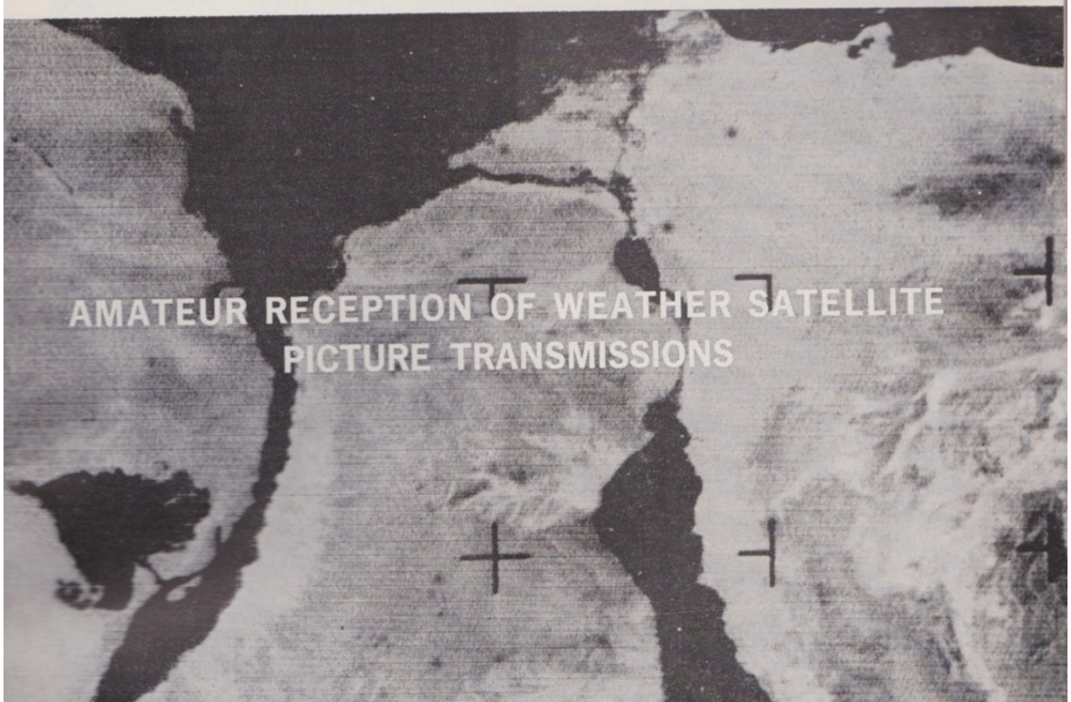
AMATEUR RECEPTION OF WEATHER SATELLITE PICTURE TRANSMISSIONS



Televised picture of the Nile Delta received at Fairbanks, Alaska, during the NIMBUS I flight using the Advanced Vidicon Camera System (AVCS). The Automatic Picture Transmission (APT) system described in the text gives approximately the same resolution but transmits the picture by slow scan. *(Photo courtesy of Goddard Space Flight Center.)*

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THE NIMBUS and TIROS series of weather satellites provide an excellent opportunity for further amateur participation in space programs through the reception of slow-scan television pictures of the earth. These pictures are primarily intended to show cloud formations for meteorological use, but their high definition gives remarkable detail on terrain features as well.

Fig. 1 shows one of the pictures received from the NIMBUS I Automatic Picture Taking (APT) transmitter, using the relatively simple and inexpensive receiving equipment to be described. While current estimates run $32,000 for ready-made stations and $6,000 for the "do-it-yourself" type, the cost of this amateur station was cut to well under $200 by using equipment of the kind found available in most ham shacks. Modest darkroom facilities and a tape recorder are also required. For this approach, a simple home-brew picture recorder costing under $50 was used, instead of the commercial facsimile units which cost from $5,000 to $35,000.

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The simplicity of this ground station equipment is made possible by the slow-scan APT camera system (see box on page 16) and the high-power (5-watt) transmitter in the satellite. This combination gives enough signal-to-noise ratio for effective operation without the giant parabolic dish antennas usually associated with satellite signal reception.

With APT, the satellite camera shutter is opened briefly, storing the picture in the vidicon camera tube. The picture is then transmitted by slow-scan television, completing the frame in 200 seconds. After 8 seconds for recycling, the operation is repeated. Pictures can be received as long as the satellite is within line of sight to the ground station. Usually, three pictures can be received on each pass.

