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A New Unity Gain Frequency Converter

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With the development of the 202H and 202J VHF Signal Generators, the design of an improved version of the 207 Univerter was undertaken. Designated the 207H, this instrument retains the basic concept of earlier models while offering the following additional features:

1. An improved wideband mixer to permit operation with input frequencies above and below the local oscillator frequency.
2. A redesigned local oscillator affording better stability and low residual FM.
3. A built-in 40 db attenuator to aid in making low-level measurements.
4. An -hp- modular cabinet to complement the 202H and 202J.

The 207H Univerter is basically a unity gain frequency converter covering an output frequency range of 100 kc to 55 mc. Figure 2 is a block diagram of the principal functions. A local oscillator frequency of 200 mc was chosen because it falls within the range of both the 202H and 202J Signal Generators, and because it is a convenient figure to use in determining the Univerter output frequency for a known input frequency. The output frequency of the 207H, F_o, is related to the signal generator input frequency, F_i, as follows:

$$F_o = \left|200 - F_i\right| + \left\{\begin{matrix}\text{Frequency Increment}\\ \text{Dial Reading}\end{matrix}\right\} \times 10^{-3}$$

$$145 \leq F_i \leq 199.9 \ (202H)$$
$$200.1 \leq F_i \leq 255 \ (202J)$$

F_o = 207H output frequency in mc.
F_i = Signal generator input frequency in mc.

If the Frequency Increment Dial is set at zero, the output frequency of the 207H is simply the difference between the signal generator input frequency and the 200 mc local oscillator frequency.

When loaded with 50 ohms, the unity gain or X1 output level is within ± 1 db of the signal generator input level in the operating ranges previously defined. The X.01 output provides a signal level 40 db below that obtained at the X1 output and the High Output provides a minimum level of one volt for 0.1 volt input. The input, X1 output, and X.01 output have a nominal impedance of 50 ohms and the High Output has a nominal impedance of 300 ohms.

Figure 1. Type 207H Univerter

MIXER

Previous models of the 207 Univerter were designed to operate only with input signals of a higher frequency than the local oscillator frequency. Small variations in mixer response over the input frequency range could be compensated for by adjusting the response of the wideband amplifier. In the 207H Univerter, however, any departure from flat mixer response appears as an asymmetry in the upper and lower halves of the overall response curve. The amplifier can be used to correct for mixer non-flatness for either input frequency range, but not for both ranges simultaneously.

Two possible solutions for this problem are: (1) a switching circuit to provide the proper compensation for each range, or (2) a mixer circuit which is sufficiently flat over the input frequency range. The latter approach was chosen.

Figure 3(a) is a schematic diagram of the mixer circuit employed in all previous models of the 207 Univerter. The signal generator input signal is fed to the cathode of a triode mixer and the oscillator signal is applied to the grid by means of a coil coupled

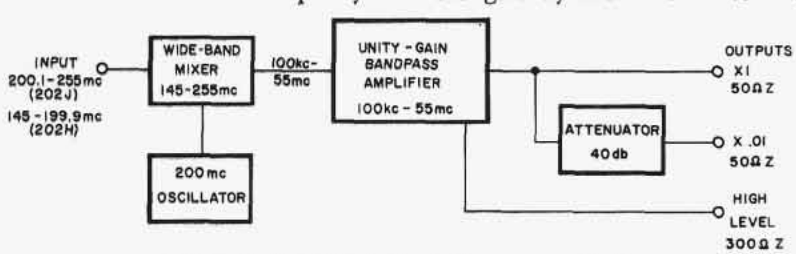

Figure 2. Functional Block Diagram — 207H

YOU WILL FIND . . .

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to the oscillator tank circuit.

Figure 3(b) is a simplified Norton equivalent circuit with the grid leak bias components and all but one of the interelectrode capacitances omitted. The output of the mixer is determined by the conversion transconductance g_c, the signal frequency load impedance Z_L and the grid to cathode voltage V_{gk}. V_{gk}, however, is not always equal to the signal generator input voltage V_{in}, and the relationship between them is frequency dependent. At some frequency F_r, series resonance occurs between C_{gk} and L_c. For input frequencies near F_r, V_{gk} will be larger than V_{in} by a factor which depends, in part, on the Q of the resonant circuit. Because the series resonant circuit forms a feedback circuit between the grid and cathode of the mixer, the actual resonant frequency is slightly higher than the natural resonant frequency. For the circuit of Figure 3(a), F_r is 230 mc. This undesirable resonance effect can theoretically be eliminated by either shifting F_r to a higher frequency (by reducing C_{gk} and L_c), or by reducing the effective Q of the circuit to unity. These possibilities suffer from practical circuit limitations which are difficult to overcome.

A much better solution to this problem would be non-resonant coupling from the mixer to the oscillator. Rather than add a buffer or cathode follower stage, an attempt was made to take the oscillator signal directly from the cathode of the oscillator tube. A small value of resistance in the cathode circuit would provide the RF voltage necessary to saturate the mixer and also discourage mixer grid circuit resonance effects because of the low Q it presents. In addition, the mixer would be operating essentially in the grounded-grid configuration with respect to input signals, resulting in a lower input VSWR.

