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The AR6A Single-Sideband Microwave Radio System:

Special Test Equipment

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This paper describes two specialized test sets designed specifically for AR6A transmit-receive radio equipment alignment. The scanning intermodulation (IM) test set can adjust the transmitter for proper gain shape and optimum predistorter performance. It can also confirm that the transmitter is meeting its IM requirements. The pilot selection test set is used to test the radio intermediate frequency receiver units for proper operation during changing received signal conditions. This test set provides signals to simulate either flat or selective fades and can be used to check the pilot resupply function or space-diversity switch transition levels.

I. INTRODUCTION

It was realized early in the development of the AR6A† Radio System that special test equipment would be needed to ensure that performance objectives of this new single-sideband (SSB)‡ system were met. Two specialized test sets have been designed for this purpose: (1) the scanning intermodulation (IM) test set, and (2) the pilot selection test set. Both sets are self-contained in carrying cases with handles and

* Bell Laboratories.

† Amplitude Modulation Radio at 6 GHz for the initial (A) version.
‡ Acronyms and abbreviations used in the text and figures of this paper are defined at the back of the *Journal.*

are provided with the necessary cables and other accessories for use in the field.

The scanning IM test set has been developed to adjust the transmitters in the AR6A Radio System to meet the critical linearity requirements necessary for a multihop radio route. Swept wideband measurement of IM single-sideband amplitude-modulated (SSBAM) radio is required for predistorter and up-converter alignment and to verify that the high degree of linearity necessary for this type of transmission has been obtained. The transmitter alignment is accomplished by one single-tone level measurement/adjustment and three separate three-tone, third-order IM measurement/adjustments made with the test set. An auxiliary oscilloscope (the display section of the radio transmission test set) is used to display the resulting transmitter intermodulation characteristics over the frequency band of interest.

The AR6A receiver conditions the received signal prior to retransmission to the next station. The circuits that perform this function require special test signals to verify the correct functioning of this portion of the AR6A System. The pilot selection test set was developed to supply the required signals in a convenient manner.

II. SCANNING INTERMODULATION TEST SET

2.1 General

The single-sideband amplitude-modulated transmitters in AR6A are required to be extremely linear so that the third-order IM noise that accumulates over a long route is held to an acceptable level. Transmission with very low IM noise is accomplished by using a traveling-wave tube (TWT) operated well below its maximum power output capability and by the use of predistortion. Use of the predistorter requires flat transmitter third-order IM characteristics and precise alignment to obtain maximum third-order IM reduction. Predistortion operates by generating third-order IM noise that is equal in amplitude and opposite in phase to the third-order IM noise generated by the nonlinearities in the transmitter. These nonlinearities result in cancellation (nulling) of the IM noise. To obtain wideband predistortion, the overall third-order IM from the transmitter must have a flat IM frequency characteristic. The IM test set is used to adjust the up converter and predistorter in the transmitter for the required third-order IM flatness and third-order IM distortion cancellation. In addition to the linearity requirement, the transmitter output power level is required to be held within certain limits. The alignment of the transmitter requiring IM slope adjustment and predistorter IM null adjustment interacts with the transmitter gain. As a result, the output power must be monitored as adjustments are made to maintain the required power level.

A portable scanning IM test set has been developed to provide easy and rapid alignment of transmitters in the field where the three-tone, third-order IM distortion product from the transmitter can be rapidly scanned and displayed over the entire frequency band of interest. The set is divided into two modules (Figs. 1 and 2) to reduce the weight

Fig. 1—Test module of scanning IM test set.