While the presently operating weather satellites are not using this mode, both TIROS VIII and NIMBUS I transmitted the APT signals. By early 1966, APT systems are expected to be in constant operation, providing high-quality pictures of the earth from altitudes of 500 to 750 miles.

When NIMBUS I was launched in the fall of last year, the simple receiving and display sys-

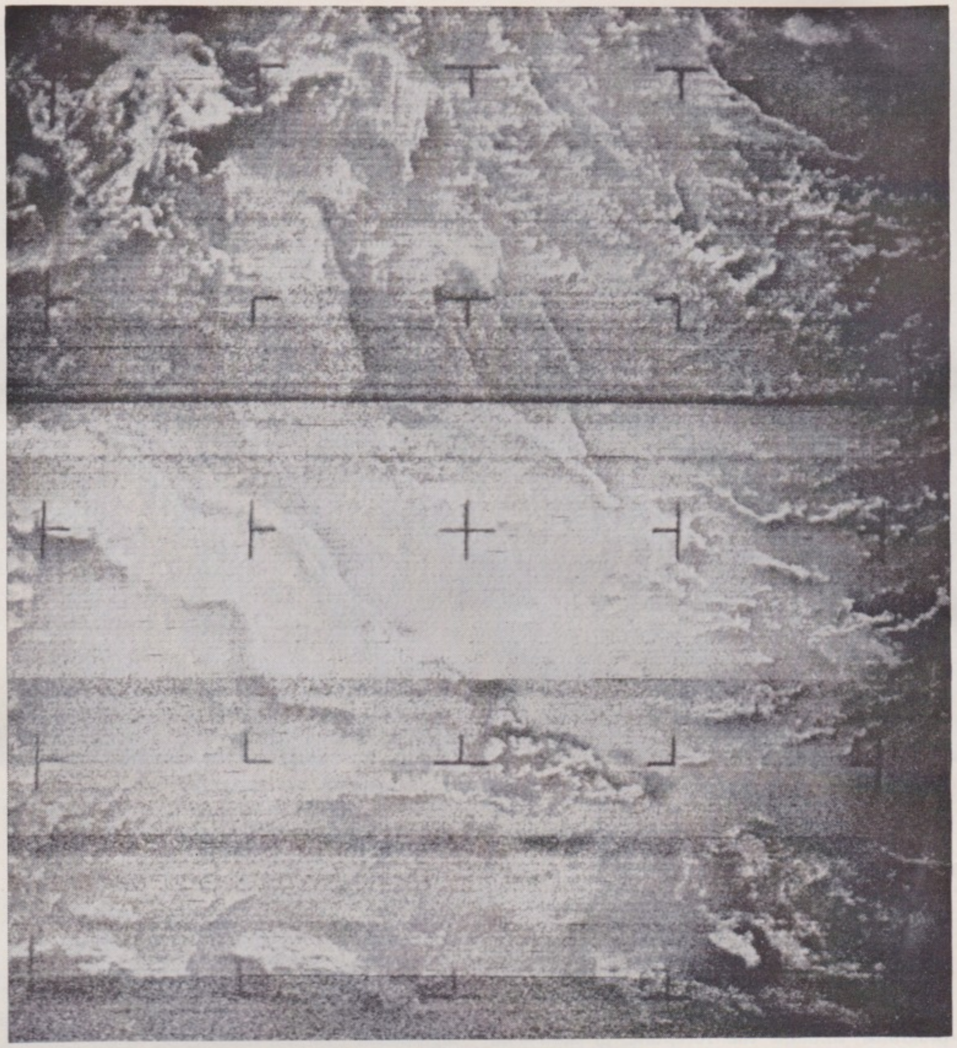


Fig. 1—Photograph of the Caribbean area, transmitted from a Nimbus satellite, made with the equipment shown in block form in Fig. 2. Outline map of the area is shown below. Light crosshatching indicates shallow water.