The result of this development is shown in Figure 4. A 6ER5 VHF triode is used as a mixer because its transconductance can be made to swing over a large range with a small change in grid voltage, thus providing a large conversion transconductance with small drive voltages. Approximately 3 volts rms of 200 mc signal is developed across a 15-ohm resistor in the oscillator cathode. The Q of the resistor varies from 0.6 at 150 mc to unity at 250 mc. The 100-ohm resistor in the cathode of the mixer provides a 50-ohm nominal input impedance.

$$Z_{in} = \frac{R_k}{1 + g_m R_k} = \frac{100}{1 + (.01)(100)} = 50 \text{ ohms}$$

This formula neglects interelectrode capacitance and assumes grounded-grid operation. In prototype models, the maximum input VSWR is 1.7 at 255 mc and the flatness over an input frequency range of 145 mc to 255 mc is approximately ½ db total variation.

200 Mc OSCILLATOR

The Colpitts oscillator circuit of previous Univerters has been improved for use in the 207H. The modifications are:

1. Substitution of a Type 6AF4A tube for the Type 6C4.
2. Use of a metalized glass tank coil.
3. Temperature compensation for improved stability.

The 6AF4A, designed to operate as a UHF oscillator, is more stable and has a higher transconductance than the 6C4. The metalized glass coil is far superior to conventional wire-wound coils in this application. It is unaffacted by vibration and humidity and has a maximum temperature coefficent of only 20 parts per million per degree Centigrade. Since the warmup drift is related to temperature rise inside the oscillator compartment, temperature compensation can be employed. The frequency decreases with increasing temperature, thus, requiring a negative temperature coefficient capacitor. Best results are obtained using a grid blocking capacitor whose coefficient is —330 parts per million per degree Centigrade. All other fixed capacitors in the oscillator are of the NPO type. Figure 5 is a table of the drift characteristics of 207H prototype models. The specification allows a maximum drift of 10 kc (.005%) in any one-hour period or 2 kc (.001%) in any five-minute period after a one-hour warmup.

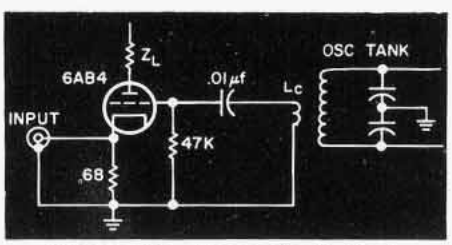

Figure 3(a). Mixer Circuit Used In Previous Univerters

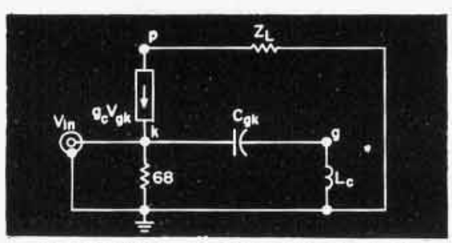

Figure 3(b). Simplified Equivalent Circuit of Figure 3(a)

The 207H oscillator circuit has two frequency adjustments. An uncalibrated Frequency Adjust trimmer gives a tuning range of approximately four megacycles to permit zero beating the oscillator with an external standard. This control is a recessed screwdriver type on the front panel. The Frequency Increment capacitor is controlled by the large knob on the front panel and permits a change in frequency of 300 kc either side of the center frequency. The dial is calibrated in 5 kc increments and the accuracy is ± (3% of the dial reading + 1 kc).

The residual FM of the oscillator due to the 60-cycle power line frequency and 120-cycle power supply ripple is 65 db below 10 kc or 6 cps deviation typically.

WIDEBAND AMPLIFIER

If the Univerter is to have unity gain at 50 ohms output impedance, an amplifier must be used to restore the power insertion loss of the mixer. A two-stage, low-pass filter coupled amplifier with an output cathode follower is used. An additional low-pass filter section couples the mixer to the first amplifier.

Each filter consists of a constant K pi section followed by an m-derived half section (m = 0.6) terminated in a resistance which is approximately equal to the characteristic impedance of the filter. The input and output capacitance of the amplifier tubes become the capacitance elements of the filter as shown in Figure 6. Small trimmer capacitors of the glass piston type parallel the tube capacitances and compensate for tube variations and component tolerances. The gain that can be obtained for a given bandwidth is limited by the input and output capacitance of the tubes and the tube transconductance. In order to be useful in this circuit, a tube must have a large transconductance combined with small input and output capacitance. Both the 6AK5 and 6688 used in this circuit are suited for wideband amplifier use. Variable resistors for gain control are placed in the cathode circuits of both amplifiers. One of these controls is a recessed screwdriver type on the front panel; the other is a locking potentiometer located at the rear of the casting. The 6AK5 amplifier stage produces a maximum gain of 1.5, and the 6688 has a maximum gain of 8.4. Although the 6AK5 gain seems quite small, it serves to isolate the relatively high input capacitance of the 6688 from the mixer output, and thus permits an additional 6 db of gain in that stage. The final 6AK5 provides two outputs. It acts as a cathode follower to supply the 50-ohm unity gain output and as an additional stage of amplification to supply the high level, 300-ohm output from the plate circuit. The High Output must be loaded externally with a 10 pf capacitance if maximum output flatness is desired. (The resistance loading is not critical). Although the low-frequency limit of the 207H is specified as 100 kc, the response extends down into the audio range to facilitate zero beating the oscillator with a signal generator oscillator, using headphones or a VTVM as a null indicator. The premium quality 6688 frame grid pentode not only produces a large gain, but offers reliable operation and long life. The mixer and amplifier together provide flat response within ± 0.7 db over the entire operating frequency range.

