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Four-way electronic switch for tracking balloon borne transmitter using sequential lobe switching

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सार–मोटर चालित यांत्रिक यू एच एफ फेज़िंग स्विच की सहायता से अनुक्रमिक लोब स्विचन द्वारा डाइपोल मैट्रिक्स व्यूह एन्टेना के प्रयोग से मौसम गुब्बारों का पथन हमारे उपरितन वायु राष्ट्रीय नेटवर्क में पिछले 25 वर्षों से प्रचलित है। पुराने मोटर चालित यांत्रिक फेज़िंग स्विच के प्रयोग को बदलने के लिए उच्च चालकत्व-उच्च गतिस्विच डायोड के प्रयोग से 400 मेगाहर्टज पर एक ठोस अवस्था वाले चतुष्पक्षी इलैक्ट्रॉनिक स्विच की अभिकल्पना की गई है। समुचित प्रतिबाधा सुमेलन, मार्ग निर्धारण और चार एन्टेना व्यूह खंडों से प्राप्त यू एच एफ सिगनलों के परिवर्धन प्राप्त करने के लिए यू एच एफ स्विच की अभिकल्पना (डिजाईनिंग) में सूक्ष्म संचरण रैखीय तकनीक का प्रयोग किया गया। एन्टेना व्यूहों के अनुक्रमिक स्विचन और आंकड़ा अभिग्रहण तथा प्रदर्श प्रणाली के तुल्य कालन के लिए फेज़िंग स्विच में निर्मित संहत तर्क द्वारा आसूचना उत्पन्न की गई है। यांत्रिक स्विच से अलग, वर्तमान प्रणाली में किसी प्रकार की स्विचन ध्वनि नहीं है और इसमें न्यून सन्निवेश क्षति (2 डी बी) है, इस प्रकार भू-अभिग्रहण प्रणाली की आंकड़ा अभिग्रहण क्षमता में सुधार हुआ है। स्विच का डिजाईन माड्यूली, हल्का और अत्यन्त कड़ा है जो कि सभी प्रकार की पर्यावरणीय अवस्थाओं के अनुरूप है।

ABSTRACT. The tracking of meteorological balloons using dipole matrix array antenna by sequential lobe switching with the help of a motor driven mechanical UHF phasing switch had been in operational use in our national upper air network from last 25 years. A solid state four-way electronic switch at 400 MHz using high conductance-high speed switching diodes has been designed to replace the aged motor driven mechanical phasing switch. Microstripline technique has been used in designing UHF switch to achieve proper impedance, matching, routing and addition of UHF signals received from the four antenna bays. For sequential switching of antenna array and synchronisation of data reception and display system the intelligence is generated by a compact logic in-built in the phasing switch. Unlike mechanical switch, the present system has no switching noise and has low insertion loss (2 dB), thus improving the data acquisition capability of ground reception system. The design of switch is modular, light weight and highly rugged to suit all types of environmental conditions.

Key words — Conical scanning, Lobe switching, Balloon radiosonde, UHF switch.

