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Report

on

Comparative Consideration of Performance Characteristics of Existing Ultra-High Frequency Radio Receivers

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1. The intent of this report is to show what has been accomplished in receivers designed for ultra-high-frequency communications operation as regards characteristics which might differ considerably between these receivers and receivers designed for low-frequency operation, due to the nature of the frequencies under consideration.

2. For this compilation, six receivers have been chosen, of which four were designed to meet Naval specifications, one was modified from a commercially available receiver with special consideration to Naval requirements, and one was a commercially available receiver. These receivers, in order of consideration, are the Models XRAQ, RAR, TBS, XAP, N-S27C, and the Hallicrafter's S27 equipments.

3. The factors under consideration in these receivers, when the data were available, are

1. Oscillator stability
2. Selectivity
3. Sensitivity
4. Ultra-high-frequency radiation
5. Image rejection
6. Type of tuning and tuned circuit construction
7. Frequency coverage
8. Ease of alignment

Other characteristics such as recovery from surge inputs, or input impedance variations were not considered due to lack of sufficient data at the time of test.

4. The Model XRAQ receiver was manufactured by the RCA Manufacturing Company, and covers the range from 60 to 200 Mc. in two bands with individual tuned circuits. The R-F and oscillator tank circuits consist of concentric lines, capacity tuned. The receiver is of conventional superheterodyne design, with internal calibration means. It consists of two stages of tuned-radio-frequency amplification preceding the first detector, a temperature-controlled heterodyne oscillator, four stages of intermediate-frequency amplification, noise suppressors, second detector, automatic gain control, a crystal calibrating oscillator, and three stages of audio-frequency amplification arranged for head telephone or loudspeaker signal reproduction. Power for operating the receiver unit is obtained from a conventional rectifier power supply system which operates from a 115 volt, 57-63 cycle, single-phase service and is integral with the receiver unit.

5. The Moder RAR receiver was manufactured by the General Electric Company to cover the frequency range from 132-156 Mc. with one ganged tuning control. The receiver is also of superheterodyne design, with one stage of radio-frequency amplification, and two stages of audio amplification, with provision for calibration from a standard crystal oscillator, automatic gain control, and a temperature controlled high frequency oscillator. The receiver operates from a standard 115 volt

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60 cycle line. The tuning circuits of the receiver are also of the concentric line type, capacity tuned. The oscillator circuit consists of a small solenoidal inductance, capacity tuned.

6. The Model TBS receiver was manufactured by the RCA Manufacturing Company. The receiver is essentially a single-frequency receiver covering the range from 60-80 Mc. with an oscillator whose tuning is controlled by crystals for each desired oscillator frequency. The receiver is of conventional superheterodyne design with one stage of radio-frequency amplification followed by three stages of audio amplification. The receiver has automatic volume control, a noise suppressor, and two doublers for the oscillator frequency. The circuits are capacity tuned, and have conventional solenoidal inductances in the tuning circuits. The receiver tuning is not ganged and involves 6 tuning controls. The unit operates from standard 115 volt 60 cycle line. In present form, this receiver has no competitive value.

7. The Model XAP equipment consists of a receiver capable of the reception of either double or single modulation in the frequency range from 130-210 Mc. The single modulation part of the receiver contains one R-F stage, three stages of I-F amplification, and two stages of audio amplification. The receiver also provides automatic gain control operation. The receiver is tuned with a single dial and employs capacity-tuned two conductor lines in the preselector and oscillator circuits. Another preselector and oscillator unit was made for this receiver, employing concentric lines instead of frames.

Due to the fact that the concentric line preselector contained no radio-frequency stage, and the data on that preselector are incomplete, no further reference will be made to it. The receiver operates from a 115 volt, 60 cycle source. Great care was taken in the design of this receiver to provide it with good temperature compensation and stability of operation, so that it is believed that the results obtained with this receiver are probably the ultimate in practicability, and for the design employed not suited for production purposes, where individual complete testing and compensation of each receiver cannot be afforded. In addition, the receiver intermediate-frequency amplifier stages were a compromise between optimum operation on both single and double modulated signals, so that the results obtained on the intermediate-frequency amplifier must be evaluated in this light.

8. The Hallicrafter Model N-S27C is of conventional superheterodyne design, with two stages of radio-frequency amplification and three stages of I-F amplification, covering the range from 130-210 Mc. with one tuning control. The tuning circuits consist of coil inductances, capacity tuned. The receiver provides automatic noise limiting, automatic gain control, FM operation, and variable audio fidelity. The receiver operates from a standard 115 volt, 60 cycle source.

9. The Hallicrafter S27 is a commercially available receiver with one stage of radio-frequency amplification and three stages of I-F amplification. The receiver has two stages of audio-frequency amplification, a beat-frequency oscillator, automatic gain control, variable I-F

selectivity and automatic noise limiter, with provision for FM reception, and several degrees of audio fidelity.

