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A Study of Meteor Scatter Communications.

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I. Introduction.

Communications over long distances (500 - 2000 km) by means of forward scatter from meteor trains has enjoyed a resurgence of interest of late due to improvements in both the available technology and the coding schemes and protocols. Some security of communications is provided in both the geographic sense (the reception area from a given meteor is quite limited) and in the inherent resistance to disturbance (natural and man-made).

Such systems have the advantage of being relatively easy to implement, at least for the basic requirements, are of relatively low cost and contribute little pollution to the electromagnetic environment. Set against this are the rather low rates of data transmission due to the sporadic nature of the appearance of suitable scatterers and the high excess transmission loss which limits the bandwidth for reasonable transmitter power levels,

Perhaps the first published note on the possibility of communications via meteor trains is that of Pickard [1]. A good deal of interest in forward scatter was generated in Canada in the 1950s leading to the development of the JANET system [2, 3, 4]; the state of the art at that time is well covered by the December 1957 issue of Proceedings I.R.E.. Recent reviews of the field include the work of Yavuz [5] and Schanker [6].

At the present time, much is known about the characteristics of the various aspects of such systems. In order to improve the overall performance though, several areas would seem to offer fertile ground. Amongst these are "software" improvements in coding and protocol to increase the throughput under given echo conditions, "hardware" developments including both the traditional (antennas, etc) and the more exotic (DSP techniqes), and measurements to improve the knowledge of "background" statistics such as meteor rates, duration times, etc. It is this last area to which the work described here is mainly addressed, although the ultimate findings should provide food for the others.

II The Equipment.

II.1 Principle of the System.

The primary aim of the work described here was to develop a system capable of measuring accurately the direction of the echoes obtained from meteor forward scatter on a path of medium length. Additionally, the distribution in amplitude and duration of the echoes was felt to be of importance and echo sampling methods and rates were to be consistent with this. In order to measure accurately the angle-of-arrival (AOA) of the incoming signal, the basic technique used involves phase measurements of the signals received on spaced antennas as illustrated in fig.1.

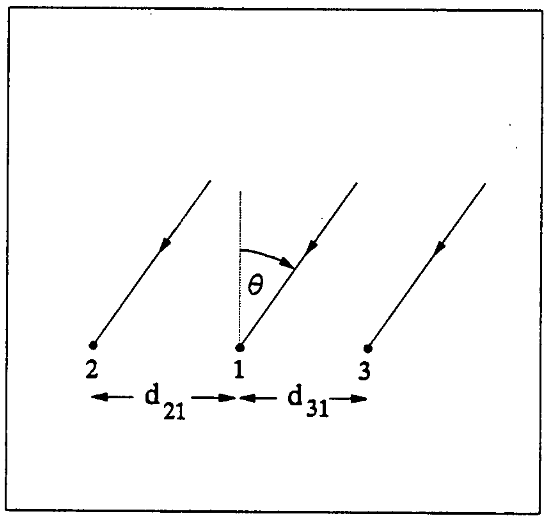


Fig. 1 Spaced antennas used for the determination of angle-of-arrival (θ).

Choosing antenna #1 as reference, the phase (ϕ) of the signal on an adjacent antenna is given by,

$$\phi = \frac{2\pi}{\lambda} d \sin\theta$$

where θ is the AOA relative to the normal to the line between the antennas; λ is the wavelength. If the separation, d, between the antennas is $\leq \lambda/2$, then the value of θ is determined unambiguously from the measured value of ϕ. On the other hand, the uncertainty ($\Delta\theta$) in the AOA due to measurement error ($\Delta\phi$) is inversely related to the separation, d, so that a wide separation is desirable for accurate estimates. For such a "wide-aperture" arrangement, ambiguities (in multiples of 2π in ϕ) can be **eliminated** only if the aperture is filled to the extent that individual elements are separated by $\sim\lambda/2$. Such systems suffer from the practical complexities introduced by the use of many interacting elements.

However, providing that the phase measurements are made with sufficient accuracy, the possibility of ambiguity can be made very small by using only three antennas arranged in a linear fashion with separations (d_{21} and d_{31}) differing by $\lambda/2$ (see fig 1); the values used in this experiment are $d_{21} = 2.5\lambda$ and $d_{31} = 2.0\lambda$. The variation of measured phase (ϕ) with AOA (θ) varying in the range $-\pi/2$ (point A) to $+\pi/2$ (point B), is then as illustrated in fig. 2; the lines are continuous in both ϕ_{21} and ϕ_{31}

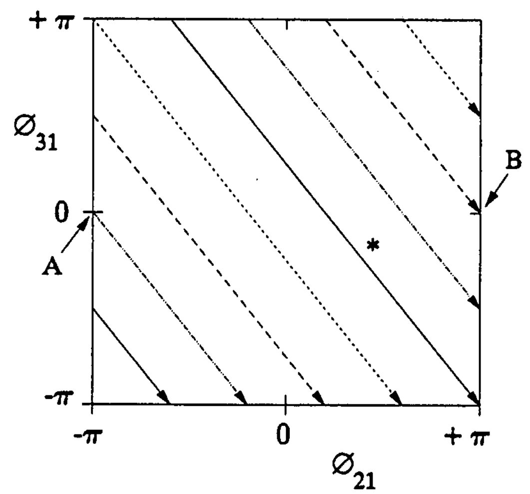


Fig. 2 The variation of phases ϕ_{21} and ϕ_{31} as the AOA (θ) is varied from $-\pi/2$ (point A) to $+\pi/2$ (point B).

and may be followed through the diagram. A representative measured value is shown by the asterisk (*) with the departure from the actual value (i.e. distance from the correct line) being a function of the noise level. The ambiguity in 2π is resolved provided that the noise level is not so high that the wrong line is chosen by the computer phase routines. The choice of spacing between the elements of the array represent a compromise between signal:noise (s:n) ratio and accuracy of the final result since the spacing between lines in fig. 2 is inversely related to the separation of elements so that higher s:n is needed to avoid the ambiguity problem. The values chosen here give good isolation between elements and provide AOA estimates of better than 1^{o} for all but the lowest elevation angles. This is illustrated in fig. 3 where such a system is modelled with signal directions randomly distributed