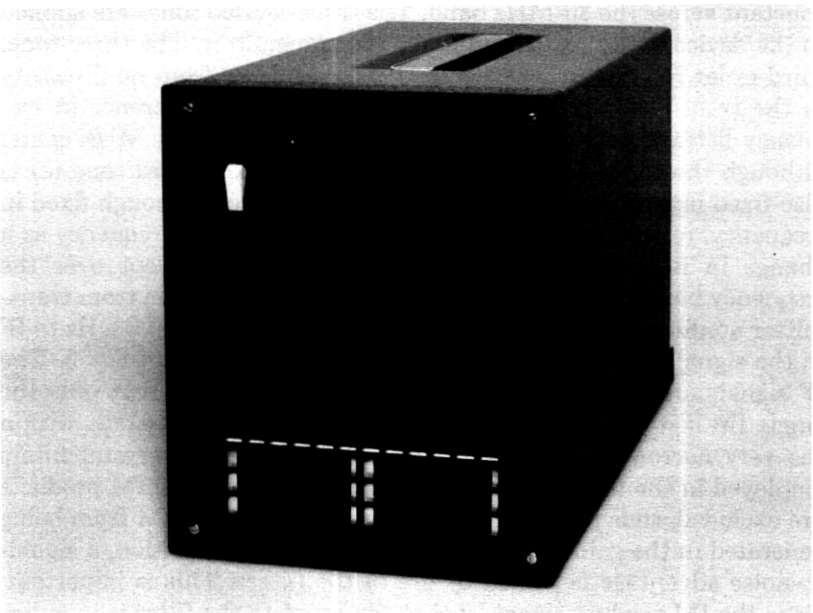

Fig. 2—Power module of scanning IM test set.

and size to acceptable values. The units are housed in metallic cases with retractable carrying handles. Separate lightweight soft-pack and hard-pack shipping cases are available to protect the modules during transportation. Space has been provided in the power module soft-pack and hard-pack to store the ten cables required for operation of the test set. An auxiliary oscilloscope is required for use with the test set to display the IM characteristics as a function of frequency. An auxiliary power meter is also required to monitor the output power during alignment.

2.2 Principle of operation

The test set can be divided into two basic sections consisting of a tone-generating section and a receiving- or signal-processing section. Referring to the simplified block diagram of Fig. 3, the three-tone generating section is located on the upper left. A manually swept, voltage-controlled oscillator (VCO) tone is split and applied to two mixers. Also applied to the two mixers are tones from crystal oscillators with frequencies that differ by 1 MHz. The two down-converted tones fall within, and can be manually swept over, the required 30-MHz intermediate frequency (IF) band. In addition, a third tone fixed in level and frequency near the center of the IF band is combined with the two manually swept tones. The three tones are sampled at the output coupler and applied to the automatic gain control (AGC) unit and then to the variolosser to maintain the level of the swept tones constant across the 30-MHz band. The three-leveled tones are applied to the device under test (DUT), i.e., the transmitter. The three-tone, third-order IM distortion product P_{a-b+c} resulting from nonlinearity in the transmitter is fixed in frequency since the difference in frequency between tone (a) and tone (b) remains fixed (1 MHz apart) although the tones are swept in frequency and the third tone (c) is also fixed in frequency. As a result, the IM product, although fixed in frequency, reflects any change in IM distortion versus frequency as a change in its amplitude when the two tones are swept over the frequency band. The tones and the resulting IM products from transmitter nonlinearities are coherently down converted from 6 GHz to IF in the signaling processing circuits shown on the right of Fig. 3. The IF signals are down converted again to 315,920 Hz so that only the single IM distortion product P_{a-b+c} from the transmitter falls within the very narrow passband (50 Hz) of the monolithic crystal filters employed in the test set. As a result, all other tones and IM products are excluded, thus preventing any spurious three-tone IM from being generated in the gain stages following the filter. In addition, a signal-to-noise advantage is gained by use of the filters. This is important, since the IM product signal level at the input to the filter is very low and therefore requires high amplification. Very stable crystal oscilla-

