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The AR6A Single-Sideband Microwave Radio System:

Frequency Control

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The AR6A Radio System requires precise control of the local oscillator frequency at repeaters and main stations, so that the IF equalizer pilots will be accurately located with respect to the narrowband crystal pick-off filters. In addition, the accumulated frequency error from each repeater and main station must be limited to a value that can be corrected by the tracking receiver of the multimastergroup terminal. Precise frequency control is maintained along the route by locking local oscillators to a stable and accurate frequency reference provided at each repeater station by the Microwave Carrier Synchronization Supply (MCSS). The MCSS provides a source and a backup for this signal. Extensive monitoring circuitry in the MCSS detects failed conditions. The accuracy of the two oscillators is continuously monitored by making frequency comparisons of their output. These frequency-monitoring circuits are also used to make yearly adjustments to the oscillators using a rubidium frequency standard as reference. This paper describes the MCSS System that has been developed for the AR6A Radio System.

I. INTRODUCTION

Compared with current 6-GHz FM Radio Systems like TH-1 or TH-3, the new AR6A† Radio System requires much tighter radio-frequency tolerances to keep radio-line pilots within narrowband pick-

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* Bell Laboratories.

† Amplitude Modulation Radio at 6 GHz for the initial (A) version of the system.

off filters. These pilots should remain within ±2 kHz of the center frequency of their pick-off filters, which translates to a frequency tolerance of about three parts in 10^7 compared to the TH-3 tolerance of two parts of 10^5. This tighter tolerance is beyond the capability of currently available microwave generators used as carrier sources for up conversion and down conversion in the radio Transmit-Receive (TR)* units. The required stability is obtained by synchronizing the microwave generators and shift oscillators to a highly stable frequency synchronization supply located in each radio station. This AR6A Microwave Carrier Synchronization Supply (MCSS) is described in the following sections. The paper then presents an overall block diagram description of the MCSS and discusses in more detail the various subsystem components.

II. FUNCTIONAL DESCRIPTION OF THE MCSS

The MCSS distributes a highly accurate sine-wave frequency of 308.8735416 kHz (abbreviated as 308.9 kHz) to each TR-bay microwave generator and shift oscillator as illustrated in Fig. 1. All microwave-generator frequencies and the shift-oscillator frequency are harmonics of this reference signal and are locked to it by phase-locked loop circuitry located in the frequency control units. The distribution bus provides 32 isolated outputs that can supply reference signals to a fully loaded route of eight two-way AR6A radio channels (eight channels by two directions by two oscillators per bay).

Figure 2, a block diagram of the MCSS, shows two symmetrical sections (frequency supplies), one of which is used for on-line operation and the other for standby. The major component in each of the two sections is a crystal-controlled, 4.94197666-MHz (hereafter abbreviated to 4.94 MHz) oscillator that has a long-term frequency stability of 1.8 parts in 10^7 per year. Each oscillator is associated with a divider/switch unit, which performs both a frequency division of 16 and power monitoring functions. Although only one of the two oscillators is used at a time, a continuous frequency comparison between them checks for an excessive frequency difference and generates appropriate alarm signals if the difference exceeds certain values. The interconnection between the two sections is accomplished through the control unit, which offers automatic switching between output signals under trouble conditions or manual switching for maintenance purposes.

Figure 3 is a picture of the MCSS that shows the major component parts described above.

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* Acronyms and abbreviations used in the text and figures of this paper are defined at the back of this *Journal*.