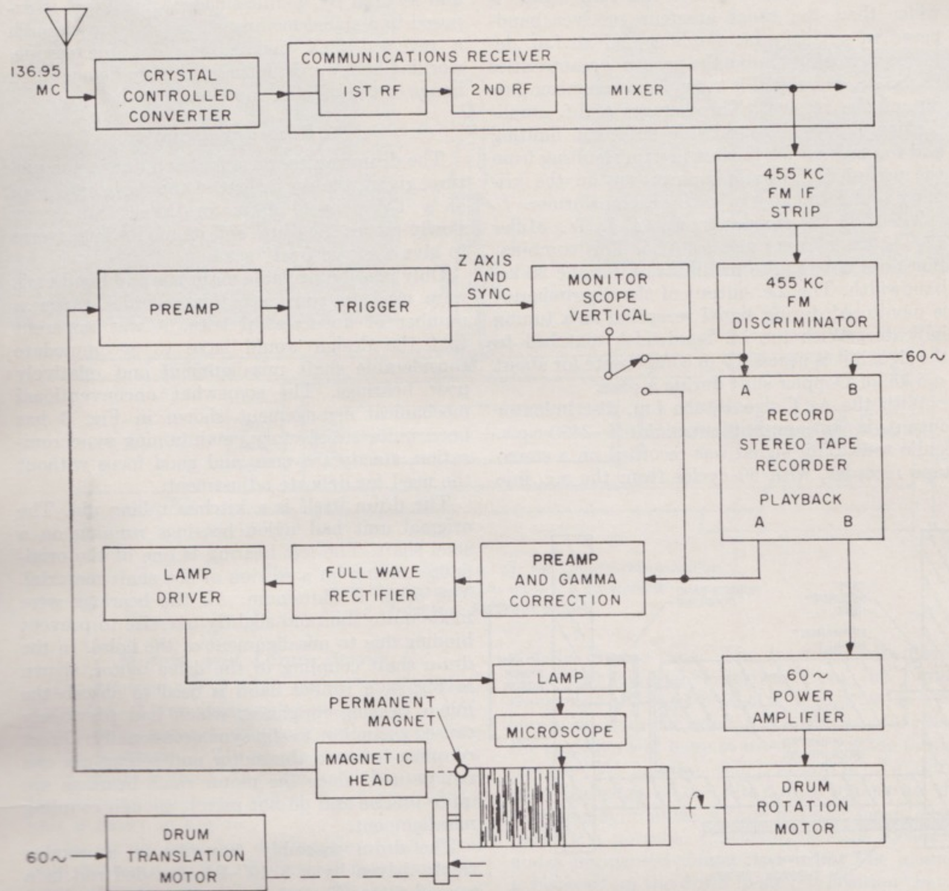


Fig. 2—Block diagram of the recording and photo-reproducing system used in making the picture shown in Fig. 1. A modified version which uses the 2400-cycle audio carrier and frequency dividers to obtain the 60-cycle power for operating the drum-rotation motor is described in the text. The special circuits for the modified arrangement, which requires only a monaural tape recorder, are given in Figs. 6 to 9, inclusive.

tem shown in Fig. 2 was assembled from readily available components, most of them from the junkbox. The crystal-controlled converter for 136.95 Mc. was built along the lines of a regular two-meter converter. An outboard i.f. for the station receiver was built to increase the bandwidth to 20 kc. and to add an f.m. discriminator.

With this arrangement, the signals were strong enough to be received with a folded dipole antenna laid out on the roof, but there were some obvious nulls from local reflections as the satellite passed over. More work is definitely required here. A dipole in the clear would probably overcome much of the difficulty. The next series of weather satellites will transmit the APT pictures from a horizontal whip, which might seem to be an ideal match to a horizontally-polarized rotary beam. However, as the satellite passes a line directly to the East and West of the station, the whip is seen from below one end and the received signal is vertically polarized. Some of the commercial stations get around this problem by using a circularly polarized antenna; others use separate receivers for the horizontal and vertical polarizations with diversity combining at the receiver outputs. The circular polarization appears to be less complex, but has a 3-db. loss compared to matched polarization. A fixed dipole facing north-south avoids this problem since it always has the proper polarization. The extent of the improvement needed will depend on the picture quality desired, of course. Fig. 1 shows both "snow" (the TV type, not the cold, white stuff) and the effects of the nulls in the folded dipole pattern.

Receiver System

The r.f. section of the receiver is quite conventional. A low-noise 2-meter converter, tuned to 136.95 Mc., provides a simple front end. (Provision should also be made for future APT satellites, which will operate near 137.5 Mc.)

