

#### ABSTRACT

This paper discusses four high sensitivity receivers and IF (Intermediate Frequency) strips which utilize intermediate frequencies of 10.7MHz or greater. Each circuit utilizes a low-power VHF mixer and high-performance low-power IF strip. The circuit configurations are

1. 45 or 49MHz to 10.7MHz narrow-band,
2. 90MHz to 21.4MHz narrowband,
3. 100MHz to 10.7MHz wideband, and
4. 152.2MHz to 10.7MHz narrowband.

Each circuit is presented with an explanation of component selection criteria, (to permit adaptation to other frequencies and bandwidths). Optional configurations for local oscillators and data demodulators are summarized.

#### INTRODUCTION

Traditionally, the use of 10.7MHz as an intermediate frequency has been an attractive means to accomplish reasonable image rejection in VHF/UHF receivers. However, applying significant gain at a high IF has re-

quired extensive gain stage isolation to avoid instability and very high current consumption to get adequate amplifier gain bandwidth. By enlightened application of two relatively new low power ICs, Signetics NE602 and NE604A, it is possible to build highly producible IF strips and receivers with input frequencies to several hundred megahertz, IF frequencies of 10.7 or 21.4MHz, and sensitivity less than  $2\mu\text{V}$  (in many cases less than  $1\mu\text{V}$ ). The Signetics new NE605 combines the function of the NE602 and the NE604A. All of the circuits described in this paper can also be implemented with the NE605. The NE602 and

NE604A were utilized for this paper to permit optimum gain stage isolation and filter location.

#### THE BASICS

First let's look at why it is relevant to use a 10.7 or 21.4MHz intermediate frequency. 455kHz ceramic filters offer good selectivity and small size at a low price. Why use a higher IF? The fundamental premise for the answer to this question is that the receiver architecture is a heterodyne type as shown in Figure 1.

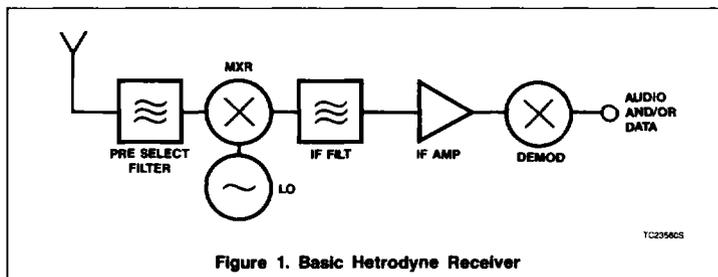


Figure 1. Basic Hetrodyne Receiver

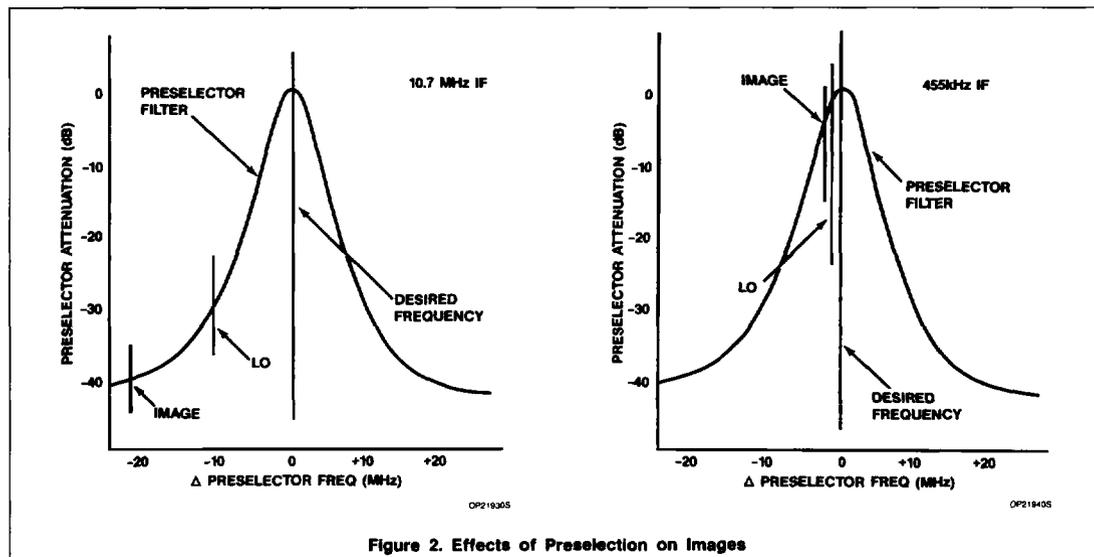


Figure 2. Effects of Preselection on Images

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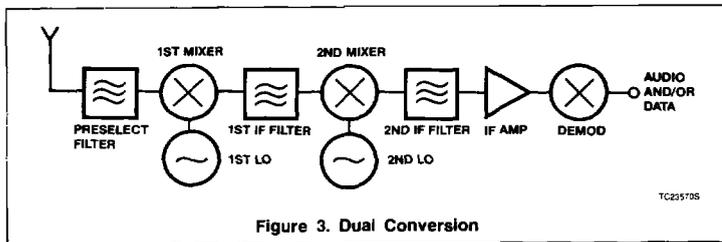