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10. A general caution is inserted here to call attention to the fact that most of the receivers tested were not production models and would probably represent more nearly the ultimate in possible production design.

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11. Table 1 of the addenda gives the results of measurements made on these receivers to determine oscillator stability. Since the overall accuracy of the calibration of the receiver is affected by the calibration device as well as the oscillator stability, data on calibrator accuracy have been included in Table 2 as well as errors in the driving mechanism. The results have been expressed as percentages of the receiver frequency, since the performance stability of conventional superheterodyne circuits, such as are represented here, is dependent on the overall effective frequency displacements resulting from the oscillator instability.

12. Of all the oscillators, those of the Models XRAQ and RAR receivers were the only ones that were temperature controlled. The oscillator of the Model XAP receiver was temperature compensated, with no provision for ventilation. The extent of the temperature compensation of the tuning elements of the Hallicrafter's receivers is not fully known. Both oscillators in these receivers were thermally exposed in a cabinet ventilated by means of slots. The crystal of the model TBS receiver was also thermally exposed.

13. Adequate measurements were not taken to provide comparative results on the effect of vibration on oscillator frequency.

14. The use of tuning frames, with temperature compensation, has been demonstrated, as seen in Table 1, to be practical in obtaining low oscillator drift with variation of temperature, instead of temperature-controlled oscillators. The warm-up oscillator drift of the Hallicrafter's receivers is appreciable as compared with the temperature controlled concentric line oscillators. It should be remembered however, that great care was taken in compensating the oscillator of the Model XAP equipment.

15. Table 3 presents the selectivity of the intermediate-frequency amplifier system along with other pertinent data. The ratio columns for effective band-pass at the receiver frequency were included to give a comparative basis of overall receiver gain stability, when checked against the 'total maximum listed error' column of Table 1, which includes all of the tabulated oscillator variations except that due to tube interchange. From this comparison, it is evident that the oscillator of the N-S27C and S27 receivers can drift so as to completely lose any signal during changes in ambient conditions. For reliability on receiver calibration

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and ability of the receiver to retain a signal within its pass band, the band-pass range of the intermediate-frequency stage should maintain constant gain for fixed frequency signals, with consideration given to the stability of the received signals, and the likelihood of both receiver and transmitter being affected by the worst conditions at the same time. Table 3 also shows that ratios as low as 3 for the 6:60 DB points are feasible with a reasonable number of I-F stages.

16. Sensitivity is tabulated in Table 4 along with signal to noise ratios and receiver range in each case. Sensitivities of the order of 5 microvolts with a 7.4 DB signal to noise ratio do not appear to be impracticable.

17. Table 5 gives the amount of voltage appearing at the antenna terminals due to the ultra-high-frequency oscillator. It is believed that radiation voltages can be appreciably improved in U-H-F receivers with good shielding. Cavity resonances make complete slimination of oscillator radiation over a large oscillator frequency range very difficult.

18. Table 6 gives the image rejection ratios and Table 9 the resultant Q of the R-F tuned circuits when used in the receiver. The Q of the circuits were calculated from the image rejection ratios and are subject to great error, due to the assumptions that all the tuned circuits were similar, all tuned circuits had the same loading, and that no R-F leakage occurred in the measurements of image rejection ratios. The following formula was used:

$$Q = \frac{\sqrt[n]{P_n}}{K^2 - 1}$$

where

Q = Q for each tuned circuit
n = Number of tuned circuits
P_n = Image rejection ratio
K = Ratio of image frequency to receiver frequency

From both Tables 6 and 7 we see that satisfactory Q's for good image rejection ratios are obtainable with either tuned concentric lines or tuned parallel lines, and at lower frequencies with solenoidal inductances. The image rejection ratios of the model XAP receiver are not constant throughout the band, believed to be due to cavity resonances, and hence the value of image rejection ratio used to compute the Q of the tuned circuits was taken from that range of frequencies of the receiver over which the image rejection ratio was practically constant.

19. The tuning in all instances is principally capacity tuning. The tuned circuits however, are tuned frames, or parallel lines, in the case of the Model XAP receiver; concentric lines in the case of the models

RAR and XRAQ receivers (oscillator of Model RAR receiver has solenoidal inductance in tuned circuit); solenoidal inductance for the Models TBS, N-S27C, and S27 receivers. In no instance but that of the S27 is the oscillator switched. Measurements taken of the oscillator switching, showed that frequency deviations of about $\pm$ 6 Kc. were noted at 140 Mc. when the band switch was changed to Band 1 and then back to Band 3. On the S27B receiver, covering a higher range, the same measurements showed a deviation of about $\pm$ 20 Kc. at 160 Mc. it is seen from Table 1 that these deviations are not as great as other oscillator deviations that are noted, making bandswitching feasible for certain applications. The oscillator of the XRAQ is continuously variable over the complete tuning range of the receiver, being higher in frequency on the low frequency band, and lower in frequency on the high frequency band than the receiver frequency.