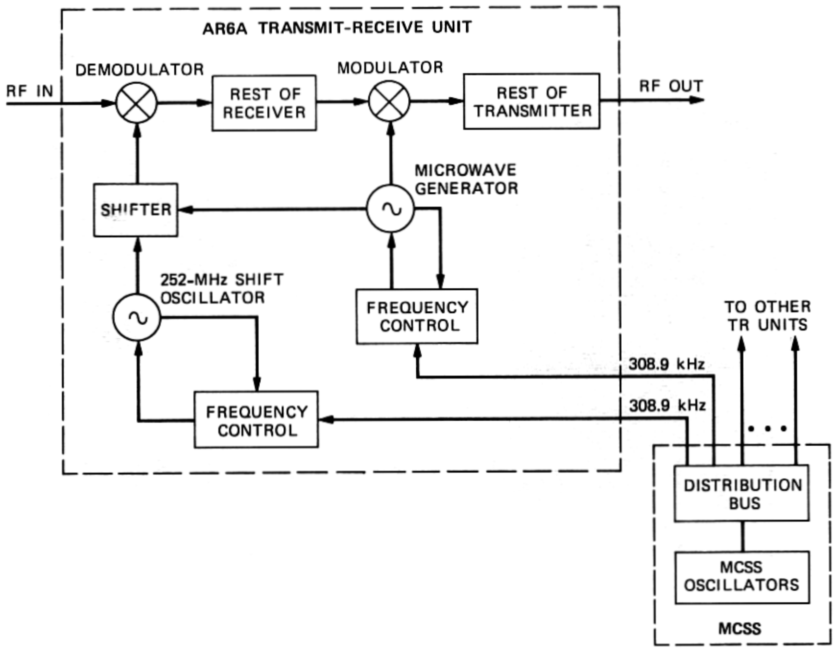

Fig. 1—Synchronization of AR6A TR units to MCSS.

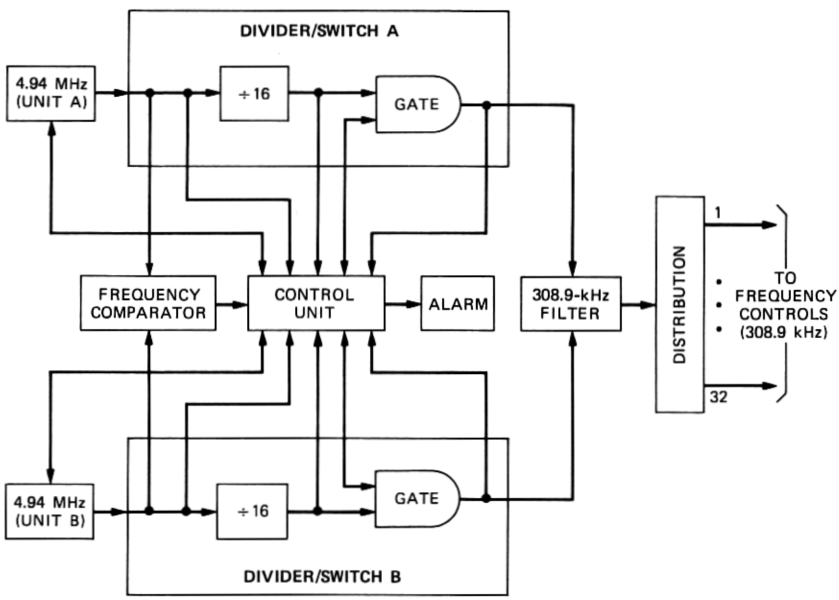

Fig. 2—Block diagram of MCSS.