ATTENUATOR

A mixer, followed by a wideband amplifier, has an inherently high output noise level. The noise power output is proportional to bandwidth within the passband of the amplifier. For the 207H Univerter, the noise level at the unity gain output is a maximum of eight microvolts over a one-megacycle bandwidth. This corresponds to a noise figure of approximately 25 db. This noise level can be troublesome when making measurements with sensitive,

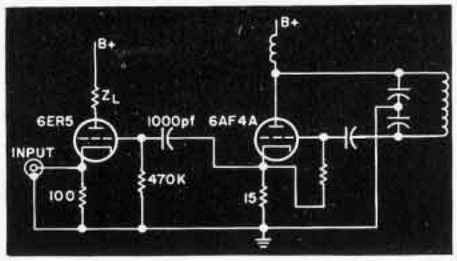

Figure 4. 207H Univerter Mixer Circuit

TIME INTERVAL (T = O, Cold Start)	T = 60 Min. To T = 65 Min.	T = 60 Min. To T = 120 Min.	T = 5 Min. To T = 60 Min.
Published Specification	< .001%	< .005%	None
Best Unit	.0001%	.001%	.0027%
Worst Unit	.00035%	.002%	.004%

Figure 5. Local Oscillator Stability — Typical Performance (Nominal Oscillator Frequency is 200mc)

wideband devices. A simple solution to this problem is the use of an attenuator between the wideband amplifier and the device being tested at low signal levels. A 40-db attenuator for this purpose has been incorporated in the design of the 207H.

Figure 7 shows the multisection frequency compensated attenuator which serves a dual purpose. It provides 3.5 db attenuation between the X1 output and the cathode follower output of the amplifier in order to obtain a low VSWR. It also provides a X.01 output which gives a level 40 db below the X1 output level. Output levels are specified across a 50-ohm load connected to the output in use. Both outputs should never be loaded at the same time or a serious error in attenuation will result.

The resistors used are half watt, one percent, carbon film types (MIL RN 20X). The maximum possible error in attenuation due to the resistance tolerance is ± 0.4 db. Change in attenuation with frequency, due to the rising impedance of the 10-ohm resistors at high frequencies, is compensated with shunt capacitors. The total maximum error in attenuation, due to both effects, is approximately 1 db. Typical attenuators have errors of less than ½ db. The attenuator exhibits a rise in attenuation above 55 mc. This is desirable because the transmission of spurious signals above 55 mc is reduced. For instance, at 200 mc the attenuation is 60 db. The X1 output has a maximum VSWR of 1.22 and the X.01 output has a maximum VSWR of 1.17.

The attenuated output should be used for making measurements at levels below 1000 microvolts. The attenuated output noise power is less than the noise produced by a 50-ohm resistor at room temperature. Therefore, the X.01 output noise power is essentially only that associated with the 50-ohm internal resistance.

POWER SUPPLY

Two power supplies are available with the 207H Univerter, a 95-130 volt, 60-cycle model and a 95-130 volt or 190-260 volt, 50-cycle model. The dual voltage supply has a voltage changeover switch mounted on the power supply chassis. Both supplies employ resonant stabilizers for ± 1% voltage stabilization over the indicated range of input line voltages. The B+ is developed by a conventional voltage doubler circuit, using selenium rectifiers and a two-section, choke-capacitor filter. As a result of voltage stabilization, the local oscillator frequency change, due to a 1-volt change in line voltage, is less than 400 cycles.

PHYSICAL CHARACTERISTICS

The oscillator, mixer and amplifier are constructed on a silver plated brass plate mounted on an aluminum casting with a silver plated brass cover plate. The shielded attenuator subassembly is mounted to the side of the casting, while the regulated power supply is a separate chassis. The entire unit is housed in the new Hewlett-Packard Modular Cabinet. This cabinet matches