1. Introduction

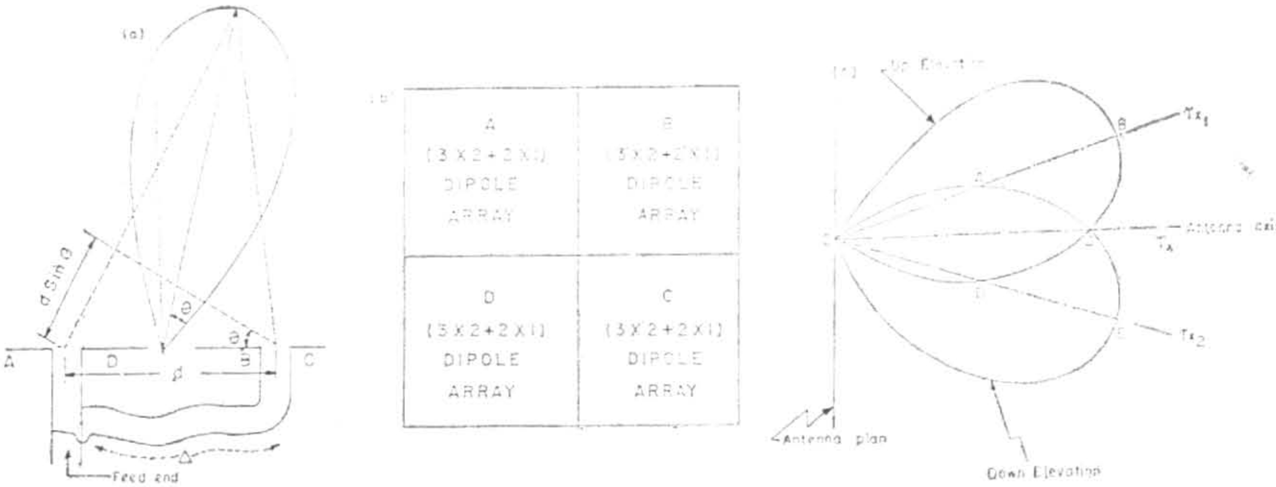
Conical scanning and lobe switching are the two most popularly used techniques for locating the position of a balloon borne radiosource. Though conical scanning is a more accurate technique, its use is limited to microwave frequency band only as a very sharp beam is required for this purpose. The mechanical manoeuvrability due to the large size of antenna required for achieving beam width of less than 2° puts a limitation on the application of conical scanning in UHF bank. Hence lobe switching is found to be the best compromise for radiosource tracking in 400 MHz meteorological radio frequency band. Radiotheodolites utilised this technique most effectively by the deployment of a motor driven mechanical UHF switching for obtaining the multi-position antenna beam.

The mechanical RF switch has several inherent disadvantages such as high power consumption and higher failure rate due to mechanical wear and tear. The main drawback is due to its high insertion loss which considerably reduces the sensitivity of reception. This, in turn, limits the maximum range for clear reception. Also the mechanical and electrical noise produced interferes with the actual signal and deteriorates the quality of reception. Keeping this in view, the design and development of a solid state phasing switch, using high quality solid state UHF devices and integrated logic circuits, was undertaken. The principle of lobe switching, design and operation of the solid state phasing switch are given in the following pages. This paper is concluded with the performance of solid state phasing switch as in actual use.

2. Principle of operation

2.1. *Lobe switching*

A broad-side dipole array can easily yield a squinting lobe pattern if the feed lines of unequal phase path length are chosen. The angle of squint of the main lobe Q may be determined in terms of spacing of dipole 'd' and the additional path length of feed line $\triangle$ from simple geometry as shown in Fig. 1 (a) $\sin\ \theta = \frac{\triangle}{d}$.



Figs. 1 (a-c). (a) Lobe switching by introduction of phase path shift, (b) arrangement of 32 dipoles in four bays of a metox antenna, and (c) tracking of balloon borne active target by lobe switching method