The 20-kc. bandwidth of the f.m. signal is wider than the usual amateur receiver band-pass. An auxiliary i.f. amplifier and an f.m. detector were built to give the proper characteristics at 455 kc. The signal is taken from the mixer output of the receiver. Three stages of i.f. amplification are used to provide sufficient limiting and to make up for the loss in gain resulting from the use of 47K swamping resistors on the primary and secondary of each i.f. transformer.

The f.m. discriminator uses a J. W. Miller 12-C45 transformer and a 6AL5. This combination does not require modification for the 20-kc. bandwidth. The d.c. output of the discriminator is monitored during signal reception as a tuning indicator. With the i.f. bandwidth matched to the signal, it is necessary to compensate for about ±5 kc. of Doppler shift during a pass.

With the APT signals, the f.m. discriminator output is an amplitude-modulated 2400-c.p.s. audio tone. This signal was recorded on a stereo tape recorder, with 60 cycles from the a.c. line used on the second channel for synchronization on playback. Although use of the tape recorder was not absolutely necessary, it provided a means for testing the picture-recording equipment when the satellite was not overhead (which was most of the time, of course).

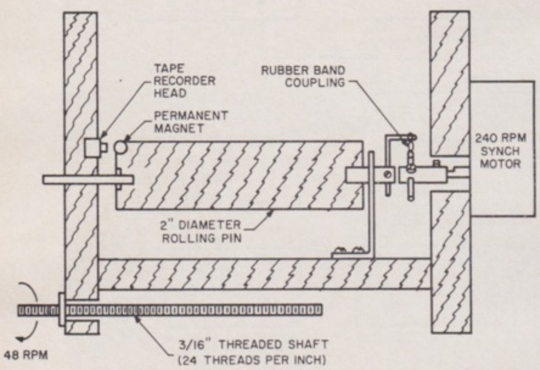


Fig. 3—The drum and carriage assembly, showing the synchronizing system using a tape-recorder head and permanent magnet. The carriage is moved along a track by the lead screw for line-by-line scanning.

Picture Recorder

The picture recorder evolved over a fairly long period of experimentation. The first efforts were with a modified Heathkit oscilloscope and a camera. The slow-scan sweeps worked reasonably well, but the resolution was considerably less than the 800-line capability of the signal, and the 60-cycle hum bars were never satisfactorily removed. The present recorder is built along the lines of a facsimile recorder, but it is operated in a darkroom instead of having a light-tight case. An 8 × 10 sheet of Royal-X Pan photographic film, wrapped on a rotating drum and secured by double-sided Scotch tape, is exposed to a signal-modulated argon lamp through a reversed 50X microscope. The microscope, working backwards, focuses a highly-demagnified image of the bulb on the film.

Recorder Drum

The drum rotates once for each line of the picture, giving the equivalent of the horizontal scan of a TV picture. A motor-driven lead screw slowly moves the drum and its mount in traverse to give the "vertical" scan.

Only readily available materials and hand tools were used to construct this recorder. After a number of unsuccessful tries, it was apparent that the design would have to accommodate considerable shaft misalignment and relatively poor bearings. The somewhat unconventional mechanical arrangement shown in Fig. 3 has been quite satisfactory, maintaining synchronization, steady traverse, and good focus without the need for delicate adjustment.

The drum itself is a kitchen rolling pin. The original unit had nylon bearings running on a steel shaft. The left bearing is one of the originals, running on a section of the shaft material. The other is aluminum. All the bearings were made quite thin and slightly oversize to prevent binding due to misalignment of the holes. In the drum shaft coupling to the drive motor, shown in Fig. 4, a rubber band is used to absorb the minor bearing roughness which had previously caused the motor to slip sync occasionally. Direct coupling between the motor and rolling pin can not be used since the motor shaft bearings are quite precise and do not permit enough coupling misalignment.

The drum assembly traverses in a wooden track, driven by a 3/16″–24 threaded rod in a tapped plate. The track must be smooth to prevent irregular movement, which results in line-pairing or worse. Talcum powder is sparingly used as a lubricant. The bearing for the traverse drive was made from a 3/16-inch lead anchor. It was threaded and locked onto the lead screw; it turns in a ¼-inch panel bushing. The motor mount is adjustable to remove residual misalignments, which cause a bar pattern in the picture at a five-line pitch (the drum makes five revolutions for each turn of the lead screw).