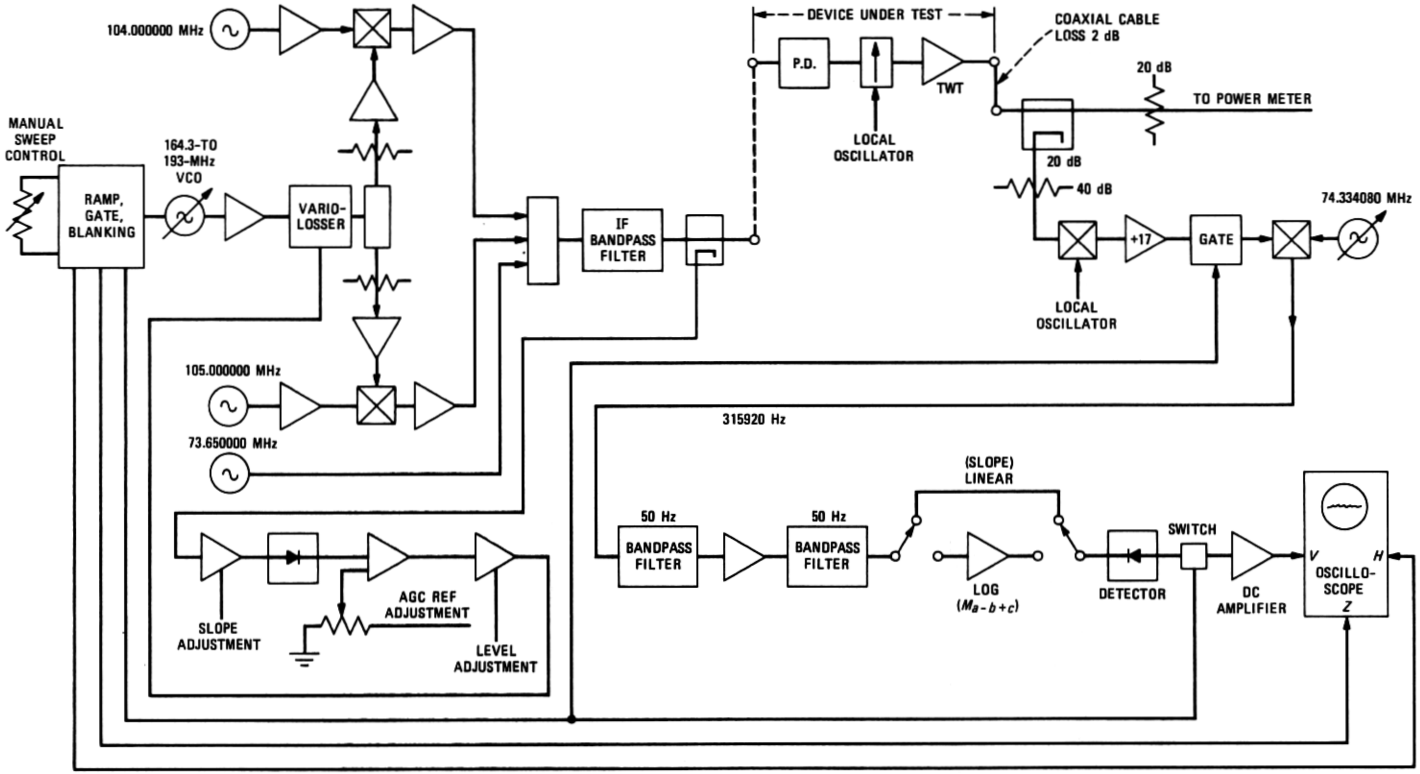

Fig. 3—Simplified block diagram of a scanning IM test set.

tors are employed to ensure that the IM product remains within the very narrow passband of the filters. Four oven-stabilized crystal oscillators are used for this purpose and have a stability of better than one part in 10^7 per day. One oscillator, employed by the signal processing section, is made adjustable by means of a knob on the front panel of the test set to center the IM product in the filter passband when necessary to compensate for crystal oscillator drift.

2.3 Tests performed

The first test (LEVEL) provides a calibrated tone to the input of the transmitter so that the power output may be set to the required level. The remaining three tests are three-tone, third-order IM distortion tests. The test set supplies three IF tones, two manually swept and one fixed in frequency, to the input of the transmitter for this purpose. In the second test (SLOPE) shown in Fig. 4, a three-tone,