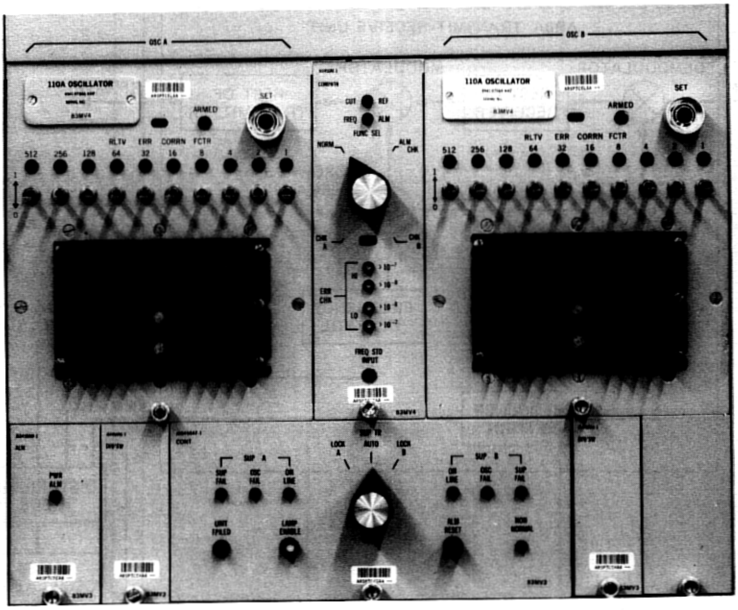

Fig. 3—Actual MCSS.

III. DETAILED CIRCUIT DESCRIPTION

*3.1 4.94-MHz oscillator**

The 4.94-MHz oscillator, shown in block diagram form in Fig. 4, consists of a crystal-controlled oscillator, RF amplifier, frequency-controlling network, and temperature-control network in a thermally stable environment. Because of repeater-station temperature variations, use of a stable oven is necessary to obtain the required frequency stability. Other peripheral circuitry such as the heater power amplifier, the binary frequency-controlling switches, and their display Light Emitting Diodes (LEDs) are exposed to ambient temperature.

3.1.1 Radio Frequency (RF) oscillator and amplifier

The RF oscillator is a modified Pierce-type crystal oscillator using a precision quartz crystal unit. A capacitance and varactor-diode network is in series with the crystal for frequency adjustment of ±3 ppm from the nominal frequency of 4.94197666 MHz. This stage has automatic gain control to ensure stable frequency operation. The crystal unit is a third-overtone AT-cut resonator having a turnover temperature between 76 degrees and 86 degrees Celsius. The output

* The MCSS oscillator was designed by M. W. Zuidervliet, Jr. of Bell Laboratories in Allentown, PA.