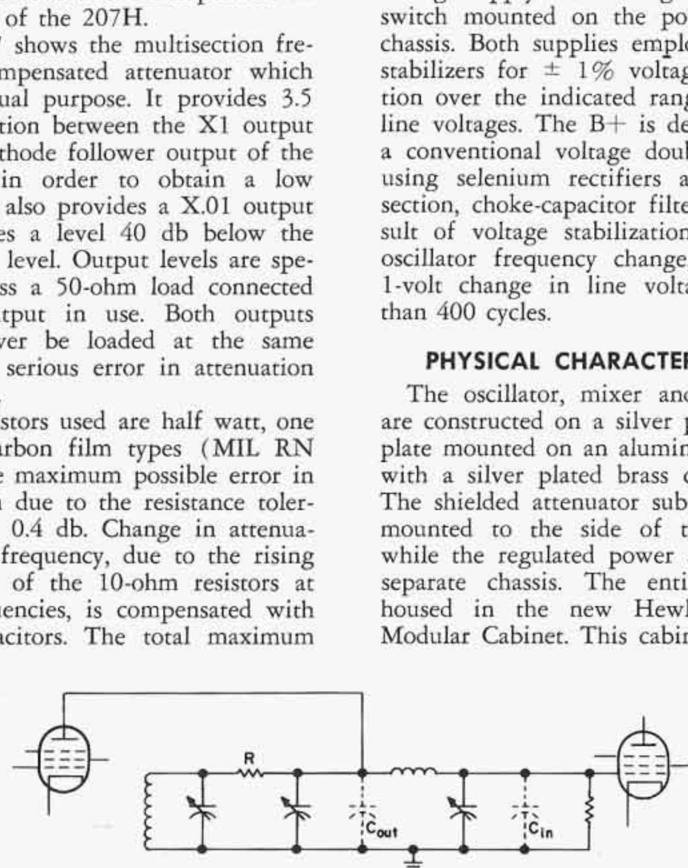

Figure 6. Wideband Amplifier Interstage Filters (Bypass and Coupling Capacitors Omitted for Simplicity)

the appearance of the 202H and 202J cabinets and permits stacking the 207H with either generator.. The simple addition of flanges permits rack-mounting. The front panel layout of the 207H is designed to complement the appearance of the 202H and 202J front panels when the units are stacked. A short accessory cable, Type 524A, is used to connect the signal generator output to the Univerter input.

It is desirable to have the Frequency Increment Dial indicate the sense of output frequency change as well as magnitude. The sense is opposite for input frequencies above and below 200 mc. To avoid possible confusion, the input frequency ranges are color coded to correspond to the appropriate Frequency Increment Dial calibrations.

OPERATION WITH 202H AND 202J

The major advantage of the Univerter principle is the extension of the superior modulation characteristics and precision piston attenuator of the VHF signal generator to the lower frequency range.

The 207H will reproduce the modulation of the 202H or 202J, with negligible distortion, provided the following precautions are observed. Care should be taken when using low carrier frequencies that significant modulation sidebands do not fall below 100 kc, otherwise severe distortion may result. The following simple rules will avoid this condition:

Modulation—Lowest Permissible Output Carrier Frequency
AM—100 kc plus Modulation Frequency
FM—100 kc Modulation Frequency plus Deviation Frequency

In addition, input amplitude modulated signal levels should be kept below .05 volts for minimum envelope distortion.

The X1 output level of the 207H Univerter can be read directly from the 202H or 202J attenuator dial with an accuracy of ± 1 db plus the accuracy of the signal generator attenuator itself. In this way the 207H effectively extends the range of the 202H or 202J precision piston attenuator to cover frequencies of 100 kc to 55 mc.

The stability of the output signal of the 207H depends upon the stability of the 207H local oscillator and the stability of the signal generator with which it is used. Much effort has been

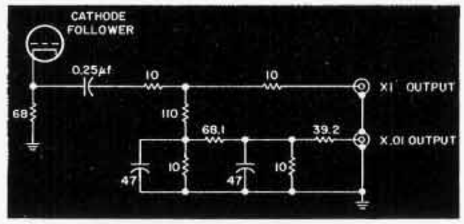

Figure 7. 40 db Attenuator

put into stabilizing the 207H local oscillator in order that the output frequency stability of the Univerter will be controlled almost entirely by the stability of the signal generator. Very little could be gained in output frequency stability with a crystal controlled local oscillator. In addition a crystal controlled oscillator would preclude the use of the Frequency Increment capacitor for calibrated frequency deviations of ± 300 kc. The drift specifications for the 207H refer only to the local oscillator and not to the output frequency.

$$(\%\ \text{change in}\ F_o) = \frac{(\%\ \text{increase in}\ F_i)\ F_i - (\%\ \text{increase in}\ F_L)\ F_L}{F_o}$$

F_i = sig. gen. input freq. in mc.
F_L = local oscillator freq. in mc.
F_o = output freq. in mc.

The percent change in output frequency is a function of the magnitude of input and local oscillator drift, the direction of the drift and the output frequency itself. It is possible for the output frequency drift to be zero while both the input and local oscillator frequencies are changing.

For some applications, especially at low frequencies, the output frequency drift may be larger than desirable. It is possible to lock the output frequency of the 207H to an external discriminator using a simple AFC arrangement. The dc output of the discriminator must be amplified for best results and aplied to the DC FM INPUT of the 202H or 202J. Care must be taken to use the proper polarity of feedback signal. Figure 8 shows the recommended setup. The dc amplifier should have a high input impedance, a low output impedance, a polarity reversing switch and a gain of at least 15. Both the discriminator and amplifier should be as stable as possible. The time constant of the dc amplifier must be short enough to prevent "hunting" and long enough to prevent carrier demodulation and the introduction of FM hum modulation. Experimentation may be necessary to determine the best value for a given application.

Spurious output frequencies from the 207H Univerter result mainly from signal generator spurious outputs which are converted to lower frequencies along with the desired signal and appear in the output.