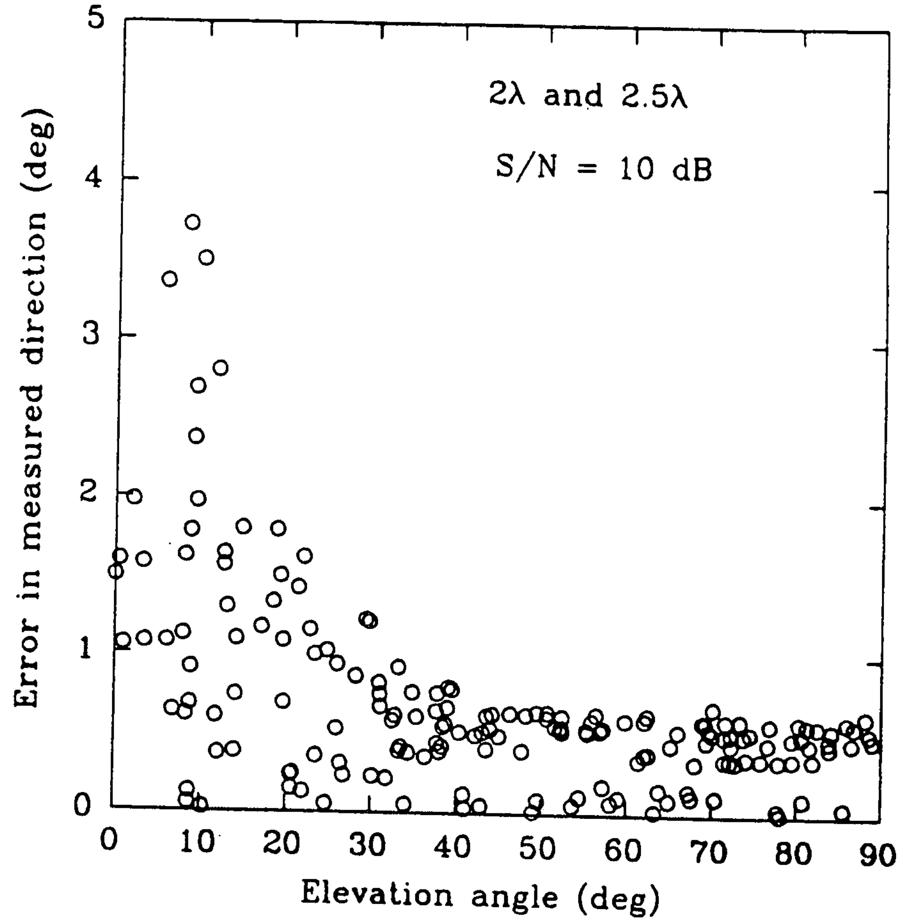


Fig. 3 Errors in AOA produced from simulated data for the array with separations of 2.0λ and 2.5λ.

and s:n of 10dB. At elevation angles above 20° or so, the mean error is in the order of 0.5°.

II.2 The Transmitter.

The transmitter consists of a crystal controlled oscillator (Hamtronics T51 VHF/FM exciter) at the assigned operating frequency of 48.70 MHz feeding a commercial driver amplifier (Hamtronics LPA 2-45). A second commercial power amplifier (Motorola AR305), capable of providing up to 300W, then feeds a 100 m. length of RG-8 coaxial transmission line and on to a horizontal two-element Yagi antenna pointing directly at the receiver. Losses of about 4 dB in the transmission line result in a nominal transmitted power of 100W.

II.3 The Receiver.

The layout of the antennas at the receiving site near London, Ontario is shown in fig. 4; two orthogonal arrays are used oriented respectively in, and perpendicular to, the direction of the transmitter located near Ottawa. The centre antenna serves as the reference for both directions.

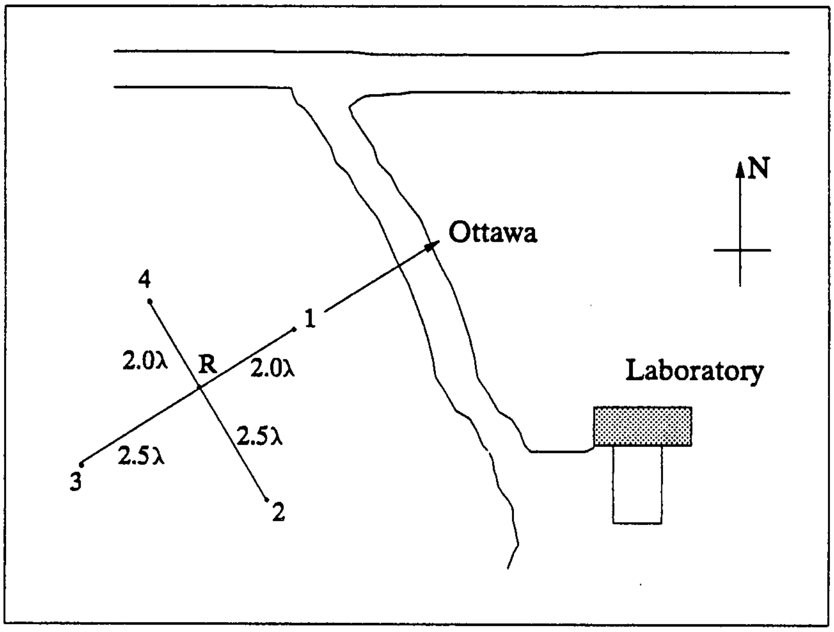


Fig. 4 The receiving site layout.

The receiver itself is based upon the phase-swept interferometer principle as illustrated in fig. 5. The phase (ϕ) of the incoming signal from a given antenna is compared to that of the reference antenna by using phase-locked local oscillators separated by f_0 in frequency to convert the two signals to an intermediate frequency where they are added. The phase is preserved in this process and detection at the output allows a direct measure of the required phase. Post-detection narrow-band filtering is used to improve the s:n and the associated time-constant is adjusted to allow for the anticipated rise-time of the meteor echo ($\leq$100 ms.); the initial setting of this bandwidth is 40 Hz. A more complete block diagram of the receiving system is shown in fig. 6. Five separate channels are used comprising one reference and four phase channels. The four phases are measured in turn using separate phase meters at the rate of one hundred complete sets of 4 phases per second for the first 0.5 seconds of a perceived echo. Amplitude measurements are made at the same