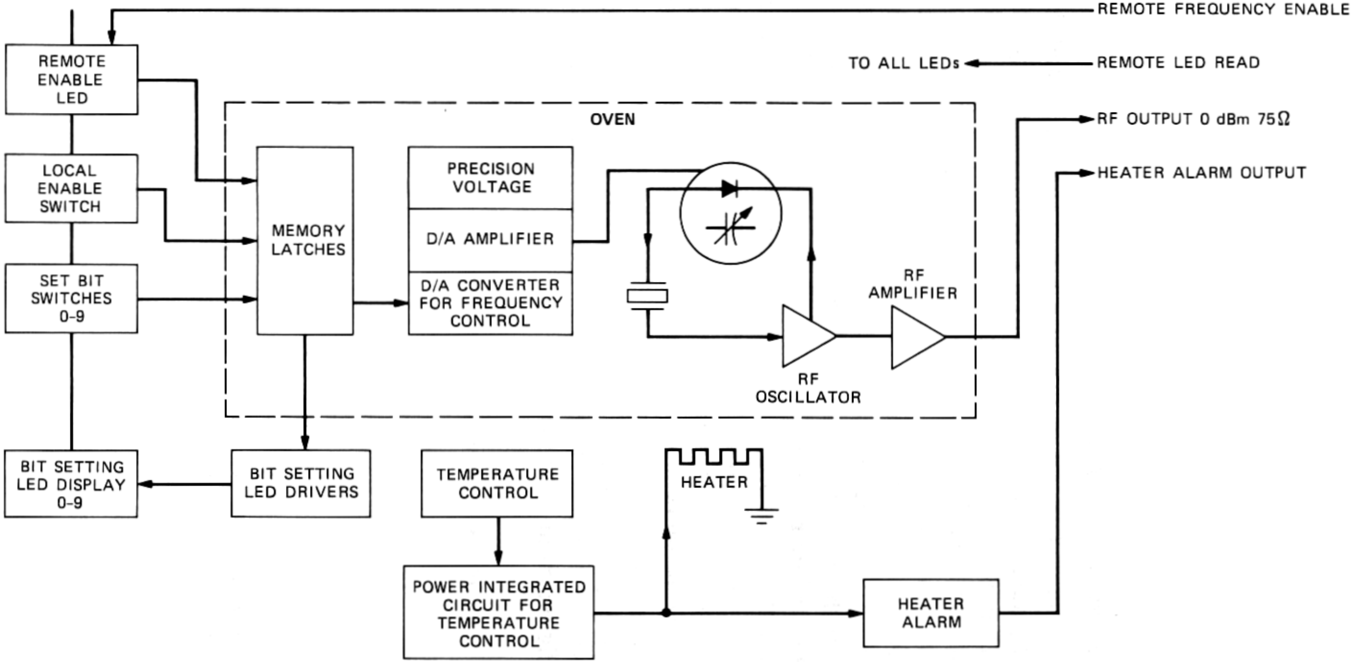

Fig. 4—Block diagram of MCSS oscillator.

of the oscillator is at the base of a low-noise transistor that uses the crystal unit to filter out any noise generated in the transistor that is more than a few hertz from the operating frequency. The output impedance of the oscillator is 50 ohms.

The RF amplifier consists of four transistor stages that buffer the oscillator from the output and boosts the output signal level of 0 dBm at an output impedance of 75 ohms.

3.1.2 Frequency tuning circuitry

The varactor diode, in series with the crystal, is biased from the frequency adjust circuitry made up of a precision voltage reference source, Digital-to-Analog (D/A) converter, and current-to-voltage operational amplifier. Front-panel toggle switches control memory-latch circuits that, when enabled, supply digital input to the D/A converter. The D/A converts this input to a precision current value utilizing the precision voltage reference. A voltage proportional to this current is applied as bias to the varactor diode. The ten toggle switches are arranged for binary weighting with the least-significant bit giving a frequency change of one part in 10^8. A new switch setting is input to the memory latches only when a remote enable signal is present and a load button on the oscillator is depressed. At other times the position of the toggle switches has no effect. This feature is present to prevent accidental detuning of the oscillator. Since the switch settings do not necessarily agree with the status of the memory latches, display LEDs are provided on the front panel that, when enabled, indicate the value of the digital input to the D/A.

3.1.3 Temperature control and heater alarm

The temperature of the oven is maintained by a proportional temperature control using a Wien Bridge oscillator where the sensing elements are two thermistors in series. These thermistors are imbedded in the wall of the oven and are tightly coupled to the heater winding. The output of the Wien Bridge oscillator is buffered by an amplifier that has variable gain for adjustment of the sensitivity of the temperature-control circuit. This amplifier drives a power integrated circuit that provides the dc power to the heater winding. The power stage limits the current into the 15-ohm heater winding to approximately 1-1/3 amps.

There is an alarm circuit that senses the heater-winding control voltage and emits an alarm if this voltage moves beyond the window for normal operation. This is an indication that the oscillator already has or is about to lose temperature control and therefore change frequency.

3.2 Divide-by-16 circuit

The main purpose of this circuit is to convert the 4.94-MHz input to 308.9 kHz and gate this signal to the distribution bus when the supply is on-line. There are two identical circuits corresponding to sides A and B.

Figure 5 shows a block diagram of the divide-by-16 circuit. Following the main signal path, the 4.94-MHz sinusoidal input signal is converted to a Transistor-Transistor Logic (TTL)-compatible square wave and divided by 16. The signal from the divider is input to one side of an AND gate. If this supply is to be selected as on-line, a select signal from the control unit enables the other gate input and the 308.9-kHz signal is output to the distribution bus.

Various monitors in the circuit detect improper operation. At the input, a detector monitors the level of the incoming 4.94-MHz signal and, if that level drops 2 dB, outputs an alarm to the control unit. A gradual 2-dB drop in level is not sufficient to cause the sine-wave-to-square-wave comparator to fail; thus, the alarm to switch to the other supply can be given before actual loss of 308.9 kHz occurs.