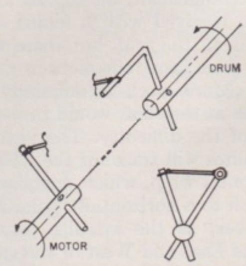


Fig. 4—Detail of the rubber-band drive.

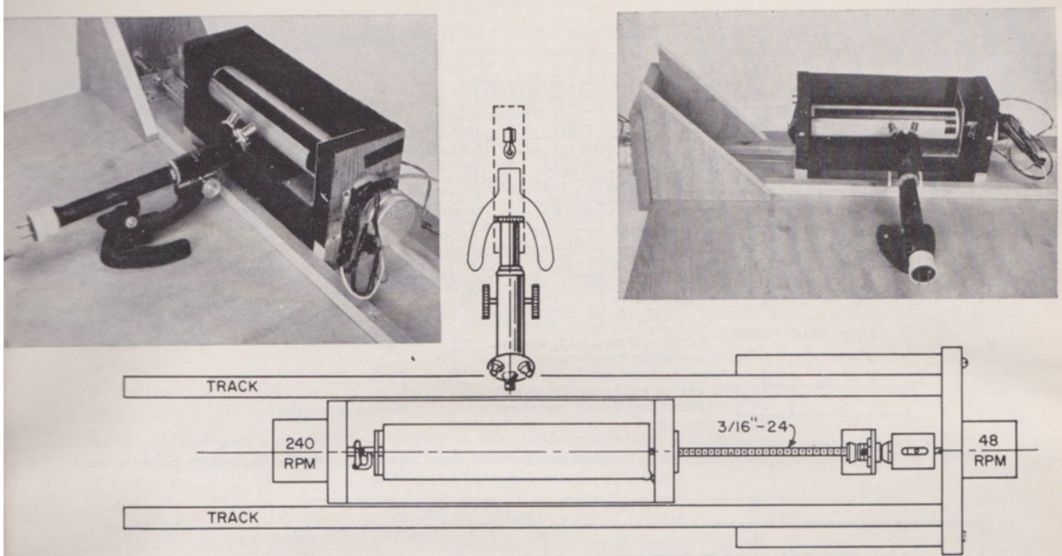


Fig. 5—Top-view drawing of the photo-reproduction assembly. Photographs show the equipment from two different angles.

Motors and Lamp Driver

The motors are 5-watt Hurst synchronous, Type CA. These inexpensive motors have limited torque, but are adequate with proper care of the bearings. A 240-r.p.m. model is used for drum rotation and a 48-r.p.m. model is used for the traverse lead-screw drive. The layout of the unit is shown in Fig. 5.

The circuit used for driving the AR-3 argon bulb is shown in Fig. 6. Several more complex arrangements were tried, but this one worked quite well. At the beginning, provision was made for assurance that the bulb would fire at low signal levels. However, this is apparently not a problem, since no threshold is observed down to currents less than 1% of full drive. The space between the AR-3 electrodes should be made vertical to avoid line-pairing when the position of the glow discharge shifts.

Film Exposure and Development

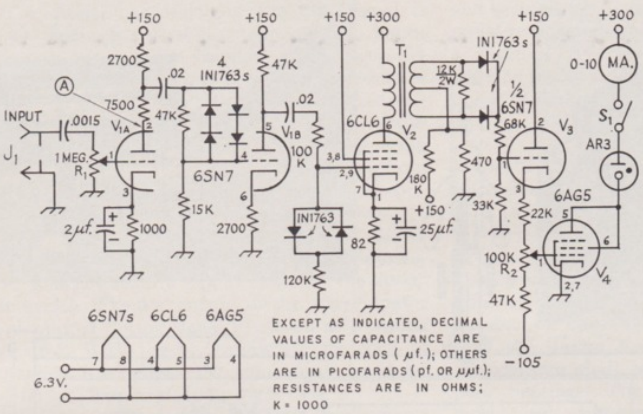
The over-all linearity of the signal driver circuit was adjusted by the 1N1763 networks to give a fairly good gray scale match between the APT signal and the Royal-X Pan film. The APT signal characteristic provides equal signal level steps for each gray step. By setting the sync pulses to 7.5 volts peak-to-peak at test point A in Fig. 6, the networks correct the gamma to provide equal density steps on the film for equal signal amplitude steps. The film was developed as recommended by Kodak to achieve a gamma of 1.0 (10 minutes in HC-110 diluted 1:15).