Figure 3. Dual Conversion

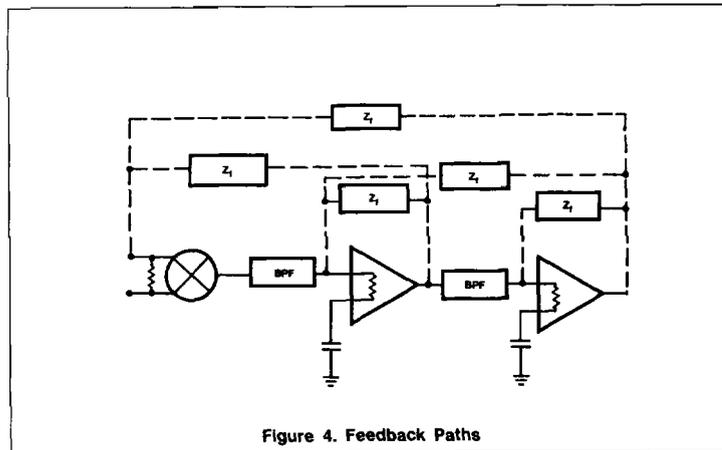


Figure 4. Feedback Paths

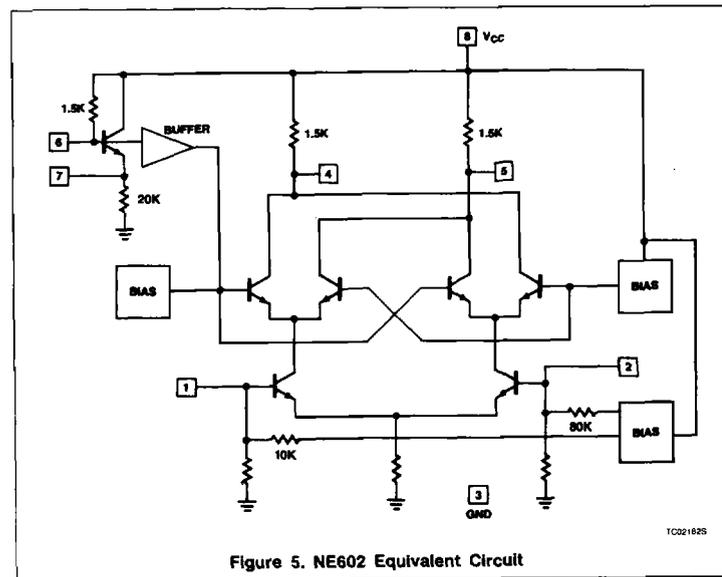


Figure 5. NE602 Equivalent Circuit

A pre-selector (bandpass in this case) precedes a mixer and local oscillator. An IF filter follows the mixer. The IF filter is only supposed to pass the difference (or sum) of the

local oscillator (LO) frequency and the pre-selector frequency.

The reality is that there are always two frequencies which can combine with the LO: The pre-selector frequency and the "image" frequency. Figure 2 shows two hypothetical pre-selection curves. Both have 3dB bandwidths of 2MHz. This type of pre-selection is typical of consumer products such as cordless telephone and FM radio. Figure 2A shows the attenuation of a low side image with 10.7MHz. Figure 2B shows the very limited attenuation of the low side 455kHz image.

If the single conversion architecture of Figure 1 were implemented with a 455kHz IF, any interfering image would be received almost as well as the desired frequency. For this reason, dual conversion, as shown in Figure 3, has been popular.

In the application of Figure 3, the first IF must be high enough to permit the pre-selector to reject the images of the first mixer and must have a narrow enough bandwidth that the second mixer images and the intermod products due to the first mixer can be attenuated. There's more to it than that, but those are the basics. The multiple conversion heterodyne works well, but, as Figure 3 suggests, compared to Figure 2 it is more complicated. Why, then, don't we use the approach of Figure 2?

## THE PROBLEM

Historically there has been a problem: Stability! Commercially available integrated IF amplifiers have been limited to about 60dB of gain. Higher discrete gain was possible if each stage was carefully shielded and bypassed, but this can become a nightmare on a production line. With so little IF gain available, in order to receive signals of less than 10µV it was necessary to add RF gain and this, in turn, meant that the mixer must have good large signal handling capability. The RF gain added expense, the high level mixer added expense, both added to the potential for instabilities, so the multiple conversion started looking good again.

But why is instability such a problem in a high gain high IF strip? There are three basic mechanisms. First, ground and the supply line are potentially feedback mechanisms from stage-to-stage in any amplifier. Second, output pins and external components create fields which radiate back to inputs. Third, layout capacitances become feedback mechanisms. Figure 4 shows the fields and capacitances symbolically.

If  $Z_F$  represents the impedance associated with the circuit feedback mechanisms (stray capacitances, inductances and radiated fields), and  $Z_{IN}$  is the equivalent input imped-

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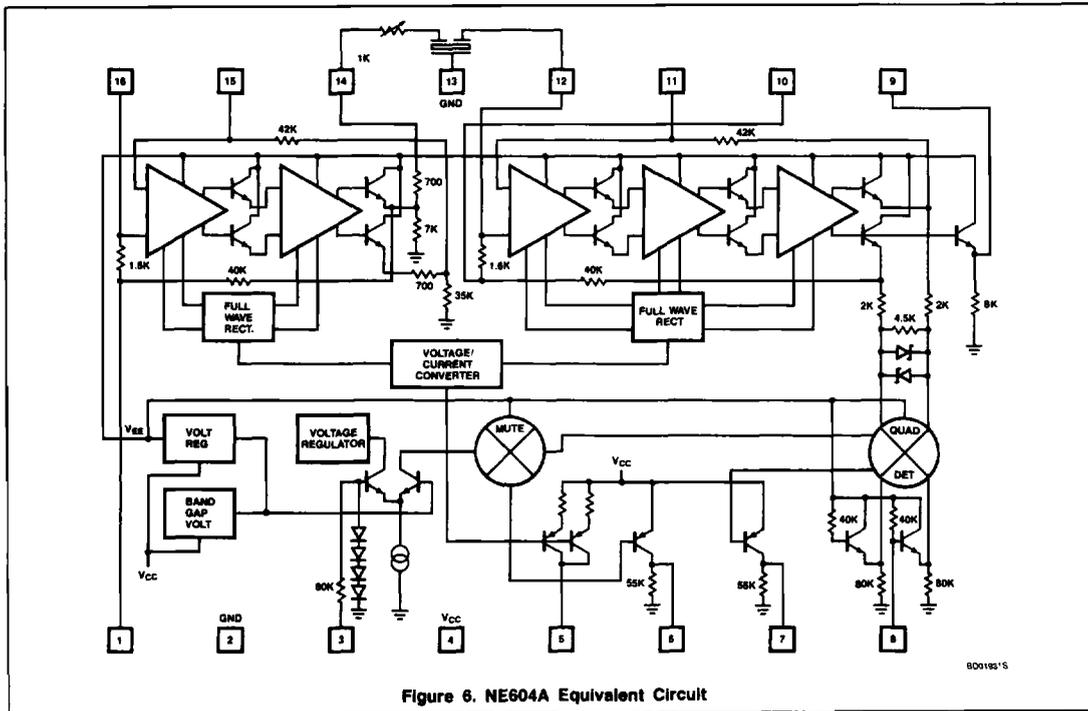