The total harmonic distortion of the 207H is less than 2.5% at a level of 0.1 volts. The second and third harmonics are at least 30 db below the

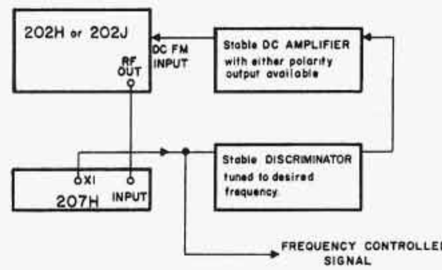

Figure 8. AFC Circuit Using External Discriminator

fundamental for levels up to 0.1 volt. Approximately 200 microvolts of 200 mc local oscillator signal appears at the unity gain output. Output frequency signal leakage is at least 60 db below the unity gain output level in the vicinity of the output panel connectors.

The results of a series of environmental tests indicate that the 207H is capable of withstanding any shock, temperature and humidity conditions likely to be encountered in normal laboratory use.

Figure 9. Typical 207H and 202H Setup

SUMMARY

The 207H is a valuable accessory to the 202H and 202J Signal Generators. The three instruments together offer calibrated output levels with both AM and FM modulation over a frequency range of 100 kc to 270 mc.

CORRECTION

The block diagram shown in Figure 9, Page 5 of Notebook Number 33 is not correct as shown. The blocks designated "FM SIG. GEN. UNDER TEST" and "REFERENCE FM SIG. GEN.", together with the output designations "f_{c_1}" and f_{c_2}", should be interchanged. The Notebook is indebted to Mr. K. E. Farr of Jerrold Electronics Corp. for pointing out this error.

New Techniques in FM Fidelity Measurements

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INTRODUCTION

Common methods of measuring a signal source FM fidelity involve the use of a receiver or detector with known fidelity characteristics. This article describes a method of determining fidelity by measuring the deviation of an FM source as a function of a constant amplitude modulating signal, without dependence on the receiver's fidelity characteristic. Any relatively good narrow band AM receiver will suffice for the measurement since the fidelity requirement is not critical.

In the absence of AM, the frequency spectrum of an FM signal shows the amplitude relationship between the carrier and the various sidebands. The modulation index, m, is defined as $\Delta f/f_{mod}$; where Δf is the peak frequency deviation of the carrier from its center frequency, and f_{mod} is the modulation frequency.

The various carrier and sideband amplitudes that result from values of m are related to the Bessel Functions of the first-kind, J_n (m), with order equal to n where nf_{mod} equals the separation between the carrier frequency and the sideband or spectrum component of order n.

The carrier amplitude is $E_c = E_o J_o$ (m), the first-order sideband is $E_1 = E_o J_1$ (m), and the n_{th} order sideband is $E_n = E_o J_n$ (m); where E_o is the amplitude of the unmodulated carrier.

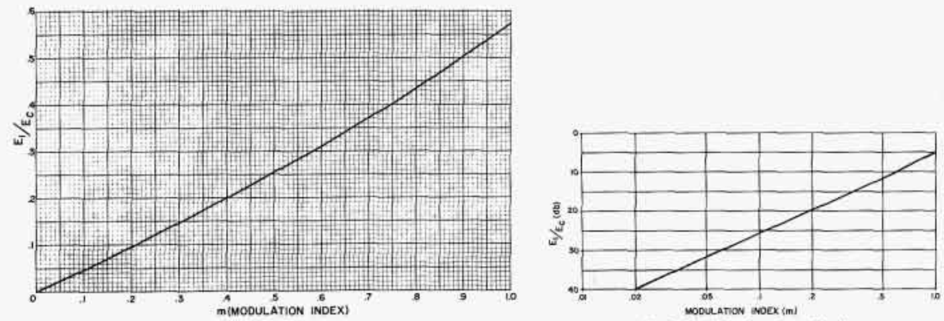
BESSEL ZERO METHOD

For years, frequency deviation has been measured by using the fact that the carrier amplitude, related to the Bessel Function J_o (m), goes to zero at certain values of modulation index (m= 2.405, 5.520, 8.653, 11.79, etc.). For this type of measurement all that is needed is an accurately known modulation frequency source, and a receiver selective enough to precisely indicate the carrier null in the presence of a first-order sideband. The procedure is simply to tune to the carrier with no modulation present, and then increase the amplitude of the modulating signal until the desired n_{th} order null is reached as indicated by the disappearance of the carrier, for the n_{th} time[1]. For example, the deviation of an FM signal source can be set to 150 kc using the second-order Bessel Zero modulation index (m) of 5.520. In this case the modulation frequency used is

$$f_{mod} = \frac{\Delta f}{m} = \frac{150 \text{ kc}}{5.520} = 27{,}173 \text{ cps.}$$

Tuning to the carrier, without modulation, and then increasing the amplitude of a 27,173 cps modulating signal until the second null is reached, will set the deviation of the signal source to 150 kc. Table 1 contains frequently used Bessel Zero frequencies and resulting deviations.

The minimum receiver bandwidth that can be used with a VHF FM signal source of good stability limits the modulation frequency to a minimum of about 5 kc. This puts a limit of approximately 12 kc on the minimum deviation that can be measured by Bessel carrier zeroes. On the other hand, nulls above the 4th order become difficult to identify and precisely locate. This limitation is not serious, however, because most FM telemetry and entertainment receivers are quite flat, before de-emphasis, from 50 cps to 15 kc. Most FM Signal Generators are also quite flat in this frequency range.