A coarse frequency monitor of the 308.9-kHz signal guards against a failure of the divider. This will detect a gross error that would occur if the divider malfunctioned to produce the wrong division ratio. A detected error of this type is output as an alarm to the control unit.

The level of the 308.9-kHz signal output to the distribution bus is monitored. The output gate for this signal is the last active circuit component of the reference signal path to the TR-bay frequency control units. The alarm indication for loss of level is output to the control unit but is meaningful only if the gate output is on-line.

The circuit buffers and provides a TTL line driver output of the 4.94-MHz signal to the frequency comparator unit where precise frequency comparisons between the two oscillators occur.

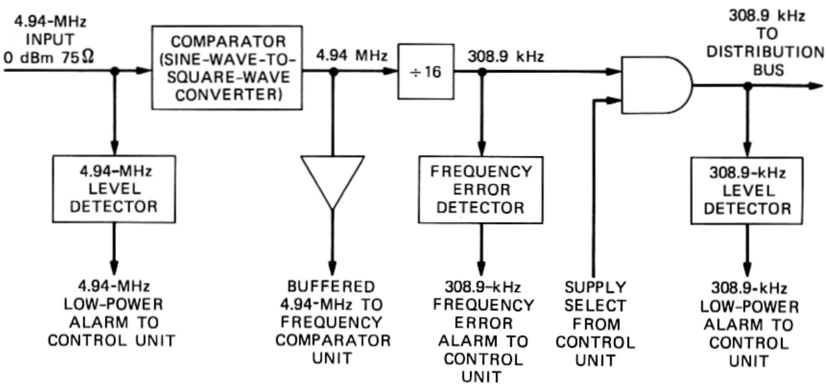

Fig. 5—Block diagram of MCSS divide-by-16 circuit.

3.3 308.9-kHz distribution

The outputs of the two divider switch circuits are gated to the distribution circuit. Either circuit, but only one at a time, provides a 308.9-kHz TTL signal for the distribution bus. The two signal inputs are combined in a resistive power combiner followed by a 308.9-kHz bandpass filter that provides at least 40 dB of loss to frequencies of 618 kHz and higher with a passband loss of less than 1 dB.

The 308.9-kHz sine-wave output from the filter, at an impedance level of 135 ohms, is fed to a balanced transformer with a 135- to 8.06-ohm impedance transformation. This output drives a passive resistive distribution bus that provides 33 outputs balanced at an impedance of 135 ohms. Thirty-two of the outputs are for distribution to the TR bays and are terminated if not used. The remaining tap provides a monitor port for measurement of signal level at the bus output. There is 18 dB of signal loss from the filter output to any tap output, and the tap-to-tap isolation is 36 dB.

3.4 MCSS control unit

The interconnection between the two 308.9-kHz sources of the MCSS is accomplished through the control unit. The control unit handles all MCSS alarms, as well as power and frequency sensor functions, and performs four separate major functions:

1. Selects (puts on-line) one of the two MCSS oscillators as the 308.9-kHz source.
2. Offers automatic switching to the other MCSS oscillator should the on-line unit develop any trouble.
3. Originates the general MCSS alarm together with visual indications pinpointing the specific alarm condition.
4. Furnishes the interface for the two oscillators, two divider and switch units, the frequency comparator unit, and the alarm unit.

All of the above-listed functions can be performed in either the auto or manual operating modes. The auto mode of operation is the normal operating condition of the control unit. In this mode, all sensors are monitored and an automatic switch will occur if there is a failure in the on-line supply. The sensors monitor the following items:

1. Power output of the 4.94-MHz oscillators
2. Operation of the oven within the oscillator unit
3. 308.9-kHz coarse output frerquency and power
4. Frequency difference between the two oscillators.

The sensors for items 1 and 3 are located on the divider and switch units and for item 4 on the frequency comparator unit.