Figure 6. NE604A Equivalent Circuit

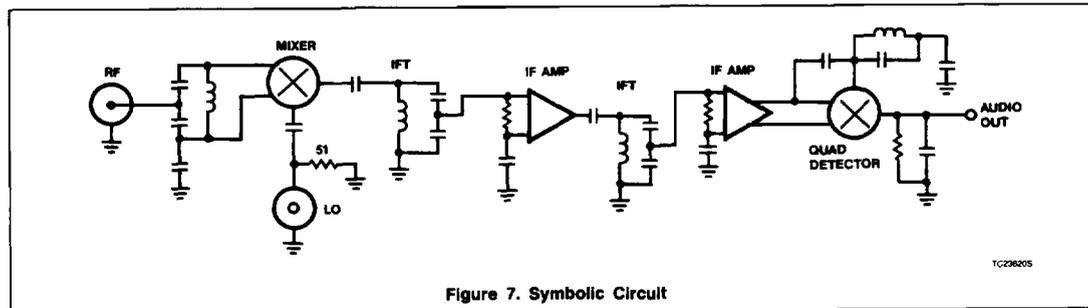


Figure 7. Symbolic Circuit

ance, a divider is created. This divider must have an attenuation factor greater than the gain of the amplifier if the amplifier is to remain stable.

◆ If gain is increased, the input-to-output isolation factor must be increased.

◆ As the frequency of the signal or amplifier bandwidth increases, the impedance of the layout capacitance decreases thereby reducing the attenuation factor.

The layout capacitance is only part of the issue. In order for traditional 10.7MHz IF amplifiers to operate with reasonable gain

bandwidth, the amount of current in the amplifiers needed to be quite high. The CA3089 operates with 25mA of typical quiescent current. Any currents which are not perfectly differential must be carefully bypassed to ground. The higher the current, the more difficult the challenge. And limiter outputs and quadrature components make excellent field generators which add to the feedback scenario. The higher the current, the larger the field.

### THE SOLUTION

The NE602 is a double balanced mixer suitable for input frequencies in excess of 500MHz. It draws 2.5mA of current. The NE604A is an IF strip with over 100dB of gain and a 25MHz small signal bandwidth. It draws 3.5mA of current. The circuits in this paper will demonstrate ways to take advantage of this low current and 75dB or more of the NE604A gain in receivers and IF strips that would not be possible with traditional integrated circuits. No special tricks are used, only good layout, impedance planning and gain distribution.

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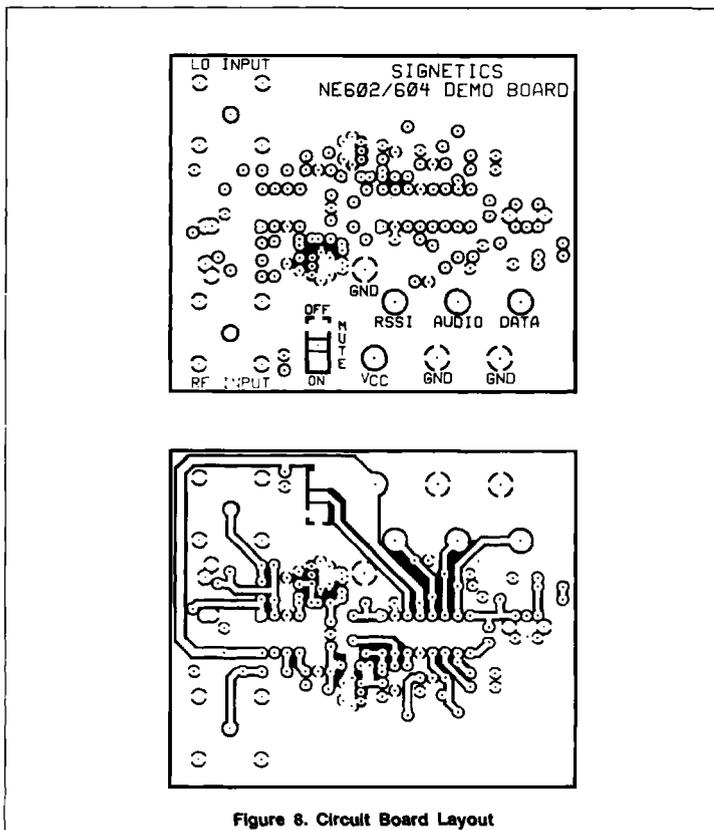


Figure 8. Circuit Board Layout

## THE MIXER

The NE602 is a low power VHF mixer with built-in oscillator. The equivalent circuit is shown in Figure 5. The basic attributes of this mixer include conversion gain to frequencies greater than 500MHz, a noise figure of 4.6dB @ 45MHz, and a built-in oscillator which can be used up to 200MHz. LO can be injected.

For best performance with any mixer, the interface must be correct. The input impedance of the NE602 is high, typically  $3k\Omega$  in parallel with 3pF. This is not an easy match from  $50\Omega$ . In each of the examples which follow, an equivalent  $50:1.5k$  match was used. This compromise of noise, loss, and match yielded good results. It can be improved upon. Match to crystal filters will require special attention, but will not be given focus in this paper.

This oscillator is a single transistor with an internal emitter follower driving the mixer. For best mixer performance, the LO level needs to be approximately  $220mV_{RMS}$  at the base of the oscillator transistor (Pin 6). A number of oscillator configurations are presented at the end of this paper. In each of the prototypes for this paper, the LO source was a signal generator. Thus, a  $51\Omega$  resistor was used to terminate the signal generator. The LO is then coupled to the mixer through a DC blocking capacitor. The signal generator is set for 0dBm. The impedance at the LO input (Pin 6) is approximately  $20k\Omega$ . Thus, required power is very low, but 0dBm across  $51\Omega$  does provide the necessary  $220mV_{RMS}$ .

The outputs of the NE602 are loaded with  $1.5k\Omega$  internal resistors. This makes interface to 455kHz ceramic filters very easy. Other filter types will be addressed in the examples.