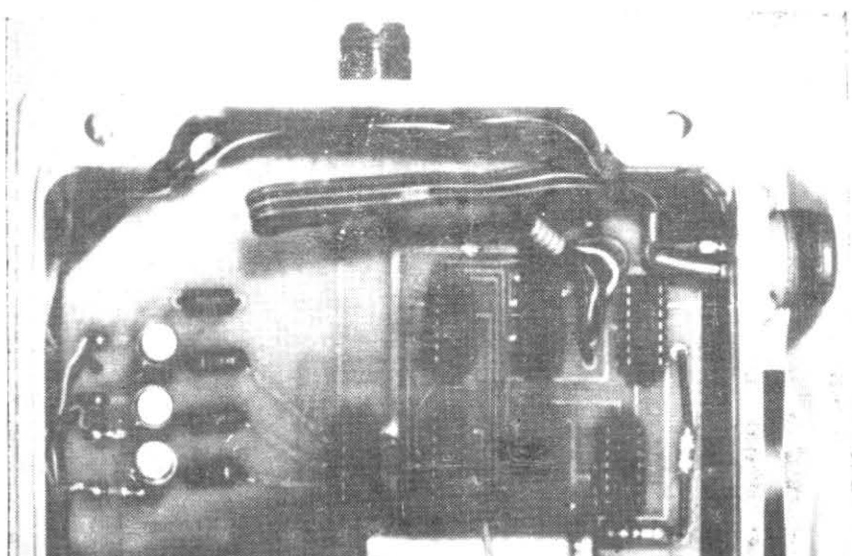


Fig. 2. Assembled solid state phasing switch

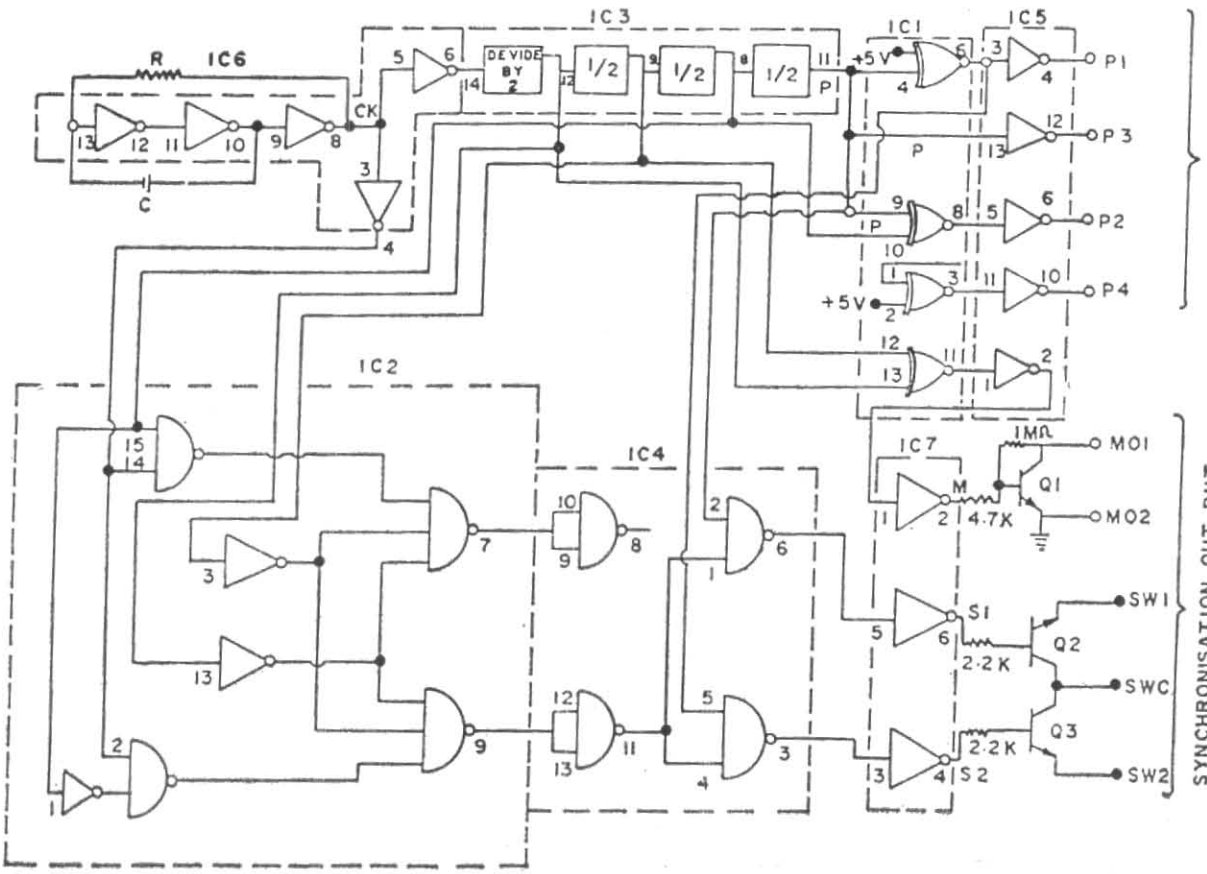


Fig. 3 (a). Logic circuit for the generation of switching and synchronisation pulses

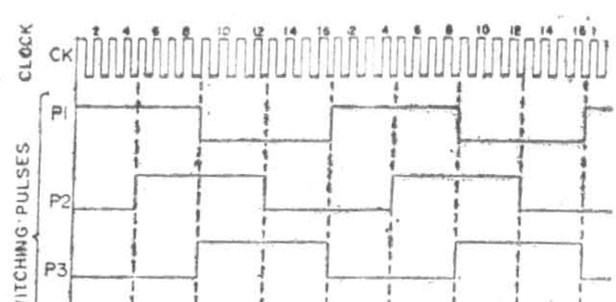


Fig. 3 (b). Timing diagram

It is evident from this equation that squint angle (θ) can be adjusted by selecting a proper value of $\triangle$. For tracking purposes the squint angle is always selected as $\phi/2$ so that the half power point always falls over the antenna axis when lobe is switched to various desired positions. ϕ is the half power beam width of the main lobe.