Synchronization Techniques

In setting up the recorder at the beginning of a picture, it is necessary to synchronize the drum and the tape recorder. The drum motor is driven by a 60-cycle signal derived from the timing track, but the start of the picture must be synchronized with the edge of the film — otherwise, the negative will have to be cut to get the proper picture. To monitor the position of the drum (and the edge of the film) with respect to the incoming sync pulse, a tape recorder head (spare part for a portable transistorized tape recorder) and a permanent magnet are used. The magnet is fastened on the drum in such a position that it passes the recorder head, fixed on the frame, at the place where the film edge passes the modulated light source. The pulse from the recorder head is amplified and shaped with the circuit shown in Fig. 7, then used to Z-axis modulate the monitor scope. This signal can also be used for scope sync. In operation, the drum motor drive is interrupted momentarily to allow the drum to slip back into sync, as indicated on the scope.

Maintaining synchronism for the drum drive depends on the exact 15:1 relationship between the 60-cycle line and the horizontal line rate generated in the satellite. For the pass from which the picture shown in Fig. 1 was received, the sync was close enough to get a relatively good image without using a special device. This was only a fortunate coincidence, apparently, and cannot be expected in the future.

A stable 60-cycle oscillator with vernier frequency control could be used to maintain the required sync, but adjustment would be difficult, although certainly not impossible. The 2400-cycle per second subcarrier frequency provides an alternate approach. This frequency is exactly 600 times the horizontal scan frequency, related



J1—Phono jack.
R1—Audio-taper control.
R2—Linear-taper control.
S1—S.p.s.t. toggle.
T1—Driver transformer, 3:1 pri. to ½ sec., 30-ma. primary (Stancor A-4723).

Fig. 6—Lamp driver and preamplifier. Fixed resistors are ½ watt; fixed capacitors may be ceramic or paper except those with polarity indicated (electrolytic).

APT SIGNAL DESCRIPTION

Carrier:	136.950 Mc.
Modulation:	f.m.
Deviation:	±10 kc.
Subcarrier:	2400 c.p.s.
Modulation:	a.m.
Polarity:	Max. amplitude sync. 80% amplitude max. white
Video:	0–1600 cps
Line Rate:	4 per second
Frame Time:	208 seconds
Gamma:	Equal voltage increments per gray step
Orbit Parameters:	
Duration of Overhead Pass:	approximately 10 minutes, or about 3 frames
Sun synchronous, 80° retrograde.	

by a count-down chain in the satellite.

A 40:1 frequency divider is used on the ground to derive the 60-cycle drum motor drive. Since the signal is often noisy, a phase-locked oscillator is used to provide a clean signal to the count-down chain. These circuits are shown in Figs. 8 and 9. The p.l.o. circuit has given excellent results, holding synchronism during fades of several seconds. To achieve this holding ability, the oscillator was adjusted to free-run at the proper frequency with zero signal-to-noise ratio by observing the drift in synchronization after a signal fade. These fades are automatically available at the beginning and end of a pass. This adjustment is relatively simple with tape-recorded signals, since the tape can be replayed several times if necessary.

This approach has the further advantage of being operable with a single tape-recorder channel (monaural instead of stereo).

Conclusion

The choice of components was primarily determined by the availability of parts in the junkbox and the most inexpensive components obtainable. The microscope is the $15.00 model from Edmund Scientific Co. but almost any low-power microscope should work as long as the image of the light source is about the same size as the line-to-line spacing on the film.