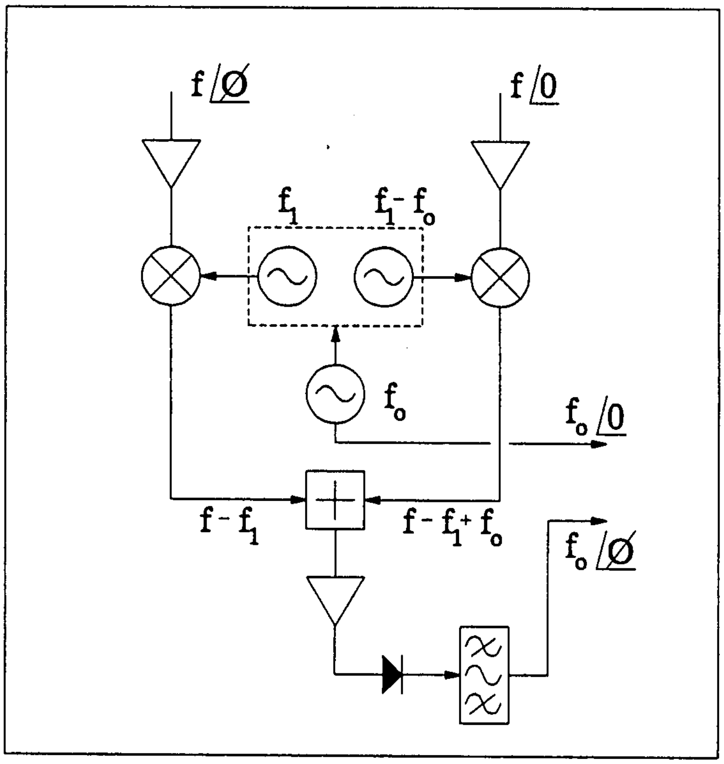


Fig. 5 The principle of the phase swept interferometer for measuring the phase difference between the signals from two antennas.

rate over the same period using the amplitude from channel 1 and are continued at a reduced rate of 5 per second for a further 9.5 seconds. All measurements are stored as 1 byte with the 256 levels covering 360^{O} in phase or 45 dB in amplitude, as appropriate. Complete circuit diagrams for the receiving system are given in Appendix I.

The entire receiving operation is controlled by an XT compatible personal computer, with raw data stored without further processing on magnetic tape cartridges of 40 MByte capacity (equivalent to about one month's data depending on the meteor echo rate).

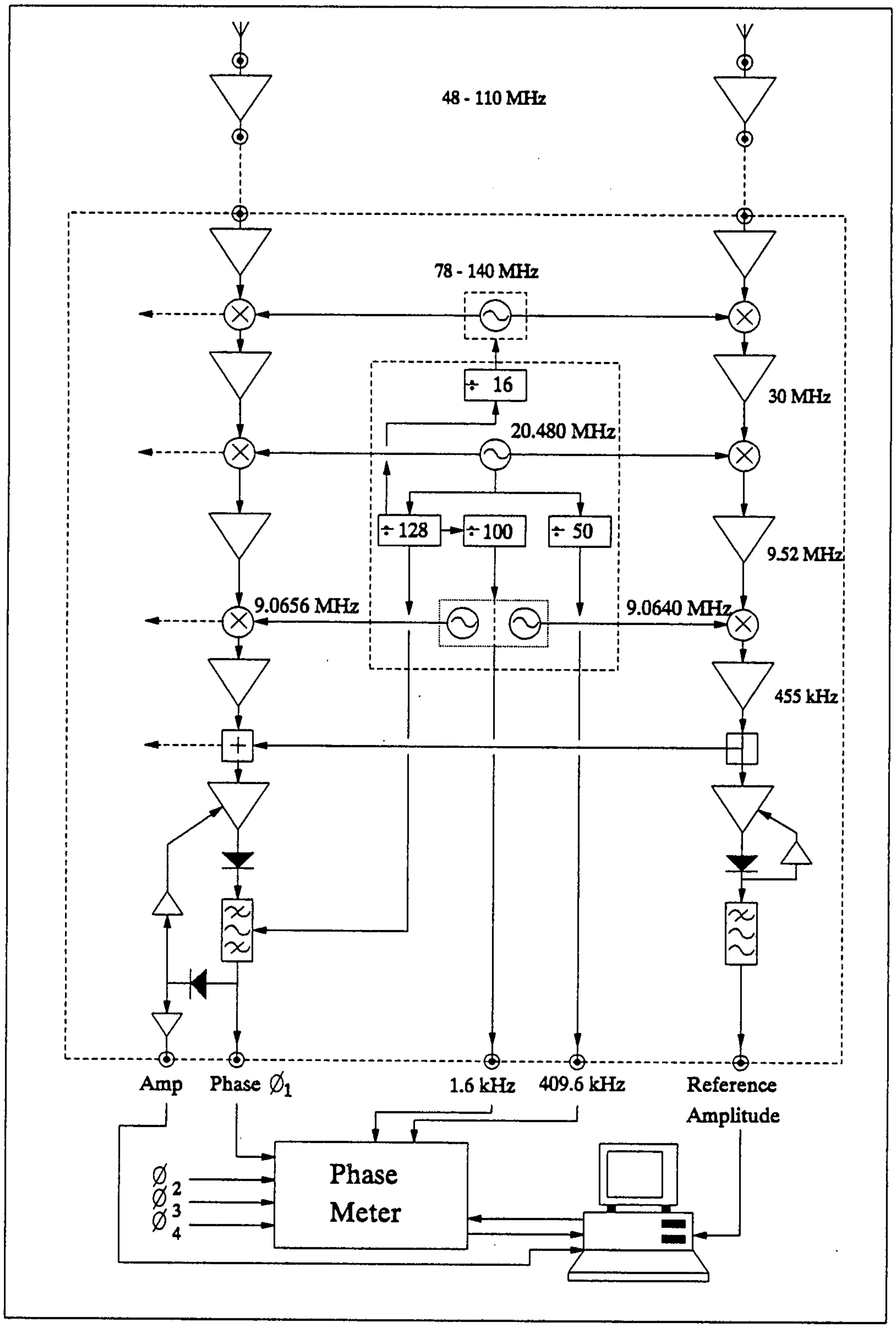


Fig. 6 A detailed block diagram of the receiving system; a total of five channels are used to measure the phase of the outer antennas relative to the centre reference.

III Experimental Results.

Experimental data collection was started on February 19, 1991 (day 50 from the beginning of the year) and continues to the present time. Around 500 meteor echoes per day have been recorded and some of the initial findings are presented here. Quite representative of the overall data are the echoes recorded on day 61 (March 2, 1991) and fig. 7 shows the individual phase measurements for each echo from the four peripheral antennas relative to the centre reference antenna. The linear relationship between the two phases in each pair is apparent and consistent with that expected from the geometry; for example, the clustering of phases 1 and 3 at the lower left of the diagram indicates most echoes are seen in the direction of the transmitter. Translated into actual angles-of-arrival, and projected onto the 100 km. surface, the echoes fall within the anticipated "hot-spot" regions on either side of the line from transmitter to receiver as shown in fig. 8.