The arrangement of broad-side array antenna consisting of 32 dipoles in form of 4 bays, each having a matrix 8 dipoles in a radiotheodolite is shown in Fig. 1(b). For tracking purpose the additional phase path length $\triangle$ is introduced in the feeder line to the four bays in sequence with the help of phasing switch such that it yields four squinting lobe orientations corresponding to up and down elevation and left and right azimuth. The four selected lobe orientations may be expressed as :

$A+B+\triangle(C+D)$ = Down elevation

$C+D+\triangle(A+B)$ = Up elevation

$A+D+\triangle(B+C)$ = Right azimuth

$B+C+\triangle(A+D)$ = Left azimuth

The above four lobe positions are achieved in one cycle of approximately 40 milliseconds. Thus, the lobes are rotated with a frequency of 25 cycles approximately. As the speed of lobe switching is very fast during a cycle, the balloon borne target may be considered as stationary within first degree of approximation. Fig. 1(c) gives the methodology of pointing the antenna towards the balloon borne active target by lobe switching method. It may be mentioned that additional phase path/length $\triangle$ is selected such that the squint angle of lobe, in all the four positions is equal to half the beam width. Thus, on any of the 4 positions, the half power point 'C' always falls on the axis of the antenna. Hence, when the active target is not aligned on the axis of the antenna

