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Author: William Squires, W2PUL

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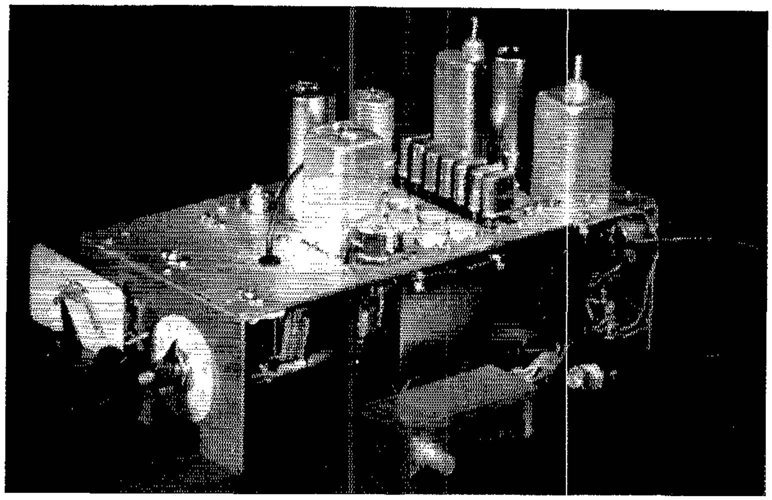
Improved Performance with a Beam-Deflection Mixer



An experimental receiver front end using two beam-deflection mixers.

A New Approach to Receiver Front-End Design

BY WILLIAM K. SQUIRES,* W2PUL

Six years ago some of the principal weaknesses of contemporary communications receivers were outlined and a technique for alleviating at least some of the ills was described[1]. *At that time it was pointed out that* **overload** *and* **cross modulation** *were serious offenders and that "modern" multiple-conversion receivers behaved extremely badly in this respect. Six years later, most still do.*

CURRENT receivers, having two or three stages of conversion plus one (or two) r.f. stages before any *appreciable selectivity*, perform very poorly under exactly those conditions that are most important, when the desired signal is weak and the undesired signal is strong. Even though the receiver's stated selectivity is superb and should be capable of rejecting the unwanted strong signal, cross modulation and overload result in the strong signal "riding through", often in the form of key clicks, "monkey chatter," squeaks and apparent noise. Often the operator is unaware of his receiver's misbehavior; he assumes the band *is* that crowded and noisy. But some of those commercial radioteletype stations, foreign phones, and big military signals are not even in the amateur bands!

While *cross modulation* and *overload* are not the only deficiencies (spurious responses, tweets, and inadequate i.f. and image rejections are frequent offenders), the major attention in this article will be toward describing techniques for reducing both of these deficiencies while simultaneously offering a number of performance advantages.

General Principles

First, the principles outlined by Goodman[2] are still very valid:

1) As little gain as possible before taking full selectivity.
2) Superb linearity in any stage preceding selectivity.

To achieve (1), the ideal receiver should have *no r.f. stage* and have as few conversions as possible. Then what about sensitivity? Image and i.f. rejection? Oscillator radiation? We have been taught over the years that the more r.f. stages — and the more conversions — the better the receiver. But r.f. stages are simply an apology for poor mixer performance and inadequate image re-

* % Squires-Sanders, Inc., 475 Watchung Av., Watchung, N. J.

[1] Goodman, "What's Wrong with our Present Receivers?", *QST*, January, 1957.

[2] Op. cit.

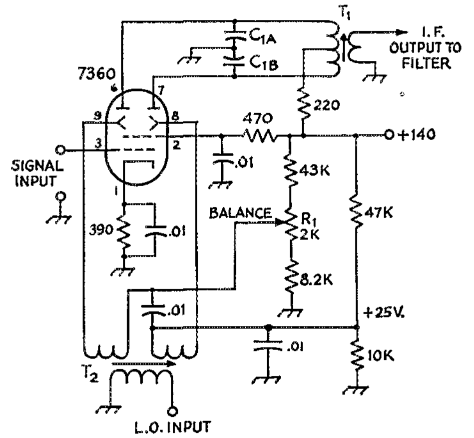


Fig. 1—Circuit diagram of the 7360 low-level mixer circuit.

jection, while numerous conversions make i.f. selectivity easy at the expense of miserable cross modulation behavior (and can cause serious spurious and tweet problems).