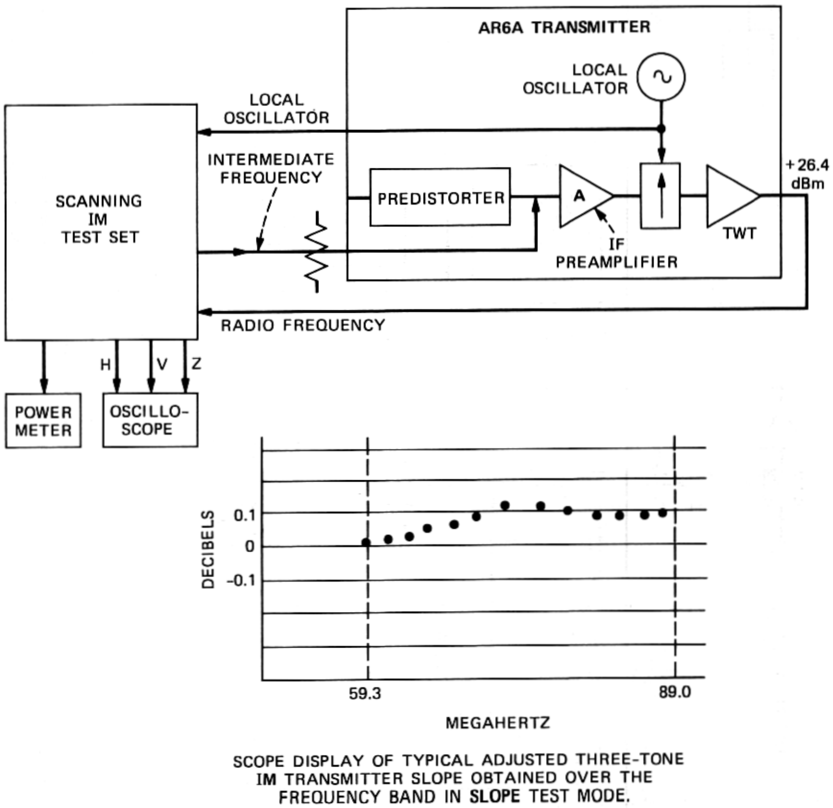

Fig. 4—Transmitter slope adjustment.

third-order IM distortion product, resulting from distortion in the transmitter, is adjusted for flatness over the 30-MHz band by means of a slope adjustment control located in the up-converter preamplifier (A) in the transmitter. In the third test (NULL) shown in Fig. 5, the predistorter in the transmitter is now included in the transmitter circuit and is switched on and three tones are held fixed in frequency. The IM distortion product is minimized (nulled as shown diagrammatically in the figure as a spot moving downward) by adjustment of the phase and amplitude controls on the predistorter in the transmitter. The fourth test (IM) also shown in Fig. 5 displays typical reduction of manually swept three-tone IM distortion versus frequency obtained by predistortion. It can then be determined on the calibrated display if the IM distortion reduction meets or exceeds requirements over the entire frequency band and, if so, this indicates that the preceding tests and alignments have been satisfactorily completed.

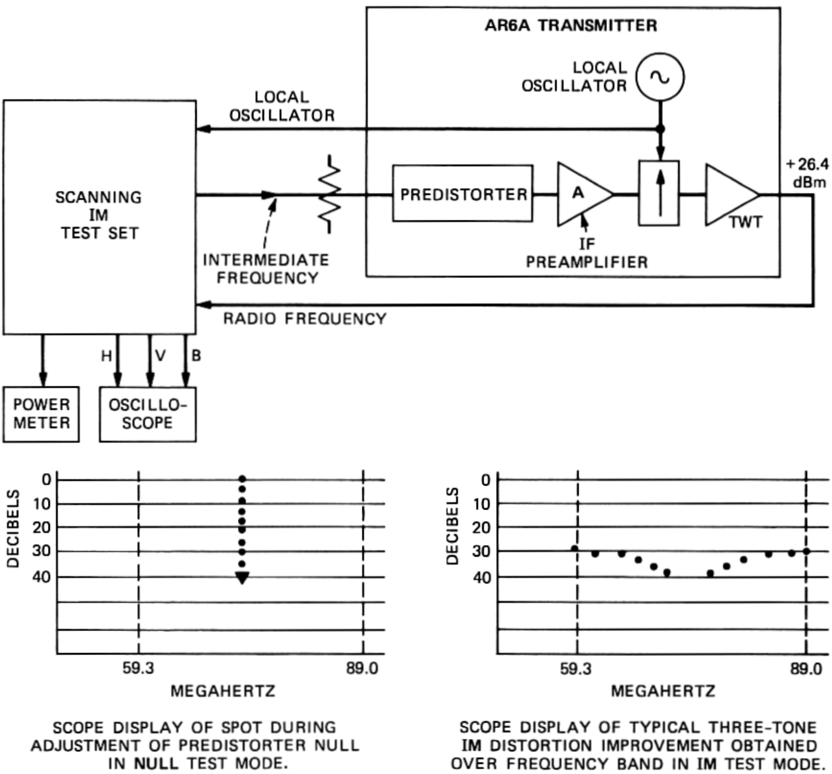

Fig. 5—Predistorter adjustment and IM improvement obtained.