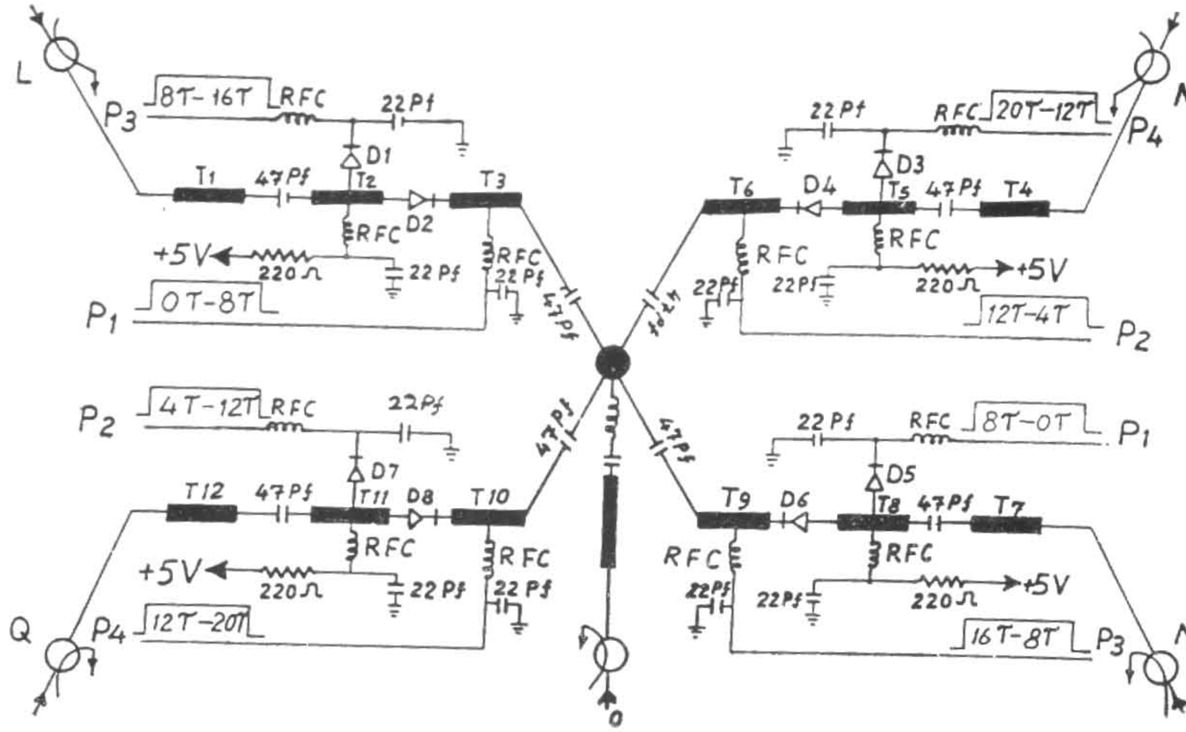


Fig. 4. R F switch

(*i.e.*, position of TX_1 or TX_2) the signal strength received is proportional to $\vec{OA}$ and $\vec{OB}$, or $\vec{OD}$ and $\vec{OE}$, which are unequal. Same is the case for lobe switching azimuthally. When the active target is aligned on the axis of antenna, the signal strength 'C' from all the four positions of the lobe is equal ($\vec{OC}$). The signal strengths sampled during four antenna positions are displayed on the oscilloscope as pulses. When the amplitude of the four pulses is same, the strength of the signal received is equal and the active target will be on the axis of the antenna. This gives direct method for finding azimuth and elevation of the active target with reference to the antenna plane.

3. Circuit description and working

A photograph of the assembled solid state phasing switch is shown in Fig. 2. The electronic hardware to construct the phasing switch is accommodated on two double-side copper laminated epoxy printed circuit boards having identical size. One contains the complete logic circuit and electronically regulated power supply required to operate the phasing switch while another accommodates the solid state UHF switch. Two tier system is adopted to place the electronic hardware inside an aluminium cast box of size 15×15×10 cm which has been designed to take care of the adverse environmental conditions. The mechanical design is such that once the upper lid is closed the box becomes completely water tight and the working of electronic circuitry is unaffected even if the phasing switch is exposed to most adverse weather conditions.

3.1. *Logic circuit*

Fig. 3(a) shows the logic circuit employed to generate a set of switching and synchronisation pulses for evolving a phasing switch exactly compatible with mechanical switch. Seven digital integrated circuit of TTL family have been used to construct the logic circuit. A set of four pulses (P1, P2, P3 and P4) in a predetermined sequence are generated for operating the UHF switch. For synchronising the oscilloscope display, pulses S1 and S2 are produced which generate the split sweep for display, and the pulse train M is used for switching the IF stages in AM-channel of the receiver which samples the amplitude of RF signal received during the four lobe positions as discussed earlier. The timing diagram of sequence of pulses generated by the logic board is shown in Fig. 3 (b) which will be discussed in greater detail while dealing with the operation of solid state phasing switch.

The circuit consists of an inverter oscillator for production of clock pulses (IC6). The clock frequency 'f' is adjusted around 400 Hz by selecting proper value of C and R. The clock pulses are fed to a binary counter (IC3) to obtain the divided pulse outputs with time periods 2τ, 4τ, 8τ and 16τ where τ is time period of the basic clock. The finally divided pulse output (time period 16τ) decides the time period of one complete lobe switching cycle. Each lobe position as mentioned earlier is generated for 4τ duration and repeats after every 16τ with the lobe switching frequency of about 25 Hz which is same as that in the motor driven mechanical phasing switch.

The pulse train P1 to P4 is generated by taking 16τ (divided by 16) pulse as basic pulse P1 which when inverted yields pulse P3. To obtain a 4τ delayed pulse

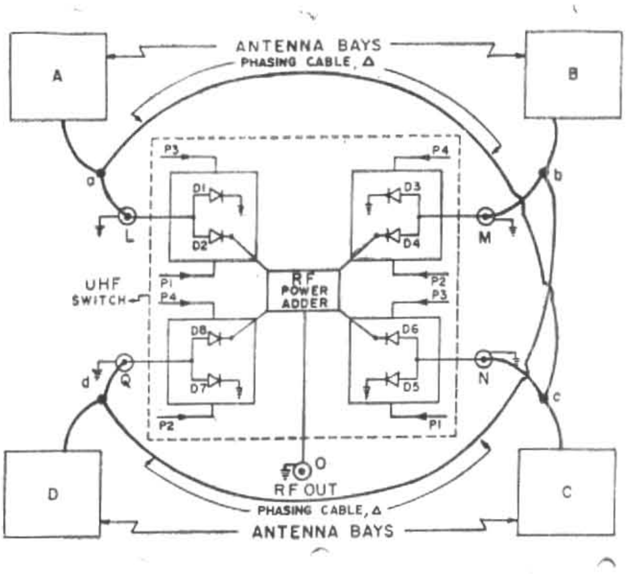


Fig. 5 (a). Schematic diagram showing sequential switching of antenna bays by phasing switch