Fig. 9 shows individual echoes (from day 55) illustrating the characteristics of the two basic kinds. The first is a classic "underdense" echo where the radio wave penetrates the column of ionization left by the passage of the meteoroid and the second shows an "overdense" case with the echo persisting until the electron density falls to levels which allow penetration. The third example is one where the echo persists for a sufficient length of time to allow train distortion and consequent interference effects between different points on the train as specular conditions become satisfied at those points.

IV. Discussion and Recommendations.

The results presented here are intended to demonstrate that the equipment, as designed, performs the intended function. It seems clear that this is so, and the next step will be to accumulate sufficient data to allow a statistical base to be established for the prediction of the performance of meteor burst communications systems. The broad features of meteoroid influx rate, for example, are reasonably well known, the peak in activity around 6 a. m., the seasonal variations, and so on, but much can be done to fill in the detailed structure.

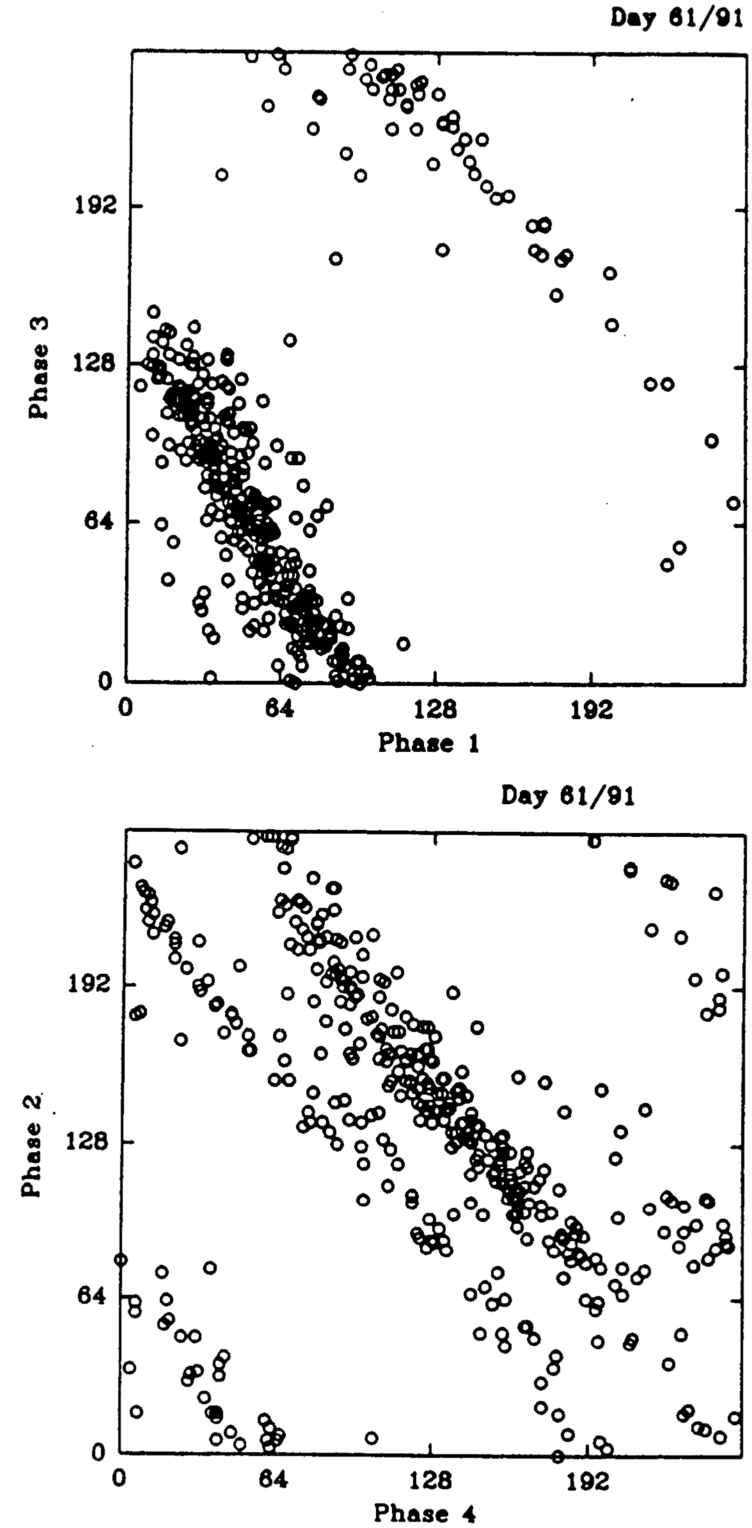


Fig. 7 Measured phases for echoes obtained on day 61; compare with fig, 2.