The photographic film negative size was determined by the circumference of the rolling pin. The traverse motor speed and lead screw threads per inch are set to give a picture that is approximately square. If a photographic enlarger is available, a smaller diameter drum and slower traverse might be used to get all three pictures for one pass on a single strip of film. The microscope would have to be higher power to accommodate the smaller line-to-line spacing, and

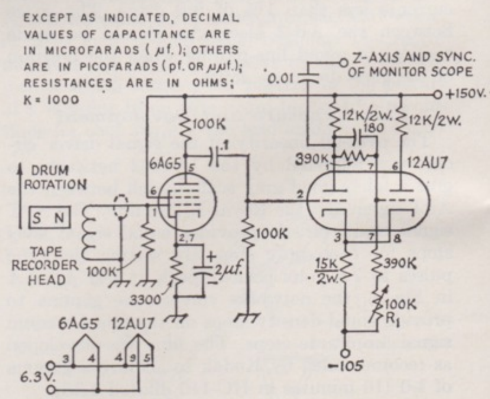


Fig. 7—Synchronizing-indicator circuit. Capacitor with polarity indicated is electrolytic; others may be paper or ceramic. Fixed resistors are ½ watt.

R1—Linear-taper control.

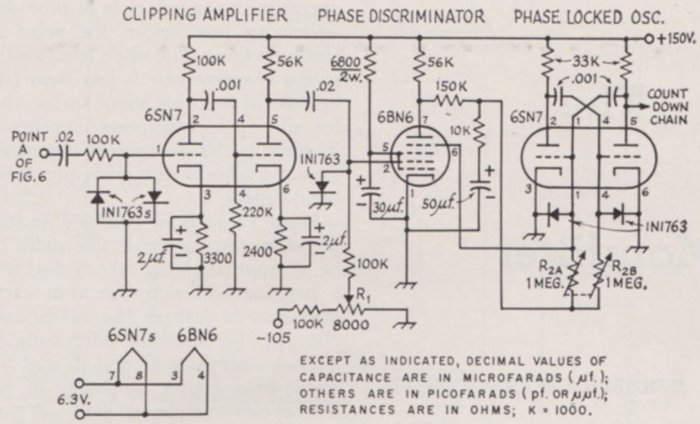


Fig. 8—Phase-locked oscillator circuit. Capacitors with polarity indicated are electrolytic; others may be paper or ceramic. Fixed resistors are ½ watt. R_1—Linear-taper control. R_2—Dual control, linear taper.

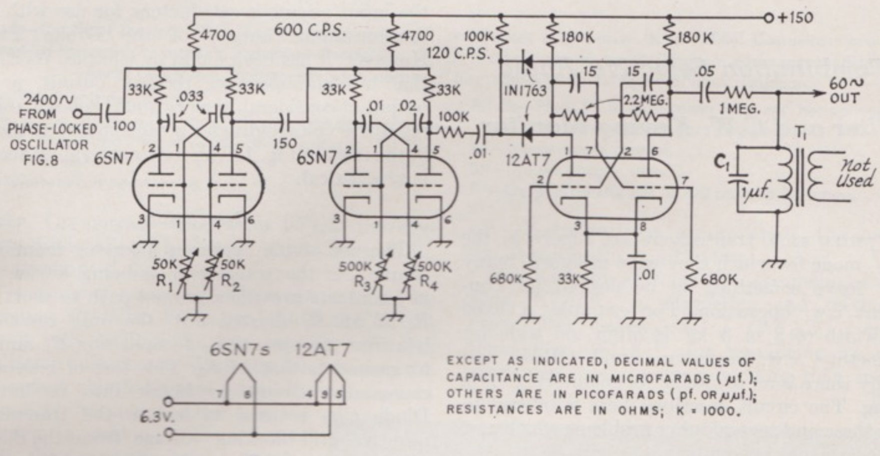


Fig. 9—Frequency divider, 2400 to 60 c.p.s. Capacitors are paper or ceramic; fixed resistors are ½ watt.
R_1, R_2—Dual control, linear taper.
R_3, R_4—Dual control, linear taper.
T_1—Small output transformer, primary tuned by C_1 to 60 c.p.s. Capacitance of C_1 may need to be varied to obtain resonance; value given (1 μf.) is based on an inductance of about 7 henrys.

somewhat more care in the mechanical construction would be required.

The electronics used for driving the AR-3 and in the synchronizing circuits are not particularly critical since they operate at mid-audio frequencies. The tube types already on hand determine the design in most cases; many of the tubes used were 20-year-old surplus. The liberal use of 1N1763's was primarily due to their 41¢ price tag. Their 500-ma. 400-volt rating reduced the amount of calculation required to be sure of safe operation.

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