## THE IF STRIP

The basic functions of the NE604A are ordinary at first glance: Limiting IF, quadrature detector, signal strength meter, and mute switch. However, the performance of each of these blocks is superb. The IF has 100dB of gain and 25MHz bandwidth. This feature will be exploited in the examples. The signal strength indicator has a 90dB log output characteristic with very good linearity. There are two audio outputs with greater than 300kHz bandwidth (one can be muted greater than 70dB). The total supply current is typically 3.5mA. This is the other factor which permits high gain and high IF.

Figure 6 shows an equivalent circuit of the NE604A. Each of the IF amplifiers has a  $1.6k\Omega$  input impedance. The input impedance is achieved by splitting a DC feedback bias resistor. The input impedance will be manipulated in each of the examples to aid stability.

## BASIC CONSIDERATIONS

In each of the circuits presented, a common layout and system methodology is used. The basic circuit is shown symbolically in Figure 7.

At the input, a frequency selective transformation from  $50\Omega$  to  $1.5k\Omega$  permits analysis of the circuit with an RF signal generator. A second generator provides LO. This generator second generator provides LO. This generator is terminated with a  $51\Omega$  resistor. The output of the mixer and the input of the first limiter are both high impedance ( $1.5\Omega$  nominal). As indicated previously, the input impedance of the limiter must be low enough to attenuate feedback signals. So, the input impedance of the first limiter is modified with an external resistor. In most of the examples, a  $430\Omega$  external resistor was used to create a  $330\Omega$  input impedance ( $430 // 1.5k\Omega$ ). The first IF filter is thus designed to present  $1.5k\Omega$  to the mixer and  $330\Omega$  to the first limiter.

The same basic treatment was used between the first and second limiters. However, in each of the 10.7MHz examples, this interstage filter is not an L/C tank; it is a ceramic filter. This will be explained in the first example.

After the second limiter, a conventional quadrature detector demodulates the FM or FSK information from the carrier and a simple low pass filter completes the demodulation process at the audio outputs.

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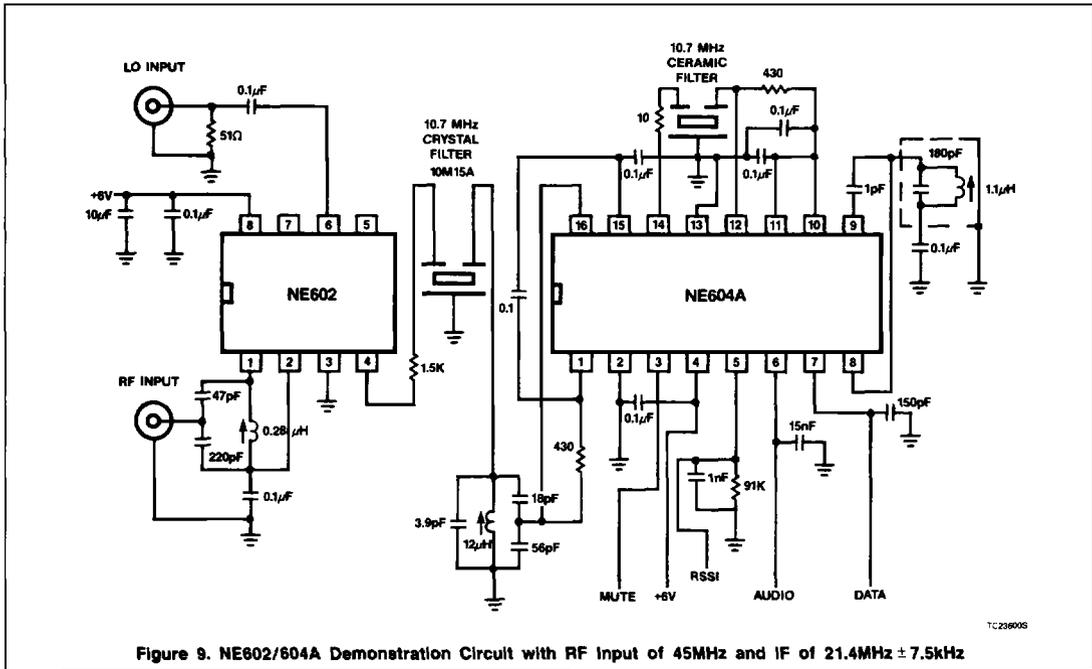


Figure 9. NE602/604A Demonstration Circuit with RF Input of 45MHz and IF of 21.4MHz ± 7.5kHz

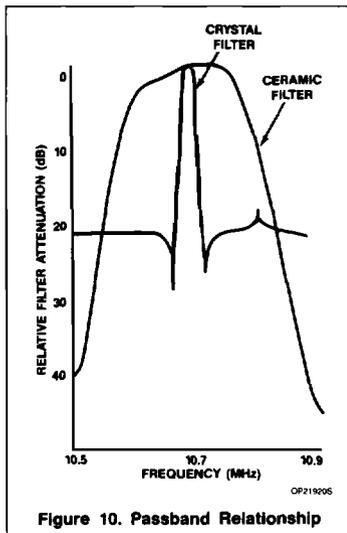
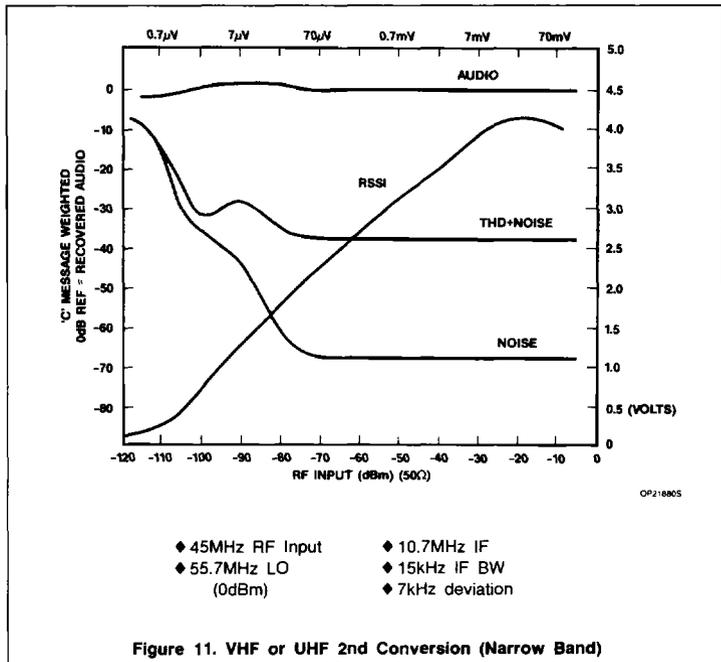