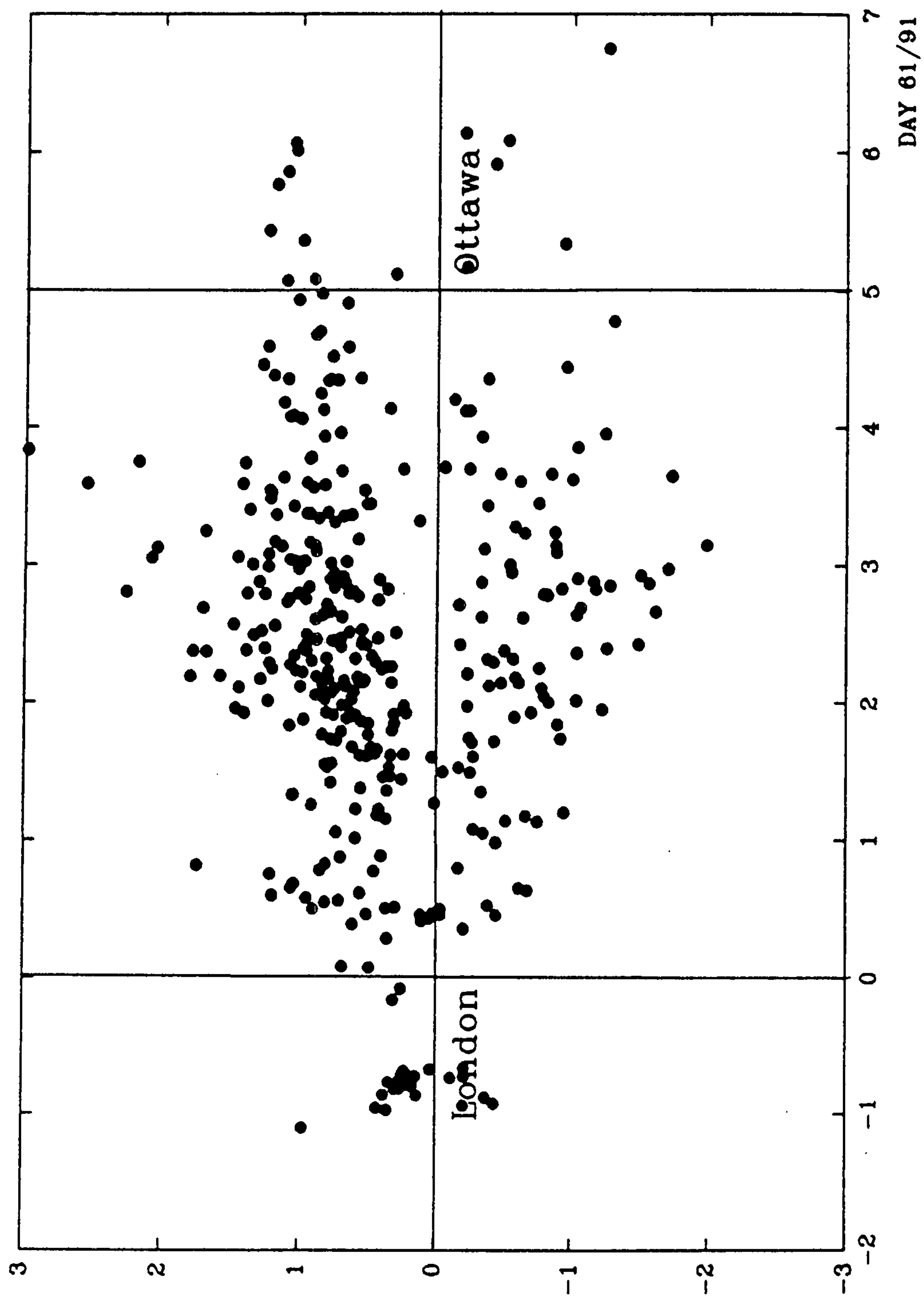


Fig 8 The directions of the received echoes projected onto the 100 km height surface for day 61.

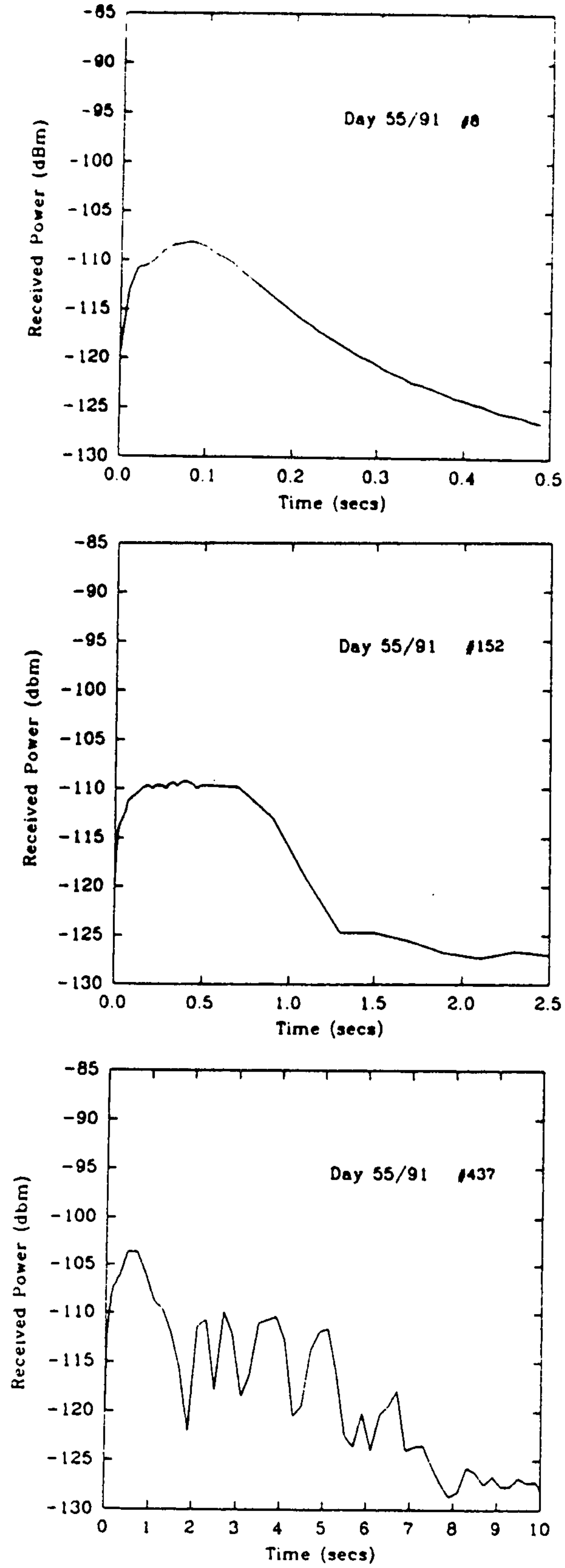


Fig. 9 Typical echoes showing (top to bottom) an underdense, an overdense and an overdense with interference type of echo. Note the different time scales.

The data obtained from this experiment are retained in a fairly basic raw form with the expectation that further software developments will take place to allow a full exploration of the relevant characteristics. These will include radiant distributions of the incident meteors, and echo amplitude and duration distributions to allow predictions to be made for performance of meteor burst systems in any location.

References.

[1] Pickard, G.W., "A Note on the Relation of Meteor Showers and Radio Reception", Proc. IRE, 19, 1166-1170, 1931.

[2] Vogan, E.L. and Campbell, L.L., "Meteor Signal Rates Observed in Forward Scatter", Can. Jnl. Phys., 35, 1176-1189, 1957.

[3] Forsyth, P.A. et al, "The Principles of JANET - A Meteor Burst Communication System", Proc. IRE, 45, 1957.

[4] Davis, G.W.L. et al, "The Canadian JANET System", Proc. IRE, 45, 1666-1678, 1957.