(a) E_1/E_c in Absolute Values *(b) E_1/E_c in Decibels*

Figure 1. Amplitude Ratio — m vs. E_1/E_c

DEVIATION	NULL ORDER		
(kc)	1	2	3
50	20,792	9,058	5,778
75	31,188	13,587	8,667
150	62,375	27,173	17,334
250	103,959	45,289	28,889
300	124,750	54,347	34,667

Table 1. Bezzel Zero Modulating Freq.

The first-order Bessel Zero appears at a modulation index of 2.405, which is the minimum value useable with the Bessel Zero method. Obviously, the Bessel Zero method fails, and hence a problem arises at modulation indices less than 2.405. For instance, a 50 kc deviation at a modulating frequency of 500 kc gives a modulation index of 0.1 and is not measurable by the Bessel Zero method.

SIDEBAND AMPLITUDE METHOD

Analyzing the Spectrum

A ratio measurement of the first-order sideband to carrier amplitudes fills this gap. The ratio under consideration, E_1/E_c, equals $J_1(m)/J_o(m)$, because $E_1 = E_oJ_1(m)$ and $E_c = E_oJ_o(m)$ and therefore, E_1/E_c is a function of the modulation index ($m = \frac{\Delta f}{f_{mod}}$). Therefore, the actual deviation can be determined since f_{mod} is known and m can be calculated from E_1/E_c, which equals $J_1(m)/J_o(m)$. If $J_1(m)/J_c(m)$ is known, m can be found in any table of Bessel functions of the first kind. When m is less than 0.5, a good approximation is $\frac{J_1(m)}{J_o(m)} = \frac{m}{2}$. For convenience, m vs. $J_1(m)/J_o(m)$ is plotted in Figure 1. The values of $J_1(m)/J_o(m)$ or E_1/E_c, for some of the more common modulation indices, are listed in Table 2.

m	Δf (kc)	f_{mod} (kc)	E_1/E_c RATIO	E_1/E_c db
.5	50	100	.258	−11.7
.25	50	200	.125	−18
.1	50	500	.050	−26
.05	50	1000 (1 mc)	.025	−32

Table 2. Modulation Indices —

$$m = \frac{\Delta f}{f_{mod}}$$

Effects of AM Distortion

For the sideband method to give accurate results, the FM spectrum can not be distorted by AM. Residual AM on an FM spectrum usually increases the amplitude of one sideband and decreases the amplitude of the other, as shown in Figure 2. If the FM signal is distorted by incidental AM, the IF signal obtained by beating it with a local oscillator will also have AM distortion. This distortion can be minimized by adjusting the relative RF levels of the AM distorted FM signal and local oscillator. If the distorted signal is made large enough to operate the diode in its saturated region, clipping by the diode will reduce the AM distortion. Reducing the AM content, while maintaining a constant IF amplitude, can be obtained by increasing the level of the distorted signal and decreasing the level of the local oscillator.

Receiver Requirements

The receiver to be used must be selective enough to locate the carrier in

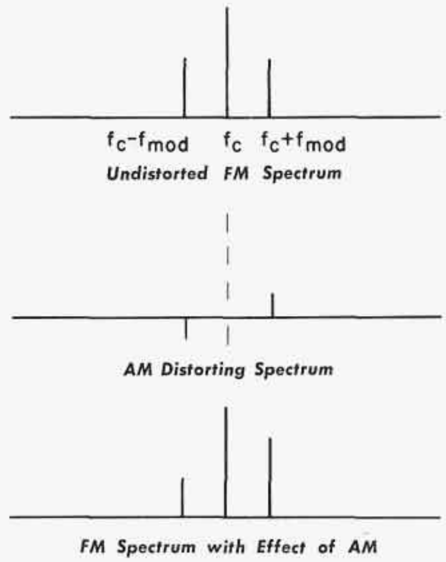


Figure 2.

the presence of first-order sidebands for modulation frequencies down to 9 kc. Beating the RF signals to an IF carrier allows the use of a receiver with average selectivity. A receiver with adjustable selectivity, such as the Hammarlund SP-600, makes it possible to adjust the bandwidth as the modulation frequency varies. For example, with a 20 mc carrier and a 10 kc modulation frequency, the receiver must be able to distinguish the carrier (20 mc) from the first-order sidebands (19.99 mc and 20.01 mc). At higher modulation frequencies, the spectrum components have wider spacing and the receiver bandwidth can be increased for easier tuning to the carrier and sidebands.

The RF amplitude of the sideband carrier is indicated on a VTVM connected to the second detector output of the receiver, which should vary in a somewhat linear manner with the signal. The meter does not measure the absolute amplitudes of the carrier and sidebands, but it is used to set and match equal levels at the receiver input; therefore, its nonlinearity is not too important to the measurement.

Sideband-to-Carrier Ratio

There are many ways to measure the sideband-to-carrier ratio, two of which will be discussed. The first, and probably the faster, shown in Figure 3, uses step attenuators to determine the amount of attenuation needed to reduce the carrier amplitude down to the sideband amplitude. This gives the ratio E_1/E_c directly in decibels.

The second method (Figure 4) uses a reference generator operating at the Intermediate Frequency, matching its output level (as indicated on the VTVM), to the levels of the carrier and sidebands.

Using either method, the modulation signal applied to the FM generator must be held at a constant amplitude over the range of modulation frequencies used.