2.4 Requirements for the scanning IM test set

2.4.1 Tone requirements

The test set is required to supply a single IF tone of a specified power level for the LEVEL test mode, and three tones, one fixed and two that can be manually swept in frequency, of specified power levels for the other three IM test modes. The single-tone level has been specified to have a power level equal to the full-load signal level and is used to adjust the transmitter gain to the required level. The total power of the three tones has been specified to be the same as that for the single tone. Intermodulation testing is required over the entire frequency range of each transmitter to ensure linear operation over the entire frequency band of each channel. The test set is required to produce tones that can be manually swept over the 30-MHz IF band (59.3 to 89.0 MHz). A worst-case maximum intermodulation condition has been found to exist when the three tones are held fixed in proximity to each other. The test set is designed with the three tones held fixed in frequency near the center of the band in the NULL mode so that the predistorter is nulled under worst-case conditions.

2.4.2 Spurious tone requirement

All spurious tones from the test set are required to be at least 40 dB below the power levels of the three tones. Any spurious tones that coincide with the fundamental tones as they are swept should be at least 50 dB below the power levels of the three tones so that they will add less than 0.025 dB to any of the fundamental tones. This will ensure that spurious signals will be held low enough that they will have negligible effect on the IM product. However, with swept measurements, this effect is almost unnoticeable since the spurious signals move at two or more times the rate of the fundamental tones and pass rapidly through them unnoticed, allowing the 50-dB criteria to be relaxed by 10 dB to the 40-dB requirement.

2.4.3 Tone flatness requirement

The tones from the test set are required to be flat with frequency to within 0.03 dB as they are swept over the 30-MHz frequency band. This requirement ensures that the tone levels and consequently the IM derived from these tones in the transmitter will reflect mainly the IM characteristics of the transmitter with minimum contribution of IM from the test set. The tones are set to be flat (0-dB variation) at the band edges with the maximum allowed variation of 0.03 dB at midband. The maximum variation of each of the two swept tones contributes 0.06-dB error to the CRT display of transmitter slope at midband. This small error is of little consequence, particularly since the slope can be adjusted using only the extreme frequency points.

2.4.4 Test set IM requirements

The three-tone, third-order IM generated by the test set is required to be at least 50 dB below that of the transmitter without predistortion. This requirement ensures that any three-tone, third-order IM originating in the test set is much less than the IM originating in the transmitter (with predistorter on) that is being measured. Therefore, the IM contributed by the test set to the measurement (less than 1 dB) would be barely discernible on a cathode ray tube (CRT) display of a 25-dB PDI (predistorter IM improvement in dB). Test set tone flatness and thermal noise from the transmitter and test set limit the amount of PDI that can be measured with reasonable accuracy to about 40 dB.

III. PILOT SELECTION TEST SET

3.1 General

The IF shelf of the AR6A Radio System contains a number of circuits to condition the received signal prior to retransmission. It was necessary to provide a way to check these circuits for proper operation when they were connected together in the system. A test set was designed that would condition test signals fed to the AR6A IF shelf to be representative of the type that would be experienced during normal system operation.

3.2 Principle of operation

The required test signal is composed of three pilot tones at frequencies of 62.448, 75.122, and 85.856 MHz. These three tones are varied in amplitude in certain prescribed ways to exercise the IF shelf signal correction circuits. This signal simulation technique checks for the proper functioning of the shelf, resupply switch, pilot detector, receiver control, AGC amplifier, and the dynamic equalizer.

3.3 Description of test set

The pilot selection test set (PSTS) is a portable unit that can be easily transported for field testing of the AR6A System. The unit is completely passive and requires no source of power. The PSTS must be used in conjunction with a suitable power meter.

The PSTS is made up of narrowband filters, shape networks, continuously variable attenuators, and a precision step attenuator. These components are interconnected in various ways by means of patch connectors on the front panel of the test set. All attenuators, shape networks, and filters can be used as individual items by access from the front panel jacks (see Fig. 6).