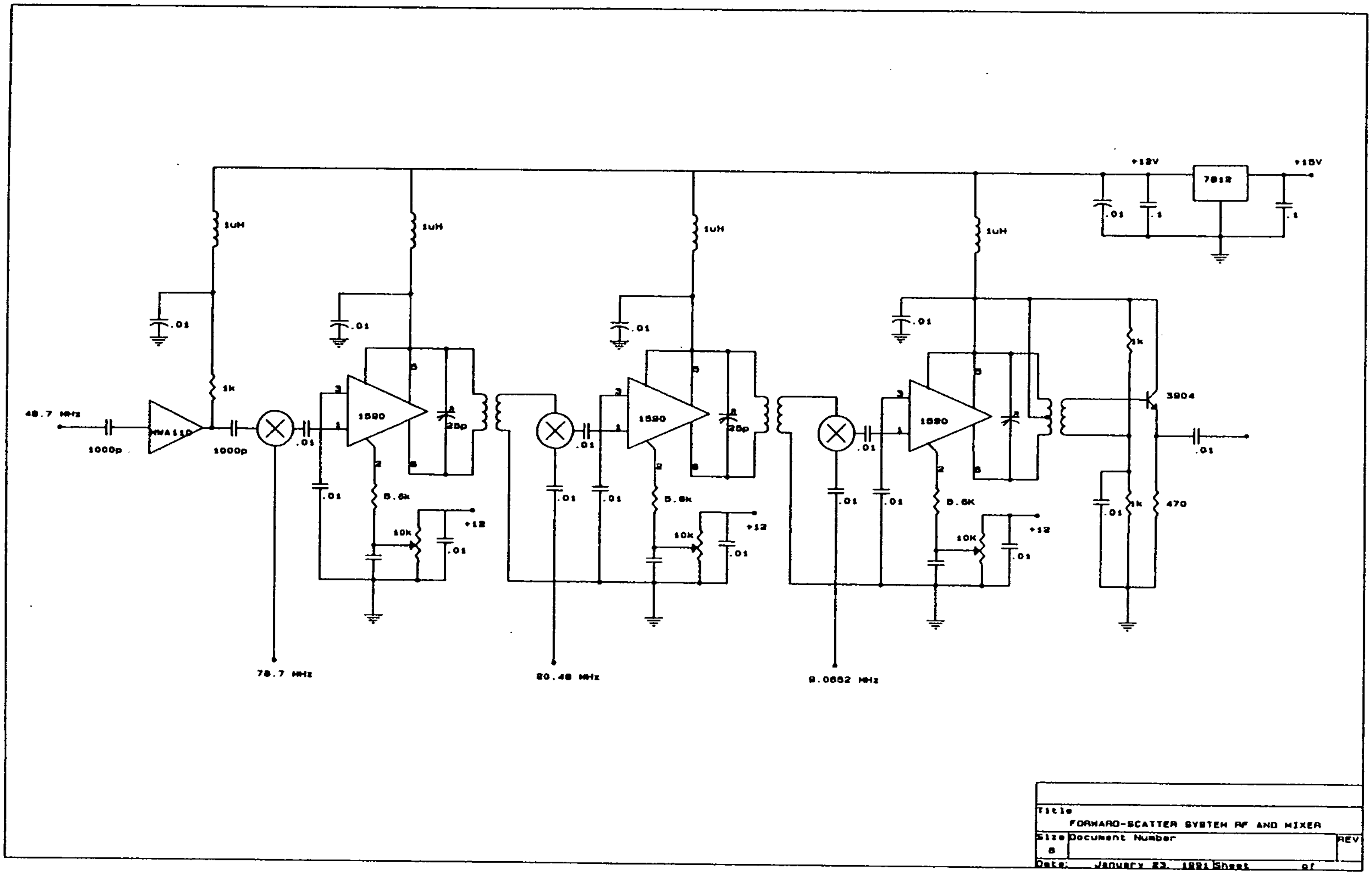
[5] Yavuz, D., "Meteor Burst Communications", IEEE Comm. Mag., 28, #8, 40-48, 1990.

[6] Schanker, J.Z., "Meteor Burst Communications" , Artech House, 1990.

APPENDIX

Detailed circuit diagrams:

A1	RF and first two IF stages.
A2	Final IF stage.
A3	Phase meter
A4	20.48 MHz oscillator.
A5	9.065 MHz oscillator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1000p
MWA110
1000p
1k
1uH
.01
78.7 MHz
1590
25p
5.6k
10k
+12
20.48 MHz
9.0652 MHz
10K
5.6K
3904
470
+12V
7812
+15V
.1
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Size
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Document Number
REV
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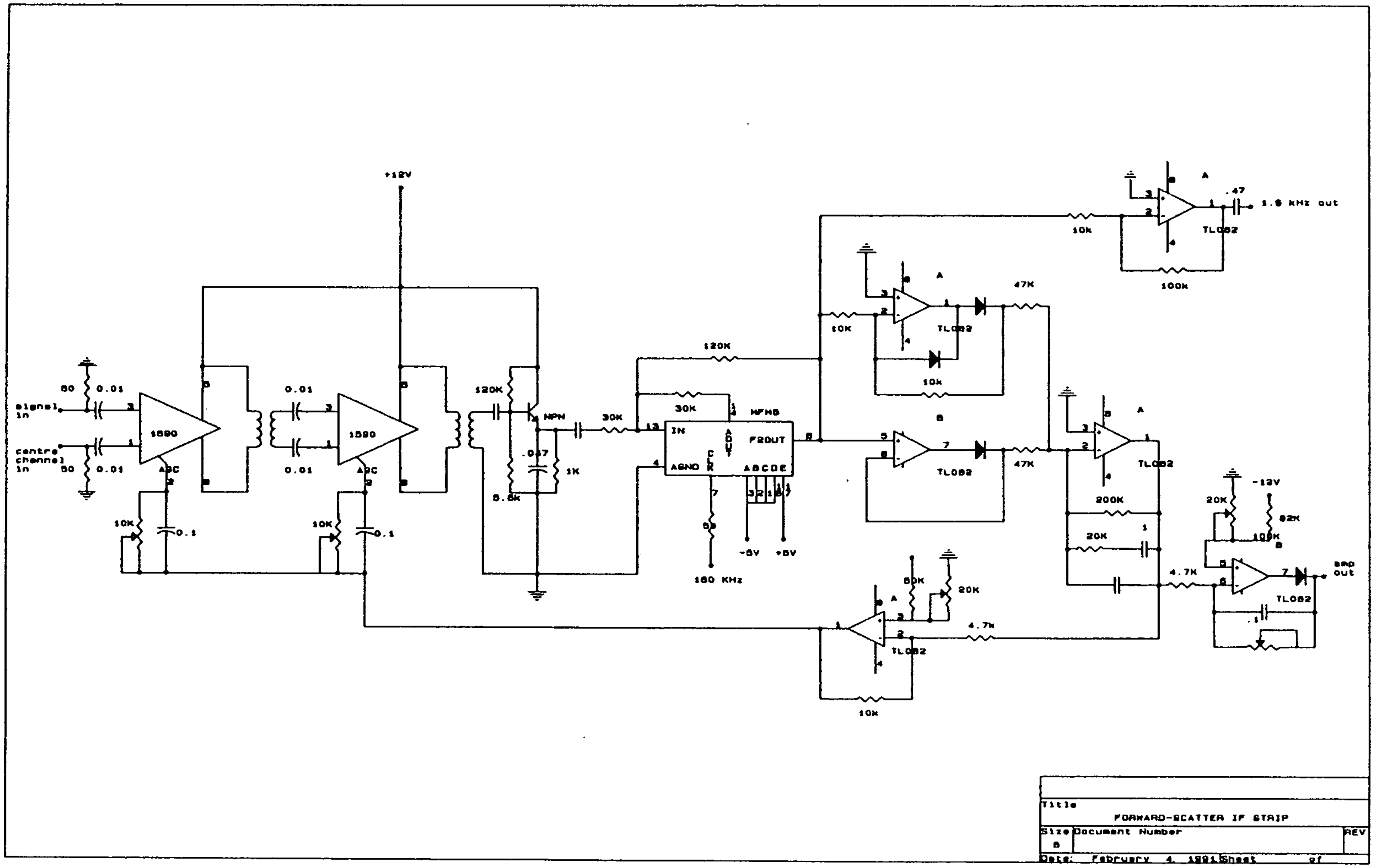