20. The frequency coverage of each receiver is given in Table 4.

21. Alignment of the R-F tuned circuits of all the receivers, except Models XRAQ and TBS receivers appears to be more difficult than alignment of receivers at lower frequencies. The Hallicrafter Models N-S27C and S27 receivers have serrated plates for alignment purposes, as well as small trimmer condensers. The Models XRAQ and TBS receivers do not have any provision for alignment since their tuned circuits are not ganged. The Models RAR and XAP receivers have small trimmer condensers.

22. In considering the requirements of a good ultra-high-frequency communications receiver, several conflicting requirements are to be found. The requirements stated in paragraph 15 would predicate a wide pass band for the I-F amplifier. A wide pass band brings about a reduction in sensitivity, so that in order to allow for the instability of the oscillator a loss must be taken for the overall sensitivity. Due to the tendency for line of sight reception at the ultra-high-frequencies, a loss in sensitivity might be tolerated. However, with receivers covering wide frequency ranges, high sensitivities would be desired to compensate for the loss in gain through poor transmission lines, or unmatched and compromise-tuned antennas, as would probably be the case where expensive wide-band matched antenna systems are not available because of space limitations.

The tendency at present seems toward intermediate frequencies higher than 10 Mc. in order to reduce image response and to obtain the required band-width without need for wide band-pass filters. The Model RAR receiver used low Q intermediate-frequency transformers to obtain the required band width. However, despite the ease which this circuit might allow in alignment, it can be seen from Table 3 that the number of intermediate frequency stages is greater than in other receivers considered, the intermediate frequency is higher than any of the other intermediate frequencies, and yet the band pass and the ratio of the 6 to 60 DB points does not seem to justify the extra number of stages.

Despite the care taken to provide ultra-high-frequency oscillator tubes with voltage -regulated 'B' supplies, in no instance has

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a current regulator been used to regulate the heater current of the oscillator. Since filament emission can be assumed to follow approximately the 3/2 power law, small changes in filament current have relatively large effects on the space current, and may thus affect the oscillator frequency.

Probably the most important problems affecting ultra-high-frequency receiver design is the frequency range of the receiver, and the tuned circuits used to obtain that range, including the mechanical drive for such circuits. Suggested problems which might be worthy of further investigation are the use of split-stator design to eliminate moving contacts in tuning capacitors; and a continuation of the study of the relative merits of parallel lines, concentric lines, and resonant cavities. Satisfactory means for band switching have not been demonstrated, thus requiring further investigation and development.

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Table 1
Oscillator Stability-% of Receiver Frequency

	Oscillator Variation For Temp. 0-50°C	Oscillator Variation For Humidity 30-95%	Oscillator Variation For Supply Voltage 109-121v	Oscillator Variation For Supply Frequency 57-63cps	Oscillator Drift -- Last 60 Min.of 62 Min.Warm-up	Oscillator Drift -- 1 hr. After 1 hr. Warm-up	Oscillator Variation With Variation of Controls	Oscillator Change with Tube Interchange (Normal G_m)	Total Max.Listed Osc. Variation Except Tube Interchange
XRAQ	.014% at 60 Mc .0047% at 200 Mc	.005% at 60 Mc .007% at 200 Mc	.0035% at 60 Mc .006% at 200 Mc	0% at 60Mc 0% at 200Mc	.0078% at 160Mc	.0013% at 60 Mc 0% at 200 Mc	.0019% at 160 Mc with variation of input control	.01%	.0333% at 60 Mc .0187% at 200 Mc
RAR	.034% at 144 Mc	.017% at 144 Mc	.0049% at 144 Mc	.0028% at 144 Mc	.01% at 144 Mc	.005% at 144 Mc	No Data	No Data	.0747% at 144 Mc
TBS (Crystal Osc.)	.018% at 80 Mc	.0059% at 80 Mc	No Data	No Data	.0133% at 80 Mc	.0047% at 80 Mc	No Data	No Data	.0419% at 80 Mc
XAP	.062% at 140 Mc .014%at 200 Mc	No Data	.0057% at 150 Mc.	.0019% at 150 Mc	.0036% at 160 Mc	.0005% at 160 Mc	No Data	No Comparable Data Available	.074% at 150 Mc
N-S27C	.093% at 150 Mc .18% at 200 Mc	.045% at 150 Mc	.028% at 200 Mc (Bet.110-123v)	.005% at 200 Mc	.043% at 150 Mc .107% at 200 Mc	.086% at 150 Mc .016% at 200 Mc	.001% at 200 Mc With Send-Rec. Switch	.075% at 130 Mc .13% at 150 Mc	.387% at 200 Mc
S27	.341% at 140 Mc	.0855% at 140 Mc	.071% at 140 Mc	.0072% at 140 Mc	.0855% at 140 Mc	.0064% at 140 Mc	.007% at 140 Mc Bandswitching	.64% at 140 Mc	.604% at 140 Mc