To achieve (2), the converter, or mixer, should be a *linear* device like a class-A amplifier, able to retain full linearity for big signals — as large as a volt! Conventional mixers perform only because they are nonlinear (for large signals), *i.e.*, the local oscillator voltage swings the tube from nearly cut-off to nearly zero bias and no tube is linear near cut-off or near zero bias. As long as the signal is very small compared to the local oscillator voltage, the mixer is quite linear; but when the signal grows large, violent cross modulation occurs.[3]

The Beam Deflection Mixer

While most of us are familiar with beam deflection tubes like the 7360, used as high-level mixers and product detectors, little has been published on their use as low-level receiver mixers. Theoretical analysis and experimental work have shown exceptional performance to be attainable with proper circuitry. The tube performs the mixing function by "switching" the current emerging from the screen-grid region back and forth between two plates. At the time the beam is centered on either plate, the tube operates as a conventional Class-A pentode. Properly driven it is *always* in the linear region. Moreover, since the two output plates can be operated in push-pull, the tube can be inherently balanced against the input signal frequency [4] (hence, good i.f. rejection).

A typical low level mixer circuit is shown in Fig. 1. It should be noted that signal is applied to the No. 1 grid, local oscillator applied *balanced* to the deflection electrodes, and plates connected push-pull and balanced at the i.f. Used in this way, the mixer has a conversion conductance of one-half its g_m as an amplifier (compared to one-fourth for conventional mixers). Operated as described later, the plate-to-plate output impedance is relatively low, from 15,000 to 25,000 ohms.

T_1 must be constructed for optimum balance, with windings symmetrical for both inductance and capacitance to ground. Even with this precaution, the *effective* center-tap is established by the two identical output capacitors C_{1A} and C_{1B}, and the T_1 physical center-tap is not bypassed. With this careful attention, i.f. rejections of greater than 60 db. have been obtained, *excluding* any r.f. selectivity. The balance is affected not only by the current balance, set by R_1, but by magnetic fields. If used on a steel chassis, or near power transformers, a mu-metal shield is necessary.

While not necessary for i.f. balance, the deflection electrodes are also carefully balanced, and T_2 must be given as much care as T_1. In most designs to date T_2 is resonated by the tube and circuit stray capacities with the balance set to optimum with the slug (*not* used for tuning). The deflection-electrode balance achieves two things: (1) it reduces mixing at local-oscillator harmonics (and hence spurious and tweets) and (2) it reduces local-oscillator radiation since, at perfect balance, no oscillator voltage appears at the No. 1 grid.

The voltages shown are optimum for bogey 7360s. Certain tubes, or the presence of permanent magnetic fields, may require readjustment of the deflection electrode divider. For other plate voltages, the deflection electrodes should be set at 15 to 18 percent of the plate voltage.[5] Apart from attention to balance and circuit symmetry, the tube is not "fussy", and considerable variation in parameters does not deteriorate performance.

The r.m.s. oscillator voltage at a deflection electrode can be from one to ten volts. The higher voltages produce slightly greater conversion gain but may lead to harmonic mixing problems caused by curvature of the deflection electrode characteristics. Three volts is adequate and near optimum. A shield across the socket (between pins 9 and 1 to between pins 5 and 6) is useful at high frequencies, to aid i.f. rejection and to lower local oscillator leakage. A complete "front-end" bandswitched 80 through 10 meters and employing two such mixers is shown in the photograph. The i.f. rejection is greater than 80 db., and oscillator leakage to the antenna is less than 50 microvolts.

Cross Modulation Performance

Since the tube operates (as far as input signals are concerned) much as a Class-A amplifier followed by a good switch, its cross-modulation

[3] How violent? At Squires-Sanders, cross modulation measurements on several current high-priced receivers showed that the *best* produced *serious* cross modulation with the unwanted signal 100 kc. away at a level at the antenna of 50 millivolts. The worst simply collapsed in *silence* at a level of 35 millivolts.

[4] M. B. Knight, "A New Miniature Beam Deflection Tube", *RCA Review*, June 1960.

[5] One precaution: if deflection-electrode voltages exceed about 10 volts, even briefly, their secondary emission ratio may exceed unity and "sticking" or blocking can occur. The d.c. resistance in their returns should be kept low, 50,000 ohms or less.

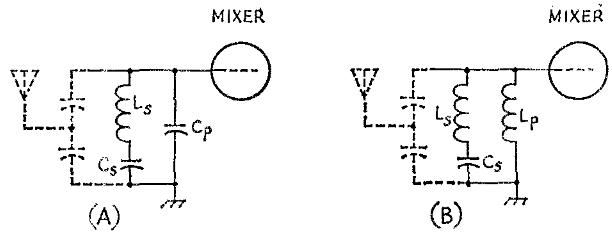


Fig. 2—Image rejection circuits. (A) Local oscillator below signal. (B) Local oscillator above signal.

behavior is superb. With this circuit, followed *immediately* with a steep-skirted crystal bandpass filter, the following measurements were made.