Time (τ)	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	S_6	S_7	S_8	S_9	Remarks
0-4	□	◪	◪	□	◪	□	□	◪	□	◪	◪	□	S_6 & S_9 Grounded S_7-S_8 To output
4-8	□	◪	□	◪	◪	□	◪	□	□	□	◪	◪	S_6-S_7 Grounded S_8-S_9 To output
8-12	◪	□	□	◪	□	◪	◪	□	◪	□	□	◪	S_7-S_8 Grounded S_6 & S_9 To output
12-16	◪	□	◪	□	□	◪	□	◪	◪	◪	□	□	S_8-S_9 Grounded S_6-S_7 To output

□ Conducting - Grounded ◪ Non conducting - Connected to output

Fig. 5 (b). Time chart

P2 with respect to P1, the 8τ (divided by 8) pulse is fed to an exclusive OR gate (IC1) alongwith the pulse P1 and the inverted wave from P2 yields switching pulse P4. Thus we are able to get pulses P1, P2, P3 and P4, each delayed by 4τ with respect to each other in a sequence as shown in Fig. 3 (b). Modulation pulses M of 2τ duration are obtained by feeding divided pulse outputs of 4τ and 2τ into an exclusive OR gate (IC1) which results into a symmetrical pulse train M of 4τ time period but delayed by τ with respect to original 4τ divided pulse train. The utility of delaying the modulation pulses would be more clear when we shall discuss the operation of phasing switch. The sweep synchronisation pulses S1 and S2, the clock pulse CK and divided pulse outputs of 2τ, 4τ and 8τ duration are fed to dual 2-line to 4-line decoder/demultiplexer (IC2) which gives out the sharp pulse of $\tau/2$ duration with repetition time of 8τ. The output of IC2 is then inverted and fed to two, 2-input NAND gates (IC4) one of which is fed with 16τ pulse while another is fed with inverted 16τ wave form. The outputs of the NAND gates are inverted (IC7) to give out pulse train S1 & S2 of $\tau/2$ period with 16τ period but delayed by 8τ with respect to each other as shown in Fig. 3(b). The high voltage switching transistors Q1, Q2 and Q3 (2N 3440) are used as interface between logic board and 401 AM/FM receiver which requires high voltage (120 volts) switching.

3.2. *UHF switch*

A schematic circuit diagram showing a four input UHF switch working at 400 ($\pm$10) MHz is given in Fig. 4. It consists of four identical circuit blocks marked L, M, N and Q for switching four corresponding antenna bays in the desired sequence. All four circuits contain two high speed and high conductance switch diodes (D1 to D8) and three micro-strip transmission lines (T1 to T12). The diodes are selected to give effective UHF switching with lowest attenuation. Double side copper laminated high quality epoxy printed circuit board has been selected for effective design of very low attenuation micro-strip transmission line (T1 to T12), the criterian of the design of each set of three micro-strip transmission lines (*e.g.*, T1 to T3) in each circuit block (*e.g.*, L) is that the effective electrical length of each set of lumped transmission lines is $\lambda/2$ at 400 MHz. One of the diodes (*e.g.*, D1) in each circuit block (*e.g.*, L) is connected to ground in the mid-way of the micro-strip transmission line such that effective transmission line length from the junction to the feed-end is $\lambda/4$. The above design is adopted for achieving the matching of the UHF signal to both input and output ends of all switching combinations. The diodes are normally conducting in absence of switching pulses as the +5 volts is applied through a resistance at the common anode junction of diodes in each block. With the application of switching pulses P1 to P4 the diodes are switched off in a predetermined sequence to achieve sequential switching off input UHF signals to output. The scheme in which switching pulses are applied to the diodes array is also shown in Fig. 4.

The UHF outputs from all the four switching blocks is combined by an adder circuit consisting of a series resonant circuit with a micro-strip line. The inductance L together with micro-strip line T is used for finer adjustment of the centre frequency and matching the impedance of input and output lines. The alignment of UHF switch is done with the help of polyskop before the phasing switch is sent for field use.