Setting Reference Deviation

The modulation signal amplitude is set for each carrier frequency to be tested by making a Bessel Zero calibration for the reference deviation being used. Using a frequency counter, set the frequency of the modulation source (-hp- 650A Test Oscillator). Tune the receiver to the carrier with no modulation, and then increase the amplitude of the modulation signal until the desired order null occurs. The null can be detected on the meter or with earphones using the receiver BFO. This amplitude of modulation signal will be used for the rest of the measurements and the results will be based on a known reference deviation. The reference deviation can be set to 50 kc by setting the modulation signal amplitude

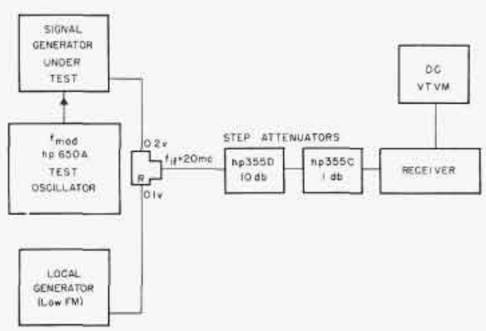


Figure 3. Fidelity Measurement — Step Attenuator Method

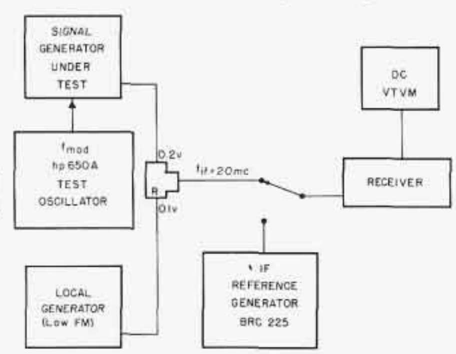


Figure 4. Fidelity Measurement — Reference Generator Method

for the second-order Bessel Zero at a modulation frequency of 9.058 kc.

$$f_{mod} = \frac{\Delta f}{m} = \frac{50 \text{ kc}}{5.520} = 9.058 \text{ kc}$$

After a Bessel Zero calibration is made for 50 kc deviation, it is now known that at a modulation frequency of approximately 10 kc, "X" volts of modulation signal gives 50 kc deviation. Now that the amplitude of the modulation signal has been set, the fidelity measurements can be made. We want to know how the deviation will differ from 50 kc for "X" volts of modulation signal at other modulation frequencies.

Using Step Attenuators

Referring to Figure 3, the ratio E_1/E_c is determined by the amount of attenuation needed to reduce the carrier amplitude to the amplitude of the first-order sideband. The step-by-step procedure for making this determination is as follows:

1. Calculate the theoretical value of the modulation index (m) for the deviation and modulation frequency being used.
2. Using Figure 1B, convert m to E_1/E_c and set the step attenuators to a value at least 3 db greater than this value.
3. Tune the receiver to the unmodulalated carrier.
4. Apply the modulation signal and adjust its level to the same value obtained for the reference deviation Bessel Zero.
5. Adjust the receiver RF gain to give a convenient upscale reading on the VTVM.
6. Tune the receiver to a first-order sideband ($F_{if} \pm f_{mod}$).
7. Reduce the step attenuator settings to give the *same* VTVM indication as for the modulated carrier. (The -hp- 355C step attenuator has 1 db steps, however, the VTVM reading can be interpolated to at least one-quarter db).
8. The amount of attenuation removed to adjust the VTVM sideband indication to the same indication as the carrier, is the actual ratio, E_1/E_c, in decibels.
9. This value, minus the theoretical value, is the departure of the signal source from a perfectly flat fidelity characteristic.
10. Both upper and lower sidebands should be checked to make sure the IF signal is properly limited and not distorted by AM. If the amplitudes of the upper and lower sidebands are within 1 db, the average can be used to determine the ratio E_1/E_c.

Checking the fidelity at $f_{mod} = 500$ kc, and $\Delta f = 50$ kc, might produce the results shown in the following example. Under these conditions the theoretical modulation index is

$$m = \frac{\Delta f}{f_{mod}} = \frac{50 \text{ kc}}{500 \text{ kc}} = 0.10$$

From Figure 1 or Table 2, for $m = 0.10$, E_1/E_c theoretically equals 0.05, or —26 db.

The BRC Type 202J FM fidelity specification is ± 1 db from 5 cps to 500 kc, therefore at $f_{mod} = 500$ kc and $\Delta f = 50$ kc, a E_1/E_c ratio of —25 db to —27 db would be within limits.

Suppose the ratio E_1/E_c was —26.5 db. Since Figure 1 shows a nearly linear relationship between m and E_1/E_c at low values, if E_1/E_c is one-half db (6%) low, m would also be 6% low. Then, the actual modulation index would be 0.094 compared to the theoretical value of 0.1. This means that "X" volts of modulation, which gave 50 kc deviation at approximately 10 kc, would not give 50 kc deviation at $f_{mod} = 500$ kc, but would actually give 6% less deviation or

$\Delta f = f_{mod} = .094 \times 500 \text{ kc} = 47$ kc.

Using a Reference Signal

The reference generator method uses the same IF and procedure for determining modulation signal amplitude. In this set-up, Figure 4, the calibrated output of the reference generator is matched to the carrier and sideband amplitudes. The step-by-step procedure follows.