The PSTS does not contain the oscillators that supply the three required pilot tones (see Fig. 7). Each AR6A support bay contains a

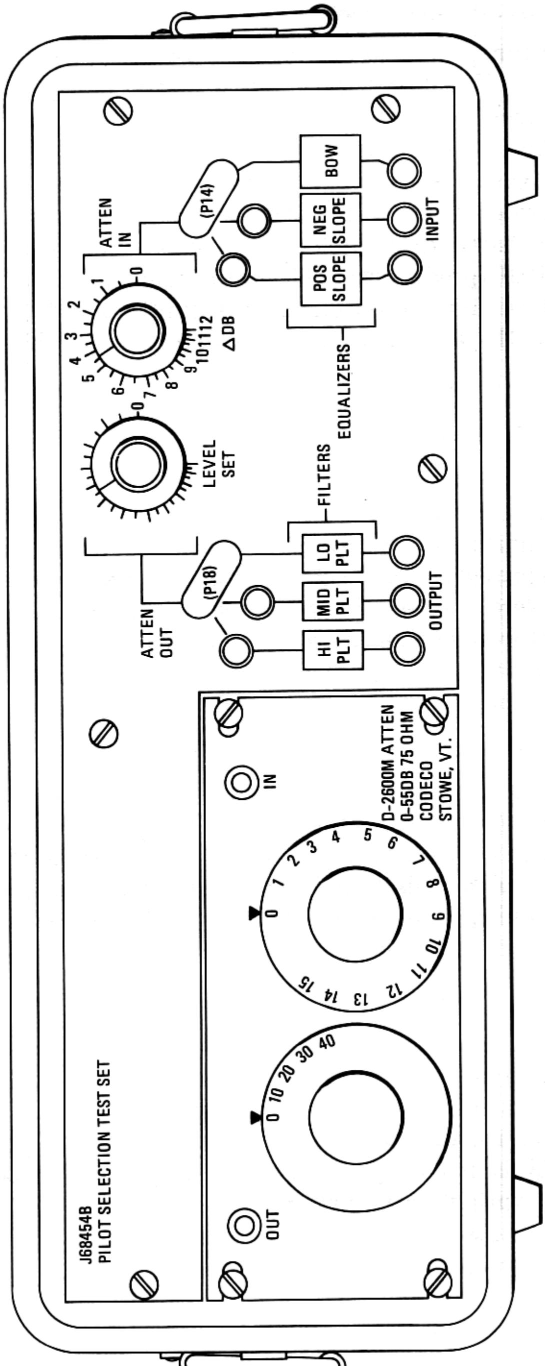

Fig. 6—Pilot selection test set.

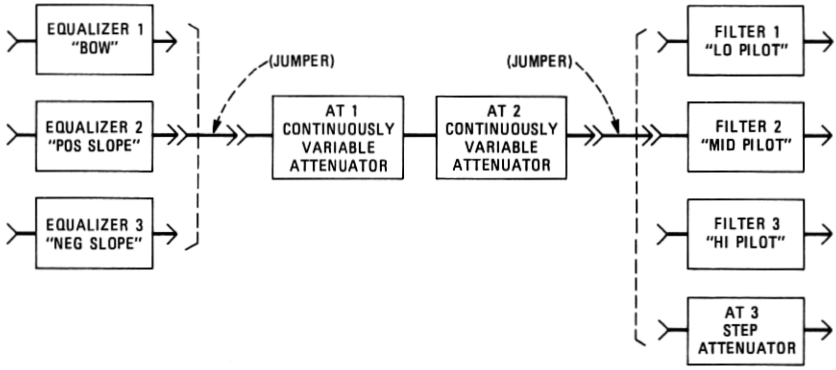

Fig. 7—Block diagram of the pilot selection test set.