+12V
signal in
centre channel in
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0.01
1590
AGC
10K
0.1
120K
NPN
.047
1K
6.8K
30K
IN
AGND
MFHB
F2OUT
ABCDE
-5V
+5V
160 KHz
120K
10K
TL082
10k
47K
200K
20K
4.7K
-12V
82K
100K
amp out
1.6 kHz out
100k
50K
4.7k
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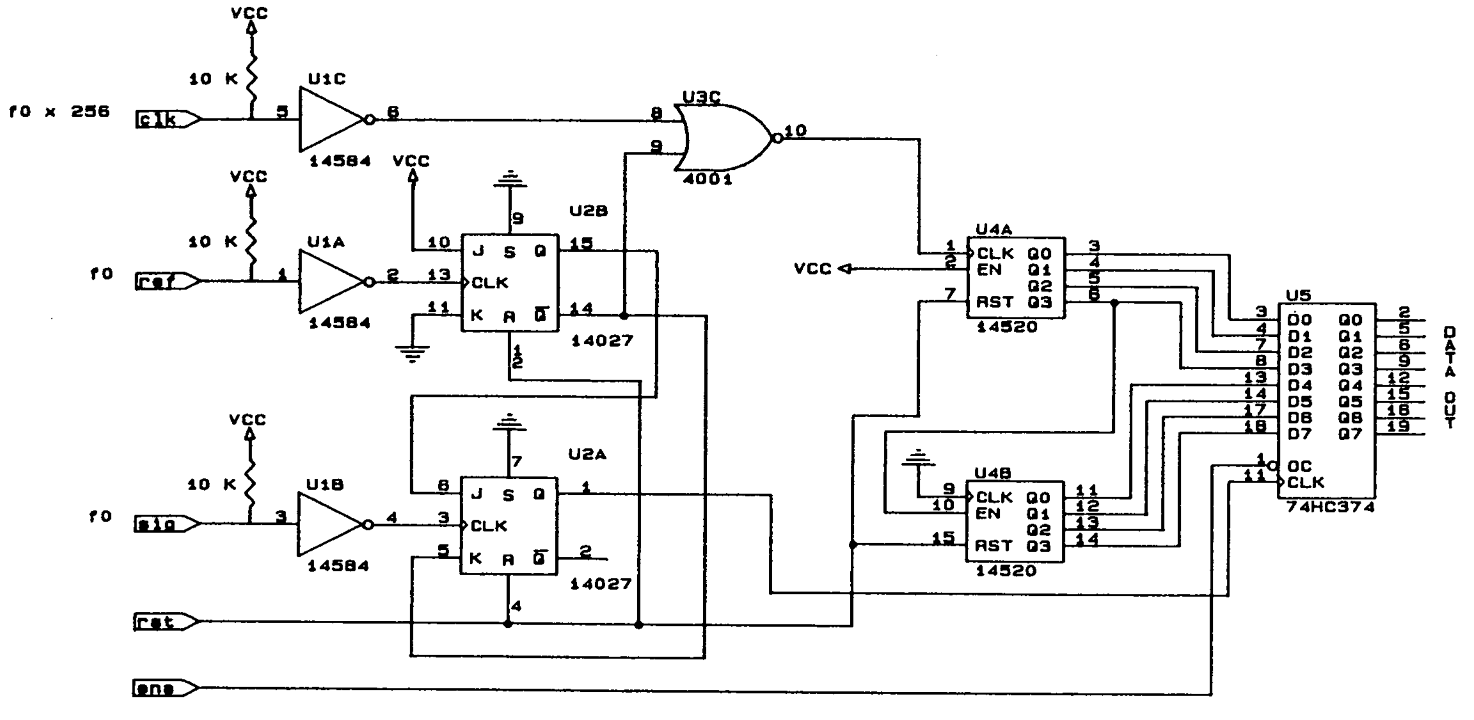