The most severe alarm condition is the cut-reference alarm. When this alarm is generated the MCSS outputs to the TR bays are removed and the microwave generators and shift oscillators become free running. This alarm can be generated for two reasons:

1. The frequency offset between the two oscillators is greater than 39.3 parts in 10^8 (measured by the frequency comparator unit).

2. A failure has occurred first in the on-line section, causing an auto switch, and then in the former standby section, which was put on-line by the auto switch mentioned above. If the failure is in the standby supply, an oscillator fail alarm is generated and all switching between supplies is inhibited. Subsequent failure of the on-line supply will cause a cut-reference alarm.

The manual mode of operation is primarily for maintenance and repair of the MCSS. It permits a manual switch resulting in an interchange of the on-line and the standby section of the MCSS. However, consideration had to be given to the fact that whenever a manual switch to the standby supply is executed, a check has to be performed to determine if the newly selected supply does have a signal output of correct amplitude. Therefore, once a new supply is selected and on-line, enough time has to be allowed to permit a switchback to the previous on-line supply should the new one fail to produce a suitable output signal. Delay circuits permit this.

Since an auto switch will only occur as a result of a failure in the on-line section of the MCSS, a switchback is not possible and the check for a good output signal of the standby section is not necessary.

3.5 MCSS comparator unit

3.5.1 Functional description of the MCSS comparator unit

The comparator unit performs two major functions in the MCSS.

1. For normal operation, there is continuous monitoring of the frequency difference between the two 4.94-MHz oscillators. An alarm signal is generated if the frequency difference exceeds 16.6 parts in 10^8. A second alarm and cut-reference signal is generated when this difference increases to, or exceeds, 39.3 parts in 10^8. The cut-reference signal removes the synchronization tone from the microwave generators and shift oscillators, and these units become free running.

2. Replacement or yearly routine maintenance requires frequency adjustment of the 4.94-MHz oscillator. In the frequency check mode of operation, the comparator aids in oscillator adjustment by indicating the frequency difference between the oscillator being adjusted and an external frequency calibration standard. In this mode, the comparator has a resolution of ± 1 part in 10^8, which is based on the settability of the 4.94-MHz oscillators whose smallest frequency adjustment increment is one part in 10^8.

The position of the front-panel mounted function select switch, which can be in either the check A or check B position, determines which 4.94-MHz oscillator is being checked against the external frequency standard. In the check B position, the external frequency standard takes the place of oscillator A and in the check A position the external frequency standard takes the place of oscillator B.

When in the check A or check B position, all frequency alarms are inhibited. The four light-emitting diodes on the front panel of the unit are enabled. These LEDs are labeled and arranged in the following manner:

10^{-7}
HIGH
10^{-8}

10^{-8}
LO
10^{-7}

The HIGH or LO indicates the direction of frequency deviation of the checked 4.94-MHz oscillator in comparison with the frequency standard. By observing the LEDs, the oscillator can be adjusted to within one part in 10^8 of the 4.94-MHz signal.

Adjusting the oscillator is accomplished through ten toggle switches, labeled zero through 9, arranged in a binary weight fashion with the least significant bit being switch zero.

3.5.2 Method of detecting frequency offset

The conventional method of detecting a frequency difference between two oscillators, in which one oscillator will generate a gate pulse during which the other oscillator is counted, results in large time intervals to detect small offsets. For example, to detect one part in 10^8 for the MCSS 4.94-MHz oscillators would require a minimum time of $1/\Delta f = 20$ seconds, which is an unreasonable time interval.