Figure 10. Passband Relationship



- ◆ 45MHz RF Input
- ◆ 55.7MHz LO (0dBm)
- ◆ 10.7MHz IF
- ◆ 15kHz IF BW
- ◆ 7kHz deviation

Figure 11. VHF or UHF 2nd Conversion (Narrow Band)

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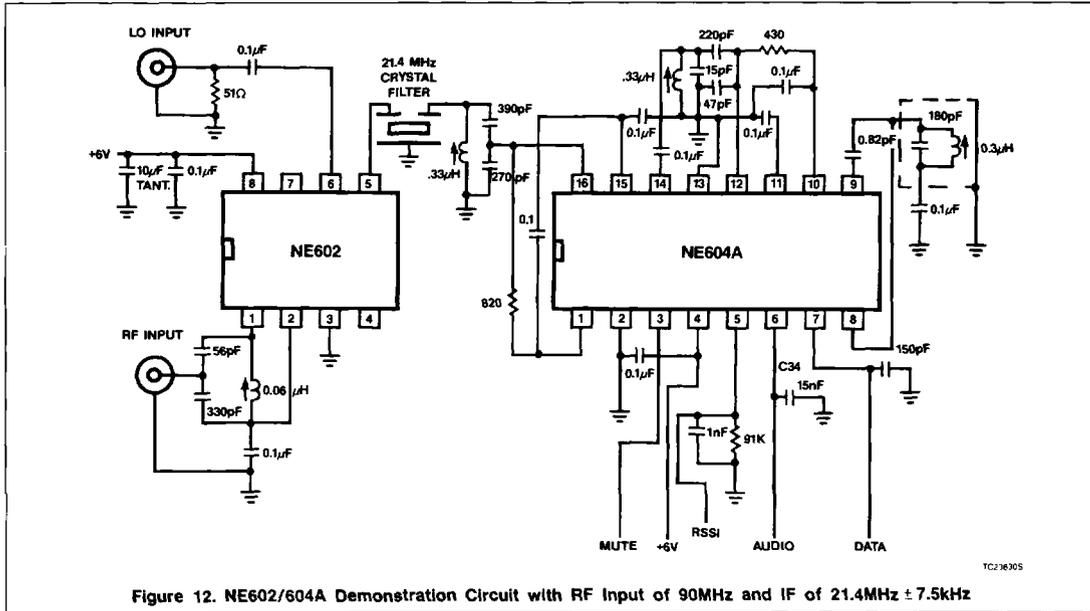


Figure 12. NE602/604A Demonstration Circuit with RF Input of 90MHz and IF of 21.4MHz ± 7.5kHz

As mentioned, a single layout was used for each of the examples. The board artwork is shown in Figure 8. Special attention was given to: (1) Creating a maximum amount of ground plane with connection of the component side and solder side ground at locations all over the board; (2) careful attention was given to keeping a ground ring around each of the gain stages. The objective was to provide a shunt path to ground for any stray signal which might feed back to an input; (3) leads were kept short and relatively wide to minimize the potential for them to radiate or pick up stray signals; finally (and very important), (4) RF bypass was done as close as possible to supply pins and inputs, with a good (10µF) tantalum capacitor completing the system bypass.

### EXAMPLE: 45MHz to 10.7MHz NARROWBAND

As a first example, consider conversion from 45MHz to 10.7MHz. There are commercially available filters for both frequencies so this is a realistic combination for a second IF in a UHF receiver. This circuit can also be applied to cordless telephone or short range communications at 46 or 49MHz. The circuit is shown in Figure 9.

The 10.7MHz filter chosen is a type commonly available for 25kHz channel spacing. It has a 3dB bandwidth of 15kHz and a termination requirement of 3kΩ/2pF. To present 3kΩ to

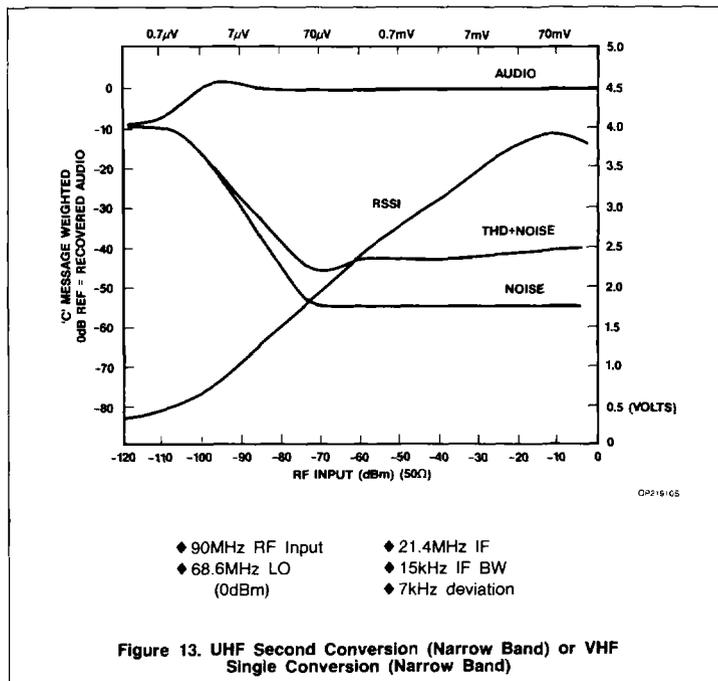


Figure 13. UHF Second Conversion (Narrow Band) or VHF Single Conversion (Narrow Band)

the input side of the filter, a 1.5kΩ resistor has a 1.5kΩ impedance) and the filter. Layout was used between the NE602 output (which

has a 1.5kΩ impedance) and the filter. Layout capacitance was close enough to 2pF that no

