14 HR
6
7
9
11
13
15
17 Mc/s
FREQUENCY

FIG. 1 *(b)*