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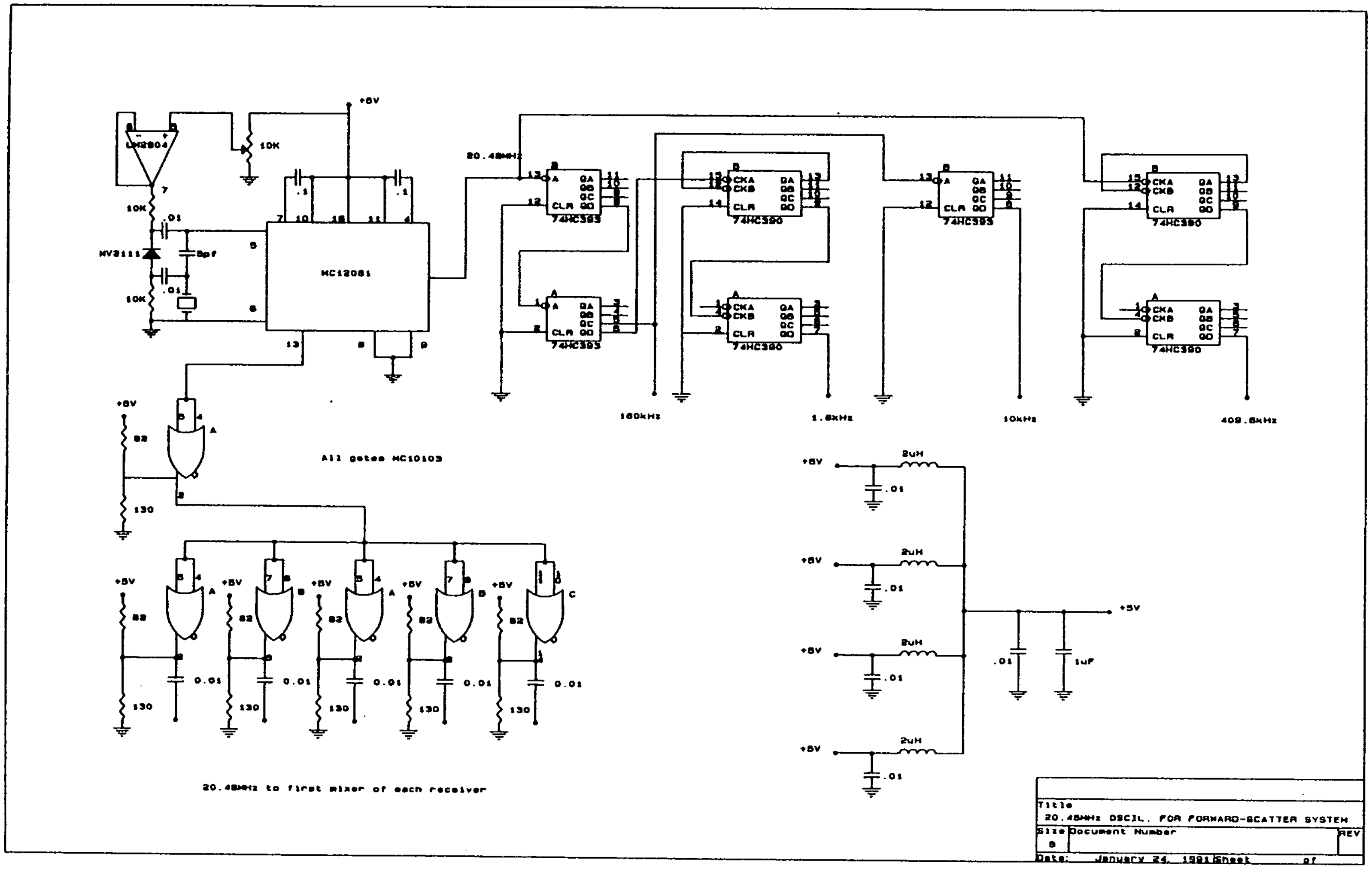
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10K
MV2111
.01
5pf
MC12061
20.48MHz
74HC393
74HC390
CKA
CKB
CLR
QA
QB
QC
QD
160kHz
1.6kHz
10kHz
409.6kHz
All gates MC10103
82
130
0.01
2uH
.01
1uF
20.48MHz to first mixer of each receiver
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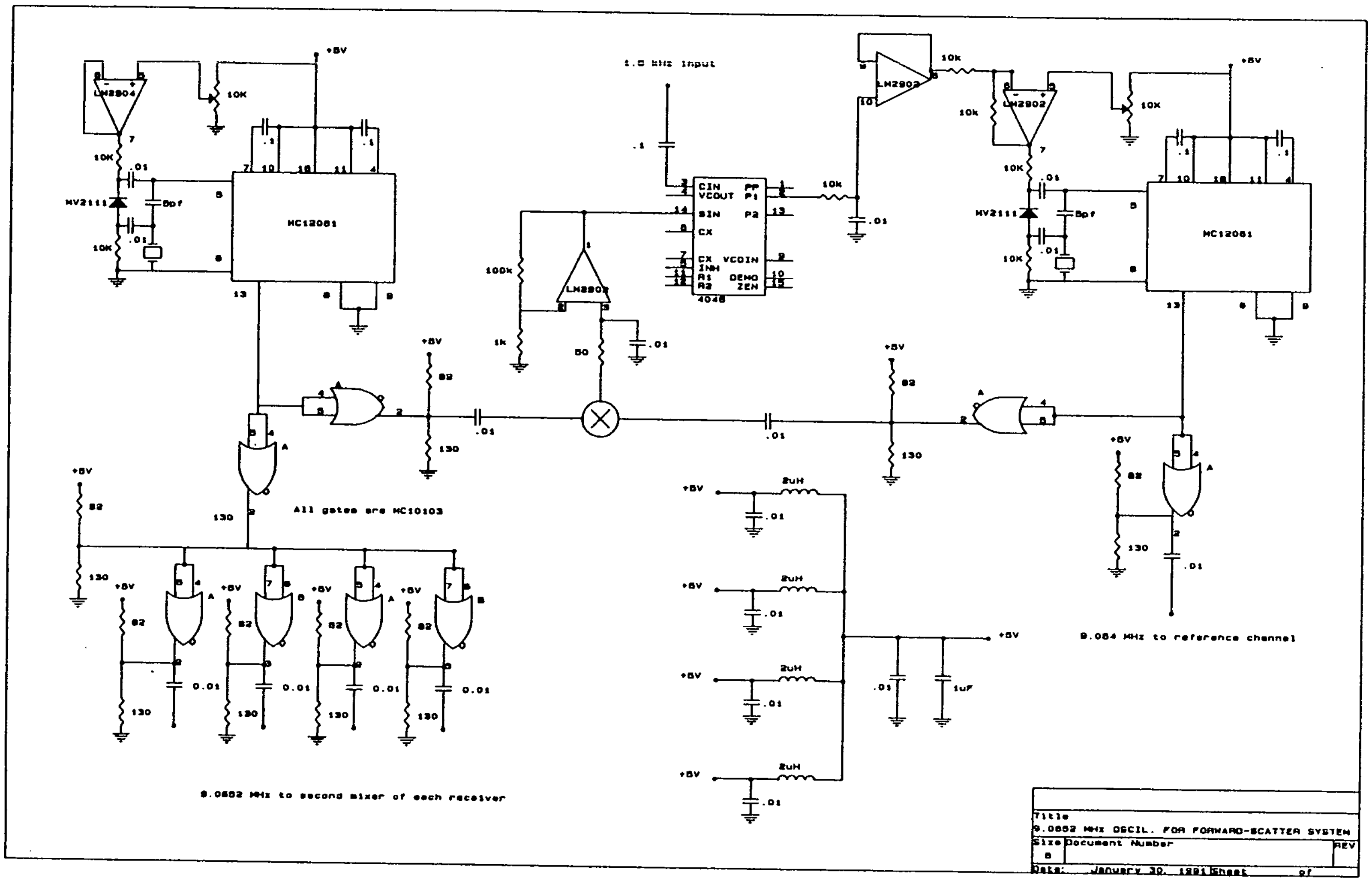
LM2904
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+5V
MV2111
5pf
MC12061
LM2902
4046
100k
1k
50
All gates are MC10103
82
130
.01
0.01
2uH
1uF
9.0852 MHz to second mixer of each receiver
9.064 MHz to reference channel
Title
9.0852 MHz OSCIL. FOR FORWARD-SCATTER SYSTEM
Size B
Document Number
REV
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