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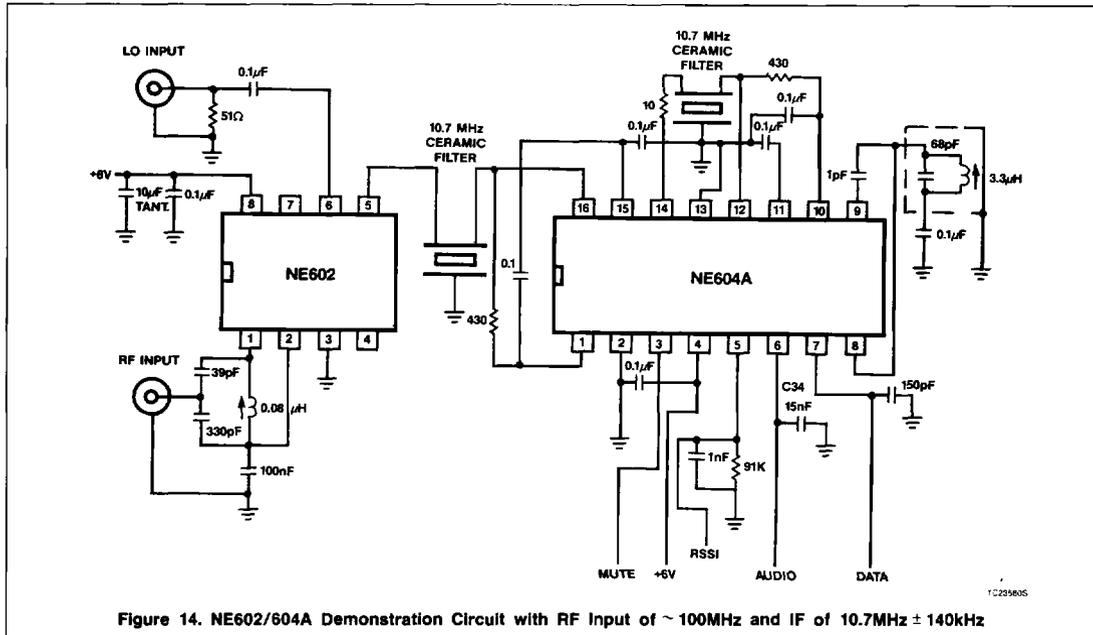


Figure 14. NE602/604A Demonstration Circuit with RF Input of ~100MHz and IF of 10.7MHz ± 140kHz

adjustment was necessary. This series-resistance approach introduces an insertion loss which degrades the sensitivity, but it has the benefit of simplicity.

The secondary side of the crystal filter is terminated with a 10.7MHz tuned tank. The capacitor of the tank is tapped to create a transformer with the ratio for 3k:330. With the addition of the 430Ω resistor in parallel with the NE604A 1.6kΩ internal input resistor, the correct component of resistive termination is presented to the crystal filter. The inductor of the tuned load is adjusted off resonance enough to provide the 2pF capacitance needed. (Actual means of adjustment was for best audio during alignment).

If appropriate or necessary for sensitivity, the same type of tuned termination used for the secondary side of the crystal filter can also be used between the NE602 and the filter. If this is desired, the capacitors should be ratioed for 1.5k:3k. Alignment is more complex with tuned termination on both sides of the filter. This approach is demonstrated in the fourth example.

A ceramic filter is used between the first and second limiters. It is directly connected between the output of the first limiter and the input of the second limiter. Ceramic filters act much like ceramic capacitors, so direct connection between two circuit nodes with different DC levels is acceptable. At the input to

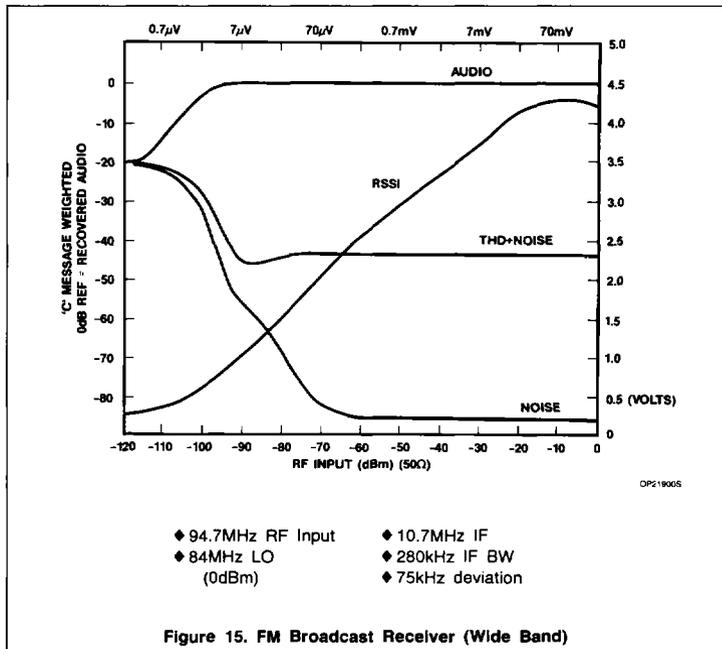
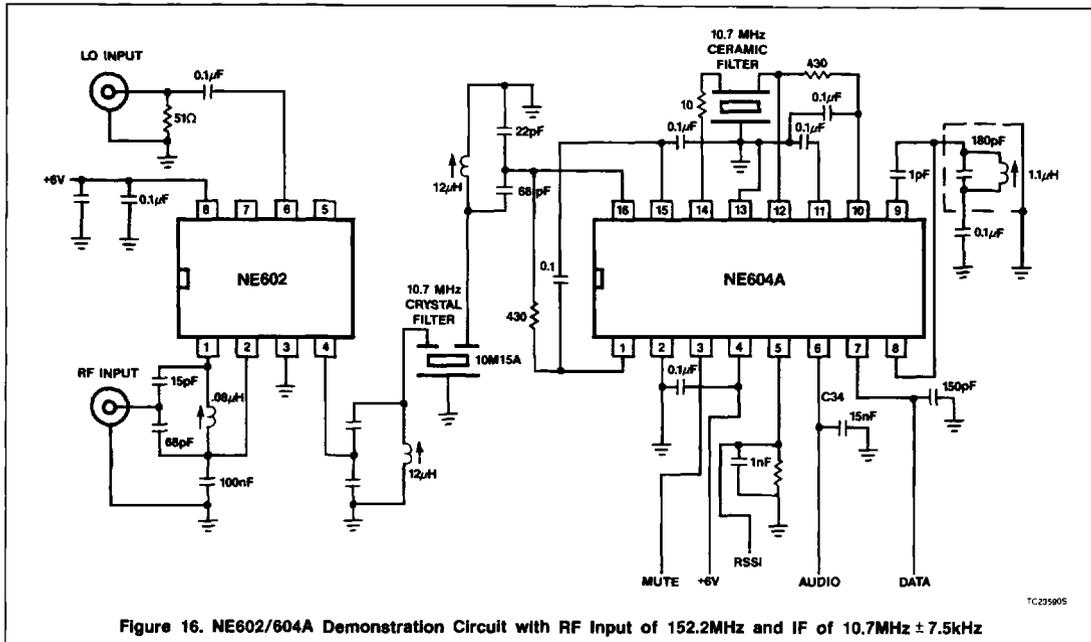