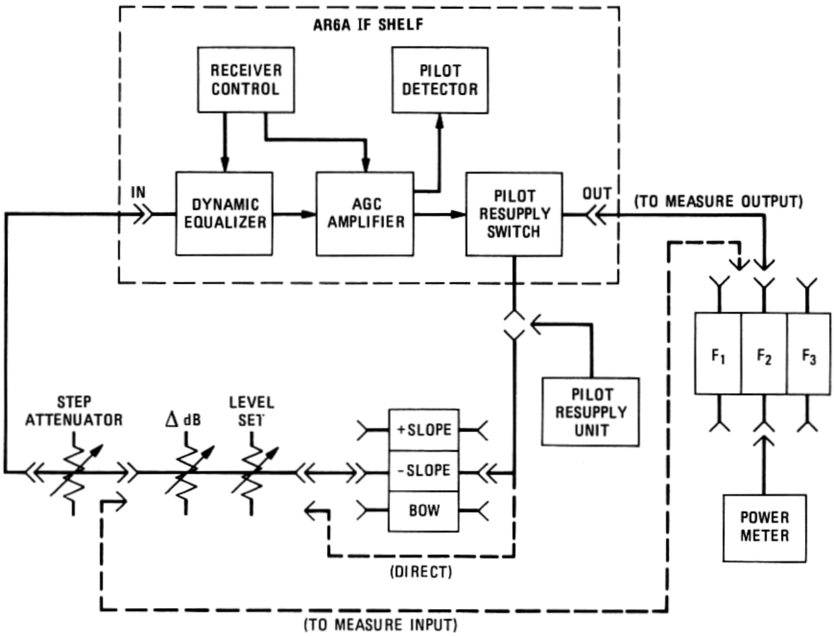

Fig. 8—Shelf-test functional diagram.

pilot source that is used for the pilot resupply mode of operation of the TR bay. The pilot resupply unit supplies the fixed amplitude pilot tones and the PSTS then modifies their amplitudes as required to test the AR6A bay (see Fig. 8).

The output from the pilot resupply unit contains all three pilot tones mixed together. The PSTS contains a narrowband monolithic crystal filter for each of the tones. These filters, when used in conjunction with a power meter, allow each tone to be measured individually. This arrangement is used to set the pilot reference power levels initially and then to observe the pilot levels after being acted upon by the AR6A receiver under test.

The PSTS checks the performance of the AR6A dynamic equalizer by first establishing equal pilot signal levels and then introducing known level differences in the pilots by the use of shape networks. Signal correction by the dynamic equalizer can then be observed.

The three shape networks are a positive slope, a negative slope, and a bow shape. All three shape networks attenuate the center frequency pilot 10 dB. The positive slope network attenuates the low-frequency pilot 18 dB and the high-frequency pilot 2 dB. The negative slope network attenuates the low-frequency pilot 2 dB and the high-frequency pilot 18 dB. Thus, the two networks can exercise the end pilots relative to the center pilot by ±8 dB. The bow network attenuates the center pilot frequency 10 dB and both the upper and lower pilot frequencies 2 dB. The resulting signal transmission through the network will be a bow with the end pilots 8 dB higher than the center pilot.

The PSTS checks the performance of the AR6A AGC amplifier by varying the amplitude of all three pilots together with a step attenuator while monitoring the AGC function. A precision step attenuator is provided to adjust signal levels over a 55-dB range in 1-dB steps. This step attenuator can also be used with the linearity test set if desired. The pilot resupply and space-diversity threshold levels are checked by varying the amplitude of all three pilots together with a continuously variable attenuator while watching for trip levels to occur.

Two continuously variable attenuators are provided. One is used to set the input power level accurately while the other is used to determine trip levels. The use of two variable attenuators allows the input power level adjustment to remain undisturbed while the second attenuator searches for trip levels. The original test set input power level can then easily be restored by turning the second attenuator back to zero. The use of continuously variable attenuators eliminates the transient effects on trip levels associated with step attenuators.

For convenience, hairpin patch plugs simplify the interconnection of the shape networks to the variable attenuator input. Also, a second hairpin plug interconnects the variable attenuator output to the pilot filters.

IV. CONCLUSION

The scanning IM test set has proven to be essential in the field for the initial transmitter predistorter linearity alignment and for the continued confirmation and maintenance of the high degree of linearity required by the AR6A Radio System.

The pilot selection test set is essential in the field to verify the correct functioning of the IF receiver circuits and to provide simulated fading for checking trip levels of the pilot resupply and space-diversity circuits.

AUTHORS

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