Two signal generators (properly isolated and matched to the antenna input impedance) were used. One, the *signal*, was set at 2 µv.; the other, the *unwanted*, was set to 100,000 µv. The front end was tuned, of course, to the weaker signal. Then the unwanted was tuned as closely as possible to the signal frequency until interference was *just barely discernable*. Both generators were 30 per cent modulated at 400 c.p.s. With two different bandpass filters, the following results were obtained:

Signal = 2µv. Unwanted = 100,000 µv. (+ 94 db. above signal)

Filter Bandwidth	*— 6 db.*	*— 60 db.*	*Unwanted (Frequency from Signal)*
(s.s.b.)	2.5 kc.	5.0 kc.	14 kc.
(c.w.)	.35 kc.	1.7 kc.	9 kc.

This means that when receiving a weak (2-µv.) s.s.b. signal, an unwanted signal only 14 kc. away must be 94 db. stronger — to be *just* noticeable. (That's about S9 + 60 db. on an honest S meter).

Placing the unwanted signal 100 kc. away (to simulate a big local, or an out-of-band commercial) and increasing the level of the unwanted until a *just noticeable reduction* in signal level occurred (using the same filters) required *400,000 µv.* to just affect a 1-*µv. signal*. When the unwanted signal was increased still further, it required 1,500,000 microvolts (yes, 1.5 volts), to produce a 3-db. reduction in *wanted*-signal output.

With cross modulation and overload well in hand, the next question is what kind of sensitivity, or noise figure, can be obtained.

Sensitivity

Although limited by outside (high antenna noise temperature) noise on the h.f. bands, low noise is still of some importance — and of course increasingly so as we go above 20 Mc. Theoretical analysis of the 7360 tube indicated excellent noise characteristics below 30 Mc. before the onset of transit time loading. The calculated value of the equivalent shot-noise resistance was 1500 ohms, leading to a calculated 5.3-db. noise figure (with 20-db. conversion gain) at 30 Mc. Measured noise figures are listed below:

Freq. Mc.	*Noise figure, db.*
29.5	5.5
21.25	4.4
14.25	4.3

This results in about 0.4 µv. for 10-db. (S + N)/N sensitivity in typical s.s.b. bandwidths on 10 meters, which is more than adequate (goodbye r.f. stage!).

Image Rejection

With single conversion and no r.f. stage the problem of obtaining good image rejection remains. Either a comfortably high i.f. can be used (*à la* Goodman), or something must be done in the input circuit of the mixer. An extremely useful technique, particularly for our relatively narrow amateur bands is to employ an "image-rejection circuit" of the types shown in Fig. 2.

When the local oscillator frequency is *below* the signal, 2A is used and L_S and C_S are made series-resonant (and low impedance) at the image frequency. For any h.f. band except 10 meters they may be set at the center of the band minus twice i.f. and left alone. Then at the signal frequency, L_S and C_S look inductive and are parallel-resonated with C_p.

When the local oscillator is *above* the signal, 2B is used, and L_S and C_S are set at the image as before. At signal frequency they look capacitive and are resonated by L_p.

As a result, a curve of impedance versus frequency as shown in Fig. 3 results, using circuit 2A. The degree of image rejection is simply the ratio of the two impedances Z_S/Z_I (ignoring antenna-coupling effects). With coil Qs of 200 and good shielding and grounding, measured rejection on 10 meters, with a 1.0-Mc. i.f., was greater than 90 db. With Qs of 150, a 1.0-Mc. i.f., and normal care, 60 db. can be readily obtained on any h.f. amateur band. The "rejection notch" remains relatively broad and need not be tuned over an amateur band, except in covering 10 meters at one bite. The signal peak must be tuned for best sensitivity, but this is done with the usual antenna trimmer.