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Table 2

Calibration Errors and Backlash

	Backlash	Dial Calibration Error	Calibrator Device Errors	Maximum Total Listed Errors	Ability To Estimate Settings
XRAQ	.022% @ 60 Mc .0025% @ 200 Mc	.08% @ 60 Mc .015% @ 200 Mc	.017% @ 60 Mc .017% @ 200 Mc	.119% .035%	± .003 Mc
RAR	.01% @ 144 Mc	.035% @ 144 Mc	No Data	.045%	± .01 Mc
TBS	No Data Osc. Tuned by Meters	No Data	.013% @ 80 Mc	.013%	No Data
XAP	.31% @ 200 Mc	Dial not Calibrated in Frequency	No Calibrator	.31%	± .2 Mc from Chart
N-S27C	.03% @ 200 Mc	± .18% Max.	No Calibrator	.21%	± .2 Mc
S27	.096% @ 140 Mc	1.1% Max.	No Calibrator	1.196%	± .1 Mc @ Low Freq. ± .2 Mc @ High Freq.

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Table 3

Weak Signal Selectivity

	Inter-mediate Freq.	Band Width @ 6DB Down	Band Width @ 60DB Down	Ratio Bandwidth @ 6 DB / Bandwidth @ 60 DB	Ratio Bandwidth @ 6 DB / Lowest Rec.Freq.	Ratio Bandwidth @ 6 DB / Highest Rec.Freq.	No. of I-F Stages	No.of I-F Tuned Cir-cuits
XRAQ	10 Mc	290 Kc	645 Kc	2.2	.48%	.14%	4	10
RAR	18.84Mc	190 Kc	1100 Kc	5.8	.15%	.125%	5	12 (Filt-ers)
TBS	5.3 Mc	147 Kc	357.5 Kc	2.4	.24%	.18%	3	8
XAP	13 Mc	210 Kc	911 Kc	4.3	.16%	.1%	3	8
N-S27C	16 Mc	156 Kc	620.5 Kc	4	.12%	.075%	3	8
S27	5.25 Mc	61Kc (Broad)	360 Kc	6	.22%	.043%	3	8

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Table 4

Sensitivities

	Sensitivity Minimum and Maximum Values	Sig. + Noise: Noise Ratio	Signal Freq. Eange	Ratio Highest Freq. / Lowest Freq.
XRAQ	1 - 4.3 µv	7.4 DB	60 - 200 Mc	3.33
RAR	5 - 11 µv	7.4 DB	132 - 156 Mc	1.18
TBS	.65 - 1 µv	3.5 DB	60 - 80 Mc	1.33
XAP	1.1 - 4 µv	7.4 DB	130 - 210 Mc	1.76
N-S27C	.6 - 1.7 µv	7 DB	130 - 210 Mc	1.62
S27	.75 - 10 µv (Ant. Trimmer Peaked @ One Freq. in Each Band)	7 DB	28 - 140 Mc	5

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Table 5

Voltage at Antenna Terminals of U-H-F Receivers

	Number of R-F Stages	Tuned Circuits	Oscillator Voltage Minimum - Maximum
XRAQ	2	3	47 - 1100 µv
RAR	1	2	800 - 1200 µv
TBS	1	3	- - -
XAP	1	2	- - -
N-S27C	2	3	1610—>20,000 µv
S27	1	2	1200 - 5,000 µv

[redacted]

Table 6

Image Rejection

	No. of R-F Stages	No. of R-F Tuned Circuits	Intermediate Frequency	Highest Signal Freq.	Image Rejection
XRAQ	2	3	10 Mc	200 Mc	> 86 DB
RAR	1	2	18.8 Mc	156 Mc	67 - 74 DB
TBS	1	3	5.3 Mc	80 Mc	> 80 DB
XAP	1	2	13 Mc	220 Mc	54 - 62.5 DB
N-S27C	2	3	16 Mc	210 Mc	45 - 77 DB
S27	1	2	5.25 Mc	140 Mc	32 - 75 DB

Table 7

Q's of R-F Tuned Circuits*

	Receiver Frequency	Band	Q of Each R-F tuned Circuit
XRAQ	60 Mc	1	> 39
	120	2	> 88
	160	2	> 115
RAR	132.5 Mc	---	95
	144.3		123
	156.3		110
TBS	60 Mc	---	> 109
	80		> 100
XAP	170 Mc	---	158
N-S27C	130 Mc	---	41
	178		30
	210		23
S27	47	1	38
	82	2	76
	140	3	112

* See Paragraph 18

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