4. Operation of solid state phasing switch

The arrangement of phasing cables connecting the four antenna bays (A, B, C and D) of radiotheodolite to the solid state phasing switch is schematically shown in Fig. 5. The actual operation of phasing switch for switching the four lobe positions as described earlier, sampling of amplitude of RF signal during four lobe positions and its display on the oscilloscope for tracking purposes may be understood with the help of Figs. 3 (b), 5(a) and 5(b).

For the systematic understanding of lobe switching the cycle may be divided into four equal time segment each of 4τ duration. During the first time segment (0 to 4τ) pulses P1 and P4 have high voltage level (1 level) while P2 and P3 are at low voltage level (0 level). Under this condition, the diodes D2, D3, D5 and D8 are switched off while D1, D4, D6 and D7 remain conducting. As diode D1 is conducting and D2 is non-conducting the input at L looks into a $\lambda/4$ shorted transmission line which offers a very high input impedance for the signal appearing at input of L. Therefore, the signal from bay A takes longer path through phasing cable and goes to input through N alongwith the signal from bay C as D5 is non-conducting and D6 is conducting. So the

TABLE 1

Summary of operation of solid state phasing switch

S. No.	Time segment	P1	P2	P3	P4	Conducting diodes	Switched off diodes	Phased output	Lobe position
1	0 to 4τ	1	0	0	1	D1, D4, D6, D7	D2, D3, D5, D8	$B+C+\triangle(A+B)$	Left azimuth
2	4τ to 8τ	1	1	0	0	D1, D3, D6, D8	D2, D4, D5, D7	$C+B+\triangle(A+B)$	Up elevation
3	8τ to 12τ	0	1	1	0	D2, D3, D5, D7	D1, D4, D6, D7	$A+B+\triangle(B+C)$	Right azimuth
4	12τ to 16τ	0	0	1	1	D2, D4, D5, D7	D1, D3, D6, D8	$A+B+\triangle(C+D)$	Down elevation

phase condition of signal entering through N may be given by $(C+\triangle.A)$. Similarly high impedance is offered at input Q so that the phase condition of signal entering through M is given $(B+\triangle.D)$. Thus the added signal at the output and 0 may be given as $[B+C+\triangle(A+D)]$ which corresponds to left azimuth lobe position. Similarly, during other three time segments, lobe positions corresponding to up elevation, right azimuth and down elevation are switched on in sequence and cycle repeats after every 16τ period. A summary of switching operation of UHF phasing switch is given in Table 1.

The IF stages of AM channel of valve receiver of 401 MHz radiotheodolites are normally kept non-conducting by the application of positive bias of the order of +50 to +70 volts on the cathodes. The terminal MO1 [Fig. 3(a)] is connected to the common point which provides positive bias to the cathode. The transistor which is normally non-conducting starts conducting when the modulation pulse M appears on the base. During this period, the cathode bias of IF stages comes down to zero thereby allowing the IF signal to pass to the output of AM channel. By this method the amplitude of received signal from radio target is sampled during four lobe positions which is demodulated and displayed as four tracking pips corresponding to four lobe positions on the oscilloscope. The utility of τ delay given to modulation pulse train M allows midway sampling of amplitude in each time segment and avoids clipping of edges of display pips.

The pulses S1 and S2 are used for generating split sweep each of 8τ duration in conjunction with receiver for producing synchronised visual display of tracking pulses. Left azimuth and up elevation pulses are displayed on the first sweep ($0\ \tau$ to 8τ) while right azimuth and down elevation pips are displayed on the other sweep which remains from 8τ to 16τ duration. The split sweep helps in super-imposition of corresponding pips for exact comparison of their amplitude to enable accurate tracking of balloon borne target.

5. Conclusion

Solid state phasing switch designed and developed has been found to work satisfactorily both in laboratory and in actual field use. It was introduced in operational use in more than ten national upper air network stations for routine use and is in use till date. It is a very reliable sturdy and low cost device and exactly compatible with the present mechanical switching system. Unlike the motor driven mechanical phasing switch, this system with integrated circuit design consumes very low power and assures very long trouble free operation. The performance of the phasing switch is also not affected when exposed to extreme weather conditions. Low insertion loss improves the overall sensitivity of the UHF signal reception thereby improving data acquisition capability of the ground equipment. As the solid state phasing switch is free from switching noise, it has also brought in the improvement in the quality of FM data reception the radiotheodolite.