The method chosen for measuring frequency differences in the MCSS is the same as that used on the Jumbogroup Frequency Supply (JFS) of the L5 System, which Fig. 6 shows utilizing the block diagram of the MCSS comparator. In this method, one of the two frequencies being compared is divided by D and then mixed with itself, with the sum signal A + A/D chosen by a bandpass filter. This signal is mixed with oscillator B and passed through a low-pass filter with the resulting signal difference of frequency

$$A + \frac{A}{D} - B = \frac{A}{D} + \Delta f.$$

This signal is used as a clock signal for an N divider that generates a gate pulse. During the gate-pulse interval, counts are accumulated by the C counter. This has the effect of multiplying the real fractional

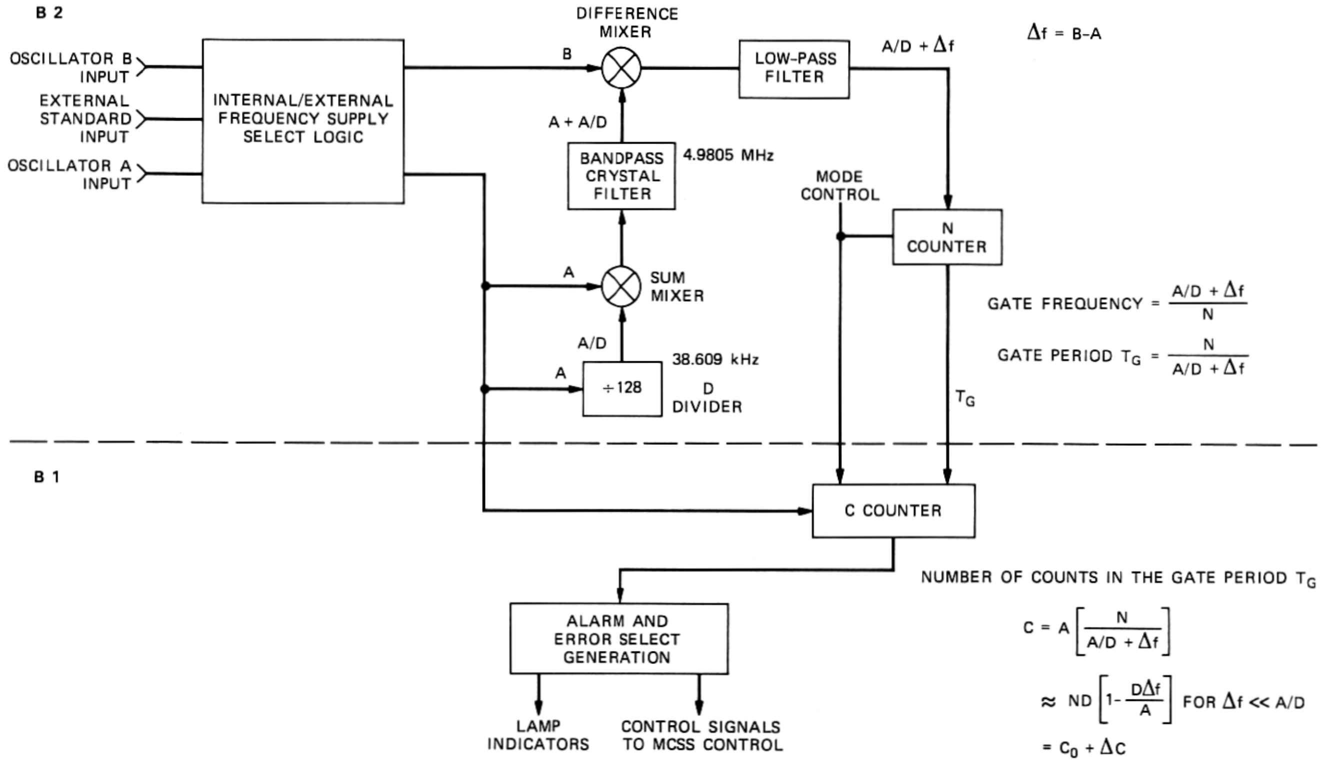

Fig. 6—Block diagram of MCSS comparator unit.

frequency error by a factor D. For the MCSS a value of D = 128 was chosen as realistic when considering the need for the bandpass filter that must pass A + A/D and reject A − A/D. Now the minimum time to detect an error of one part in 10^8 is the time for $ND^2\Delta f/A$ to equal one, i.e., one extra or one less count than normal for no frequency error. Solving for N, one obtains

$$N = \frac{A}{D^2\Delta f}$$

The gate interval for the minimum count to occur is $T_G \approx ND/A = 1/D\Delta f$. This time interval is shorter than that for the conventional methods by a factor of 128.