1. Calculate the theoretical value of m for the deviation and modulation frequency being used.
2. Convert m to E_1/E_c.
3. Tune the receiver to the unmodulated IF carrier of the beating RF signals.
4. Apply the modulation frequency signal and adjust its amplitude to the level obtained for the reference deviation by the Bessel Zero calibration.
5. Adjust the receiver RF gain to give a convenient upscale reading on the VTVM.
6. Switch the receiver to the Reference Generator (tuned to the carrier frequency) and adjust the attenuator for the same vtvm reading as in step 5. Note the attenuator setting.
7. Switch back to the Beating Generators and tune the receiver to the first upper (or lower) sideband.
8. Adjust the receiver RF gain and/or the VTVM range to get an upscale indication.
9. Switch to the Reference Generator and tune it to the Sideband Frequency ($F_{if} \pm f_{mod}$). Adjust the Reference Generator attenuator for the same VTVM reading as for the sideband. (Note Attenuator Setting.)
10. The ratio of the Reference Generator attenuator settings (sideband amplitude divided by carrier amplitude) equals E_1/E_c. The difference in attenuator settings (on the decibel scale) also equals E_1/E_c in decibels.
11. Both upper and lower sidebands should be checked to make sure the IF signal is properly limited and not distorted by AM. If the amplitudes of the upper and lower sidebands are within 1 db, the average can be used to determine the ratio E_1/E_c.

As an example, for $f_{mod} = 200$ kc and $\Delta f = 50$ kc; $m = 0.25$. Referring to the graphs in Figure 1 or to Table 2, $m = 0.25$ results in a sideband-to-carrier ratio (E_1/E_c) of 0.125 or —18 db. Therefore, if the modulated carrier amplitude equals 2 K μv (Step 6), the first-order sideband should equal 2K μv $\times$ 0.125 = 250 μv (Step 9).

A fidelity specification of ± 1 db at $f_{mod} = 200$ kc means the sideband will be within ± 12% of its ideal values, or 220 to 280 μv, with m = .25 and 2 K μv carrier. Again, using the linear approximation of Figure 1, suppose the ratio of E_1/E_c measured 0.120; 4% below the desired value of 0.125 at $f_{mod} = 200$ kc. In this case, m would also be 4% low, but for "X" volts of modulation signal at $f_{mod} = 20C$ kc, the deviation would be 48 kc, or 4% less than the 50 kc deviation observed for "X" volts of modulation signal at $f_{mod} = 10$ kc

CONCLUSION

The numerical examples used in this article are based on measurements made on the BRC 202J Telemetering Signal Generator. However, the concept of the sideband amplitude method of measuring FM fidelity is applicable to any frequency-modulated signal or source.

BIBLIOGRAPHY

1. "A Method of Measuring Frequency Deviation," J. Wachter, BRC Notebook #9.
2. "Useful Concepts of Frequency Modulation," W. Cullen Moore, BRC Notebook #10.
3. "Microwave Mixers," R. V. Pound, MIT Radiation Laboratory, Series #16, McGraw-Hill.
4. Bessel Functions — Reference Data for Radio Engineers, ITT, 4th Edition, p 1066, 1118.

EDITOR'S NOTE

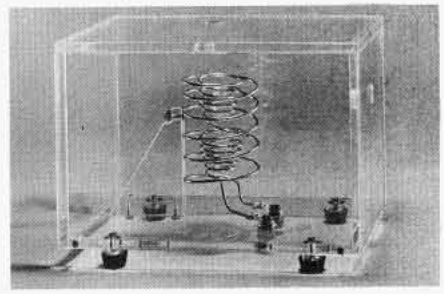
Q Contest Winner

The Q of the coil displayed in the BRC booth at the 1963 IEEE show was 313, as measured on the BRC Type 260-A Q Meter. Two estimates of 313 were actually submitted: one by Mr. Seymour Krevsky of RCA Surfcom Laboratory, and the other by Mr. E. A. Zizzo of the Polytechnic Institute of Brooklyn. In accordance with our contest rules, a drawing was made and we are pleased to announce that the winner is Seymour Krevsky. It is also interesting to note that Mr. Krevsky was a near winner in 1957 and again in 1959, when his estimates were just a shade off the actual value.

Nearly 1000 estimates were submitted, ranging from zero to infinity. In addition to the 313 estimates, there were ten estimates within 1% of the measured Q. A list of the persons who submitted these estimates is given below.

Estimate	*Submitted By*
310	T. D. MacCoun Budelman Electronics Corp.
311.5	J. H. Humphries Western Electric Co.
312	"Nick" Tarry Electronics
312	D. Bickor Sperry Gyroscope Co.
312	R. Lafferty Boonton Electronics Corp.
314	R. Dormagen E. Stanwyck Coil Co.
314.16	F. Kilkenny RCA Institute
314.2	H. P. Hall General Radio Co.
315	F. J. Logan NASA, Goddard Space Flight Center
315	R. Haindel New York University

A photograph of the display coil is shown here for those Notebook readers who did not see it at the show. The unusual configuration, consisting of two conical-wound coils wound inside a helical-wound coil, was devised by "Chuck" Quinn, BRC Sales Engineer.



Q Contest Coil

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