Figure 15. FM Broadcast Receiver (Wide Band)

the second limiter, the impedance is again reduced by the addition of a 430Ω external resistor in parallel with the internal 1.6kΩ input load resistor. This presents the 330Ω

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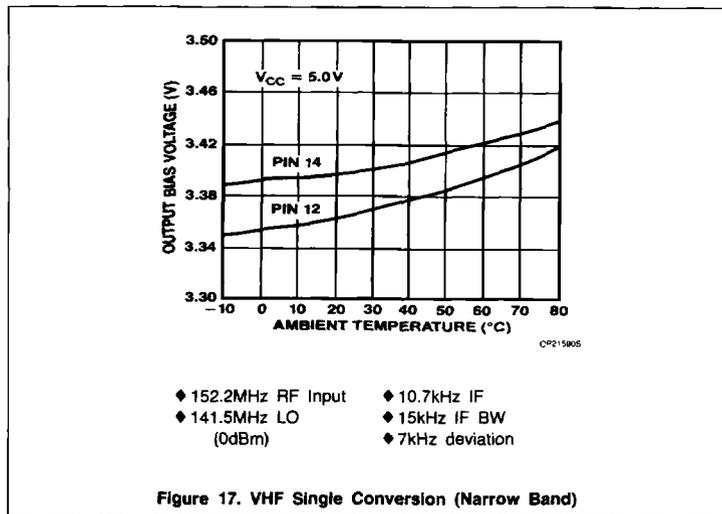
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termination to the ceramic filter which the manufacturers recommend.

On the input side of the ceramic filter, no attempt was made to create a match. The output impedance of the first limiter is nominally 1kΩ. Crystal filters are tremendously sensitive to correct match. Ceramic filters are relatively forgiving. A review of the manufacturers' data shows that the attenuation factor in the passband is affected with improper match, but the degree of change is small and the passband stays centered. Since the principal selectivity for this application is from the crystal filter at the input of the first limiter, the interstage ceramic filter only has to suppress wideband noise. The first filter's passband is right in the center of the ceramic filter passband. (The crystal filter passband is less than 10% of the ceramic filter passband). This passband relationship is illustrated in Figure 10.

After the second limiter, demodulation is accomplished in the quadrature detector. Quadrature criteria is not the topic of this paper, but it is noteworthy that the choice of loaded Q will affect performance. The NE604A is specified at 455kHz using a quadrature capacitor of 10pF and a tuning capacitor of 180pF. (180pF gives a loaded Q of 20 at 455kHz). A careful look at the quadrature equations (Ref 3.) suggests that at 10.7MHz a value of about 1pF should be substituted for the 10pF at 455kHz.



The performance of this circuit is presented in Figure 11. The -12dB SINAD (ratio of Signal to Noise And Distortion) was achieved with a 0.6μV input.

### EXAMPLE: 90MHz to 21.4MHz NARROWBAND

This second example, like the first, used two frequencies which could represent the intermediate frequencies of a UHF receiver. This circuit can also be applied to VHF single conversion receivers if the sensitivity is appropriate. The circuit is shown in Figure 12.

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Most of the fundamentals are the same as explained in the first example. The 21.4MHz crystal filter has a  $1.5k\Omega/2pF$  termination requirement so direct connection to the output of the NE602 is possible. With strays there is probably more than  $2pF$  in this circuit, but the performance is good nonetheless. The output of the crystal filter is terminated with a tuned impedance-step-down transformer as in the previous example. Interstage filtering is accomplished with a  $1k\Omega:330$  step-down ratio. (Remember, the output of the first limiter is  $1k\Omega$  and a  $430\Omega$  resistor has been added to make the second limiter input  $330\Omega$ ). A DC blocking capacitor is needed from the output of the first limiter. The board was not laid out for an interstage transformer, so an "XACTO" knife was used to make some minor mods. Figure 13 shows the performance. The  $+12dB$  SINAD was with  $1.6\mu V$  input.

## EXAMPLE: 100MHz to 10.7MHz WIDEBAND

This example represents three possible applications: (1) low cost, sensitive FM broadcast receivers, (2) SCA (Subsidiary Communications Authorization) receivers and (3) data receivers. The circuit schematic is shown in Figure 14. While this example has the greatest diversity of application, it is also the simplest. Two 10.7MHz ceramic filters were used. The first was directly connected to the output of the NE602. The second was directly connected to the output of the first IF limiter. The secondary sides of both filters were terminated with  $330\Omega$  as in the two previous examples. While the filter bandpass skew of this simple single conversion receiver might not be tolerable in some applications, to a first order the results are excellent. (Please note that sensitivity is measured at  $+20dB$  in this wideband example.) Performance is illustrated in Figure 15.  $+20dB$  SINAD was measured with  $1.8\mu V$  input.

## EXAMPLE: 152.2MHz to 10.7MHz NARROWBAND

In this example (see Figure 16) a simple, effective, and relatively sensitive single conversion VHF receiver has been implemented. All of the circuit philosophy has been described in previous examples. In this circuit, tuned-transformer termination was used on the input and output sides of the crystal filter. Performance is shown in Figure 17. The  $+12dB$  SINAD sensitivity was  $0.9\mu V$ .