3.5.3 Block diagram and description

Figure 6 shows the block diagram representation of the comparator unit. Two printed circuit boards (B1 and B2) are used to accommodate the large number of integrated circuits and the relatively large inductors comprising the low-pass filter. The inputs to the comparator unit, during normal operation, are two 4.94-MHz TTL signals derived from oscillators A and B. For routine maintenance and oscillator calibration, a third input signal, also TTL compatible, from an external frequency standard is also connected to the comparator unit.

The input signal frequency to the 14-stage N counter is $A/D + \Delta f$. The output of this counter is the gate pulse (T_G) for the C counter. The 22-stage C counter is preset to a value C_0 dependent on the operating mode. The clock input signal is from oscillator A, which counts down the C counter during the gate period T_G. If oscillators A and B are identical in frequency, the C counter will count down from C_0 to zero. The value of the C counter is determined by monitoring the Q signals of each counter stage. The Q signals are gated together to detect values of ΔC which correspond to frequency differences. The count can be either positive or negative, depending on whether the counter went through zero or not. For normal operation, only the magnitude of the ΔC count is significant. However, during frequency adjustment of the two oscillators, the sign of the count is also important because the frequency of the oscillator being adjusted is compared to an external frequency standard and the sign of the frequency error must be known for proper adjustment. In the frequency check modes, instead of generating alarms for excessive frequency differences, the comparison circuit uses the four LEDs on the front panel to indicate the magnitude and direction of frequency deviation of the oscillator.

3.5.4 Other design considerations

Except during oscillator adjustment and routine maintenance, the comparator unit operates in the normal mode. In this mode, only a frequency alarm and cut-reference signal and alarm are generated when the frequency difference between MCSS oscillators is 16.6 parts in 10^8 or 39.3 parts in 10^8, respectively. The frequency comparison period in this mode of operation is only 78 milliseconds. It is possible for erroneous counts to occur because of plant battery hits or other office transients. To guard against false alarms occurring due to these erroneous counts, four-stage shift registers are used to output the frequency alarm and the cut-reference signal. To obtain an output from these shift registers, four consecutive readings exceeding the appropriate ΔC limit must occur. This, of course, delays the alarm signals by 312 milliseconds, but is quite acceptable in this application and does eliminate false alarms or, more seriously, loss of sync to an entire station because of an erroneous cut-reference signal.

3.6 MCSS dc power

The MCSS dc power is provided by regulated dc-to-dc converters (−24 to +5 volts dc), which are current limited, over-voltage protected, and low-voltage alarmed. The two 4.94-MHz oscillators are powered by separate 5-volt dc converters. These same converters also individually power the divider/switch circuits. The comparator and control unit are dual fed from the two converters using diodes. These procedures are used in the MCSS to guard against reference signal loss due to failure of any single power unit.

3.7 Alarm unit

The alarm unit in the MCSS provides visual and audible alarms of low power and other trouble conditions in the MCSS. It generates remote indications via telemetry systems to the alarm center, as well as local station alarms. Standard ACO features are available that can be activated at any miscellaneous key, jack, and lamp panel in the support bay or at any TR-bay display panel.

IV. SUMMARY

The paper has described the important features of the AR6A MCSS. The MCSS provides a precise reference signal at 308.9 kHz to which the microwave generator and shift oscillator in a repeater bay are locked. The MCSS is settable to one part in 10^8 and is stable to within five parts in 10^{10} per day. Extensive monitoring of performance and the provision of a standby reference signal ensure a high degree of reliability to the system.

V. ACKNOWLEDGMENTS

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J. R. Scoville, who contributed greatly in the MCSS design and evaluation.

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AUTHORS

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