Summary

To obtain really good cross modulation and

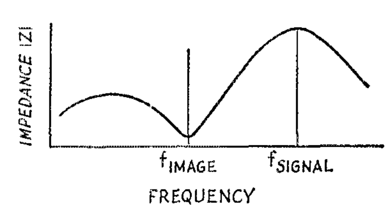


Fig. 3—Impedance curve of the image-rejection circuit of Fig. 2-A.

overload behavior, the r.f. stage must be eliminated and as few highly linear mixers used as possible, so that full selectivity is taken promptly after mixing. Using a beam-deflection tube as a balanced low-level mixer, high conversion gain, good i.f. rejection, and low noise can be obtained together with extremely linear operation—and consequent freedom from cross modulation. However, with no r.f.-stage selectivity, either a very high i.f., or unconventional image-rejection circuits must be used to obtain adequate attenuation of image frequencies. For amateur band use such circuits are comparatively simple, need not be tuned once set, and provide from 60 to 90 db. of rejection.

The resulting "front-end", followed by a steep-skirted crystal bandpass filter, produces the expected results. On-the-air use shows a remarkable ability to "dig out the weak ones", particularly when the band is crowded with big signals. The bands appear refreshingly cleaner and many of those "foreign phones" are gone. There is no wilting, collapse or distortion on big locals (in a really tough location, *delayed* a.g.c. can be applied to the 7360). Since the front end does not overload or "hang-up" on noise pulses the suggestion of protecting the *i.f.* with a *pre-i.f. silencer* appears attractive. This has been done with genuinely amazing results, as will be described in a subsequent article. QST

Strays

When W9CN and K6KP got together recently on s.s.b., it was their first meeting in thirty-seven years. They had met in April, 1926, when Art was u-9CN and Lee was signing 3JK in Maple Shade, New Jersey.

Speaking of the old days, WA4LIG tells us this one. Seems that an amateur friend, using a carbon mike coupled to the plate coil of his transmitter, started to say "hello" into the microphone when it exploded, blackening his face and filling his mouth with mica and smoke. He later found that his young brother, curious tyke, had taken the microphone apart, spilled the carbon granules, and replaced the carbon with shotgun powder.

K1YMY was first licensed thirty years ago while he was a high school student. His first QSO was with W1AAJ. Followed 25 years' inactivity as a ham until last summer, when Dick was assigned his present call. His first contact? Sure — W1AAJ!

To the ARRL's new Newington, Connecticut address has been added the "Zip" number 06111. Use it when you write League Headquarters. The Zip code number should be placed two spaces to the right of the state.

The Tower ARC is appropriately named: their beam antenna is 465 feet above New York's Madison Avenue, on the roof of the Metropolitan Life Insurance Building. Tower members are Metropolitan employees.

Passengers in the *same* jet flight to England recently, and in adjacent seats, were four hams: WA2WQA, K2MHH, W3HZP, and K7LTT.

Calling all dental hams: Doctor Matt Eisenman, K3LEC, will speak on amateur radio at the American Dental Association Convention in Atlantic City, New Jersey, October 16. Dentist-hams are invited to join a Dental Ham Net. For information, write Matt at 907 Jefferson Street, Wilmington, Del.

FEEDBACK

In the circuit for the Two-Tone Test Oscillator (page 20, July *QST*), the resistor labeled 68K should have been *6800* ohms — the same as the resistor to its right.

In the circuit diagram of the "High Quality Speech Compressor," page 21 of the February, 1963 issue, the 470-pf. capacitor C_3 has been labeled twice, possibly causing some uncertainty as to the value of the adjacent cathode resistor. The cathode resistor is 10K, and the grid resistor 2.2 megohms.

In the circuit diagram of W4KCW's d.s.b. transmitter on page 26 of the April, 1963 issue, the No. 1 and No. 2 grids of the lower 6BQ6GTB have been interposed. The pin numbering is, however, correct as shown.

IN QST — 25 Years Ago this month

September 1938

. . . J. A. Pierce, W1JFO, summarized 1938's exciting experiments in five-meter DX. The big news of the month was the announcement of the first "trans-con" QSO on 56 Mc. W6DNS and W1EYM did it.

. . . Clinton B. deSoto reported on "Ham Radio and Model Airplane Control," an aspect of hamming then only two years old. (For model control a quarter-century later, see the cover of this issue and page 11).

. . . The winners of the 1938 W/VE contest were announced. First place went to VE2EE. The U.S. winner was W6MVK.

. . . W3EMM and W3BEK detailed the efforts of Norfolk, Virginia amateurs to establish a city-sponsored emergency communications system, one of the country's first.

. . . And technical features included a W1CC five-band 807 exciter with crystal or e.c. oscillator control; a deluxe rotary beam support by W9TMP; portable equipment used by the Norfolk emergency communicators; and a W1TS auxiliary transmitter for 160 and 80 meters. QST