## OSCILLATORS

The NE602 contains an oscillator transistor which can be used to frequencies greater

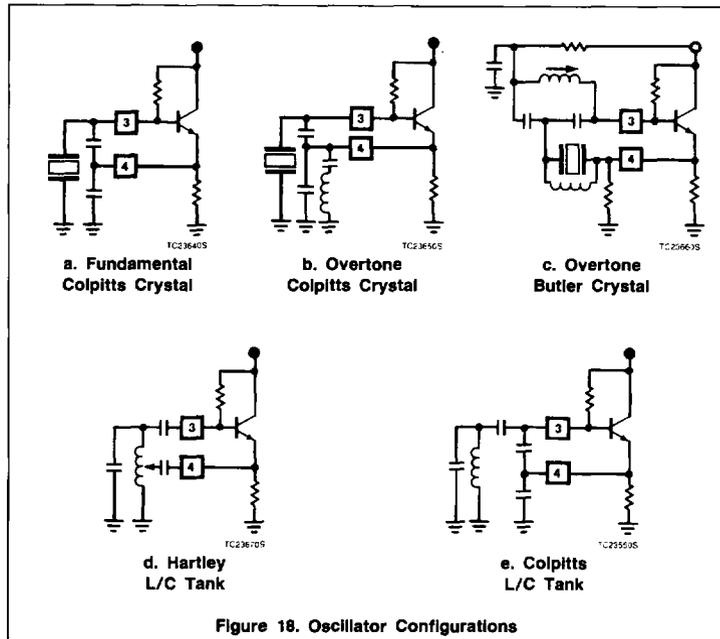


Figure 18. Oscillator Configurations

than 200MHz. Some of the possible configurations are shown in Figures 18 and 19.

## L/C

When using a synthesizer, the LO must be externally buffered. Perhaps the simplest approach is an emitter follower with the base connected to Pin 7 of the NE602. The use of a dual-gate MOSFET will improve performance because it presents a fairly constant capacitance at its gate and because it has very high reverse isolation.

## CRYSTAL

With both of the Colpitts crystal configurations, the load capacitance must be specified. In the overtone mode, this can become a sensitive issue since the capacitance from the emitter to ground is actually the equivalent capacitive reactance of the harmonic selection network. The Butler oscillator uses an overtone crystal specified for series mode operation (no parallel capacitance). It may require an extra inductor ( $L_0$ ) to null out  $C_0$  of the crystal, but otherwise is fairly easy to implement (see references).

The oscillator transistor is biased with only  $220\mu A$ . In order to assure oscillation in some configurations, it may be necessary to increase transconductance with an external resistor from the emitter to ground.  $10k\Omega$  to

$20k\Omega$  are acceptable values. Too small a resistance can upset DC bias (see references).

## DATA DEMODULATION

It is possible to change any of the examples from an audio receiver to an amplitude shift keyed (ASK) or frequency shift keyed (FSK) receiver or both with the addition of an external op amp(s) or comparator(s). A simple example is shown in Figure 20. ASK decoding is accomplished by applying a comparator across the received signal strength indicator (RSSI). The RSSI will track IF level down to below the limits of the demodulator ( $-120dBm$  RF input in most of the examples). When an in-band signal is above the comparator threshold, the output logic level will change.

FSK demodulation takes advantage of the two audio outputs of the NE604A. Each is a PNP current source type output with  $180^\circ$  phase relationship. With no signal present, the quad tank tuned for the center of the IF passband, and both outputs loaded with the same value of capacitance, if a signal is received which is frequency shifted from the IF center, one output voltage will increase and the other will decrease by a corresponding absolute value. Thus, if a comparator is differentially connected across the two out-



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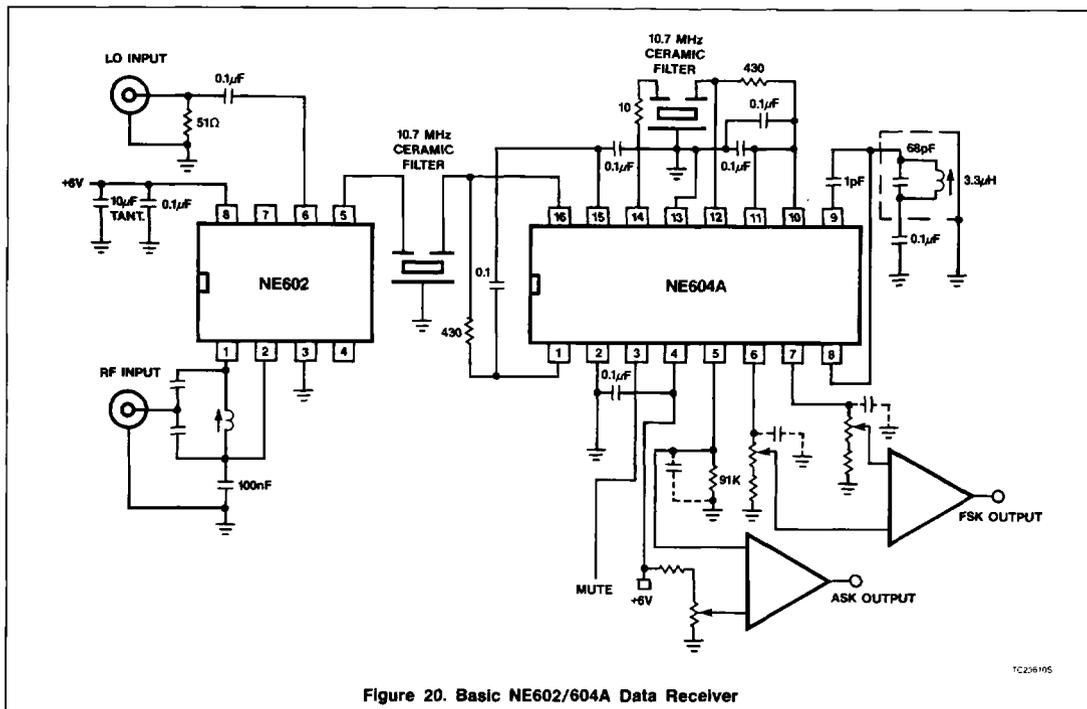


Figure 20. Basic NE602/604A Data Receiver

## SUMMARY

The NE602, NE604A and NE605 provide the RF system designer with the opportunity for excellent receiver or IF system sensitivity with very simple circuitry. IFs at 455kHz, 10.7MHz and 21.4MHz with 75 to 90dB gain are possible without special shielding. The flexible configuration of the built-in oscillator of the NE602/605 add to ease of implementation. Either data or audio can be recovered from the NE604A/605 outputs.

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